ERDWISSENSCHAFTLICHE FORSCHUNG

IM AUFTRAG DER KOMMISSION FÜR ERDWISSENSCHAFTLICHE FORSCHUNG
DER AKADEMIE DER WISSENSCHAFTEN UND DER LITERATUR · MAINZ
HERAUSGEGEBEN VON WILHELM LAUER

BAND XVIII

Natural Environment and Man in Tropical Mountain Ecosystems

Natur und Mensch in Ökosystemen tropischer Hochgebirge

Herausgeber

WILHELM LAUER

FRANZ STEINER VERLAG WIESBADEN GMBH · STUTTGART

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Proceedings of the Symposium of the Akademie der Wissenschaften und der Literatur, Mainz
– Kommission für Erdwissenschaftliche Forschung –
in Connection with the International Geographical Union
– Commission on Mountain Geoecology –
February 24–26, 1983 at Mainz

Verhandlungen des Symposiums der Akademie der Wissenschaften und der Literatur, Mainz
– Kommission für Erdwissenschaftliche Forschung –
in Verbindung mit der International Geographical Union
– Commission on Mountain Geoecology –
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FRANZ STEINER VERLAG WIESBADEN GMBH

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Preface

The problem of interaction between nature and man in tropical mountain areas has in more recent times increasingly become the study object of a great number of disciplines. Scientists give their opinion on the ever growing and lasting manipulations to which these areas are exposed due to man's misuse and the effects of which also spread to the forelands. Since the many studies and programs of individual researchers or larger cooperative projects have produced a great number of results, which, however, only seldom reach all interested parties, it is all the more necessary to exchange results and experiences in symposia and colloquia and to discuss relevant problem areas.

In this connection, several symposia have been held since 1969 within the framework of the Commission of Earth Science Research of the Akademie der Wissenschaften und Literatur, Mainz and in conjunction with the Commission on Mountain Geoecology of the International Geographical Union (cf. Bruno MESSERLI in the following contribution).

With this symposium on "Natural Environment and Man in Tropical Mountain Ecosystems" this tradition was continued. Scientists were brought together again to make their contribution to interdisciplinary talks in the form of lectures and discussions on selected subjects. Special attention was devoted to the aspects of interaction between ecological and socio-economic systems in tropical mountain areas. Methods for identifying natural hazards were dealt with and the interaction between mountain areas and forelands discussed as well. In addition, information gaps in the various subdisciplines were to be closed, e.g. in geobotanics, climatology, geology and geomorphology in the tropical high mountain areas.

23 lecturers and 10 additionally invited experts on tropical mountains participated in the symposium (see list of participants). The following disciplines were represented: Geography with its physical and socio-economic branches, geobotany, zoology, geomedicine and geology. The limited number of participants and the profound knowledge of the material permitted a fruitful discussion. The interdisciplinary composition of the group of participants also proved to have an extremely positive effect. Lectures and discussions were held in German, English, French and Spanish. The participants agreed to submit the text of their lectures for the proceedings in English to allow a wide international distribution of the results of the symposium. In view of the sometimes lively discussions, the written text of several contributions was revised for this volume and, therefore, deviates slightly from the lecture given. Unfortunately, it was not possible to fully incorporate in the volume the illustrated documentation shown during the lectures.

According to the participants, the interdisciplinary discussion and the comparative approaches for all tropical mountain areas were extremely useful and particularly successful. Many lectures came to the conclusion that the convergent natural potential of the tropical mountain areas results in similar socio-cultural structures which, however, allow for independent special developments. This concept was the subject of intensive discussions. A considerable number of lectures concentrated on the biological aspects of ecosystems in the tropical high mountain areas, and for good reason, since the biotic world forms the center of the nature-man-system and because it is the vegetation which most clearly reflects the state of an ecosystem. It became most strikingly clear that man has changed the ecosystems of the mountain areas in various directions. This is partly attributable to the fact that the climatic history developed differently in the individual regions, thus causing different cultural courses. A further important result was that most of the lectures viewed man as part of the ecosystem who in nature-oriented systems is still strongly embedded in the system, whereas in developed areas he proves to be the crucial factor in the change of high mountain areas which are particularly sensitive to human interference.

At the end of the conference the participants expressed spotaneous interest in a continuation of such symposia, which clearly showed the great importance attached to meetings of this type with emphasis on the exchange of information between the disciplines and representatives of the different countries.

The Akademie der Wissenschaften und der Literatur in Mainz deserves our special gratitude. The President, Professor Dr. Heinrich OTTEN, insisted on a welcome address on behalf of the academy. The Secretary General, Dr. Günter BRENNER and his colleagues, particularly Frau Brigitte HERTRAMPF and Herr Reinhard LUKAS, provided great assistance in the technical management of the symposium. Food and drink were provided in the rooms of the academy and together with an evening spent at a wine-growing estate in Nierstein created a familiar atmosphere.

Dr. Winfried GOLTE of the Geographical Institute of Bonn University has assisted me in the preparation of the symposium, and Dr. Joan KENWORTHY was kind enough to check linguistically the manuscripts of participants from non-English speaking countries. The Cartographic Department of the Bonn Geographical Institute has, if necessary, revised maps and diagrams of the individual authors and produced composition patterns. Herr Walter ERLENBACH, Geographical Institute of Bonn University, undertook the tedious work of proof-reading and editing the manuscripts. The typographical preparations within the framework of the Akademie der Wissenschaften und der Literatur were the responsibility of Herr Ludolf HENN. My special thanks go out to all persons mentioned.

Bonn, April 1984 *Wilhelm Lauer*

Vorwort

Das Problem der Interaktion von Natur und Mensch in den tropischen Gebirgsräumen ist in jüngerer Zeit häufiges Studienobjekt einer Vielzahl von Disziplinen geworden. Wissenschaftler nehmen Stellung zu den immer stärker werdenden nachhaltigen Eingriffen, die diese Räume durch eine Mißnutzung des Menschen erfahren, und deren Wirkung auch auf die Vorlandräume übergreift.

Da die vielen Studien und Programme einzelner Forscher oder größerer Gemeinschaftsprojekte bereits eine hohe Anzahl von Ergebnissen zeitigen, die aber nur selten alle Interessenten erreichen, ist es um so dringender geboten, in Symposien und Kolloquien Ergebnisse und Erfahrungen auszutauschen und relevante Problembereiche zu diskutieren.

In diesem Sinne fanden im Rahmen der Kommission für Erdwissenschaftliche Forschung der Akademie der Wissenschaften und der Literatur, Mainz, in Verbindung mit der Commission on Mountain Geoecology der International Geographical Union seit 1969 mehrere Symposien statt (s. Bruno MESSERLI im folgenden Beitrag).

Mit diesem Symposium über „Natur und Mensch in Ökosystemen tropischer Hochgebirge" wurde diese Tradition fortgesetzt. Wissenschaftler wurden erneut zusammengeführt, um mit Vorträgen und Diskussionen zu ausgewählten Themen ihren Beitrag zum interdisziplinären Gespräch zu liefern. Das besondere Augenmerk wurde auf Aspekte der Wechselwirkung ökologischer und sozioökonomischer Systeme im tropischen Gebirgsraum gerichtet. Ebenso wurden Methoden der Erfassung von Naturgefahren (hazards) behandelt und die Interaktion zwischen Gebirgsräumen und Vorländern diskutiert. Darüber hinaus sollten Informationslücken in einzelnen Teildisziplinen geschlossen werden, z. B. im Bereich der Geobotanik, der Klimatologie, der Geologie und Geomorphologie der tropischen Hochgebirge.

Am Symposium beteiligten sich 23 Vortragende und 10 zusätzlich eingeladene Kenner tropischer Gebirge (s. Teilnehmerliste). Folgende Wissenschaften waren vertreten: Geographie mit ihren physischen und sozioökonomischen Teildisziplinen, Geobotanik, Zoologie, Geomedizin und Geologie. Durch die beschränkte Teilnehmerzahl und die einschlägige Kennerschaft der Materie kam eine fruchtbare Diskussion zustande. Die interdisziplinäre Zusammensetzung der Teilnehmer aus acht Ländern erwies sich ebenfalls als äußerst positiv. Vorgetragen und diskutiert wurde in Deutsch, Englisch, Französisch und Spanisch. Die Teilnehmer einigten sich darauf, die schriftlichen Fassungen der Vorträge für den Tagungsband in Englisch vorzulegen, um damit eine weite internationale Verbreitung der Ergebnisse dieses Symposiums zu ermöglichen. Einige Beiträge wurden – auch aufgrund der zum Teil lebhaften Diskussionen – in der schriftlichen Fassung für den vorliegenden Band umgearbeitet und weichen daher vom mündlichen Vortrag leicht ab. Leider war es nicht möglich, die gesamte bildliche Dokumentation während der Vorträge in den Band aufzunehmen.

Nach Meinung der Teilnehmer war die interdisziplinäre Diskussion und die vergleichende Betrachtungsweise über alle tropischen Gebirgsregionen hin äußerst nützlich und besonders ergebnisreich. Bei vielen Vorträgen ergab sich die Feststellung, daß konvergente Naturausstattungen der tropischen Gebirge in der Anlage ähnliche sozio-kulturelle Ordnungen zur Folge haben, die dann jedoch eigenwilligen Sozialentwicklungen breiten Raum geben. Dieser Gedanke wurde intensiv diskutiert. Bei einer größeren Zahl von Referaten standen die biologischen Aspekte der Ökosysteme der tropischen Hochgebirge im Vordergrund, selbstverständlich aus guten Gründen, da die biotische Welt im Zentrum des Natur-Mensch-Systems steht und besonders die Pflanzenwelt den Zustand eines Ökosystems am klarsten wiedergibt. Deutlich wurde in auffälliger Weise, daß der Mensch die Ökosysteme der Gebirge in verschiedenen Richtungen hin verändert hat. Dies ist zum Teil darauf zurückzuführen, daß die Klimageschichte in den einzelnen Regionen unterschiedlich ablief und dadurch die Kulturentwicklung andere Wege nahm.

Ein wichtiges Ergebnis war es auch, daß die meisten Referenten den Menschen als Teil des Ökosystems betrachteten. In naturnahen Systemen ist er noch stark in diese eingebunden, in entwickelten Räumen zeigt er sich als bedeutender „Veränderer" tropischer Hochgebirgslandschaften, die sich als besonders labil gegenüber menschlichen Eingriffen erweisen.

Am Schluß der Veranstaltung wurde von den Teilnehmern das Interesse an der Fortsetzung solcher Symposien spontan ausgedrückt, womit der hohe Stellenwert dieses Veranstaltungstyps mit dem Akzent auf dem Informationsaustausch zwischen den Disziplinen und Vertretern verschiedener Länder deutlich aufgezeigt wurde.

Der Akademie der Wissenschaften und der Literatur in Mainz gebührt großer Dank. Der Präsident, Herr Professor Dr. Heinrich OTTEN, ließ es sich nicht nehmen, ein Grußwort der Akademie zu sprechen. Der Generalsekretär, Herr Dr. Günter BRENNER, und seine Mitarbeiter, insbesondere Frau Brigitte HERTRAMPF und Herr Reinhard LUKAS, leisteten viel Hilfe bei der technischen Abwicklung des Symposiums. Die Bewirtung der Teilnehmer fand in den Räumen der Akademie statt und sorgte ebenso wie ein gemeinsamer Abend in einem Weingut in Nierstein für eine persönlich-familiäre Atmosphäre.

Herr Dr. Winfried GOLTE, Geographisches Institut der Universität Bonn, hat mich bei der Vorbereitung des Symposiums unterstützt. Frau Dr. Joan KENWORTHY hat sich der Mühe unterzogen, die in Englisch verfaßten Manuskripte von Teilnehmern aus nicht englischsprachigen Ländern durchzusehen. Die kartographische Abteilung des Bonner Geographischen Instituts hat Karten und Skizzen der einzelnen Autoren, wenn nötig, überarbeitet und Druckvorlagen hergestellt. Herr Walter ERLENBACH, Geographisches Institut der Universität Bonn, hat sich der mühevollen Arbeit unterzogen, die Manuskripte in druckfertigen Zustand zu bringen und die redaktionellen Vorarbeiten auszuführen. Die drucktechnischen Vorbereitungen im Rahmen der Akademie der Wissenschaften lagen in Händen von Herrn Ludolf HENN. Allen Genannten sei an dieser Stelle herzlich gedankt.

Bonn, im April 1984 *Wilhelm Lauer*

Work and History of the Commission on Mountain Geoecology of the International Geographical Union (IGU)

Bruno Messerli

Chairman of the IGU-Commission on Mountain Geoecology

The history and activity of the Commission on Mountain Geoecology is connected closely with the Federal Republic of Germany in two ways:

For the third time, the Academy of Sciences and Literature in Mainz has offered its hospitality to our commission. After the Symposium in 1969 about the Geo-Ecology of the Mountainous Regions of Eurasia and in 1974 about the Geoecological relations between the Southern Temperate Zone and the Tropical Mountains we met again in Mainz in 1983. The topic was "Natural Environment and Man in Tropical Mountain Ecosystems". Scientists from mountain regions from all over the world are deeply grateful for this continued and traditional hospitality which is so generously offered.

Two members of the Commission on Earth Science Research of the Academy of Mainz have considerably influenced the history of the commission and its aims since its foundation. "The commission owes its existence to the inspiration and genius of CARL TROLL, who has devoted much of his long and distinguished professional career to the study of the high mountains of the world, especially to their three-dimensional characteristics and to the phenomenon of timberline" (JACK IVES, in: Arctic and Alpine Research, Vol. 5, No. 3: A 1). After his unexpected death in July 1975, WILHELM LAUER continued his work in the Academy and in the Commission, and was responsible for the editing of the Proceedings of the Second Symposium in Mainz in 1974. WILHELM LAUER, the initiator of a new research phase in the ecology of the tropical high mountains, especially in Central and South America, thereby became a leading member of the Commission on Mountain Geoecology, which culminated in the brilliant Symposium in Mainz in 1983. It was he that determined the objectives of the meeting, invited a homogeneous group of scientists from all the high mountain regions from all over the world, found the necessary support and provided the opportunity of having interesting and fascinating talks and discussions in a friendly atmosphere. We are greatly indebted to him for this.

The history of the Commission, intimately related to the Academy of Mainz and, with it, the latter's two members, CARL TROLL and WILHELM LAUER, will be outlined in a short summary:

Commission on High Altitude Geoecology 1968–1976
Commission on Mountain Geoecology since 1976
(International Geographical Union, IGU)

1966 IGU Regional Conference Mexico

Symposium in collaboration with UNESCO about the mountainous regions of the Tropical Americas.
Publication by CARL TROLL (Editor, 1968): Geo-Ecology of the Mountainous Regions of the Tropical Americas. Proceedings of the UNESCO Mexico Symposium, August 1–3, 1966. Colloquium Geographicum Bd. 9, Bonn.

1968 IGU 21st Congress New Delhi

Foundation of the Commission on High Altitude Geoecology.
First Chairman: CARL TROLL, Bonn.

1969 **IGU Commission Symposium in the Academy of Mainz (Commission of Earth Science Research)**
Publication by CARL TROLL (Editor, 1972): Geo-Ecology of the Mountainous Regions of Eurasia. Proceedings of the Symposium of the IGU Commission on High Altitude Geoecology, November 20–22, 1969. Erdwissenschaftliche Forschung der Akademie der Wissenschaften und der Literatur, Bd. IV, Wiesbaden.

1972 **IGU 22nd Congress Montreal**
Commission Symposium in Calgary: The High Mountains of North America and the Upper Timberline in the Earth's Different Climatic Zones.
Field Excursion in the Rocky Mountains.
Local Organizer: STUART HARRIS. New Chairman of the Commission: JACK IVES, Boulder.
Publication by JACK IVES and KATHLEEN SALZBERG (Editors, 1973): Proceedings of the Symposium of the IGU Commission on High Altitude Geoecology. Arctic and Alpine Research, Special Issue, Vol. 5, No. 3, Part 2, Boulder, Colorado.

1973 **UNESCO – MAB 6 Workshop Salzburg**
Some members of the Commission were participating (MAB 6: Impact of Human Activities on Mountain and Tundra Ecosystems). This workshop was followed by several regional meetings in Lillehammer 1973, La Paz 1974, Kathmandu 1975. (See UNESCO – MAB publications).

1974 **IGU Commission Symposium in the Academy of Mainz (Commission of Earth Science Research)**
Publication by CARL TROLL and WILHELM LAUER (Editors, 1978): Geoecological Relations between the Southern Temperate Zone and the Tropical Mountains. Proceedings of the Symposium of the IGU Commission on High Altitude Geoecology, November 21–23, 1974. Erdwissenschaftliche Forschung der Akademie der Wissenschaften und der Literatur, Bd. XI, Wiesbaden.

1976 **IGU 23rd Congress Moscow**
Commission Symposium and Field Excursion in the Caucasus.
Local Organizer: RIMMA ZIMINA, Moscow.
Change of the Commission's name from "High Altitude Geoecology" to "Mountain Geoecology".
Publication by JACK IVES and RIMMA ZIMINA (Editors, 1978): Mountain Geoecology and Land Use Implications. Proceedings of the Symposium of the IGU Commission on High Altitude Geoecology, Caucasus Mountains. Arctic and Alpine Research, Vol. 10, No. 2, Boulder, Colorado.

1980 **IGU 24th IGU Congress Tokyo**
Commission Symposium in Tsukuba/Tokyo and Field Excursion in the Japanese Alps.
Local Organizer: MASATOSHI YOSHINO.
New Chairman of the Commission: BRUNO MESSERLI, Berne. Publication of the Proceedings as single contributions in different issues of Mountain Research and Development 1981–1983, edited by JACK IVES.

1981 **United Nations University (UNU) – UNESCO – IGU**
Berne – Riederalp Workshop on "Stability and Instability of Mountain Ecosystems".
Local Organizer: BRUNO MESSERLI.
Publication by JACK IVES and BRUNO MESSERLI in Mountain Research and Development, Vol. 3, No. 2 and No. 3, 1983, Vol. 4, No. 1, 1984.

1982 **International Mountain Society (IMS) – IGU – UNESCO – UNU**
Mohonk (New York) Seminar: Renewable Resource Development in the Mountain Areas of the World.
Local Organizer: JACK IVES.
Report published in Mountain Research and Development, Vol. 3, No. 2, 1983, 177–181.

1983 **IGU Commission Symposium in the Academy of Mainz (Commission of Earth Science Research)**
Symposium on Natural Environment and Man in Tropical Mountain Ecosystems.
Local Organizer: WILHELM LAUER, Bonn.
Publication by WILHELM LAUER (Editor, 1984): Natural Environment and Man in Tropical Mountain Ecosystems. Proceedings of the Symposium of the Akademie der Wissenschaften und der Literatur in Mainz – Kommission für Erdwissenschaftliche Forschung – in connection with the IGU Commission on Mountain Geoecology, February 24–26, 1983. Erdwissenschaftliche Forschung der Akademie der Wissenschaften und der Literatur, Bd. XVIII, Stuttgart.

If we take a look at the history of the commission, we have discovered that a certain change has taken place since its foundation. The following is an attempt to structure its history in three phases:

The first phase was in the sixties and early seventies and was dominated by a comparative and descriptive survey of the mountain systems of the world, especially from a three-dimensional view. This was an extremely fruitful geographical-ecological orientation of research, having an important effect on future generation of scientists.

The second phase in the seventies was characterised by more measurements and experiments, by more absolute dating of ages and by introducing exact and discipline-oriented methods. This direction of research was fundamental for a better understanding of the processes in space and time.

The third phase was strongly determined by the ecological problems in the mountains of the developing world. The more academically oriented approach at the beginning changed slowly into a more application-oriented direction. This did not mean a loss of pure scientific work. On the contrary, the need for more and better basic data with a possible application as regards urgent ecological problems was a challenge for scientists of different disciplines.

This last phase also brought closer collaboration with international organizations such as UNESCO, UNU (United Nations University) and IMS (International Mountain Society). Finally, the creation of a new journal called "Mountain Research and Development" with JACK IVES as Editor-in-Chief was a result of the world-wide collaboration of mountain scientists in view of the world-wide problems in mountain development.

In the light of these considerations the Symposium of the Academy of Mainz in 1983 has a special position and significance. The high mountains of the tropics will be playing a fundamental role in future development of the Third World. This Symposium has very clearly fixed the direction of the commission's work for the next few years.

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* Participants with lecture published in this volume.
** Participant with lecture. Only abstract published in this volume.
*** Participant with lecture not published in this volume.

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Nature and Man in the Ecosystems of Tropical High Mountains – Introductory Remarks –

Wilhelm Lauer

With 2 Figures

Apart from the nival and subnival belts, tropical mountains have always been favourite settlement areas of man. This can be seen by comparing a map of the old very advanced civilizations with a map of the earth's recent population. In terms of natural resources, tropical mountains are ecologically favoured regions, where often the most advanced cultures have developed, as in the Andes of Central and South America, Ethiopia, and parts of the Himalayan Mountains. The study of tropical mountains is therefore a fascinating task and this has stimulated many disciplines to conduct research work on the subject quite early in their development.

Since its foundation the Commission on Mountain Geoecology of the IGU has considered it to be its responsibility to conduct symposia on high mountain research (see: TROLL, 1972; IVES and SALZBERG, 1973; TROLL and LAUER, 1978), and its members have always tried to look for means of cooperation beyond their specific disciplines and to engage in interdisciplinary discussions.

The "Akademie der Wissenschaften und der Literatur in Mainz" is the appropriate place for such events, as it represents a forum for contact between different scientific disciplines. Since interdisciplinary cooperation on a research topic is often extremely difficult, it seems to me all the more necessary to exchange and discuss research results at least in colloquia and symposia.

Many aspects of high mountain research have been summed up under the theme "Nature and Man". The reason for using the modern catchword "Ecosystem" as the basic concept in this connection is the fact that the processes of nature and their relationship with man's radius of action can best be described by this term.

An ecosystem approach to the relationships between nature and man is by no means new. I should like to mention in this connection a study by our past master of the IGU-Commission on High Mountain Geoecology, Carl TROLL, who – based on his field work in the Bolivian Andes in 1926/28 – presented a study in 1943 with the title: *The Position of the Indian High Cultures in the Landscape Structure of the Tropical Andes.* With regard to its content, the essay could also have been named: Indian High Cultures and Andean Eco-Systems.

It is symptomatic that approximately 10 years ago studies in the ethnology, sociology and anthropology of Andean countries started to adopt TROLL's principle of "verticality" in the landscape structure of the Andes and to incorporate it in social and sociological research. In this connection I should mention the study by John MURRA (1975): *El control vertical de un máximo de pisos ecológicos en la economía de las sociedades andinas.*

In his recent *Tansley Lecture,* the Göttingen botanist Heinz ELLENBERG (1979), by emphasizing scientific and biological aspects, has recapitulated the basic questions of a geoecological approach in the high mountain ecosystem of the Andes. He presents a very useful concept in not attributing change in mountain ecosystems exclusively to postglacial developments, which would mean giving priority to natural factors, but attaching greater importance to changes induced by man.

ELLENBERG proceeds from the assumption that the natural systems were modified by man throughout the entire Holocene, particularly since the climatic optimum. His idea goes further than the views held by

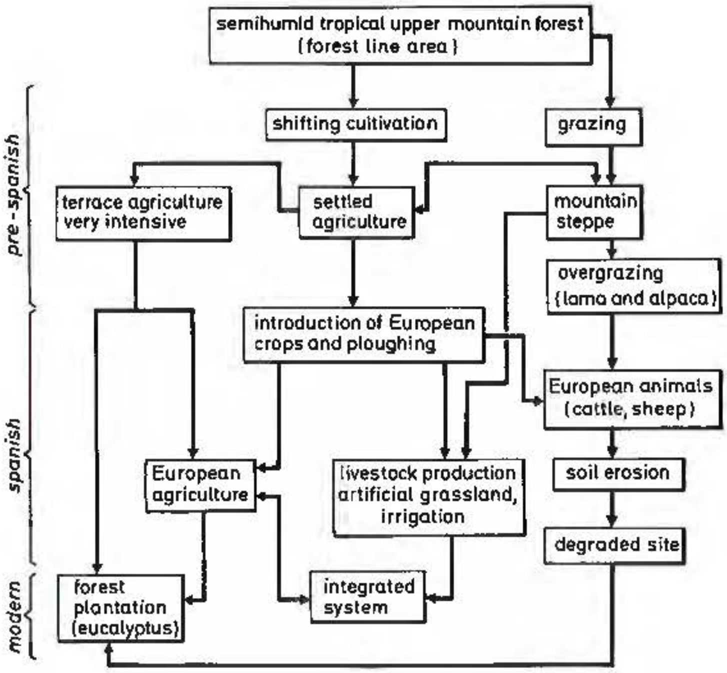

Fig. 1. Successions of Ecosystems in the Andes (modified after: ELLENBERG, 1979, p. 412, fig. 6).

TROLL and other geo-botanists, and he emphasizes the importance of man's impact on nature by pointing out that the present timberline in the Andes is largely attributable to man's intervention. Thus, he also interpretes the polylepis problem, to the effect that these high mountain trees in many parts of the Andes must be seen exclusively as the remnants of human intervention within a formerly much larger forest distribution in the Páramo and Puna landscapes of today. Even if this is a hypothesis difficult to prove, it does serve to stimulate present research.

For the mountain areas of Africa, a different but similar concept must be applied. In these regions it is not so much man but large animals that have been and still are a significant ecological factor. Any expert familiar with tropical high mountain areas in the Old and New World is aware, for example, that the flora in the mountain regions of Kenya is subject to strong changes brought about by the extremely high population of large animals.

On the basis of his assumption of "Man's Impact", and one could add the "Impact of Animals", ELLENBERG arrives at the formulation of so-called "successions of ecosystems", the main phases of which are particularly marked by the impacts of sociological and economic changes. As an example, ELLENBERG quotes the Spanish conquest in South America. Meanwhile, however, we know that the rise and fall of highly civilized nations in the Andes were also a result of changes in the ecosystem potential. Examples in the history of very advanced Mexican civilizations in the highlands prove this quite impressively. A diagram which supports this idea (see Fig. 1) may serve as an illustration.

Within the framework of the Mexico Project, carried out by the German Research Society (DFG), it was possible for HEINE (1976) and LAUER (1981) to confirm, for example, that the anthropogenic impact on the natural potential in a very early stage of farming led to extensive soil erosion, with man-made geomorphological forms (barrancas) upsetting, even irreparably damaging, the natural potential of wide landscapes.

Ever since the problems of the Third World began to strongly influence our period, such systems-ecological questions have been dealt with intensively in tropical high mountain research. This is attributable to the fact that the unnatural utilization of ecosystems by man has led to particularly pronounced effects in the high mountain areas. The steepness of the relief accelerates destruction of the natural plant cover as well as soil erosion, causing irreversible damage to the natural potential.

As the ecosystems in the high mountain areas vary both vertically and horizontally, human impact on the differing natural systems of the tropical high mountains can easily be analysed. As nature-adapted behavioral patterns of native tribes have survived in enclaves of high mountain regions, the successful study of intact natural systems is frequently possible.

The man-nature-problems of high mountain areas have given rise to the initiation of a great number of projects. These projects constitute the researcher's answer to "Mountain Mismanagement" (IVES, 1981). Scientists from almost all relevant areas of research are cooperating in these projects. Many of these studies are, for example, integrated in the MAB-6 "Study of the Impact of Human Activities on Mountain Ecosystems". Projects and concepts of the "IGU-Commission on Mountain Geoecology" are also part of this program. The International Biological Program (IBP) also constitutes an integral part of ecological mountain research within the framework of MAB-6. The work of the members of the Working Group on high mountain research, as well as the "UNU-Highland-Lowland Interactive Systems Project" under Jack IVES, is assigned to the MAB project (see: IVES, 1981; IVES and MESSERLI, 1981; LITTLE et al., 1981).

When analysing the research work of recent years with regard to the type of research on the basis of relevant journals, two directions are clearly visible: scientific basic research on the one hand and applied research on the other. Basic research, which is to form the basis of this symposium, will – according to my bibliographic investigations – concentrate on six topics:

1. The closing of gaps in the individual sub-disciplines, such as studies on vegetation and climate as well as geological and geomorphological studies.
2. Research on the interaction between natural potential and methods of management, with emphasis on the destruction of vegetation and the soil erosion resulting therefrom.
3. Socio-economic and ecological research regarding social changes and their impact on the utilization and natural potential of high mountain areas.
4. The creation of natural hazards in high mountain areas.
5. The problem of highland-lowland interaction.
6. Questions relating to agricultural ecology and, thus, the productivity of present and former systems of land utilization in high mountain areas.

Questions with a multi-disciplinary research approach almost always deal with the upsetting of the ecological balance by man. They aim at establishing bases for strategies to re-establish the balance between the natural potential and utilization, particularly since the high mountain regions represent essential supplementary areas to the lowlands.

According to an evaluation of the latest issues of "Current Geographical Publications" and the last nine annual sets of the "Bibliographie Geographique Internationale", studies on the Andes prevail regionally, with a focus on the middle Andes, i. e. Peru. A further focal point of high mountain research is the area of New Guinea, which has been and is being dealt with by Australian research groups. In Asia, studies on Nepal and the Himalayan Mountains prevail. African studies concentrate on Eastern Africa, particularly Ethiopia (see Fig. 2).

The regional distribution of studies of past years on tropical high mountains corresponds with the structure of papers given at this symposium. Thematically, the papers presented at this meeting reflect a wide spectrum of broadly based ecosystem-research. They do not provide an integrated approach from the outset. Partial aspects of an ecosystem analysis are presented, particularly in terms of basic research.

The majority of the papers concentrate on biological aspects of the ecosystems which are dealt with by geobotanists, zoologists, and geographers. The reason for this is quite obvious, for the biotic world forms the nucleus of the nature-man-system, particularly since the fauna functions as an integrator and indicates the state of the ecosystem, indirectly reflecting the extent to which man has changed the ecosystem in one direction or the other. The temporal changes of the natural systems of tropical high mountains in the course of the history of climate are the focus of another set of papers.

In other papers, attempts are made to present the interdependence and spatial distribution of the man-nature-relationships. In this connection it is important that the majority of contributers regards man as an

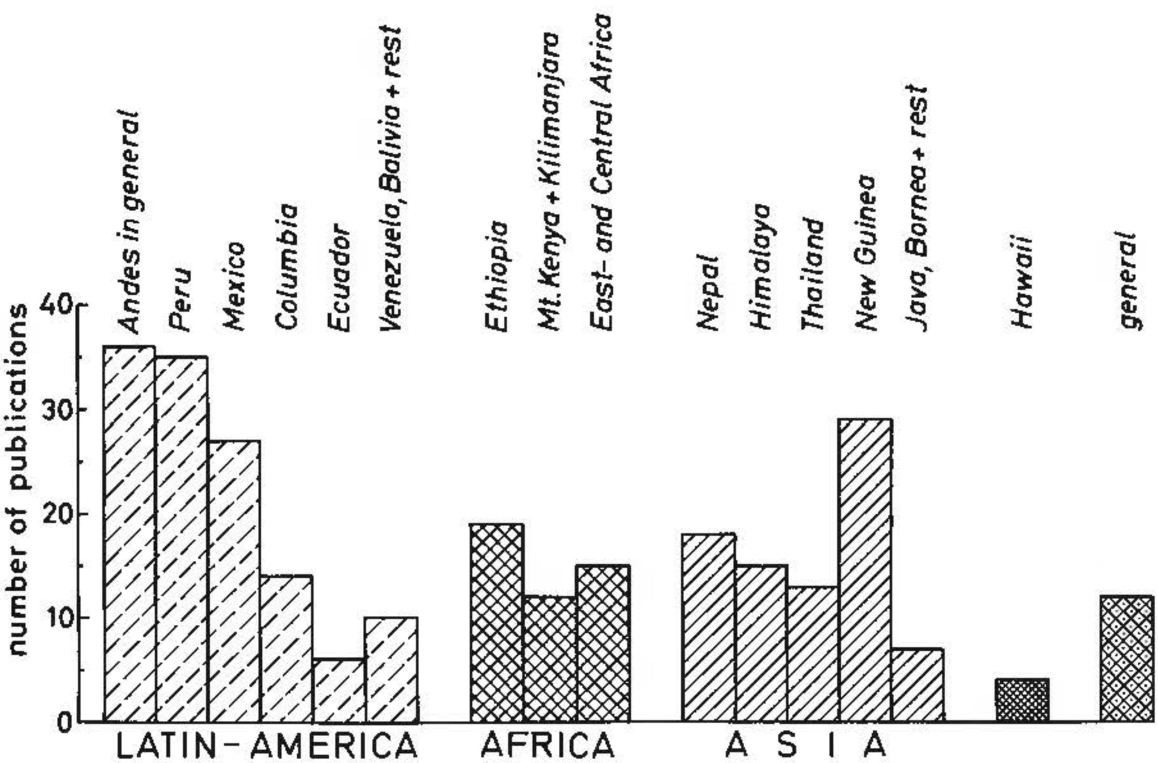

Fig. 2. Number of publications on tropical high mountains, 1972–1980 (source: Current Geographical Public., 1973–1981, Bibl. Geogr. Internat., 1973–1981).

integral part of the ecosystem, for he is embedded in it and lives from it. Moreover, man is the only creature consciously able to conceive and thus to change an ecosystem one-sidedly. It must, therefore, be the task of science to interpret the ecosystems to such a degree that the consequences of possible manipulations are predictable. As tropical high mountain areas are particularly sensitive to human manipulation, as a consequence of the steepness of the relief and increased climatic impact, research must concentrate on this area in particular.

In this connection, basic research should be conducted independently and devote itself to research on ecosystem by inventory-taking, in order to provide the practitioners with the tools needed in the preparation of strategies for the development of these areas.

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Climatic Survey in the Kenya Highlands With Particular Reference to the Needs of Farmers

Joan M. Kenworthy

With 5 Figures and 4 Tables

1. The Importance of the Kenya Highlands for Land Use and Settlement

By presenting relatively cool and wet conditions, attractive to agriculture and settlement, the climate of the Kenya Highlands has been largely responsible for the history, development and economy of Kenya and is still probably its most vital resource.

For little more than half a century, Europeans farmed lands between the densely populated area around the Kavirondo Gulf and those areas occupied by the Kikuyu and Meru east of the Aberdares, and by the Kamba to the south-east (Fig. 1). The European farmers experienced successes and failures that were influenced by a complexity of economic, political and other factors, not least "the country's perverse meteorology" (MILLER, 1972) and years of low rainfall, 1898–1899, 1909, 1918, 1921, 1933–1934, 1939, 1943 and 1945, highlighted the risk of famine in the areas of increasingly dense African populations on the fringes of the highlands. Changes in land use from 1946 to the present have included "betterment" schemes, land consolidation, irrigation schemes, growth in the cash economy of small African farms, the purchase of European farms by Africans, the conversion of large farms to small-holdings within highly organised African settlement schemes and group ownership schemes of various kinds. Throughout this century, farming in the Kenya Highlands has involved some sort of pioneering, as changes in land use and management and in the peoples concerned have presented innumerable challenges of adaptation to variable climatic conditions.

2. Climatic Data, Research and Publications Relating to the Kenya Highlands

The concentration of meteorological stations and rain gauges between approximately 1000 and 2500 m above sea level (Table 1) not only reflects a similar concentration of population and settlement, but also shows how this has biased the observation of climatic conditions in Kenya – least information is available for the semi-arid rangelands at low and medium altitudes and for areas above 2500 m. The distribution of rain gauges for which series are available for the period 1931–1960 (Fig. 2 and 4) shows a concentration in the formerly scheduled, i.e. European areas.

The first detailed description of conditions in the highlands was by Joseph THOMSON (1885), who travelled through Masai country and across the Aberdares in March 1884 and observed the Masai in despair through "almost utter loss of their cattle ... the absence of rain in the low-lying districts causing them to remain up in the cold bleak highlands". With the building of the railway inland from Mombasa came attempts at European settlement and agriculture, and a report on the *Agricultural Prospects of the Plateaux of the Ugandan Railway* was presented to the British Parliament (LYNE, 1902). The author referred to the severe drought and famine of 1898–1899 and quoted rainfall data for Kikuyu (ca. 2000 m) from 1896. Rainfall and temperature observations were made at Nairobi Railway Station (1661 m) from 1904 and a number of observing stations were set up in other districts in subsequent years, summaries of

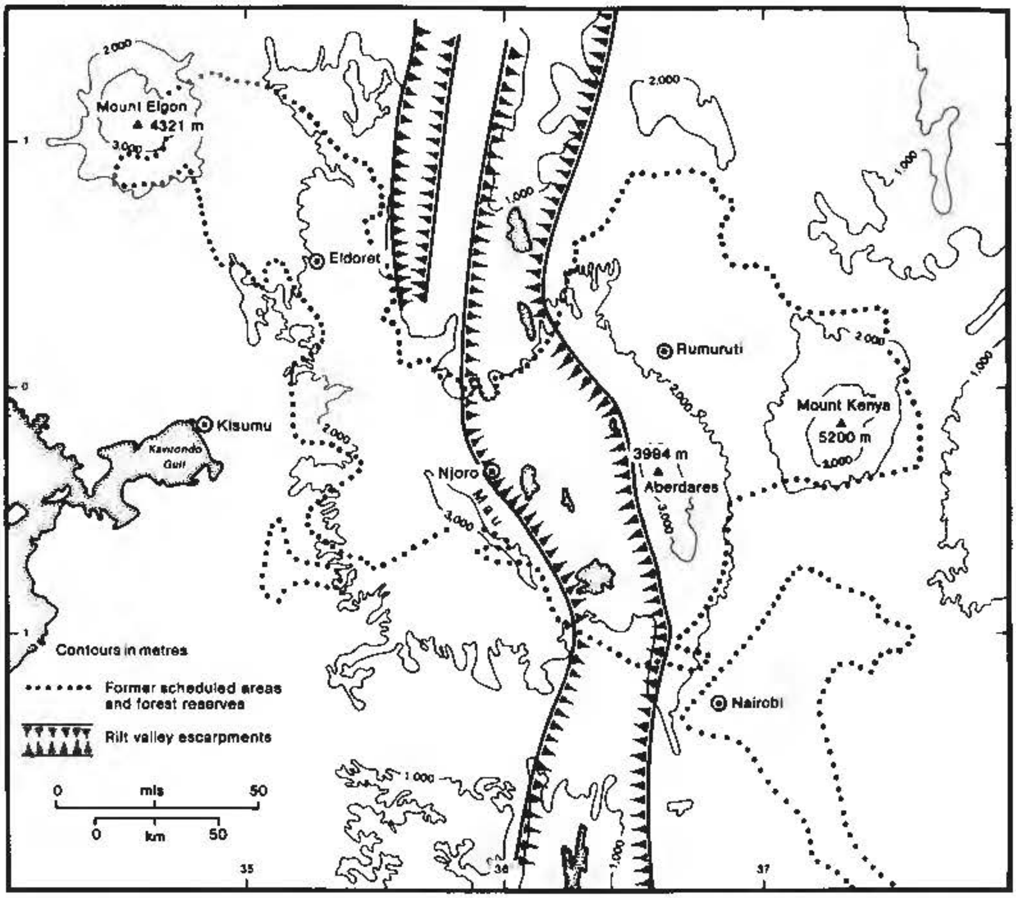


Fig. 1. The Kenya Highlands.

Table 1. Number of rain gauges and meteorological stations in Kenya

Altitude feet	meters	No. of rain gauges*	No. of met. stations**
12000	3660		
		1	
11000	3350		
		8	
10000	3050		
		19	3
9000	2745		
		62	11
8000	2440		
		108	20
7000	2135		
		215	41
6000	1830		
		171	32
5000	1525		
		143	12
4000	1220		
		73	16
3000	915		
		35	4
2000	610		
		24	3
1000	305		
		94	17
0	0		

* Source: Summary of rainfall in Kenya for the year 1971. E. AFR. MET. DEPT. (1973).

** Source: Temperature data for stations in East Africa, Part I. Kenya. E. AFR. MET. DEPT. (1970).

rainfall and temperature appearing regularly in reports of the Department of Agriculture, British East Africa.

The Joint Meteorological Service for British East Africa was inaugurated in 1929 (WALTER, 1929). Although the Meteorological Service, later known as the East African Meteorological Department, played the major role in setting up a network of meteorological stations, climatic observations and research have also been carried out by hydrological (Public Works Department), agricultural, veterinary, disease and crop research institutions (E. Afr. Met. Dept., 1967). The Kenya Meteorological Department has recently recorded most available data on magnetic tape (NYONI, 1981).

Publications of the East African Meteorological Department have been continued by the now independent Kenya Meteorological Department, an innovation from mid-1972 being a monthly summary of *Farming Weather*, and have been supplemented by research reports of the Institute for Meteorological Training and Research at Nairobi, since 1978, and by publications of the Departments of Geography and Meteorology at the University of Nairobi (e.g., ODINGO, 1962 and OBASI, 1976).

Particular stages can be identified in the application of climatic research to land use in the Kenya Highlands. A growing interest in statistical methods and the existence of records for at least fifteen years for a dense network of rain gauges, led to a study of rainfall reliability, carried out at the East African Agriculture and Forestry Research Organisation (EAAFRO). Maps showed the probability of failing to get 30 inches and 20 inches of rainfall in the year (GLOVER, ROBINSON and HENDERSON, 1954), their particular value being for those who might otherwise have had limited understanding of the inadequacy of mean rainfall values as an unqualified guide to land-use potential. The maps provided a basis for a report on European agriculture in the Kenya Highlands (TROUP, 1953) and for recommendations on land use in the Report of the *East Africa Royal Commission 1953–1955* (DOW, 1955), a report which showed as a result an exceptional awareness of geographical realities for its type (STEEL, 1956). Rainfall probability maps were also published by the East African Meteorological Department (1961). EAAFRO, now KARI (Kenya Agricultural Research Institute), led the way in other applications of climatology to the study of crops, such as pyrethreum and maize (GLOVER, 1955 and 1957), and in studies, which achieved international renown, on the hydrological effects of changes in land use in catchments in the Aberdares and on the Mau plateau, west of the Rift Valley (PEREIRA, 1962; BLACKIE et al., 1979).

The Munitalp Foundation funded an international conference in Nairobi in 1959 (BARGMAN, 1960) and the Munitalp Meteorological Laboratory for the observation of local- and micro-climatic conditions of crops (RIPLEY, 1967). A later conference (WMO, 1974) arose from an interagency project on the *Agroclimatology of the East African Highlands* (BROWN and COCHEME, 1969). Other applied climatological studies in East Africa paid attention to the Kenya Highlands. A hydrometeorological survey of the catchments of Lakes Victoria, Kyoga and Albert was inaugurated in 1968 by the governments of Kenya, Sudan, Uganda, the United Arab Republic and Tanzania, with the assistance of UNDP and WMO. A series of conferences led to a survey of *Rangeland Management and Ecology in East Africa* (PRATT and GWYNNE, 1977), and a joint *East African Rainfall Project* was undertaken by King's College, London, and the Road Research Laboratory (JONES, 1979). Detailed rainfall studies of relevance to the highlands have been conducted by the *USAID-KARI Dryland Cropping Systems Research Project* (STEWART, 1980) and by the Overseas Development Administration research project in the Departments of Applied Statistics and Agricultural Botany of the University of Reading (STERN et al., 1982). In both cases, data has been analysed for stations above 1500 m but in sub-humid areas fringing the highlands proper, though the methods used are applicable to the analysis of conditions in the rainy seasons at higher altitudes.

Reference is made by WINIGER (1981) and HASTENRATH (1984) to specialist studies at high altitudes on Mount Kenya (e.g., BRINKMAN et al., 1968).

3. Major Climatic Characteristics: Rainfall

3.1. *Amount and Seasonality*

Although in general terms the highlands receive more rainfall than the surrounding lowlands, there is no simple relationship between rainfall and altitude (BROWN and COCHEME, 1969) and orographic effects are complex (Fig. 2). Heaviest falls occur on south-east and east-facing slopes of the Aberdares and Mount Kenya, with a maximum between 2000 and 3000 m (THOMPSON, 1966), whereas west of the Rift, west-facing slopes owe their wetter conditions to the interaction between local wind systems induced by the Lake Victoria basin and the synoptic scale circulation (ASNANI and KINUTHIA, 1979). In the western part of the highlands, rainfall amounts are greater than at equivalent altitudes in the highlands flanking the Rift (TRAPNELL and GRIFFITHS, 1960). Rainfall is probably inhibited by subsidence of air in the Rift, as is suggested by the low values of rain per rain day (Fig. 2). Stations at lower altitudes elsewhere tend to show more rain per rain day than stations at higher altitudes, where orographic influence gives frequent light rainfall. Such influence is particularly evident on the upper slopes of the Aberdares, where light drizzle is common and there is a rainfall maximum between 21.00 and 24.00 hours local time, in contrast to the plateau west of the Rift, where afternoon showers of greater intensity are characteristic (EDWARDS, 1979). The Kenya Highlands are regarded as a rain generating area and the radial spread of convective

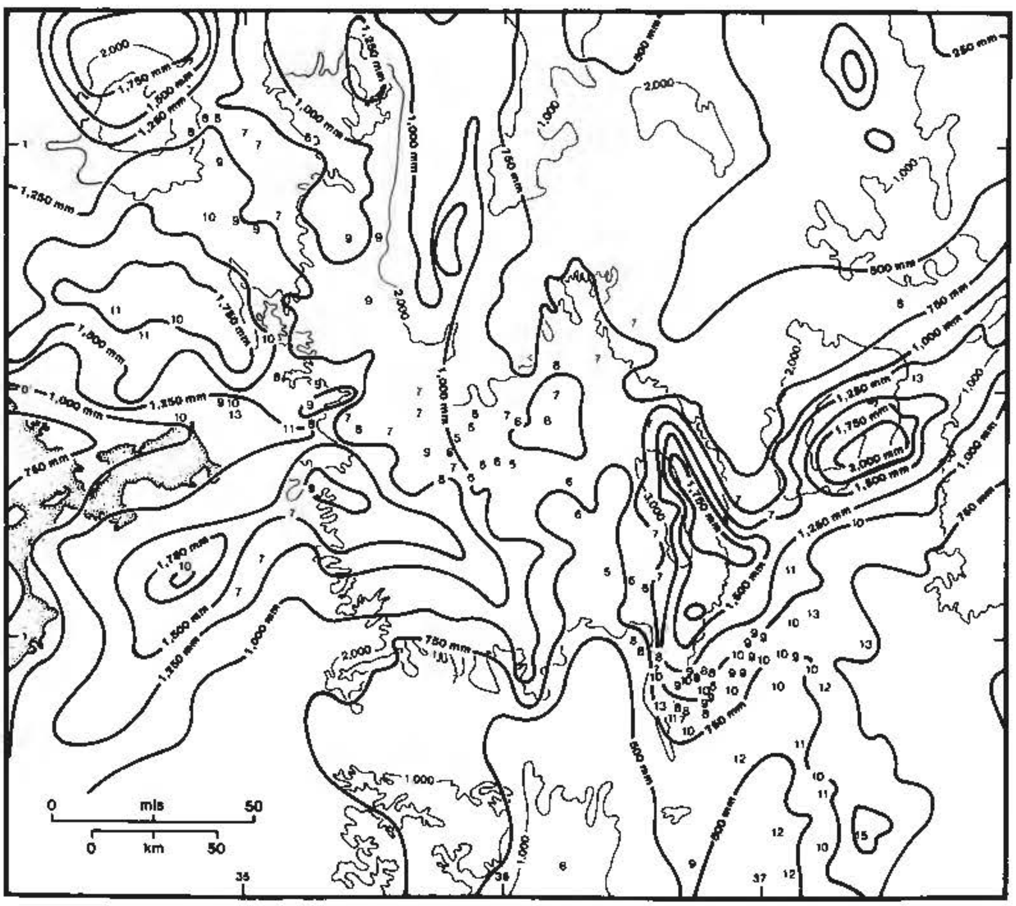
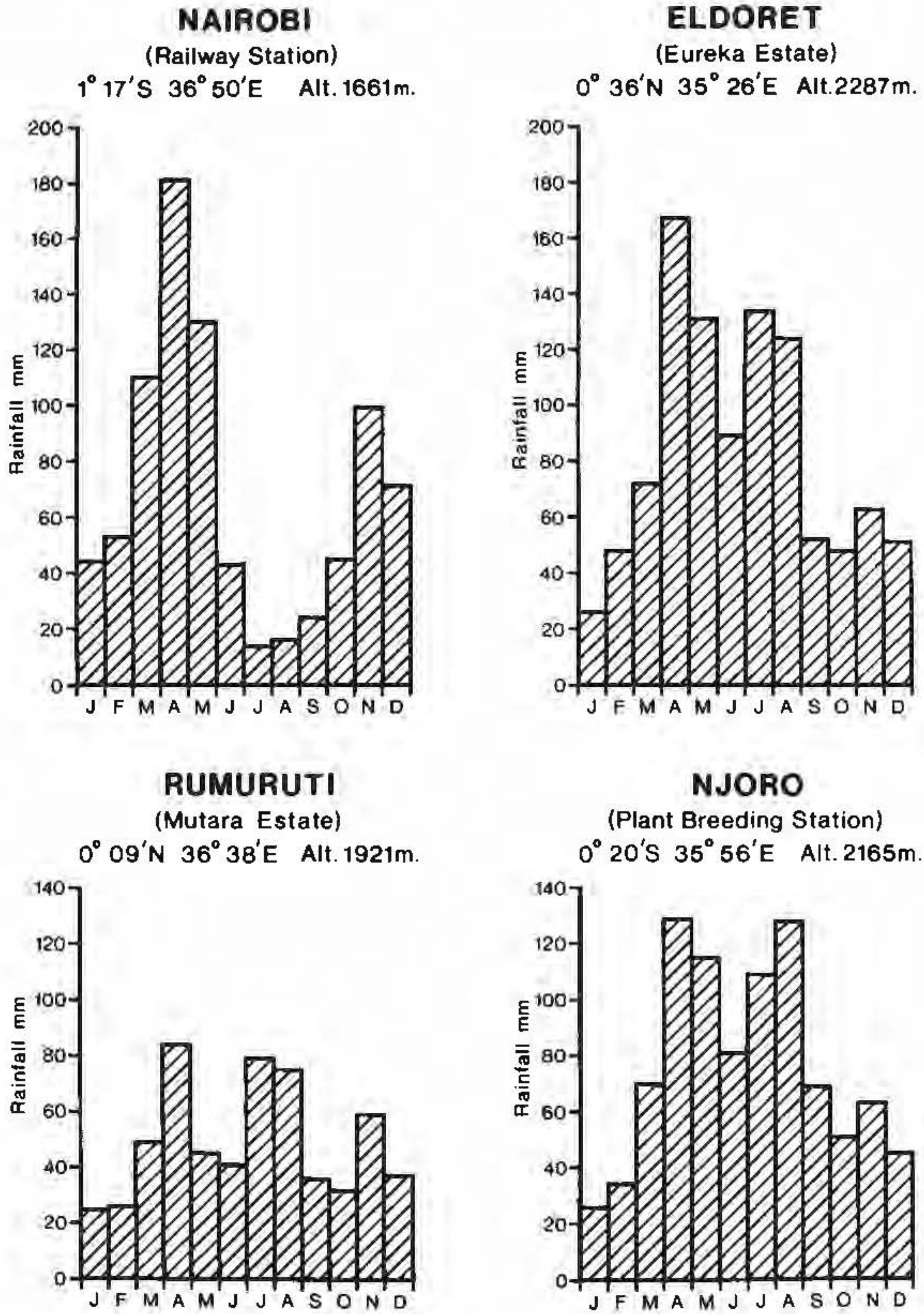


Fig. 2. Rainfall in the Kenya Highlands. Numbers indicate the mean rainfall (mm) per rain day 1931–1960. (E. AFR. MET. DEPT., 1966).



Source: East African Meteorological Department, 1966

Fig. 3. The seasonal distribution of rainfall at selected stations in the Kenya Highlands.

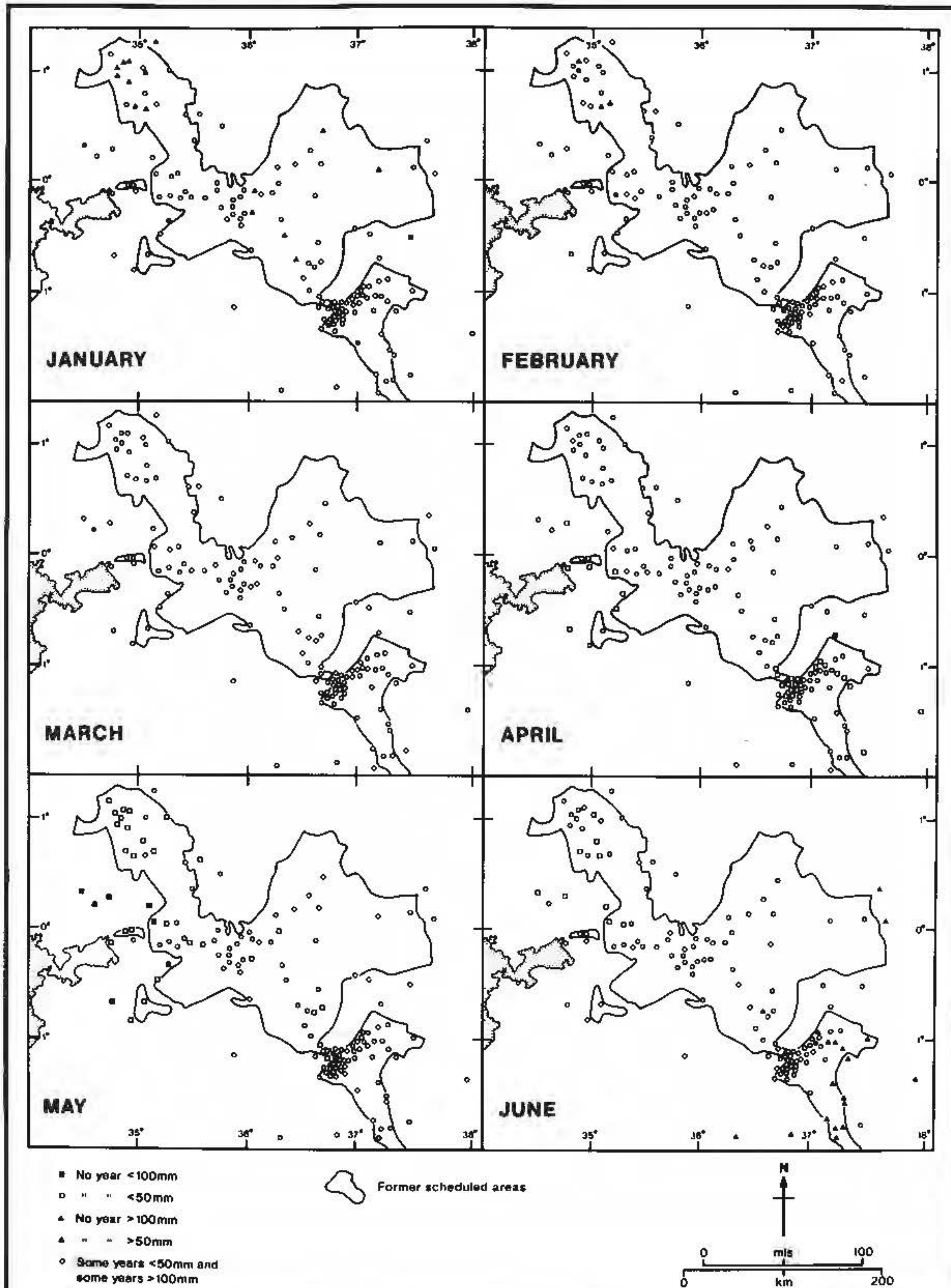


Fig. 4a. The variation of monthly rainfall during 1931–1960 in the Kenya Highlands – January to June. (E. AFR. MET. DEPT., 1966).

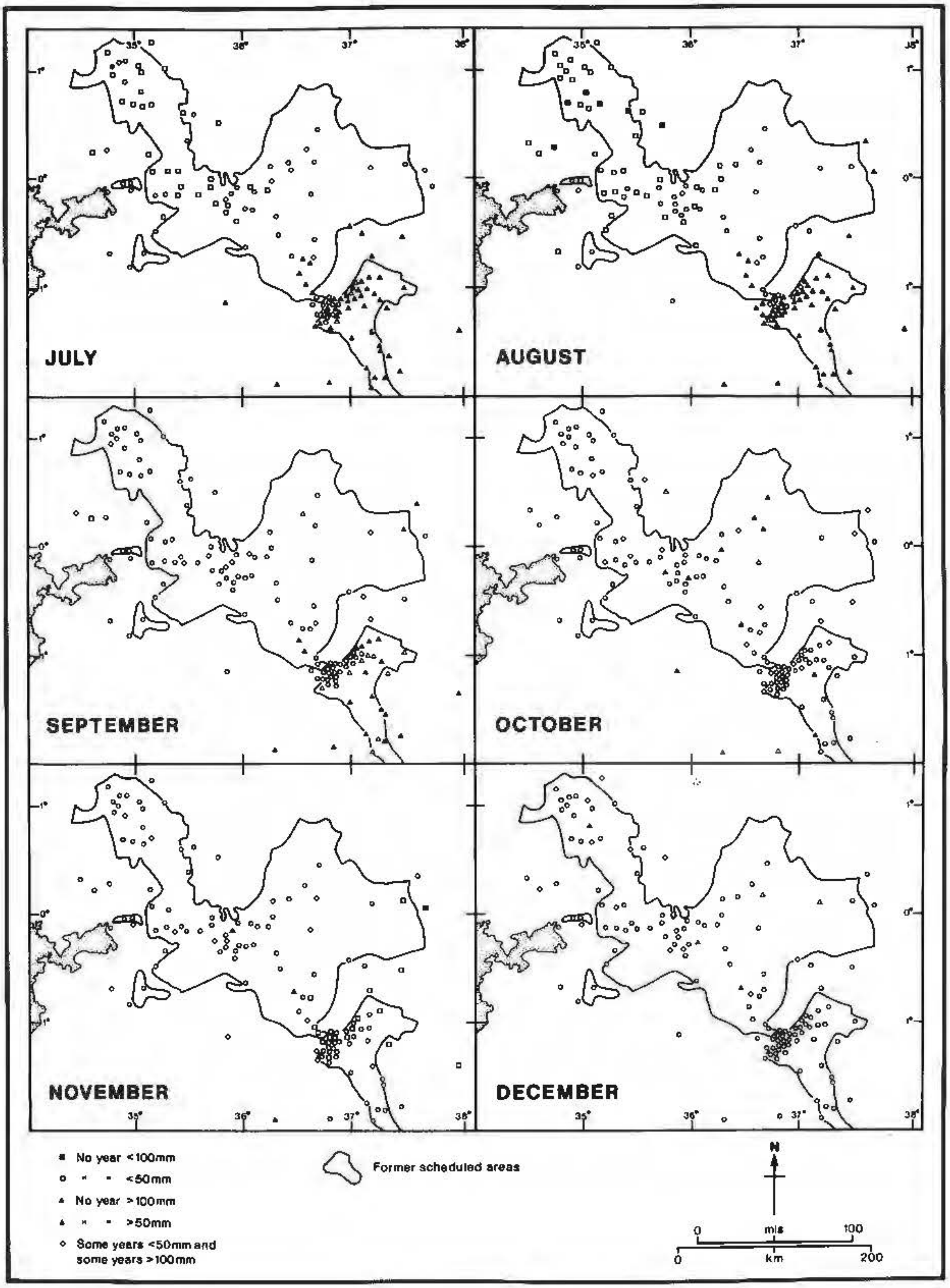


Fig. 4 b. The variation of monthly rainfall during 1931–1960 in the Kenya Highlands – July to December. (E. Afr. Met. Dept., 1966).

storms is observed to bring late afternoon rain to Kisumu, on the Kavirondo Gulf, and to Nairobi during the season of the southern monsoon (TOMSETT, 1975).

There are considerable variations in the seasonal rainfall regime from one part of the highlands to another (Fig. 3). The well-known regime of *long rains* (March – May) and *short rains* (mid-October – mid-December) is characteristic of the area around Nairobi and the highlands immediately to the north and north-east. On the plateau west of the Rift (e.g., Eldoret) and on the higher parts of the Rift, the main rains continue from April to August, August often being the wettest month, and the *short rains* are noted for their unreliability.

A transition can be identified between these two types (KENWORTHY, 1964). August rainfall forms an intermediate season between the *long* and the *short* rains at some stations (e.g., Rumuruti) north of the Aberdares and Mount Kenya while just west of the Rift Valley (e.g., Njoro) a falling off in rainfall amount in June is discernible as a break in the April – August season. HILLS (1978) showed three phases of rainfall in East Africa, each ending in a dry period: early February to late June (Phase I), late June to late September (Phase II) and early October to early February (Phase III). These phases neatly encapsulate the seasons experienced in the Kenya Highlands, a wedge-shaped rainy zone expanding eastward during the mid-year rains or Phase II.

Further examination of the seasonal variation of rainfall has been made (Figures 4 a and 4 b) by utilising the data available for the standard period 1931–1960 (E. Afr. Met. Dept., 1966) to draw attention to those places where (a) significant rains (i.e., more than 100 mm) have occurred in some years in months considered to be within a dry season and (b) rains have failed (i.e., less than 50 mm) in some years in months considered to be within a rainy season.

The expression "failure of the rains" can be most clearly understood in respect of April (Fig. 4 a), a month expected to be a wet month everywhere, although dry spells occur during the long rains that are difficult to forecast (ALUSA and GWAGE, 1980). Years in which less than 50 mm or even less than 100 mm of the rain fall in April are years of anxiety. A contrast in reliability between rainfall east and south-east of the Aberdares and that west of the Rift is evident for November (Fig. 4 b).

Clearly relief and aspect affect seasonal variations in the rainfall pattern over the Highlands. The mid-year rainfall peak is less evident east and south-east of the Aberdares and Mount Kenya, though with more data it would possibly show up clearly at higher altitudes on these mountains (VINCENT et al., 1979). NAKAMURA (1968) has suggested that areas east and south are in the lee of westerly influence in July and August. A limitation to the eastward extent of the mid-year rains seems also to be imposed by conditions in the southern monsoon. During this period, a low-level, cross-equatorial current blowing strongly over the hinterland of the East African coast, skirts the Kenya Highlands (FINDLATER, 1974). Stratus cloud gives mist and drizzle on the upper slopes of the Aberdares and Mount Kenya, but over the lower slopes and plains conditions are very dry. The dryness is more sharply defined in July and August than in June and September (Figures 4 a and 4 b). Thus we see a temporal connection between the period of enhanced rainfall activity in the western and northern parts of the Kenya Highlands and the period of most effectively suppressed rainfall further east. OKOOLA and OTENG'I (1981) have undertaken an attempt to identify the lower tropospheric flow associated with the "middle rains".

Different circumstances relate to the dry season around January, when most stations recorded more than 50 mm (some more than 100 mm) for January or February in at least one year during the period 1931–1960. The least affected area is that to the north, that is to the "lee" of the main rainfall zone, which at that time of year is south of Kenya over Tanzania. ALUSA (1978) refers to rains at this time as the "grass rains" and MAJUGA (1980) has drawn attention to the high probability of a rainy day following a rainy day in January in the West Kenya Highlands.

3.2. *Variability and Change*

The usefulness of various statistical methods of rainfall analysis has been discussed in a number of papers relating to East Africa (GLOVER and ROBINSON, 1953; GLOVER, ROBINSON and TAYLOR, 1955; GRIFFITHS, 1958; WOODHEAD, 1970; WOODHEAD and WAWERU, 1970a; HILLS, 1974 and NIEUWOLT, 1978). Both the reliability of selected rainfall amounts and the range of rainfall amounts expected with selected confidence limits have been used in examination of the quality of growing seasons and variations in the yield of crops (EVANS, 1955; DOWKER, 1963; BROWN and COCHEME, 1969). Assessment of the reliability of the seasonal rains in Kenya highlighted the agricultural importance of the longer wet season west of the Rift (KENWORTHY and GLOVER, 1958). STEWART (1980) has suggested that, as a growing season progresses, re-appraisals of the risk of inadequate rainfall and crop failure in the remainder of the season are needed, so that the farmer can decide whether the application of fertilizer is economic. At Reading University special attention has been paid to the variety of questions that can be answered by analysis of daily rainfall data and the rainy seasons have been examined at Katumani (1575 m) south-east of Nairobi (DENNETT et al., 1982) and at Perkerra (1850 m) in the northern Rift (RODGERS et al., 1983).

The effect of rainfall variability and in particular of dry years on the natural vegetation in East Africa was set out in 1938 by MOREAU, while the effect on farming in the Kenya Highlands was perhaps most eloquently described by Karen BLIXEN in *Out of Africa* (1937):

"...three times we had a year of real drought, which brought us very low down. In a year in which we had fifty inches of rain, we picked eighty tons of coffee, and in a year of fifty-five inches, nearly ninety tons; but there were two bad years in which we had only twenty-five and twenty inches, and picked only sixteen and fifteen tons of coffee, and those years were disastrous to the farm".

Mention has been made of years of low rainfall to 1945. Other notable dry years were 1953, 1959, 1960 and 1961. In 1961, the drought was broken by exceptionally heavy rains late in the year which continued well into 1962, after which the level of Lake Victoria rose to heights unprecedented in the recorded period from 1890. ODINGO (1962) described these as "abnormal and unseasonal rains", adding that "for many areas, October, November and December and part of January, 1962, brought the heaviest, the most widespread, and the most nearly continuous fall on record". The Hon. Mrs. Grant (Elspeth HUXLEY, 1980) wrote from Njoro, "Tough to have had a beautiful crop about wrecked by drought and the next probably wrecked by wet". Yet it was nothing new for prolonged drought to be broken by heavy rain at the end of the year continuing into the next. The drought of 1898–99 broke in December 1899 with "three months unseasonal rain" (MILLER, 1972).

As early as 1902, AINSWORTH recorded that "droughts appear to occur with more or less severity every ten years" and EASTWOOD (1910) wrote of Nairobi that:

"Amongst the natives of this part of the country there is a tradition that there is a cycle of 9 or 10 years, each of which cycles terminates with a drought. Our records do not go back far enough to prove whether there is any truth in the tradition or otherwise, but the information we possess as to what took place for 2 or 3 years previous to June 1899 is certainly in favour of such a tradition. The years 1898 and 1899, commonly spoken of as the 'Famine Years', were not absolutely rainless, but the rains failed in the same manner that they did in 1908 and 1909, ten years later".

Crude rainfall totals for Kenya from 1930 to 1953 suggested that minima occurred on average about every five years (KENWORTHY, 1975) and RODHE and VIRJI (1976) showed a 5–5.7 year periodicity in data for central Kenya and Lake Victoria stations. MÖRTH (1967) suggested however that "the 5-year cycle between 1935 and 1963 is a freak produced by two 10-year cycles which happened to have a phase-shift of 5 years", but in any case other periodicities stand out for relatively nearby areas, e.g. a 3.3–3.6 year period for the Kilimanjaro area (RODHE and VIRJI, 1976). There seems no reason to assume that periodicities evident in recorded data should have predictive value. As for the heavy rains from 1961–1962, the degree of change from the range of values previously recorded was greater for the drier six months of the year, September to February (BARGMAN, LUMB and MÖRTH, 1965) a conclusion borne out by FARMER (1981), who showed that step-like climatic change was evident in data for October and November only and that negative trends off-set the significance of such change towards the end of the period 1931–1972.

In no one year of the dry years of the early and mid-seventies were conditions worse than had been experienced at other times in the past, though the persistence of dry conditions for more than one year affected farming severly in sub-humid parts of Kenya (PALUTIKOF, 1977). Dry conditions recurred in 1980.

It has been suggested that wet and dry phases, each for a number of years, transcend the sequence of seasonal controls, wet phases being shorter in duration than dry (MÖRTH, 1973). Other variations in rainfall may be the consequence of more short-lived and perhaps at times locally discrete conditions. Extra-tropical influence has been identified, as in January 1975, when exceptional rainstorms in north-east Kenya were associated with frontal movements to the north (E. Afr. Met. Dept., 1975). Hail in the West Kenya Highlands is sometimes associated with a polar trough to the north (SANSOM and GICHUIYA, 1971). Variations in westerly flow across Zaire may be influential (NAKAMURA, 1968) and DEAN (1976) has shown this to be strongest in June – August and December – January, in association with "summer cyclogenesis in the appropriate hemisphere". Confluence in the easterly flow has been identified however as bringing "unseasonal" rains in January 1979 (WAIROTO and NYENZI, 1981). Whatever the influences at work, there seems no doubt that the complex relief of the region plays an important role in governing the effects in detail.

4. Major Climatic Characteristics: Temperature and Humidity

4.1. The Altitudinal Gradient

"A land of perpetual spring – of cool nights and bracing mornings, warm days and mild evenings – the Highlands boast of a climate which may be equalled, but cannot be surpassed" (O'SHEA, 1917). Thus was the climate of the Kenya Highlands described for prospective British settlers, a climate which owed its attractiveness to high altitude, that was also believed by some to be "the explanation of any mental and moral shortcomings that may occasionally be detected, and of lapses of self-control which may precipitate internal feuds and even endanger good relations with the Home Government" (KENDREW, 1946)!

The following equations have been given to describe the relationship between mean annual temperature and altitude:

For East African data: T_{mean} (°C) = 27.8 – 0.0053 h (m) (GLOVER & KENWORTHY, 1957)

For Kenya data: T_{mean} (°C) = 30.2 – 0.0065 h (m) (E. Afr. Met. Dept., 1959)

For East African data: $T_{max.}$ (°C) = 34.0 – 0.0056 h (m) (GRIFFITHS, 1968)

$T_{min.}$ (°C) = 24.5 – 0.0063 h (m) (GRIFFITHS, 1968)

$T_{mean\ coldest\ month}$ (°C) = 27.8 – 0.0059 h (m) (KENWORTHY, 1966)

A useful relationship is that between dew-point temperature and altitude:

For East African data: T_{dew} (°C) = 22.2 – 0.0053 h (m) (GLOVER & KENWORTHY, 1957)

equivalent to an exponential decrease of water vapour pressure with height above sea level.

An approximate relationship between annual values of evaporation pan data and altitude has also been given:

E_0 (mm) = 2422 – 0.358 h (m) (DAGG & WANGATI, 1965; WOODHEAD, 1968).

The relationship between potential evaporation/evapotranspiration and altitude is complex. Thornthwaite's method of estimation assumes a simple relationship with temperature and thus with altitude, but does not reflect seasonal contrasts adequately (SANSOM, 1954), nor the fact that monthly values of potential evaporation are considerably greater at high altitudes in Kenya than for comparable summer

Table 2. Temperature at the highest forest station in Kenya for which data is published

Kiptunga Forest Station	Absolute Minimum Temperature	J	F	M	A	M	J	J	A	S	O	N	D
2958 m	1961–1968	1.1	0.0	−1.1	4.4	4.4	2.2	2.2	1.1	1.1	1.1	1.1	−1.1

months in high latitudes (KENWORTHY, 1975). It has been shown that, while the efficiency of the conversion of incoming solar energy to the energy used in evaporation is reduced at lower temperatures, there is a compensator effect resulting from reduced pressure with altitude (MCCULLOCH, 1965). Estimates of potential evaporation using Penmans's method show year to year variations to be small (WOODHEAD and WAWERU, 1970 b), but local and seasonal variations in response to changes in humidity and cloudiness would repay more attention.

Both TROLL (1959) and WALTER (1959) have emphasized the tropical character of highland climates within the tropics no matter how cool they may be. The altitudes in the Kenya Highlands of suggested thermal boundaries to tropical climates have been calculated (KENWORTHY, 1966 and 1969). Suffice to say here that few meteorological stations lie at altitudes where the mean temperature of the coldest month falls below 13.5 °C (at approximately 2440 m), the value chosen by Von Wissmann as an important limit (JÄTZOLD, 1968). Even forest stations are found to be below 3000 m, the altitude suggested by Von Wissmann to be the absolute frost limit in Kenya (Table 2). It seems that climatic conditions near to these limits have been a deterrent to cultivation and settlement, although the extent of available land above 3000 m is small.

Detailed appraisal of critical limits must depend on knowledge of crop requirements. For example coffee will survive temperatures near to freezing, but will not withstand frost. The temperature limits for tea depend on the variety (BROWN and COCHEME, 1969), though temperatures in excess of 30 °C are certainly detrimental (LAYCOCK and OTHIENO, 1974). Maize trials at 1268, 1890 and 2250 m showed that yield was greatest at the highest altitude, where plant development was slower and of longer duration as a result of lower temperatures (COOPER, 1979).

4.2. The Diurnal Regime

The distinctiveness of the equatorial highland climate lies of course in its short day and in the small seasonal variation of day length and mean temperature. Some plants introduced from high latitudes will not produce seed in abundance, but many thrive. Eucalypts grow more rapidly than in their native Australia and pyrethreum, which is dependent on night chilling to stimulate flower-bud development, has an exceptionally long flowering season in the Kenya Highlands, where temperature falls sharply every night of the year (GLOVER, 1955).

The rates of change of mean annual temperature with height above sea level west and east of the Rift Valley are shown in Fig. 5. West of the Rift, day-time heating of the plateau and generally clearer skies probably account for the wider diurnal range of temperature at middle altitudes than for the eastern highlands, where cloudiness, mist and drizzle are more commonly experienced. Data for sample stations in both regions are shown in Table 3.

The diurnal distribution of temperature was examined in some detail (KENWORTHY, 1966) for five stations using daily thermograph charts (Table 4). A striking characteristic is the small diurnal range of temperature at Muguga in April, a "wet" month. In July, a "cold" month, the effect of low cloud east of the Rift and of afternoon storms west of the Rift can be seen in the suppression of afternoon temperatures.

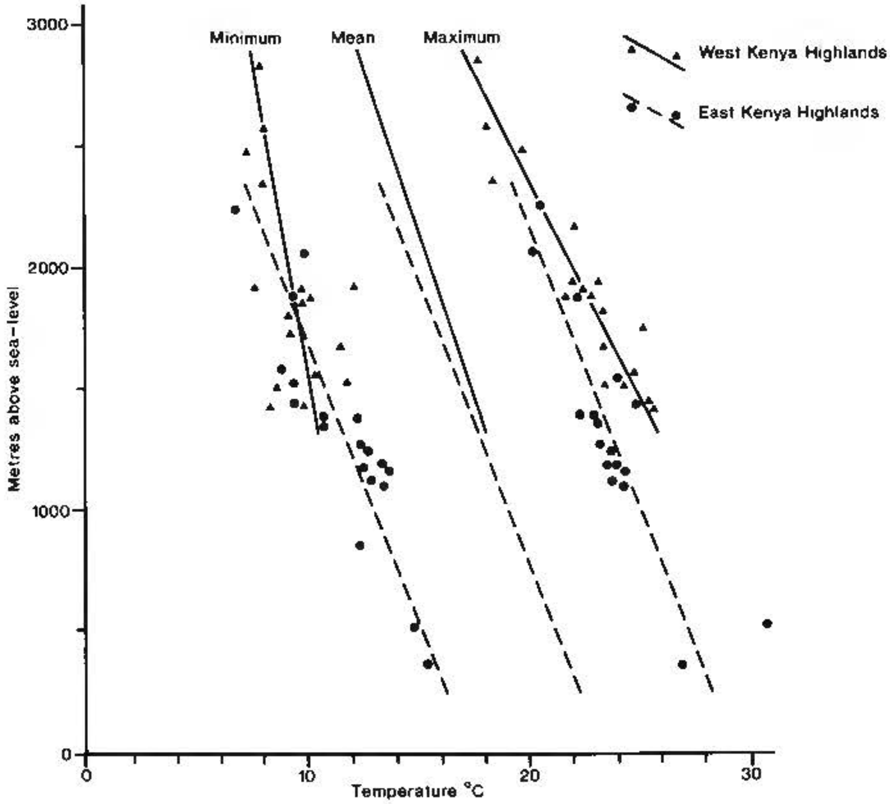


Fig. 5. Rates of change of mean annual temperature with height above sea level in the Kenya Highlands. (KENWORTHY, 1966).

Table 3. Temperatures for stations west of the Rift Valley

		J	F	M	A	M	J	J	A	S	O	N	D
Molo Pyrethreum Station 2478 m	Mean Max.	21.9	22.6	22.8	21.0	20.4	19.7	18.6	18.8	20.3	20.9	20.0	20.4
	Mean Min.	6.4	6.1	6.9	8.5	7.9	6.7	6.8	6.8	6.1	6.5	7.5	7.2
Kericho Jamji Estate 1830 m	Mean Max.	29.6	29.2	28.8	26.5	25.8	25.3	25.3	26.3	27.2	27.2	26.9	27.3
	Mean Min.	8.7	9.2	9.1	9.8	10.1	9.3	9.3	8.9	8.3	8.4	8.9	9.1

Temperatures for stations east of the Rift Valley

Kimakia Forest Station 2440 m	Mean Max.	20.1	20.6	20.1	18.6	17.5	16.5	14.7	14.9	17.3	18.3	17.7	19.0
	Mean Min.	6.8	7.3	8.4	9.6	9.0	7.5	7.2	7.1	6.8	8.4	8.9	7.3
Kabete Approved School 1830 m	Mean Max.	25.3	26.6	25.9	24.4	23.2	21.9	21.1	21.2	23.6	24.6	23.8	24.0
	Mean Min.	10.2	10.6	12.5	13.4	12.7	10.8	10.2	9.8	10.3	12.0	12.3	11.4

Table 4. The number of hours between given temperature levels at stations west (W) and east (E) of the Rift Valley (Thermograph charts for 1957 were used for Muguga and for 1964 for each other station)

			0–5 °C	6–10 °C	11–15 °C	16–20 °C	21–25 °C	26–30 °C
	April							
W	Narok	1890 m	–	18.5	241.0	296.5	163.0	1.0
W	Kitale	1890 m	–	–	325.5	248.5	139.0	7.0
E	Nanyuki	1949 m	–	54.5	295.0	288.5	82.0	–
E	Muguga	2074 m	–	–	445.5	234.5	40.0	–
W	Eldoret	2150 m.	–	17.0	237.5	262.5	200.5	2.5
	July							
W	Narok	1890 m	2.0	116.5	385.0	228.5	12.0	–
W	Kitale	1890 m	–	60.0	464.0	186.0	34.0	–
E	Nanyuki	1949 m	–	83.0	332.5	235.0	93.5	–
E	Muguga	2074 m	0.5	172.0	505.5	66.0	–	–
W	Eldoret	2150 m	–	65.0	436.0	207.0	36.0	–
	Year							
W	Narok	1890 m	72.0	1126.0	3305.0	2572.5	1588.5	120.0
W	Kitale	1890 m	Not Available					
E	Nanyuki	1949 m	32.0	1270.0	3423.0	2682.0	1438.0	2.0
E	Muguga	2074 m	0.5	544.5	5700.0	2236.0	279.0	–
W	Eldoret	2150 m	1.0	630.5	3729.0	2475.0	1876.0	72.5

Minimum temperatures are very dependent on local topography, cloudiness and dew-point temperatures and generalisation about regional differences would be unsound, but it is interesting that, for the year, longer periods with temperatures less than 10 °C are recorded at the lower rather than the higher altitude stations.

Since the variation in temperature from season to season is small and that from year to year still smaller, temperature has often been underrated as a factor in regional contrasts except as a response to altitude, although it has generally been understood by farmers in Kenya to be warmer at a given altitude in the West Kenya Highlands than in the East. Indeed there are considerable variations in temperature in both space and time that cannot be understood by reference to altitude alone. From the point of view of human health, KENDREW (1946) remarked that "the variations of physiological temperature from season to season, from day to day, and from hour to hour with the change from brilliant hot sunshine to bleak grey skies, are large enough to compensate for the larger seasonal range in higher latitudes". Likewise oscillations of temperature critical for crops may be brought about by variations in humidity, cloudiness and rainfall.

5. The Complexity of Space and Time Variations

The intricacy of spatial and temporal variations in rainfall and temperature conditions in the Kenya Highlands has been a source of frustration and puzzlement for generations of farmers. The so-called normal rainfall regimes persist in occurring only occasionally, with significant effects on the farming year. The difficulty of adjustment experienced in the early years of European farming is illustrated in the report for the year 1910–1911 by the General Manager at the Kabete Experimental Farm, north of Nairobi (DEPT. OF AGRICULTURE, BRITISH EAST AFRICA, 1911):

"Everything did very well indeed during December with but a rainfall of 1.43 over 14 days. The latter end of December was showery and then came January with only 0.04 inches of rain, and very bright dry conditions prevailing every day. This kind of weather remained until February 18th when 2.25 inches fell, but it was exactly one month too late to save the maize crop, at least in the neighbourhood. Wheat, beans and all other crops suffered in like manner.

Again on the 10th March there fell 1.37 inches. This was excellent for some maize which was planted on fallow ground after the big rains in February, but it hampered what harvesting there was, as well as retarded preparation of the land for sowing in April – the regular season. February and March have this year (1911) a rainfall of 7.82 inches spread over 18 days as contrasted with 0.15 inches in 4 days for February and March of the preceding year".

The difficulties faced by African small-holders, once again pioneers, on lands often at higher altitudes than those to which they have been accustomed, are illustrated by a report on settlement schemes in the Kenya Highlands (Central Area) for the year July 1964 – July 1965 (DEPT. OF SETTLEMENT, REPUBLIC OF KENYA, 1966):

"During the year the weather has not been particularly kind to the area; very heavy rains occurring at the beginning of the year which delayed wheat planting and considerable rain was also experienced over the small grain harvesting period, making harvesting difficult and adversely affecting the quality of the grain. In January, the area dried up and since then fairly severe drought conditions have occurred resulting in a serious shortage of grazing which impaired the condition of and production from dairy cattle and caused the loss of 20–30% (or 300–400 acres) of newly planted pyrethreum. In February and March heavy night frosts destroyed many late planted potatoes".

The Kenya Highlands are a vital source of food, of water for the surrounding lowlands and of export crops. Population growth has increased the pressure on limited land resources and the need to increase productivity will continue far into the forseeable future. A great deal of attention has already been paid to the climate of the Kenya Highlands, but there remains much to be done in the analysis of local and regional variations on which farmers need information and advice.

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Discussion to the Paper Kenworthy

Dr. M. Ward:

1. What was the altitude of the snow-line?
2. What is the level to which glaciers come?
3. Was there any area of permafrost?

Prof. Dr. S. Hastenrath:

(to Ward): Lower limits of glaciers on Mount Kenya are >4.600 m and thus stay well above the vertical domain of agriculture.

Prof. Dr. M. Domrös:

You showed very remarkable differences of the rainfall conditions in the Kenya Highlands, obviously showing "wet" and "dry" parts. Were the terms "wet" and "dry" defined from the climatological viewpoint alone, or what are the agroclimatological effects of "wet" and "dry" rainfall conditions in the Kenya Highlands?

Miss J. M. Kenworthy:

From a climatological viewpoint a minimum of 50 mm rainfall is sometimes used in Kenya to define a "wet" or "rainy" month, even though 50 mm may not be adequate to meet crop water requirements. Variations in the length of the rainy season, from place to place and from year to year, are crucial in determining patterns of agriculture, but the availability of new strains of maize, with shorter growing seasons, has been important for the drier areas in recent years.

Dr. M. Winiger:

Do you know, whether there are periodicities detectable in annual rainfall patterns?

Prof. Dr. B. Messerli:

West-facing slopes (West of the Rift-Valley) are more humid than E-facing ones. In the eastern part of Kenya it is just inverse. My questions are:

1. Why do we have these more humid W-faces in western Kenya?
2. Is there any seasonal differentiation?
3. Is there any quantitative differentiation (W–E)?
4. Can you please explain the circulation structure?

Prof. Dr. S. Hastenrath:

You showed a regression formula of temperature versus altitude. How do the coefficients compare to those of John Griffiths?

Prof. Dr. W. Weischet:

Can you please give us some information on the vertical distribution of rainfall and if there is a belt of maximum precipitation?

Miss J. M. Kenworthy:

The last four questions are answered to some extent in the full, written text of my paper.

Erdwissenschaftliche Forschung, Bd. XVIII, 41
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Climate Zoning and Land Use at Mount Kenya

Abstract

Mathias Winiger

The East African high mountains (Kilimandjaro, Mt. Elgon, Mt. Kenya) show a vertical sequence of vegetation zones, typical of the equatorial tropics, whose boundaries correspond to the climatic conditions (temperature and precipitation regimes). Naturally the traditional land use forms, too, follow the dominant climatic pattern. And in Kenya a still frequently applied division of the country into three agricultural stages of potentiality is directly derived from the mean annual precipitation.

The still persisting population pressure is one of the main reasons for the inevitable intensification and marginalization of the different land use forms and the complications of cultivation and the yield risks attaching thereto. A further differentiation of the natural conditions is inevitable for an optimized use of the existing potentials (cf. JÄTZOLD, 1981). This is all the more true as in feeble national economics the expenditure necessary for a yield increase (irrigation, fertilizer, energy, technology, seeds, etc.) finally has to be supplied from local ressources. And this particularly with regard to an effective stability of utilization which should guarantee a basic provision of the local population as independent of world market conditions as possible.

On this background the natural potential of the semiarid northwestern foot-zone of Mt. Kenya will be demonstrated and the input/output-ratio of different agricultural utilization strategies will be discussed. This approach is meant to be a basis for an eventual agricultural development conception.

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Erdwissenschaftliche Forschung, Bd. XVIII, 43–54
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Untersuchung zur Obergrenze des Naßreisanbaus in China

Yu Xiao-Gan[1]

Mit 9 Abbildungen und 6 Tabellen

1. Einleitung

China ist der größte Reisproduzent der Welt:
- 38% der Weltreisernte werden in China produziert
- 26% der Weltreisanbaufläche liegen in China.

Die Gesamterträge sowie die Anbaufläche nehmen den ersten und den zweiten Platz in der Weltrangliste ein, während die Reiserträge pro ha den 4. Platz in Asien und den 19. Rang insgesamt einnehmen.

44% des gesamten Getreideertrages in China entfällt auf Reis; 28,5% der Getreideanbaufläche wird mit Reis bepflanzt. Die Naßackerfläche nimmt 25,3% der gesamten chinesischen Ackerfläche ein.

Diese Zahlen (aus: Academia Sinica, Abt. f. Wirtschaftsgeographie am Inst. f. Geographie, 1981: Die chinesische Agrargeographie) verdeutlichen die enorme Bedeutung des Reises als Nahrungsmittel angesichts der großen Bevölkerungszahl. Lediglich 16% der Staatsfläche entfallen auf niederes Hügelland und Ebenen (bis 500 m ü. N. N.), 47% liegen 500–2000 m ü. N. N., 19% in 2000–5000 m, 18% über 5000 m ü. N. N. (REN MEI-E et al., 1980).

Von jeher war der chinesische Bauer gezwungen, Reis im Gebirge anzubauen. Aus Tab. 1 geht hervor, daß sich die Obergrenze des Reisanbaus immer höher ins Gebirge vorschob; lag die Obergrenze vor 4700 Jahren 1400 m ü. N. N., so wird heute der Reisanbau von 200 bis 2700 m Höhe betrieben.

Seit 1976 untersuche ich die regional unterschiedlichen Höhengrenzen des Reisanbaus in China. Aufgrund der in NW-Yunnan und in Tibet gewonnenen Erkenntnisse (Geographische Exkursionen, Kartierung der Landnutzung sowie der Höhengrenzen des Reisanbaus) sowie umfassender wissenschaftlicher

Tabelle 1. Änderung der Obergrenze des Reisanbaus in der Provinz Yunnan aus historischer Sicht.

Ort	Zeit	Höhengrenze (m ü. N. N.)
Kr. Binchuan	v. 4700 J.	1440
Dianchi	v. 4000 J.	1960
Lijiang	700 n. Chr.	2425
Jejue Becken	Anf. 20. Jahrhundert	2500–2600
Younning Becken	1930	2630
Younning Bajia-Gruppe	1958	2670
Younning Tuogig-Gruppe	1981	2700

(Quelle: DING YING, 1961; LI SIMIAN, 1934; sowie d. Verfasser)

[1] Herr Yu Xiao-Gan (Nanjing Institute of Geography, Academia Sinica) war vom Juni 1982 bis Ende November 1983 Stipendiat der Alexander von Humboldt-Stiftung am Geographischen Institut der Universität Gießen.

Studien konnte ich nachweisen, daß die Höhengrenzen des Reisanbaus in China einer Gesetzmäßigkeit unterliegen.

Ziel dieser Abhandlung[2] ist, die Ursachen dieser Gesetzmäßigkeiten zu analysieren.

2. Gesetzmäßigkeiten der Höhengrenzen des Reisanbaus in China

Die räumliche Ausbreitung des Reisanbaus reicht von der tropischen (18° nördl. Breite) bis zur kühlgemäßigten (53°32'), von der trockenen (80° östl. Länge) bis zur feuchten Zone (130° östl. Länge).

Bei Mohe (53°32') liegt das nördlichste Reisanbaugebiet weltweit; im Yongnin-Becken in NW-Yunnan das höchste Reisanbaugebiet Chinas (2700 m). Die ökologischen Bedingungen für den Anbau sind regional sehr unterschiedlich; außerdem beeinflussen die Reissorte und die sozialen und wirtschaftlichen Verhältnisse sowie der Fruchtwechsel die Obergrenze des Reisanbaus.

In Ostchina erhält man bis in eine Höhe von 600 m 2 Reisernten pro Jahr, während in Südwest-China (im Becken Yuangjiang) diese Grenze bei 2400 m liegt. In Ostchina liegt die Grenze für eine Reisernte pro Jahr bei 1000 m; in Südwest-China bei 2700 m.

In Abb. 1 sind die Höhengrenzen des Reisanbaus in 3 Richtungen eingezeichnet:

I. entlang des 28. nördl. Breitengrades
II. entlang des 120. östl. Längengrades
III. in NO-SW-Richtung.

Kurve II in Abb. 2 gibt den Verlauf der Höhengrenzen entlang des 120. östl. Längengrades wieder (vgl. Abb. 1). Der Einfluß der Breitengrade ist offensichtlich: Die Höhengrenze des Reisanbaus steigt mit der Abnahme der Breitengrade. Die Höhengrenzen steigen langsam vom Norden Chinas bis zum Äquator um durchschnittlich 26 m/111 km (vgl. Tab. 2). Von Tianmoshan (30°30' n. Breitengrad) bis zum Äquator steigt die Höhengrenze lediglich um 17,85 m/111 km. Kurve I stellt die Höhengrenzen aufgrund der unterschiedlichen Entfernung vom Meer bei etwa gleichem Breitengrad (28° nördl. Breite) dar. Sie steigen von 1000 m bei Wuyishan bis auf 2700 m im Yongnin-Becken; Wuyishan ist ca. 300 km, Yongnin 1670 km vom Meer entfernt. Von Wuyishan bis Yongnin steigt die Grenze durchschnittlich um 106,7 m. Auf der 850 km langen Strecke von Wuyishan nach Xiefenshan schiebt sich diese Grenze lediglich um

Tabelle 2. Minimale, maximale und durchschnittliche Werte für die Änderung der Höhengrenzen des Reisanbaus in verschiedenen Richtungen (vgl. Abb. 1).

Richtung	Ø Änderungswert	maxim. Änderungswert	minim. Änderungswert
		(m/111 km)	
Längengr. 120°E	Mohe-Sumentala 53°32'N–2°N 26,2	Tainmoshan-Wuyishan 30°30'N–28°N 160,0	Wuyishan-Sumentala 28°N–2°N 17,85
Breitengr. 28°N	Wuyishan-Yongnin 200,0	Yongnin-Fugung 467,0	Wuyishan-Xiefenshan 26,0
NO-SW-Richtung	Mohe-Nilgiri Ceylon 74,25	Zhemen-Zhaomen 230,0	Zhaomen-Hanzhon 39,0

(Quelle: ACADEMIA SINICA, Abt. f. Wirtschaftsgeographie am Inst. f. Geographie, 1981; sowie d. Verfasser)

[2] Für wertvolle Anregungen und vielseitige Unterstützung während meines Aufenthalts in Gießen bin ich Herrn Prof. W. Haffner und Herrn Prof. H. Uhlig zu Dank verpflichtet.
Mein besonderer Dank gilt Frau B. Mengel, die die kartographische Gestaltung übernahm und den in deutsch geschriebenen Aufsatz korrigierte.

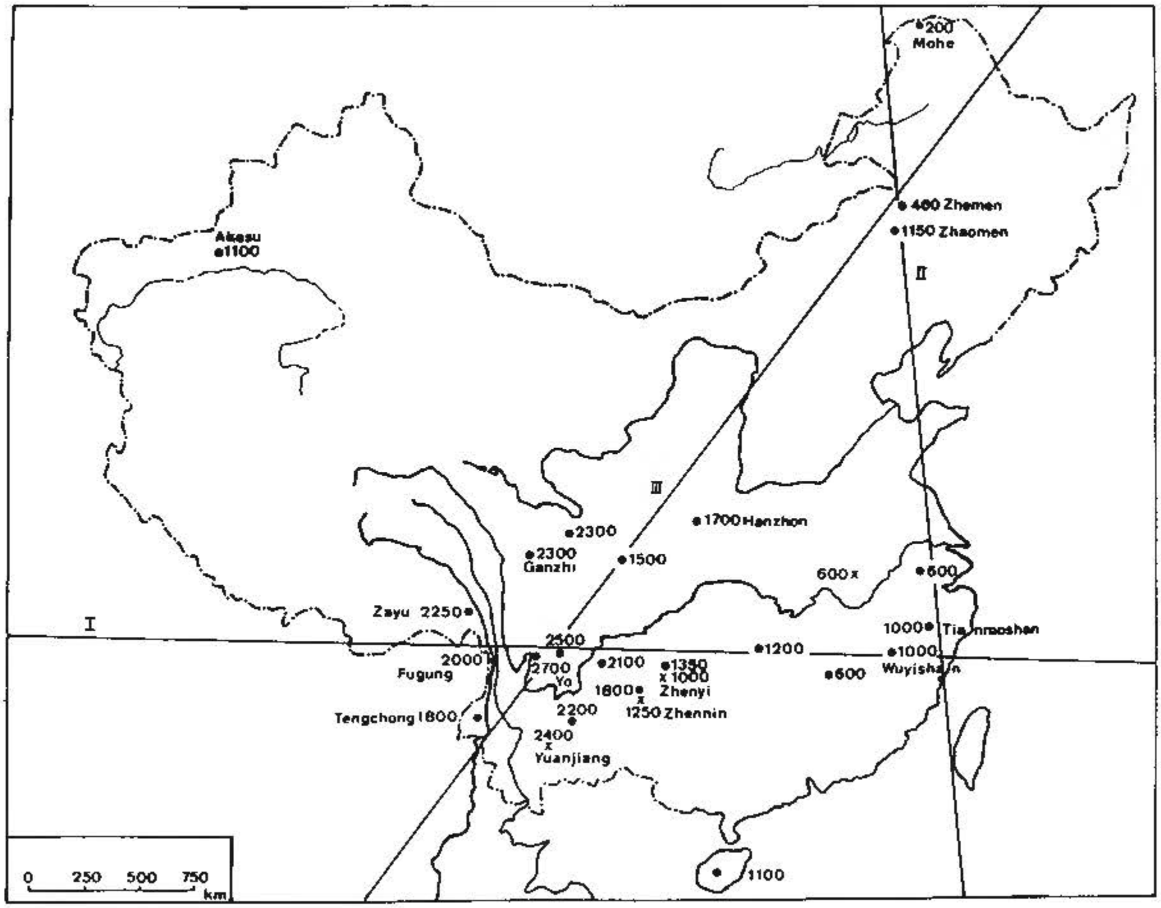

Abb. 1. Die Höhengrenzen des Reisanbaus in China. ×: 2 Reisernten pro Jahr; •: 1 Reisernte pro Jahr (Quelle: ACADEMIA SINICA, Abt. f. Wirtschaftgeographie am Inst. f. Geographie, 1981, und d. Verfasser).

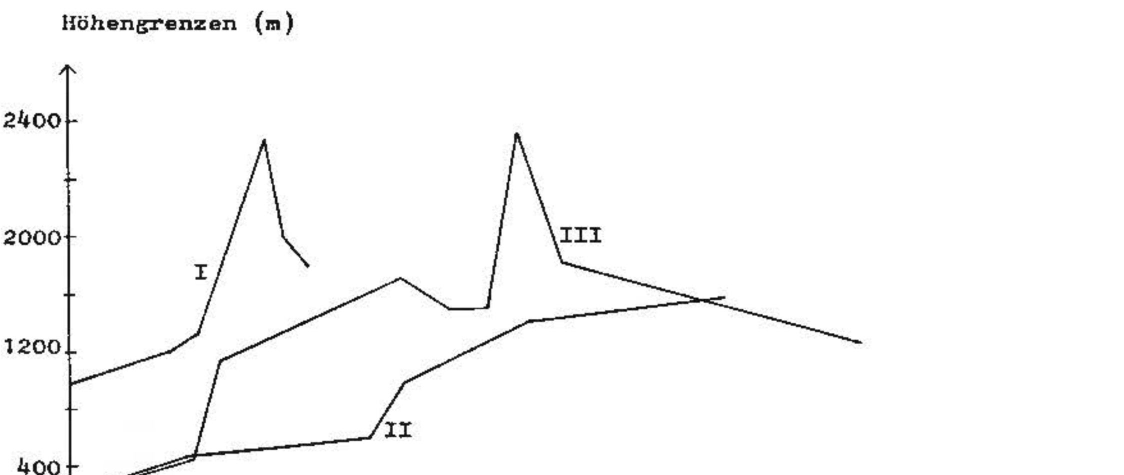

Abb. 2. Die Höhengrenzen des Reisanbaus in China. I entlang des 28. Breitengrades; II entlang des 120. Längengrades, III entlang der Geraden in NO-SW-Richtung (Quelle: DING YING, 1961; LI SIMIAN, 1934; YU XIAO-GAN und SUN SHANG-ZHI, 1981).

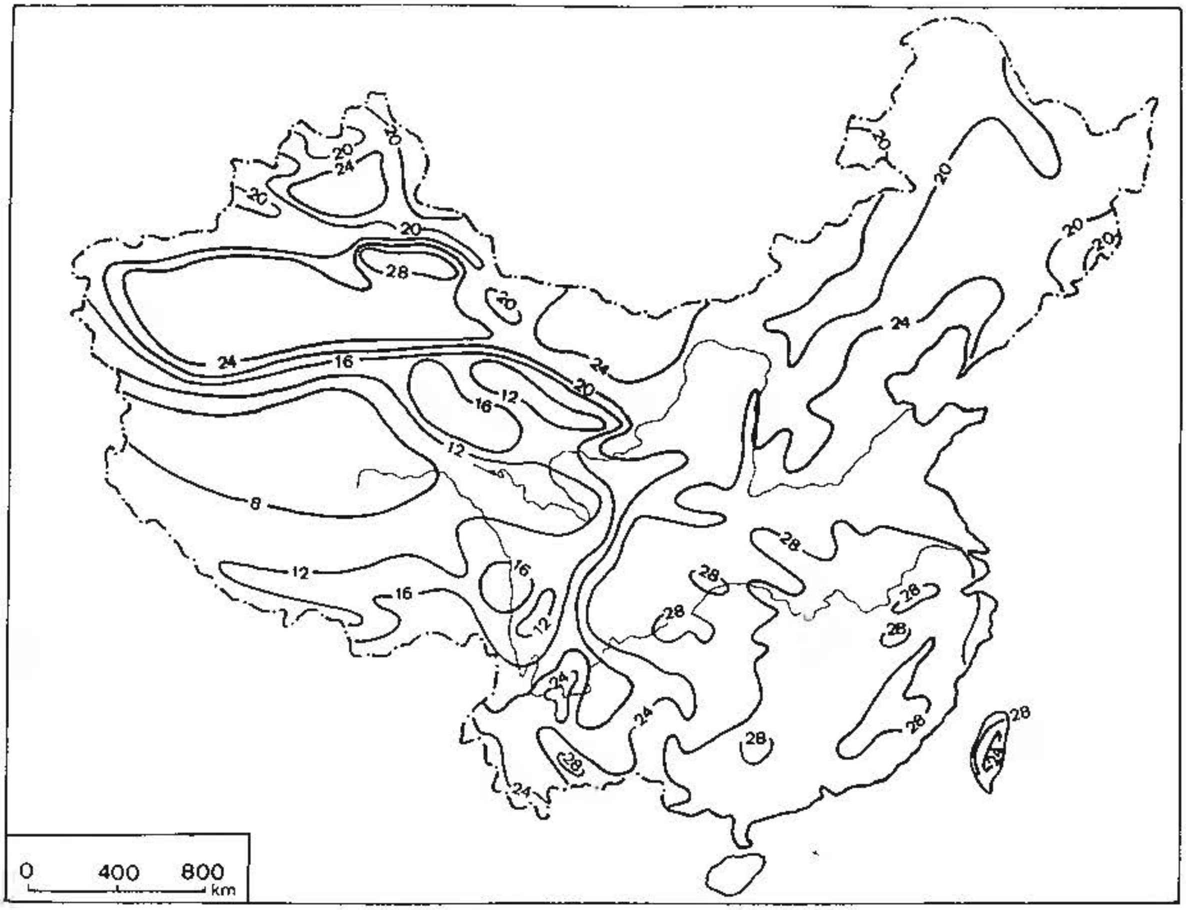

Abb. 3. Juli-Isothermen in China (Quelle: REN MEI-E et al., 1980).

26 m/111 km ins Gebirge vor, während auf der 162 km langen Strecke von Yongnin bis Fugung ein Wert von 467 m/111 km erreicht wird.

Kurve III stellt die Veränderung der Höhengrenze in NO-SW-Richtung dar. Der durchschnittliche Veränderungswert (74,25 m/111 km) liegt etwa in der Mitte zwischen den Werten entlang der Längen- und Breitengrade (Die Höhengrenze des Reisanbaus unterliegt sowohl dem Einfluß der Längen- und Breitengrade) (r = 0,957).

Von Mohe bis Younnin steigen die Höhengrenzen, während sie von Younnin bis Sri Lanka langsam sinken, da sich der Einfluß des Meeres verstärkt (Der Einfluß der Breitengrade auf die Höhengrenze im Bereich der tropischen und subtropischen Zone – südlich des 28. Breitengrades – ist gering).

Kurve II zeigt im Vergleich zu Kurve I und III die größten Differenzen hinsichtlich der Höhengrenze; der minimale und der maximale Veränderungswert ist auf dieser Strecke zu finden (vgl. Tab. 2). Obwohl die Veränderung in Ost-West-Richtung stärker ist als in Süd-Nord-Richtung, ist sie zwischen den Breitengraden langsam und stetig. Es besteht eine Korrelation zwischen der Obergrenze des Reisanbaus und dem Breitengrad (r = 0,957).

Abbildung 3 stellt den Verlauf der Juliisothermen in China dar. Die durchschnittliche Julitemperatur ist von entscheidender Bedeutung für die Reifung des Reises. Die durchschnittliche Temperaturdifferenz zwischen dem 23. und dem 45. Breitengrad im Juli beträgt lediglich 0,2 °C pro Breitengrad. Südlich des 30. Breitengrades verlaufen die Isothermen nahezu parallel zu den Breitengraden. Dies entspricht der geringen Veränderung der Höhengrenzen in diesem Bereich.

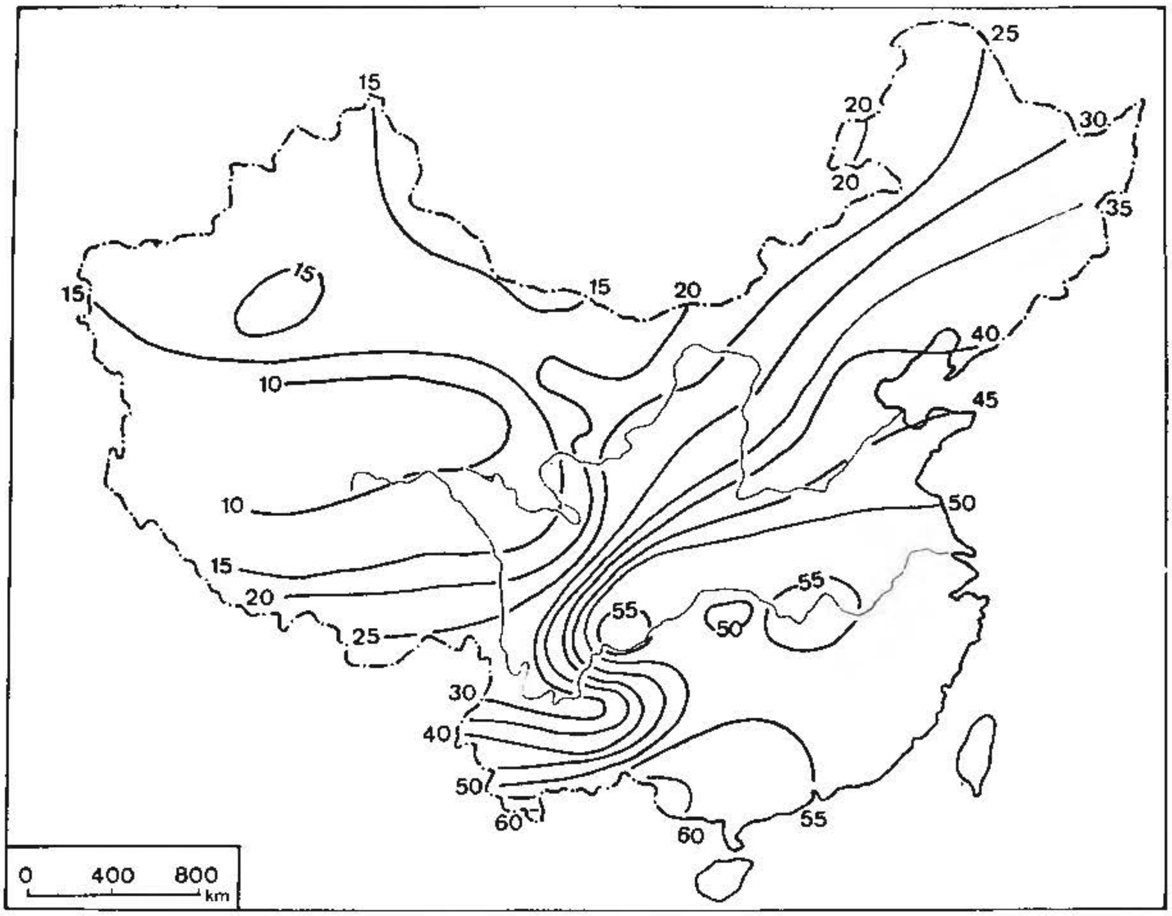

Abb. 4. Absoluter Feuchtegehalt der Luft im Juli in China (Quelle: ZHOU JINSHANG und LIU HUILAN, 1981).

Der Einfluß der Längengrade oder der Kontinentalität auf die Grenze ist verständlich. Mit zunehmender Entfernung vom Meer nimmt die Wärme- und Strahlungsintensität zu und der Feuchtegehalt der Luft ab (Abb. 4 stellt den absoluten Feuchtegehalt der Luft im Juli dar). In NW-Yunnan breitet sich eine „trockene Zunge" aus; der Einfluß des SO- und SW-Monsuns auf dieses Gebiet ist gering (dieses Gebiet umfaßt die Bezirke Lijiang, Diqin, Nujang und Westsichuan), der Feuchtegehalt der Luft ist niedrig und die Strahlungsintensität am stärksten. 6000 ha Reisfelder befinden sich in einer Höhe von 2100–2700 m; davon liegen 1300 ha im 2400–2700m-Bereich. In dieser „trockenen Zunge", d.h. im Gebirge NW-Yunnans, befinden sich die höchsten Reisfelder Chinas.

Die Höhengrenzen des Reisanbaus in SW-China sind aus Abb. 5 zu ersehen; eine Parallelität zu Abb. 4 ist offensichtlich. Es besteht eine Beziehung zwischen der Höhengrenze des Reisanbaus und dem absoluten Feuchtegehalt der Luft (r = 0,888). Die oben angesprochenen Beziehungen lassen sich nochmals am Beispiel NW-Yunnans verdeutlichen (vgl. dazu Abb. 6, 7, 8).

2.1 *Einfluß des Reliefs auf die Höhengrenzen des Reisanbaus*

Das chinesische Relief kann in drei voneinander abgrenzbare Gebiete eingeteilt werden (vgl. Abb. 5):

1. Einen relativ geringen Teil der Gesamtfläche nehmen Ebenen und Hügelländer ein.
2. Der Übergangsbereich von Ostchina zum Qinghai-Xizang-Plateau liegt durchschnittlich 1000–1500 m

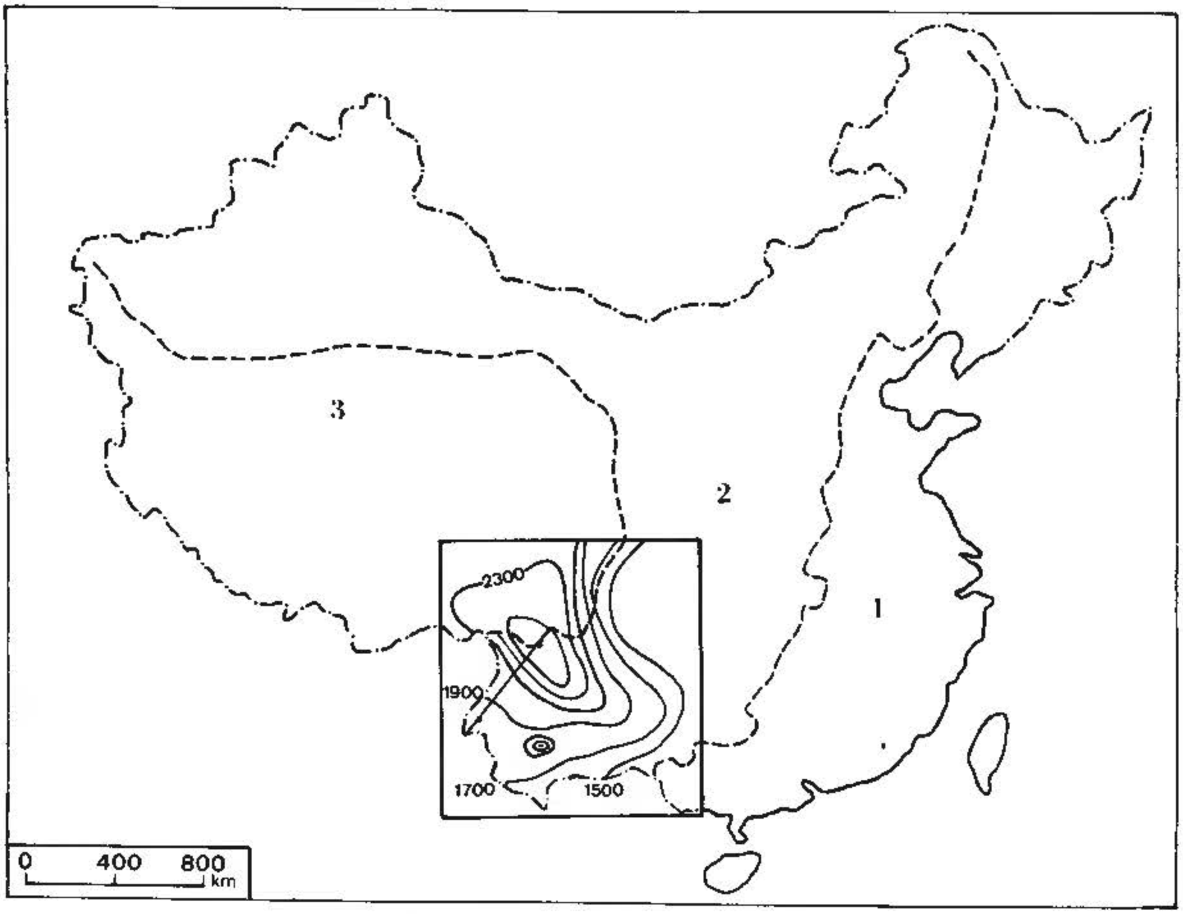

Abb. 5. Die Höhengrenzen des Reisanbaus in SW-China.

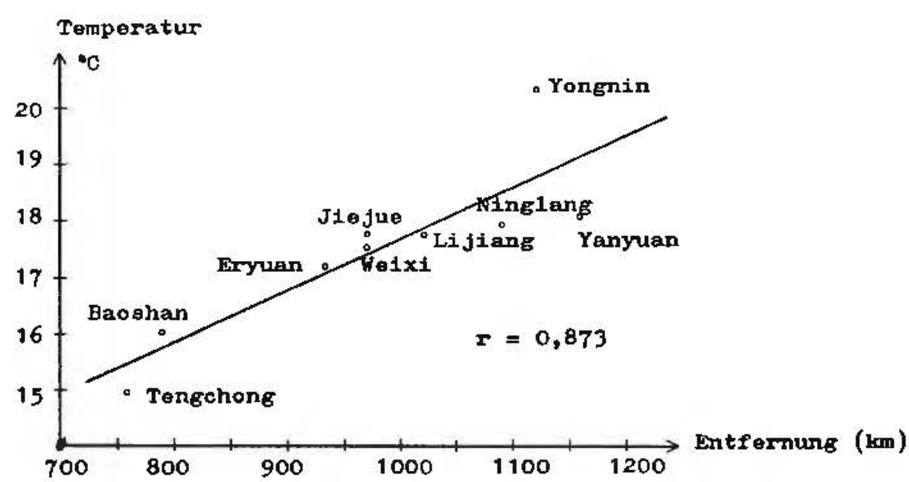

Abb. 6. Beziehung zwischen der Julimitteltemperatur bei einer durchschnittlichen Höhe von 2439 m (ü. N. N.) und der Entfernung vom Bengalischen Meer (Quelle: Meteorologische Stationen Yunnan und Sizhuan).

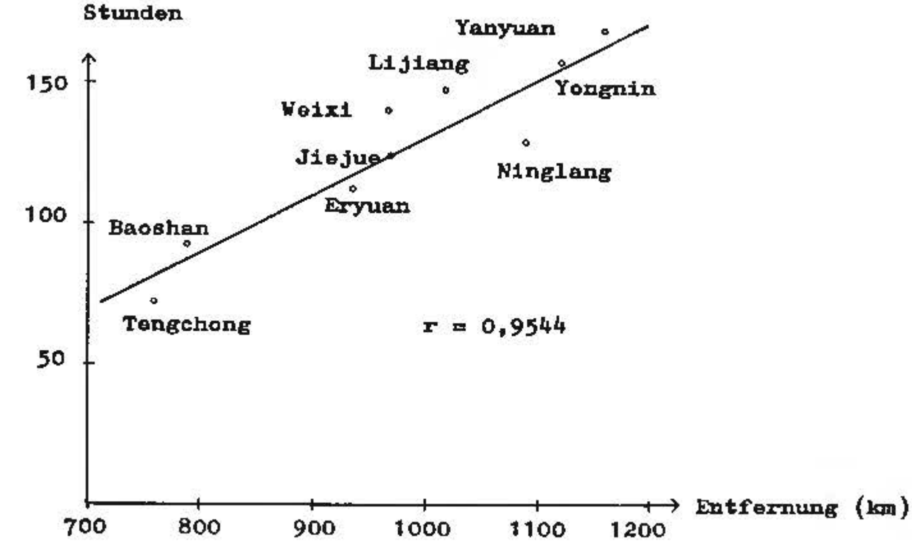

Abb. 7. Beziehung zwischen der Stundensumme der Sonnenbestrahlung im Juli und der Entfernung vom Bengalischen Meer in Westyunnan (Quelle: Meteorologische Stationen Yunnan und Sizhuan).

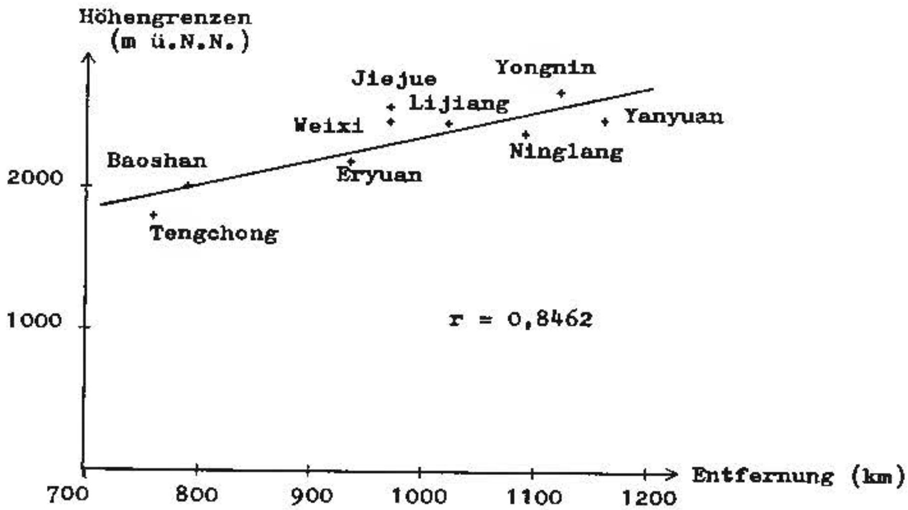

Abb. 8. Beziehung zwischen den Höhengrenzen des Reisanbaus und der Entfernung vom Bengalischen Meer in Westyunnan (Quelle: eigene Berechnungen).

höher als das erste Gebiet. Der Wärmeeffekt der Massenerhebung steigt; dementsprechend liegt die Obergrenze des Reisanbaus im allgemeinen 500–1000 m höher als im Bereich a.

Z. B. in Lijiang im Kreis Huaping (26°40′ nördl. Br., 101°10′ östl. L., 1155 m ü. N. N.) wird eine Wärmesumme von 7091,6 °C pro Jahr und eine Jahresmitteltemperatur von 19,9 °C erreicht. In Lonquanshan in der Provinz Zhejiang ist die Wärmesumme um 3000 °C und die Jahresmitteltemperatur um 7 °C niedriger, obwohl dieser Ort etwa auf dem gleichen Breitengrad liegt und dieselbe Höhe erreicht. Huaping befindet sich in der subtropischen immergrünen Waldzone, während Lonquanshan (1000 m ü. N. N.) in der gebirgigen, warmgemäßigten Nadel-Laub-Mischwaldzone liegt. In Huaping erhält man 3 Ernten pro Jahr; in Longquanshan wird eine Reisernte pro Jahr erwirtschaftet. Aufgrund der unterschiedlichen geographischen Lage und des Reliefs unterliegt die Obergrenze des Reisanbaus erheblichen Schwankungen.

3. Auf dem Plateau des Qinghai-Xizang kann aufgrund der ungünstigen Klimabedingungen kein Reis angebaut werden. Am Südhang des Himalaya hat der SW-Monsun Zutritt und bewirkt das feuchte Klima in den Tälern und Becken; in diesem Gebiet (Zayu, Medoq) wird Reis angebaut, jedoch liegen die Höhengrenzen sowie die natürlichen Vegetationszonen niedriger als in Lijiang. Abbildung 9 ver-

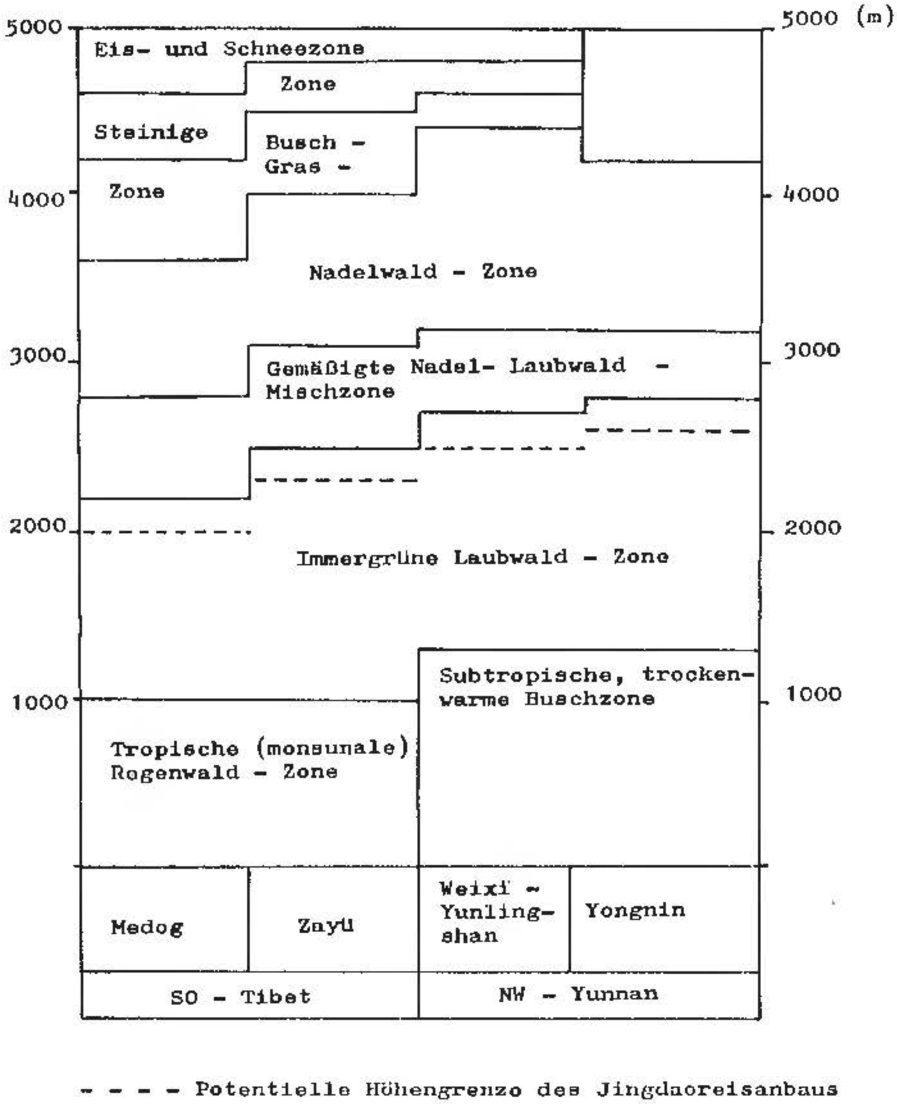

Abb. 9. Vegetationszonen in SO-Tibet und NW-Yunnan und die potentielle Höhengrenze des Reisanbaus (Quelle: YU XIAO-GAN und SUN SHANH-ZHI, 1981).

gleicht die natürlichen Vegetationszonen und die potentielle Höhengrenze des Reisanbaus NW-Yunnans und SO-Tibets. Die immergrüne Laubwaldzone liegt in NW-Yunnan 200–500 m höher als in SO-Tibet; die potentielle Höhengrenze des Reisanbaus entspricht dieser Verschiebung.

Auch der Verlauf der Gebirge beeinflußt das Mikroklima und somit die Höhengrenze des Reisanbaus. In Ostchina verlaufen die Gebirge überwiegend in NO-SW-Richtung; in SW-China in O-W- oder SO-NW-Richtung. Die klimatischen Differenzen zwischen dem Luv- und Leehang wirken sich entscheidend auf den Anbau aus. Zhanhe und Yongnin im Bezirk Lijiang liegen am Luv- bzw. Leehang; die durchschnittliche Wärmesummendifferenz beläuft sich auf 400 °C, der Unterschied in der Jahresmitteltemperatur 1,2 °C. Die Höhengrenzendifferenz beträgt 300 m.

In der Nähe des Yongnin-Beckens liegt der Rugusee (53 km^2 Wasserfläche), der eine große Rolle bezüglich der Regulierung des Klimas spielt. Durch die wärmespeichernde Wirkung des Sees liegt die durchschnittliche Nachttemperatur 2 °C höher als in anderen Gebieten.

2.2 *Einfluß der Reissorten auf die Höhengrenzen des Reisanbaus*

Neben dem Einfluß der ökologischen Bedingungen auf die Höhengrenze des Reisanbaus nimmt die verwendete Reissorte hinsichtlich dieser Fragestellung eine wichtige Stellung ein.

In China wird der Reis hauptsächlich in den feuchten und halbfeuchten Zonen angebaut; die Reiswachstumsperiode fällt in die Regenzeit. In Tab. 3 sind die Temperaturansprüche verschiedener Reissorten zusammengestellt. Während der Keimung und Blütezeit benötigt der Xiandaoreis eine um durchschnittlich 2–4 °C höhere Durchschnittstemperatur als der Jingdaoreis.

Die in China gezüchteten Reissorten sind das Ergebnis einer angepaßten standortspezifischen Zuchtauswahl; man unterscheidet grundsätzlich zwischen Xiandao-, Jingdao- und Hybridsorten, die aufgrund ihrer Anpassung an die ökologischen Gegebenheiten viele Varianten aufweisen.

Zum Beispiel werden folgende Jingdaoreissorten angebaut:

a) Schwarzer Reis, der in gebirgigen Zonen wächst;
b) Mohe-Jingdao, Reis der hohen Breiten (vgl. Tab. 4);
c) Allgemeiner Jingdao, der in Ebenen wächst.

Besonders wichtig für die Reifung des Reises ist, daß während der gesamten Wachstumsperiode durchschnittlich eine Minimaltemperatur von 10 °C herrscht. Der Jingdaoreis ist relativ unempfindlich gegen niedrige Temperaturen und Nebel im Gegensatz zum Xiandaoreis.

Die wichtigsten klimatischen Kriterien für die Höhengrenze des Anbaus von Schwarzem Reis sind:

- die Jahresmitteltemperatur sollte zwischen 11–12 °C liegen
- im wärmsten Monat muß für die Reifung des Reises eine Durchschnittstemperatur von 17–18 °C erreicht werden
- 3000 °C Wärmesumme pro Jahr
- nicht mehr als 180 Frosttage/Jahr

Mit Hilfe dieser oben angeführten Kriterien kann mit großer Wahrscheinlichkeit die potentielle Höhengrenze des Reisanbaus errechnet werden. Vergleicht man die reale Höhengrenze mit der potentiellen (mit Hilfe der Klimakriterien), so kommt man zu folgendem Ergebnis: Beide Grenzen entsprechen zum größten Teil einander; in einigen Regionen wird sogar die theoretische überschritten (durch die ungünstigen natürlichen Bedingungen sind die Reisernten zu unbeständig, die Anbaumethode zu unrationell).

In Ostchina erreicht die reale Höhengrenze weder die potentielle des Schwarzen Reises noch die des Allgemeinen Jingdaoreises. Die potentielle Anbaugrenze des Jingdaoreises liegt in 1200 m Höhe; tatsächlich wird bis in 1000 m Reis angebaut.

Aus Tab. 5 geht hervor, welchen Einfluß die jährlichen klimatischen Schwankungen auf die Ernteerträge (im Becken Jejue) ausüben.

Tabelle 3. Temperaturansprüche verschiedener Reissorten.

Reissorte	$\Sigma t \geq 10$ °C Jahr (°C)	Temp. während Keimung (°C)	Monatsmitteltemp. während d. Blüte (°C)	mögl. Höhengrenze des Reisanbaus (m)	Reale Höhengrenze d. Reisanbaus in NW-Yunnan (m)
Xiandaoreis	4000	12	22	2100	2000
Hybrid-Sorte	4000	12	22		
Jingdaoreis	3500	10	20	2400	2500
Schwarzer Reis	3000	8	16	2700	2700
Jingdao in hoher Breite	2000	10	20		

(Quelle: DING YING, 1961; YU XIAO-GAN)

Tabelle 4. Wachstums- und Temperaturkriterienvergleich zwischen Schwarzem Reis und Mohe-Jingdao.

Ort	Reissorte	Breitengrad	Höhengrenze d. Reisanbaus (m ü. N. N.)	Wachstums-zeit (Monate)	Wachstums-zeit (Tage)	Σt ≥ 10 °C in Wachstums-periode	Ø Tagestemp. während Wachstumsp.	Tage/J. mit Temp. ≥ 10 °C
Jejue	Schw. Reis	27°15′	2600	Anf. April – Mitte Okt.	170–190	2804	14,3	180
Mohe	Mohe-Jingd.	53°32′	200	Ende Mai – Anf. Sept.	101	2000	16,6	110

(Quelle: DING YING, 1961; YU XIAO-GAN)

Tabelle 5. Ernteerträge im Becken Jejue.

Jahr	Ø Ernteertrag (Pfund/Mu)	Ø Ernteertrag auf guten Böden (Pfund/Mu)	Ø Ernteertrag auf schlechten Böden (Pfund/Mu)
1977 (kaltes Jahr)	200–250	290	< 100
1980 (norm. temp. Jahr)	334	556	200
1981 (warmes Jahr)	350	500–600	250

(Quelle: YU XIAO-GAN)

2.3 Einfluß der sozial-wirtschaftlichen Bedingungen auf die Höhengrenze des Reisanbaus

In NW-Yunnan ist die reale Höhengrenze überwiegend identisch mit der potentiellen, während in Ostchina die reale niedriger liegt als die potentielle des Schwarzen sowie des Jingdaoreises. In Ostchina ist ausreichend Land für den Reisanbau vorhanden; dadurch kann der Bedarf an land- und forstwirtschaftlichen Produkten gedeckt werden. Ein gut ausgebautes Verkehrsnetz ermöglicht wiederum den Transport und den Austausch von Produkten. Entsprechend den ökologischen Verhältnissen können die landwirtschaftlichen Erzeugnisse angebaut werden.

In NW-Yunnan herrschen dagegen schlechte Verkehrsbedingungen; folglich ist der Austausch und der Transport von Nahrungsmitteln begrenzt. Die Agrarprodukte dienen fast ausschließlich der Eigenversorgung. Die relativ hohe Obergrenze des Reisanbaus ist u. a. auf die schlechte Infrastruktur zurückzuführen. In NW-Yunnan leben über 10 Nationalitäten, die durch ihre unterschiedlichen Landnutzungsmethoden die Obergrenze des Reisanbaus beeinflussen. Han-, Bai- und Nashi-Nationalitäten leben im Bereich der Obergrenze; durch ihre relativ fortschrittlichen Anbaumethoden sind sie in erster Linie für die Verschiebung der Obergrenze in den letzten Jahrhunderten verantwortlich. Bestimmte Bauerngruppen erbringen einen doppelten Reisertrag aufgrund eines höheren technischen Niveaus. In Tab. 6 sind die Reis- und Maiserträge verschiedener Bauerngruppen (1980) zusammengestellt. Die Bewirtschaftung erfolgt überwiegend extensiv. Durch eine Intensivierung des Reisanbaus (Verbesserung und Regulierung des Wasserhaushalts, Einsatz von Mineraldünger, Maßnahmen gegen die Reiskrankheit) kann der Ertrag gesteigert werden.

Tabelle 6. Reis- und Maisernteerträge verschiedener Bauerngruppen 1980.

	Höhe ü. N. N. (m)	Ø Reisertrag (Pfund/Mu)	Ø Maisertrag (Pfund/Mu)
Judian I	1870	900	805
Gudu VI	1930	757	423
Gudu XI	1980	553	591
Weixi	2350	406	
Houging V	2400	310	252
Houging IV	2500	300	295
Dianxin VI	2560	187	527

3. Zusammenfassung

Die Höhengrenzen des Reisanbaus in China variieren sehr stark von Region zu Region. In erster Linie bestimmen die ökologischen Verhältnisse die Höhengrenze; der Einfluß der sozial-wirtschaftlichen Bedingungen und die verwendeten Reissorten sind von Bedeutung für die reale Höhengrenze.

- Die Höhengrenzen des Reisanbaus in China zeigen entlang der Längen- und Breitengrade Gesetzmäßigkeiten auf; die Veränderung in Süd-Nord-Richtung in der tropischen und subtropischen Zone ist im Vergleich zur Ost-West-Richtung geringer.
- Die Differenz zwischen der realen Höhengrenze und der theoretisch möglichen (errechenbar aufgrund klimatischer Kriterien) unterliegt dem Einfluß der sozial-wirtschaftlichen Bedingungen. Die reale Höhengrenze ist abhängig von Reisnachfrage und -preis (und damit von der Bevölkerungsentwicklung) sowie dem Fortschritt der Technik.
- Hinsichtlich des Reisertrages bildet die 2000 und 2300 m-Marke in NW-Yunnan einen Wendepunkt. Unterhalb 2000 m erbringt der Jingdaoreis den größten Ertrag (Wärmesumme: 4200 °C, Jahresmitteltemperatur: 20 °C); unterhalb 2300 m ist der Schwarz-Reis-Ertrag größer (Wärmesumme ist um 500 °C und die Jahresmitteltemperatur um 2 °C niedriger).
- Einige Bauerngruppen erwirtschaften im Vergleich zu anderen einen doppelten Reisertrag aufgrund eines höheren technischen Niveaus. Die Bewirtschaftungsform ist überwiegend extensiv; Maßnahmen wie z. B. Bekämpfung der Reiskrankheit, Regulierung des Wasserhaushalts sowie der Einsatz von Mineraldünger, die den Reisertrag pro ha erhöhen, werden selten getroffen. Auch die Temperaturschwankungen von Jahr zu Jahr im Bereich der Obergrenze des Reisanbaus beeinflussen die Ernteerträge (vgl. Tab. 4). Durch die Neuzucht kälteresistenter Reissorten könnte eine Verschiebung der Obergrenze erreicht werden, was jedoch unrationell für Wirtschaft und Landnutzung ist.
- Auf den Terrassenfeldern in größerer Höhenlage sind andere Kulturpflanzen besser an die lokalen ökologischen Bedingungen angepaßt. Die Nachfrage der Bergbevölkerung nach Reis wird durch die Verbesserung der Infrastruktur leicht zu befriedigen sein.
- Meiner Meinung nach sollte sich der Reisanbau auf den jetzigen Höhen stabilisieren, da im Bereich der Obergrenze die Reiserträge zu niedrig und unbeständing sind und der Reisanbau extensiv betrieben wird. Vielmehr ist eine Intensivierung des Reisanbaus in den Tälern und Becken erstrebenswert. Herrschen günstige ökologische Bedingungen (z. B. Rugu-See), kann die Obergrenze des Reisanbaus durchaus höher ins Gebirge verlagert werden.

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Discussion to the Paper Yu Xiao-Gan

Prof. Dr. S. Hastenrath:

1. Handelt es sich bei den an der Obergrenze vorkommenden Arten um Trockenreis oder Naßreis?
2. Weshalb steigt die Obergrenze mit zunehmender Entfernung zum Bengalischen Meer an?

Prof. Dr. H. Uhlig

(auch als Antwort auf Hrn. Hastenrath):

Die Frage der Reisbauhöhengrenzen wurde erstmals auf dem Symposium dieser Kommission in diesem Hause 1971 (Vergleichende Kulturgeographie der Hochgebirge Südasiens) diskutiert. V. WISSMANN nannte bereits die 2400 m vou Lijiang, während eine andere Angabe (2700 m) von ihm nur nach unsicheren Quellen vermutet werden konnte.

V. FÜRER-HAIMENDORF erwähnte 2700 m in Jumla (W-Nepal), später fand dort KLEINERT die wohl absolut höchsten Reisfelder der Erde in 2850 m. Alle die Hochlagen im Himalaya, von Kaschmir bis Assam (gewöhnlich liegt die Obergrenze bei etwa 2100–2200 m) liegen in Hochtälern und Becken in inneren, sommerwarmen und -trockenen Teilen des Gebirges (mit hoher Strahlung), während die monsunal feuchteren Außenhänge des Himalaya nur Reis bis 1400–1600 m Höhe haben. In China ist der Unterschied offenbar ähnlich zwischen den hohen Gebirgen in N-Yunnan und dessen monsunal tropischem Süden.

Erstaunlich ist Herrn YU XIAO-GAN's Bemerkung über zwei Reisernten pro Jahr in 2400 m im Yuangjiang-Becken, während er sonst dafür 1600 m ansetzt. Normalerweise kennen die (subtropischen) Reisbau-Höhenlagen des Himalaya nur eine Ernte pro Jahr, im Winter Brache oder eine andere Rotationsfrucht.

Bergreis (d. h. Trockenlandreis mit dem Pflanzstock – „shifting cultivation") erreicht nirgends solche Höhen, die Obergrenzen werden stets von bewässertem (Naß-)Reis eingenommen.

Erdwissenschaftliche Forschung, Bd. XVIII, 55–77
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Gongga Shan (7556 m) and Yulongxue Shan (5596 m). Geoecological Observations in the Hengduan Mountains of Southwestern China

Bruno Messerli and **Jack Ives**

With 13 Figures and 1 Table

Summary

The Hengduan Mountains form the southeastern margin of the Tibetan Plateau but are orographically distinct. They consist of a series of mountain systems with a wide variety of altitudinal belts ranging from subtropical evergreen forest to permanent snow and ice. The two main culminations are the Gongga Shan (Minya Konka), reaching 7556 m at latitude 30 °N in western Sichuan Province, and the Yulongxue Shan, reaching 5596 m at latitude 27 °N in western Yunnan Province.

The Gongga Shan supports 159 glaciers, the largest being over 10 km long on the dry western side and over 16 km in length on the more humid eastern side. Snowline is estimated at 5000–5200 m. In the Yulongxue Shan the largest glaciers also occur on the eastern side and snowline, estimated by different authors, must lie between 4700 and 5100 m. Reconstruction of younger Pleistocene glacial conditions indicates a snowline at 4000 to 4400 m on Gongga Shan with end moraines near Kangding extending below 3000 m, and at 4000 to 4100 m on Yulongxue Shan, with end moraines on the eastern side extending as low as 3200 m.

Vegetation belts, timberline, and treeline are, in general, 100 to 300 m higher on Yulongxue Shan than on Gongga Shan and the east-west differences, due to exposure, are more pronounced on the latter. A timberline at 4000 to 4200 m on Gongga Shan and 4100 to 4300 m on Yulongxue Shan may have been depressed by intensive grazing to 3800 m, but can also be as high as 4500 m on the drier west-northwestern slopes.

The two mountain groups are influenced by very different climatic conditions and atmospheric circulation patterns. Gongga Shan receives most of its precipitation from the east while Yulongxue Shan comes under the influence of moist air masses deriving from the Indian Ocean. Lijiang, at a similar altitude to Kangding, has much higher temperatures (5 °C higher mean annual; 7 °C higher mean for coldest month; and 2 °C higher mean for the warmest month). Because of the warmer climate experienced by Yulongxue Shan vegetation belts are higher and the area holds the record for the highest rice cultivation in China (2400 to 2700 m); also, its more humid conditions result in a lower limit for the nival belt. It follows, therefore, that the vertical distance between timberline and snowline is less on Yulongxue Shan than on Gongga Shan.

Man's impacts on the mountain ecosystems of the Hengduan Shan are difficult to decipher. Old documents indicate that much of the deforestation, overgrazing, and slope instability (including landsliding), that is so conspicuous to the modern visitor, occurred appreciably earlier than 1930 in many areas. However, more recent environmental damage appears to have resulted from the rapid population growth and accompanying accelerated exploitation of renewable natural resources that has occurred since 1950. Reclamation of areas heavily damaged both prior to 1930 and since 1950 is urgently needed. Reforestation is today widespread, and in many areas remarkably successful; regeneration of areas subjected to extensive soil erosion, however, will require a much longer time. New research programmes are strongly recommended; rational long-term resource use will greatly benefit from an improved understanding of these fascinating Hengduan Shan landscapes, both from a natural sciences and a socio-economic and cultural point of view. The proposed programme is part of an Academia Sinica-United Nations University highland-lowland interactive systems approach.

Zusammenfassung

Die Hengduan Gebirge, obschon sie den südöstlichen Rand des Tibet-Plateaus bilden, sind orographisch selbständig und bestehen aus Gebirgssystemen, die durch ihre vielfältigen Höhenstufen vom subtropisch immergrünen Wald bis zu ewigem Schnee und Eis beeindrucken. Die zwei bedeutendsten Kulminationen sind der Gongga Shan, 7556 m auf 30 °N im westlichen Sichuan, und der Yülongxue Shan, 5596 m im westlichen Yunnan.

Der Gongga Shan hat 159 Gletscher, die größten erreichen Längen von 10 km (trockene W-Seite) und 16 km (feuchte E-Seite), die Schneegrenze wird auf 5000–5200 m geschätzt und die Endmoränen liegen auf 4000 m oder auf der Feuchtseite sogar darunter.

Im Yülongxue Shan befinden sich die großen Gletscher ebenfalls auf der E-Seite. Die Schneegrenze wird von verschiedenen Autoren auf 4700–5100 m geschätzt.

Die letzteiszeitliche Vergletscherung wurde mit Schneegrenzen von 4000-4400 m im Gongga (Endmoränen bei Kangding unter 3000 m) und 4000–4100 m in Yulongxue Shan (Endmoränen auf der Ostseite unter 3200 m) rekonstruiert.

Vegetationsstufen, Wald- und Baumgrenze sind im allgemeinen 100–300 m höher im Yülongxue als im Gongga Shan. Die W-E-Expositionsdifferenzen sind im Gongga deutlicher ausgeprägt als in Yülongxue Shan. Eine obere Wald- und Baumgrenze von 4000–4200 m im Gongga Shan (Yülongxue 4100–4300) kann durch intensive Beweidung auf 3800 m heruntergedrückt sein, in trockeneren Gebieten im WNW aber auch Höhen von 4500 m erreichen.

Klima- nnd Zirkulationsbedingungen sind in den beiden Gebirgen sehr verschieden. Gongga Shan erhält seine Niederschläge von Osten, Yülongxue Shan von Süden und Südwesten. Lijiang in einer vergleichbaren Höhe mit Kangding hat viel höhere Temperaturen, im Jahresmittel + 5 °C, für den kältesten Monat + 7 °C und für den wärmsten Monat + 2 °C mehr (Tab. 1). Die wärmeren Bedingungen heben die Vegetationsgrenzen an (höchste Reisanbaugebiete in China mit Höhen von 2400–2700 m), und die verstärkte Feuchtigkeitszufuhr senkt die Schneegrenze ab. Die Differenz zwischen Waldgrenze und Schneegrenze ist deshalb in Yülongxue kleiner als im Gongga Shan.

Die Beurteilung des menschlichen Einflusses auf die Gebirgsökosysteme ist nicht leicht zu rekonstruieren, weil Dokumente aus der ersten Hälfte unseres Jahrhunderts deutlich zeigen, daß sämtliche Erosionserscheinungen und Übernutzungsprozesse schon damals als Zeichen einer intensiv genutzten Kulturlandschaft vorhanden waren. Neue Schäden entstanden durch die rasche Bevölkerungszunahme seit 1950. Heute müssen alte und junge Schäden dringend bekämpft werden, um Summationseffekte und daraus folgende Katastrophen zu verhindern. Aufforstungen sind überall im Gang, eine Regeneration der zerstörten Böden dagegen braucht viel mehr Zeit. Neue Forschungsprogramme sind dringend: In einem Hochland-Tiefland-Interaktiven-System sind die Bewohner der Gebirge für die Bewohner der Ebenen verantwortlich.

Résumé

Les montagnes de Hengduan, quoique formant le rebord sud-est du Tibet, sont orographiquement indépendantes et sont constituées de systèmes de montagnes qui impressionnent par leurs variétés de zones d'altitude allant de la forêt subtropicale jusqu'aux neiges et glaces pérennes. Les deux culminations les plus importantes sont le Gongga Shan 7556 m à 30 °N dans le Sichuan occidental et le Yulongxue Shan 5596 m dans le Yunnan occidental.

Le Gongga Shan a 159 glaciers, les plus grands atteignant des longueurs de 10 km (côté ouest sec) et 16 km (côté est humide), la limite des neiges est évaluée à 5000 m et les moraines terminales se situent à 4000 m ou même plus bas du côté humide. Dans le Yulongxue Shan les plus grands glaciers se trouvent aussi du côté est. La limite des neiges est estimée à 4700–5100 m, par divers auteurs.

La dernière glaciation quaternaire se reflète dans une limite des neiges de 4000-4400 au Gongga (moraines terminales près de Kangding sous 3000 m) et de 4000–4100 m au Yulongxue Shan (moraines terminales du côté oriental sous 3200 m).

Les zones de végétation, la limite des forêts et des arbres se situent en général 100 m–300 m plus haut au Yulongxue qu'au Gongga Shan. Les différences d'exposition est-ouest sont plus marquées au Gongga Shan qu'au Yulongxue Shan. Une limite supérieure de la forêt et des arbres de 4000–4200 m au Gongga Shan (Yulongxue Shan 4100–4300) peut être abaissée par une pâture intensive à 3800 m, dans les régions sèches du ONO elle peut aussi atteindre une altitude de 4500 m.

Climat et conditions de circulation sont très différents dans les deux massifs de montagnes. Le Gongga Shan reçoit ses précipitations de l'est, le Yulongxue Shan du sud et du sud-ouest. Lijiang situé dans une altitude comparable à Kangding a des températures bien plus élevées, les moyennes + 5 °C, pour le mois le plus frais + 7 °C, pour le mois le plus chaud + 2 °C plus élevées (tableau 1). Les conditions plus chauds élèvent les limites de végétation (régions de cultivation du riz les plus hautes de Chine, altitude de 2400–2700 m), et l'apport d'humidité renforcé abaisse la limite des neiges. La différence entre la limite de la forêt et la limite des neiges est donc plus petite dans le Yulongxue Shan que dans le Gongga Shan.

Juger de l'influence humaine sur les écosystèmes montagnards est difficile, car des documents de la première moitié de notre siècle montrent distinctement que toutes les formes d'érosion et tous les processus de pâture abusive étaient déjà présents comme signe d'un paysage culturel intensément utilisé. De nouveaux dégâts sont apparus avec l'augmentation rapide de la population à partir de 1950. De nos jours, il est important de combattre d'anciens et de nouveaux dégâts pour éviter des effets de sommation et les catastrophes qui en découlent. Partout, des reforestations sont entreprises, mais une régénération des sols demande beaucoup plus de temps. De nouveaux programmes de recherche sont urgents. Dans un système interactif entre les hauts et les bas pays les habitants des régions de montagne sont responsable pour les habitants des plaines.

1. Introduction

As a result of scientific collaboration between the United Nations University (UNU) and the Academia Sinica, a mission of Chinese and western scientists in September–October 1982 visited two main mountain areas of the Hengduan Shan, the southeastern edge of the Tibetan Plateau, in the region of the big river gorges. The aim of the mission was to outline the possibilities for an integrated and interdisciplinary research programme for this huge mountain area. This, in turn, was motivated by widespread concern that overuse of the renewable natural resources of the region is not only a threat to the local environment and the well being of the indigenous peoples, but may also have serious consequences in terms of downstream effects in the Chengdu Basin, one of the world's most important rice producing areas and centres of high population density. As in the case of the Himalaya-Ganges Plain (ECKHOLM, 1975; IVES and MESSERLI, 1981 and 1984) assumptions to the effect that deforestation and soil erosion in the hills and mountains has led to devastation in the plains are based upon surprisingly little reliable data. Therefore, this project is considered as an important and urgent task in the overall "Highland-Lowland Interactive Systems Programme" of the Academia Sinica and the United Nations University, since a much stronger scientific base is an imperative for effective decision making and implementation.

The Hengduan Mountains, though forming the southeastern margin of the Tibetan Plateau (Qinghai-Xizang), are an orographically independent mountain system; they cover a surface area of about 500 000 km² (Fig. 1) and the two main culminations are the Gongga Shan, 7556 m (Minya Konka) at about 30° North in western Sichuan Province and the Yulongxue Shan, 5569 m, at about 27° North in western Yunnan Province. These mountain systems are well known in the literature because they have

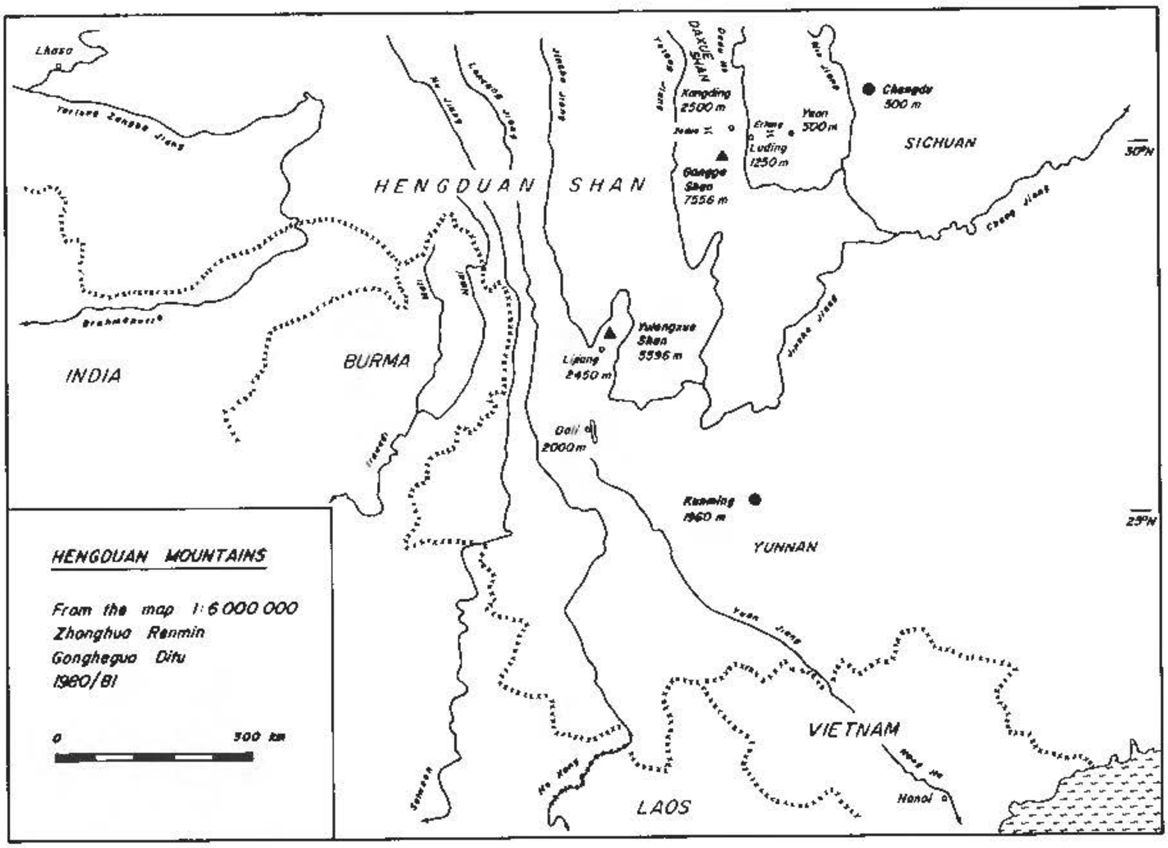

Fig. 1. Hengduan Mountains (sketch map).

been visited by travellers and scientists of different disciplines during the first half of our century (see references). Most of them referred to the "River Gorge Country" because the meridional river gorges are the characteristic feature of this area. During the Qinghai-Xizang-(Tibet-)Symposium of 1980 the name "Hengduan" was introduced and it also appears on the new English language map of China of 1980, scale 1:6000000. It is not clear, according to local and general usage, whether the name "Daxue Shan" should be given the same order as "Hengduan Shan". Nor is it established that Gongga is to be associated with the Daxue Shan or the Hengduan Shan (Map, 1:6000000). During the entire 1982 expedition, our Chinese colleagues from Beijing, Chengdu, and Kunming used the name Hengduan Shan for the whole area from north of Gongga Shan to south of Yulongxue Shan.

A more detailed description and comparison of the two highest mountain systems is of special interest. This is because they cover not only an enormous altitudinal range over relatively short horizontal distances (e.g., Gongga Shan from Luding on the Dadu River at 1250 m to the highest point at 7556 m; Yulongxue Shan from the Yangtse or Jinsha Jiang River Gorge at 1725 m to the summit at 5596 m), but also exhibit a great variety of altitudinal belts. These extend upwards from the subtropical evergreen forests on the lower slopes to permanent snow and ice. In addition this region east of the Himalaya and Tibet is well known for its floral richness, including a large number of endemic species, great climatic variation, impressive change in relief types from deep gorges to high mountains and plateaus, and finally, for its extensive ethnic differentiation with a wide variety of characteristic settlement types, land-use patterns, and techniques. In the following sections we shall introduce and discuss our geoecological observations and outline some of the problems relating to the human occupance and natural history of the area.

2. The Situation of the Mountains and Their Glaciation (A Comparison of the Highest Glacial-Nival Belt)

2.1 Gongga Shan

Figure 2 is a sketch map showing the general location of Kangding, the main settlement of the region, the Gongga Shan massif, and the most important valleys, passes, and roads. Excellent detailed maps at different scales ranging from 1:1000000 to 1:200000 (and for Gongga Shan and Kangding even 1:100,000) can be seen in IMHOF (1974, fieldwork 1930). We decided to use our simplified sketch maps, drawn from the information provided by our Chinese colleagues, because there have been some changes in names, altitudes, and roads since 1930. The maps of Imhof are unsurpassable and are still of the highest value today.

Gongga Shan in its central part was assumed to be a crystalline massive composed of granites and diorites and surrounded by sedimentary rocks. These conclusions were derived from geological investigations of the surrounding area and from the dominance of granitic material in the glacial moraines, especially on Gomba Glacier, below the highest peaks (HEIM, 1933, 1936, p. 445; IMHOF, 1974, p. 18).

In recent years Chinese expeditions from the Chengdu Branch of the Academia Sinica opened a new phase of research activity in the Gongga region. They analysed the tectonics of the different northwest- and northeast-trending rift and fault systems that provide the major controls for the structure, morphology, and hydrography of the present landscape (Fig. 2). A remarkable result is that the highest peak of Gongga Shan was found to be composed not of granitic material but of malmstone and slate of the Triassic Period. This result is also based on analysis of morainic material from the western flank of the dominant peak (LI ZHONGWU et al., 1982, p. 20). Generally accepted is the strong uplift, especially since the Quaternary, which has had a great effect on the high relief energy of the area, on the extreme altitudes on

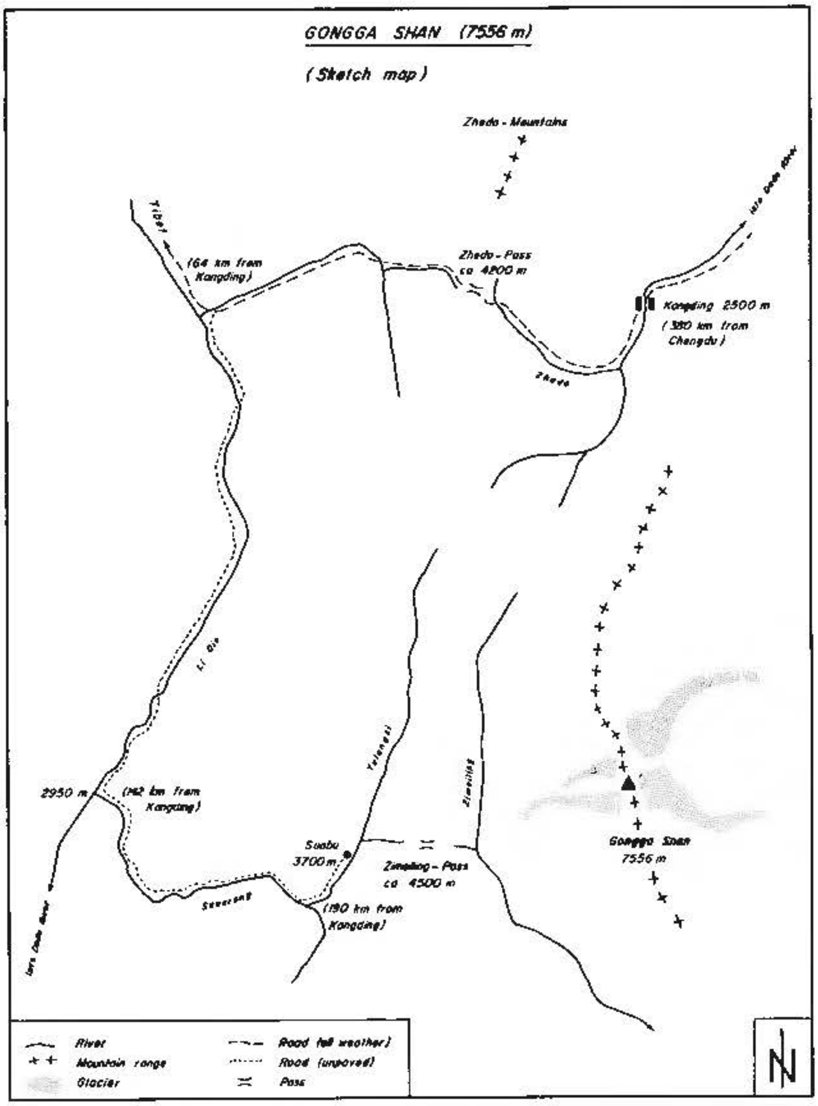

Fig. 2. Sketch map of Gongga Shan (7556 m).

the one hand and on the deep valleys and gorges on the other (e.g., Kangding Gorge, Dadu River Valley).

The glaciated area is about 360 km² and there are 159 active glaciers. According to data from 1930 to 1966 they have retreated at an average rate of about 100 m per year; data for the period 1966 to 1980 indicates a significant reduction in the rate of retreat to only 40–50 m per year (LIU SHUZHENG et al., 1982, p. 34).

The snowline has been defined by different authors. WISSMANN (1959 a, p. 1295) proposed 5300 m on the west and 5150 m on the east side, with an average of 5250 m. SHI YA-FENG (1981, p. 1597), in his general overview of the snowline in China, gives an altitude of 5000–5200 m. Of special climatic interest are the differences in exposure between the east and west sides of the massif. The largest glacier (Gomba) on the west side is about 10 km long and its end moraines are at about 4000–4200 m, 2 km northeast of the monastery. The largest glacier on the east side is H a i l o k o with a length of 16 km and end moraines in the subalpine coniferous forest far below 4000 m; HEIM supposes an altitude as low as 3000 m (HEIM, 1936, p. 445; IMHOF, 1974; Appendix map C).

Recent Chinese research indicates a similar differentiation in the belt of solifluction activity. The climatic belt of periglacial processes lies above 3600 m on the east side and above 4200 m on the west side

(LIU SHUZHENG et al., 1982, p. 34). Our observations in the Yulongxi Valley give comparable results (Fig. 5). However, where the individual slope gradient, exposure, and lithology are favourable, solifluction processes occur to even lower altitudes.

The younger Pleistocene glaciation is not yet analysed and mapped in detail. It seems that the differences between the recent and the younger Pleistocene glaciations are more pronounced on the drier western side than on the more humid eastern side. The Gomba Glacier on the western side extended to about 3400 m and had a length of 18 km during the Pleistocene, whereas the glaciers on the east side were only two to three km longer than their present-day counterparts. Their end moraines, covered by dense forests or destroyed in the more humid climate, are not yet mapped in any detail. Also observations from the Zhedo Pass (Fig. 2) show these differences very clearly. On the eastern side moraines extend down to 3000 m but on the west side only to 3800 m. WISSMANN (1959a, p. 1296) believes that a younger Pleistocene glacier extended as far as the present site of Kangding and that the moraines at 3000 m were formed during a retreat stade. This conclusion is not yet confirmed.

In the Yulongxi Valley and in the area of the Zimeiling Pass (Fig. 2) we observed younger Pleistocene moraines as low as 3500 m. Because the surrounding mountains were not very high, the snowline must have been about 4000 m. This result is similar to that of WISSMANN, who calculated 4100 m for the mountains near Kangding. Certainly, the snowline was lower on the east side of Gongga Shan and higher to the west, closer to the Tibetan Plateau. As a whole, the late Pleistocene snowline was situated between 4000 m (east) and 4400 m (further west) and on both sides about 1100–1200 m below the present snowline.

2.2 Yulongxue Shan

These mountains, about 26 km long and 13 km wide, are well-known in the German literature, especially by HANDEL-MAZZETTI, WISSMANN and others (see references in WISSMANN, 1959b; SCHWEINFURTH, 1975). A sketch map by WISSMANN (Fig. 3) shows the general situation of the mountain within the great bend of the River Yangtse (Jinsha Jiang). Though the place names have a different transliteration today, they can easily be understood.

The most important settlement is Lijiang at 2450 m (on WISSMANN's map: Lidjang, 2475 m) from where a road follows the eastern side of the high mountains (Fig. 4). No information is available for the western side which makes the determination of west-east differences in altitudinal belts rather difficult.

The northern and higher part of Yulongxue Shan is largely formed by limestone of Carboniferous-Devonian age: it is pure, massive, and more or less metamorphosed. In the southern and lower part of the range, Permian basalt is the principle stratum with interstratification of basalt and limestone. The remarkable contrast between whitish limestone and dark basalt has led to special place names such as "white" or "black" mountains. The environs of Lijiang are underlaid mainly by Triassic limestone, very often overlaid by Tertiary conglomerate and sandstone, Quaternary alluvial deposits and lacustrine sediments (JEN MEI NGO, 1958, p. 309). Tectonic movements are represented by an older north-south and east-west system and by younger NNE-SSW-Quaternary faults. The latter are especially impressive on the eastern side where the mountain rises abruptly 1500 m above the neighbouring basin (Fig. 4). The frequent occurrence of destructive earthquakes indicates continuing tectonic activity. According to historical data, five destructive earthquakes have occurred in the Lijiang area in the last 200 years (JEN MEI NGO, 1958, p. 310).

The deep gorges of the Jinsha Jiang are also a reflection of the tectonic structure. Near the narrowest place, called the Tiger Leap, the slopes on both sides tower up more than 3000 m and separate the Yulongxue and the Haba Shan (Fig. 3).

WISSMANN, summing up the knowledge from different explorers and scientists (1959b, pp. 173–175), calculates an average snowline of 5100 m on Yulongxue and 5200 m on Haba Shan, somewhat lower on

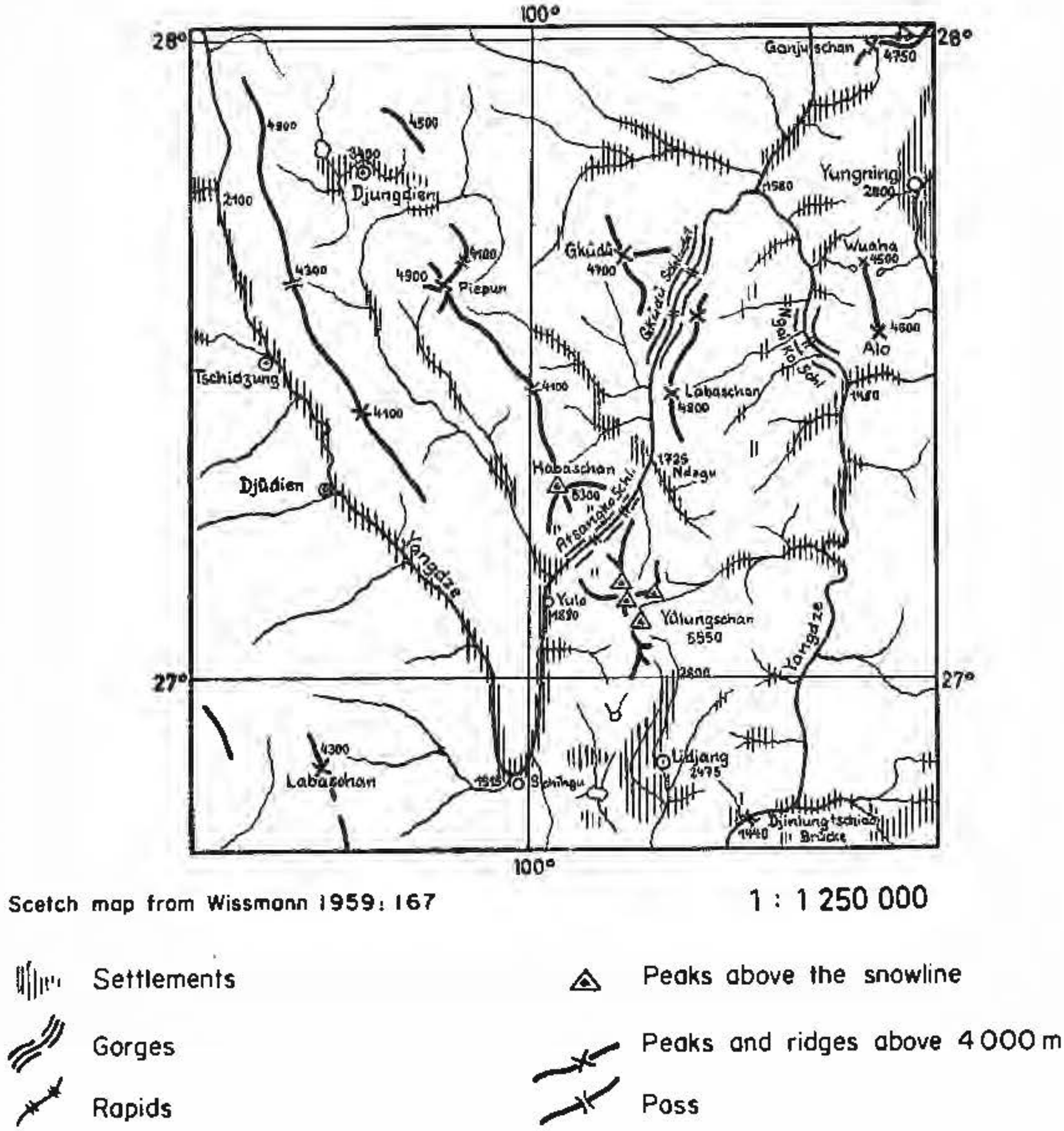

Fig. 3. Sketch map from WISSMANN (1959, Abb. 1, p. 167).

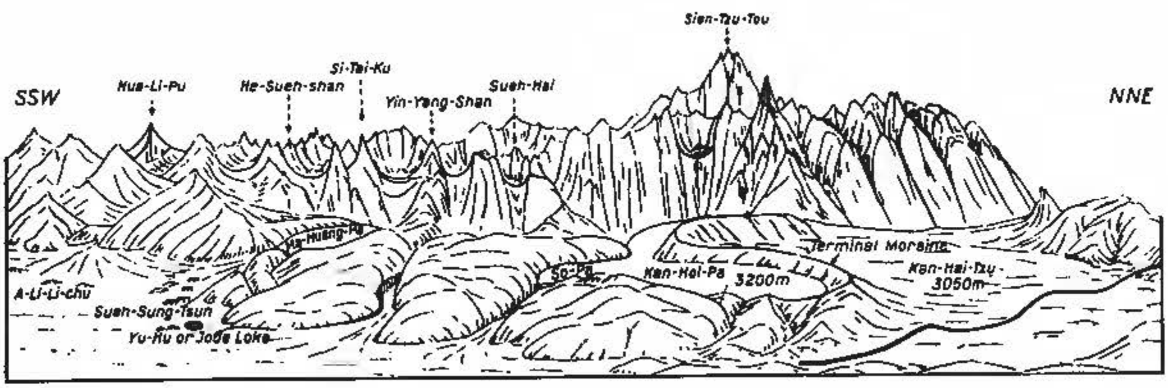

Fig. 4. The eastern part of Yulongxue Shan (sketch by H. S. BAO). From JEN MEI NGO (1958, Fig. 3).

the eastern and northern and higher on the western and southern exposures. Of special interest is the large glacier which issues from the east-facing cirques below the highest summit Sien-Tzu-Tou (Fig. 4); it regenerates twice after cascading over steep rock walls and ends in an ice avalanche at 3625 m. The real terminus of this spectacular glacier must be much higher. Haba Shan has only a glacier with northern exposure. JEN MEI NGO (1958, p. 310) observed on the eastern side of Yulongxue Shan three cirque glaciers between 4400 m and 4500 m. He concludes that the eastern-exposure snowline must be about this altitude and that the climatic snowline for the whole mountain is much higher (at about 5000 m). Finally, SHI YA-FENG, in his overview of all the glaciers in China (1981, p. 1597), assumes that the snowline on Yulongxue Shan lies between 4600 and 4800 m. However, a complete description of the glaciation can not be compiled because observations from the western side are lacking. From all the available information we assume an average climatic snowline of about 5000 m for the southernmost glaciation in Asia (Fig. 5).

The younger Pleistocene glaciation is called Dali Glaciation, because the southernmost moraines were found on the mountains above Dali (Fig. 1). The highest point reaches 4130 m and the cirque with an east-northeast exposure lies at 3920 m (WISSMANN, 1959 b, p. 180). JEN MEI NGO (1958, p. 312) uses the same terms and marks the younger glaciation Dali and the older one Lijiang. The cirques of the Dali Glaciation can be found on the eastern side of Yulongxue Shan at about 4000 m with end moraines reaching to 3200 m. During the Lijiang Glaciation glaciers descended even to 2800 m. Of special interest is the huge moraine emerging from a spectacular U-shaped valley and ending at 3000–3200 m far out from the steep mountain slope. WISSMANN (1959 b, p. 171) called it the Lokü moraine and JEN MEI NGO (1958, p. 312) the Kan-Hoi-Pa moraine (Fig. 4). The glacier that formed this moraine had a length of 12 km and terminated on a 150 m high ramp of accumulated material.

The snowline during the Dali Glaciation is assumed to have been about 4000 to 4100 m in the mountains between Dali and Yulongxue Shan; its altitude will have increased toward the north.

Comparing the recent and Dali Glaciations of Yulongxue with Gongga Shan we can assume that the present-day and the younger Pleistocene snowline was about 200 m lower on Yulongxue than on Gongga Shan. The big differences in exposure of Gongga Shan cannot be compared because of missing observations from the western slopes of Yulongxue Shan.

3. Forest and Vegetation (A Comparison of the Middle and Lower Altitudinal Belts)

Figure 5 shows the vertical belts of the two mountain systems. Although the species are quite different, we tried to bring the vegetation types into a comparable order (for much of the information introduced here we are indebted to Prof. LI WENHUA, who accompanied us, and to Lee MACDONALD, for his unpublished report of 1982).

One problem cannot be solved from Fig. 5: observations and informations were not sufficient to display the extremely interesting differentiation between east- and west- and between north- and south-facing slopes. Therefore, the horizontal borderlines between the different vegetation belts are somewhat unrealistic.

3.1 Gongga Shan

The Erlang and Zhedo passes are very instructive for observing differences in vegetation cover between the more humid eastern and the dryer western exposures. The different mountain ranges form barriers for precipitation coming from the east: for example, on the Erlang Pass, dense forests on the east and denuded slopes on the west; on the Zhedo Pass the forest is destroyed and reduced to shrubs even on the humid side. Local informants told us that the forest had been cut in the 1950s during the road construction.

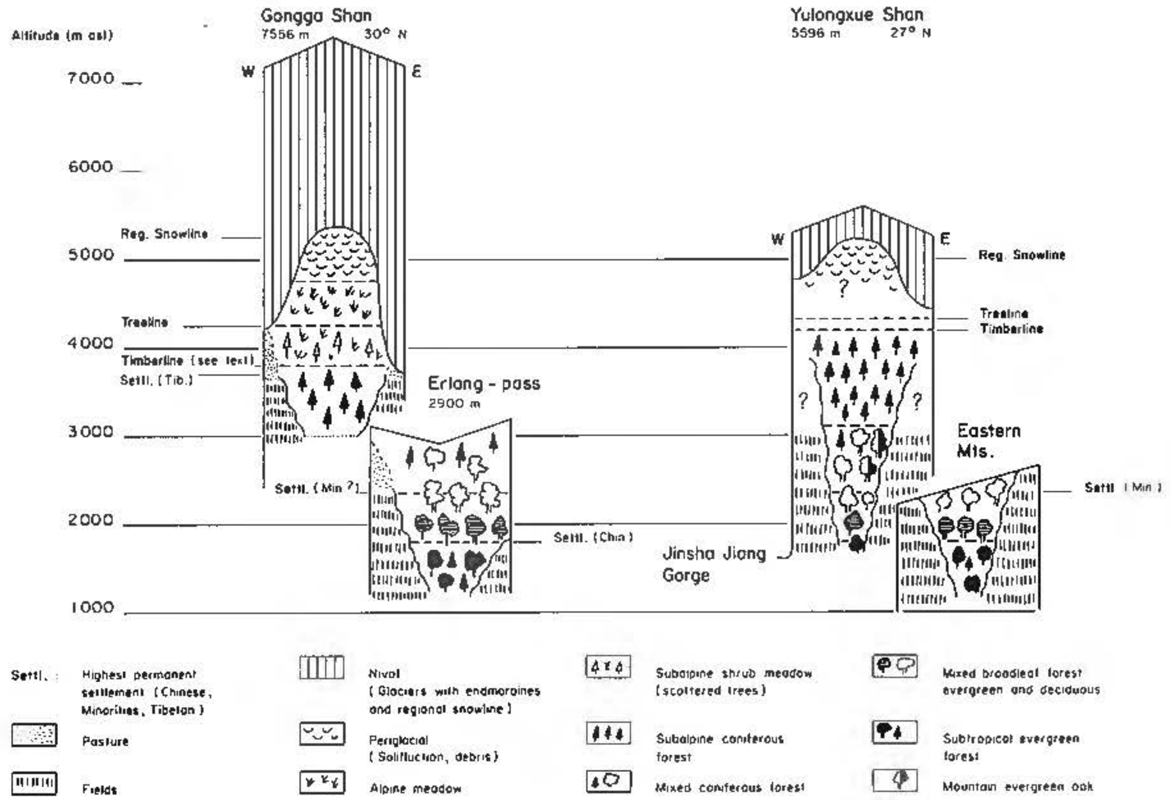

Fig. 5. The pattern of vertical belts: forest, vegetation and land use.

Older photographs (HEIM, 1933; IMHOF, 1974, with pictures from 1930) show the town of Kangding without any forests on the surrounding slopes. Perhaps the processes of deforestation are much older than only 1950.

The large Li Qio Valley (Fig. 2) is an old Tibetan landscape with sparse forest cover on the high crests and on the ridges or steeper slopes. Only in the narrow lower part of Li Qio and in the Sewurong Valley we have seen a rich, protected, mixed coniferous forest.

In the Yulongxi Valley near the Zimeiling Pass forest becomes rare and *Larix* and *Picea* extend as scattered trees and small remnant stands to between 4000 and 4200 m. The highest permanent settlement with barley fields was at about 3700 m. HEIM describes settlements with barley and vegetables in the Yulongxi at 4000 m. Does this indicate a mistake in the measurement of the altitude or was there a still higher village? (HEIM, 1933, p. 68). We have no answer, but one thing is clear: from this earlier description it is concluded that the population and cattle densities were the same in 1930 or even greater than today (Fig. 10). Therefore, the conspicuous effects of overgrazing seem to be the result of long-lasting processes and not only a phenomenon of recent decades.

The vegetation belts of Fig. 5 can be described as follows (LI WENHUA and ZHADO XIE YING, 1981, pp. 36–38; MACDONALD, 1982, p. 2):

1000–1800 m: Subtropical mountain belt:
the mean annual air temperature is about 15–20 °C; mean temperature of the coldest month is more than 7 °C; the evergreen forest is dominated mainly by Fagaceae and Lauraceae.

1800–2400 m: Mixed broadleaf forest:
mean annual air temperature 11–15 °C; mean temperature of the coldest month is more than 3 °C; these forests tend to be dominated by deciduous species at the higher levels (e.g., *Toona*, *Tetracentron*, etc.),

and evergreen species at lower levels (Lauraceae, Fagaceae, Magnoliaceae, Araliaceae, etc.); on the slopes where the forests have been disturbed, birch forests have developed.

2400–3000 m: Mixed coniferous and broadleaf forest belt:
the annual air temperature is 8–11 °C; *Tsuga dumosa* occurs on north-facing slopes; on sunny slopes pines dominate; broad-leaved species includes *Acer, Betula,* etc.

3000–3800 m: Subalpine coniferous forest:
the upper limit of this belt can be much higher, normally 4000 m–4200 m. In Yulongxi Valley, the upper limit was probably depressed to 3800 m by intense grazing. HEIM (1933, photo 88, pp. 109 and 144) observed a *Picea* forest at about 100 km WNW of Gongga Shan at 4500 m. The upper limit of this belt coincides with the upper limit of forests where the mean annual air temperature is about 2 °C; the mean temperature of the coldest month is − 8 °C, of the warmest month 10–12 °C; the typical trees are *Abies, Picea, Larix.*

3800–4200 m: Subalpine shrub-meadow-mosaic belt between timberline and treeline (it can be higher in other regions of Gongga Shan):
thus, scattered *Larix, Picea, Sabina* can be found, as well as shrubs, such as *Salix, Rhododendron,* and *Berberis.*

above 4200 m: Alpine meadow:
the vegetation becomes increasingly sparse with altitude.

3.2 Yulongxue Shan

HANDEL-MAZZETTI (1921) and WISSMANN (1960 and 1961) have provided much information about the vegetation in Yulongxue Shan. A complete comparison of all the data collected between 1920 and 1940 with the present-day situation would be of great interest. This cannot be done within the context of this paper which will concentrate on some special observations and completions to Fig. 5:

- It is possible that the mixed coniferous and broadleaved forest extends somewhat higher on Yulongxue Shan than on the Gongga Shan. Visiting a Forest Experimental Station east of Yulongxue at 2800 m (existing since 1966) we observed a rich subalpine coniferous forest with oak (*Quercus pannosa* and *Q. aquifolides*) (Fig. 6), birch (*Betula platyphylla*), and a variety of shrubs, up to 3100 m. Experiments with *Alnus nepalensis* and *Populus yuannensis* at 3000 m have been undertaken.
- We were told that the timberline here lies at 4200 m and the treeline at 4300 m. Again, the information from the western side is uncertain. It seems that the eastern side is wetter than the western side, although the differences between east and west are much less pronounced than on Gongga Shan (this was confirmed by scientists of different disciplines of Academia Sinica in Kunming with whom we conferred).
- In some places the forest cutting reached a maximum between 1950 and 1960 due to a rapid population growth combined with the pressures for intensive technological development. It would be very interesting to analyse this process by comparison with old descriptions and photographs of the first half of our century. Obviously, the big plain or plateau in front of the huge moraine of Kan Hoi-Pa (Fig. 4) should have been a forest before 1958 with *Picea, Abies,* and *Pinus* (Fig. 7). WISSMANN (1959 b, p. 170), however, describes a pasture similar to that depicted by HANDEL-MAZZETTI in 1914 and 1916. Therefore, we recommend strongly an analysis of this deforestation process for a better understanding of the ecological changes in the last 20 to 30 years.

Reforestation programmes were in evidence all over the country. The most common reforestation species are *Pinus yuannensis, P. armandii* and *P. densata*, and at higher elevations, fir *(Abies)* and spruce *(Picea).* West of Dali we visited a plantation of *Pinus yuannensis* where seeding has been accomplished by airplane. Pines are now planted in areas originally occupied by broad-leaved forests. What will be the long-term ecological effect? The question of acidification of the soils was raised. The problem remains open but a large artificial change in the forest cover is now going on over extensive mountain areas.

Lijiang and the adjacent counties became famous in China for the high upper limits for cultivation of rice and other crops. JIANG (1982, p. 15) describes the situation for Lijiang and YU XIAO-GAN (Geographical Institute Nanjing, oral communication in Mainz) for the Yunling mountainous region: 2500 to 2600 m, or even 2700 m, is probably the highest altitude for rice production in China. The climatic data are discussed by JIANG (1982) and YU XIAO-GAN (in a paper of the Mainz Symposium, in this volume).

Fig. 6. Montane forest on the eastern slopes of Yulongxue Shan at about 3100 m. The large trees in the foreground are evergreen oaks (photo: IVES).

Fig. 7. Extensive deforestation of the plain east of the Yulongxue Shan in the vicinity of Lijiang (photo: IVES).

The favourable agro-meteorological situation of the Lijiang area for rice and other crops corroborates to a certain extent the not fully proven statement that the natural vegetation belts could be a little higher on Yulongxue Shan than on Gongga Shan.

4. The Climatic-Meteorological Situation

Table 1 shows the monthly precipitation and the monthly mean temperature for two groups of selected stations. The first group represents a cross-section from Chengdu (500 m) and Yaan (500 m) in the Sichuan Basin to Luding (1250 m) on the Dadu River and to Kangding (2500 m) near Gongga Shan. The second group begins in Kunming (1960 m), the capital of Yunnan, and extends to Dali (2000 m) and Lijiang (2450 m) near Yulongxue Shan. Kangding and Lijiang are quite similar in altitude and represent the climatic conditions of the foot zone of the two high mountain systems.

Table 1. Precipitation and temperature for two groups of selected stations in the Henguan Mountains.

	Monthly precipitation (mm)					Monthly mean temperature °C						
Station	Jan.	July	Sept.	Dec.	yearly total	Jan.	July	Sept.	Dec.	yearly	Duration of record	Accumulated years
Chengdu 500 m	5.0	228.9	113.5	6.4	976.0	5.6	25.8	21.4	2.3	16.3	1951–1970	20
Yaan 500 m	18.5	398.5	226.8	22.0	1174.3	6.1	25.3	21.0	2.8	16.2	1951–1980	30
Lnding 1250 m	0.8	139.4	77.5	0.8	636.8	6.2	22.8	19.8	7.7	15.4	1964–1980	16
Kangding 2500 m	6.1	116.0	125.0	4.8	804.5	−2.5	15.7	11.9	−0.8	7.2	1951–1980	28
Kunming 1960 m	10.0	216.4	122.9	15.9	991.7	7.8	19.9	17.6	8.3	14.8	1951–1970	20
Dali ca. 2000 m	18.2	181.0	146.9	15.7	1088.2	8.7	20.1	18.1	8.8	15.1	1951–1980	30
Lijiang 2450 m	1.9	259.1	133.0	2.2	953.0	5.8	17.9	15.9	6.3	12.6	1955–1978	24

4.1 Precipitation

On the one hand, Kunming (1960 m) has about the same amount of rain as Chengdu (500 m) although it is 1500 m higher. On the other hand, Lijiang (2450 m) has significantly more than Kangding (2500 m). This comparison shows that the north-south ridges in Sichuan between the Chengdu Basin and Gongga Shan are important barriers for precipitation from the east. Yunnan has a different precipitation structure: Here the southwest direction is very important. No mountains of comparable height occur between it and the Bay of Bengal so that moist air from the source region of the Indian Ocean plays an important role in this part of Yunnan. The winds are very often channelled along the major south-north valleys which means that the differences between east- and west-facing slopes are much weaker than in the Gongga Shan area. In the Geographical Institute of Chengdu we were informed that in the Gongga Shan region the east-facing slopes receive 1700 mm and the west-facing slopes only 1000 mm. These values would represent relatively dry conditions for high mountain areas. However, they demonstrate the enormous differences in exposure, important for an understanding of the vegetation and glaciation patterns.

On Yulongxue Shan the precipitation for the high mountain areas is estimated to be 3000 mm (WISSMANN, 1959 b, p. 182). This value is not proven but it is an interesting estimation compared with Gongga Shan. This again would indicate that Yulongxue Shan has a different precipitation structure than Gongga Shan.

The southwest precipitation on Yulongxue Shan, mentioned several times by botanists and agrometeorologists, leads to an apparent contradiction. The recent and especially younger Pleistocene glaciers are and were larger, and reached lower elevations on the eastern side, indicating much wetter conditions here, than on the western side. However, more detailed results are required from the western side. Nevertheless, some preliminary questions can be raised:

1. Could it be that the east-side precipitation was heavier and the tropical southwest-precipitation weaker during the younger Pleistocene maximum?
2. Could it be that the precipitation of southwestern provenance is more important today, but is concentrated during the summer months so that it is more effective for vegetation and cultivation than for snow accumulation?

The observations of WISSMANN and HANDEL-MAZZETTI indicate a dry winter season from November to the end of February (sometimes until May). Snowfalls were observed only above 4000 m between October and May and late-April is the normal date for melting of the snowcover (WISSMANN, 1959 b, p. 170). We were told that 95 percent of the annual precipitation for Lijiang occurs between May and October. On Gongga Shan the conditions are very different: in the high valleys west of the highest mountains snow occurs mainly during the winter months, especially between October and December.

On the whole, the observations and information discussed above indicate that the climatic conditions and the circulation system affecting Gongga Shan and Yulongxue Shan must be very different. Recently a network of meteorological stations has been installed in the Lijiang area; many interesting results from this climatic-meteorological crossing-point will be obtained over the next few years.

Finally, it is important to emphasize that Kunming (1960 m) had an annual precipitation of 991.7 mm for the period 1951–1970. WISSMANN (1960, p. 261) recorded the following information:

Kunming I (1893 m)	Measurement 1908–1923: 1095 mm
Kunming II (1922 m)	Measurement 1928–1940: 1284 mm

This indicates a significant reduction in precipitation between the periods 1951–1970 and 1908–1940. The situation appears comparable for Dali: for the years 1951–1980 the recorded mean annual precipitation is 1088.2 mm. WISSMANN gives a value of 1534 mm for the period 1937–1942.

Could these enormous differences be the result of a change in climate or in environmental conditions, including deforestation? Another possible explanation is that the differences reflect changes in instruments, recording sites, or in the accuracy of observations.

The question remains open: we have not the necessary data to analyse it more precisely. The problem, however, is of great importance for any discussion on changing ecosystems and their consequences.

4.2 Temperature

Kangding and Lijiang, at comparable altitudes, have very different thermal conditions (Tab. 1): more than 5 °C difference in mean annual air temperature; more than 7 °C in the mean temperature of the coldest month; and more than 2 °C in the mean temperature of the warmest month. Even if the different relief configurations and their influence on local temperatures are taken into account, the differences are so pronounced that the existence of two independent climatic provinces must be assumed.

The extraordinary situation of Lijiang becomes apparent in the thermal definition of the natural vegetation belts. The subtropical mountain belt from 1000 to 1800 m requires a mean annual air temperature of about 15–20 °C and a mean temperature for the coldest month of more than 7 °C (LI WENHUA and ZHADO XIE YING, 1981, p. 37). This implies also that Lijiang, at 2450 m, is a special place for subtropical species. Temperate-zone crops have the highest yields (wheat, barley, beans, maize, rape); nevertheless, subtropical crop productivity is remarkable for this altitude. The temperature conditions measured at Lijiang could mean that the vegetation and the forest belts on Yulongxue Shan are a response to an unusually favourable environment for the combination of altitude and latitude, which could account for the contrasts with the Gongga Shan area. Only the steep and partly polished rocks, and especially the reduced altitude of the whole mountain range (5600 m compared with 7600 m) could result in a certain limitation, particularly for the upper timberline.

4.3 Climate and Circulation and its Significance for Glaciation and Vegetation

During the winter period (October to April) cold fronts from the continental anticyclone affect the Sichuan Basin and Yunnan only on rare occasions (JIANG, 1981). The river gorge country is especially well sheltered, as it is shown by the winter temperatures (WATTS, 1969, p. 11). In summer the southwesterlies are of special interest: the low level monsoon winds enter the Assam-Bengal area from the south and are forced by the orographic situation into a west-southwest to east-northeast direction. The northern limitation of this effect are the high mountains at the Yarlung Zangbo (Brahmaputra) gorge. Between latitudes 25 and 27.5° North the ridges between the Irrawadi, Salween, and Mekong rivers have altitudes below 3000 m. Thus the southwesterly flow prevails at the 3 km level up to the mountains along the Himalayan border, northern Burma, and in the Hengduan Mountains (FLOHN, 1968, p. 17). The barrier of Yulongxue Shan lies exactly at the location where the moist air masses are forced to rise. This could mean that the maximum precipitation belt lies below the upper timberline. Furthermore, the basic change in climatic conditions between the dry upper river gorges north of 28° N and inside mountains of 6000 m altitude, and the humid lower river gorge country could be determined by these flow patterns. FLOHN (1968, p. 20) describes the summer weather of the southern Hengduan Mountains from satellite pictures as cloudy with frequent showers and thunderstorms along the mountain ridges. In the gorges themselves intense heating and strong southerly winds prevail during daytime. The average cloud base at two selected stations was 1500–2000 m above ground, which is 3000–3500 m above sea level.

For southern China the summer south-westerlies or southerlies generally alterate with incursions of trade-wind easterlies from the North Pacific, and each change is usually accompanied by convergence and precipitation (WATTS, 1969, p. 13).

The two mountain systems of Gongga Shan and Yulongxue Shan, therefore, have very different climatic-meteorological settings. This has its consequences on the vegetation and on the glaciation. The warmer conditions of Yulongxue are reflected in the higher vegetation belts, especially at lower and middle altitudes. The more humid conditions influence the glaciation patterns. Although the winter is very dry in the Yulongxue Shan area, the higher summer precipitation at altitude induces summer snow falls and cloud cover in the mountains which favour glacierization and is reflected in a lower snowline than that of Gongga Shan (Fig. 8). Furthermore, the statement of LI JIJUN (1981, p. 224) concerning the glaciers in the summer monsoon precipitation area of southeastern Xizang, applies to a certain extent to the Yulongxue Shan, but certainly not to the Gongga Shan: "In the light of mass balance, ablation intensity, ice temperature and characteristics of movement, the glaciers closely resemble the maritime glaciers in the Alps and in New Zealand, but differ from the continental type in inland China. Heavy and successive rain and extraordinary high temperature in summer provoke abrupt gliding of the glacier with

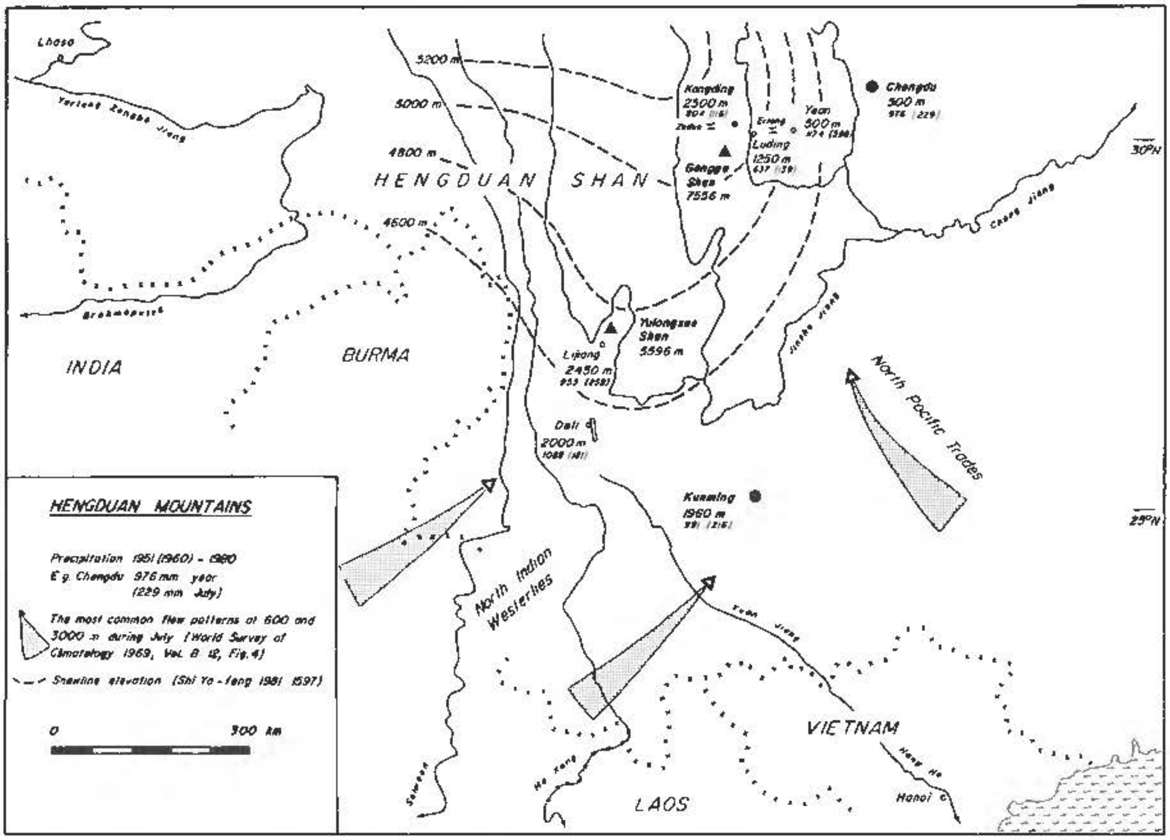

Fig. 8. Hengduan Mountains: precipitation and snowline elevation.

sometimes very low end moraines". Therefore, as SHI YA-FENG has shown (1981, p. 1597; cf. Fig. 8), the snowlines in China make a broad curve to the south in western Yunnan demonstrating the special climatic-meteorological situation of Yulongxue Shan. On the whole, it can be stated that the vegetation belts are higher and the snowline lower, and the difference between upper timberline and snowline is smaller on Yulongxue Shan than on Gongga Shan.

5. Highland-Lowland Interactive Systems (Some Remarks on Man's Impact on Mountain Ecosystems)

Deforestation, soil erosion, debris flows, and overgrazed pastures are widespread throughout the two sections of the Hengduan Mountains discussed here. If the population of China has grown from 500 million in 1950 to 1 billion in 1980, then the 1950s and 1960s were very critical years with forest cutting for land and for wood in the belief that the ecosystem would support this expansion without deleterious consequences. But since the Cultural Revolution the dangers of serious environmental deterioration have been recognized and the measures taken by the national, provincial, and local governments are very impressive. First of all the population growth appears to be under control; second, reforestation is underway throughout the country; third, the reclamation of devastated agricultural land still needs much effort and time, not only in years, but perhaps in decades or generations. Yet, despite the recent recognition of the massive ecosystem damage, we have to ask if the processes of destruction are recent or have been operating over a long period of time. By r e c e n t we mean since 1950 and by o l d we mean over the

Fig. 9. Gongga Shan 1982. Li Qio Valley: Landslides and gully erosion, old abandoned agricultural terraces near the Tibetan villages (photo: MESSERLI).

last several generations or even earlier than the beginning of the Twentieth Century. It should not be forgotten that not only the plains but also the Chinese mountains are old cultural landscapes. Very often it is tempting to infer that geomorphic processes occurring on steep slopes are the result of recent human pressures. However, comparison of present conditions with old descriptions and photographs from the first half of this century will indicate that very often little difference can be seen. Therefore, we should differentiate between older processes which are, to a certain extent, regulated within the ecological system (e.g., the run-off of rivers), and newer processes and damage which can create or augment catastrophic events.

5.1 Erlang Pass-Gongga Shan

Between Erlang Pass and Luding there are numerous landslides on both sides of the River Dadu. Some are very recent and result from the construction of roads and irrigation channels. The dry side of the Erlang Pass, especially, has changed into a hazardous place through road construction. But much gully erosion and land sliding in the loose material of old river terraces are old phenomena, as photographs from 1930 demonstrate very clearly (IMHOF, 1974).

Li Qio-Valley: Many terraces on the steep slopes near and above the Tibetan villages have been abandoned and only a few are used today for barley cultivation. Furthermore, many gullies and landslides

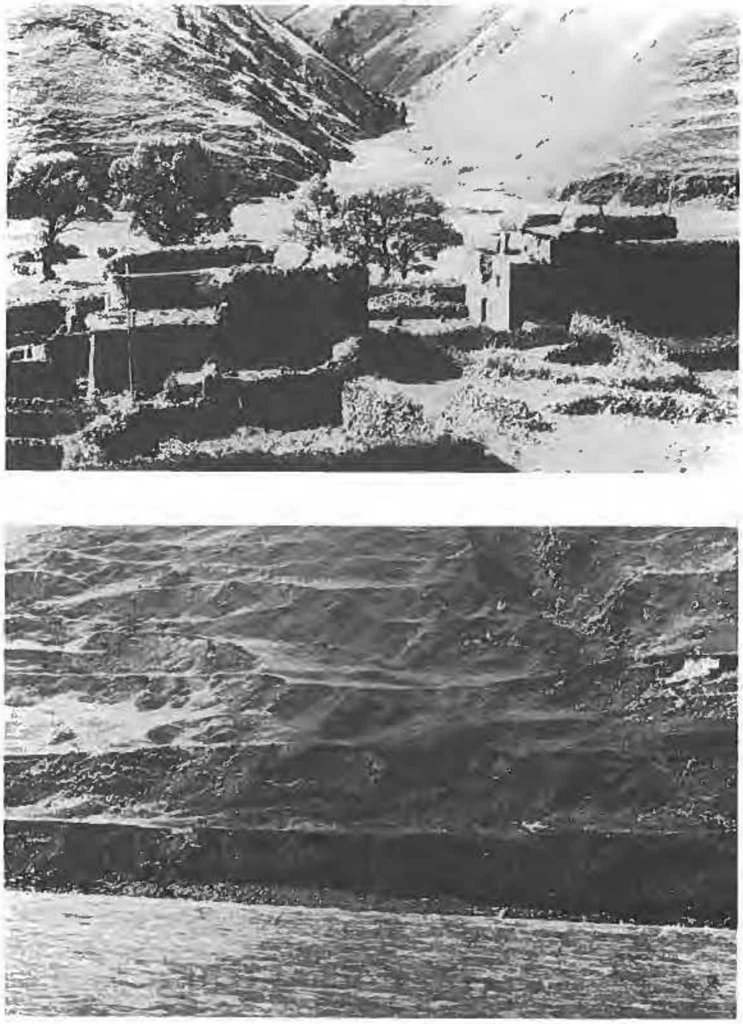

Fig. 10. Gongga Shan 1930. Li Qio Valley (IMHOF, 1974, Abb. 38 und 39).
Above: Farm houses, abandoned terraces, remnant stands of trees.
Below: Abandoned terraces with gully erosion.

can be observed, partly covered over by vegetation (Fig. 9). What is the explanation? When did the population abandon the fields and villages? Was the carrying capacity exceeded? Were the landslides and gullies a rapidly or a slowly accelerating process? During our field mission many possible explanations were examined with some preference being given to the most recent decades. Subsequent examination of old documents, however, clearly show that the main elements of land abandonment and slope instability were older than 1930 (Fig. 10a and 10b).

Yulongxi-Valley: The overgrazing by Tibetans near the timberline between 4000 and 4200 m is obvious. This could also be taken to indicate that it resulted from recent rapid population growth. However, HEIM (1933) and IMHOF (1974), who visited this area in 1930, called the Yulongxi the nomadic valley and described herds with hundreds of yaks and large numbers of nomadic camps. The photograph of 1930 shows a very similar situation to that of today with the shrub vegetation instead of trees and signs of the heavy grazing (Fig. 11). Finally it is important to record that we could not find any signs of recent flooding along the different rivers at different altitudes which would indicate rapid deterioration of the mountain environment in recent years. With continued extensive felling of trees for economic reasons, an elucidation of the questions discussed here, based upon reliable data and analysis, appears to be of critical importance. Not only must the mistakes of recent years be repaired, but also those of the more distant past. However, any such attempt will be immeasureably more effective if resource use

Fig. 11. Gongga Shan 1930: Yulongxi valley with nomad camp, herd of yaks, overgrazed and degraded vegetation (IMHOF, 1974, Abb. 15).

policy can be based upon objective scholarly research and not depend upon facile and hurridly formed assumptions.

From the above considerations it appears that the interpretation of the catastrophic debris flows that occurred between June to September 1981 in the mountains of Sichuan Province is not very simple. After heavy rainfall 1060 debris flows occurred. Such large scale damage was considered exceptional in history. With steep slopes, loose material, and reduced vegetation cover debris flows would occur with rainfalls of 50 mm per diem or 10 mm in 10 minutes (BANGXING, 1982, p. 13). Can this situation only be explained as a result of exceptionally heavy rainfall? Could it be that the deforestation and reduced vegetation cover resulting from man's impact in the past and in recent decades have played an important role? The resolution of this question requires a fuller understanding of the dynamics of the mountain landscapes of the Hengduan Shan. It is an indication that integrated and comprehensive investigation are urgently needed to prevent such catastrophic processes.

5.2 Kunming-Yulongxue Shan

Yunnan is 400 000 km² in extent and has a population of 31 million; most of its surface is mountainous. Rapid economic growth in recent years has created serious ecological problems. Deforestation and soil erosion can be seen along the main highway virtually all the way from Kunming to Dali under different geological conditions, from old metamorphic rock series to Mesozoic sediments (Trias to Cretacious) (Geol. map of China, 1 : 4 000 000, 1976). Forests have been replaced by rice or exposed bedrock (Fig. 12). Yunnan still has 30 percent forest cover and great expanses of unproductive eroded land. The Government plans for the year 2000 are impressive: 60 percent forest, 20 percent grassland, 10 percent agriculture, with 10 percent remaining. In Dali we were told that the county forest cover in 1950 was slightly more than 30 percent; it was subsequently reduced to 20 percent and today is again 26 percent. The regenerating process is admirable but reforestation is easier to achieve than reconstitution of the soils. Revegetation rather than reforestation will be the probable first step for regeneration of soils. Leguminous shrubs might be most useful for a combination of forage, ground cover, and soil improvement, after

Fig. 12. Soil erosion, slope degradation and deforestation between Kunming and Dali. Rice cultivation on the accumulated material of the valley bottom (photo: MESSERLI).

which tree species could be seeded with a better chance for their establishment (MACDONALD, 1982). The possibilities for introducing agro-forestry technology also should be examined.

5.3 Conclusions

Deforestation and erosion processes are still occurring, but are being brought under control. Even if the silt load and the variation in the run-off of the Jinsha Jiang (Yangtse) should have been increased, we could not see any signs of floods or catastrophic events along the riverbanks. But we should not forget that since the founding of new China, 84 500 reservoirs have been constructed and as much as 700 million mu have been irrigated. Furthermore, the average amount of sediment brought to the sea per year is estimated at 1.94×10^9 tons of which 59 percent comes from the Yellow River and 25 percent from the Yangtse River (QIAN NING and DAI DINGZHONG, 1980, pp. 19, 20). Therefore, it is important that a fuller understanding of the landscape dynamics be achieved (Fig. 13). The question – to what degree are human activities in the mountains affecting the people in the plains? – is a crucial one. Without a reasonable, or even partial answer, resource and land-use planning cannot be placed upon a firm foundation. On this basis four major themes for Hengduan Regional Research have been proposed (IVES, 1982, p. 12):

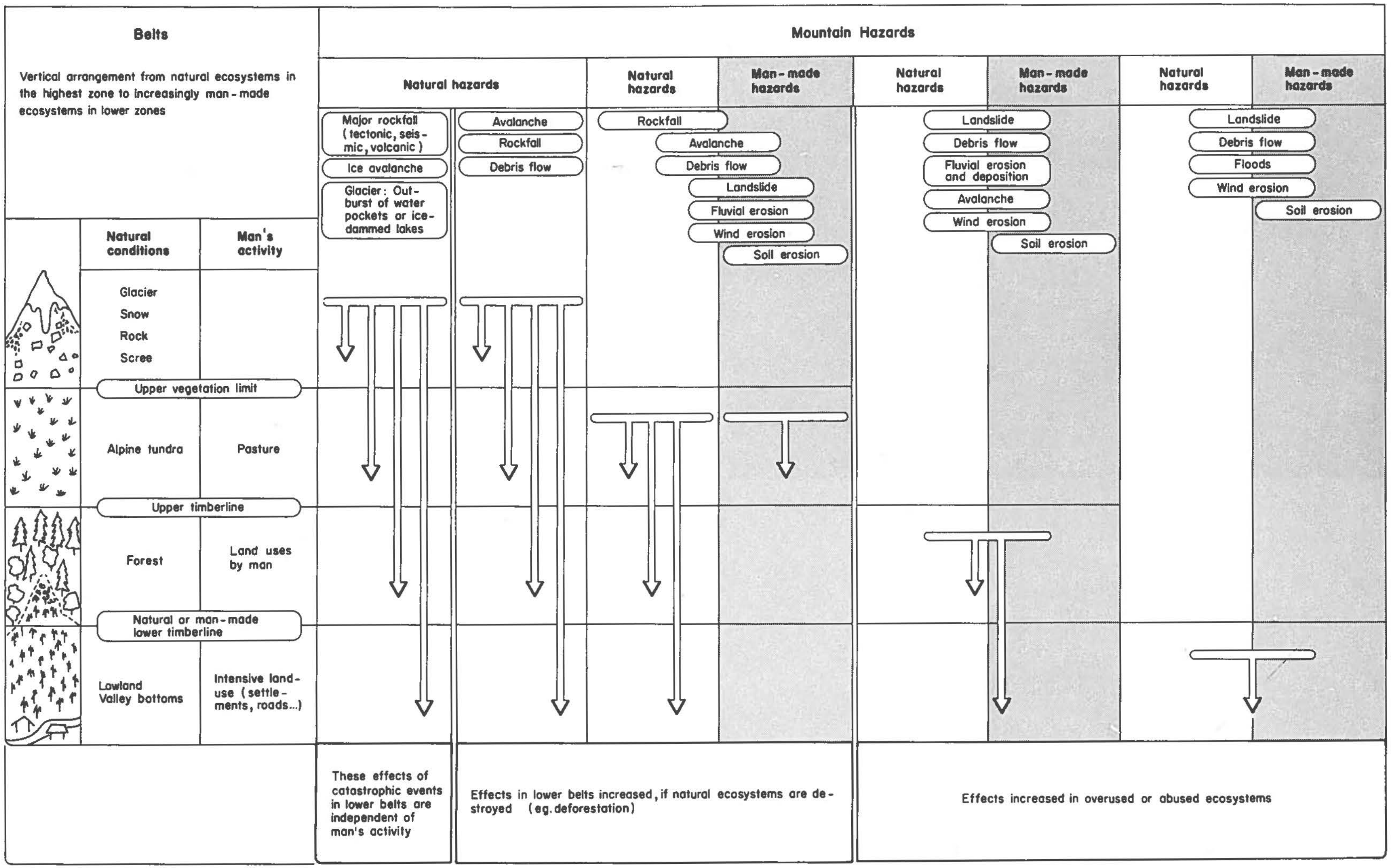

Fig. 13. Attempt at a generalised classification of mountain hazards. (Natural and man-made hazards depending of altitudinal belts).

1. Forest cover and its changes through time; present and future management.
2. Water variation in flow; highland-lowland relationships; resource development opportunities.
3. Soil erosion; rates, causes, methods of mitigation, sources, transfers, areas of deposition.
4. Population; characteristics and trends; land-use and agricultural practices.

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Discussion to the Paper Messerli

Prof. Dr. U. Schweinfurth:

Concerning the term "Hengduan Shan":

Since the Tibet-Symposium in 1980 we have been confronted with Chinese topographic terms unknown to us until that time. One of these terms is "Hengduan Shan", a name which I heard for the first time during the Tibet-Symposium in Peking, where none of the Chinese colleagues could say clearly what area was actually meant by this term. The paper of Mr. Messerli so far corresponds with the prevailing experience. Therefore, I don't consider it appropriate to replace the familiar, topographically relevant term "meridional river gorges" by "Hengduan Shan", especially since it is the deeply cut valleys which put the accent in this area – more than the remainders of erosion in between, if "Hengduan Shan" doesn't stand for an administrative unity.

Prof. Dr. B. Messerli:

The term "Hengduan Mountains" means the mountains in the area of the "meridional river gorges" (meridionale Stromfurchen), and I fully agree with Mr. Schweinfurth that this term, which does not stand for an administrative unity, is very unprecise; so much the more since the new English lettered maps don't separate clearly between "Hengduan Shan" and "Daxue Shan". Moreover the value of 500 000 km^2 may well express the extension of the Hengduan Mountains but does by no means reflect its delimitation.

Furthermore, it is correct that the deeply cut valleys and gorges, running from North to South, form the landscape. But it is not correct to characterize the mountains of this area as "plateau edges" or "remainders of erosion". They show considerable uniqueness with regard to topographic, tectonic, and geologic as well as climatic and vegetational-geographic features. Most important, however, the Chinese have so deeply fixed the term "Hengduan Shan" with their new maps and their rapidly growing scientific contributions that we can't but accept it in our literature.

Prof. Dr. S. Hastenrath:

If I understand right the region of Yulongxue is considerably more humid than the region of Gongga. Therefore, it doesn't surprise that the vertical distance between the upper limit of vegetation and the lower limit of glaciers is less.

Prof. Dr. B. Messerli:

I agree with you that this observation is kind of law. It is, however, peculiar that we do not only meet with very different humidity conditions, but also with different temperature- and therefore with different circulation conditions. It might be possible that from Gongga Shan to Yulongxue Shan even the glacier types vary, since the Chinese speak of "Monsoon Maritime Glaciers" referring to the southeastern mountains with marked summer rains. All this should justify to analyse and interprete this worldwide law more thoroughly.

Prof. Dr. H. Uhlig:

The supposed heavy rainfalls at the south-eastern flank of Yulongxue Shan were already realized by H. v. WISSMANN who emphasized them in his landscape-profiles (1940).

It might be possible that the higher humidity of southern Yunnan – up to the mountain-barrier of Yulongxue Shan – is partly responsible for the considerable lower (monsoonal-tropical) limits of cultivation in contrast to the high valleys and basins in the north, which are warmer during summer, drier, and receive more radiation.

Prof. Dr. B. Messerli:

I dispose of too less material to answer your question completely. Basically, however, I think your interpretation of the different cultivation limits between southern Yunnan and the high valleys is right. But the question can't be settled by only considering the precipitation data available to me. In spite of relatively high summer rainfalls in valleys and plateaus between higher mountains we have, however, a climate more favored by radiation, as FLOHN showed for the "river-gorge" valleys in his Tibet-paper, using satellite-photos.

Prof. Dr. W. Lauer:

1. What are the reasons for the strong degradation of your study area?
2. Do frosts occur in this area? If so: when and where?

Prof. B. Messerli:

1. In some parts of Yunnan the deforestation and soil erosion is very severe. The slope degradation is caused by overuse of a rapidly growing population in the last decades, especially in the lower parts, e.g. in the surroundings of Kunming. – But very often, a comparison with descriptions, photographs, drawings, etc. from the beginning of our century has shown that deforestation, land slides, erosion, etc. were very common features in older times, especially in mountain areas. Until now we have very little information about time, the surface concerned and the intensity of these processes in connection with demographic and political factors but also in relation with climatic, geological, topographical and pedological conditions.
2. I am sorry but I do not have the necessary data to answer these questions. I hope that Dr. YU XIAO-GAN can help us with his contribution.

Prof. Dr. W. Haffner:

How far are the Chinese people – not only State and administration – conscious of the "Natural Hazard Risks" outlined in your paper?

Prof. Dr. B. Messerli:

I think that a basic knowledge with regard to the problems of natural hazards is spreading out in China today. I was surprised that especially in places situated far from the centre the local authorities were interested in these questions or were planning measures, which partly they had already seized. The nationwide campaign of reforestation and the motivation imparted to the people for this purpose should be a good example for this.

Dr. Yu Xiao-Gan:

1. Which measures can be taken to protect the nature in the Hengduan Mountains?
2. Is it possible to reforest on the slopes of the dry-warm valleys in the Hengduan Mountains at an elevation of about 2000 m a. s. l.?

Prof. Dr. B. Messerli:

1. Nature protection ought to be ordered on a national level, planned on a regional level and performed on a local level. Besides it should be clarified what is actually to be protected in a given area, e.g. forest, animals, lakes, special landscape forms etc. It would be interesting to clarify this problem fundamentally and to list a possible inventory of elements to be protected. This would be a first step to induce considerations in these directions. There is, however, one problem which you shouldn't ignore: protecting does not only mean declaring, but also controlling. Therefore, we need a competent, responsible, and state-controlled authority.
2. I am persuaded that it is possible in the Hengduan Mountains, even in the drier areas. Of course, the species must be differentiated and adapted to the local climatic conditions. The only problem in some parts is the regeneration of the degraded soils as an important part of any reforestation programme.

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Man and Environment in the Central Cordillera of Eastern New Guinea
Pandanus, Casuarina, Ipomoea batatas

Ulrich Schweinfurth

With 9 Figures

1. Introduction

Islands, secluded valleys, i.e. clearly defined habitats, being limited in extent and, perhaps, somewhat easier to understand, represent attractive examples to study the interrelationship between man and environment. New Guinea offers the chance to study both. The topic of this symposium invites to discuss observations dating back to 1967/1968 within the light of recent literature.

The high valleys in the Central Cordillera of Eastern New Guinea are characterised by topography, altitude and, therefore, climate – their physical limits are easily recognisable. In addition, the human situation in traditional New Guinea enforced certain social limitations: beyond the boundaries of the particular clan's territory was enemy country – social pressures, like population increase, had to be contained within given limits. No doubt, relief, topography in producing such a variety of clearly defined and circumscribed habitats contributed to isolation and local development. The overall result is a wealth of specific developments in New Guinea and in the Central Cordillera in particular.

The feeling of being restricted to a particular habitat, valley, territory, "place", the limitations of which were obvious, the realization of pressures on resources, especially on agricultural land, seems to have lead in course of time to an attitude which deserves to be called "environmental awareness".

The basic truth of "survive or perish", no doubt, was ever-present under these circumstances: if the particular habitat did not warrant survival, existence was in danger under the stark conditions of traditional New Guinea. Small wonder that under the conditions of traditional New Guinea, physical and social – ecological, "territorial" constraints produced such a wealth of responses to the environmental challenges. One of the lasting recollections of the high valleys is the idea of a certain devotion expressed in the "tilling of the soil" – as well as a sense of beauty pervading the man-made landscape as expressed, for instance, in the care applied to the sing-sing-grounds.

The relationship between man and environment in the high valleys of Eastern New Guinea will be dealt with under three aspects: *Pandanus, Casuarina,* and *Ipomoea batatas* – three plants basic to man's survival in the high valleys.

2. Pandanus

Pandanus, wide-spread in the Indo-Pacific world and in the Central Cordillera, until recently taxonomically a difficult case (SCHWEINFURTH, 1970 b), has now been the subject of a first taxonomical treatise by STONE (1982), which represents a welcome step forward in clearing the taxonomical problems of *Pandanus* in New Guinea. For the present treatment it may suffice to refer to STONE's contribution – all the more so, as the New Guinea highlanders have their own differentiation of *Pandanus* – distinguishing not only male and female plants, wild and cultivated ones – indeed, going far beyond what taxonomic botany

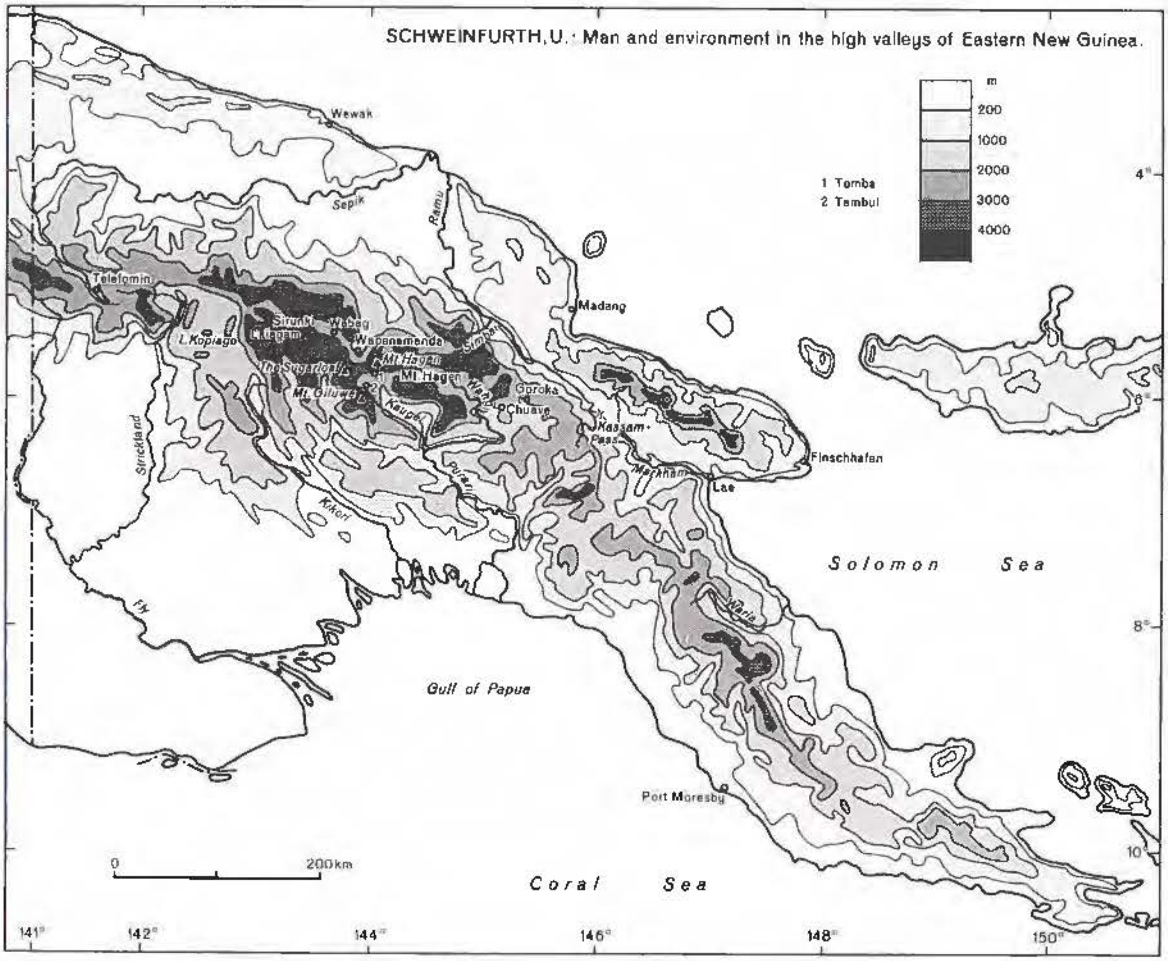

Fig. 1. Morphographic Map of Eastern New Guinea.

is at present able to offer (upper Kaugel valley: 35 local "varieties" acc. to N. BOWERS in files, Depart. of Agriculture, Stock, and Fisheries, Mt. Hagen).

The borderline between – remaining – forests and the area under cultivation – in common geographical usage between "natural" and "cultural" landscape – is generally quite obvious within the valleys of the Central Cordillera: an altitude of 2700 m may be accepted as a general figure bearing in mind the variations effected by local conditions. This borderline is a conspicuous feature in the high valleys. A closer study of the situation reveals every so often a striking concentration of *Pandanus* trees towards the lower fringe of the montane forest (as, for instance, in the Mount Hagen Range) – *Pandanus* easily recognisable by a "tuft" of green leaves and the "collar" of dead, yellowish leaves below, quite distinct physiognomically in the sombre darkgreen of the montane forest. Such a concentration of a particular species resp. tree always attracts attention.

A visit to the site of an Australian timber contractor on the slopes of the Mount Hagen Range in 2500 m together with the local forester, responsible for the orderly conduct of the operations, revealed a rather surprising sight: to extract the timber required, the removal of the trunks followed, it seemed, strangely winding tracks, obviously avoiding with great care a good many trees, standing there like sentinels in the area of extraction – all these "sentinels" were *Pandanus* trees. The explanation was easily obtained: during the negotiations for the contract concerning the extraction of certain forest trees it was laid down that under no circumstance the *Pandanus* trees within the area of operation will suffer any harm – otherwise the contractor would be liable for heavy compensation; these rules of exploitation were laid down under

Fig. 2. Mt. Hagen Range, W of Tomba, 2600 m: selective felling, *Pandanus* spared. – 28. 12. 1967, 14 h.

Fig. 3. Sirunki, 2650 m: highland road Wabag – Lake Ipea – Laiagam: *Ipomoea batatas*-mounds and *Pandanus* trees. – 04. 01. 1968, 10 h.

the auspices of the local forest officer. This method of "selective felling" resp. extraction from the montane forest may suffice to indicate a first, basic reason for local concentration of *Pandanus* trees – it, also, indicates a definite interest of the local people in *Pandanus*.

Further, *Pandanus* trees within the montane forest, that means far away from settlements, are claimed as "private property" by individual owners, families, or clans. Also *Pandanus* is planted in the forests, next to "wild" ones and within the immediate neighbourhood of huts resp. settlements, too, sometimes by transplanting seedlings from the forests. What may be looked upon as "untouched", "virgin" tropical montane forest is not as "natural", "original", "primeval", as it may seem at first sight; indeed, it experienced, at least, locally, change by human interference, which may be regarded as a first stage of "afforestation" resp. "silviculture". What matters, is the interest of the local population resulting in so much attention towards a certain species of tree. This interest indicates the importance the local people attach to *Pandanus*.

Pandanus in the New Guinea highlands is, first of all, valued as a source of seasonal food. The staple food in the high valleys is supplied by *Ipomoea batatas*, sweet potato, up to 95% (see below); this plant is sensitive to frost. Any additional source of food is highly valued – so, in particular, the "nuts" of *Pandanus*, the kernels, oily seeds of *Pandanus brosimos, P. jiulianettii, P. foveolatus* (see STONE, 1982; POWELL, 1976), which even in years without frost provide for a highly appreciated addition to the diet. In the limited economy of the high valleys of New Guinea, the *Pandanus* "nuts" represent a priceless asset, all the more so as they can be stored[1]. The harvest of the *Pandanus* "nuts" – about December/January – amounts to an operation, when entire families leave for the forest to gather the "nuts", staying in temporary shelters and living on *Pandanus* only during that time (SCHWEINFURTH, 1970 b; BARTH, 1971).

Pandanus "nuts" – at lower altitudes: *Pandanus* fruits – have been held in high esteem as luxury crops and as an important item of trade in traditional New Guinea (HUGHES, 1973; BULMER, 1982; POWELL, 1982). Within the Enga country west of the Mount Hagen Range, an important differentiation in the economy between the "Central" Enga living at somewhat lower elevations in the densely populated high valleys, and the "Fringe" Enga inhabitating in a much sparser way the central watershed area between the headwaters of Sepik, Fly, Kikori, and Purari is noticeable: the otherwise far less richly endowed Fringe Enga are the owners of most of the *Pandanus* trees in the montane forests, therefore holders of the much appreciated commodity of the *Pandanus* "nuts", of life-saving consequence in times of need, in particular under drought and frost conditions, also highly esteemed in gift exchanges (WADDELL, 1973).

The importance of *Pandanus* in the local diet is one aspect only of the interest in *Pandanus*. The dry, dead leaves, so conspicuous on the trees, are the source material for a great number of items in the material culture of the highlanders: sewn together they form mats used for bedding and all sorts of cover, of daily appearance as protection against rain, neatly folded together, when not in use. The originally rather scant body cover consisted largely of *Pandanus* material. Old *Pandanus* leaves are the source material for head-wear, belts, babycots, cigarette paper, torches etc.; they serve in the construction of huts to cover roofs, walls etc. The green leaves are used for steaming pork.

To mention the use of old, dry *Pandanus* leaves for the building of huts leads to another aspect of importance: some clans of the Enga construct huts, used for certain rituals, with *Pandanus* material only (MEGGITT, 1965). Likewise, in the Simbai Valley, a tributary to the Ramu and actually not one of the high valleys under consideration here, the huts destined for the nose-piercing ceremonies are built with *Pandanus* material only. In the Waria, another valley not within the Central Cordillera sensu stricto, dead warriors are wrapped for burial in *Pandanus* leaves (DETZNER, 1928/1929). MEGGITT reports from the Enga, that the hair of a male person "placed in *Pandanus* seedlings" may effect "that he will grow tall as the tree does".

[1] Concentrating on the high valleys in this contribution, *Pandanus sp.* at lower altitudes, likewise of importance as food sources etc., may remain outside consideration, as, for instance, the fruits of *P. conoideus* (marita) (see POWELL, 1976).

Fig. 4. Highland road below Kamaga, 2300 m: *Pandanus*-made cover in use during daily afternoon-shower. – 28. 12. 1967, 15 h.

To sum up: planting and harvest, consumption and use made of *Pandanus* material are subject to rituals and taboos. In this connection it seems appropriate to refer to a recent contribution dealing with a "ritual *Pandanus* language" (FRANKLIN, 1972), as a means of communication understood by certain families resp. clans in the Mount Giluwe area only, which are exclusively connected by this secret, ritual language. This example may serve to point once again to the outstanding position *Pandanus* occupies in the life of the people in the high valleys and the intimate relationship of man with his environment – beyond the more easily recognisable facts of purely utilitarian appeal.

The importance attached to *Pandanus* leads to strict observance of ownership: the trees carry marks of ownership. A planted *Pandanus* tree remains in the possession of the planter, even when the land, where the tree was planted, changes the owner (WADDELL, 1972 a, p. 74). Thefts of *Pandanus* "nuts" have been cause of tribal fighting; disputes over *Pandanus* trees lead to murder, and death warrants were issued in compensation for damage done to *Pandanus* trees. BOWERS (1963, in files, kept at Department of Agriculture, Stock, and Fisheries, Mt. Hagen) reports "periodic fights over *Pandanus*" from the Kaugel Valley. The destruction of *Pandanus* groves has always been looked upon as a particular serious escalation in tribal fighting (WADDELL, 1972 a, p. 186; VAYDA, 1976, p. 24–35; ALLEN & GIDDINGS, 1982).

BRASS (1941, p. 561) paralleled the importance of *Pandanus* to the inhabitants of the Central Cordillera with that of coconut palms to the lowland people resp. those living along the coast. Today, with a much more extended knowledge, it seems appropriate to place the importance of *Pandanus* to the highlanders at a much higher level, especially taking into consideration the comparatively rather limited resources in the high valleys.

The importance attached to *Pandanus* by the inhabitants of the high valleys finds, first of all, its visible expression in the landscape: *Pandanus* is a "native" of the montane forest and, in addition, it is planted and cultivated; it may serve as an example for silviculture resp. afforestation (RAPPAPORT, 1967; CLARKE, 1971). It does not actually matter what the local people attracts in particular: the food or the material provided or the taboos connected with the tree – there is a specific attachment obvious and the plant, tree is carefully attended to. This is reflected in the landscape of the high valleys and signalizes a conspicuous degree of environmental awareness[2].

3. Casuarina

The high valleys of the Central Cordillera of New Guinea provide the visitor with many lasting memories amongst which *Casuarina* excels by the gracefulness of its appearance. These trees, whether single or gregarious, add an element of beauty to the high valleys, unexpected, perhaps, in a tropical mountain habitat. The main reason seems to be the "lightness" of the physiognomy of the tree and the particular shade of colour, a grayishgreen, striking within the natural scale of sombre, dark colours in the Central Cordillera: both these characteristics derive from the peculiar leaves of *Casuarina* resembling *Equisetum* more than anything else (*C. equisetifolia* (!) – on sand dunes along the coast) with the effect that the "canopy" appears more like a "veil" allowing for much light to filter through (the nearest manifest parallel seem to be the forests of *Larix* in certain central valleys of the European Alps).

Casuarina is widely distributed in the Indopacific world, and well-known from its habitats along the coast. Its species are well-represented as pioneer plants in areas of recent resp. active volcanism (for instance: Java – *C. junghuhniana*, "tjemara": VAN STEENIS, 1972; Réunion – "filaos": RIVALS, 1952; New Britain – *C. papuana:* PAIJMANS, 1976, p. 80, fig. 34).

Fig. 5. Lai Valley (between Wapenamanda, 1780 m, and Wabag, 1980 m): sweet potato-cultivation in various stages of development; *Cordyline* hedges; *Casuarina* along river banks and bordering cultivation plots. – 04. 01. 1968, 9 h.

[2] For further reference see the author's earlier contribution on *Pandanus* (SCHWEINFURTH, 1970 b).

For occurrence and distribution of *Casuarina* in coastal and lowland New Guinea, PAIJMANS's treatise (1976) is a useful introduction. The situation of *Casuarina* in the Central Cordillera is different, primarily, because of the particular interest of man. Riverbanks and shingle beds seem to be natural habitats of pioneering *Casuarina (C. oligodon* and *C. cunnighamiana)* in the high valleys; its wide distribution in the high valleys, however, *Casuarina* owes to man: *Casuarina* is conspicuous everywhere in the cultural – man-made – landscape: around the sing-sing-grounds, near huts and settlements, and – with local variations – in the sweet potato gardens, and there are also *Casuarina* woods, of varying extent, interspersed in the man-made landscape.

A number of material attractions for man's interest in *Casuarina* are obvious: man's immediate and growing interest in firewood with further reduction resp. retreat of the montane forest uphill, i.e. further away from settlements; *Casuarina* also represents a readily available supply of material for building, for construction of fences (to keep the ubiquitous pigs out of the gardens), for tools (so important in pre-European times, when iron was not yet known); *Casuarina* logs are used for terracing steep slopes (BROOKFIELD and BROWN, 1963) etc.

Perhaps, the most sophisticated use of *Casuarina (C. oligodon)* is made by its inclusion in the cultivation of *Ipomoea batatas,* when *Casuarina* serves as a fallow tree. BROOKFIELD maintains that the Chimbu have some understanding that *Casuarina* plantings aid the restoration of soil fertility – which it does by producing humus and fixing nitrogen (BROOKFIELD, 1961; BROOKFIELD and BROWN, 1963, p. 51; BROOKFIELD and HART, 1971; CONROY, 1960; POWELL, 1976; GLASSE, 1968, p. 41)[3].

As an example of local variation, WADDELL (1972 a) describes, how the Aruni Enga (in the vicinity of Wapenamanda) plant *Casuarina* as fallow tree in their mixed gardens only (when abandoned), whereas in the areas of their most intensive horticulture (high mounds with *Ipomoea batatas*) *Casuarina* – and all other trees – are noticeably absent (see below)[4].

It may serve as a further explanation of the intimate relationship between man and *Casuarina* to refer to the many examples of *Casuarina* used in rituals and magic (compiled by RIESENFELD, 1950, in his work on the megalithic culture in Melanesia). Besides all utilitarian aspects of its distribution in the high valleys today, *Casuarina* is planted widely for ritual and magic purposes (as related already by VICEDOM und TISCHNER, 1943–1948, from their experience in the Upper Waghi Valley). Perhaps, it is this longstanding relationship, the origin of which seems to lie somewhere back in the remote past, which lead man to develop such an intimate interest in and understanding of *Casuarina.* Recent palynological and archaeological research (WALKER and FLENLEY, 1979; GOLSON, 1977, 1982; POWELL, 1982) seems to imply a spread of *Casuarina* together with a spread of cultivated land, i.e. with the introduction of *Ipomoea batatas.*

Last not least, the attention paid to *Casuarina* to the extent of actually cultivating it (MEGGITT, 1977, p. 7: for the Enga: "practical forestry", "silviculture"), is in itself an enormous step in civilisation resp. "environmental awareness". This fact alone deserves much more attention then hitherto devoted to it, though it seems such an obvious way: to transplant *Casuarina* seedlings to village environs – to render sources of wood more easily available (C.S.I.R.O., 1965) and to develop the transplanted seedlings into domestic plantations. Few comparable societies took this step. Today's man-made landscape in the high valleys bears witness to the success of this development, made necessary by the ever further reduction of forest, supported by pacification and actively encouraged by the Australian Administration (MCINTOSH, 1960)[5].

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[3] WADDELL (1972 a, pp. 143–144) expresses a more cautious opinion: stating that, though out of 35 species of *Casuarina* 12 bear root nodules and 4 of them fix atmospheric nitrogen, this is not yet affirmed for the most widespread *Casuarina* in the highlands *(C. oligodon),* though the species is known for having root nodules.

[4] WADDELL (1972 a, p. 77): long-term calculations are made amongst the Raiapu Enga with reference to the growthrate of *Casuarina* which may be used to determine the duration of a fallow period etc.

[5] Planim diwai yar, 1965; C.S.I.R.O., 1970.

What is needed is a comprehensive ecological treatment of *Casuarina* in the Central Cordillera of New Guinea – its natural distribution, the impact of man in its further advance with due emphasis to local variations and, if possible, some more research into the past, of man's early relationship to the genus.

4. Ipomoea batatas

Ipomoea batatas represents the third case chosen here to demonstrate man's relationship with the environment in the high valleys of the Central Cordillera of New Guinea. The importance of this link with the environment is easily explained by the fact, that *Ipomoea batatas*, sweet potato, is the staple crop representing roughly 95% of the highlanders' diet. In contrast to the examples mentioned before, *Ipomoea batatas* is not a native of New Guina, it originates from South America and has been introduced comparatively recently (pre-16th century (BROOKFIELD and HART, 1971), post-15th or 16th century or (?) pre-1200 BP (POWELL, 1982, p. 215); see also GOLSON, 1977 and 1982; YEN, 1974).

Taxonomically, *Ipomoea batatas* is a species of the Convolvulaceae.Locally, a good number of "types" are distinguished by their leaves, colour, texture of tubers etc., to which already VICEDOM und TISCHNER (1943–1948) refer for the Upper Wahgi Valley (WALKER, 1966, for Lake Ipea: 13 distinct types, 11 of which used before the Europeans arrived; WADDELL, 1972 a: 35 varieties distinguished amongst the Aruni (Raiapu Enga); see also YEN, 1974, pp. 226–227 and 230; BROOKFIELD, 1973).

Ipomoea batatas is cultivated all year round with the result, that it is possible to see the plant in all stages of development within one garden plot: while one bed is just harvested, the other is in the stage of being prepared for planting, the next newly planted etc. *Ipomoea batatas* cannot be stored for long under the conditions of the high valleys, therefore is consumed directly from the garden all year round.

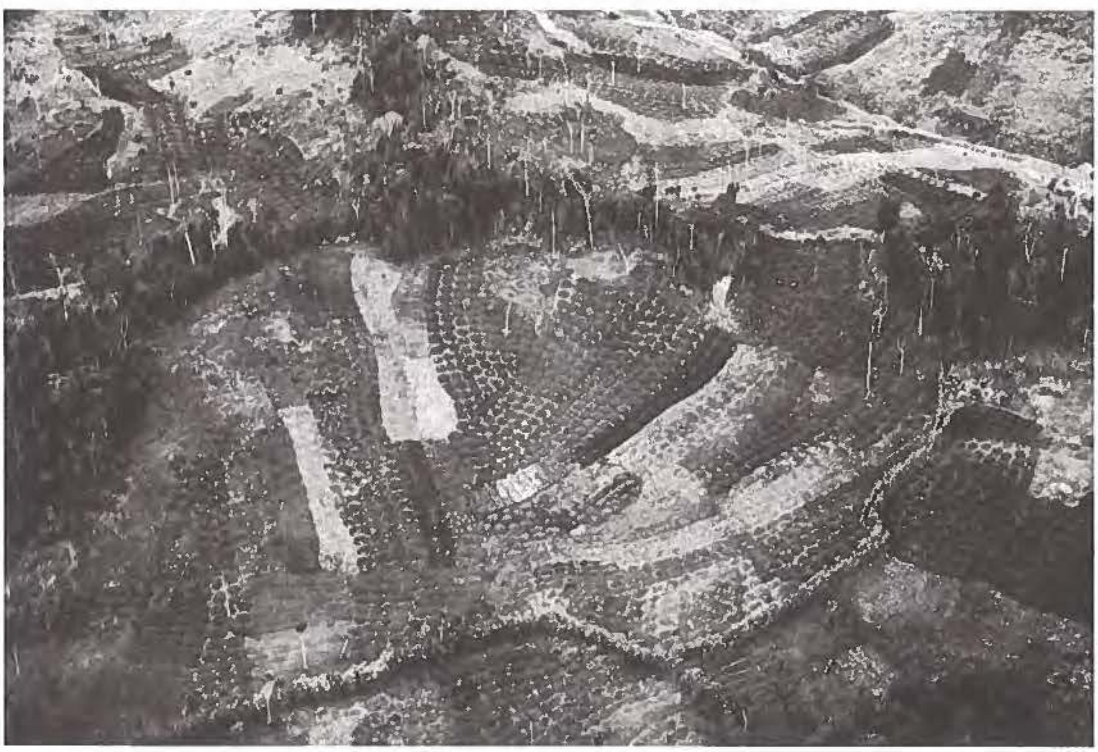

Fig. 6. Lai Valley, south flank (between Sirunki, 2650 m, and Wabag, 1980 m): sweet potato-mounds in various stages of development; *Cordyline* hedges; *Pandanus* trees within plot and amongst bordering trees. – 04. 01. 1968, 13 h.

The cultivation of *Ipomoea batatas* in the high valleys of New Guinea displays the most ingenious perception of local ecological conditions. Physiognomically, two systems predominate: mounds of various sizes and the chequerboard system (gridiron ditching) – the mounds at the high-level areas of cultivation, the chequerboard system in valley bottoms.

The mounds seem to originate amongst the Enga, living in the Central Cordillera west of the Mount Hagen Range, where the mounds are most strikingly developed and can be observed in all possible variations neatly adapted to the ecological requirements of the „place" – for instance, on slopes alternating to break run-off. But the most impressive development is seen in the high mounds at the upper levels. The mounds disappear at an elevation, where frost is no longer expected (about 1600 m in the Enga country). This observation is basic, as mounding is conceived as a response to the particular challenge provided by frost. There is a population, living within certain natural and social constraints, i.e. at comparatively high altitudes, with limited resources and relying on a staple crop, *Ipomoea batatas*, which is sensitive, vulnerable to frost: the mounding system of the *Ipomoea batatas*-cultivation seems to have developed as a means to overcome the ever-present danger of frost, or, at least, to minimize the risks living at such altitudes.

WADDELL, who spent a year amongst the Enga (Raiapu), studying their system of "mound building" gives the most detailed description and vivid insights in their attempts to eke out a living under given circumstances. The basic idea of mound building is to apply vegetable matter – and the higher up the more so, hence with increasing altitude increasing height and diameter of the mounds. WADDELL (1972 a, p. 151) gives the following figures:

altitude:	height:	diameter:
1864 m	0.55 m	3.14 m
2079 m	0.79 m	4.27 m
2657 m	0.85 m	3.93 m

Experiments conducted at about 2650 m indicated a difference in temperature on the surface of cleared, unmounded ground and on the top of an 84 cm – high mound of the order of 2 °C (WADDELL, 1973, p. 35).

The shape of the mounds itself serves to modify the climatic regime close to the ground: the higher the mounds, the more increasingly *Ipomoea batatas* plants are concentrated on the top of it, i.e. sweet potato plants are kept above the danger zone of ground frost; together with clean weeding of the slopes of the mounds and of the intervening channels to facilitate drainage of air this indicates some microclimatological perception (WADDELL, 1972 a, p. 153) – and it results, in addition, in the neat appearance of the sweet potato mounds.

WADDELL emphasises that there is no single purpose of mounding: at 1600 m, where there is scarcely any frost danger, the purpose seems to be to maintain soil fertility; at Sirunki, in 2653 m, the purpose is more specifically to reduce the risk of frost:

a) by creating the microtopography essential to raise the sweet potato plants above the danger zone, and
b) by generating heat in the mound by way of decomposing vegetable matter (WADDELL, 1973, p. 36: decomposition raises soil temperatures by the order of 1.2 °C).

Sirunki people (WADDELL, 1972 a, p. 136) notice a difference between plants grown on top or at base of mounds, they seem to draw connections between techniques and environmental hazards: mulched mounds are considered to be "hot" – that means, there is a perception that mulching resp. mounding is a way to respond to risks encountered in cultivating *Ipomoea batatas* at these altitudes.

In short: the higher up cultivation is performed, the greater the risk of frost, the more mulching material is applied, the higher the elevation of the mounds above ground level, the higher the soil temperature generated – until the frost risk becomes too great: a typical "frontier" situation and an example of experiments in cultivating an ecologically vulnerable crop in a – naturally and socially –

Fig. 7. Nebelyer Valley, S of Mt. Hagen Range, S of Kamaga, 2300 m: *Ipomoea batatas*-mound, height 40 cm; background corner right: mounds in various stages of preparation. – 28. 12. 1967, 11 h.

Fig. 8. Kaugel Valley, Tambul, 2200 m: *Ipomoea batatas*-mounds on river terrace in basin ("frost-hollow"); height: 70 cm; background: Mt. Giluwe. – 14. 01. 1968, 12 h.

marginal environment, designed to permit continuous production (no fallow period!), a continuous cultivation cycle, which, in addition, requires considerable investment of labour (see WADDELL, 1972 a, p. 44).

Frost in the tropics is of high academic interest, in the Australasian tropics as elsewhere. Because of the scarcity of data, a population cultivating a highly frost-sensitive plant in more or less constant danger of frost, is therefore a heaven-sent opportunity to find out more about the climatic situations at these altitudes (SCHWEINFURTH, 1978). Viewed from the home grounds of the "Fringe Engas" in the central watershed area of Fly-Strickland, Kikori, Purari, Sepik, there is the constant danger of frost descending down upon their sweet potato gardens, of cold air filling notorious frost hollows ("Frostlöcher") further down with cold air masses stagnating (for instance, Kaugel Valley near Tambul, 2200 m, at the foot of Mt. Giluwe). In New Guinea, frost periods occur normally in connection with preceding dry periods and clear nights; the "normal" occurrence of light frosts during June to October is "a fact of life" for the inhabitants of the high valleys, above 2400 m – and they have learned to cope with it, as the "mound building" indicates. When in Mt. Hagen in 1967/68, the present author carefully searched the patrol reports in the files of the Department of Agriculture, Stock, and Fisheries, for frost evidence – there were only some dim recollections of a major calamity reported in the 1940s – so, the "normal" impact seems to have been not particularly worthy of note. When in Sirunki (2653 m), where the Lutheran Mission had just started to keep temperature records, there was evidence of one night with light frost (18./19. 7. 1967), which produced damage on the sweet potatoes vines in the neighbourhood according to local information – the sort of annual light frost, keeping the people on the alert to the possible dangers – WADDELL (1972 a, p. 136) relates that the Sirunki people distinguish between two types of "ice": ground frost, which is destructive, and light frost, which "burns" the vines and retards growth[6].

The year 1972 presented many parts of Australasia, from Southern India (Nilgiris) to New Guinea, with a prolonged spell of drought together with frosts, unusual by its frequency and severity, lasting in New Guinea from June to October – a meteorological incidence, as far as the inhabitants of the Central Cordillera were concerned, without parallel in living memory. WADDELL (1974), on the base of his earlier experience and a visit in December 1972–January 1973 to the country and the people concerned, discussed the calamities of the 1972 situation; he comes – in general – to the conclusion that the publicity given was not helpful and the subsequent relief operation overdone. Basing his judgement on his intimate knowledge of how the Enga would cope with such an emergency, he points to the fact that the many "safety measures", the Enga have in store for such calamities, were actually not applied – inspite of the acknowledged severity of drought and frosts. The challenge was there, but the locally available responses were not asked for, as "everything was done by the government" (resp. by the Australian Administration). WADDELL deplores the lack of local initiative apparent in consequence of overgenerous official reaction. On the other hand, the 1972 calamity clearly manifested by its severity the "vulnerability of the system" (WADDELL, 1973, p. 54), i.e. the constraints. Ingenious as the concept of the mound building obviously is, as far as the prevention of "normal" frost risk is concerned, it, nevertheless, is counterproductive with regard to drought – even WADDELL with his detailed knowledge of the Enga way of cultivation cannot point to any device to prevent or to combat drought. Mounding facilitates drainage during wet seasons; it also adds to rapid drying out of the soil under abnormally dry conditions – while risk of saturation is minimized, that of drought is increased: the system itself generates a hazard which – in turn – threatens its viability (WADDELL, 1973, pp. 45–47; see also BROWN & POWELL, 1974).

The events of 1972 may have focussed attention on the Engas and their way to come to terms with their environment. There are, nevertheless, more ecological niches in the high valleys presenting their own and specific problems, as, for instance, the bottom of the Upper Waghi Valley, east of Mt. Hagen, where the problem was, respectively is, to get rid of the surplus water. Here the chequerboard system (gridiron ditching) of *Ipomoea batatas*-cultivation displays no less ingenious insight in the ecological situation

[6] see also WADDELL (1972 a, pp. 234–235): Sirunki: 2653 m: nightly minimum temperature, July 17–September 11, 1966.

Fig. 9. Upper Wahgi Valley, N of Mt. Hagen Town, 1600 m: gridiron ditching (chequerboard) system of sweet potato cultivation; *Casuarina* trees in background. – 19. 12. 1967, 15 h.

producing outstanding results in turning a natural, untamed site into production. VICEDOM und TISCHNER (1943–48, pp. 184 ff.) describe at length and in detail the cultivation of sweet potatoes as performed by the Mbowambs stating: "Die Liebe und Hingabe, mit der die Mbowambs diese Rechteckfelder anlegen, ist bewundernswert und zeugt von ihrem ästhetischen Empfinden" (p. 187), and: "Verunkrautete Felder sind für sie eine Schande" (p. 187). They also refer to the change of the same bed from square-form at first planting to round-form later and give as dimensions amongst the Mbowamb: height 50 cm, diameter 150 cm. According to their informants, these round beds came originally from the neighbourhood of Mt. Kilower (most probably Mt. Giluwe) (VICEDOM und TISCHNER, 1943–1948, p. 184). In 1967/1968 there was increasing mound building visible on the eastern slopes of the Mt. Hagen Range, but in the Wahgi Valley bottom the chequerboard system seemed to reign unchallenged. Pacification, of course, enabled exchange of views and experiences here as elsewhere.

The overall importance of the introduction of *Ipomoea batatas* into the Central Cordillera has led, years ago, to the idea of an "Ipomoean revolution". Meanwhile the combined efforts of palynological and archaeological research in particular, conducted by various departments of the Research School of Pacific Studies, Australian National University, Canberra, provided new material especially with reference to a pre-Ipomoean intensive swamp cultivation in the Upper Wahgi Valley based on taro (and yams) (GOLSON, 1977, 1982; see also WATSON, 1964). This pre-Ipomoean intensive agriculture indicates that there was local expertise available, when the sweet potato arrived, which could be applied to the new arrival. GOLSON (1982) concludes, that the arrival of *Ipomoea batatas* led to a spatial and temporal extension of cultivation out of the Wahgi Valley bottom up-hill – to the detriment of the former taro (and yams) cultivation, obviously performed under a remarkable perception of the ecological situation, with the result to gain "more room at the top" (GOLSON, 1977). When the Europeans arrived, the valley floor of the Upper Wahgi displayed swamps again and was very thinly populated. The idea of an "Ipomoean revolution" has met with criticism, in favour of a more evolutionary development of the establishment of *Ipomoea batatas* – but in this context here this may be regarded as a matter of speed in the development only, as both concepts whether "revolutionary" or "evolutionary" produced the same results in the move of the cultivation frontier to elevations impossible to use profitably in pre-Ipomoean days.

5. The High Valleys as Examples for Environmental Awareness

Within the framework of this symposium the topic of environmental relations in the high valleys of Eastern New Guinea has been dealt with in discussing *Pandanus, Casuarina,* and *Ipomoea batatas.* The Central Cordillera resp. the inhabitants of the high valleys stand for a great variety of "challenges and responses" – according to local conditions. In all their variety, the overall impression is of achieved equilibrium between man and environment as exemplified, for instance, by the high densities of population, also, for instance, by the conspicuous lack of accelerated (soil) erosion, from Kassam Pass in the East to Lake Kopiago in the West (in 1967/1968) – in spite of a juvenile relief and frequent earth-quakes.

The three plants discussed – *Pandanus* and *Casuarina,* both of long standing relationship with man, and the late arrival *Ipomoea batatas* – are a selection only. Other plants could have been chosen to describe man's relationship with his environment; the one genus which springs to mind immediately is *Cordyline,* a manifest component of the man-made landscape and extensively dealt with by RIESENFELD (1950) in his treatise of the megalithic culture. It may suffice here to refer briefly to *Cordyline* as a boundary marker and its connection with many functions in ritual. As a boundary marker *Cordyline* occupies a place of outstanding importance in the societies of the Central Cordillera so conscious of territory and, consequently, of territorial boundaries[7] – it would make for an interesting study to pursue the importance of *Cordyline* in the relationship of man and his environment in the high valleys of the Central Cordillera. Today, many a slope at present not actively cultivated still shows the boundaries of (former) cultivation plots and territories by the living fences of *Cordyline (C. terminalis)*[8] – with the welcome side-effect of an additional protection against soil erosion.

One aspect referred to above deserves to be highlighted in particular in conclusion: that is the attention paid to trees. Both, *Pandanus* and *Casuarina* provide examples, and it is the treatment or, rather, the "management" of *Casuarina,* which seems to warrant the term "silviculture" resp. "practical forestry" – which is something quite different to the mere protection of trees (and forests). MEGGITT (1960) reports from the Mae Enga that every male from childhood plants for his own use "scores, if not hundreds" of *Casuarina* seedlings, gathered from riverbanks; felling and lopping of trees is forbidden and liable to punishment (MEGGITT, 1965, 1977; similarly BROOKFIELD and BROWN, 1963, for Chimbu); RAPPAPORT (1967) and CLARKE (1971) refer to tree-consciousness, in particular concerning *Pandanus,* from the Simbai valley (N of the Bismarck Range, actually outside the „high valleys"). The Australian Administration encouraged the growing of *Casuarina* (see MCINTOSH, 1960; also "Planim diwai yar", 1965) and when dealing with conservation in New Guinea (GAGNÉ & GRESSITT, 1982), this deep-rooted tree-consciousness ought to be encouraged as a most valuable asset towards the future.

This interest of the highlanders seems all the more commendable, if the situation in New Guinea is briefly compared with what is known about silviculture, for instance, in the Himalayas, in "traditional" societies, i.e. outside the influence of scientific forestry. There is only one case, so far, known, which warrants to be mentioned in comparison: the Apa Tanis, living in a small, secluded valley of the Assam Himalaya, confined to their own clearly limited valley habitat for survival, surrounded by hitherto potential enemies, discovered only during the early forties, represent in many ways a fitting parallel for a

[7] see, for instance, VICEDOM und TISCHNER (1943–1948), RIESENFELD (1950), MEGGITT (1960), BROOKFIELD (1964), BROOKFIELD and BROWN (1963), RAPPAPORT (1967), POWELL (1976), STEENSBERG (1980), ALLEN (1982), AUFENANGER (1961) etc.

[8] In Java, the author observed *Cordyline* (red-leaved variety) used as boundary marker amongst the tea-fields of Kertasari (1973).

comparison with the high valleys in the Central Cordillera in New Guinea. This brief reference to the Himalayas emphasizes the extraordinary achievement of the inhabitants of the Central Cordillera in New Guinea in their attitude towards trees. The beauty of the man-made landscape in the high valleys bears witness to this achievement.

Finally, it seems appropriate in this all too short treatment of man and his relationship with his environment in the Central Cordillera to refer again to the importance of ritual and magic, in short: taboos, ritual restrictions, for instance, in hunting (BULMER, 1968) and diet, that may lead, in due course, further towards explaining the environmental awareness or some "conscious conservationism" (BULMER, 1968) of the highlanders. Of course, fire was used "in the beginning", when forest had to be cleared, and it is used today primarily for hunting, which is, anyway, not of great importance in the Central Cordillera, and in the Enga country outside the populated areas only, or above the upper timberline, i.e. outside the high valleys as the term has been used here. A former "primitive" use of fire is no contradiction to the development of an intimate relationship between man and his environment in course of time.

The present author was every so often struck by a sense of beauty vividly manifest in the man-made landscape of the high valleys, though there are only comparatively few allusions to this aspect in the literature, above all VICEDOM und TISCHNER (1943–1948).

As the result of pre-European times, it seems fair to sum up: in the high valleys of the Central Cordillera man has, within the set of natural and social constraints, achieved balance to a remarkable degree – thanks to ingenious adaptation to the many different challenges – perhaps, helped by a deep-rooted – magic? – relationship to certain plants and, therefore, to the "place", the environment.

6. Winds of Change: De-Stabilisation?

The interior of New Guinea, i.e. the Central Cordillera and what there lies hidden in its many valleys, escaped an early discovery. Exploration began at the coast, but the fringe of lowland tropical rain forests and swamps stretching inland acted as a formidable barrier. The mountains were recognised from the distance. The first to have gained some sort of an idea about the inhabitants of the mountainous interior and the density of the population hidden in the valleys, seems to have been Hermann DETZNER, who during the First World War managed to survive somewhere in the interior; the loss of all his notes cast doubt over his possible achievement (BROOKFIELD, 1961; SOUTER, 1963). In 1927, CHAMPION and KARIUS crossed the island from Fly to Sepik through the Telefomin area. LEAHY, in search of gold, entered the Central Cordillera from the East in the 1930s; the discovery of the Chimbu and Wahgi Valley followed in 1933. HIDES and O'MALLEY penetrated into the Central Cordillera from the South (HIDES, 1935, 1936).

After the Second World War it took sometime until Australia developed some interest for the eastern part of the island, for which it was responsible. In course of time, the introduction of new plants was initiated: coffee, tea (SCHWEINFURTH, 1970 a), *Pyrethrum* (SCHWEINFURTH, 1969), the "Irish" ("English") potato[9].

Cattle followed. Roads began to penetrate the interior and the Central Cordillera. New political organisations came into being and, last not least, a medical service was introduced after the various missions had established hospitals and some health care, initially. All these new ideas and activities entered the high valleys in a comparatively short period of time; their impact cannot yet be summed up in perspective. A destabilising effect in the hitherto carefully balanced ecology of the high valleys must be envisaged.

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[9] WADDELL (1972 a, p. 132, footnote) concludes from the Kate (Finschhafen area) word "Katofen", that the potato ("Kartoffel") was first introduced by German missionaries into the Finschhafen area and was taken into the mountains from there.

The Australian Administration has been extremely sensitive in its attitude to land and was at pains not to interfere with local customs and rights. But the new possibilities are there – will the "Irish potato", less sensitive to frost than *Ipomoea batatas*, lead to another intensification of cultivation at the higher altitudes – to make "more room at the top"? Cattle – an unknown quantity in the New Guinea highlands so far: what will happen if cattle rearing proves profitable and is accepted on a broader scale? Roads, the possibility of communication, praiseworthy, perhaps, in itself, may carry wanted and unwelcome and unexpected effects. Medical care, without question a pressing need for the highlanders – but the spectre of a rising population is already there[10].

With independence new political organisations were developed; the "Kiapdom", to which the local people became used, declined in importance and some of its power went to more central authorities, i.e. decision making was taken away from the local stage (MEGGITT, 1977; GORDON, 1983). On the other hand, population increase and a new recognition of the value of land – as a result of population increase and innovations, while land itself became proportionately scarcer – triggered off a resurgence of tribal fighting, which until recently seemed to be a matter of the past, when during the later years of Australian Administration most of the country was more or less under some sort of control. Significantly, tribal fighting reappeared, where population is densest and, consequently, land scarcest and in constant demand (MEGGITT, 1977; ALLEN & GIDDINGS, 1982; GORDON, 1983; see also BERNDT, 1964; VAYDA, 1976). Under these circumstances, tribal fighting in itself is an indicator of de-stabilisation to a degree, which cannot be neglected. It seems a formidable task for the new nation "Papua New Guinea" to reestablish balance, where it was disturbed under the impact of the new, changed conditions. What the inhabitants of the high valleys achieved within the limitations of their natural and social constraints in course of time was some sort of balance between man and environment. The „Ipomoean revolution" or evolution, resp. its realisation, proved the adaptability of the highlanders. What we witness today, is a by far more complex invasion of new plants, new animals, new techniques, new organisations, new values – a daunting prospect, in which the resourcefulness of the highlanders may be the most promising asset.

Summary

The relationship between man and his environment in the high valleys of Eastern New Guinea is dealt with under three topics: *Pandanus, Casuarina, Ipomoea batatas.*

Pandanus sp. grows wild in the montane forests and is also cultivated; the oil bearing seeds ("nuts") serve as an important and, in times of need, vital food supply; they can be stored. The dry, old leaves are used for mats, rain cover, clothing, roofing etc. Each individual *Pandanus* tree, even those growing wild in the montane and cloud forests, is marked as "private property" and the rights are jealously guarded – an indicator of the importance attached to *Pandanus* by the people in the high valleys of Eastern New Guinea.

Casuarina in the high valleys of Eastern New Guinea is physiognomically striking by the greenish-grey colour and the generally "light" character of its leaves, somewhat "alien" within the altitudinal belt of sombre, dark green montane forests. Common as a pioneer along the coasts in the Indopacific World, *Casuarina* owes its wide-spread distribution in the high valleys of Eastern New Guinea to man: planted with obvious care around the traditional meeting places (sing-sing grounds), *Casuarina* has been introduced into the cultivation of *Ipomoea batatas* as a fallow tree, it is used as a stabiliser on steep slopes and is highly appreciated as a source of wood. The interest of the inhabitants of the high valleys shown against *Casuarina* displays likewise knowledge of the particular qualities of the plant as well as understanding for the "ecology of the place".

Ipomoea batatas is of South American origin and introduced into the Pacific World by man. This species is the traditional staple food of the population in the high valleys. The sensitivity of the plant towards frost sets the upper limit of cultivation in the high valleys – 2700 m, bearing in mind all possible local variations. *Ipomoea batatas* is cultivated and likewise harvested all year round –

[10] A discussion of "man and environment" in New Guinea, though here confined to a discussion of man's relationship to the environment as far as *Pandanus, Casuarina*, and *Ipomoea batatas* are concerned, must, at least, refer in passing to the enormous potential of geomedical problems hidden in the island's ecosystem, mention may be made of plants used for medical purposes (POWELL, 1976), malaria distribution (SCHWEINFURTH, 1974) or the case of Kuru amongst the Fore in the Eastern Highlands, as a prime example, finally solved by GAJDUSEK, a few years ago.

the tubers do not bear storing. Its cultivation indicates intimate understanding of site factors; the *Ipomoea batatas* plots amongst the Enga deserve special mention: mounds of unusual size are constructed by lavish application of green plant material as precaution against frost. The recently introduced "Irish" potato provides by its greater resistance to frost a serious challenge to the dominance of *Ipomoea batatas.*

The people in the Central Cordillera of New Guinea seemed to have acquired a remarkable degree of ecological perception – a necessity in the old days, when beyond the clan territory there was enemy country and consequently each clan was confined to its own particular territory to survive or perish. Pacification, new plants, the cash economy, construction of roads, independence and new political organisations resulting, in general: "modern developments", are likely to upset the hitherto carefully preserved traditional "ecological balance".

Zusammenfassung

Mensch und Umwelt in der Zentralcordillere des östlichen Neuguinea – *Pandanus, Casuarina, Ipomoea batatas.*

Drei Pflanzen – *Pandanus, Casuarina, Ipomoea batatas* – sollen dienen, die Beziehungen zwischen Mensch und Umwelt in den Hochtälern des östlichen Neuguinea vorzuführen.

Pandanus kommt wild in den Bergwäldern vor und wird angebaut; die ölhaltigen Samen sind eine wichtige, in Notzeiten lebenswichtige Zusatznahrung, noch dazu lagerfähig. Die trockenen Blätter dieser Schopfbäume finden Verwendung für Matten, Regenschutz, Bekleidung, Hüttenbedeckung etc. Jeder einzelne Baum, auch im Höhen- und Nebelwald, ist in Privatbesitz, das Besitzrecht wird eifersüchtig gewahrt.

Casuarina fällt, einzeln oder im Verband, durch die fahlgrüngraue Farbe und den lichten Charakter ihrer Beblätterung in der Stufe der Höhen- und Nebelwälder als fremd auf. An den Küsten, insbesondere auf Dünen, aber auch allgemein als Pionierpflanze in der indopazifischen Welt vertreten, verdankt *Casuarina* ihre weite Verbreitung in den Hochtälern der Zentralcordillere dem Menschen: überall an den Sing-sing-Plätzen angepflanzt, als Brachpflanze in den Anbau von *Ipomoea batatas* zur Bodenverbesserung übernommen, auf Hanglagen als Schutz gegen Bodenerosion verwandt und als Holzlieferant geschätzt, zeigt das Interesse der Bevölkerung für *Casuarina* intime Kenntnis der Pflanze und ihrer besonderen Qualitäten, sowie Einsicht in die ökologischen Verhältnisse.

Ipomoea batatas ist in den pazifischen Raum von Südamerika aus eingeführt. Die Batate ist das Grundnahrungsmittel der Bevölkerung in den Hochtälern. Ihre Frostempfindlichkeit bestimmt die Anbaugrenze – 2700 m, sofern man sich der lokalen Differenzierung bewußt ist. Die Batate wird ganzjährig angebaut und ganzjährig geerntet; die Knolle ist nicht lagerfähig. Der Anbau beweist hohe Einsicht in die Standortverhältnisse; die Haufenbeete der Enga verdienen besondere Aufmerksamkeit: in Hanglagen stehen die Einzelhaufen stets auf Lücke; in frostgefährdeten Lagen werden durch zusätzliche Kompostzugaben als Frostvorsorge Riesenhaufenbeete aufgetürmt.

Aus dem Eingebundensein in engbegrenzte Lebensräume, unentrinnbar unter den traditionellen Verhältnissen in Neuguinea, hat die lokale Bevölkerung ein bemerkenswertes Umweltbewußtsein entwickelt. Geldwirtschaft, neue Anbaupflanzen, Straßenbau, Folgen der Unabhängigkeit mit ihren neuen politischen Organisationen, sind geeignet, das traditionelle Bild ökologischer „balance" aufzulösen.

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Discussion to the Paper Schweinfurth

Prof. Dr. W. Lauer:

At which altitudes does frost occur, and are there any relations between the cultivation of sweet potatoes and the occurrence of frosts?

Prof. Dr. U. Schweinfurth:

As already mentioned both questions have to be answered together: official meteorological stations are far and few, especially seen against the background of the topography of the Central Cordillera. Sweet potato, the staple crop of the highlanders, is highly sensitive to frost; the basic reliance of the population on this particular plant lead by experience to elaborate measures of protection, summarised under the term "mounding". A fair idea about the extent of frost expectation by the local people in the Central Cordillera could, for instance, be gathered by an evaluation of the occurrence of mounding from available air photographs, as already suggested (SCHWEINFURTH, 1970 b). In general: from 2400 m on upward, occurrence of frost is more or less "normal"; 2700 m may be referred to as the absolute upper limit of cultivation resp. lower limit of montane forest; in the Enga country mounding disappears below 1600 m indicating that frost is not expected below this altitude (WADDELL, 1972 a). But frost periods like the one experienced in 1972–1973 (see WADDELL, 1972 a, 1973, 1974; BROWN and POWELL, 1974) serve as a stark reminder of what is possible under a certain combination of circumstances.

To sum up: all "general" figures are, in a way, only of academic usefulness so to say; reality is, indeed, much more diverse in the varied topography and under the more or less unpredictable meteorological and climatological circumstances of the Central Cordillera of New Guinea.

Prof. Dr. W. Weischet:

You consider the cultivation of sweet potatoes on compost mounds a well-balanced ecosystem. For an assessment of this ecosystem two aspects would be of interest:

1. What about the budget of organic mass? Is organic material carried from outlying fields on the mount-plots?
2. Are there any quantitative statements concerning the heat generated by decomposition and its influence on the prohibition of frost damages?

Prof. Dr. U. Schweinfurth:

The best answers to these questions are provided by Eric WADDELL in his monograph "The mound builders – agricultural practice, environment, and society in the Central Highlands of New Guinea. U. of Wash. Pr., Seattle, 1972". WADDELL spent about a year in doing field research in a relatively small area of the Enga Province (as it is called today), west of the Hagen Range amongst the Raiapu Enga in the vicinity of Wapenamanda, a local administrative centre. The importance of local variation in the Central Cordillera makes it imperative to keep in mind that his research concerns the Raiapu first of all, and that things may be different elsewhere. The strength lies in WADDELL's devotion to detail. He gives the best descriptions and analysis of mulching available and there is also reference made to the heat generated within the mounds during the process of decomposition: decomposition raises soil temperatures by the order of 1.2 °C. There is another contribution by WADDELL in "The Pacific in Transition", London, 1973, referring to both these aspects as well.

I may add, that besides personal impressions gained amongst the high valleys, WADDELL's detailed research in the problems of mound building, respectively "cultivation under particular environmental hazards", prompts me to refer with emphasis to "environmental awareness" in dealing with the highlanders, especially as WADDELL pursues a geo-ecological approach, with an eye for the country, the people, their interrelationship. We need more detailed field work of this calibre.

Prof. Dr. W. Eriksen:

Concerning frost I would like to ask the following questions:

1. What kind of frost is meant? Frost on station- or ground-level?
2. Does frost have any impact on the limit of cultivation of other plants?

Prof. Dr. U. Schweinfurth:

Dealing with frost in connection with sweet potato cultivation in New Guinea always means: frost on the ground. Frost in New Guinea has been a phenomenon of concern only for the "mound builders", to use WADDELL's phrase, the sweet potato cultivators – until the frost period of 1972 gained the phenomenon wider publicity by means of modern communication and, not to forget, in the years immediately preceding independence, for political reasons. Before that, few people, if any, outside the areas concerned, have been aware of the possibility of frost in highland New Guinea. Further, meteorological stations in New Guinea and, especially, in the Central Cordillera are far and few, established only recently to help in the management of air traffic, i.e., they are practically of no help for the problems dealt with here. Consequently, all frost evidence has to be gained by observation in the field. And the only plants affected are the only plants cultivated at the altitudes concerned – *Ipomoea batatas*.

However, the local people are aware of microclimatological effects: that plants on the top of the mounds have a better chance to escape frost damage than those on the bottom may have lead them to build these enormous mounds, where necessary, and they, obviously, learned by experience, that "clean weeding" of the "channels" between the mounds facilitates the "flow" of air – adding in so doing greatly to the neat appearance of sweet potato horticulture in the areas concerned (remember slide – from Kaugel Valley, Tambul, 2200 m, shown earlier).

Sweet potato is *the* staple crop in the high valleys, i.e. *Ipomoea batatas* is the only plant cultivated in the area under consideration and therefore the only frost indicator. As mentioned before, the "Irish" potato is less sensitive to frost under New Guinea conditions; in 1967/68 it was cultivated here and there together with sweet potatoes on mounds, perhaps, a typical experimental stage. It remains to be seen whether people will take to them at any larger scale.

Incidentally, during the unprecedented 1972 frost period even trees, indigenous to the montane forest, showed some frost damage, as, for instance, *Pandanus* and a few others – an event unheard of within living memory.

Dr. W. Golte:

My question concerns the seasonal differentiation of frost risk in New Guinea. How much higher is the lower limit of frost expectation during the "North-West-Season" as compared with the "South-East-Season"? An answer to this question should be interesting in regard to the possibility of cultivating potatoes above the upper limit of sweet potatoes.

Prof. Dr. U. Schweinfurth:

Frost to us, concerned with tropical mountains, is, needless to say, a phenomenon of top-importance, especially where it concerns man and his gardens, his food supply, i.e. his existence. This is why the New Guinea situation is of such interest. The degrees of frost and the resulting damage has been, so far, of local impact only. Only very recently, temperature recording has been inaugurated. This has to be kept in mind in answering the question; as far as can be stated today: frost occurs in the Central Cordillera of New Guinea during the Southern hemispheric winter, i.e. during the months of June to October (as, for instance, in 1972); it is "normally" connected with a period of drought. The drought 1972 was noticeable from South India (heavy frost in the Nilgiris!) right through to Ceylon, Java and, no doubt, other suitable localities in the region, to New Guinea.

Prof. Dr. W. Klaer:

1. It is interesting to observe how a (cultivated) plant (sweet potato) could be "channelled" from the coast through an intact virgin forest up to the highland. This led to an agrarian revolution (sweet potatoes in exchange for taro) without a handing over of agricultural tools (until 1930 absolute Stone-Age culture in the highland). Should *Casuarina* also have got to the highland like this? Without the shade-throwing *Casuarina* tea and coffee plantations would be unthinkable.
2. Do the inhabitants really show "environmental awareness"? When I see the vast cultivated savannah areas in the highland, which give proof of an incredible forest devastation by local Stone-Age cultures, when I see the seasonal, absolutely useless burning of savannah-areas by today's residents, I question their "environmental awareness", thus stressed by the author.

Prof. Dr. U. Schweinfurth:

Of course, we could speculate here at length, but I won't do it. We better wait what further results research at the Australian National University, especially, palynological and archaeological research, will produce about the New Guinea past!

As far as *Casuarina* is concerned, I think, I was careful to say, that *Casuarina oligodon* and C. *cunninghamiana* occur widely on riverbanks and in shingle beds – these occurrences can be regarded as natural. But today's wide distribution of *Casuarina* in the high valleys is the result of man's interest in the tree: planting around the ceremonial grounds, its use as fallow tree in sweet potato cultivation, as stabilizer on slopes, as a source of material for tools, fences, housebuilding etc. – and as firewood – MEGGITT pointedly speaks of "practical forestry", "silviculture" in the case of the Engas and so does BROOKFIELD for the Chimbu. I like to draw attention again to *Casuarina* as a plant deeply connected with the Megalithic culture all over Melanesia, involved in rituals and magic – the present use in coffee plantations is just a modern application of a tree well-known to the people. In short, the connection between man and *Casuarina* is intimate and seems to go far back in history. Palynological research established a rise in *Casuarina* presence probably connected with the "*Ipomoean* revolution", the spread of the sweet potato in the high valleys.

This leads me to the other comment challenging me using the term "environmental awareness". Firstly, in using the term I refer to the inhabitants of the high valleys and what they do there – not what may happen above the upper timberline where there are the hnnting grounds. With reference to environmental awareness I am concerned with the restricted, limited habitats of the – densely populated – valleys, and, see title, the three plants mentioned.

Of course, the highlanders used fire, when they first entered the Central Cordillera – there is no denying of this – our ancestors in Central Europe did the same and, in course of time, developed Forstwirtschaft and Forstwissenschaft! The New Guinea highlanders may still be atavistic in the use of fire when it does not concern their immediate habitat, territory, but the land of their neighbour-enemy – "across the border" (this has not so long ago happened in "developed" Europe as well). But someone, who paid at least some attention to the way, *Ipomoea batatas* is cultivated, to the ingenious responses to environmental challenges or the obvious sense for beauty in the care of the ceremonial grounds, not to mention the very fact that trees are planted, cannot but admit that there is a deep awareness, even an understanding for the habitat, the environment, at work. The planting of trees to me is a definite, unquestionable attribute of environmental concern, exhibited in the Central Cordillera with *Pandanus* and *Casuarina,* to mention only these two – developed out of necessity, pressing circumstances. Survive or perish, may have been a formidable task-master in the limited territorial constraints of highland New Guinea.

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Studies on the Mountain Climatology and Geoecology of the Central Highlands in Sri Lanka

Manfred Domrös

With 8 Figures und 5 Tables

1. Introduction: The Broad Climatic Outline

The climate of Sri Lanka is commonly described as both monsoonal and tropical, due to the position of the island between 6 and 10 degrees north of the equator and close to the southernmost tip of India, monsoonal referring to the seasonality of rainfall and tropical to the temperature pattern, which is characterized by a large diurnal variation in comparison to the small seasonal range. The "Indian" monsoon, which affects Sri Lanka, consists of two components:

(i) the South-west monsoon, corresponding dynamically to the equatorial westerlies,
(ii) the North-east monsoon, being part of the tropical easterlies.

The alternating regimes of these two components are controlled by the seasonal shift of the ITCZ, which crosses Sri Lanka in April and September. The South-west (or summer) monsoon is rather wet, while the North-east (or winter) monsoon is comparably dry.

This tropical-monsoon climate of Sri Lanka is much modified by the landforms and relief of the island. Although a small island, covering only 65 680 km², Sri Lanka shows a distinct division into mountains and lowlands and also considerable relief energy. In general terms, the mountains occupy the inner parts of the island, like a strong massif surrounded by vast plains, above which the mountains arise steeply, and stretches of flat or gently undulating lowland. Although somewhat to the south, the mountains are called the Central Highlands; they consist of a rather inhomogeneous complex of ridges and peaks, valleys and river gorges, upland plains and intramontane basins. Several peaks exceed 2000 m, the highest reaching 2524 m: Pidurutalagala. Some 30 per cent of the total area are located above 150 m.

2. The Horizontal Climatic Division

Although of only medium elevation, the Central Highlands modify the climate both in a horizontal and a vertical sense. A distinct regional division of Sri Lanka results from the rain-shadow effect of the Highlands acting as a barrier to the monsoon winds. Evidence of this is found in the commonly used division of Sri Lanka into a Wet Zone and a Dry Zone for which there are as yet no generally accepted definitions, although for practical purposes, from the point of view of tropical land use, the seasonal distribution of rainfall seems to be the most useful criterion. Thus, the Dry Zone can be delimited according to the occurrence of an "effective dry period" or a period of agricultural drought, the Wet Zone having a more even rainfall distribution. Agricultural drought has been defined as a period of at least three consecutive months each of which receives less than 102 mm of rainfall (Wikkramatileke, 1963; Domroes, 1971 and 1974).

According to this criterion the Wet Zone covers a small south-western sector of Sri Lanka, whereas the Dry Zone occupies the remainder and thus about three quarters of the island (Fig. 1). The border-line

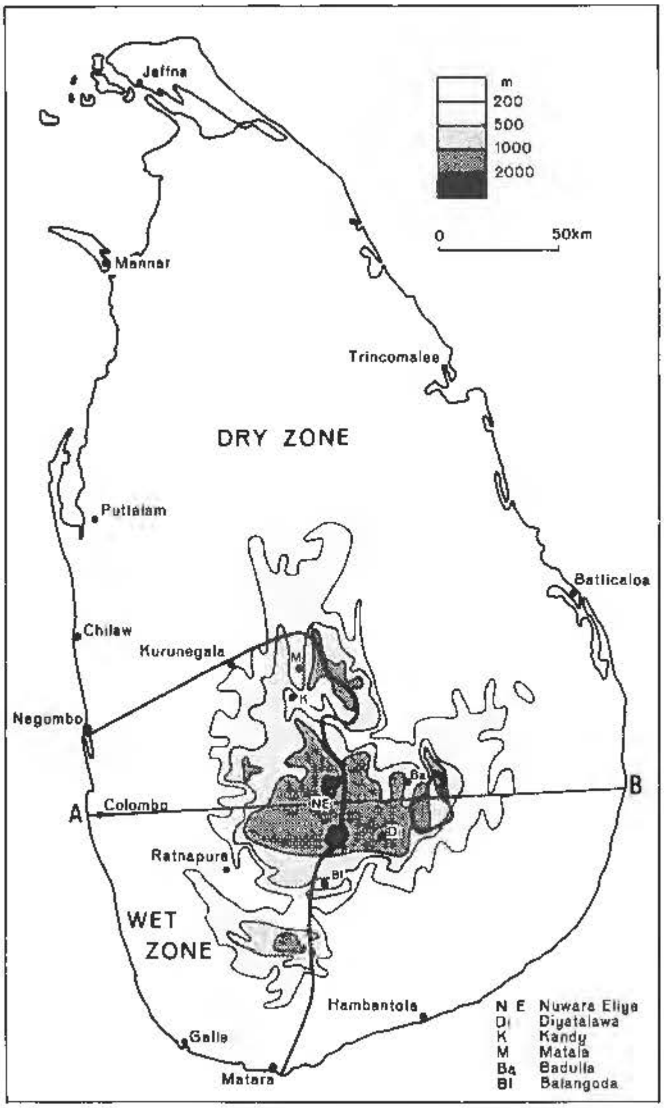

Fig. 1. The boundary line between the Wet Zone and Dry Zone of Sri Lanka, according to the 'effective dry period' with regard to tropical crop cultivation (after: DOMROES, 1971). A–B shows the cross-section in Figs. 4 and 6.

Table 1. Monthly rainfall totals for selected stations in the Wet and Dry Zones (averages in mm for 1931–1960)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Colombo	88	96	118	*260*	*353*	*212*	140	124	153	*354*	*324*	175	2396
Watawala	112	109	197	196	*702*	*911*	*713*	*656*	*515*	*646*	364	217	5450
Nuwara Eliya	145	76	97	154	*237*	*266*	*223*	180	165	*222*	*209*	*190*	2162
Anuradhapura	*123*	54	99	*187*	100	19	32	47	70	*233*	*248*	*242*	1447
Amparai	*351*	131	93	112	73	34	42	70	72	*191*	*272*	*363*	1879
Hambantota	*101*	58	66	*109*	*121*	55	43	42	46	*126*	*188*	*121*	1076

Italics – months receiving more rainfall than the average per month in the case of even rainfall distribution through the year.

between the Wet and Dry Zones crosses the central mountains, dividing them into the wetter western slopes and the seasonally dry eastern slopes. It is quite interesting to notice that SCHMIDT-KRAEPELIN confirms this boundary by comparing various aridity indices (1981, pp. 40–45). From the viewpoint of land use, the Wet Zone is characterized by the cultivation of perennial and annual crops, whereas in the Dry Zone only annual crops are profitable.

The differing rainfall regimes for selected stations in the Wet and Dry Zones are clearly indicated by:

(i) monthly rainfall totals through the year, and
(ii) climatic diagrams showing rainfall-temperature relationships, according to the aridity index of DE MARTONNE/LAUER.

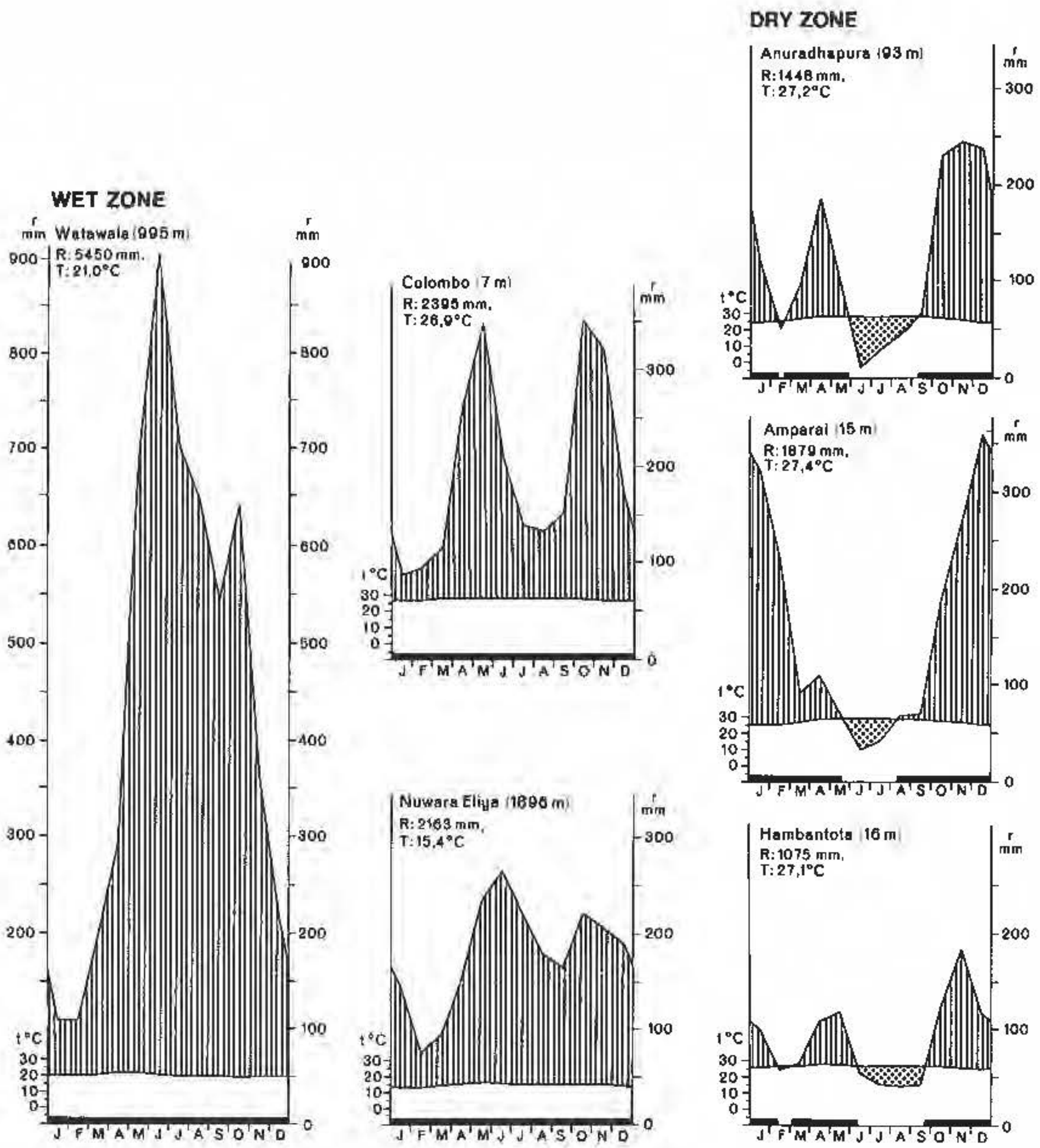

Fig. 2. Rainfall–temperature diagrams for selected Meteorological Observatories in the Wet Zone and Dry Zone of Sri Lanka, based on the 'aridity index' of DE MARTONNE/LAUER (1952); mean values from 1931 to 1960.

Reference stations are: Colombo, Watawala and Nuwara Eliya in the Wet Zone; Anuradhapura, Amparai and Hambantota in the Dry Zone (Table 1 and Fig. 2). The rainfall values for all stations are averages for the 30-year period 1931 to 1960. Although all the stations show variations in the seasonal distribution of rainfall, only the Dry Zone stations show the occurrence of an "effective dry period".

3. The Vertical Climatic Division: Mountain Climates

In the Central Highlands climate is modified by the effects of altitude to give distinctive climatic conditions according to the various climatic elements.

3.1 Temperature

The diurnal and annual temperature regimes. – The tropics in general are characterized by a larger diurnal than seasonal temperature regime and this rule applies in the mountains as well as in the lowlands. While the (mean) annual range of temperature varies between 1.5 and 4.3 °C (for the whole of Sri Lanka), the (mean) daily variation of temperature amounts between 5 and 10 °C. These values are small in comparison to values for other tropical countries, due to the strong maritime and thus moderating influence of the Indian Ocean upon temperature. With respect to the diurnal temperature range, the highest values in Sri Lanka occur in the mountains, where the maritime influence is least. The greatest mean values of the diurnal temperature range for the year amount to:

9.8 °C Badulla (670 m),
9.3 °C Nuwara Eliya (1896 m),
8.3 °C Talawakelle (1375 m).

These values are exceeded on a monthly basis, and over almost the whole of the island, February and March record the greatest diurnal temperature ranges, which – again – reach maximum values in the Central Highlands:

13.8 °C March/Nuwara Eliya (1896 m),
12.4 °C March/Talawakelle (1375 m),
11.9 °C February/Talawakelle (1375 m),
11.7 °C March/Kandy (477 m),
11.6 °C February/Kandy (477 m).

It is interesting to note that these stations are situated in the uppermost mountain zone (Nuwara Eliya) and on the western slopes (Talawakelle, Kandy), and that it is in the dry North-east monsoon period that the greatest diurnal temperature ranges occur. By contrast, on the eastern slopes of the Highlands, the greatest diurnal temperature ranges occur during the dry South-west monsoon period:

12.2 °C July/Badulla (670 m),
8.6 °C July/Passara (1007 m).

Naturally the mean values given so far are exceeded by the actual diurnal temperature range. Values recorded in Sri Lanka reach as high as 30 °C in the uppermost mountain zone during the North-east monsoon period, as records from the Nuwara Eliya Observatory (1896 m) show.

The altitudinal temperature gradient. – The thermal-climatic differences between the tropical lowlands and mountains of Sri Lanka result from the decrease of temperature with increasing altitude. The lowlands record a mean annual temperature slightly varying around 27 °C. In the upper mountains, however, mean annual temperatures drop to about 15 °C in the Nuwara Eliya region (c. 1900 m) and to 11.5 °C on the Pidurutalagala (2524 m).

A similar drop of temperature is indicated for mean monthly data. Comparing values for Colombo (7 m) and Nuwara Eliya (1896 m), the decrease in temperature varies from 11.0 °C (October, November) to 12.3 °C (March) for the altitudinal range of nearly 1900 m. This results in a lapse-rate of temperature varying slighly between 0.60 and 0.65 °C for every 100 meters (THAMBYAHPILLAY, 1955: 0.64 °C/100 m). The sharp drop of temperature in the Central Highlands is clearly illustrated by the mean monthly temperatures for four stations: Colombo (7 m), Kandy (477 m), Diyatalawa (1248 m) and Nuwara Eliya (1896 m) (Table 2).

The decrease of temperature with increasing altitude is also unterlined by considering the mean daily maximum and minimum temperatures on a monthly basis. The differences in temperature between Colombo (7 m) and Nuwara Eliya (1896 m) in °C are as follows:

	J	F	M	A	M	J	J	A	S	O	N	D
Max. temp.	12.0	12.1	12.3	11.8	11.2	11.4	11.4	11.3	11.5	11.0	11.0	11.3
Min. temp.	13.5	14.6	15.4	14.3	13.2	11.9	12.1	12.4	12.8	12.5	12.1	12.7

It can be seen that for each month the drop in temperature from Colombo to Nuwara Eliya is greater for minimum than for maximum temperatures.

Frost. – The most notable climatic phenomenon in the Central Highlands is the occurrence of frost. Detailed studies (DOMROES, 1970 and 1974) have shown the occurrence of frost in the mountains of Sri Lanka to be a typical, although irregular, phenomenon which is temporally and spatially limited: to the period of the North-east monsoon, and to depressions, small basins and valleys. It can be seen from Table 3 that frost is more often ground frost only and, in any case, that it is the radiative type of frost which occurs in the night and which mostly affects small-scale depressions forming "frost pockets" or "frost hollows". It is impossible to define an accurate frost boundary in the Central Highlands of Sri Lanka, due to the nature and type of frost, but the occurrence of irregular night frosts in depressions has certainly to be taken into account above altitudes of 1800 to 1900 m.

Observations of the temperature conditions show a very distinct change from the hot lowlands to the comparably cool mountains. The vertical temperature decrease can be summarized in the distinction of

Table 2. Mean monthly temperature (°C) (1931–1960)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Colombo (7 m)	26.3	26.5	27.2	27.7	28.0	27.4	27.1	27.2	27.2	26.6	26.3	26.1	27.0
Kandy (477 m)	23.1	23.8	25.3	26.0	25.6	24.6	24.1	24.4	23.8	24.2	24.0	23.2	24.4
Diyatalawa (1248 m)	18.2	19.0	21.1	20.8	21.4	21.4	21.3	21.1	20.8	20.1	19.5	18.6	20.2
Nuwara Eliya (1896 m)	14.3	13.9	14.9	16.0	16.7	16.0	15.7	15.8	15.7	15.6	15.4	14.9	15.4
mean max.	19.9	20.9	21.8	21.9	21.3	18.7	18.5	19.0	19.4	19.8	19.9	19.8	20.1
mean min.	8.7	7.7	7.9	10.0	12.1	13.3	12.8	12.6	11.9	11.3	10.8	9.7	10.7

Table 3. Nuwara Eliya (1881 and 1896 m): Thermo-climatic indices

		Nov.	Dec.	Jan.	Feb.	March	April	Year
(1)	Average number of ground (grass) frosts	0.1	0.8	2.5	3.6	1.5	0.2	8.7
(2)	Average number of frosts in the air	0.0	0.1	0.5	0.8	0.1	0.0	1.5
(3)	Mean daily minimum temperature (°C)	10.8	9.7	8.7	7.7	7.9	10.0	10.8
(4)	Mean daily maximum temperature (°C)	19.9	19.8	19.9	20.9	21.8	21.9	20.1

Observation period for (1) and (2): 1897–1970, for (3) and (4): 1931–1960.

the "hot" tropics from the "cold" mountain tropics, according to LAUER (1975). Such altitudinal divisions reflect a gradual variation in temperature, however, rather than a sharp division of the mountains into two zones. Accurate delimitation of each belt is therefore problematic, and it seems advisable to characterize only the uppermost mountain parts of Sri Lanka, that is above 1800/1900 m, as cold-tropical, according ot the occurrence of frost which can be taken to be the most critical temperature value in mountain climates. The thermo-climatic indices for Nuwara Eliya (Table 3) represent the cold tropical conditions of the uppermost Central Highlands of Sri Lanka.

3.2 Rainfall

Annual rainfall totals. – Mean annual rainfall varies considerably (Fig. 3). The lowest annual values of less than 1000 mm are recorded in the coastal lowlands of Southeast- and Northwest-Sri Lanka, while the highest annual rainfall of 5700 mm is recorded for the Kenilworth Tea Plantation, Ginigathena (890 m) which is situated on the western slopes of the Highlands (both values being for the 30-year period 1931–1960). Naturally the greatest meso-scale differences in rainfall are recorded in the Central High-

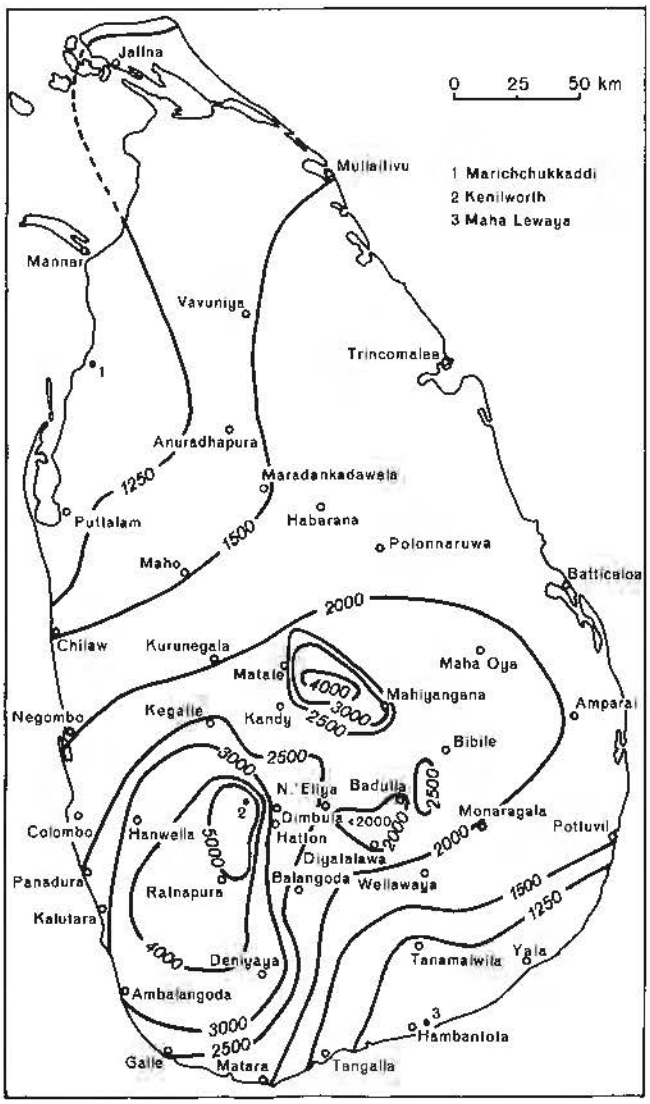

Fig. 3. Mean annual rainfall in Sri Lanka; observation period 1931 to 1960 (after: DOMROES, 1974).

Table 4. Mean monthly rainfall (mm) for selected stations in Sri Lanka (1931–1960)

Station	Altitude (m)	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Colombo	7	88	96	118	260	353	212	140	124	153	354	324	175	2396
Kandy	477	116	85	122	181	171	153	136	128	110	264	253	234	1953
Diyatalawa	1248	152	86	121	210	143	46	59	89	95	248	278	204	1731
Nuwara Eliya	1896	145	76	97	154	237	266	223	180	165	222	209	190	2162

lands. In this respect, the most notable observations are the high annual rainfall values on the western compared to the eastern slopes. Evidence of this is found on the values for annual rainfall for the wettest parts of both slopes, amounting to over 5500 mm on the western, but only to 2500 mm on the eastern slopes. Generally speaking, as a whole the western slopes record more, the eastern slopes less than 2500 mm. The reason for this remarkable difference is found in the amount and regional distribution of the South-west monsoonal rainfall: during the 4 to 4,5 months period from mid to end of May until the end of September, the heavily rain-bearing South-west monsoonal air masses give rise to ample orographic rains on the windward, western slopes of the Central Highlands, while on the eastern slopes the South-west monsoon occurs as a dry, katabatic, foehn-like wind which brings very little rain.

The Central Highlands act as a clear-cut orographic barrier which causes considerable variation in the South-west monsoonal rainfall totals on western and eastern slopes: the western slopes record on most parts 1500 to 2500 mm at this time of year, the eastern slopes only around 500 mm. In no other season of the year can such a remarkable difference of rainfall, due to the influence of the Central Highlands, be observed. The remarkable differences in the annual distribution of rainfall in Sri Lanka, and in the Central Highlands in particular, can be seen by comparing the monthly rainfall totals for selected stations (Table 4): Colombo (a typical wet lowland station), Kandy (in the western hill country), Diyatalawa (on the eastern slopes) and Nuwara Eliya (in the uppermost mountains).

Altitudinal rainfall "inversion". – As in other tropical countries (WEISCHET, 1965) a distinct vertical pattern of rainfall distribution can be seen (DOMROES, 1977), characterized by increasing annual totals with increasing altitude in the lower parts of the Highlands, whereas, in the middle and upper parts of the mountains, the rainfall totals decrease with increasing altitude. This peculiar pattern of rainfall distribution has been indicated for Sri Lanka by drawing a cross-section (Fig. 4) through the island from Colombo on the West coast, across the highest mountain parts, to Timitar (some 15 km north of Pottuvil), on the East coast. Mean annual rainfall values for the 30-year standard period 1931 to 1960

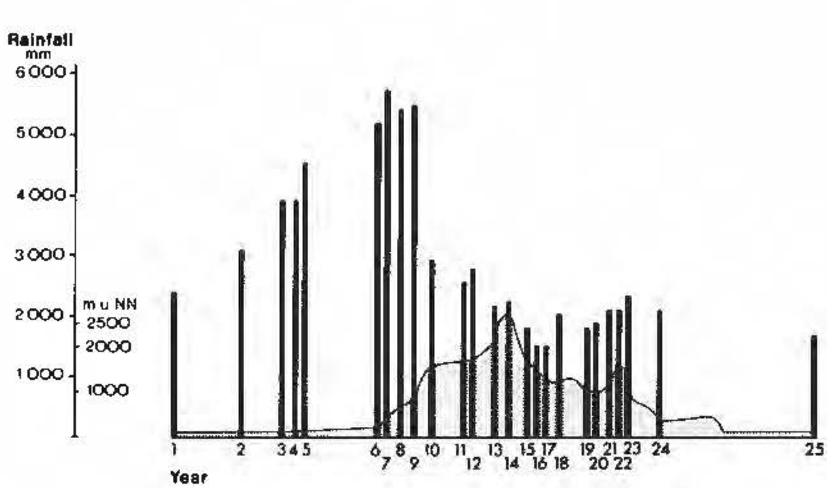

Fig. 4. West to East cross-section of the mean annual rainfall through Sri Lanka; observation period 1931 to 1960, see Fig. 1 (after: DOMROES, 1977).

have been plotted for 25 stations. The result shows the occurrence of a belt of maximum rainfall between 300 and 1000 m on the western slopes, while on the eastern slopes only a comparably weak to uncertain belt of maximum rainfall could be observed between 800 and 900 m.

Also on the basis of monthly rainfall totals the "tropical-convective type of the vertical rainfall distribution" (according to WEISCHET) could be proved – with the exception of the North-east monsoon months December, January and February. The altitude of the maximum belt of rainfall varies from as little as 50–100 m to 1000 m (DOMROES, 1977).

3.3 Wind

The "Kachchan". – The Central Highlands also act as a very strong orographic barrier on the wind. The most remarkable effect is the occurrence of the dry, foehn-like, descending "Kachchan" winds which heavily affect the eastern slopes and the eastern lowlands during the South-west monsoon from late May until the end of September. This seasonal katabatic wind has no counterpart on the western slopes during the North-east monsoon. For this, the stronger velocity of the South-west monsoonal winds and the landforms of the mountains are responsible. The Kachchan can be proved by many indicators in the field, such as windbreaks and shelter-belts as well as roofs fortified by sand-bags, pieces of rock, tires etc. (SCHWEINFURTH and DOMROES, 1974).

Besides the seasonal "Kachchan" foehn-wind certainly the diurnal, small-scale wind systems of mountain- and valley-winds have to be considered, too, about which however only meagre and unsystematic observations are existing so far.

3.4 Sunshine

The Central Highlands differ strikingly from the lowlands of Sri Lanka also in terms of sunshine, expressed by the number of sunshine hours (whether for a year, month or day). Mean annual totals of sunshine vary between about 2900 and 1400 hours, a regional variation of more than 100%. The highest values are recorded in the lowlands of North- and East-Sri Lanka, the lowest in the Highlands, where there is a rather small variation between 1400 and 1800 hours. In addition, it can be observed that the

Table 5. Mean daily hours of sunshine (1962–1971)

	J	F	M	A	M	J	J	A	S	O	N	D
Western slopes of the Highlands												
Balmoral	4.5	4.8	5.3	5.3	3.2	2.4	1.9	2.1	2.8	3.0	3.8	3.6
Bagahawatte	4.6	6.2	5.6	5.3	3.5	2.1	1.7	1.8	2.5	3.1	3.2	3.1
Frotoft	5.5	6.7	6.1	4.5	3.5	2.3	1.8	2.5	2.9	3.1	4.3	4.2
Galamuduna	5.7	6.5	6.4	4.3	2.2	1.1	1.0	1.7	2.5	3.2	4.5	4.4
Eastern slopes of the Highlands and "top country"												
Sarnia	3.5	5.4	6.3	6.2	6.3	6.2	5.8	5.2	5.6	4.5	3.6	3.0
Haputale	3.7	5.3	5.2	4.3	4.9	4.5	5.1	4.8	4.6	3.5	3.3	2.8
Pedro	4.9	5.9	6.5	5.5	4.9	4.4	4.4	4.3	3.8	3.8	4.0	3.7
Lowlands												
Colombo	7.5	8.2	8.6	8.3	6.2	6.6	6.1	6.4	6.1	6.1	6.3	6.2
Trincomalee	6.1	7.7	8.4	8.7	7.9	8.1	7.4	7.8	7.6	6.6	5.4	4.8

sunshine totals are smaller on the western than on the eastern slopes, where the greater sunshine totals in the Uva Basin are most striking.

The difference in sunshine duration between the western and eastern slopes is most significant during the season of the South-west monsoon. The high amount of cloudiness and rainfall result in low sunshine totals on the western slopes, while, on the eastern slopes, greater sunshine totals are associated with the foehn-like "Kachchan" winds. The lowest monthly sunshine totals occur during the South-west monsoon on the western slopes (Table 5), when, according to records from several tea plantations, the average daily sunshine duration in June, July and August can drop to 1–2 hours, while in the Uva Basin, on the eastern slopes of the Highlands, the average daily sunshine duration can reach up to 6 hours.

During the season of the North-east monsoon the opposite situation can be observed, with a sunshine minimum on the eastern slopes and a maximum on the western slopes in December and January.

In both intermonsoon periods (March–May, October–November) no significant differences in duration of sunshine occur between the western and eastern slopes. Most parts of Sri Lanka record a sunshine maximum in the first intermonsoon period.

3.5 Sultriness

On the basis of the Lancaster-Castens formula, revised by SCHARLAU, the seasonal variation of sultriness in Sri Lanka has been studied with special reference to differences with altitude (DOMROES, 1981). The results show a clear zonation into three altitudinal belts:

a) the tropical lowlands and lower parts of the hill country up to about 1100 m, which are characterized by sultriness of the air every day throughout the year;
b) the intermediate slopes between about 1100 and 1500 m with alternating conditions of sultriness and non-sultriness through the year;
c) the upper mountain region above 1500 m where non-sultriness occurs every day throughout the year.

The vertical zonation into three belts of sultriness is illustrated by the annual diagrams of sultriness (according to SCHARLAU) for four selected stations: Colombo (7 m), Kandy (477 m), Diyatalawa (1248 m) and Nuwara Eliya (1896 m); see Fig. 5.

Summarizing the climatological observations, the Central Highlands of Sri Lanka represent a distinct type of tropical mountain climate which varies considerably from the tropical lowlands. The mountain climate is undoubtedly "tropical", still experiencing greater daily than annual temperature range, but due to the incidence of frost, the term "cold tropical" represents the temperature conditions in the Highlands more accurately. The incidence of frost may be the critical factor in the definition of the tropical mountain climates of Sri Lanka, but other conditions of rainfall, wind, sunshine and sultriness, characteristic of the Central Highlands of Sri Lanka, have also to be taken into consideration.

4. Geoecological Observations

It is the aim of the second part of this study to examine the geo-ecological aspects of the Central Highlands, consequent upon the tropical mountain climate.

4.1 Agriculture

Vertical land-use belts. – Agricultural land-use in the Central Highlands is characterized by a significant vertical zonation. Three major altitudinal belts of land-use, each with characteristic

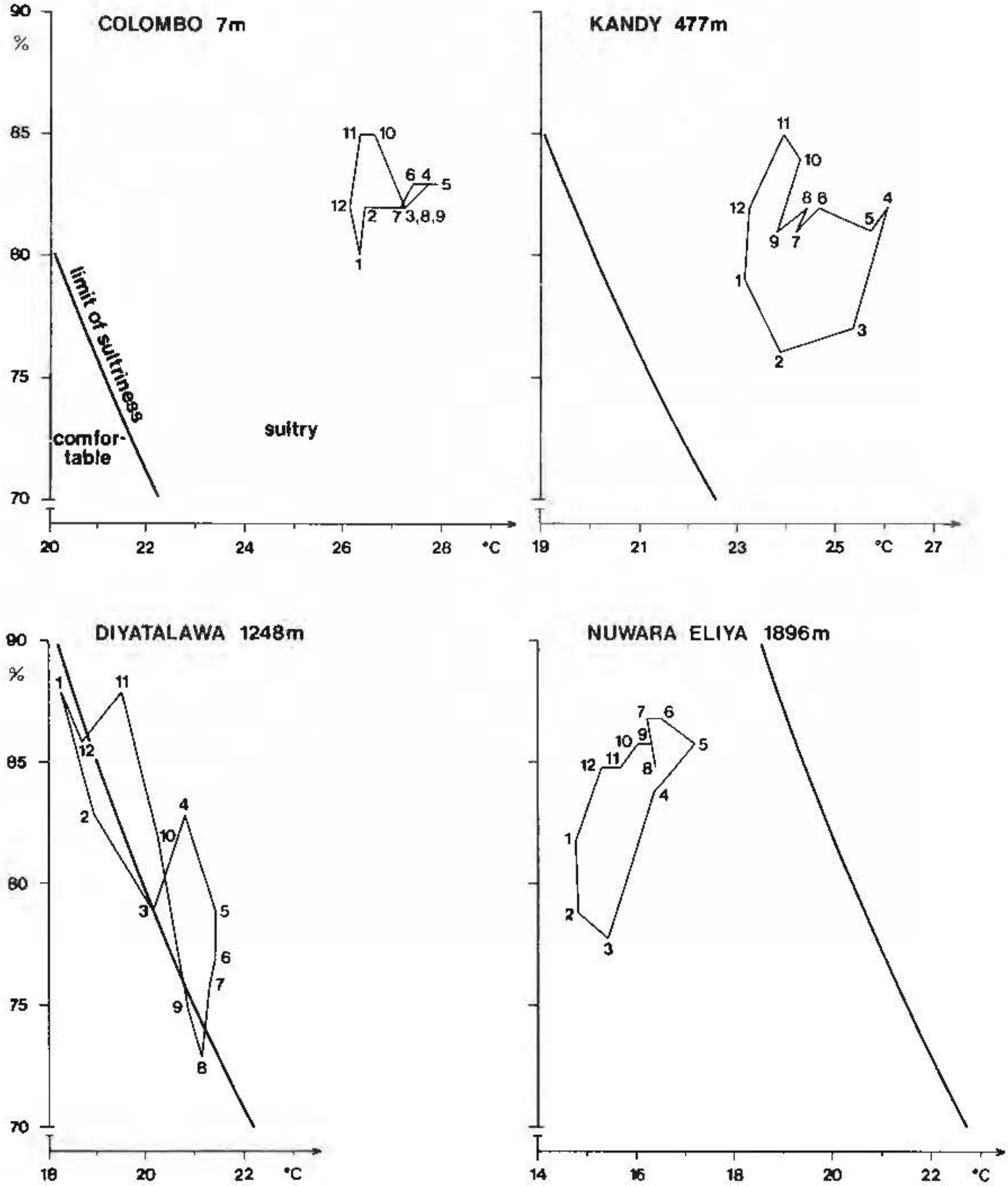

Fig. 5. Annual sultriness diagrams (according to SCHARLAU) for four selected Meteorological Observatories in Sri Lanka, showing the relation between temperature and humidity (based on mean values from 1931 to 1960).

crops, can be distinguished (Fig. 6). They are best documented on the western slopes of the Highlands:

a) The low-country belt, between sea-level and some 200 m, is characterized by a strongly developed system of dual cultivation. Coconut palms and paddy are the chief crops, grown under various cultivation practises. In the main, these two crops are characterized on the one hand by monoculture, but are also grown in small-holdings. Plots of palms and paddy fields are therefore clearly separated from each other, although, coconut palms are also an important crop in homestead-gardens, associated with other fruit-trees.

b) The mid-country belt, between about 200 and 900 m, is characterized by intensive rubber cultivation, for the most part in plantations, less frequently in small-holdings. Also in this belt, paddy fields occupy the valley bottoms, again representing a system of a dual cultivation. Homestead-gardens are not as representative as in the low-country belt.

c) The upper mountain belt covers the altitudinal belt between about 900 and 2250 m. The main crop is tea, introduced and planted by the British during the second half of the last century and since then representing the main export crop of Sri Lanka. The tea bushes, mostly in plantations, form a spectacular, homogeneous cultivation pattern, covering the gentle slopes like a huge green carpet.

Compared with this three-storied cultivation pattern, the eastern slopes, to a large extent occupied by the Uva Basin, show a rather inhomogeneous agricultural land-use pattern. Perennial crops are no longer prevalent. Here tea is grown extensively and we find the famous Uva tea of Sri Lanka, but the cultivation of coconut palms is limited to some coastal plots, and the few rubber plantations are uneconomic or marginal. To a remarkable extent are there large areas under vegetables and under permanent so-called "patana" grasslands. Finally, there is a fairly large number of small-scale homestead cultivators, growing a wider range of annual crops.

"Exotic" cold-tropical vegetables. – In the uppermost regions of tea cultivation, above 1800 m, a remarkable change in agriculture started to take place just before independence, with a rapid increase in the cultivation of temperate vegetables, known in Sri Lanka as "exotic" or "British" vegetables. These include carrots, beans, leeks, beet root, cabbage, raddish, tomatoes and potatoes. The demand for these vegetables has recently increased rapidly, in the main due to the growth in international tourism in Sri Lanka in the seventies and to changing local vegetable consumption in the direction of "exotic" vegetables. Obviously it is the cold-tropical environment of the upper Highlands that offers the most favourable growing conditions for vegetables throughout the year so that in the uppermost tea belt a system of a dual cultivation has also recently developed. Tea bushes are grown on the slopes while vegetable cultivation is carried out in the valley bottoms. The best example of this system can be seen in the Nuwara Eliya-Kandapola area. This dual system clearly reflects the small-scale climatic differences.

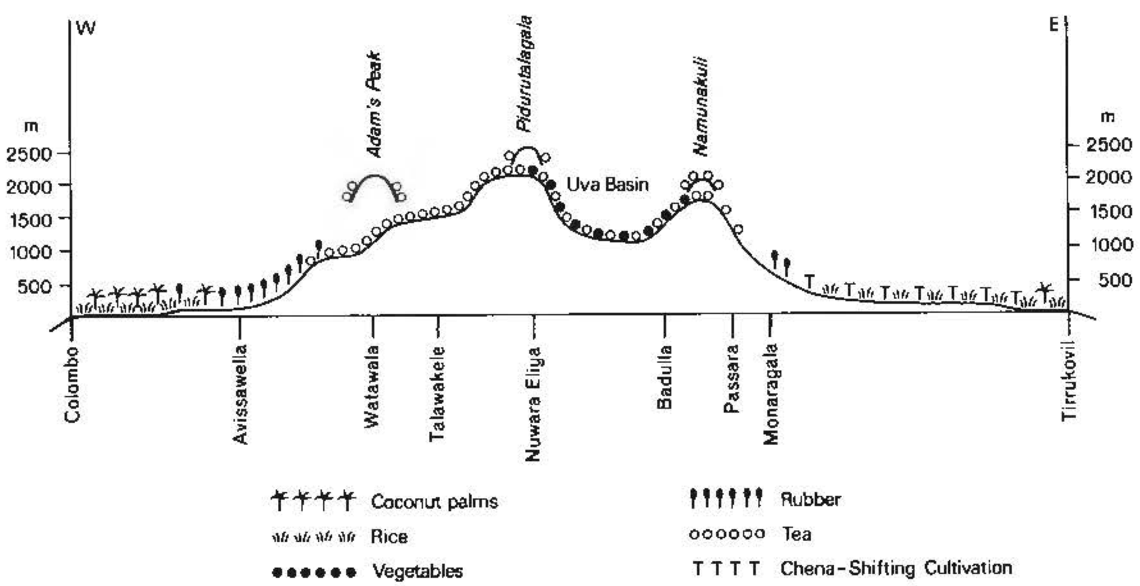

Fig. 6. The altitudinal distribution of the major crops in Sri Lanka on a West to East cross-section (see Fig. 1).

As shown earlier the slopes are not affected by frost so that tea can be cultivated without risk; in the valley bottoms and depressions, however, the occurrence of slight frosts are of no great harm to vegetable cultivation and in the case even of severe frost, the production loss is less than in the case of tea.

4.2 Natural Vegetation

Evidence of specific conditions of mountain climates is to be expected in the natural vegetation cover. Today, however, primary vegetation is found only in the uppermost Highlands above 2000 m, while the major part of the Highlands has been cleared for tea plantations during British colonial times.

Two types of primary vegetation are found:

a) The evergreen montane cloud forest. – This represents the uppermost belt of tropical forest, above the tropical lowland forest (up to 500 m) and the tropical montane forest (between 500 and 1500 m). While lowland and montane forests today cover only a very small proportion of their original large extent, montane cloud forest still occupies the larger part of the more limited extent of the uppermost Highlands and is best developed above 1800 m. In their structure and composition the areas of cloud forest reflect the comparably cool, rainy and cloudy conditions of the upper Highlands. The forests are floristically rich. Tree species are arranged in a single storey and usually the forest-floor is densely carpeted. Climbers are not abundant, but epiphytes and orchids grow profusely in the forest and most trees are covered with lichens. Trees are gnarled and stunted, the canopy layer being between 6 and 9 m high, in some parts as little as 1 m high in what is then called "pygmy forest". The crowns are small and flat topped, an adaptation probably to the strong winds which are often experienced at high altitudes. The leaves of the trees are small and leathery. The trees are all of small girth and the volume of timber is low.

b) The "Wet Patanas". – Also called "Highland Wet Savannahs", the Wet Patanas comprise a short-grass savannah which covers the high plains (around 2000 m): the Horton Plains, Elk Plains, Moon Plains and Bopatalawa. The Patanas prefer the poorly drained flats to the better drained slopes which are occupied by the montane cloud forest. The grasses of the Patanas are dominated by a single species, *Chrysopogon zeylanicus,* a short, tufted and perennial grass, while intermixed with the grasses are herbaceous plants, chiefly orchids, ferns and lillies. The only tree species is *Rhododendron arboreum,* which is found scattered throughout the Wet Patanas, but never forms a closed forest. The Rhododendron trees are short (about 3 m high), gnarled and flat-crowned, with a relatively thick, coarse bark.

The cold tropical climate of the upper Highlands offers suitable conditions for animal husbandry, since throughout the year pasture grass production is guaranteed (DOMROES, 1979). The "Wet Patanas" can thus be transformed into productive pastures for animal husbandry and dairy farming. The best example is the Ambawela-Bopatalawa Cattle Farm, which is among the largest farms in Sri Lanka. Besides animal husbandry, the Wet Patanas also offer suitable climatic and edaphic conditions for the cultivation of temperate vegetables, as in recently established small villages, among them Mipilimana, Blackpool and Shantipura, which have become prominent in the cultivation of vegetables.

The cold tropical environment of the upper Highlands is also evident in the many plots under afforestation dating back to the last century. The use of exotic or non-tropical species, such as *Eucalyptus, Acacia, Pinus* and *Cypressus,* clearly underlines the cold yet tropical nature of the mountain climates.

4.3 Tourism

Recreation and tourism also represent an important aspect of the mountain geo-ecology of Sri Lanka. The famous British-colonial "Hill Station" Nuwara Eliya (1900 m) can be taken as evidence of the salubrious, cold-tropical mountain climate. Founded in 1829, following the establishment of a hunting lodge, Nuwara Eliya soon developed as a prominent hill resort for British colonial administrators, businessmen and later for the British tea and rubber planters. With a golf course, race course and trout fishing, sporting facilities were ideal. There were several parks for recreation, and at Hakgala, some kilometers to the east, even a small Botanical Garden. The majestic Grand Hotel, opened at the beginning of this century, and the Hill Club offered the facilities necessary for and evidence of the fashionable sociability of the British colonial society. Governor's Lodge and in due course more lodges and bungalows were built. Today, Nuwara Eliya (1981: 21 000 inhabitants) is "still a somewhat strange assortement of colonial grandeur, old style bungalows plus a few accessories reminiscent of the British founders" (SCHWEINFURTH, 1982, p. 155). Only the bazaar and the main shopping street in the centre of Nuwara Eliya have an indigenous appearance.

At first, after the independence of Sri Lanka (1948), Nuwara Eliya became an attractive destination for the indigenous elite. With the establishment and systematic development of international tourism in Sri Lanka in the seventies, Nuwara Eliya quickly developed into a favourite destination for European tourists. It is the centre of what, in Sri Lanka's tourism campaign, is called "high country resort region". The region is praised for its cool "atropical" climate which attracts many tourists who pass through or stay a night or two in Nuwara Eliya. Even so, the monsoonal rainfall conditions limit the European tourist season to the period of the dry North-east monsoon and the intermonsoon periods, reaching together from November to March. At these times, the monthly occupancy rates of the hotels amount to between 44 and 53%, which is much higher than the annual average occupancy rate of 34%.

4.4 Geomedicine: The Example of Malaria

Consideration of the geo-ecological conditions of the Central Highlands of Sri Lanka also require special attention to be paid to malaria. This may at first seem surprising, but it is nonetheless certain, since it has been established that the conditions of the distribution of malaria agents and vectors depend upon the temperature of the environment concerned. To put it in simpler terms: for the agents and vectors of malaria optimal conditions of life occur in lowlands with high tropical temperatures (in excess of 25 °C), whereas decreasing temperatures result in a worsening of the living conditions. It follows that, due to the supply of heat, the risk of malaria is directly related to altitude. Thus in the context of Sri Lanka the question arises as to what effect the Central Highlands have upon the risk of malaria, bearing in mind that they are characterized as cold tropical from the thermal point of view.

In a recently completed Ph.D. thesis Gisela PETERS (1982, Mainz University, Faculty of Geosciences) makes a detailed study of the conditions of distribution of malaria agents and transmitters in Sri Lanka in terms of their dependence upon the natural and human environment. In this critical attention is paid to climatic locational factors in particular, revealing remarkable relationships, especially between temperature conditions and the risk of malaria. In Sri Lanka only two malaria agents have been proved to occur: *Plasmodium vivax* and *Plasmodium falciparum*. The germs attack and infect *Anopheles culicifacies*, the only mosquito indigenous to Sri Lanka, and transmit malaria to man. The biological functions of the malaria agents (as well as of their transmitters) depend decisively upon the temperature conditions. Thus *Plasmodium vivax* requires a minimum temperature of 16 °C, *Plasmodium falciparum* at least 18 °C.

This minimal supply of heat, however, only enables the plasmodia to mature very slowly and with difficulty; optimal conditions for life for the malaria germs only come about with temperatures from 25 °C. This results in a difference in the development rate of plasmodia, depending upon temperature, and thus in Sri Lanka upon altitude above sea-level (see Fig. 7). As far as the living conditions of malaria germs are concerned, this means that conditions are most favourable in the hot-tropical lowland of Sri Lanka, as also in the foothills (up to about 400 m above sea-level), where temperatures remain above 25 °C

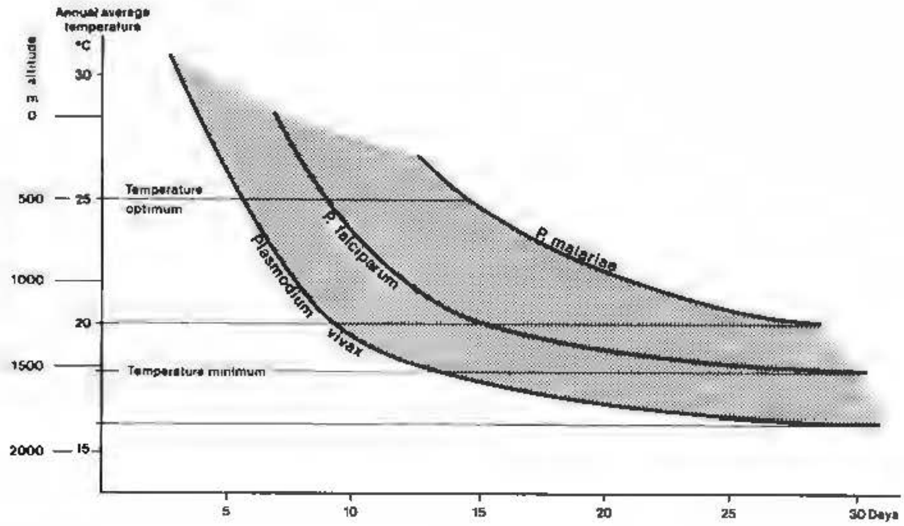

Fig. 7. The development rate of *Plasmodia*, in relation to the temperature of the air (after: PETERS, 1982).

throughout the year, whereas the most unfavourable ones are in the uppermost cold-tropical regions of the Central Highlands. In regard to the living conditions of *Plasmodium* the temperature minimum required for malaria germs draws the following thermally conditioned altitudinal lines in the Central Highlands of Sri Lanka:

Plasmodium vivax (16 °C) = about 1800 m above sea-level,
Plasmodium falciparum (18 °C) = about 1500 m above sea-level.

PETERS (1982) has calculated a direct altitudinal dependence of malaria risk from the dependence of the living conditions of the malaria germs upon temperature (see Fig. 8). In this PETERS discerns four grades of malaria risk in Sri Lanka, each related to a specific altitudinal region:

severe:	coastal lowlands,
increased:	up to about 400 m above sea-level,
moderate:	up to about 1800 m above sea-level,
slight:	over 1800 m above sea-level.

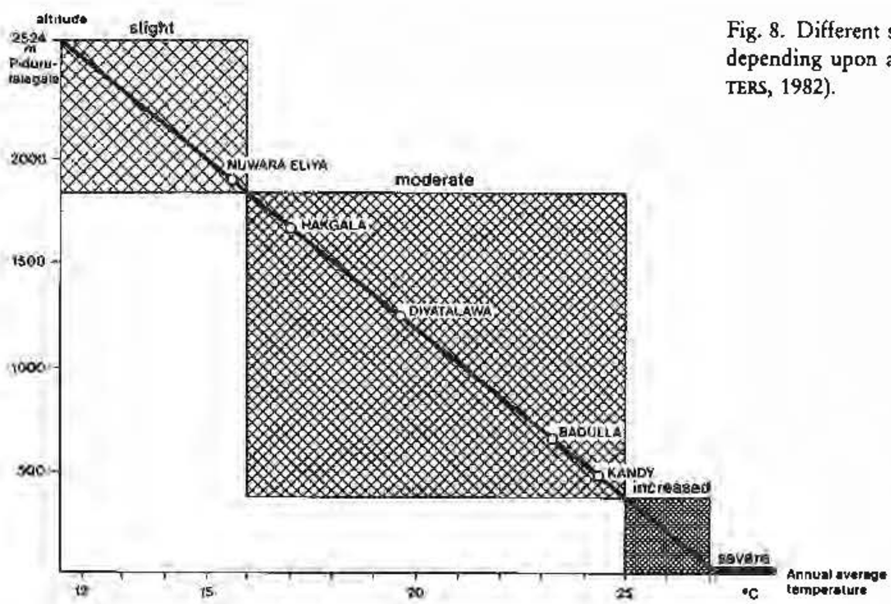

Fig. 8. Different stages of malaria risk in Sri Lanka, depending upon altitude above sea-level (after: PETERS, 1982).

From this the risk of malaria described as being "slight" by PETERS, but in actual fact not even existing in the Central Highlands above 1800 m, is clearly evident. From a thermal point of view and because of the resulting limit conditions of life for malaria germs, even altitudes between 400 and 1800 m above sea-level can be described as only moderately at risk to malaria. Yet by far the largest part of Sri Lanka, with at least about three-quarters of the country's total area and more than 90 per cent of its inhabitants, is very much at risk from malaria, although, temperature, one of the many factors restricting or promoting malaria, was the only one to be investigated here. Nonetheless, malaria is eminently suited to a case study in the context of the geo-ecological conditions of Sri Lanka's Central Highlands.

Summary

The Central Highlands, reaching only 2524 m, show nevertheless a considerable relief energy in comparison with other regions of the island of Sri Lanka. From the climatological point of view, the Highlands form a distinct region which can be classified as "cold tropical", not only because of the generally lower temperatures, but in particular because of the occurrence of frost above 1800/1900 m, though irregular, infrequent and mostly at only ground-level. Other climatic elements are affected by the Central Highlands: for rainfall, they act as a clear-cut climatic divide, separating the western and eastern slopes according to the alternating monsoon regimes; the Highlands cause strongly developed katabatic local winds, well-known als 'Kachchan'; and the duration of sunshine is considerably reduced by cloudiness. Finally the absence of sultry weather conditions is, in fact, the most noteworthy bio-climatic feature of the tropical mountain climate of the Central Highlands of Sri Lanka.

The climatological conditions of the Highlands are of wide-ranging significance for the mountain geoecology. This has been underlined by considering the pattern of land utilization in the mountains which is characterized by different altitudinal crop belts, according to their specific temperature requirements. Most remarkable is the steadily increasing cultivation and distribution of "exotic" vegetables from mid-latitudes, which grow very successfully above 1800 m. Also the two main types of natural vegetation, the evergreen montane cloud forest and the 'Wet Patanas', reflect the cold tropical environment in the upper Central Highlands. Tourism represents another geoecological aspect of the tropical mountain climate. The salubrious climate of the famous 'hill station' Nuwara Eliya attracted the British colonialists in the past and continues to attract European tourists. Moreover, the cooler mountain climates offer unsuitable breeding and living conditions for the virusses of malaria, so that the upper mountains of Sri Lanka can be called 'malaria-free'.

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Discussion

Prof. Dr. W. Eriksen:

What was the experience (in the field or empirically) due to which WIKKRAMATILEKE has defined the 'effective dry period' by a period of three or more consecutive months each of which gets less than 4 inches (102 mm) rainfall?

Prof. Dr. M. Domrös:

WIKKRAMATILEKE (1963) has developed this criterion on the basis of field observations on the growing conditions of tropical crops in the southeastern parts of Sri Lanka. It is not a criterion which was proved in other countries. The definition of 'effective rainfall' is as controversial as the term 'effective dry period'.

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Potentials and Limits of Agricultural Production in Nepal as seen from an Ecological-Geographical Standpoint

Willibald Haffner

With 3 Figures and 1 Table

1. Introduction

In the Himalayas of Nepal, the altitude belt which is put to agricultural use reaches approximately twice the height of that of the Alps, due to the favourable climate of its monsoon tropical location (± 27° northern latitude). Arable farming is carried out from the foreland up to an altitude of over 4000 m. High altitude pasture land for the grazing of yaks can even be found at over 5000 m. Thus the diversity of crops varies accordingly from tropical cereals (rice, millet, maize) and fruit trees at the frost-free, lower altitudes to northern types of cereals and potatoes in the higher mountains (Fig. 1). A correlation of vegetation, climate and land-use will show, that the traditional agriculture in the Nepalese Himalayas has been closely adapted to the climatic conditions and in particular to the turn of the seasons. Thus, the vertical gradation of vegetation and agriculture is astoundingly consistent (Fig. 2). From a climatic viewpoint, an area at medium elevation of between approximately 1300 and 2800 m above sea-level would appear to be particularly favourable, as this altitude belt is suitable for rain-fed agriculture the whole year round, an exceptional case in these monsoonal tropics of seasonal change in climatic humidity. In contrast Himalayan valleys, deeply incised into the mountains and the mountain foreland (below 1300 m) are too dry for rain-fed agriculture in 'winter' and the high-altitude valleys at above 3000 m are too cold (HAFFNER, 1979).

For centuries, the efforts of the Nepalese to wring a living from their mountainous land by means of terrace construction, irrigation channels, the building of bridges and coolie tracks trough malaria-infested valleys and over high, snowy passes were at least adequately rewarded with success. The manifestation of this perfected Nepalese high altitude and mountain farming is, after all, the rotation systems and complicated forms of pasturalism for which the whole of the Himalayas have become renowned. To sum up, the use or rather exploitation of natural resources was developed to perfection by means of the labour-intensive facilities of a pre-industrial society. This made a rural population density of up to 100 inhabitants per square kilometer possible even in the mountains. However, it would now seem that a basic change is occurring, as the population of Nepal has doubled during the last 20 years. As in neighbouring India and Tibet, it is the successful eradication of disease (e. g. malaria, small-pox and cholera) and general improvements in hygiene and medicine which are mainly responsible for the tremendous increase in population from c. 7 million inhabitants in 1963 to c. 15 million in 1983 (cf. Table 1).

As in many other high mountainous regions, a main characteristic is the exceedingly unbalanced distribution and development of the population: extremely densely populated agricultural areas exist alongside almost uninhabited stretches of forest and high mountain regions (cf. Fig. 3). All in all, the population growth has been approaching a critical threshold during the last decade; indeed it may have already crossed it. The daily, per capita, calory consumption already lies on average below 2000 calories (cp. Switzerland: 3240 cals.). Above all towards the end of the dry season when the stores from the previous year are all used up and the new harvest has not yet been brought in, only one meal a day is eaten.

The question is, what can be said from an ecological-geographical point of view to the incongruity between population and agricultural production which is increasing from day to day? Is it actually possible to increase agricultural production or is the 'agri-potential' of the land already exhausted?

It is possible to simplify and reduce the problem of increasing agricultural production in an attempt to answer the following three questions:

1. Is it possible to extend the area of agricultural acreage in Nepal?
2. Can the harvest area still be enlarged?
3. Is an increase in yield per hectare possible?

In attempting to answer these questions, which are so elementary for the planning of land-use in Nepal, one must, however, accept one basic restriction. Plans for improvements should not be based on the idea of an increase in production, of growth at all costs. Too much has been reported during the last two decades of forest decimation and soil erosion, of ecological damage caused by agricultural overutilization (see, for example, KIENHOLZ et al., 1982). On no account should the ruthless exhaustion of natural resources be propagated. The absolute aim should be an increase of agricultural production using ecologically tolerable methods.

In pursuing this aim, ecological and plant-geographical observations and investigations can play an important role in compliance with the much-quoted principle which states, that the collective manifestation of ecological conditions of a certain location, and thus also that of its agricultural potential, may be observed in its vegetation. Furthermore, the ecophysiological cycle of functions and the ecological stability of autochthonous natural or seminatural ecosystems (e. g. forest ecotopes in natural forested areas) can furnish us with patterns for at least sufficiently stable agricultural ecosystems and the development of ecologically adapted types of agricultural land-usage.

HUECK (1953) sets a similar aim in his treatise: "Urlandschaft, Raublandschaft und Kulturlandschaft in der Provinz Tucumán im nordwestlichen Argentinien". The "appropriate creation of a healthy agricultural landscape" (LAUER, 1956, p. 12) is the main aim in LAUER's work "Vegetation, Landnutzung und Agrarpotential in El Salvador". The longterm protection of our natural environment and its resources is, after all, the aim of the concept of ecological farming as propagated by EGGER (1982); retention and increase of the "humane-ecological capacity" is the content of V. MAYDELL's (1982) agroforestry concept.

2. Expansion of the Agricultural Acreage in the Remaining Forest Belts of Nepal: Possibilities and Limits

The main ecological factor for the almost complete retention of the belt of forest in the Bhabar Zone and the Churia mountains is the shortage of surface water throughout the year. The relief of the two areas is different but the geological subsoil in both consists to a large extent of coarse, young gravel (Upper Siwaliks) and is thus so porous, that even during the monsoon season, the rivers (except for a few allogenous ones) only contain water episodically (after heavy rain), although there is annual rainfall of about 2000 mm.

Besides the unfavourable geoecological factors which have hindered an extensive colonization of the Bharbar and Churia regions, strategic and political reasons also played a decisive role for Nepal in retaining these forest landscapes. Nepalese kings and rulers were well aware of the value of this fever-infested southern border, difficult to traverse, as a buffer zone between them and the British Colonial Empire. It was this belt of forest which made Nepal's policy of isolation possible, which lasted for over a century until 1951. In particular, following the compromise peace of Sagauli in 1814 between Nepal and the British colonial forces in India, strict forestry protection laws came into being, which not only forbade the clearing of forests and the laying out of settlements and fields, but also even the scattered use of these forested areas (REGMI, 1963, p. 37). The protection of the forests in the Nepalese lowlands was also in the interest of the ruling feudal upper-class, as they were thus provided with one of their best big-game hunting areas (elephants, tigers, wild buffalo, rhinoceros etc.). Although the scarcity of surface water and springs, i. e. of drinking water, did complicate and actually hinder colonization, the porosity of the subsoil is compensated for by rainfall of roughly 2000 mm, as the lush Sal Forest shows. This same Sal

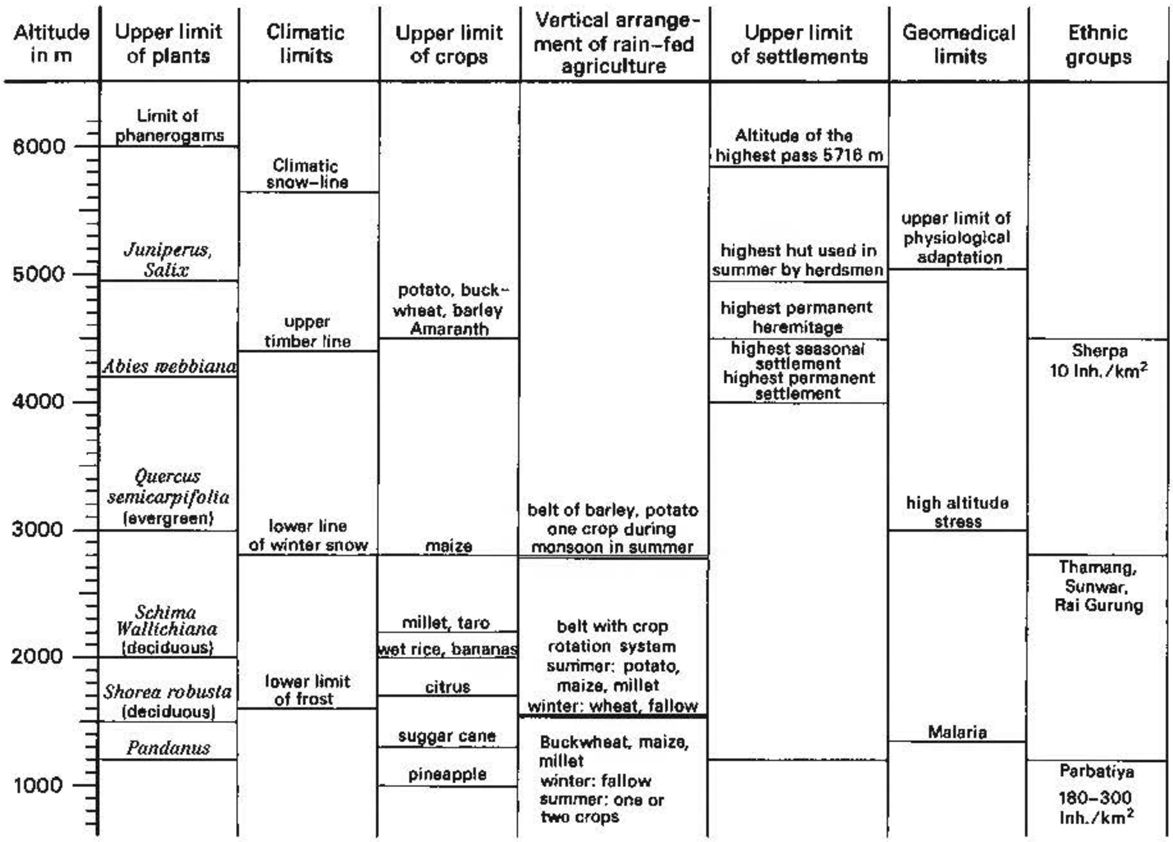

Fig. 1. Altitudinal Belts and Limits in the Himalayas of Nepal – Correlation of Vegetation, Climate and Land-use.

Forest is also perfectly adapted to the seasonal cycle of rain and dry spells. It is a timber forest consisting of thickets of deciduous trees with a closed canopy of foliage. Leaves fall at the height of the dry season from March to May. Characteristic for the rainy season is the lush ground vegetation of shrubs and grasses, which are only able to survive the unfavourable season of the year in their seed state or just with their subterranean parts like roots, rhizomes etc.

What could be more natural than to assume, that all that is needed to create extensive areas suitable for farming in the rainy season, is the axe-bearing hand of man to clear the forest? It will, therefore, come as a surprise to learn, that maize and millet suffer from lack of water here in spite of heavy monsoon rainfall. Maize begins to wilt and problems with water provision occur even in short dry periods of about 10 days during a break in the monsoon; a period in which the neighbouring Sal Forest continues to flourish. Several factors are to blame for this incongruous state of affairs.

We need not go into details here about the fact that trees and bushes flourish here. Their roots go much deeper than the quick-growing, annual crops and also have a greater potential for water retention. Ecologically speaking, the above-mentioned crops cannot be compared to forest trees; rather they are compatible to the undergrowth of shrubs and, above all, grasses, i. e. plants with the same or a similar form of life.

As far as the amount of water available is concerned, the conditions for growth on a maize field and in the undergrowth of a forest vary greatly. The soil erosion in a freshly ploughed maize field caused by only a short period of heavy rain will suffice to considerably reduce the potentiality of the soil layer for water retention. A further factor is the relatively high loss of water from the soil of a maize field due to direct evaporation from the unprotected surface, whereas in the forest, desiccation of the surface soil layers is greatly arrested by the permanent shade.

Vegetation	Agriculture	Pasturalism
Alpine meadows/Tibetan steppe of high altitude valleys ca. 3700–5000 m t > 10 °C: 0–2 months leeward location: N < 1000 mm dry and cold winters, very often snowfree	rainfed agriculture during summer (potatoes, buckwheat), partly by additional irrigation (barley), intensive agriculture with high input of dung	dominating: permanent grazing on high altitude meadows, hay production, shortage of fodder during the dry season and in snowy winters
Rhododendron-Abies-forest ca. 2800–4000 m t > 10 °C: 4–8 months frost luvward location: N > 2000 mm often > 3000 mm altitude of maximal humidity March–November: extremely cloudy and misty snowcover in winter	potato cultivation in forest clearings	dominating: permanent extensive grazing shortage of fodder in snowy winter no hay production cheese dairies
Tropical evergreen mountain and cloud forest ca. 1300–2800 m t > 10 °C: 8–11 months from 1500 m onward frost free of Malaria luvward location: N > 2000 mm altitude of maximal precipitation short dry season: Nov.–Febr. high edaphic humidity caused by long rainy season and diminished evapo-transpiration	dominating: permanent rain-fed agriculture summer: rice (up to 2000 m), maize, millet winter: winter corn, potatoes	permanent grazing: goat, sheep, cows, water buffalo forest meadow pruned fodder shortage of fodder from Dec.–April
Tropical deciduous forest; dry and moist Sal Forest ca. 100–1300 m t > 10 °C: 11–12 months Malaria free of frost, temperature no limiting factor long dry season from Dec.–June shortage of drinking water N < 1500 mm	dominating: rainfed agriculture: rice, maize, wheat, mustard fields seasonal fallow during dry season local: permanent agriculture with irrigation	cow, water buffalo, goat grazing on fallow fields no fodder storage

Fig. 2. Altitudinal Arrangement of Vegetation, Agriculture and Pasturalism.

In the ecosystem of, say, a Sal Forest, water is mainly lost by evaporation from the surface of the leaves especially from the upper foliage and by way of transpiration. Of vital importance is also the fact that the level of air-humidity in the interior of a forest is higher than that existing in an open field, thus, evapo-transpiration is decreased to a relatively large degree and survival of short, dry periods is facilitated even for hygrophile plants.

One can also clearly see the extent to which the undergrowth has adapted to the particular climatic conditions peculiar to the confines of this forest in the fact, that at the onset of the rainy season, a closed canopy of foliage first developes in the upper tree layer before the growth of the underlying vegetation begins. If the covering of trees were to be removed, the layers of shrubs and grasses would dry out and decay after only a few days of sun. During the dry season in winter, the compensating effect of the forest and its particular climate on the amount of water in the Sal Forest ecosystem can be seen very clearly. The water retained in the soil from the monsoon period will last for months under cover of the foliage (shade). The Sal Forest is of a fresh, green colour even in December and January, whilst farming at this time is only worthwhile in the fields of the Terai if artificial irrigation is employed.

Which conclusions may be drawn to be of profit to agriculture from the above partial analysis of a Sal Forest-type ecosystem?

1. From an ecological point of view, the cultivation of perennial tree crops in the edaphic dry Bhabar Zone must prove to be more successful than the cultivation of annual crops. That is unless
2. we cultivate annual crops (maize and millet) underneath the protective foliage canopy of the trees. Furthermore, a combination of forest and agricultural farming would reduce the loss of essential forest resources.
3. Finally, the water problem could be solved by the construction of irrigation canals. The water for these could be obtained from the few allogenous rivers or from deep wells.

Recent colonization and irrigation projects in the Bhabar Zone of Kumaon could serve as models. However, Nepal is so far lacking in both the technical and financial means for large irrigation projects, which require a great deal of capital. It seems to me that it would be more realistic to experiment with combined forest and conventional farming. Methods of agro-forestry are traditionally known in the Nepal Himalayas, especially in areas where a combination of annual crops and fodder trees is grown.

The question of why the Rhododendron and Fir-wood belt (2900–3700 m) is not perennially settled but used only for extensive grazing, is not easy to answer. It is true that podzolized, infertile soil and slight frost and snow in winter are characteristic for this Fir-forest belt, but from an ecological point of view the cultivation of northern types of cereal, of buckwheat and potatoes is not hampered by such a winter, which, compared to that of Europe, is mild. As Nepalese farmers themselves will stress, the qualitatively best potatoes are even grown at this altitude. Hence, the Himalayas of Nepal are no exception from the rule which generally applies to the tropics and subtropics, i.e. that humid mountain forests with plenty of cloud and mist are avoided in the choice of locations for permanent settlements. Here one can quote examples from South American Andes and Africa (Kilimanjaro). Although I cannot provide an absolutely satisfactory explanation for the lack of permanent settlements in the Fir-belt of Nepal, the following reasons would seem to me to be important and also plausible from the point of view of the Nepalese mountain peoples:

1. Storage of cereals etc. is almost impossible in the particularly cloudy and damp climate of the monsoon summer. Anyone who has travelled at these altitudes during the rainy season will know how quickly clothing, blankets and household implements of all kinds attract the dampness, go mouldy and decay.
2. Many types of crop (e.g. the spices, fruit and vegetables so prized by the Nepalese, and in particular maize and rice) do not flourish at this altitude as a result of summer temperatures being too low. Therefore the limit to the altitude at which permanent settlements are built, especially those of the Indian- and Hindu-influenced cultural groups, more or less corresponds to the upper limit of maize and millet cultivation. Potatoes and northern types of cereal are simply alternative products, according to traditional eating habits of these ethnic groups.

Thus, the real reasons for the lack of settlements so far in the humid Fir-belt should be sought in ethnic traditions; climatically speaking, the upper limit of cultivation and perennial settlements has not yet been reached in the Nepalese Himalayas.

However, a warning must be issued here, that extensive clearing activities would be unwise for geo-ecological reasons, even if the increase in population density in the lower-lying, main settlement areas would seem to make this unavoidable. This cloudy, misty Fir-belt is actually the natural reservoir for the drinking and irrigation water needed by the so densely populated lower altitudinal belts. It is the only source of the perennial rivers (if one disregards the even higher mountain belts) and in particular of very many mountain rivulets and springs. Thus, one cannot emphasize enough the danger of incorporating this forest belt, which has so far merely been used for extensive grazing purposes, into the lower-lying, densely populated and intensively farmed areas. Forest clearance also does nothing to increase the amount of cattle feed available. An analysis of the plant-succession following clearance and burning of the trees will show that it is rather the opposite which occurs. The cattle refuse the types of plant which are then dominant (*Arundinaria*-Bamboo, *Berberis*, *Euphorbia*, *Cotoneaster* and Ericaceas).

To sum up we must bear in mind, that an extension of the settlement and agriculturally used areas in the region of the great forest belts of Nepal would, from an ecological standpoint, indeed be possible, i. e. seen from this angle the agricultural potential of the land is by no means exhausted. However, one should caution against areal development of the forest belt in order not to disturb the balance of the supply of water from the Rhododendron and Fir-tree belt and, as far as the irrigation projects in the Sal Forest belt are concerned, for reasons of profitability. Combined traditional and agro-forest farming seems to have potential here. In practice this means that peripheral extension of the main, intensively farmed agricultural area of Nepal can only be partially advocated from the planners point of view, at least at the present time. Thus, as far as an increase in agricultural production is concerned, the densely populated areas of Nepal, the Terai and the Lower Himalayas, gain in central importance (Fig. 3).

The Terai has been forest-free agricultural land for centuries now. Even in the area of the Lower Himalayas all the land has been carefully terraced and cultivated for generations, as far as local relief and soil conditions permit. An extension of the agriculturally used area is therefore out of the question. All the more important then, would seem to be the question of increase the degree of intensity, with which the land is farmed. During the winter dry season, 90% of the monsoonal rice and maize fields lie fallow, both in the Terai and the densely populated valley belt of the mountains. With winter rainfall of less than 100 mm, the fields remain uncultivated due to scarcity of moisture. It would therefore seem a good idea to compensate for the lack of rainfall with the aid of irrigation and thus to considerably extend the double or multiple cropped area. This should certainly be feasible in the Terai even without much technical effort. Although most of the channels are seasonally dry, the ground water remains close to the surface all the year round. Even at the height of the dry season an adequate amount remains available in the drinking water wells and it is only necessary to excavate tub-like holes in the dried-up river beds for the water buffalo to be able to wallow there.

Thus the supply of ground water definitely allows for cultivation of the fields in the dry seasons and one must ask oneself why water is not supplied to the fields by means of simple pumps, as it is the case in other parts of India. Probably the main reason for this is, that the main harvest during the rainy season is seldom threatened by lack of moisture. Often the exact opposite is the case, and the level of the ground water is too high. In spite of high population density, the Terai has so far always produced a surplus of grain, ensuring the supply of basic foodstuffs. Why then, should there be wells and canal systems exclusively for

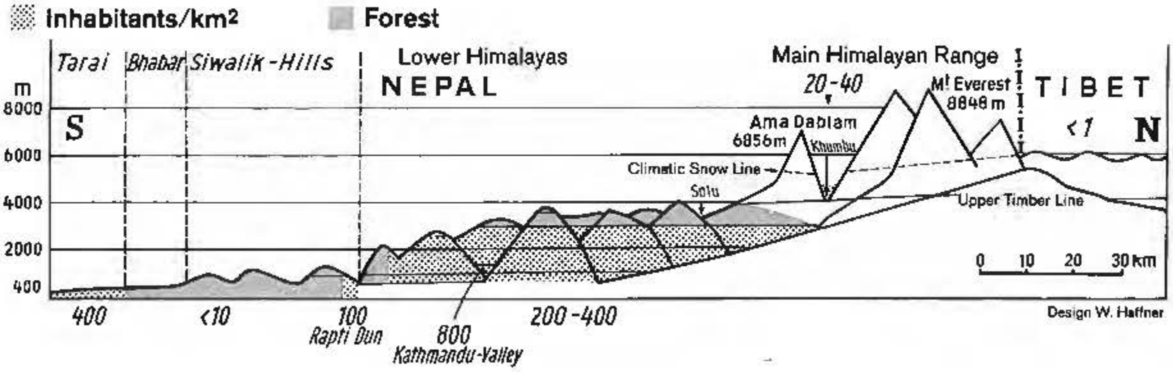

Fig. 3. Nepal Himalaya: Forest Distribution and Population Density in Profile.

Table 1. Population Density and Growth by Region in Nepal.

	Population 1971	Population density Inh./km² (1971)	Population 1981	Population density Inh./km² (1981)	Decennial growth of population	Growth in %
Nepal	11 555 983	80	15 021 460	103	3 464 469	+ 30,0
Terai	4 403 378	129	6 559 525	192	2 156 147	+ 49,0
Hill	5 997 642	98	7 170 853	117	1 173 211	+ 19,6
Mountain	1 154 963	23	1 291 082	26	136 119	+ 11,8
Eastern Dev. Region	2 797 500	100	3 703 848	132	906 348	+32,4
Terai	1 387 558	196	2 115 220	299	727 662	+ 52,4
Hill	1 105 590	88	1 254 787	100	149 197	+ 13,5
Mountain	304 352	36	333 841	39	29 489	+ 9,7
Kathmandu Valley	618 911	650	766 820	805	147 909	+ 23,9
Chitwan	183 644	74	257 332	103	73 688	+ 40,1

farming in the dry season? Furthermore, the farmers also need the stubble fields as they have no system of fodder storage for the cattle. Finally, allowing the field to lie fallow improves the soil fertility, which is particularly important for the cultivation of rice, as rice fields are seldom fertilized. The cycle of rainy season cultivation and fallow land in the dry season constituted a system of farming, which was adapted to climatic conditions and which was at the same time suited to the traditional population density. However, since the successful eradication of malaria during recent years, population density has increased extremely rapidly (Tab. 1). This is the reason why the traditional agricultural system should be abandoned in favour of permanent cultivation (multiple cropping) based on artificial irrigation. Hydrological and climatic requirements are fulfilled.

In the mountainous areas, the prospects for extending the double or multiple cropped area at the cost of land lying seasonal fallow (which, as in the Terai, includes almost the whole of the summer rice and maize fields), are however, considerably less favourable. Ground water can only seldom be used for irrigation, at the most only at the bottom of the valleys. Most mountain streams and springs periodically run dry or fluctuate so greatly in the amount of water they contain, that, although they are useful in irrigating the wet rice fields during the rainy season, they are out of the question for dry season irrigation of, say, wheat or potato fields.

Irrigation water can thus only be drawn from the few perennial rivers, the sources of which lie in the Rhododendron and Fir-tree belt or in the high mountains. However, the traditional methods of canal construction are technically incapable of conveying water for irrigation from the often deeply incised river beds onto the level of the areas to be fed. It is technically possible to pump river water up to fallow mountain slopes and on up to the ridges, but the question of profitability immediately arises. It is therefore impossible to extend the multiple cropped area by ⅔ or more in the mountains, as would seem to be a plausible prospect in the Terai. It then becomes even more important to utilize the last reserves of potential irrigation water.

In some of the smaller lateral valleys with perennial river water it would be quite feasible to channel off water for irrigation purposes on the upper course by constructing a sloping canal. However, such projects would be of a scale hardly possible for a single village to undertake.[1] Irrigation of the alluvial fans provides further opportunities of extending permanent farming of irrigated fields. It would be possible to prevent most of the water oozing away by lining the canals with plastic sheeting and that at very little cost. Using this method one could also tap the overflow of certain drinking water wells for the cultivation of vegetables in winter. Even so, the very limited opportunities for expanding the irrigated fields, farming of

[1] Example: The Khate Khola Canal: 8 km, 1 m Ø, 4 million Rs = 260 ha. Relatively not very effective, although large amounts of capital invested.

mountain valleys in the dry season provide a challenge to search for other ways of extending the multiple cropped area at the cost of seasonal fallow fields.

Here too, we can be aided by a comparison with the natural vegetation. I have already pointed out in the example of the Bhabar Zone, that deciduous trees typical of this location can retain their leaves for a period of months during the onset of the dry season, due to the fact that sufficient ground water is still available, left over from the monsoon. This edaphic moisture, retained from the monsoon season, has so far rarely been exploited for agricultural purposes. It is true that the soil layer of a fallow field dries out much quicker than the shaded ground in a forest, but the remaining moisture, in particular in the soil of wet rice fields after the harvest, is so considerable that weeds appear and dropped grains of rice begin to sprout only a few days after the crop has been gathered in. Should a last monsoon shower fall and if the cattle are kept away, the stubble field will be covered with a carpet of green in a matter of weeks. There is usually even enough moisture for weeds to reach the seed stage, proof of the fact that plants for cattle feed can be cultivated here, but only of those types with the same ecological requirements as the weeds.

Which plants should be considered then for cultivation? I would suggest both northern cereals and fodder plants, in particular certain Leguminosae, e. g. *Trifolium subterraneum, Medicago* and *Stylosanthes* strains, for their pronounced resistance to aridity and their high protein content. This would more than compensate for the loss of fallow land. Finally, the Leguminosae, with their capacity for soil improvement, would to a certain extent provide an alternative to soil regeneration by laying the land fallow. In conclusion, I would like to point out one problem. It may be assumed, that it is possible to reach a sufficiently satisfactory level of feed production even in extremely dry years. The production of seeds, however, always constitutes a risk. In summing up, the following main points should be observed: the introduction of the previously unknown fodder cultivation and the fact that Leguminosae as a post-monsoon crop are, ecologically speaking, quite feasible. The multiple cropped areas could thus be considerably enlarged and a main evil of cattle breeding, i. e. the chronic shortage of fodder during the dry season, would ultimately be removed.

3. Increase of Agricultural Production by Means of Improvement of Areal Yield

Yield in agriculture has been levelling out over centuries now at a low level typical for Southern Asia: rice ± 20 dz/ha, maize 18–20 dz/ha, winter grain crops are only 10 dz/ha. The productivity is also extremely low on the pasture land. The obstacles which lie in the way of an increase in yield can best be drastically illustrated in the example of this pasture land. An analysis of meadow vegetation will support this.

Present-day pastures are exclusively made up of former forest land on slopes which are too steep for terraced cultivation. Permanent farming, the pruning of deciduous trees, the occasional burning of forested slopes, removal of firewood, soil erosion which accompanies the degradation of the trees etc.; all these factors have contributed to the natural selection of a type of plants which can endure being torn off and trodden down by cattle, regular burning and edaphic aridity, and can survive on a low level of soil fertility. This process of natural selection can go so far as to reach a state where only certain strains remain which the cattle refuse to eat, e. g. Ericaceas, Lauraceas and thorny *Berberis* species, herbs like primulas, *Euphorbia* and *Anaphalis* in the undergrowth. This extreme state of natural selection has already been reached in many cases in the tree and shrub layers.

Which methods of pasture improvement can be implemented at all under such unfavourable conditions? The first step should aim at the reduction of the number of cattle per area unit and a limit to the time they spend grazing there. This should at least put a stop to the continual, steady degradation of pasture land. That in itself would be a considerable step in the right direction. However, this is only possible, if the time spent by the cattle in the pastures could at least partially be compensated for by the introduction of fodder cultivation. At present this remains quite a theoretical demand.

One means of improving the pastures could be to fertilize some of the smaller meadows and to sow more productive grasses and types of clover there. As can be seen in the example of the Sherpa summer settlements in the high mountains, and even under Nepalese seasonal dry climatic conditions, the typical lush meadows only come into being if regularly manured. However, in future, the dung available in the lower-lying regions will remain destined exclusively for the cultivated fields, i. e. for the cultivation of basic foodstuffs and not that of fodder.

In my experience, the most promising course of action would seem to be the cultivation or rather the attentive care of fodder trees in so-called 'fodder orchards'. Such fodder orchards can regularly be found in certain valleys of East and Central Nepal. The leaves of the trees are removed but never so many as to kill the tree off. The planting of trees for this purpose is an example of the best possible sort of fodder storage for the dry season. There are few ecological problems involved in planting fodder orchards on degraded pasture land, if local types of tree, adapted to the terrain, are used. In many cases one could even fall back on the remains of forests and protect and spare the trees for a time from further tearing off by cattle, too much leaf pruning and so on. It is not the ecological reasons which are to blame for being an obstacle to the further expansion of fodder orchards, but claims to land ownership. Pasture land is almost always common land or in the hands of the state. Therefore farmers collect leaves and chop wood as they think best and necessity dictates. On the other hand, well cared for fodder orchards are always privately owned.

A little more optimism would be appropriate in the following discussion of an increase in the yield in agriculture, but even in this field there are many-sided problems which have not all been recognized as yet. It is a fact, that the yield per acre cannot be increased by further mobilization of labour. An increase of agricultural yield with the aim of an adequate level of self-subsistance amongst the population can thus only be achieved by the concentrated implementation of yield-improving capital intensive methods. This would essentially mean the use of chemical fertilizer and improved seeds. With the introduction of improved seeds of the so-called high-yield varieties we would then be confronted with a key ecological problem. These varieties of grains which have so far been grown have not only adapted themselves to the seasonal cycle of rainy and dry seasons, but also to the length of the day, the acidic soil, low soil fertility and, last not least, to traditional methods of cultivation. We can paraphrase this by saying that the autochthonous strains fit in with the ecosystem. Interference with this established system by, for instance, spreading chemical fertilizer or sowing new types of seed, results in often rather unpleasant surprise. For example, the reaction of local strains of wheat even to large amounts of chemical fertilizer is often negligible. Local varieties are bad convertors of fertilizer. If one spreads chemical fertilizer on certain local strains of rice, they will develop a long, fragile stem and tend to hang their heads. The grain yield, however, is not increased. Swiss farmers have experimented with European, high-yield varieties of cereal. The harvest was satisfactory but these varieties ripened during the monsoon. High-yield strains of Mexican wheat, which were further developed in Northern India, are well adapted to the seasonal cycle. Sometimes it is possible to more than double the amount produced per hectare with these high-yield varieties, but only if large amounts of chemical fertilizers are applied and water for irrigation is supplied in plenty. The results of experiments with high-yield rice varieties from Japan and the Phillipines have not always been satisfactory. In particular the constant level of water in the fields which is required by these types can only be maintained to a certain extent in Nepal, with its typical systems of canal irrigation and collection of rain water.

The extremely specific ecological conditions required by the high-yield rice varieties are even more difficult to fulfil than, say, those of wheat. If errors are made when sowing the fields or in irrigation, the yield may drop considerably below that of local types. Thus, some farmers have fallen back on traditional, local strains, which produce a lower but relatively constant, risk-free yield.

Finally, if we ask ourselves where one could most effectively employ such methods of yield improvement as chemical fertilizer and improved seeds, the answer must be in the areas of the Terai which are opened up to traffic. During the dry season, irrigated farming could be considerably expanded. The greatest successes on record so far in Northern India have been with regular irrigation, ample supplies of chemical fertilizer and use of high-yield varieties. However, we are still a long way from a "green revolution". Which suitable solution can be put forward for the densely populated mountain regions and for settled valleys with up to 400 inhabitants per km^2?

Methods of yield improvement and therefore of saving land which require large capital investment are certainly not unknown. However, there are local disadvantages (relief, lack of roads and means of transport), which, together with the chronic lack of capital of the small to minute farm units, either delay or prevent entirely the introduction of technical innovations in the agricultural field. In certain Himalayan valleys which are sufficiently open to traffic, e. g. in some parts of the Kathmandu Valley (MÜLLER, 1982 and 1984), the use of mineral fertilizer, insecticide etc. is quite normal and profitable, in particular in the production of cash crops (e. g. seed-potatoes and vegetables, but also of rice). In some cases it has proved possible to considerably increase the yield per acre, especially in those areas influenced by projects set up by the Agricultural Advisory Service.

The increase of productivity in the cultivation of crops in remote mountain regions where cereal farming is practised (maize, wheat, millet and rice) and which have a capital-extensive, self-sufficient economy, can only be conceivable, if alternative agricultural methods are applied, based on the use and further development of autochthonous, labour-intensive techniques and a greatly increased use of humus (see EGGER, 1982). Of course, the techniques of ecofarming have yet to mature in many ways. In particular there is a great lack of experience of local conditions. Critics stress the fact that there is not enough definite data on yield, ultimately there is no information on profitability. At the present time there remains only one course of action for the majority of small farms and those which have been even further reduced by the population explosion and land inheritance laws to take in order to increase production, i. e. the expansion of the agriculturally used area. With the population steadily increasing, there is usually plenty of labour available. The clearance of bush forests and pasture land, already often greatly degraded by the removal of firewood and fodder and the advance of cultivated fields on to much too steep slopes, which in the long run prove to be unsuitable, i. e. into typical areas of marginal yield, are to blame for those irreversible, morphodynamic processes, beginning with scarcely visible soil erosion and often ending in land slides of catastrophic dimensions. However, we should not allow ourselves to believe, that this negative development has remained unnoticed by the mountain farming population, with their rich, traditional store of experience. In view of the limited opportunities available to them, they know of no other alternative but to move to the mountain foreland, overpopulated as it is.

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Discussion to the Paper Haffner

Prof. Dr. J. Martens:

I feel that you have described the condition of the Nepalese forest too optimistically. Certainly, forests do still exist in many areas, but it would seem that they are overexploited everywhere man comes into contact with them.
The population needs the forest as a source of raw materials. Ecologically speaking, to push it still further back in order to accomodate more terraces for crop cultivation is an extremely risky thing to do. The foremost goal must be protection of the remaining forests and their possible expansion.

Prof. Dr. W. Haffner:

A glance at a satellite map will show that there are still extensive areas of forest left in Nepal. Often these are degraded forests, but I should still wish to term them "forest". The population explosion from c. 7 millions in 1963 to 15 millions in 1983 makes it unavoidable to incorporate even those areas which are ecologically not always exactly suitable and those of marginal yield into the agriculturally used land – usually at cost to the forests. A solution to this problem may be summarized as follows:

1. The increase of the productivity in farming.
2. The introduction of controlled forest management. This should on no account function only at government level, but also on a village level. In this connection, I would like to mention the forests, the care of which lies in the hands of the villages and which may also be used by them. First, positive steps in this direction may be observed for instance in the Gorkha region.

Dr. H. Kienholz:

Concerning forests of the Siwalik Mountains:
According to your statement, the forests which grow on the gravel sediments of the Siwaliks are not being threatened by the claiming of land for agricultural purposes (because they are not edaphically suitable). However, you must agree with me in saying that these forests are being impaired by the removal of timber (in particular of firewood) and are thus in acute danger of being affected by deteriorating water retention and increasing erosion with all the consequences this involves.

Prof. Dr. W. Haffner:

I agree with you in the main, but am personally of the opinion, that removal of firewood in the Siwalik Range is not leading up to total deforestation with all its ecological consequences. It is the recurrence of forest fires in the dry season which seems to me to constitute a worse problem.

Prof. Dr. B. Messerli:

1. Concerning statistics of the population: Are they official and from wheu (earliest year of census)?
2. The use of fertilizer is on the decline. What is meant by this? Which types of fertilizer, in which areas?

Prof. Dr. W. Haffner:

1. All population data are taken from the official Population Statistics, especially from 1971–1981.

2. The use of chemical fertilizer has decreased during recent years. One reason for this was the rising cost. Neither was there enough fertilizer available. I know this state of affairs to exist, in particular in the areas which have not yet been opened up to traffic by roads and not least in the Kathmandu Valley.

Prof. Dr. A. B. Mukerji:

On the basis of vegetation, soil, ground-water table, agriculture, settlements and history of human occupance the Bhabhar and Terai and Dun of Nepal can be distinguished from those of Western Himalaya extending from Jammu to Dehra Dun and Naini Tal and eastern Uttar Pradesh. Hence, generalisations from Nepal need to be modified before applying them to the Western Himalaya. Also in Punjab and Jammu the Terai is almost totally absent, thus changing the locational setting and its significance.

Prof. Dr. W. Haffner:

I agree in all details with your statement.

Dr. M. Winiger:

You compare the political potential of China and Nepal as regards the introduction of new agro-technical measures.
Your conclusion is that China is in a position to organize, say, irrigation projects better than Nepal. The hope of foreign capital investment is all that remains for Nepal.
My question is: will this dependency on other countries not increase the vulnerability of the agro-economy even more? Is it not exactly this dependency on others which should be reduced by all means available with a view to long-term stability?

Prof. Dr. W. Haffner:

I do not by any means regard this dependency on other countries mentioned by you as ideal for the future. It simply strikes me as being unrealistic to promote it as things stand at the present.
Just a few centuries ago, traditional, autochthonous ways of life and forms of farming were still dominant in Nepal. They fulfilled the basic demands of the population for food, clothing and accommodation. However, even the mountain peoples of Nepal (why should the Nepalese be any different from the rest of the world?) have a further elementary need, i. e. of health, longer life etc. Thus, after the country was politically opened up at the beginning of the Fifties, an extremely successful campaign was started from abroad to conquer disease and provide adequate medical treatment. The result was the much quoted population explosion to 15 million inhabitants. This medical technology of foreign origins was the beginning of a disruption of the traditional agro-economy and of the overexploitation of natural resources, which is so lamented today. I personally, along with many Nepalese, am indeed of the opinion, that Nepal will not be able to exist independently of foreign countries in the agricultural sector for the next decades – the height of the population explosion has by no means yet been reached. The reasons for this are as follows:

1. Because additional foodstuffs must be imported in years of a bad harvest (e. g. following the dry summer of 1982).
2. Because the chemical fertilizer necessary for self-sufficiency in the production of foodstuffs must be imported.
3. Because the Nepalese government is unable to raise the capital for the larger aid projects itself (e. g. for the development of artificial irrigation).

The people and not just merely the government have made the decision to be dependent on foreign aid because of their extremely concrete and acute needs and the present predicament. This they have done (and this fact strikes me as being particularly important) without having given up their political and cultural identity during the last 30 years of demographic, political and economic upheaval.

Erdwissenschaftliche Forschung, Bd. XVIII, 127–146
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Geomorphic Damages in the Western Himalaya: Regional Patterns and some Human Dimensions Revealed by Newspaper Reports

Anath Bandhu Mukerji

With 10 Figures and 14 Tables

Summary

Landslides and avalanches, which form the core of geomorphic damages in the Western Himalaya, reveal two aspects of their distribution, spatial and temporal. The data on these two aspects of the landslides and avalanches, which have occurred along four major highways and the damages and casualties caused by them, have been extracted from the daily prints of two national and two regional newspapers covering the period 1957–1981. An analysis of the data reveals a high concentration of landslides in the Outer, Lower, and Lesser Himalayas and of the avalanches in the Central and Trans Himalayas. Everywhere the occurrences of the post-1967 era largely outnumber those of the pre-1967 era. Mainly, landslides are correlated with the geological formations dominated by shale, slate, and limestone and are most numerous at elevations of 800 to 2000 metres where precipitation is in the form of rain, large in amount, has a high intensity, and is concentrated in the summer monsoon. These areas have been under high pressure of human occupance and have experienced since 1967 the impress of extensive developmental activities, mainly urban growth, transportation elaboration, industrialisation, extension of cultivated land, deforestation, and mining and quarrying. Avalanches characterize areas which are located at higher elevations of 2000 to 2400 metres or more, dominated by shale, slate, and orthoquartzite rocks, and receive most of their precipitation in the form of snow concentrated during the winter. Damages to property and human casualties caused by both landslides and avalanches have been most extensive in the middle and higher elevation zones and reveal a much larger dimension during the period following 1967 than before it. During this period were implemented the fourth, fifth, and sixth five-year plans. The principal correlates are lithology of shale, slate, and limestone, high intensity, large, monsoonal rainfall and winter snow, fault zones, steep slopes, and elevation zones constituting the natural complex and urban development, transportation densification, industrialisation, deforestation and mining and quarrying comprising human occupance. Relationships are distorted by elevation and developmental variations. Ultimately, the main villain seems to be the ecology-neutral developmental activities.

1. Introductory Statements

Ecologically neutral development processes are, in the ultimate analysis, destructive to both ecology and society. Destruction is most widespread and intensive, both to natural and cultural landscapes, in fragile environment. Himalaya provides us with an exceptionally instructive example of such a tropical mountain environment. The most significant element destroyed, significant for both nature and man, is the slope. Slope damages constitute the most widely recognized and discussed phenomena among the natural hazards encountered by human communities in the Himalaya.

Landslides, avalanches, and other types of mass movements are the most widespread and most frequent among the changes in the geomorphic landscape of the hills and mountains and they form the core of geomorphic damages. All geomorphic landscapes can be resolved into slopes, "the lowest common denominator" as BUTZER (1976, p. 79) describes them. All geomorphic damages in the mountains are really slope damages.

The objectives of the paper are twofold:

(i) to analyse the regional and temporal patterns of landslides and avalanches, and
(ii) to identify the human dimensions.

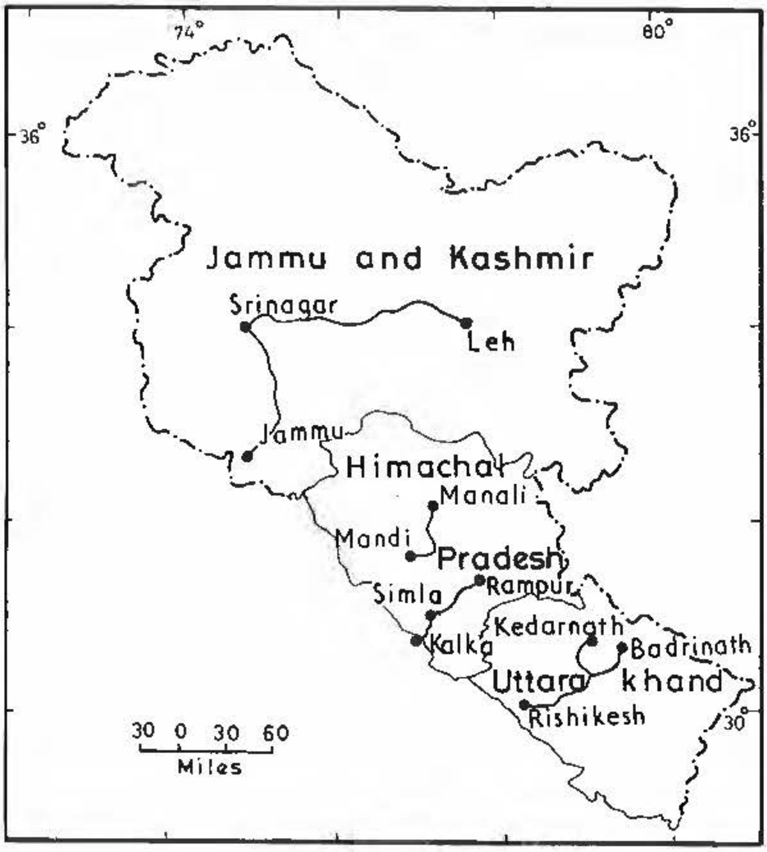


Fig. 1. Western Himalaya. Sketch Map.

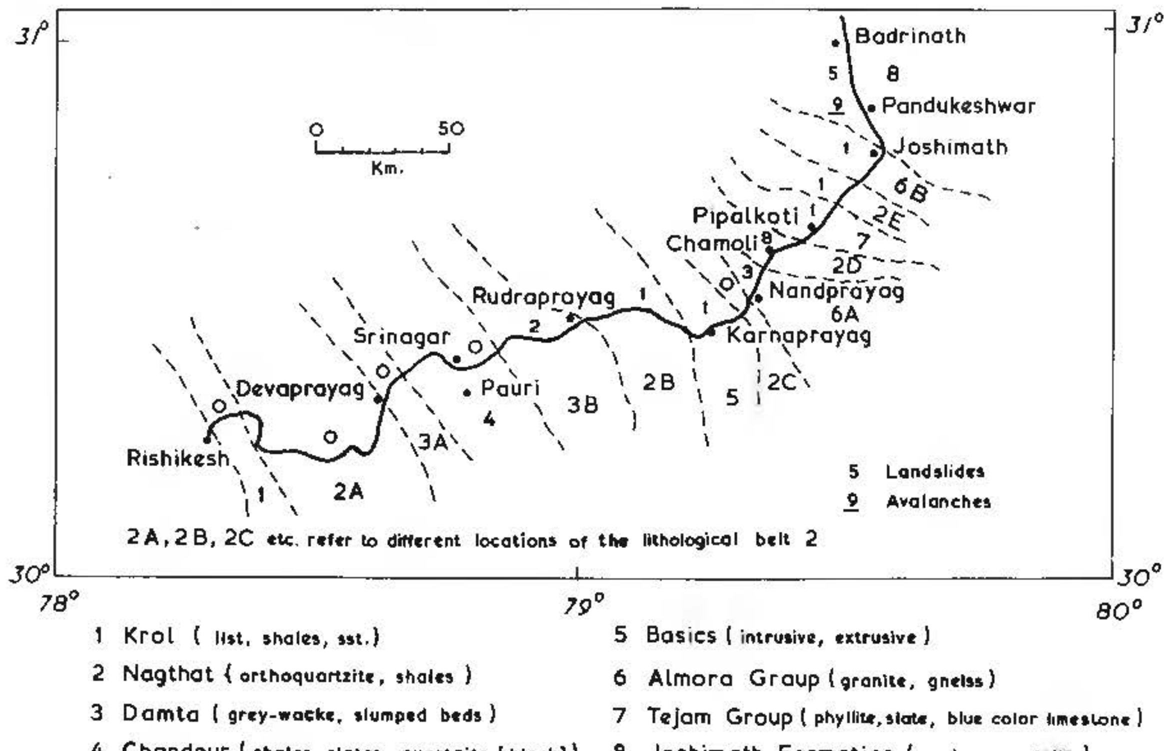
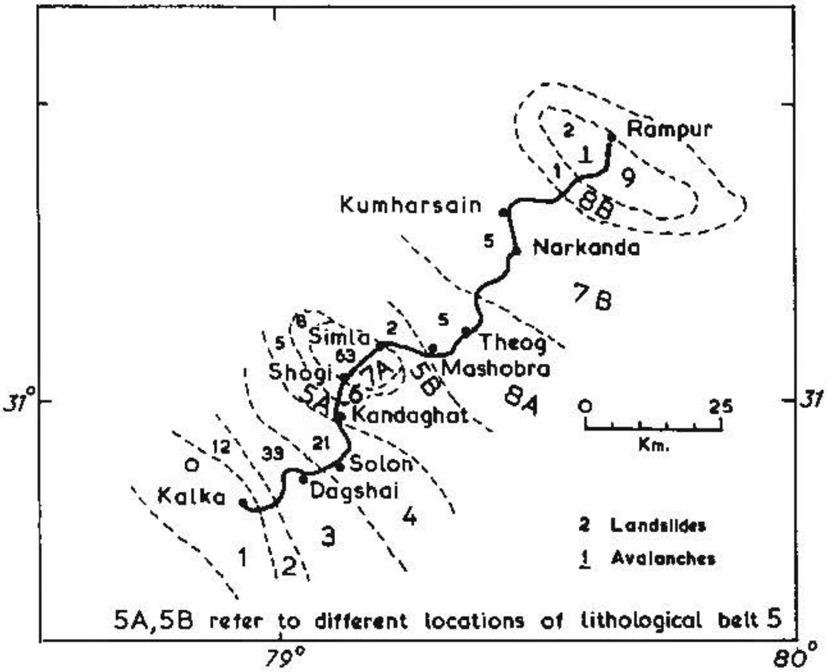
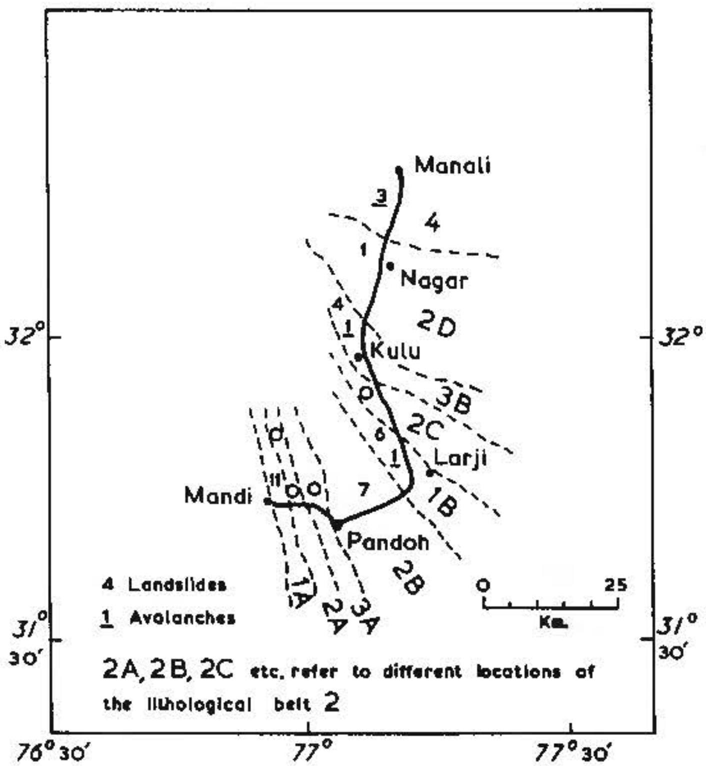


Fig. 2. Rishikesh-Badrinath Highway. Lithological Zones.

Fig. 3. Kalka-Rampur Highway. Lithological Zones.



1 Alluvium
2 Lower Siwalik (grey-wack, conglomerate)
3 Subathu / Murree (red sh., list)
4 Krol (shales, list, sst.)
5 Nagthat (orthoquartzite, shales)
6 Blaini (siltstone, slates)
7 Low Grade (quartzite, slate, phyllonites)
8 Basantpur (black sh., basics)
9 Basics (intrusive, extrusive)



1 Larji Shali Formation (lime stone, dolomite)
2 Salkhala Formation (schist, quartzite)
3 Manjir Formation (conglomerate)
4 Central Gneiss Formation (gneiss, schist)

Fig. 4. Mandi-Manali Highway. Lithological Zones.

2. Hypothesis

The basic hypothesis of the paper is that most geomorphic damages like many natural hazards are caused, in fragile environments and settled areas, by rapid developmental activities. It follows that these damages become more frequent and concentrated during the times of intense human activities and in the areas where nature is sought to be destructively transformed.

In the Western Himalaya (Fig. 1), a ravaged ecological setting, the geomorphic damages would reveal a striking increase in number and intensity of destruction during the post-Independence era and in the lower and middle elevation zones, both related to development activities. Also, the era experienced the effects of the implementation of the five-year development plans and the area receives heavy and high intensity monsoon rainfall and is composed of weak rocks.

3. Methodology

From the reports of the residents and observations of the landscape it is known that a larger number of landslides and avalanches have occurred than reported in the national and regional newspapers. However, most of the occurrences along the highways and the main roads and those which have caused large

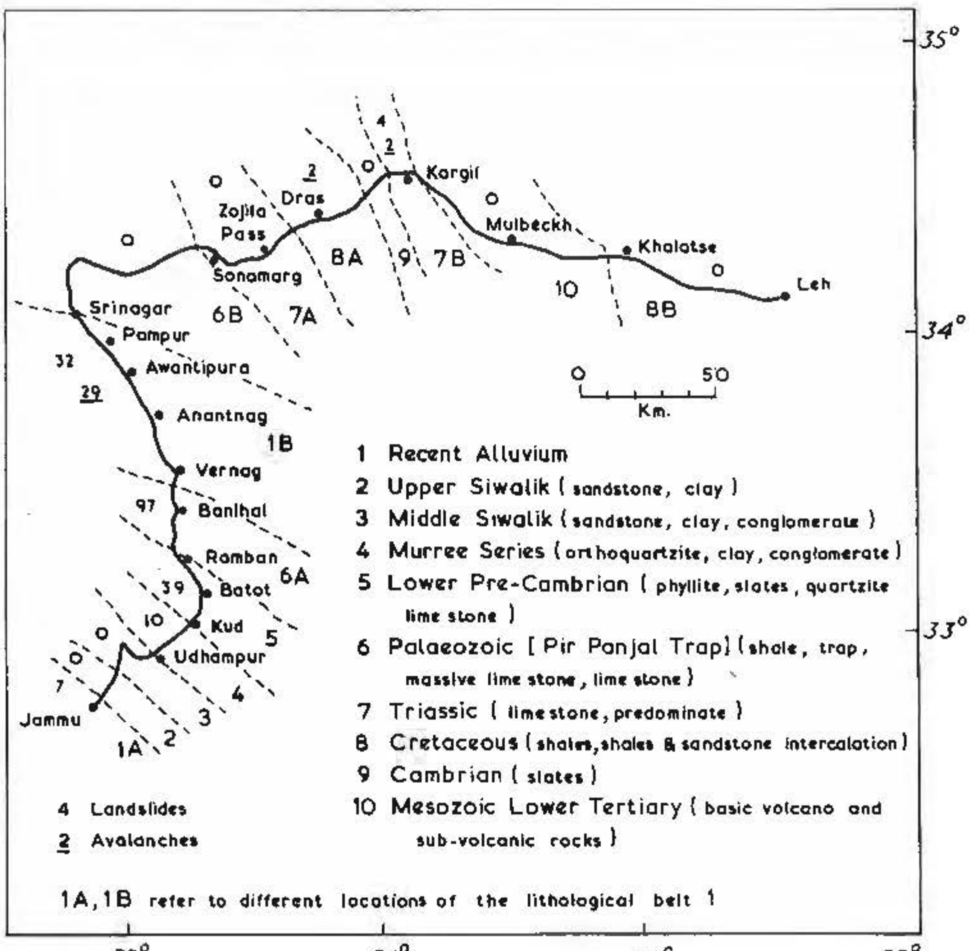


Fig. 5. Jammu-Leh Highway. Lithological Zones.

damages to life and property, and some of those located at distances from the highways in the interior and less accessible areas are also reported. These reports cover the period 1957–1981, during which six five-year development plans were implemented, and are abstracted from two national, daily newspapers, the *Hindustan Times* and *Times of India*, and two regional, daily newspapers, *Tribune* and *Indian Express*. Each day's issues of all the four newspapers were scanned. These reports have provided significant data on the spatial and temporal distribution and causes of landslides and related damages and provide a pointer to the assessment of man's role in generating them.

The landslides and avalanches reported for four national highways, Rishikesh–Badrinath (275 km), Kalka–Rampur (200 km), Mandi–Manali (100 km), and Jammu-Leh (650 km), have been analysed to illustrate the basic theme of the study (Figs. 2, 3, 4 and 5).

The roads extend through the following Himalayan zones: Outer Himalaya, Lower Himalaya, Lesser Himalaya, Greater Himalaya, and Trans Himalaya. The zones are differentiated among themselves in terms of location with reference to the North Indian Plains, elevation, lithological formation, climate, vegetation, soil, hydrography, and types and patterns of human occupance. The first three roads traverse the first four zones while the Jammu-Leh road cuts through all the five zones.

4. Natural Determinants

Lithological formation with its internal micro-structures, elevation zone, and the form, nature, and amount of precipitation, the former an internal and the latter two external, emerge as the dominant natural determinants of the site and regional pattern of landslides and avalanches.

For the purposes of correlation, description, and explanation of distribution of landslides the roads have been divided into their constituent elevation and lithological zones, each experiencing different frequencies of landslides.

4.1. Elevation Associations

The four highways have their origins and destinations at different elevations and therefore the range of height through which they extend is different (Table 1). The second and the fourth road, the former having a high origin and the latter a high destination, have experienced larger number of landslides. The Jammu-Leh road which has a much longer traverse in the central and the trans-Himalayan zones has recorded the largest number of avalanches. On the other hand the Mandi-Manali road originating at a high elevation has a higher linear density (Table 2). The highest density of 79 is suggestive of the instability and man's destructive role in natural-ecological system along the Kalka-Rampur road. This highway has been widened to permit two-way traffic and for most of its length it is two-lane movement line.

Table 1. Topographic Range of Highways and Number of Landslides and Avalanches (Heights in metres).

Origin	Height	Destination	Height	Range of Height	Landslides and Avalanches
1. Rishikesh	348	Badrinath	3096	2748	35 (26 + 9)
2. Kalka	680	Rampur	1007	327	158 (157 + 1)
3. Mandi	754	Manali	1926	1172	34 (29 + 5)
4. Jammu	366	Leh	3514	3148	222 (189 + 33)

(The first aud second figure in the parenthesis are respectively for landslides and avalanches)

Table 2. Linear Density of Landslides and Avalanches.

Name of the Road	Length (km)	Landslides and Avalanches	Number of landslides and avalanches per 100 km
1. Rishikesh-Badrinath	275	35	13
2. Kalka-Rampur	200	158	79
3. Mandi-Manali	100	34	34
4. Jammu-Leh	650	222	34
Total	1225	449	36

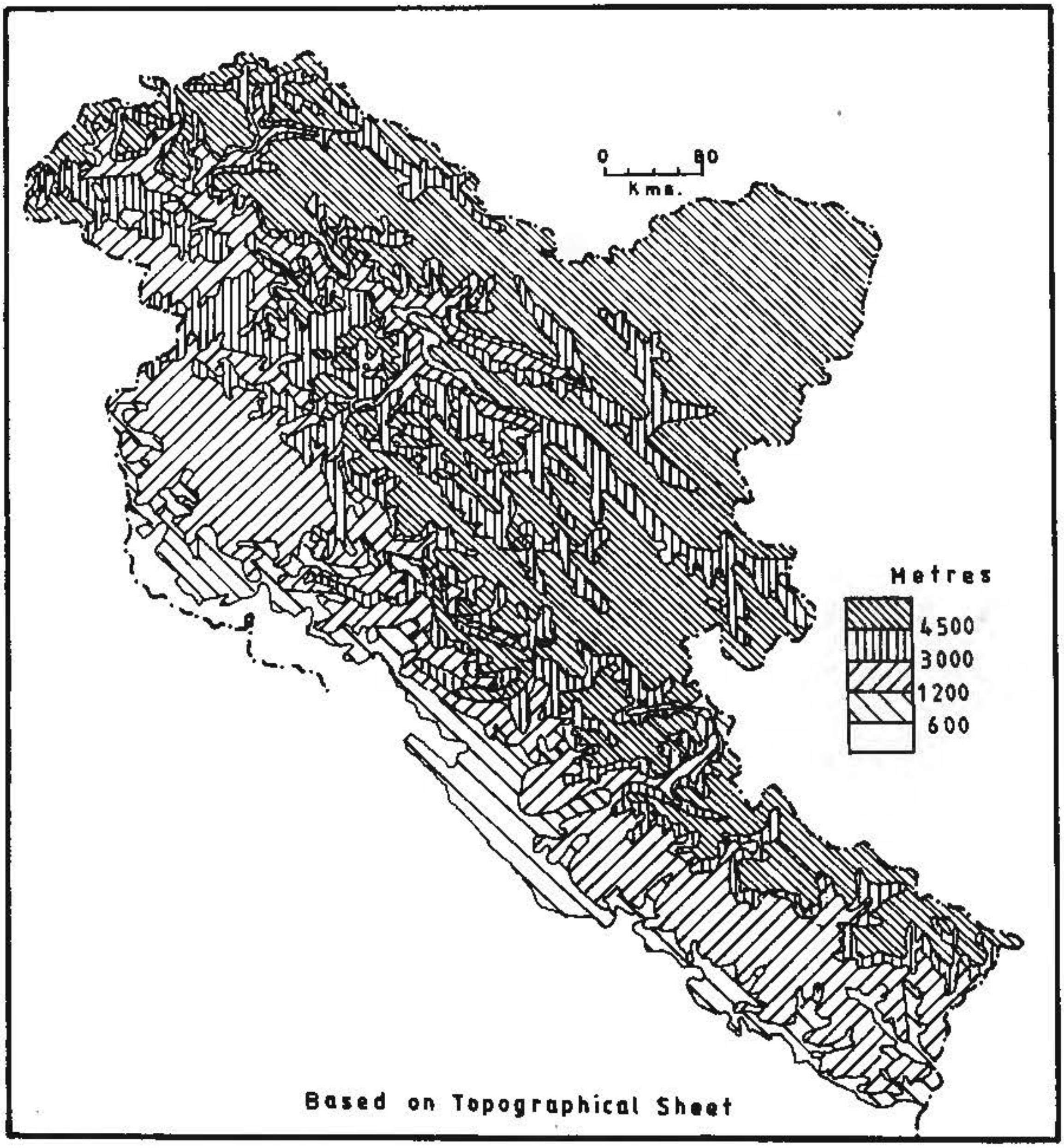


Fig. 6. Elevation Zones in the Western Himalaya.

Table 3. Landslide Occurrences in Elevation Zones.

Road	< 800 m	800–1199 m	1200–1599 m	1600–1999 m	2000–2399 m	> 2400 m	Total
1. Rishikesh-Badrinath	1	5	15	0	1	4	26
2. Kalka-Rampur	0	29	66	13	48	1	157
3. Mandi-Manali	0	18	11	0	0	0	29
4. Jammu-Leh	3	63	97	15	5	6	189
Total	4	115	189	28	54	11	401

Table 4. Avalanche Occurrences in Elevation Zones.

Road	< 800 m	800–1199 m	1200–1599 m	1600–1999 m	2000–2399 m	> 2400 m	Total
1. Rishikesh-Badrinath	0	0	0	0	0	9	9
2. Kalka-Rampur	0	0	0	1	0	0	1
3. Mandi-Manali	0	0	2	3	0	0	5
4. Jammu-Leh	0	1	1	5	11	15	33
Total	0	1	3	9	11	24	48

Table 5. Concentration of Landslides in Specific Lithological Zones.

Road	Lithological Zone	Elevation Range (in metres)	Zone Length/ Road Length	Zonal Slides/ Road Slides	Location Quotient
1. Rishikesh-Badrinath	Nagthat 2 D (Shale, Ortho-quartzite)	1200–2000	12/275	8/23	7.9
2. Kalka-Rampur	Subathu-Murree 3 (Shale, Limestone)	1200–1400	30/200	33/157	1.4
3. Kalka-Rampur	Krol 4 (Shale, Limestone, Sandstone)	1400–1600	17/200	21/157	1.6
4. Kalka-Rampur	Low Grade 7 A (Shale, Quartzite)	1600–2100	17/200	63/157	5.0
5. Mandi-Manali	Larji Shali 1 A (Limestone, Dolomite)	1000–1300	5/100	11/29	7.4
6. Jammu-Leh	Lower Precambrian 5 (Slate, Limestone, Quartzite, Phyllite)	800–1900	45/650	39/189	2.8
7. Jammu-Leh	Palaeozoic 6 A (Shale, Limestone)	800–2400	57/650	97/189	6.4

2 D refers to the number in the highway maps (Figs. 2–5).

In contrast to the concentration of avalanches in the elevation zones of higher than 2000 metres, the landslides are concentrated between 800 and 2000 metres (Table 3) (Fig. 6). As many as 84 per cent of the landslides have occurred in the lower elevation zones which constitute the locale of heavy, high intensity monsoon rainfall and of weak, sedimentary, formations of the Lower Himalaya. Also, the most devastating effects of human occupance have been experienced here.

There is a striking increase in the occurrence of avalanches with elevation as is clearly indicated by the Jammu-Leh road and the Mandi-Manali segment (Table 4). Even on the former road as many as 31 of the total of 33 avalanches have occurred at elevations of more than 1600 metres, the zone above 2000 metres having recorded more than 26. Undoubtedly, this elevational concentration is related to heavy winter snowfall in the Srinagar-Leh and Kulu-Manali segments where the slopes, typical of the trans-Himalayan zone, are bare of vegetation and soil and intense mechanical weathering produces extensive grus cover. Likewise all the nine avalanches of the Rishikesh-Badrinath road occurred at elevations of more than 2400 metres.

While landslides are more characteristic of the Jammu-Srinagar section south of the Zanskar Range the avalanches are concentrated in the Srinagar-Leh segment running north of it. The former is related to monsoonal rainfall, the latter to heavy, high intensity snowfall.

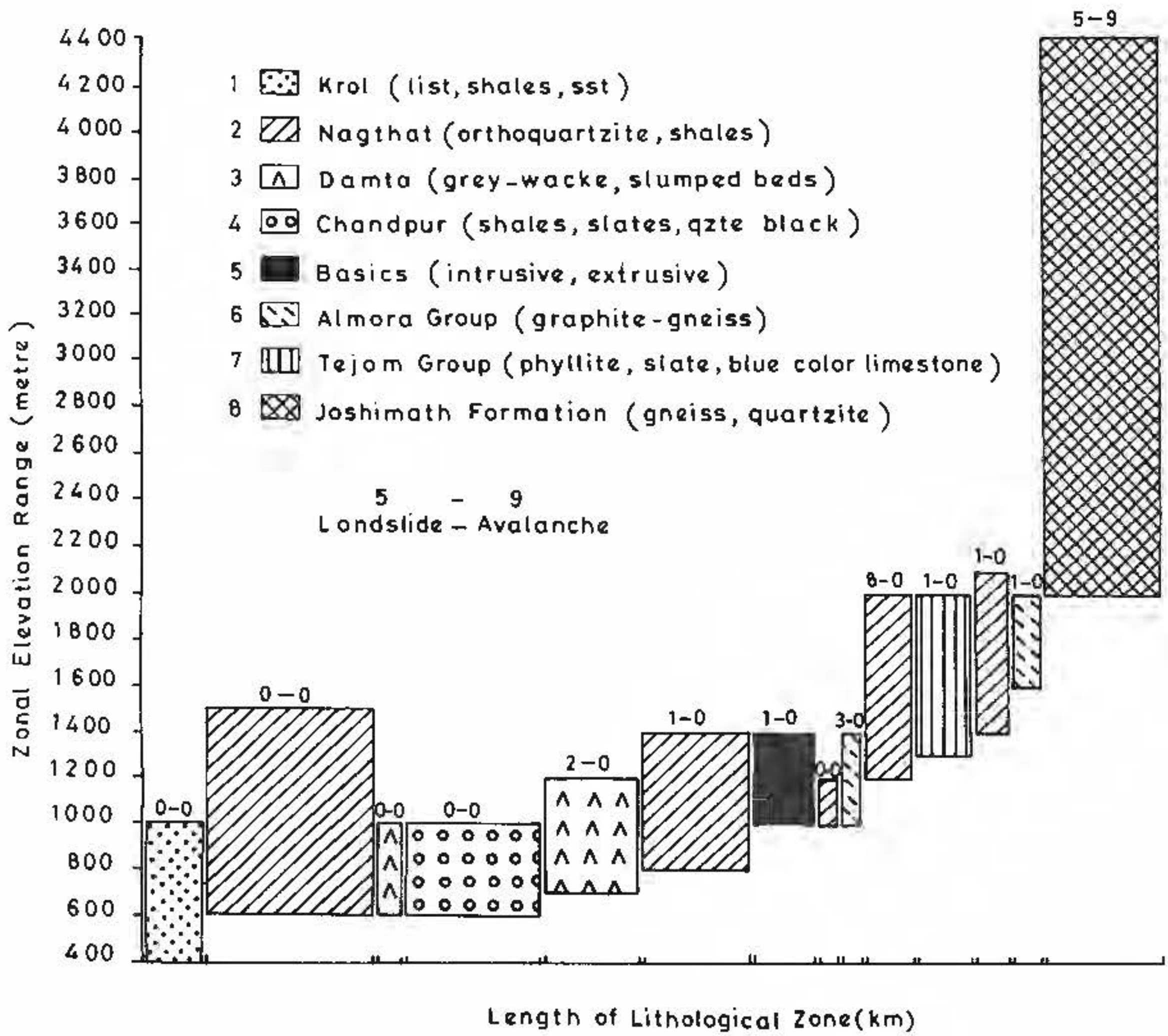


Fig. 7. Rishikesh-Badrinath Highway. Number of Landslides and Avalanches (1 cm to 16.0 km).

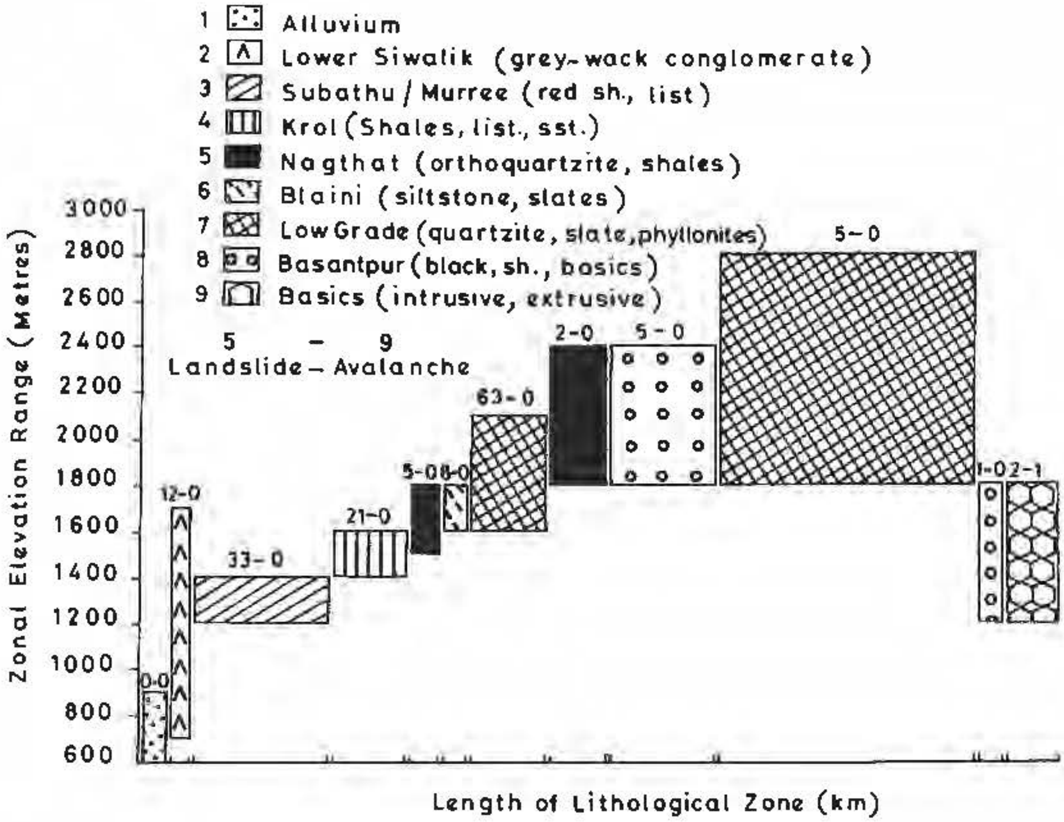


Fig. 8. Kalka-Rampur Highway. Number of Landslides and Avalanches (1 cm to 13.0 km).

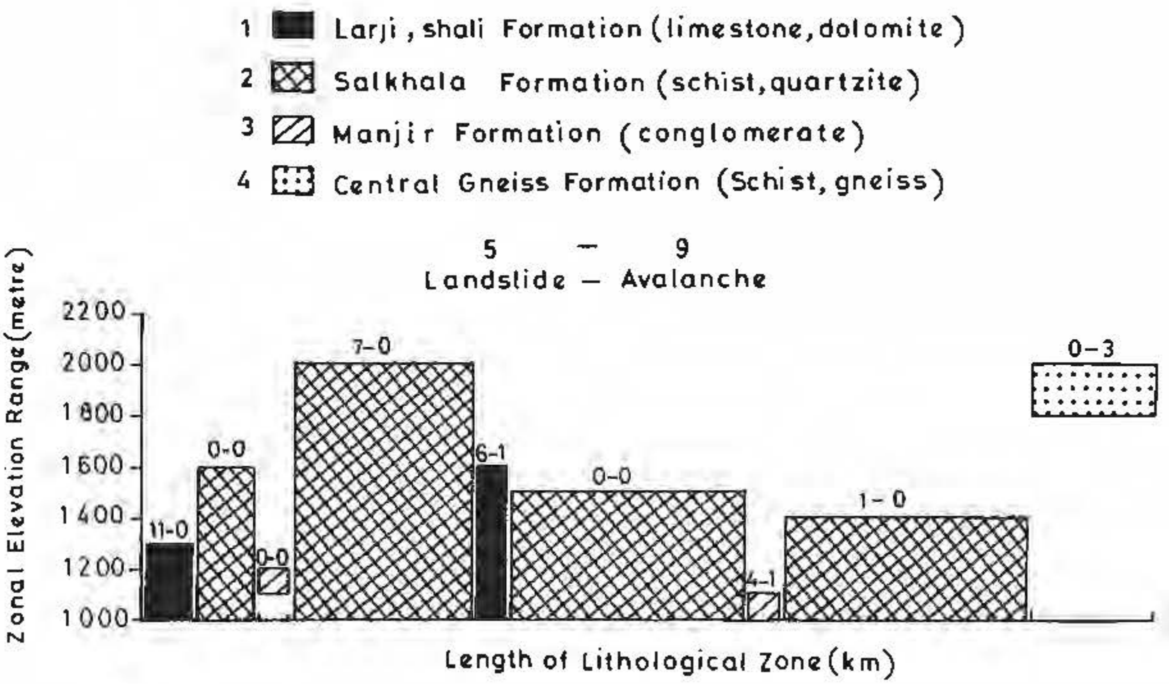


Fig. 9. Mandi-Manali Highway. Number of Landslides and Avalanches (1 cm to 7.5 km).

4.2. Lithological Correlates

There are several repetitions at different elevations of the lithological belts across the highway traverses. The lithologies are distinguished from each other by their characteristic proneness to landslides. This explains why the different belts of the same lithological formation located at different elevation zones and receiving different types, intensities, and amounts of rainfall experience different frequencies of landslides (Table 5 and Figs. 7, 8, 9 and 10).

Lithological zones which are located at lower elevations and in cis-Himalaya receive the maximum impact of monsoon rain and record high values of location quotient. Nagthat formation (Belt 2 D) has recorded the highest value of 7.9 among the belts (Table 5). In all but one belt the dominant rock type is shale or slate and the other types are limestone, quartzite, and sandstone. The sedimentaries and the zones afflicted with several intercrossing, major and tributary faults have also recorded a high frequency of landslides.

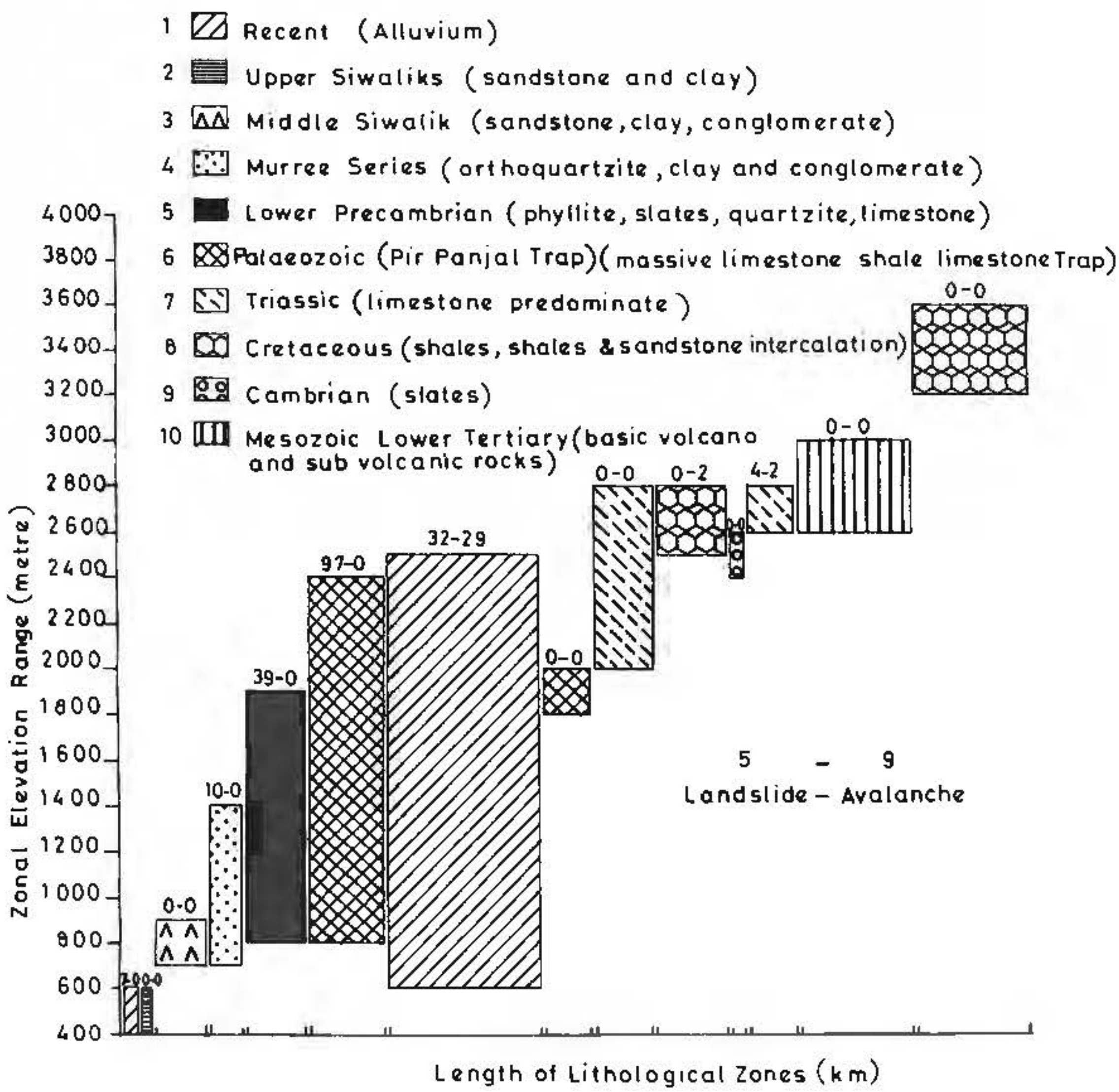


Fig. 10. Jammu-Leh Highway. Number of Landslides and Avalanches (1 cm to 41.7 km).

In order to measure the concentration of the landslides in specific lithological zones the following location quotient formula has been applied:

$$\text{Index of Concentration} = \frac{\text{Zonal Landslides}}{\text{Total Landslides}} : \frac{\text{Length of Zone}}{\text{Length of Road}}$$

4.3. Precipitation Correlates

Although precipitation is highly variable in the region, three basic tendencies relevant to the understanding of the regional patterns of landslides and avalanches must be noted. Firstly, precipitation is mainly in the form of rain south of the central Himalaya and in the form of snow in the trans-Himalaya. Secondly, precipitation in the former region increases with elevation till the peak belt extending over the central Himalaya is reached. Thirdly, while snow is almost entirely concentrated during the winter, rain is heavily concentrated, about 70 to 80 per cent of the annual total, during the summer monsoon (June through September).

The three tendencies of precipitation explain why the landslides are concentrated in the cis-Himalaya and during the summer monsoon period. As many as 84 per cent (336) of the total (401) reported landslides occurred in the region and about 65 per cent (219) of them occurred during the monsoon. In contrast 35 of the reported 48 avalanches occurred in the trans-Himalaya and all but one in winter and spring (October through May).

5. Temporal Aspects

Temporal distribution of landslides and avalanches is expressed through two dimensions, variations through the years and variations through the seasons. All the highways have experienced larger number of landslides in the post-1967 period, which coincides with the tenure of the fourth, fifth, and sixth five-year plans, than in the pre-1967 period (Table 6). Similarly, of the 33 avalanches which have occurred along the Jammu-Leh highway as many as 29 were concentrated in the post-1967 era. The era was particularly marked by extensive development of roads, towns, agriculture, and industry. Largescale removal of forests for creating agricultural, terraced fields became widespread.

During the fourth, fifth, and sixth five-year plans two special programs, *Sensitive Border Area Roads* and *Hill Region Roads*, resulted in a rapid and large expansion of road network, particularly in those parts where the vegetation is sparse, mechanical weathering is intense, and rocks are weak. Middle, Central, and Trans Himalayan zones, in particular experienced a large number of landslides as a response to these developments.

Table 6. Seasonal Occurrence of Avalanches (Total of 1957–1981).

Road	Monsoon (June–Sept.)	Percentage in Total	Winter and Spring	Percentage in Total
1. Rishikesh-Badrinath	Nil	Nil	9	100
2. Kalka-Rampur	Nil	Nil	1	100
3. Mandi-Manali	1	20	4	80
4. Jammu-Leh	Nil	Nil	33	100
Total	1	2	47	98

Table 7. Seasonal Occurrence of Landslides (Total of 1957–1981).

Road	Monsoon (June–Sept.)	Percentage in Total	Winter and Spring (Oct.–March)	Percentage in Total
1. Rishikesh-Badrinath	24	92.30	2	7.70
2. Kalka-Rampur	134	85.35	23	14.65
3. Mandi-Manali	17	58.62	12	41.35
4. Jammu-Leh	44	23.28	145	76.72
Total	219	54.61	182	45.39

Table 8. Temporal Concentration of Landslides.

Road	Pre-1967 (1)	Post-1967 (2)	Percentage of (2) in total
1. Rishikesh-Badrinath	9	17	66
2. Kalka-Rampur	48	109	69
3. Mandi-Manali	7	22	75
4. Jammu-Leh	23	166	88
Total	87	314	78

Seasonality of occurrence of landslides both for the total and for the first three roads is very marked (Table 7). The first two roads which are located in the eastern parts of the Western Himalaya have had more than 85 per cent of the annual totals concentrated in the monsoon season. The characteristically high intensity of rainfall is particularly conducive to deep lubrication in large masses of weathered and crushed rock bodies resulting in massive landslides. Bare hillside slopes with thin soil covers are the immediate victims of landslide processes. In the aggregate of the four highways as well the monsoonal concentration (219) is higher than the winter occurrences (182).

In contrast to monsoonal concentration of landslides in eastern parts, the Mandi-Manali and Jammu-Leh roads, central and western locations respectively, have experienced a higher frequency in the winter and spring seasons. The Jammu-Leh road has had about 77 per cent of the occurrences during the winter. Essentially this is attributed to the larger proportion of rainfall and snowfall occurring during the winter. During July to September the Kashmir Valley section of the road receives only 20 per cent of the annual rainfall (KAUL, 1980, p. 22).

It is interesting that of the 48 avalanches reported for the study area as many as 33 had occurred along the Jammu-Leh road and all of them were concentrated during the winter and spring seasons. This is true for all other roads as well (Table 8). Obviously, the relationship here is with heavy snowfall concentrated in the winter. Further, the Jammu-Leh road has its major segment in the trans-Himalayan zone beyond the Zanskar ranges where most of the precipitation falls in the form of snow and during the winter season.

6. Human Dimensions

While a fairly large and conclusive body of literature exists on the natural conditions and correlates of landslides and avalanches the role of human activities and human occupance of the earth has tended to be ignored. Observations made in the field suggest the following human activity generated causes of the landslides which have occurred in the area:

a) Ill-maintenance of narrow irrigation channels;
b) Removal of forests by uncontrolled felling without a proportional reforestation and of vegetation cover by grazing and of grass by cutting for fodder;
c) Mining and quarrying;
d) Urban growth through increase in the number of towns and through physical expansion of towns; and
e) Increase in the transportation network.

Irrigation channels (kulhs) descending from one to the other terraced field either down the slope or along the contours are widespread in the region. Constructed of mud the channels carry water throughout the year except severe winters. Breaching of channels because of poor maintenance and freeze expansion is quite common, leading to large seepage and surface run-off. Cumulative effect of repeated breaching ultimately contributes to the generation of landslides. KIENHOLZ et al. and SPATE have emphasized that the most serious form of erosion leading to landslides as well results from damaged chanals and gullying (KIENHOLZ et al., 1983, p. 212; SPATE, 1967, p. 455). Since the Middle Himalaya (1200 to 2000 metres) contains the densest network of channel (kulh) irrigation it is here that the number of landslides related to this factor is the highest.

Forests are being continously felled as a part of largescale commercial exploitation and there is not much reforestation. There is widespread grazing by cattle, goat, and sheep, and the destructive effect is particularly marked in the higher, steep slopes and in the Trans-Himalayan Zone.

Mining and quarrying, particularly along the highways, were intensified during the last decade along with the increase in construction activities of urban buildings and roads. Particular mention must be made of extensive quarrying of limestone in the lower Himalayan zone along some of the major roads and of slate in the middle zone.

A whole series of new market centres, administrative towns, and industrial complexes have emerged along the four highways, with their major concentration in the Lesser and southern flanks of the Central Himalayas. What accelerate the slope damages are the upward expansion from the road of these construction activities on the slopes which have already been weakened, the construction of multi-storey houses almost to the edge of overhanging cliff against which the niche of the road has been cut, and extensive lineation of urban built-up belts without any drainage, leading to heavy infiltration in small pockets.

There has been a continuous increase in the number of urban places in the region, 104 in 1961, 126 in 1971, and 170 in 1981. Most of the towns tend to remain concentrated in the Lower and Lesser Himalayan zones and play a destablishing role in their ecologies.

There has been a significant increase in the length of the existing roads and in the construction of new roads. Elaborate networks of border roads constructed for strategic reasons and as a major component of regional development plans have also contributed significantly to an increase in the number of landslides. Particularly significant as a causal factor has been the widening of the roads without the construction of protective measures such as the retaining wall. Further, the absence of bridges on steeply sloping wide gullies which carry enormous and rapid discharge during the monsoon days results in local damming and rapid drainage within the regolith finally leading to massive landslides.

A contributory factor, not generally recognised, has been the blasting of large bodies of slopes in road construction which leads to internal disintegration of the regolith and rock body promoting landslides. Many sites of landslides are associated with the widening of roads through blasting of rocks.

All the five conditions became acute during the post-Independence period and more so in the post-1967 era when the later five-year development plans were being implemented assiduously.

6.1. Human Casualties and Property Damages

The casualties and damages have been analysed at two levels and presented in six tables (Tables 9, 10, 11, 12, 13 and 14). Tables 9 to 12 give details of casualties and damages caused by landslides and

Table 9. Rishikesh-Badrinath Highway. Casualties and Damages within the Lithological and Elevation Zones.

Index No.	Lithological Zones	Zonal Elevation Range (in metres)	Landslide casualties		Avalanche casualties		Landslide Damages	Avalanche Damages
			Killed	Injured	Killed	Injured		
1	Krol	400–1000	0	0	0	0	–	–
2 A	Nagthat	600–1500	0	0	0	0	–	–
3 A	Damta	600–1000	0	0	0	0	–	–
4	Chandpur	600–1000	0	0	0	0	–	–
3 B	Damta	700–1200	0	0	0	0	–	–
2 B	Nagthat	800–1400	34	0	0	0	4 big houses and 8 shops were buried.	–
5	Basioo	1000–1400	0	0	0	0	–	–
2 C	Nagthat	1000–1200	0	0	0	0	–	–
6 A	Almora Group	1000–1400	0	0	0	0	In the Mandakini valley 17 km long stretch of Nandprayag Ghat, motor road had been badly damaged. Several houses collapsed and damaged.	–
2 D	Nagthat	1200–2000	146 25 cattle	7	0	0	Buried the whole of the small montainous village named Daduwa. All the terraced fields of the villages have disappeared. Total loss of crops, property cattle is Rs. 1 lakh. Destroyed 8 houses, 8 goshalas, 19 houses, 23 cattlesheds and grains valued Rs. 40 000 damaged.	–
7	Tejam Group	1300–2000	0	0	0	0	–	–
2 E	Nagthat	1400–2100	0	0	0	0	14 villages are sinking.	–
6 B	Almora Group	1600–2000	0	0	0	0	–	–
8	Joshimath	2000–4400	128	3	24	4	–	Half of the Nepali house, kitchen building of Andhra Dharmsala Site, power house, temple establishment building, Paliwal's Gujrati Niwas, Vaishanava Bhavan, Sant Niwas and some private houses damaged. Some buildings of Kali Kamli Wala, the outhouse of Andhra Building of Badrinath temple damaged. All the houses in the market area of the 10 300 feet town at the base of the Nilkantha damaged. Birla house was partly damaged. Also destroyed the civil police post, barracks and all the three schools.

Table 10. Kalka-Rampur Highway. Casualties and Damages within the Lithological and Elevation Zones.

Index No.	Lithological Zones	Zonal Elevation Range (in metres)	Casualties Killed	Casualties Injured	Landslide Damages	Avalanche Damages
1	Alluvium	600– 900	0	0	–	–
2	Lower Siwalik	700–1700	0	0	–	–
3	Subathu/Murree	1200–1400	0	0	A sudden landslide pushed down a running truck along with parapet. The truck fell about 200 feet below.	–
4	Krol	1400–1600	0	0	–	–
5 A	Nathat	1500–1800	1	0	–	–
6	Blaini	1600–1800	0	0	–	–
7 A	Low Grade	1600–2100	9	2	The landslide has resulted in the slipping down of the circular road below the Rivoli Cinema and damaged a building close by. Disrupted electricity and water supply of Subhash Nagar area. Damaged a saw mill. Houses have sunk about 30 cm while a number of others had developed cracks due to landslides. Telegraph and telephone line have been disrupted at several points.	–
5 B	Nagthat	1800–2400	10	2	–	–
8 A	Basantpur	1800–2400	0	0	–	–
7 B	Low Grade	1800–2800	4	8	–	–
8 B	Basantpur	1200–1800	0	0	–	–
9	Basics	1200–1800	8	0	–	–

Table 11. Mandi-Manali Highway. Casualties and Damages within the Lithological and Elevation Zones.

Index No.	Lithological Zones	Zonal Elevation Range (in metres)	Landslide casualties Killed	Landslide casualties Injured	Avalanche casualties Killed	Avalanche casualties Injured	Landslide Damages	Avalanche Damages
1 A	Larji Shali Fm	1000–1300	7	3	0	0	Breach in water mains	–
2 A	Salkhala Fm	1000–1600	0	0	0	0	–	–
3 A	Manjir Fm.	1100–1200	0	0	0	0	–	–
2 B	Salkhala Fm	1000–2000	6	11	0	0	A motor truck rolled down and was wrecked "A major landslide on the top of one of the 2 support hills of the proposed dam ... upset the construction" (Site at Pandoh).	–
1 B	Larji Shali Fm	1000–1600	2	4	0	0	Roads have been breached at several points	–
2 C	Salkhala Fm	1000–1500	0	0	0	0	–	–
3 B	Manjir Fm	1000–1200	0	0	5	5	The landslide has disrupted water supply.	–
2 D	Salkhala Fm	1000–1400	0	0	0	0	–	–
4	Central Gneiss Fm	1800–2000	0	0	4	5	–	–

avalanches in different lithological and elevation zones. Tables 13 and 14 provide details of casualties and damages along each road in the pre-1967 and post-1967 periods.

In the first two roads (Tables 9 and 10) the two formations worst affected are Nagthat and Joshimath, both located in elevation zones 800 to 2400 metres. The casualties highlight human life lost and the damages reflect a wide spectrum of property, not limited to roads. The worst hit are the terraced fields which involve the efforts of several generations. Effects of continuous urban building are indicated in the avalanche damages in Joshimath and its surroundings.

Larji Shali formation of limestone and dolomite is associated with extensive damages in the elevation zone 1000 to 1400 metres along the Mandi-Manali Highway. Interesting is the obstruction to the construction of Pandoh dam (Table 11). Palaeozoic shales and slates and recent alluvium at elevations of 400 to 2400 metres are associated with damages and deaths, both indicating the suddenness and major impact of movements, along the Jammu-Leh highway (Table 12).

Both landslide and avalanche damages and casualties have been more numerous in the post-1967 than in the pre-1967 era (Tables 13 and 14). The Rishikesh-Badrinath highway has recorded the most gruesome destruction of the burial of a whole village and the killing of as many as 173 persons. Both landslides and avalanches have recorded the largest number of deaths along the Jammu-Leh highway traversing through limestone and shale formations.

Table 12. Jammu-Leh Highway. Casualties and Damages within the Lithological and Elevation Zones.

Index	Lithological Zone	Zonal Elevation	Landslide casualties		Avalanche casualties		Landslide Damages	Avalanche Damages
			Killed	Injured	Killed	Injured		
1 A	Recent	400– 600	25	34	22	–	Destroy a labour-shed near the site of a Hydal project at Salal.	–
2	Upper Siwalik	400– 600	0	0	0	0	–	–
3	Middle Siwalik	700– 900	0	0	0	0	–	–
4	Murree Series	700–1400	0	0	0	0	Road was badly damaged	–
5	Lower Precambrian	800–1900	0	0	0	0	–	–
6 A	Paleozoic	800–2400	93	0	0	0	A truck was caught in the landslide	–
1 B	Recent	600–2500	25	0	132	35	–	Destroys a house. Some huts were also destroyed. Power supply disrupted. The "blackout" was caused by disruption of electric lines and suspension of the working of the Ganderbal power house whose feeding channel choked by avalanche. Telecom also disrupted.
6 B	Paleozoic	1800–2000	0	0	0	0	–	–
7 A	Triassic	2000–2800	0	0	0	0	–	–
8 A	Cretaceous	2500–2800	0	0	0	0	–	–
9	Cambrian	2400–2600	0	0	0	0	–	–
7 B	Triassic	2600–2800	0	0	0	0	Srinagar-Leh Road suffered extensive damage	One of the huts was completely washed away.
10	Mesozoic	2600–3000	0	0	0	0	–	–
8 B	Cretaceous	3200–3600	0	0	0	0	–	–

Table 13. Landslide Damages and Casualties, Pre- and Post-1967.

Highway	Casualties				Property Damages	
	Pre-1967		Post-1967		Pre-1967	Post-1967
	Killed	Injured	Killed	Injured		
Rishikesh-Badrinath	135	–	173	10	Buried the whole of the small mountainous village named Daduwa. All the terrace fields of the villages have disappeared. Total loss to crops, property, cattle Rs.one lakh.	Road had been badly damaged. House collapsed. Destroyed 8 houses, 8 goshalas. 19 houses and 23 cattle sheds were destroyed. Grains valued Rs. 40 000 damaged. 14 villages between Pipalkoti and Joshimath are sinking.
Kalka-Rampur	13	12	19	0	Resulted in the slipping down of the circular road below the Rivoli cinema. Number of buildings have been damaged. Damaged telegraph and telephone communication from and to Simla. Damaged a saw mill.	Houses have sunk about 30 cm while a number of others had developed cracks due to landslides. Telegraph and telephone line have been disrupted at several points.
Mandi-Manali	2	4	13	14	A motor truck rolled down and was wrecked. Mandi-Kulu road have been breached at several points.	Breach in water mains. Disrupts the construction of dam at Pandoh site. Disrupted water supply.
Jammu-Leh	25	0	118	34		Destroyed a labour shed. Road was badly damaged. Destroyed one truck. Extensive damage to Srinagar-Leh Road.

Table 14. Avalanches Damages and Casualties, Pre- and Post-1967.

Highway	Casualties				Property Damages	
	Pre-1967		Post-1967		Pre-1967	Post-1967
	Killed	Injured	Killed	Injured		
Rishikesh-Badrinath	8	–	16	4	Half of the Nepali house. Kitchen building of Andhra Dharmsala Site. Power house, temple establishment building, Paliwal's Gujrati Niwas, Sant Niwas and private houses damaged. Some buildings of Kalikamliwala, the outhhouse of Andhra Building of Badrinath temple damaged. All the houses in the market are damaged. Birla house was partly damaged.	Avalanches also destroyed the civil Police Post, barracks and all the three schools.
Kalka-Rampur	0	0	0	0		
Mandi-Manali	9	10	0	0		
Jammu-Leh	15	0	139	38		Some huts were destroyed. Power supply disrupted. The "blackout" was caused by disruption of electric lines and suspension of the Ganderbal power house. One of the huts was completely washed away.

The avalanches and landslides which occur at higher elevations and in the trans-Himalayan zone pose the greatest difficulty to the problems of their management. They are relatively inaccessible and are located at large distances from the local and regional centres of administration and have poor or practically no communication facilities with the main settled areas.

7. Conclusion

Developmental activities accompanied by landslides have two dimensions, spatial and temporal. Accordingly, landslides have also two distributional components, spatial and temporal. Spatially, the landslides and the human casualties and property damages caused by them are concentrated in the cis-Himalaya. Temporally, they were concentrated in the post-1967 period of the post-Independence era.

Slate, shale, limestone, and orthoquartzite, particularly in the zone of crushing along the faults, comprise the lithological factor. The steep slopes mainly a function of the original structural dips provide a conducive topographic setting. High intensity and high amount of rainfall and snowfall complete the list of natural causal factors of landslides.

Removal of forests, development of urban mesh, and elaboration of transportation network have been the principal human correlates.

Man, through imprudently operating the processes of development, causes extensive damages to the ecological resources and distortions in the arrangement of ecological settings. The damages and the distortions retard the development processes. Development, thus, implemented neutral to ecology becomes counter-productive to both man and nature.

There is hardly any part in Himalaya which is not standing at the threshold of destruction because of the conspiracy being hatched continuously against it by the combined role of lithology, topography, and precipitation, among the natural factors and their relationship with the patterns and activities of human occupance. It is not only the natural but human factors as well which trigger off the geomorphic damages and once they are initiated they set out on an unending chain of self-destruction.

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Discussion to the Paper Mukerji

Prof. Dr. B. Messerli:

The landslides increased after 1967 by human intervention. Did you check, if not also the structure of precipitation changed, that means, that the days with heavy rainfall increased in some years. Could you compare the number of landslides with the number of heavy rainfalls (e.g. more than 70 or 100 mm per day)

Prof. Dr. A. B. Mukerji:

There are very few rain-gauge stations in this part of the Himalaya. The regional newspaper reports suggest that the total annual and summer monsoon rainfall has not changed to any significant extent. Enquiries with local people supports the suggestion. The local meteorological office informs that the change in the number of heavy rainfall days has been marginal. A more careful search is definitely needed. The number of landslides and the number of heavy rainfalls have not been compared but the newspaper reports are full of details regarding the heavy rainfall and associated landslides occurring in quick succession. The burst and pulses of the monsoon are definitely related to the occurrences of the landslides and the two are concurrent.

Prof. Dr. B. Messerli:

Could you differentiate the landslides caused by the road constructions from the ones independent of the road.

Prof. Dr. A. B. Mukerji:

Yes, the landslides near the road occur at lower elevations, involve cultivated fields and irrigation channels, are many in number but smaller in volume, and are on moderately steep slopes. There is a large volume of rock fall off the slope which has its foundation destroyed. In contrast the landslides occurring at distances from the road have sites at higher elevations, on steeper slopes, barren or eroded surfaces, and thin soils with lot of grus. These landslides are massive. However, their frequency reported in the newspaper is much smaller which may be attributed to their limited accessibility.

Prof. Dr. P. Höllermann:

Did you find any correlations of the occurrence and frequency of the landslides or avalanches with seismic events (i. e. earthquakes)?

Prof. Dr. A. B. Mukerji:

There have been many more landslides than earthquakes but each earthquake has generated a number of landslides either concurrently or subsequently. The earthquake of January 19, 1975, generated a large number of landslides in Himachal Pradesh along a stretch of about 100 km of the National Highway.

Prof. Dr. M. L. Salgado-Labouriau:

In Venezuela high mountain landslides occur in densely forested areas with no connection with roads and therefore with no connection with human use of the land. Have you noticed this also in the Western Himalaya?

Prof. Dr. A. B. Mukerji:

Yes, such sites are also known, but their reported number is small. Mostly they occur on the north-facing slopes of the east-west ridges. They involve a huge mass of soil as well along with regolith and have higher sites on steeper slopes.

Prof. Dr. S. Hastenrath:

Could an increased effectiveness of news reporting have contributed to the apparent secular increase of landslides?

Prof. Dr. A. B. Mukerji:

Yes, it surely has done so. But the limited resources of the regional newspapers have increased only little between the pre- and post-Independence periods in India. Hence, the entire or even a major part of the increase cannot be explained by the increased effectiveness of reporting. The number of slides has increased from 87 during the pre-1967 period to 301 during the post-1967 period, and between these two periods there was little change in the network of news reporting.

Prof. Dr. H. Uhlig:

I think the fast increasing use of heavy machinery in construction and clearing (after landslides) of the mountain roads causes a good deal of the growing extent of destruction by land-slides. The impact of these heavy machinery is much worse than former work by use of hand-tools.

Prof. Dr. A. B. Mukerji:

I am grateful to Professor Uhlig for this suggestion. I agree with it. In the zone of breccia along the Main Boundary Fault the effect of heavy machinery and blasting of the rocks is intensified. The heavy machinery generates local tremors and further loosens the already weakened clastic rocks helping the process of landslide.

Dr. C. Schubert:

How old are the roads you report on? Could it be that construction and improvement are recent and, therefore, landslides are more frequent now, before stabilization of the slopes and road-cuts? There are good examples of this sort of thing in the Venezuelan Andes.

Prof. Dr. A. B. Mukerji:

All the four roads reported on are old. But before the 1950s they were narrow and untarred, with concretionary, limestone nodule pressed on the surface. In the early 20th century most parts of the roads were meant for pony and mule rides and people were also transported in a version of palanquin. The tarred, wide roads have been constructed recently. They are being widened continuously by cutting into the hill-side slopes. Heavy vehicular movements are intensified and the load on the slopes has been increased considerably. You support my basic hypothesis that development has lead to destruction. Development which is supposedly ecology-neutral is ultimately ecology-destructive.

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Methods for the Assessment of Mountain Hazards and Slope Stability in Nepal

Hans Kienholz, Heini Hafner, Guy Schneider and **Markus Zimmermann**

With 2 Maps, 11 Figures and 2 Tables

Summary

The primary concern of the Monntain Hazard Mapping Project, sponsored by the Nepal National Committee for MAB and by the United Nations University, is research on slope stability and mountain hazards in three test areas in Nepal, and the preparation of maps precisely defining the level and type of hazard. The first test area is in the Kathmandu-Kakani Region. The site of approximately 60 km² consists of steep slopes, most of which have been terraced for irrigated or rain-fed cultivation. Chapter 2 provides some basic data on this area, including:

- a land-use map and a map of geomorphic processes, both at a scale of 1 : 10000;
- results of the research on geomorphic processes; and
- the perception of hazards by the local people.

This is followed by a description of the procedure being used to assess slope stability and mountain hazards and an overview of the ongoing work to develop an index of slope lability.

In the last part of the report there is a brief outlook concerning hazard index mapping in the Khumbu (Everest) Area. The mapping is primariliy modelled on the "Natural Hazard Index Map for Forest Maintenance Projects in the Swiss Alps".

1. Introduction

The "Schesatobel" in Austria is considered the biggest recently generated concave landform in central Europe. Since 1796 4 million cubic meters of material have been eroded. This erosion was directly caused by man's activity when in 1796 political disagreements between 2 communities led to radical deforestation. Despite high financial expenditures and advanced technology, it has not been possible in almost a century to get the process of erosion fully under control (FIEBIGER, 1974).

The situation in the Himalaya region is even much less favorable!

Two natural factors account for the higher hazard potential of this region:

- the tectonic uplift is 5 to 10 times greater than in the Alps; and
- the subtropical monsoon climate on the southern slopes of the Himalayas causes heavy weathering of the bedrock and great oscillations in runoff.

Socio-economically, the hazard potential is greatly increased by population pressure which leads to deforestation and farming on steep slopes.

The financial and technical resources available to the Nepalese are much more restricted than in Europe so that only very few measures against natural and man-made hazards are available to them.

Therefore, under the conditions in areas such as the Nepalese Midland Hills, preventive measures or, at the most, economical corrective measures have to be used to control natural and man-made hazards instead of sophisticated and expensive technical measures (Fig. 1).

This means that measures which focus on adapted land-use are our primary concern. Of course, instituting proper forms of land-use leads to major difficulties arising from economical, political and also

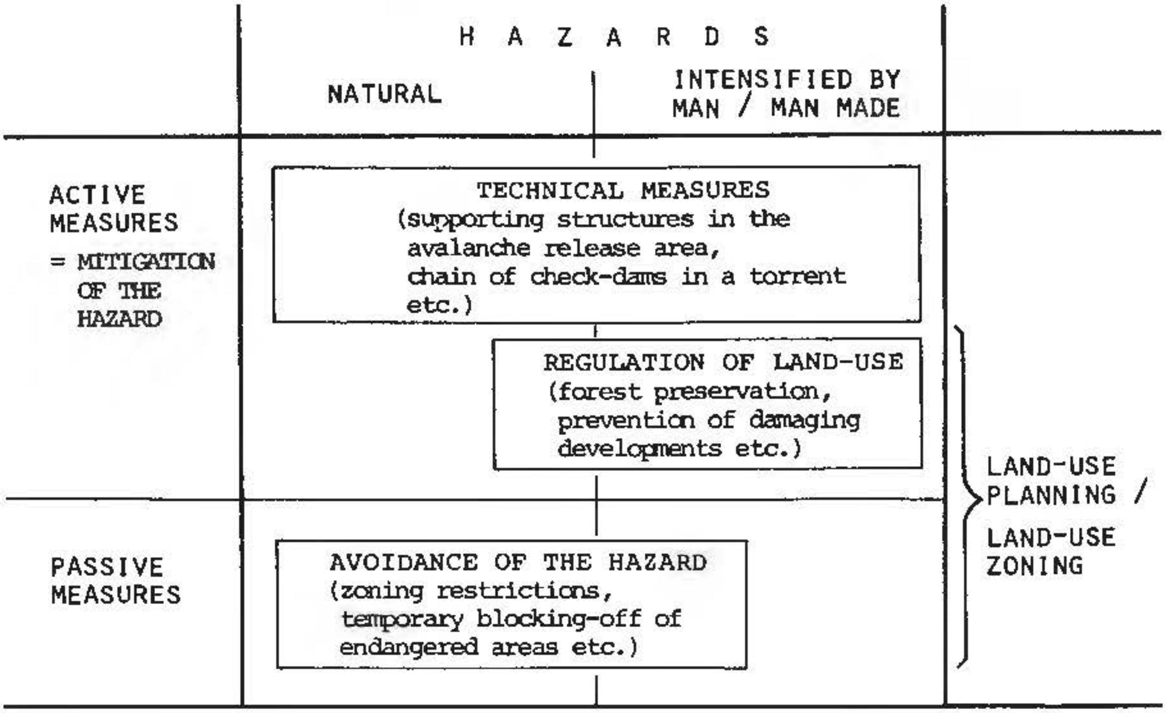

Fig. 1. Countermeasures against hazardous processes in and from mountain areas.

ethical constraints. However, despite all these problems, there is an imperative need for scientific and technical data in order to propose clear guidelines for proper land-use.

As a first step in the development of such guidelines, we need to show the spatial distribution of the areas which are endangered by natural or man-made hazards.

In this context, the Nepal National Committee for Man and the Biosphere and the United Nations University are carrying out a research project in Nepal: the "Mountain Hazard Mapping Project". It is integrated in the subproject "Highland-Lowland Interactive Systems" of the Development Studies Division of the United Nations University (IVES and MESSERLI, 1981).

The following institutions are in charge of the realization of this project:

- Nepal National Committee for Man and the Biosphere
- University of Berne, Switzerland
- University of Colorado, Boulder, Colo., USA
- Clark University, Worcester, Mass., USA

The main goal of the MHM Project is to evaluate methods for assessing and mapping mountain hazards and slope stability in three test areas in Nepal.

The work in the first test area, the Kathmandu-Kakani area, is almost completed, while work in the second test area, the Khumbu region, is still going on. For a part of the Kakani area we have already proposed a follow-up program which should result in a management plan.

The problems of hazard and slope stability assessment that were encountered in the Kathmandu-Kakani test area, an area which can be considered typical of the Nepalese Midlands, will be discussed, followed by a brief outlook of methodological aspects of the hazard assessment in the Khumbu area.

2. The Kakani-Kathmandu Test Area and Its Problems

The center of the Kakani-Kathmandu Test Area lies about 9 km northwest of the Nepalese capital Kathmandu. Here we are dealing with the portion of the Kakani Area which is situated north of the Royal Forest and which belongs to the uppermost region of the Kolpu Khola Watershed.

This region is characteristic of the Nepalese Midlands, having great variations in altitude (from 1100 to 2300 m) within a short distance, resulting in steep slopes and pronounced relief.

The research area in the Kakani Region is made up of various lithologic units whose layers have a generally east-west strike and an 80 to 90 degree southward dip. In the north, there are gneiss series of variable resistence and in the south, quartzites and phyllites. Tourmaline pegmatite dikes and a granite intrusion in the central part disturb the structural unity (PETERS and MOOL, 1983).

The annual precipitation regime clearly follows a seasonal, monsoonal cycle with distinct rainy and dry seasons. Eighty percent of the rain falls from June to September.

The mean rainfall during this period varies from 1100 mm (at Kathmandu Airport) to 2400 mm (in the Kakani Region). The greatest possible (maximum) rainfall in a single day with a recurrence interval of one hundred years is computed to be almost 200 mm for Kathmandu (CAINE and MOOL, 1982, p. 168).

The average annual temperature in Kathmandu is 18 °C. May, the warmest month, has an average maximum temperature of 30 °C, and January, the coldest month, an average minimum temperature of 10 °C.

The relatively low resistance of biotite gneisses, phyllites and quartzites in combination with climatical and other environmental conditions leads to a generally heavy weathering of the substrates in the Kakani Area. The bedrock is very deeply disintegrated.

The soils were probably able to develop continuously since the Pleistocene Epoch. Red, weathered soils in a few areas could indicate an even earlier date. Therefore, even in spite of acidity and a lack of phosphates, the arable soils are quite fertile.

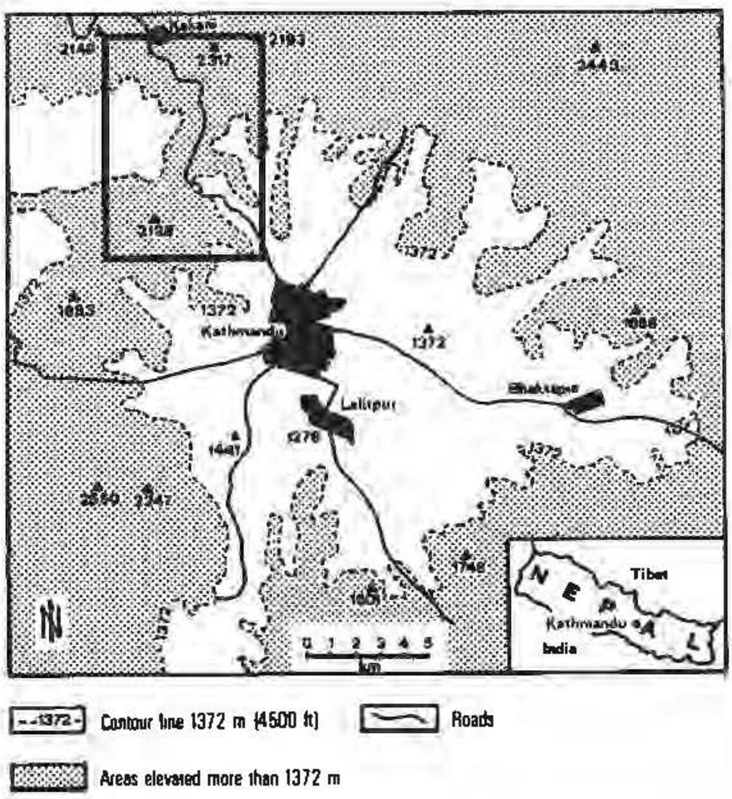

Fig. 2. Location of the Kakani-Kathmandu test area.

Fig. 3. Part of the Kolpu Khola Watershed within the Kathmandu-Kakani test area.

Fig. 4. Flooding of terraced fields.

In the test area of the Kakani Region our estimates indicate a population density of 250 to 300 inhabitants per square km. The people belong to several ethnic groups. The Tamangs and the Newars are of tibeto-nepalese origin; the Brahmans and Chetris of indo-nepalese origin. These people depend primarily on agriculture for their livelihood.

Most of the land is used for farming. The cultivated fields are terraced and are either irrigated or non-irrigated.

The irrigated terraces are level and have a embankment on the valley side to retain irrigation water. Rice is grown on these terraces mainly during the rainy season. Wheat is grown during the rest of the year (Fig. 4).

The non-irrigated terraces are inclined and depend solely on rainfall for water. Corn, millet and buckwheat are the main crops. Various other crops of secondary importance are also grown. Almost all of the non-irrigated terraces are left fallow for about 2 months each year.

In many irrigated as well as non-irrigated areas we find gullies, slumps and landslides. Particularly in areas with non-irrigated terraces, these damages have developed into actual badlands (Fig. 5). In the vicinity of irrigation channels, erosion and landslides are frequent.

The key processes which lead to the above mentioned phenomena are water erosion, gullying, slumping and landsliding.

The main effect of these processes is an endangerment of the soil. If no counter-measures are taken, it leads to a loss of soil, which, despite the relatively favourable substrate, causes a reduction in the basis of production for the local population. The eroded surface soil is carried downstream and increases the rate of siltation in the lower lying areas. In certain places of the research area, these processes can directly endanger houses, cattle and even people (Fig. 7).

2.1. Basic Data and Hazard Assessment in the Kathmandu-Kakani Area

There are several possible ways of approaching the problem of slope stability assessment in the Kakani-Kathmandu Test Area:

- by consulting experts; this is subjective and difficult to verify.
- by measuring the necessary parameters and calculating stability; this involves technical problems of measurement and is very time-consuming.
- by analysing "silent witnesses" and comparing them with the pattern of actual damages.

Main emphasis was placed on the last method, because with this method we hope to obtain the optimal fulfillment of the following 3 postulates:

Fig. 5. Gully surrounded by non-irrigated terraces and pasturage.

Fig. 6. Piping below furrows of non-irrigated terraces.

1. a high degree of accuracy;
2. a high degree of objectivity; and
3. reasonable time expenditure.

In the Kathmandu-Kakani Research Project quantitative methods are also used in some areas for the first step of gathering data.

Along with the geological study (PETERS and MOOL, 1983) this basic data consists of a land-use map, a map of geomorphic damages, studies about morphodynamic processes and local risk assessment.

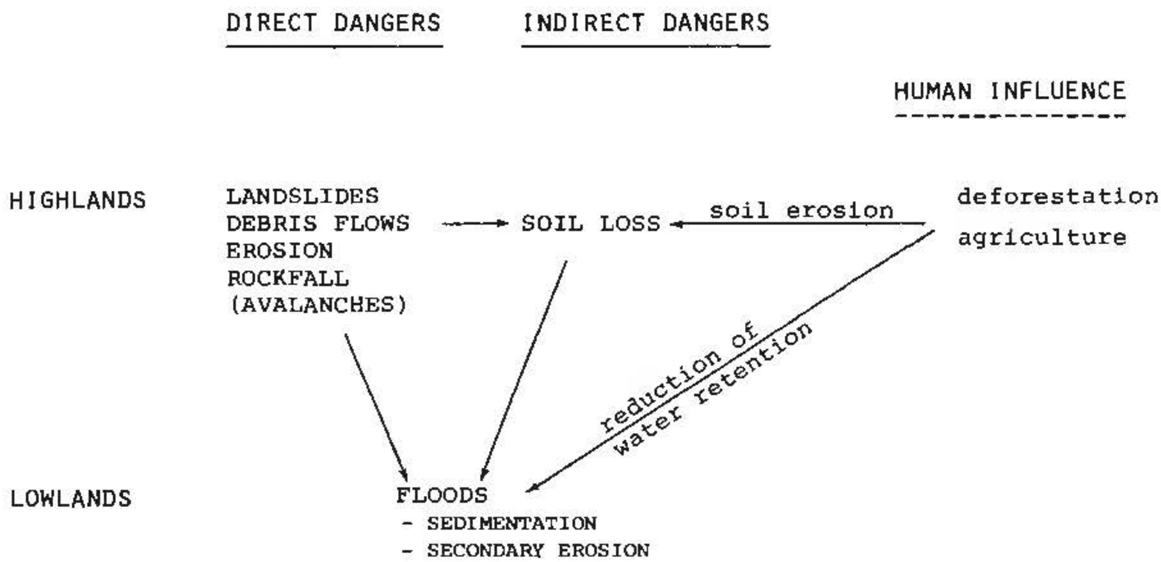

Fig. 7. Geomorphic dangers and the effects of human influence in highland – lowland systems.

2.1.1. Land-Use Map and Map of Geomorphic Damages at a Scale of 1 : 10 000

(The entire maps are published in KIENHOLZ et al., 1983.)

The land-use map shows the formal aspects of land-use as they are presented in the landscape (cf. the section shown on map 1):

- The irrigable terraces in the test area are found for the most part in the Kathmandu Valley, as well as along rivers and on gently sloping (not so steep) ridges in the Kolpu Khola area.
- There are non-irrigable terraces, pastures and shrubland on the steeper slopes.
- Other types of land-use shown on the map are: forest (mostly deciduous forest, in some areas also *pinus roxburghii*), areas with idle terraces and barren land.

It was possible to get an indication of formal changes in land-use for a few parts of the test area by comparing aerial photographs taken in 1964 and 1971 with the actual situation in the winter of 1979/80.

The area on Figure 8 of about 350 hectares shows a considerable increase in terraced area at the expense of pastureland in eight years.

Processes of erosion make-up the major and most detailed part of the legend of the map of geomorphic damages (cf. the section shown on map 2). The most important processes are:

- gully and badlands formation;
- landsliding; and
- sliding caused by vertical cutting of creeks.

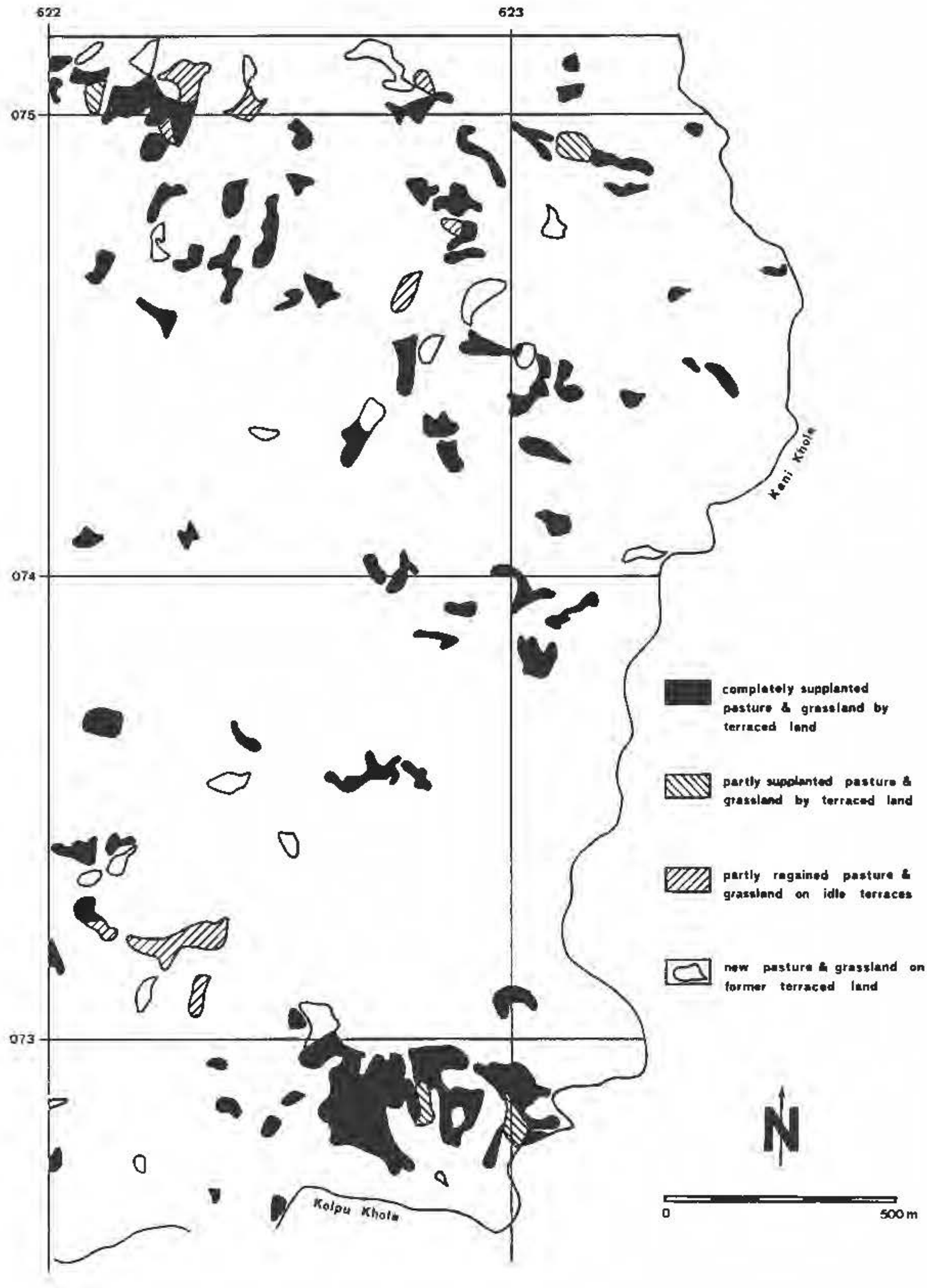

Fig. 8. Dynamics of pasturage and grassland with respect to the arable land; comparision of the conditions 1971 and 1979/80.

These 2 maps provide a detailed, site-specific illustration of the phenomena that were surveyed as well as the following results:

- Forested areas are the least susceptible to geomorphic damages, although they are probably increasingly being degraded by overuse, for example, in the form of woodcollecting and forest grazing.
  Because the lower stratum of large parts of the Jamacok hills consists of limestone, these hills are relatively resistent to erosion anyway.
- Irrigable as well as non-irrigable terraces often show signs of damage. However, particularly in the case of valuable irrigable terraces damages are industriously repaired each time.
- Serious damages generally occur less often on pasturage than on cultivated land. On the other hand pasturage often shows numerous, slight damages caused by overgrazing and neglect. No doubt, many areas that have been mapped as barren land are former pastures that have been destroyed by severe erosion.
- Man plays an important part in the formation of geomorphic damages. Extensive irrigation networks with defect-prone canals and problematic drainage aggravate the situation. Although the farmer takes steps to stem erosion on his own land, the upkeep of community installations generally seems to be poor!

2.1.2. Morphodynamic Processes

Research on morphodynamic processes in the Kathmandu-Kakani Area by CAINE and MOOL (1982) has led to the following information:

1. The phyllites, quartzites and biotite gneisses of the central southern part of the area appear to be appreciably weaker than the augen gneisses or granites in the northern part.
2. The critical slope angles derived from the shear strength of each material in a drained and in a saturated state are shown in Table 1. Even though these values should be applied with discretion due to their model-oriented nature, we must bear in mind that large parts of the test area have slope angles between 20 and 40 degrees and that these slope angles, which lie in the critical range, have been altered by terracing.
3. Many of the surficial materials of the Kathmandu-Kakani Area behave in a brittle manner. This is demonstrated by the large reduction in their strength following disturbances such as landslides, earthquakes or cultivation.
4. Even though rainfall intensity often exceeds the empirical limit for triggering landslides, groundwater conditions are apparently more influential. This is confirmed by the fact that most events happen during the second half of the monsoon season.
5. Erosion is generally caused by a combination of different processes. Although totally unrelated processes are involved in the initial stages, in the course of further development they tend to converge into gully-building.

Table 1. Critical slope angles on debris (CAINE and MOOL, 1982, p. 164).

Lithology	θ_{crit}(drained)	θ_{crit}(saturated)
Phyllite	32.8°	18.5°
Biotite Gneiss	41.5°	20.8°
Augen Gneiss	44.2°	24.4°
Granite	42.8°	21.8°

2.1.3. Local Risk Assessment and Human Response

An American-Nepalese group conducted a study with the aim to document local knowledge of hazards in the physical environment and to establish the relationship of this knowledge to commonly practiced hazard control measures (JOHNSON et al., 1982).

In spite of many linguistic and psychological problems that are naturally connected with such interviews, important information was gained. For example, farmers clearly distinguish between 2 major forms of landslides: One is the result of gradual deterioration, erosion and gullying and the other is characterized by sudden slumping of irrigated terraces. While gradual deterioration is viewed as the result of natural processes in combination with human activity, the unpredictability of sudden landslides on irrigated terraces gives rise to explanations with reference to supernatural causes.

2.2. The Actual Assessment of Slope Stability and of Hazards

As already mentioned, the method consisted in observing past events and in making comparisons. The following two questions were asked about each slope unit:

- what has happened here until now; and
- what is happening or has happened on neighboring slopes of similar appearance?

Of course, the basic information described above was indispensable for answering these questions. The use of this method is relatively unproblematic in those areas where damages are evident. However, its application on outwardly intact slopes is more difficult for the following reasons:

1. Due to the lithological, geological-structural and climatic conditions already mentioned, as well as frequent slope angles in the 20 to 40 degree range, the slopes are probably generally labile.
   Numerous concave forms that are faintly pronounced and that have been effaced by intensive cultivation can be viewed as indicators of previous landslides and other processes of erosion.
2. "Silent witnesses" indicating earlier morphodynamic processes are apparently so well masked by intensive cultivation that after just a few years they are imperceptible even to the trained eye.

The assessment method is divided into the following steps (Fig. 9):

The first step consists in dividing the test area into circa 2000 unit areas according to hydrographic and geomorphic criteria (cf. Table 2).

In the second step the instability in an unit area is assessed with the help of a form. This form is divided into five sections (cf. Fig. 10):

Table 2. Delimitation of slope-stability unit areas (Kathmandu-Kakani Area).

Priority	Criterion
1	Border between depressions of streams/creeks and "open" slopes
2	Accumulation of certain types of damage (from map of geomorphic damages)
3	Change in lithology
4	Change of general slope angle
5	Change in land-use (from land-use map)
6	Change of slope direction (of more than 90°)

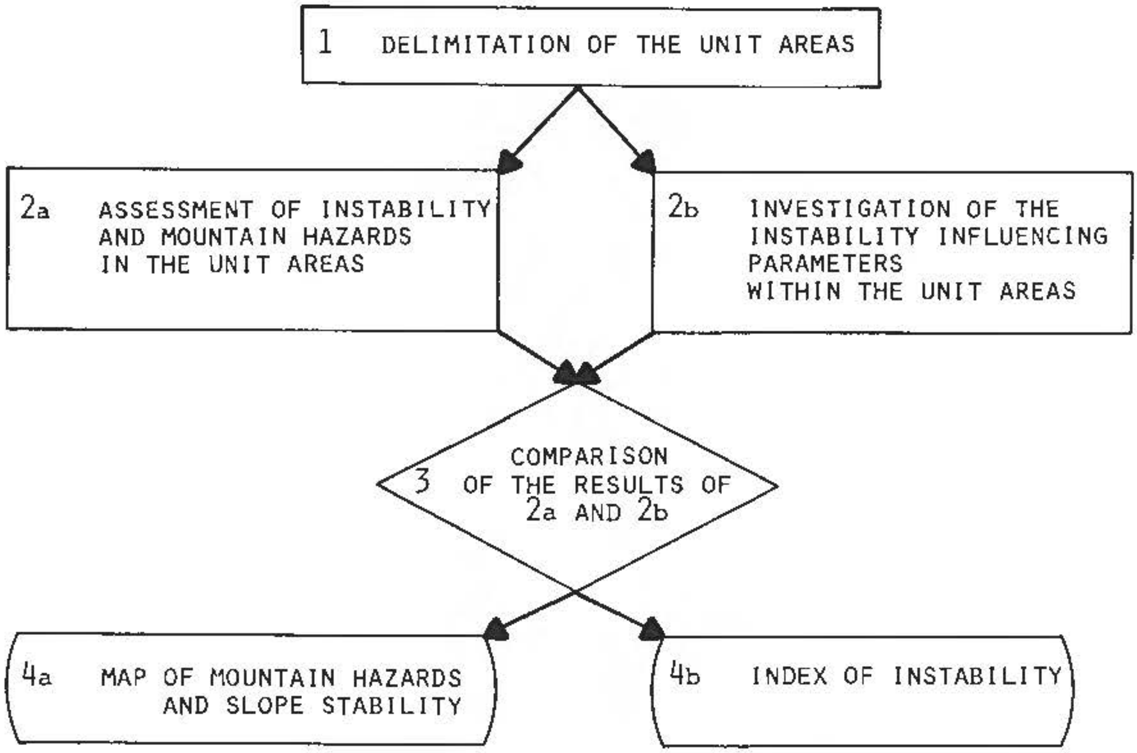

Fig. 9. Procedure for assessing and mapping slope instability and mountain hazards and for the compilation of an index of instability.

In the first section of the form confirmed instabilities are registered, whereby instabilities that affect almost an entire unit area are distinguished from those which only affect a small part of a unit area.

In the second section of the form, if such information is available, any assessments gained from interviews with local informants are noted.

The third section of the form consists of the fieldworker's assessment of the unit areas. If there is a high probability of occurrence of a certain process, it is entered in the column "inferred"; if there is a slight probability of occurrence, it is noted in the column "supposed".

The fourth section of the form refers to the interpretation of factors thought to influence slope stability (e.g. type of bedrock, strike and dip, type of clastic material, hydrogeological situation, slope angle etc.). This corresponds to step 2b in Figure 9.

The fifth section of the form contains supplemental data about any eventual endangerment by processes occurring in neighbouring areas; for example, lateral erosion by a stream in the neighbouring area.

The third step in the evaluation process involves contrasting the data collected about influential factors with the actual damage configuration and with the "inferred" and "supposed" processes and hazards. If, for example, certain data concerning influential factors significantly coincides with a specific damage configuration or with an "inferred" or "supposed" hazard configuration, other unit areas with the same or similar data are examined for the corresponding type of endangerment.

The first part of step four (4a) consists in processing the results of steps one to three and then compiling them in the actual map of mountain hazards and slope stability which will be published in KIENHOLZ et al. (1984).

I CONFIRMED INSTABILITY

WHICH PROCESSES OCCUR OR HAVE VISIBLY OCCURRED IN THE UNIT AREA CONCERNED ?

E = deep erosion by water (> 2 m)
e = superficial erosion by water (< 2 m)
e' = very superficial erosion by water (topsoil only)
L = deep landslide (> 2 m)
l = superficial landslide (< 2 m)
l' = collapse of single man made terraces
T = major torrential activity
t = minor torrential activity
D = debris flow
A_D = accumulation of debris flow
A_W = accumulation of water-transported material
F = flooding
R = rockfall source area
A_R = accumulation by rockfall / rockfall area

PROCESS	FEW < 50% OF UNIT AREA	MANY / > 50% OF UNIT AREA	
E			
e			e'
L			
l			l'
D			
A_D			
A_W			
F			
R			
A_R			

15 … 24

II ASSESSMENT OF UNIT AREA BY LOCAL PEOPLE

1. ANSWER: ------------------------------------
2. ANSWER: ------------------------------------
3. ANSWER: ------------------------------------

------------------ 25

III SUBJECTIVE ASSESSMENT OF INSTABILITY

HOW IS THE UNIT AREA ASSESSED BY THE ELABORATOR ?

PROCESS	INFERRED FEW / < 50% OF UNIT AREA	INFERRED MANY / > 50% OF UNIT AREA	SUPPOSED FEW / < 50% OF UNIT AREA	SUPPOSED MANY / > 50% OF UNIT AREA
E				
e				
L				
l				
D				
A_D				
A_W				
F				
R				
A_R				

26 … 37

IV OBJECTIVE ASSESSMENT OF INSTABILITY

SEE CHECKLIST ON THE REVERSE SIDE !

V "IMPORTED" INSTABILITY, CAUSED BY PROCESSES WHICH ORIGINATE IN OTHER UNIT AREAS

COMING FROM UNIT NO.:								
TYPE OF INSTABILITY :								

38 … 48

Fig. 10. Excerpt of the preliminary form for assessing slope stability (see text for explanations).

Cartographically, the map of mountain hazards and slope stability follows the traffic light concept:

- Each degree of hazard is illustrated by a different color:
  - red stands for danger;
  - brown for labile/instabile with regard to soil loss;
  - yellow for warning; and
  - green for supposedly not endangered.

  The degree of hazard is classified first according to the type of process involved and then according to the type of evidence ("confirmed", "inferred" or "supposed") on which the assessment is based.
- The type of hazard process found in each unit area is indicated by a letter.

The second part of step 4 (4 b) consists of an index of instability. The purpose of this index is to provide a simple instrument for assessing the endangerment of slopes in the Nepalese Midlands by different processes in a quick but accurate and objective way.

It hasn't been decided yet whether this stability index will be based on a point system or on a system of logical decisions. The latter has been proven very effective for landslide hazard assessment in the Alps and in the Rocky Mountains.

We hope to succeed in developing such a stability index that could be used in other areas of the Nepalese Midland Hills. In the meantime, work in the Kakani area is proceeding. Based on the data gathered until now, as well as on complementary investigations, the development of a realistic management plan for a part of the area is planned.

3. A Brief Outlook Concerning Hazard Assessment in the Khumbu Area

A hazard index map is being made for Sagarmatha National Park (Mt. Everest region), including the major access corridor to the park between Lukla and Namche Bazar. The topographic maps at a scale of 1 : 50 000 from the "Arbeitsgemeinschaft für Hochgebirgsforschung" in Munich form the basis.

Fig. 11. Dudh Kosi River between Namche Bazar and Lukla. (The fresh cuts are caused by a flash flood after a jokulhaup in 1977).

The hazard index map is primarily modelled on the "Natural Hazard Index Map for Forest Maintenance Projects in the Swiss Bernese Oberland" (GRUNDER, 1980; GRUNDER and LANGENEGGER, 1983). Four major kinds of natural hazards are being mapped:

- rockfall;
- landslides;
- mountain torrents;
- avalanches.

Additionally it is determined whether the endangerment of a certain area by a specific hazard is "confirmed" or only "supposed".

The major hazards in the area between Lukla and Namche Bazar, which is on the main tourist route and where many new lodges are being built, are instable rockwalls and unpredictable flooding from the Dudh Kosi River (Fig. 11). Flooding is caused by the outbreak of ice-dammed lakes, by "jokulhaups".

In addition to the above-mentioned hazards, in the higher-lying zones, which are also permanently settled and frequented by tourists, severe forms of erosion which can lead to debris flows are to be expected in the pleistocene fluvio-glacial sediments. There is also historical evidence that Namche Bazar is threatened by avalanches.

In order to make the results of our research in an area that is constantly undergoing change (mainly due to expanding tourism) available for use in management planning, we plan to illustrate the results in a simplified map, using traffic signal colors.

The aim of our research in the Khumbu Region and in the Midland Hills is not only to solve methodological questions of hazard assessment, but, hopefully, also to help solve some of Nepal's vital problems.

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Discussion to the Paper Kienholz

Prof. Dr. E. Löffler:

Your assessments depend heavily on the reliability of your mapping. What are the criteria for the mapping, and how homogeneous are the units?

Dr. H. Kienholz:

- The hazard assessment in the Kathmandu-Kakani Area is extensively supported by basic information which was gathered as mentioned in the paper. This basic information is mainly the result of detailed fieldwork and mapping.
  The map of mountain hazards and slope stability shows whether the hazards are confirmed, inferred or supposed. A hazard is "confirmed" if there are actual damages or "silent witnesses" (e.g. tensile cracks) or former or actual movements in the considered "unit area". A hazard is "inferred" if there are no actual damages in the considered area, but if there are such damages in comparable areas. A certain subjectivity in the case of "inferred", and, to a greater extent, of "supposed" hazards is inavoidable. However, as it is mentioned in the paper (step 4a of Figure 9) we are in the process of elaborating a procedure which will produce more objective and transparent results. Unfortunately, due to organizational constraints it was not possible to have this procedure ready for the actual mapping.
- The so-called "unit areas" very often are not as homogenous as it would be desirable. This is due to the pronounced relief and to the restrictions inherent in the map scale. Changes of hazard degree within short distances are shown on the map by special colours and signatures.

Prof. Dr. W. Haffner:

Is there a correlation between the number and the extent of damages caused by landslides and special, ethnically conditioned forms of terrace-building, shaping of the landscape or cultivation methods in general?

Dr. H. Kienholz:

We have not directly studied this problem and therefore it is not possible to give a final answer. It seems that natural factors (slope angle, geology, water, soil etc.) and terracing and irrigation per se are predominantly responsible for landsliding.

Prof. Dr. G. Abele:

Which is the influence of terrace-agriculture on size and type of landslides and related phenomena?

Dr. H. Kienholz:

In the long term weathering and erosion, which are natural processes, cannot be stopped. Most of the agricultural terraces are *cut* into weathered material in situ; very few *constructed* terraces are found. It seems that terracing generally causes more, but smaller and shallower erosion and landsliding than there would be in a natural slope:
- Interruptions of slope angle, caused by terracing (mainly by non-irrigated terraces) are the origin of small linear erosional phenomena and of small slope failures.
- Piping is probably accelerated by irrigation but also by water concentration in the furrows of non-irrigated terraces (cf. Fig. 6).
- The remoulded material of the terraces facilitates terrace collapse and the beginning of gullying or surficial landsliding.

However, these phenomena only remain small, as long as the farmers quickly repair the terraces.

Prof. Dr. W. Weischet:

1. Does the delimination of the unit areas result from the superimposition of six maps representing factors as lithology, slope angle, erosion phenomena etc., which all exercise an influence on stability or instability?
2. The calculation of an instability index as the sum of the different risk factors may be necessary for cartographic representation, but, for the interested, the index obscures the regionally differing causes of instability. A scheme for representing these causes should be developed.

Dr. H. Kienholz:

1. The delimitation of slope-stability unit areas is mainly based on informations from the topographic map (creeks/slopes, slope angle, slope direction), the map of geomorphic damages, a lithologic draft map and the land-use map (cf. Table 2).
2. The assessment procedure we are developing will basically be a system of logical decisions. This will provide a high degree of objectivity and transparency.

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Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Effects of the High Mountain Environment on Man
A Study of an Isolated Community in the Bhutan Himal

Michael P. Ward

With 1 Figure

About 400 million people live in mountainous areas and of these 20–25 millions inhabit regions above 3000 m (10 000 ft). In South America the highland population was estimated in 1946 as being about 28 million, whilst on the Central Asian plateau and Himalayan valleys between 4–6 million live above 4000 m (13 500 ft) (see: WEINER, in HARRISON et al., 1964; DE JONG, 1968).

Considerable stress, biological and environmental is placed on these populations and adaptation to these stresses can be illustrated in the study of an isolated population living between 4000 m (13 500 ft) and 5000 m (16 000 ft) in Lunana on the Bhutan-Tibet border.

Topographical and political factors suggest that this could be one of the most isolated high-altitude populations yet studied.

In their standard geographical and geological work on the Himalaya, BURARD and HAYDEN (1932) group all the peaks east of Sikkin into one group, the Assam Himalaya. This includes mountains in Bhutan and the North-East frontier agency. In fact the peaks of the Bhutan frontier region are quite distinct and are better referred to as the Bhutan Himal (WARD, 1965 and 1966b; GANSSER, 1964 and 1968).

The mountains of North and West Bhutan are drained by two main rivers, Wang Chu and Punakha Chu, which join just before they enter the Brahmaputra in India.

The Ha, Paro and Thimphu rivers drain the Western part of the Bhutan Himal and join to form the Wang Chu, whilst the Punakha Chu through its two main tributaries, Mo Chu and Pho Chu, drains the adjacent Northern part of the Bhutan Himal.

The main administrative centre for North and West Bhutan is Gaza Dzong (9600 ft) which lies on the west bank of the Mo Chu and is part of an extensive area of cultivation extending South to Tamji (7550 ft). Four districts lie under the jurisdiction and the Head of the Administration, Tinpen, lives at Gaza Dzong. Each district is divided from its neighbour by a definite geographical feature, usually a high ridge and each is drained by a separate river.

The populations of each area are:

Lunana	520
Laya	up to 800
Lingshi	up to 300
Soe	460

Soe

This area is drained by a tributary of the Paro river. At its South West border lies the Tremo LA (16 500 ft), for centuries on a main trade route with Phari in Tibet.

Through Paro in Bhutan this route is connected with Cooch Behar in India. The main village Soe (13 800 ft) lies under the East face of Chomolhari (23 997 ft), a mountain which is a well recognised landmark in the area and which was first climbed from Tibet in 1937 (CHAPMAN, 1938).

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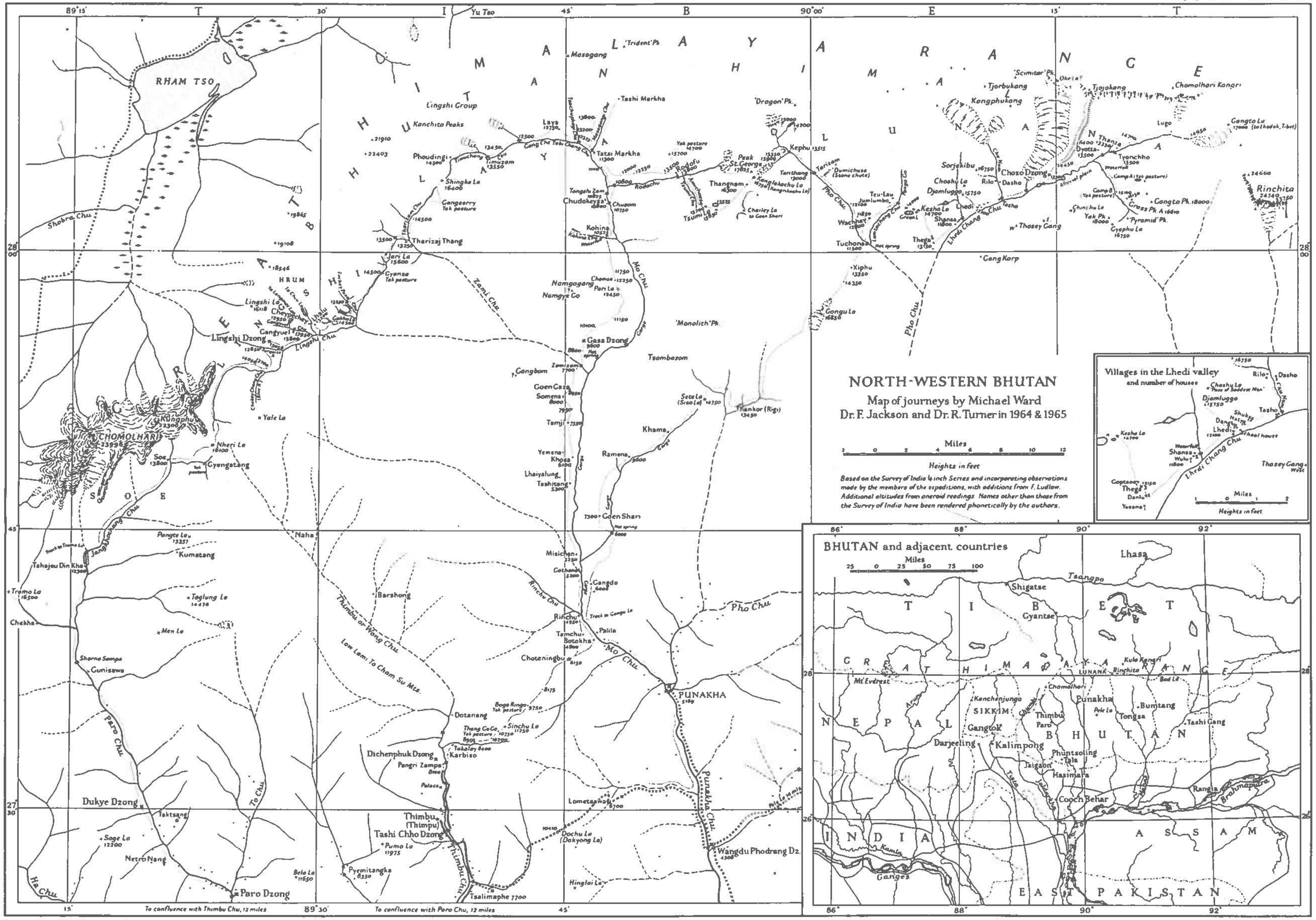

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Fig. 1. Sketch Map of North-Western Bhutan (from: WARD, 1966 a).

Soe comprises mainly yak pastures up to 15–16 000 ft though a certain amount of grain is grown. The boundary with Lingshi is crossed by a pass the Nheri LA (16 000 ft).

Lingshi

This is a wealthier district with more yak pastures. Its main centre is Lingshi Dzong (13 050 ft). This is perched on a hill 400 feet above the surrounding country. It has withstood many Tibetan raiders as water for the defenders was obtained by a secret passage from a river at its foot.

The country is mainly grassland and provides excellent pasture for both yaks and horses.

Lingshi extends from the Nheri LA (16 000 ft) which separates it from Soe in the South to the Shingke LA (16 400 ft) which separates it from Laya to the North and East. A third pass the Yale LA gives access to the Thimpu Chu to the South and East.

Lingshi is drained by the Zami Chu which joins the Mo Chu near Gaza.

Laya

This has the best yak pastures in the North and West Bhutan and there is a large population with extensive fields of barley and mustard. The main village is Laya (12 750 ft). From Tatsi Markha (11 300 ft) trade used to be carried out with Tibet.

The region is drained by the head waters of the Mo Chu. Just South of Tatsi Markha a tributary, the Rodo Chu, joins the Mo Chu. This tributary drains the peaks and glaciers of the Tibet border and of a North-South range which divides Laya from Lunana. From the Rodo Chu, two passes, Tsumi LA (15 700 ft) and Kangla Kachu LA (16 750 ft), give access to the head waters of the Pho Chu and Lunana.

Lunana

This region is drained by the head waters of the Pho Chu. About 520 people live in the area, mainly in the valleys of the Eastern branch of the Pho Chu. Communication with the rest of Bhutan is difficult involving the passage of glacier passes over 17 000 ft. Communication with Tibet was also by means of a glacier pass, which is now closed for political reasons. These passes are often closed due to snowfall, and between January and April the inhabitants of Lunana are effectively isolated.

There are two main tributaries of the upper Pho Chu. The Western is formed by the junction of streams from several glaciers running down from peaks on the Bhutan-Tibet border. A North-South range runs from the range on the Tibetan border towards the valleys of Central Bhutan. This North-South range, which forms the Western border of Lunana, is crossed by two main passes – the Kanglaka Chu LA (16 750 ft) in the North and the Gongu LA (16 850 ft) which is the main communication with Central Bhutan in the South. The Kanglaka Chu LA is glaciated on its Eastern but not Western aspect and is approached from the West over a high plateau with another pass the Tsuui LA (15 850 ft) from the Rodo Chu. A series of sharp pointed peaks, the Rodofu needles lie North of the Kanglaka Chu LA. The Southern most, Peak St. George (17 850 ft), has a very characteristic shape. From its summit a wide panorama of the Bhutan Himal could be obtained with Kangchenjunga and Chomolhari recognisable in the West and Rinchita to the East.

The Gongu LA (16 850 ft) some twenty miles to the South is also a glacier pass and is on the main trade route between Lunana and Central Bhutan.

The valley of the Western branch of the Pho Chu suffered a disastrous flood in about 1950 when a moraine dam burst. This caused flooding as far South as Punakha.

A minor tributary joins this branch of the Pho Chu about twenty miles from the peaks of the Tibet border. This drains a series of minor peaks of yet another North-South spur and crossing this range in the Kesha LA (15 000 ft).

Wachhey is a small group of houses with only about 33 inhabitant lying on a shoulder between the tributary and the Western valley of the Pho Chu.

The Kesha LA (15 000 ft) provides access to the main population of Lunana which lives in the upper part of the Eastern tributary of the Pho Chu. The junction between the Eastern and Western tributaries of the Pho Chu occurs about 5 miles South of Wachhey, but no access is possible with Central Bhutan.

The Northern border of Lunana is the continuation of the peaks of the Tibet border rising to 23 000 ft. Yak pastures rise to about 17 000 ft whilst below about 12 000 ft the slopes of the gorges which descend to the central more populated and cultivated part of the country are covered with both deciduous and evergreen trees. This pattern of vegetation appears to be common to the four other regions of North and West Bhutan. The peaks of the Tibet border run East and West ending in the vast snow plateau of Chomolhari Kangri which dominates Lunana. The Gangto LA (17 000 ft) which provides access to Lhodak, the first village in Tibet, is due South of the East end of Chomolhari Kangri and separates it from Rinchita, a pyramidal shaped peak about 5 miles further to the South.

The position of Chomolhari Kangri and Rinchita appear to be similar to that of Kula Kangri and Kangri as plotted on the Survey of India map of the region. Inspection of photographs taken from the Yu Tso, a lake in South Tibet, identifies Kula Kangri. It is not possible to identify these peaks with those in Lunana, nor is it possible to identify photographs taken of peaks in this area from the South.

The Southern border of Lunana may be divided into two parts. The Eastern portion is high pasture land with rounded peaks of up to 18 000 ft extending for many miles towards the valleys of Central and Eastern Bhutan. Two long and little used routes transverse this region. The Western portion consists of two mountain groups, Thasey Gang and Gang Karp.

Lunana itself is divided into upper and lower regions by the terminal moraine of a glacier which flows from the Oke LA and the peaks of the Tibet border. Above the moraine there is an alluvial plain some 8 miles long and up to 1 mile wide, upper Lunana. At the far end is the Gangto LA. Lower Lunana consists of villages on the steep sides of the Pho Chu.

Administration

Each area has a Headman or "Gup" and each village a "Chipep".

The Gup deals with petty crime, serious cases were sent to the "Tinpen" at Gaza. He organises the payment of taxes and sees that his area provides individuals to work on Government projects. This is done in lieu of direct taxation but a wealthy man can hire a substitute. Before any decision involving the whole area is taken the Gup calls a meeting with representatives from each village.

Economy

The people are semi-nomadic pastoralists. The main crops are barley, sem (a small black round pea), potatoes and turnips (yungdo). A wild carrot (raphu) is also eaten. Rice is imported from Central Bhutan. Wild edible berries and rhubarb are eaten.

Yaks are grazed up to 16 000 ft during the monsoon (August and September) but during the Autumn and Winter they return to grazing areas near villages where they spend the night in the courtyards of houses. They seldom go below 8000 ft. Certain villages, for instance Kama on the route to Central Bhutan via the Gongu LA, serve as a local pasture whilst the herders carry their produce to lower levels. At Gaza Dzong yaks are brought down for a few hours only so apprehensive are the owners of disease.

Yak milk produces rich butter which is sold in Punakha and is one of the main sources of income for the Lunana people. Yak cheese is kept soft in wooden jars or allowed to harden in small pieces and kept on a string around the neck – like a string of beads. Yak wool is used for weaving and the manufacture of clothes and blankets.

In general the diet is vegetarian because meat is scarce. Salt is obtained from India.

There was no sign of malnutrition and babies are breast fed sometimes until 2–3 years old when they are fed an adult diet. Wheat, flour and butter are premasticated and fed to the baby after the age of one month.

Even before the closures of passes with Tibet only the richer families were involved as trade with Punakha was better. In main the community is oriented towards Bhutan rather than Tibet.

The houses in Lunana normally consist of one storey with two or more joined in a terrace or back to back. A partially roofed courtyard is common in which livestock is kept during the winter nights. This is in contrast to houses in Central Bhutan and to the Khumbu region of Nepal where the ground floor is used to shelter animals in the winter. A dry stone construction is used with gaps between stone filled by turf, or a layer of turf with a layer of stones is used.

The richer houses have outside decoration with different colours, the dyes being imported.

In all but the very poor houses a room or a space is set aside for prayer and meditation and there may be an altar with musical instruments.

The living space is clear with usually no chairs, tables or beds. The floors are made of wood or earth, whilst rugs or skins are used for sitting on the floor.

An open fire with no chimney is the rule and no house had any glass, but sliding wood structures are used to keep out the wind and snow.

The majority have one main room with a store room and the walls have shelves for pots and pans which appear to be a symbol of wealth. Some are very old. Wooden ladles are used and wooden tubs are used as receptacles for milk or flour.

Religion

Lamaism, the religion of Bhutan, seems to be derived from an amalgamation of pre-existing Bon with Bhuddism introduced from Tibet. The main Dzong is at Chozo and the people are very superstitious. They have a strong belief in the spirits of seven Tibetan brothers who were defeated in Tibet and each of their spirits dwells in a particular locality. The most powerful Chumna lives in a wood near Chozo Dzong and the spirits of upper Lunana are especially strong. Woods are their main abode and no wood can be cut at these sites.

Other religious observances are smoke offerings produced by burning wood in a special oven incorporated in the wall of a house. These appease spirits and atone for sin.

Spirits of Lunana

Locality	*Name*
Thanza	Parip
Tyonchho	Chhuzap
Chozo	Chumna
Lhedi	Thasip
Thega	Gume Bup
Wacchey	Yangop
Punakha	Chanyo Gandum

Population

(see: WARD, 1966 a; JACKSON et al., 1967; WARD and JACKSON, 1965). The total population of the North and North West frontier region of Bhutan was about 2000–2500 – of those about 520 lived in Lunana at an altitude of between 12–13 500 feet. The distribution was 335 people (154 males, 181 females) in Upper Lunana and 185 people (88 males, 97 females) in Lower Lunana.

The distribution by villages was as follows:

1. Upper Lunana

Village	*Male*	*Female*	*Total*
Thanza	38	58	96
Tyonchho	47	57	104
Dyotta	18	16	34
Total	154	181	335

2. Lower Lunana

Dasho	7	5	12
Rilo	13	8	21
Tasho	4	3	7
Lhedi	22	25	47
Shansha	5	12	17
Thega	22	26	48
Wachhey	15	18	33
Total	88	97	185

The stillbirth rate was 42 per 1000 births which compares with 28.4 per 1000 births in Scotland. The infant mortality rate was 189 per 1000 births which compares with 50 per 1000 births in Scotland in recent years but 87 per 1000 births 50 years ago.

Though no figures were available for childhood mortality there is little doubt that the rate in Bhutan is considerably higher than in the U.K. and was probably due to respiratory and gastro-intestinal infections.

As far as menarche is concerned there was some evidence that as in the Khumbu region of Nepal and on the South American Altiplano, the onset was late and the majority gave an age of 18 to 20 years. The first child was usually born one to two years after this. The age given for menopause was usually within the range given for the U.K. The oldest man was 82 years and woman 78 years old.

Life expectancy is though to be increased in certain mountain regions. Populations in Ecuador, Hunza (Karakorum) and the Caucasus have been investigated, and unlike Lunana, where a birth register was kept, difficulty was found in obtaining exact ages. There appears to be little good evidence to suggest that in fact individuals as suggested live longer. However, all highlanders undertake physical exercise from childhood, and simply ascending and descending every day ensures a certain degree of physical fitness. As myocardial ischaemia is rare in mountain communities this must be a factor. Also elderly people are incorporated into the family unit (LEAF, 1973).

Fertility in sea level visitors to altitude is lower than in indigenous high altitude populations. In South America, Spanish mothers used to leave high altitudes to give birth and the birth of the first Spaniard at Potosi (4000 m) did not take place until 53 years after the founding of the city and the occasion on Christmas Eve 1593 was attributed to a miracle by St. Nicholas of Tolentino.

One effect of high altitudes appears to be to arrest spermatogenesis and immature forms are produced. In Asia the presumption is that the Tibetan plateau was populated long after more favoured regions, and the upper Himalayan valleys are relatively fertile by comparison. The world's highest permanent dwellings are at 5300 m at a mining village, Auconquilcha, in South America, whilst in Tibet gold mines are worked at 5000 m. Above 5300 m it is not possible to live permanently as was shown in 1960/61 when a high altitude laboratory was placed at 5800 m in the Everest region and occupied for 4 months.

The inhabitants of Lunana were by anthropometric measurement smaller than those of the U.K. though their proportions were similar. As far as physique is concerned it is difficult to decide if the retardation of growth noted in some populations is due to hypoxia, genetic factors or economic conditions.

The main physical hazards to which a mountain population is exposed are cold and high altitude and these impose biological changes. At high altitude the percentage of oxygen remains the same as at sea level. In other words the barometric pressure which depends on the concentration of molecules is less at altitude. This in turn means that the pressure exerted by oxygen is less and the uptake of oxygen by the tissues falls with increasing altitude.

Acclimatisation to oxygen lack is very efficient if it is allowed to take place over a long period and those born and bred at high altitude show a more efficient adaptation than sea level visitors to altitude. The transport of oxygen through the tissues is more effective and the systems investigated in the Bhutan population confirmed this (WARD, 1975; HEATH and WILLIAMS, 1981).

One of the best known is an increased haemoglobin and the average in Lunana was 17.9 gm/100 ml as opposed to 14.0 gm/100 l in sea level man.

High altitude populations usually show evidence of enlargement of the right ventricle of the heart which pumps blood through the lungs and to which there is at high altitude some resistance due to arterial spasm. In the Bhutan population there was no evidence of this enlargement.

This is in contrast to South American studies which show considerable right ventribular enlargement and pulmonary hypertension. Recent Tibetan studies suggest that this is not marked. Perhaps a genetic factor is at work as Asian populations appear to have lived for longer periods at high altitude than South American.

There was no evidence of chronic intolerance to altitude (Monge's disease) which is found in South America (MONGE, 1928; HEATH and WILLIAMS, 1981). As the Lunana population lives between 12–13 000 feet, and herd yaks for weeks on end at 16 000 feet this is difficult to explain. Monge's disease presents a complex clinical picture composed of cardio-vascular, haematological, respiratory and neuro-psychiatric symptoms. It is common in men of a mean age of 40, rare in women, absent in children. Essentially the clinical picture is of an exaggeration of the normal physiological features of altitude acclimatisation. The most important cause may be an inability to respond to altitude by an increase in respiration – in other words the individual takes in less oxygen than other high altitude dwellers. This may be an expression of ageing since increasing age is associated with decreasing ability to increase respiration in response to oxygen lack. Monge's disease can be fatal unless individuals are quickly removed to lower levels where symptoms improve. On return to high altitude recurrence is common. No cases have been reported in Himalayan populations though some have been reported by Chinese scientists from Tibet where about 15% of lowlanders who go to altitude and stay for 2 years or more develop chronic mountain sickness.

Mining may be a factor in the development of Monge's disease in both South America and Tibet but it is more likely that altitude is the sole cause as populations in Tibet and the Andes live permanently at a higher altitude than those in the Himalayan valleys.

Only one case of a congenital abnormality of the heart (patent ductus arteriosus) such as found in other high altitude populations was observed in Bhutan. No tumours of the carotid body (chemo-dectoma) were observed. This tumour is comprised of cells which sense the oxygen content of the blood going to the brain, and is found in high altitude inhabitants in Central and South America but so far has not been diagnosed in Asia (SALDANA and SALEM, 1970; SALDANA et al., 1977).

No evidence of high blood pressure was found in the indigenous population and this coincides with observations from South America. However, recent work has suggested that the combination of altitude and exercise may cause a very high blood pressure with the possibility of cerebral haemorrhage and strokes in sea level visitors (WARD, 1975; RICHALET et al., 1983).

No cases of mountain sickness and its complications cerebral and pulmonary oedema were observed.

There was no obvious clinical evidence of coronary artery disease and this correlated well with the low serum cholestrol and triglyceride levels. The diet was relatively low in fat, little sugar was taken and all the population lead active lives from the point of view of physical exertion. By contrast a recent study over 21 years of the Tibetan population has recently been published by the Chinese press. This was carried out between 1959 and 1980 and involved 2627 men and women of all ages and various nationalities living between 2500 and 4500 m. The causes of death were: high blood pressure 27.7%, rheumatic heart disease 19%, altitude heart disease 15%, coronary heart disease 13.65% and pulmonary heart disease 9.6%. Males were slightly more susceptible than females and the incidence in Han Chinese was lower than in native born residents. The overall morbidity was 13.4% and heart disease accounted for 90% of deaths in the population studied. The cause of death was attributed to shortage of oxygen, hereditary factors, excessive intake of fats and smoking. The population of Lunana smoked very little.

Cold is as great a hazard as high altitudes and is probably a more important factor in colonising mountain regions. Protection is obtained by cultural means and the Bhutanese wore clothing made from yak wool and their boots were of skin stuffed with straw. Children were covered with butter as a protection against cold. Obviously some local adaptation had occurred probably by the increased blood flow through skin vessels as all were able to work with bare hands in extremely cold conditions and walk for long periods on snow in bare feet. It is generally considered that general adaptation to cold does not occur in man and studies on a Nepalese holy man who slept in light cotton clothing at a temperature of −13 °C at 4500 m showed that he maintained his metabolic rate 50% above normal by comfortable and controlled shivering (PUGH, 1963). In this way he avoided hypothermia and frost-bite. Cold injury such as hypothermia where the body temperature drops below 35 °C and frost-bite where the tissues actually freeze occurs when protection is inadequate, and are often associated with illness or injury.

Recently a lung condition has been discovered among Eskimos of the Canadian Arctic due to exposure for many months each Winter to −30 °C whilst trapping. A decrease in lung function with impairment of the cardio-respiratory system and enlargement of the right ventricle has been recorded in young men who are engaged in this type of activity. Called "Eskimo Lung" a similar condition has been recorded in immigrant Russian workers in Siberia. Sled dogs who are worked too hard in extremely cold conditions become increasingly short winded and some may have episodes of acute oedema of the lung (SCHAEFFER et al., 1980). Although high altitude dwellers are not exposed to such conditions cold may play a minor part in the incidence of pulmonary hypertension of altitude.

Goitre

Goitre was the commonest clinical condition observed in the Lunana population. In general this was less marked below the age of 20 years and in younger patients the enlargement of the thyroid was diffuse, whereas with age a nodular goitre was more common. Some nodules were hard presumably due to calcification. No cases of over activity (thyrotoxicosis) nor of cancer of the thyroid were seen. Two cretins were observed which is in striking contrast to those reported from Khumbu in Nepal where 30 cretins were found among 220 villages.

The incidence of goitre in Lunana was 66% in females and 19% in males, whereas in the Karakorum the overall incidence is between 70%–80% in some areas with a similar higher incidence in females (CHAP-

MAN et al., 1972). Although the degree of iodine deficiency in Bhutan and the Karakorum is probably similar the goitre incidence is different and other factors possibly genetic may be involved.

Whilst the incidence of goitre in the southern valleys of the Central Asian plateau seems to be high, the incidence on the Pamir plateau is very low. No cases were observed amongst Kirghiz tribesmen who inhabit the valleys of the Kun Lun Shan which borders the Pamir plateau to the north, nor in those who lead a semi nomadic existence on the plateau itself (WARD, 1983).

Over 200 million people have endemic goitre many of whom live in mountain regions. Although not a killing disease there is a marked morbidiry. Certain complications can be fatal, infant morbidity is raised, cretinism is present and mental subnormality more common. The over all work capacity of the populations is therefore impaired.

Iodine in the diet enters the bodies plasma iodine pool which perfuses all organs. The main competitors are the kidneys and the thyroid gland. When trapped in the thyroid, iodine is used to form hormones, T_3 and T_4, and if secretion of these hormones is insufficient a feed-back mechanism via the hypothalamus in the brain causes an increased secretion of thyroid hormone. In these conditions the thyroid takes a greater proportion of the iodine from the plasma iodine pool and the kidneys excrete less in consequence. The thyroid is thus continually stimulated and enlarges, leading to a visible goitre. The typical individual secretes enough thyroid hormone (is euthyroid) so that essentially goitre is an adaptation to iodine deficiency – however as indicated above a number of individuals are iodine deficient.

Iodine deficiency may occur due to insufficient uptake, goitrogenic substances which destroy iodine in the body and deficient intra thyroidal enzymes leading to decreased production of thyroid hormone.

Although it has been noted that the iodine content of the soil may decrease on passing inland from the sea this is not universal and sea littorals are known where the soil is iodine deficient. However, iodine content of the soil is not necessarily a guide to available iodine, whereas iodine content in the vegetation is important.

Various factors affect the iodine content of vegetation among which are calcium. An excess of calcium in the presence of iodine deficiency leads to a higher incidence of goitre than in non-calcareous areas with a similar degree of iodine deficiency.

Increased goitre may also occur in areas where the fluoride content of the water is increased in an iodine deficient area (DAY and POWELL-JACKSON, 1972).

Infection

Despite the isolation of the community examination of the blood revealed that antibodies to a number of common viral infections were present. A high proportion of the population had been exposed to influenza, mumps, measles, herpes simplex, the common cold and other relatively common infections. There was a very high incidence of exposure to the psittacosis-lymphogranuloma-trachoma group despite no clinical evidence of associated disease. Probably a virus of this group must be endemic. By contrast examination of nasal swabs showed that there was only a 4% carrier rate of coagulase positive staphylococci, a common organism in Western communities found in between 29–46% of the population. Another interesting feature was the high frequency of B haemolytic streptococci found in throat cultures that were highly sensitive to penicillin. This is in contrast to Western communities where sensitivity to penicillin would be minimal.

Genetic Investigations

Blood groups

(see: GLASGOW et al., 1968)

As far as the samples from Lunana were concerned the frequency of B is high. The exceptionally high B gene frequency of 52% may in part be due to unavoidable statistical accidents of sampling but even allowing for this an extremely high frequency of Gene B is present with an unusally low frequency of Gene 0. This is presumably the result of inbreeding in an isolated mountain population but in Europe isolated mountain and island populations seem to be high in 0 and low in both A and B. In South America there is a remarkable preponderance of Group 0 in the Indian population of the Andes. In the Andes of North Peru 100% of the population is group 0, whereas in Liverpool in the U.K. it is only 50%. In the MNS-system, the MS gene complex was more frequent than in Nepal and this suggests relationships with the Caucasoid population of India. The Rh-system also suggested some degree of Indian ancestry, although the high incidence of some genes in this system suggested an association with Tibet. The high frequency of other genes in this system are found also in most Eskimo and American Indian populations. The high frequency of the Diego gene noted in Lunana is found in the people of Eastern Asia and the American Indians though rarely in other populations and it is also present in the Nepalese and Tibetian.

The presence of Haemoglobin E showed a specific connection with S.E. Asia possibly entering Bhutan from the South.

Dermatoglyphics

(see: ROBERTS et al., 1968)

In general the pattern of the fingerprints from the population of Lunana suggested that populations from India may have made an appreciable contribution to the gene pool. This does not mean that the Lunana population is closely akin to the group of populations from India, but there does seem to be a closer association with the Khasi of Assam several of whose fingerprint samples are very close to those in Lunana. It is thought too that certain Assam tribes originated in Bhutan.

The apparent discrepancy between blood group and dermatoglyphic studies demonstrate the importance of taking into account a spectrum of genetic characteristics when assessing the affinities of a certain population.

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Discussion to the Paper Ward

P. Pohle:

Which are the differences in physiological adaptations between the native population of the high altitude areas of South America and the Asian highlanders?

Dr. M. P. Ward:

Basically the physiological adaptations of both Asian and South American highlanders appears to be the same. However failure of adaptation (Monge's disease) has not been reported in highlanders who live on the southern slopes of the Himalaya.

P. Pohle:

Did the Himalayan high altitude population reach a better adaptation to the lower oxygen pressure than the Indian population of the Andean highland, probably because of the longer stay of their ancestors at high altitude?

Dr. M. P. Ward:

This is possible but not proven.

Prof. Dr. U. Schweinfurth:

With reference to isolation:
for how long is Lunana (Northern Bhutan) actually accessible from South and from North?

Dr. M. P. Ward:

The cultural affinities of Bhutan are more allied to Tibet than with populations to the South. The population of Lunana used to trade with both Tibet (before the frontier was closed) and Central Bhutan. Physical access to Tibet was probably easier; as Lunana is seperated by a 4-day journey and passes of up to 17 000 ft with the rest of Bhutan.
However the population of Lunana considered that they were Bhutanese, not Tibetan.

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Natural Potential and the Land-Use-System of the Kallawaya in the Upper Charazani Valley (Bolivia)

Wilhelm Lauer

With 22 Figures

1. Introduction

The Kallawaya are an Indian ethnic group living in an elevated valley of the northern East-Cordillera of Bolivia. Although their land is less than 300 km from the capital city of La Paz, it is located in a peripheral and comparatively isolated settlement area when applying todays standards of accessibility (see Fig. 1). There has been just one gravel road since the Seventies leading to this area and to a small market-town (Charazani), founded by the Spaniards, and also, in the meantime, to two further Indian communities. All other villages – there are 12 more – can only be reached via peripheral paths. However, this assessment of the accessibility of the area reflects to some extent ways of thinking in the automobile age, for the settlements communicate quite well with each other, having maintained since pre-colonial times a close-meshed network of exchange of goods within the population group itself and with the people living in the neighboring villages. Long-distance trade links are maintained down to the Amazon Valley via old Indian paths, to Peru and in the direction of the capital city of La Paz. In other words, this population group is well linked with the outside world, even when applying criteria of space and time different from ours.

The settlement area of the Kallawaya is located in the Muñecas Highlands, at the southern foot of the Apolobamba Cordillera in the system of valleys of the upper Rio Charazani, whose widely branched upper reaches are partly fed by the glacier creeks of the Apolobamba Cordillera and partly from the low ice-free tops of the Muñecas Highlands. The upper region of the Kallawaya settlement area was transformed by the glaciers in the glacial period and is partly characterized by wide valleys. On its further course, however, the Charazani River – in narrow valley sections interrupted by drier and wider valleys – dissects the Muñecas Highlands in the direction of the Rio Mapiri, which flows into the Rio Beni and thus unites with the Amazon River system.

Today, there are still approximately 8000–10 000 Kallawaya living in the Charazani Valley, their way of living largely based on the agro-ecological conditions established in pre-colonial and colonial times.

Today, the entire agrarian, Ketschua-speaking population, living in this area around the small district town of Charazani, is generally called Kallawaya. This term applies to the area occupied by 12–14 villages. In a stricter sense, however, the term actually refers only to a group of doctors and herb dealers. According to studies by W. SCHOOP (1982), there are about 150 whose leaders are still engaged in this highly important activity, but the question of whether their tradition goes all the way back to pre-colonial times is as yet unanswered. At any rate, a representation in the 16th century Chronicles of POMA DE AYALA shows Kallawaya who were working as dignitaries at court in Cuzco and who were worthy of carrying the sedan-chair of the ruler and his wife. Today the Kallawaya doctors have a collection of approximately 20 medicinal herbs, which, by the way, are not from that area. Furthermore, as W. SCHOOP (1982) was able to determine, the Kallawaya doctors come particularly from the smaller villages of the area, where this activity was apparently performed as a secondary occupation due to the insufficiency of arable land.

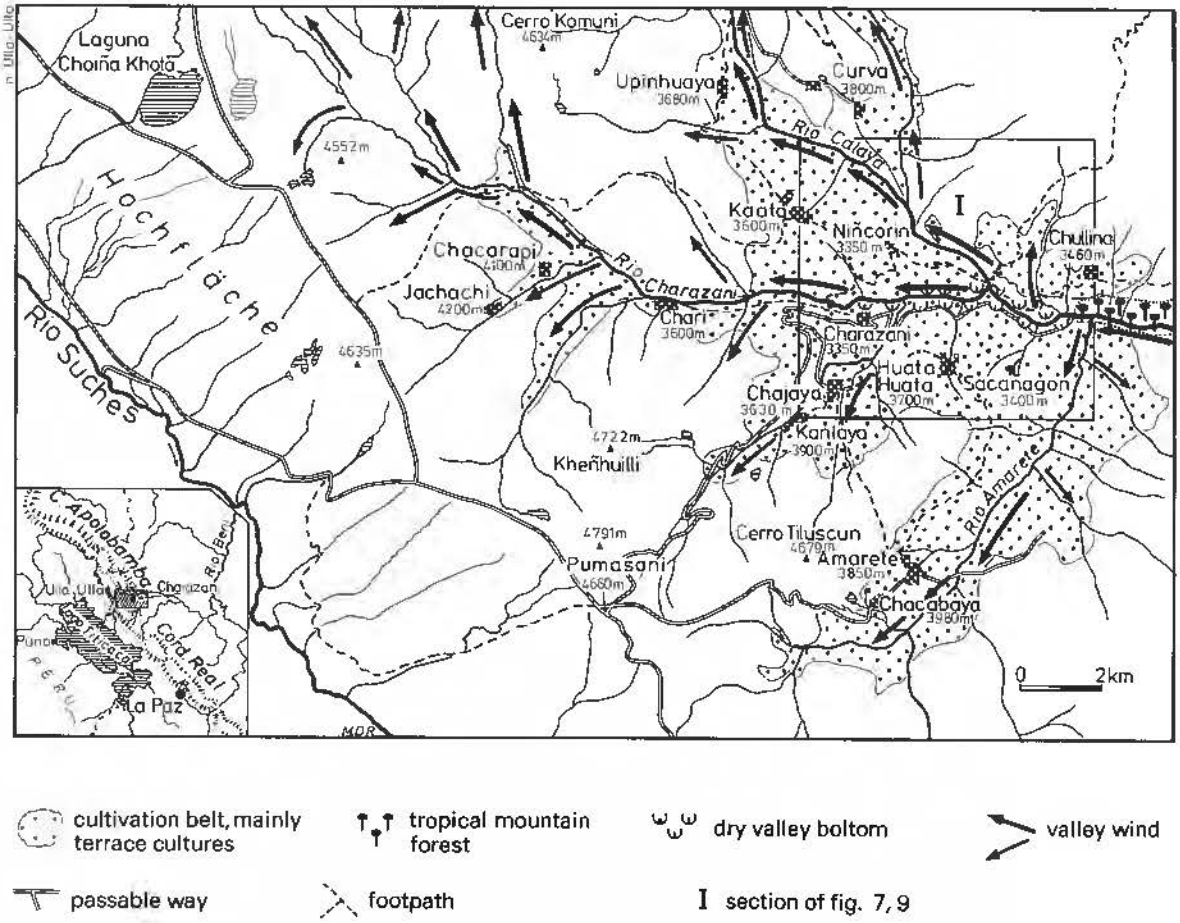

Fig. 1. Survey map of the study area.

While the Kallawaya undertook long trips throughout the Andes particularly in former times to exercise their profession, nowadays they travel mainly through the Ketschua-speaking highlands of Bolivia, so that they also work as doctors in southern Bolivia where Ketschua is spoken by the majority of the population.

The zones of settlement and agriculture of these Kallawaya people are located in the hygro-thermal altitudinal zone of the "tierra fría" above the forest line, between 2700 and 4300 m a.s.l., where the semi-humid climate with winter dryness still permits cultivation of land. The entire belt of cultivation shows a threefold vertical zonation. One can distinguish between a lower, a medium and an upper land-use belt, the characteristics of which are influenced by both eco-climatological and socio-economic factors. The large Kallawaya villages participate in all three land-use belts, each complementing the other and providing the Kallawaya with an almost self-sufficient economic system (compare Figs. 3 and 13).

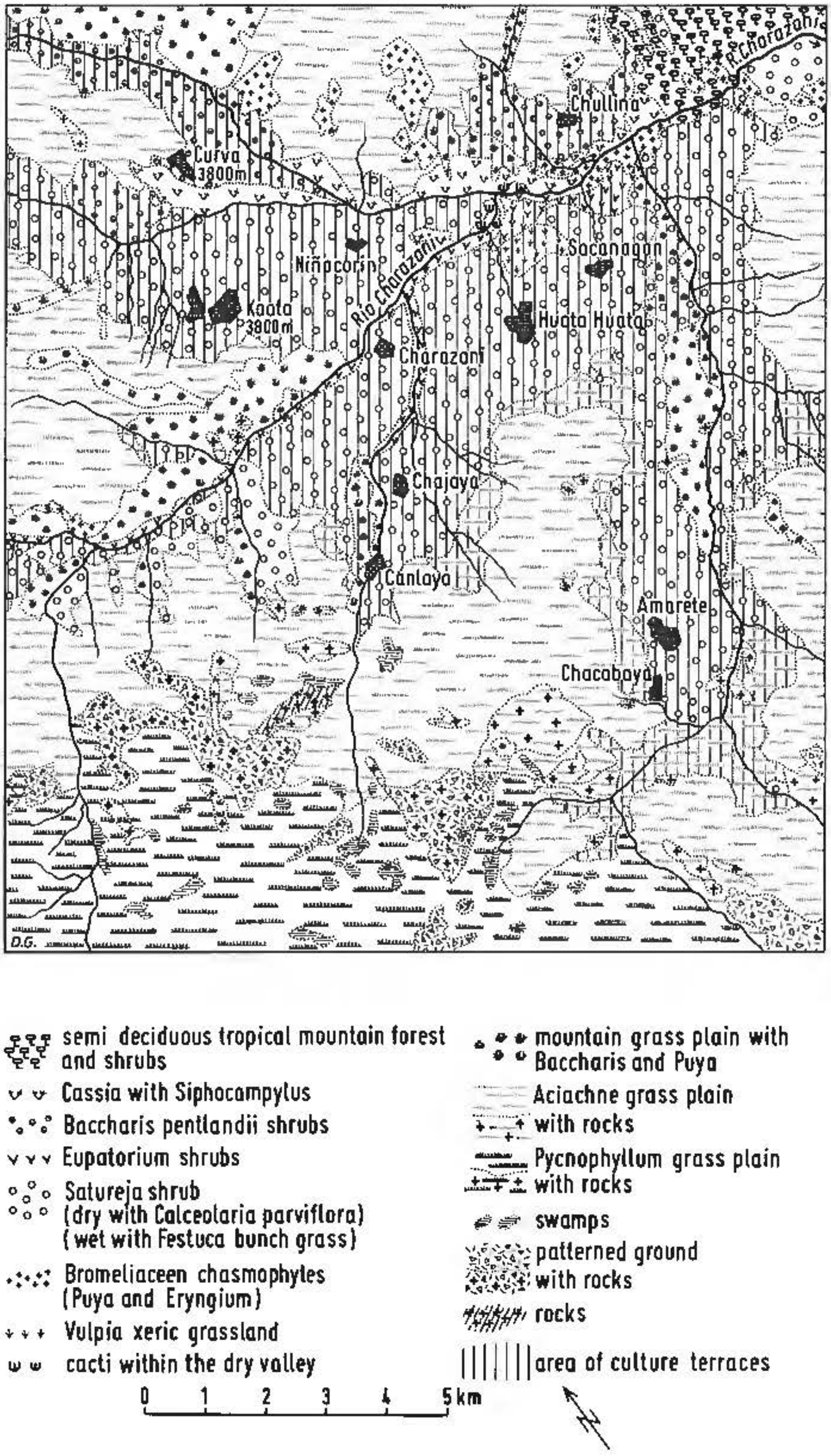

Fig. 2. Vegetation map of the inner Charazani region (part of the vegetation map of P. SEIBERT, 1982; revised form in preparation, 1984).

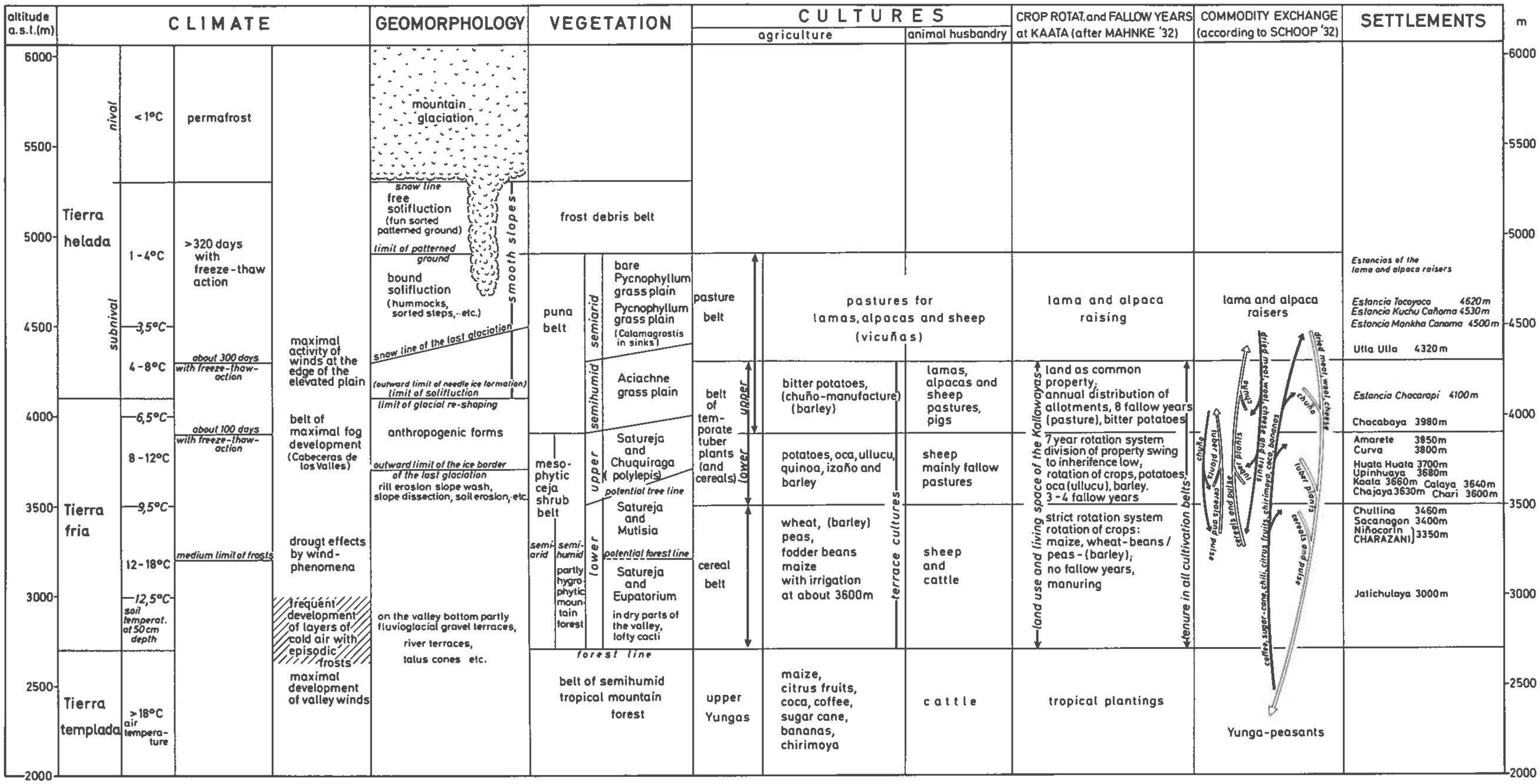

Fig. 3. Eco-climatic altitudinal belts of the Charazani region.

2. Geo-ecologial Conditions of the Agricultural Area

The altitudinal land-use zones may be described by means of climatic parameters, such as temperature, frost, precipitation and soil moisture, as well as by the potential natural vegetation.

Meanwhile, plant sociological surveys have been conducted and climatic parameters studied in the Kallawaya area. A group of botanists (P. SEIBERT and colleagues) has determined plant societies that are also suitable in the indication of ecological site conditions (Fig. 2).

On the basis of microclimatic studies in each altitudinal belts (W. LAUER and colleagues), it is possible to assign the plant communities to a three-dimensional temperature and humidity model, which provides an ecological description of the agricultural zone.

A survey (Fig. 3) shows the results of the studies carried out so far. It is a first attempt at a synopsis of the characteristics of the natural potential and of the Kallawaya land-use system.

The dependence of the arrangement of the plant sociological units on the adversely exposed slopes on both sides of the Charazani Valley is shown in a drawing (Fig. 4, compare also Fig. 2). The profile presents a picture of conditions in the valley area just above the present forest line. It reveals that during the winter-dry season, particularly when the sun is in its most distant position in the northern hemisphere, the northern and southern slopes differ greatly with regard to their thermal budget and thus in moisture conditions.

While the drier and warmer side of the valley between 3000 and 3900 m is characterized by an association of shrubs, the main species of which is *Satureja boliviana*, the opposite cooler and more humid slopes of the same altitudinal zone are distinguished by *Baccharis pentlandii* associations. Here then, the northern and southern exposures relative to the sun become clearly effective. On the lower slopes of the drier side of the valley, *Mutisia* shrubs predominate. In the driest positions (Fig. 5), cacti grow together with dry grass of *Vulpia spec.* These sites are exposed to an up-valley wind during the day. The strongly sunlit areas of *Satureja* shrubs at medium elevations are marked by *Calceolaria parviflora*. Only at higher elevations, where the up-slope winds condense and fog banks develop – mostly above 3600 m, does *Satureja* become physiognomically more prominent and dominate the vegetational picture more distinctly; here it is in association with *Chuquiraga*, representative of more humid locations. Islands of *Baccharis pentlandii* bushes can also be found.

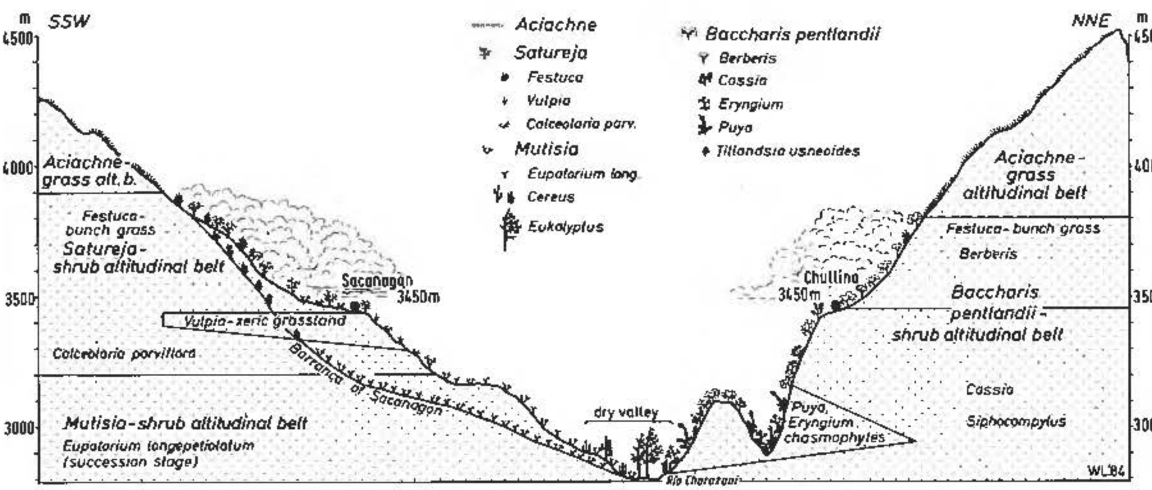

Fig. 4. Thermic and hygric asymmetry of the altitudinal vegetation belts in the upper Charazani valley (profile Chullina – Sacanagon).

Fig. 5. Dry part of a northerly exposed slope with cacti.

Likewise, on the opposite side of the valley with *Baccharis pentlandii* shrubs, which lies in shadow during the winter, the steep slopes are covered with grasses, especially the tall fascicle grass *Festuca dolichophylla*. Scattered within this area are *Eryngium* societies associated with *Puya* as the main species. *Puya* is found mainly on rocky sites, which, on these humid slopes exposed to the valley winds, are covered abundantly with terrestrial Bromeliaceas and *Tillandsia usneoides*.

Found particularly at the humid upper valley ends (Cabecera de Valle), remnants of *Polylepis* possibly mark a mesophytic bush-type forest line at an elevation between 3400 to 3600 m a.s.l. Other tree-like species, such as *Buddleya* and also *Fuchsia* and *Berberis* bushes, grow in the moist niches of the creeks.

The entire bush belt, on both exposures of the valley section described above, shows clear dependence on decreasing temperature with encreasing altitude, as well as on a moisture component, which makes itself felt in the greater dryness of the lower valley sections and greater humiditiy of the "Cabeceras".

Above 3900 m the bush belts of both slopes merge into the grass belt, where *Aciachne pulvinata* is dominant. This altitudinal belt corresponds to the upper belt of tuberous plant cultivation, as can be seen from Figs. 3 and 13. Here, steep rocky areas are covered with *Festuca* of medium height. The *Aciachne* grass is arranged in hexagonal patterns. The space between the grassy areas, seemingly bare from a distance, is actually densely covered with mosses and lichens. The most humid vegetational units of this altitudinal zone are *Plantago* and *Distichia* moors.

The gradiation of heat and humidity is not only reflected in the altitudinal zonation but also in the asymmetric arrangement of belts, depending on aspect and exposure. The contrast between slopes favoured and unfavoured by insolation is clearly marked. This contrast in insolation between slopes with different exposures plays an important role in the agricultural land-use of this altitudinal belt. The altitudinal boundaries of cultivation may vary between the sunny and shadowy slopes by up to 200 m.

3. Topoclimatic Bases

The climatic parameters were ascertained by several methods of measurement. By means of measuring journeys along the only road in the area at altitudes between 2700 and 4600 m, it was possible to determine three distinctive phenomena regarding air temperature and humidity in the hours of the early morning. A marked temperature and humidity inversion layer of differing thickness occurs between 3400 and 4100 m, depending on the meteorological conditions. Very often during the night cold air accumulates just at the bottom of the valley at an altitude of 2700 m and builds up to 3200 m.

During all measuring journeys in the dry season (Fig. 6), the daily frost limit was observed and measured, lying in most cases between 3600 and 4100 m. In this area, the ground freezes only on the surface and develops the so-called "needle-ice" phenomenon, while the snowfall boundary follows the frost limit.

The temperature and humidity inversion is mostly accompanied by a thick fog bank of differing vertical expansion. It disappears one hour after sunrise. At the same time, the temperature and humidity inversion remains measurable throughout the day. Only during the hours before and after the noonday position of the sun is it at a minimum though it disappears during the rain-producing weather types of the humid season.

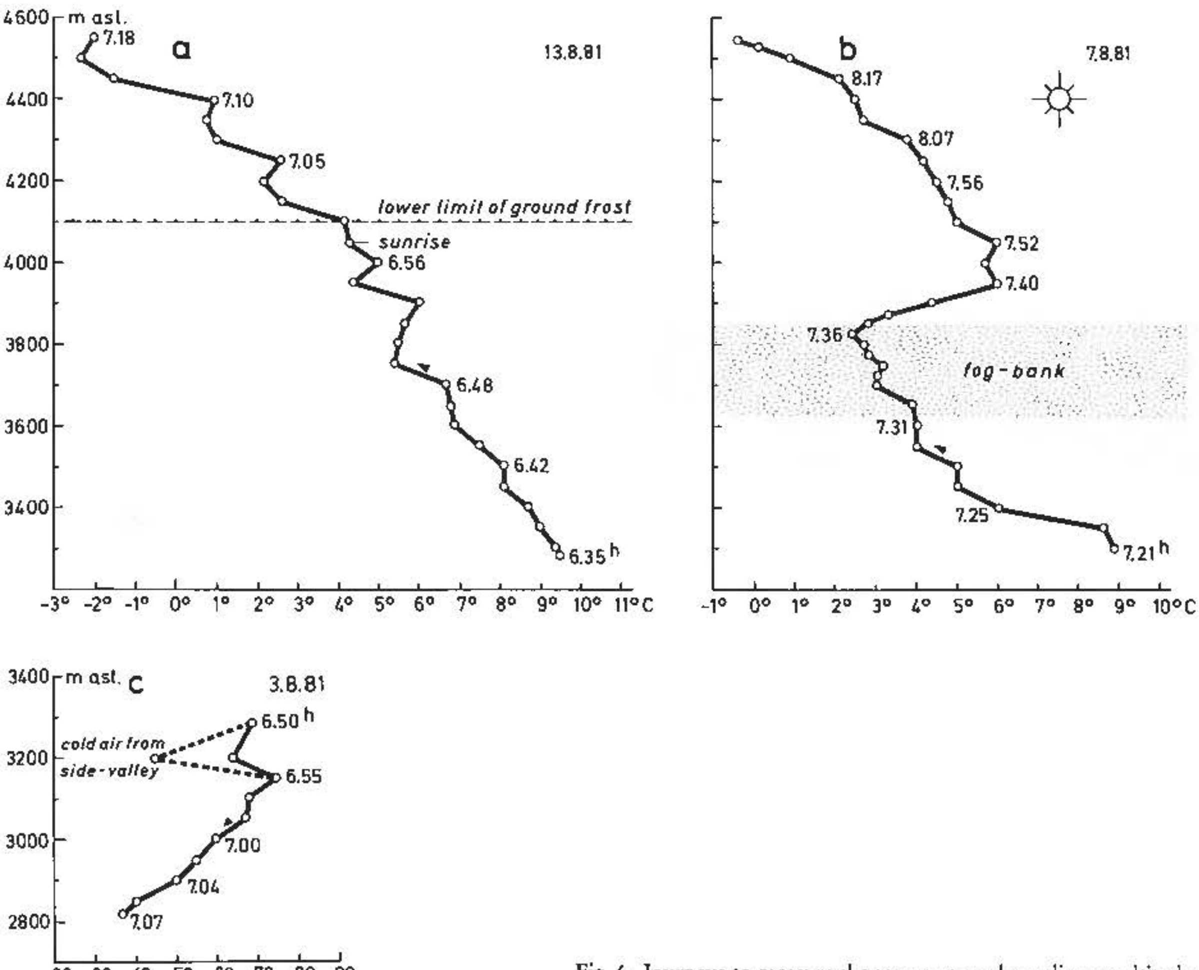

Fig. 6. Journeys to measure the temperature depending on altitude.

Fig. 7. Eucalyptus trees with wind shear features.

The altitudinal temperature and humidity zonation so far described is enhanced by a valley-mountain wind phenomenon, which is marked by intensive insolation, particularly during the dry season and on days with insolation during the rainy season. The valley wind flows up the valley and the slopes and promotes condensation and the formation of fog over the upper slopes. Over the middle section of the valley a downslope wind dries out the valley bottom.

Groups of cacti occur on the valley bottom and on the lower slopes as a result of dryness (see Fig. 5). The slope wind, which becomes more and more humid, favours the growth of *Bromelia* and *Tillandsia usneoides* already mentioned. The trees of the eucalyptus groups that have been planted everywhere show striking wind shear features (Fig. 7). Moreover, the transition from *Satureja-Chuquiraga* societies at higher elevations is attributable to the increased humidity with altitude, which is enhanced by the wind phenomenon.

The valley wind shows a daily cycle (Fig. 8). It sets in weakly between 9 and 10 hrs in the morning, reaches its maximum strength between 12 and 15 hrs – sometimes later – decreases sharply after 16–17 hrs and ceases to blow completely at approximately 19 hrs. The mean wind velocities range between 3 and 10 ms. Peak wind velocities over an average period of 3 minutes may be as high as 25 ms or more.

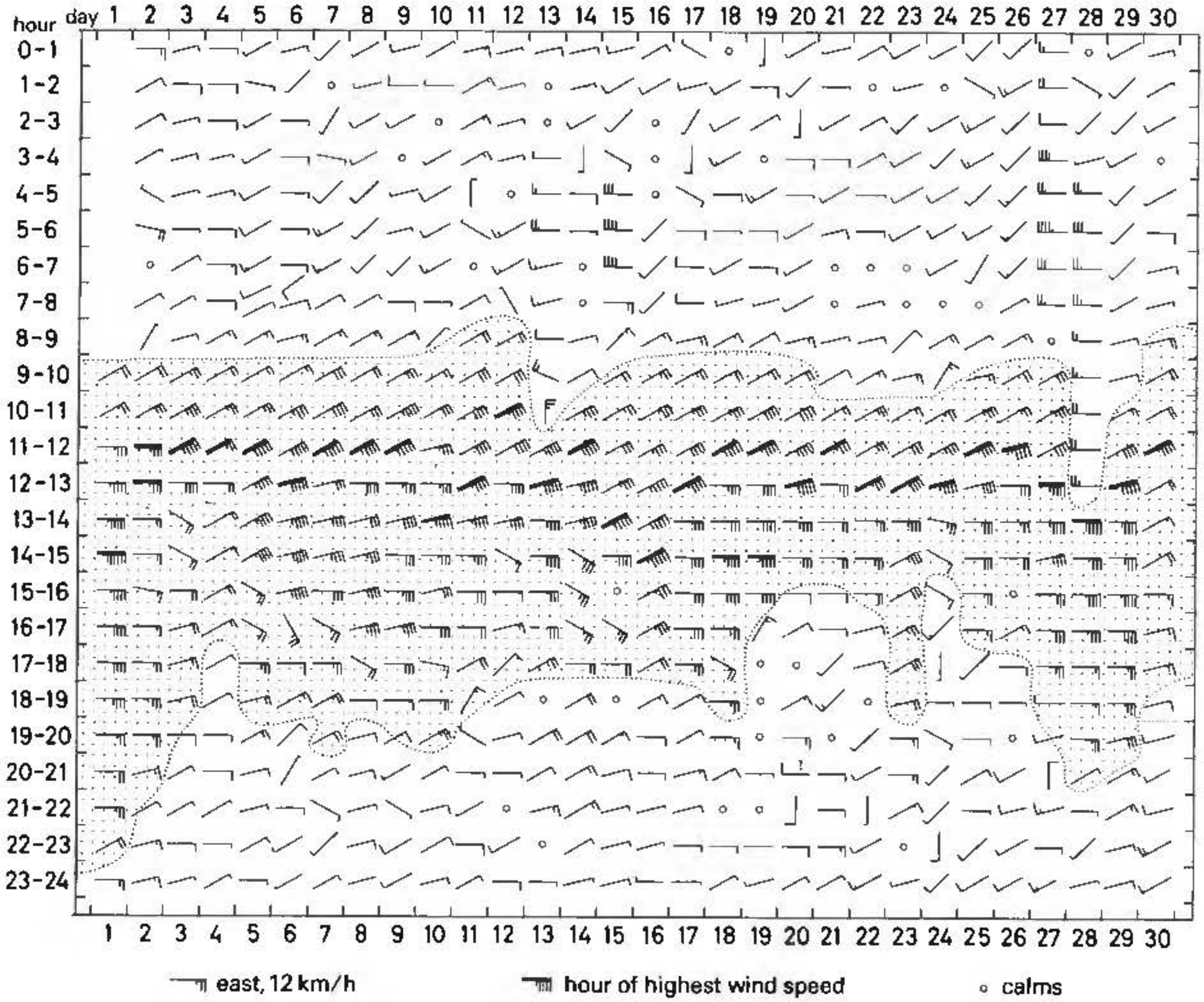

Fig. 8. Wind direction and wind speed during September 1981 in Charazani.

The valley wind phenomenon during the day has only a weak counterpart during the night. There may be considerable deviations, however, depending on the meteorological conditions. Normally, the velocity of the mountain wind ranges between 1 and 2 ms, but depending on the meteorological conditions, downslope gusts of 20 to 25 ms may occur and show bora-type features in the upper sections and on the valley bottom. Strangely enough, these gusts are often warmer on the slopes than the mean temperature of the season measured there. In such places they have foehn-like effects. Depending on the meteorological conditions, particularly in cases when cold air masses are present on the elevated plains and supported by katabatic winds from the nearby glaciers, they may occur extraordinarily strong bora-type downslope winds in the main section of the valley, which build up a pool of cold air just before the river reaches the narrow valley at an altitude between 2700 and 3200 m.

There is an extremely sharp contrast between the favoured and unfavoured slopes. This contrast in aspect plays an important role in the agricultural land use of the Charazani valley, and the altitudinal limits of cultivation may differ by up to 200 m between the sunny and shaded slopes.

The theoretical insolation (Fig. 9) of the area selected for investigation shows this spatial differentiation in the form of the possible insolation by the sun which shows how slopes with a northern aspect are favoured by insolation (Slope of Sacanagon) whereas slopes with a South-facing aspect receive the least insolation (Slope of Chullina) (Fig. 10).

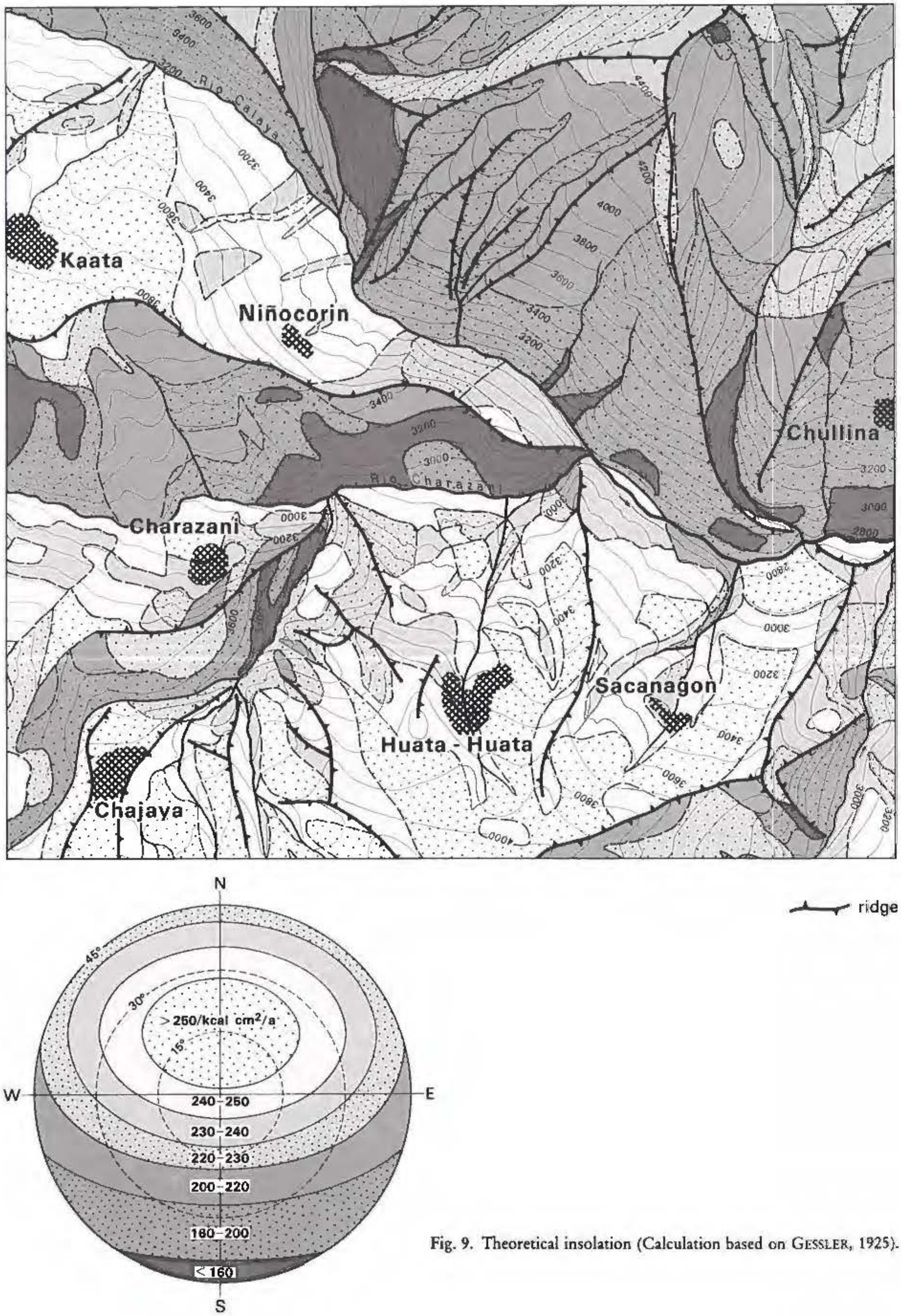

Fig. 9. Theoretical insolation (Calculation based on GESSLER, 1925).

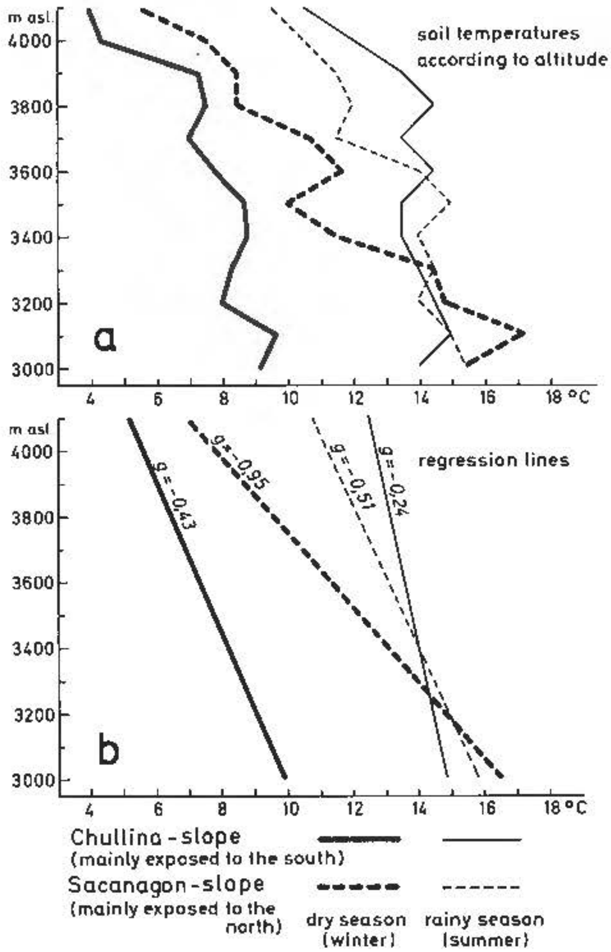

Fig. 10. Altitudinal variation of the 50cm-soil-temperatures on differently exposed slopes.

Since in the difficult terrain of the area under investigation it was impossible to install a climatological network of sophisticated equipment due to the lack of infrastructure, attempts were made to measure soil temperature as an ecological heat index at a minimum number of observation points. In this connection, the following methods were applied.

In the tropics, soil temperature, measured at a depth of 30–50 cm, at a shady location on an even surface, corresponds to the mean temperature in a meteorological screen. This fact is based on the observation that, under tropical thermal conditions, daily isothermic conditions occur at a depth of 20–30 cm.

In the area of investigation, located in the outer tropics, it is at all events possible to determine the monthly mean temperature by soil temperature measurements at this depth. By means of measurements at different sites with differing aspect and slope inclination, temperature patterns emerge that correspond with the terrain. An isothermal map of soil temperature at a depth of 50 cm (Fig. 11) thus reflects the thermal conditions of a selected area during a certain period of time. When averaged for the year, the measurements confirmed the thermal disadvantages of the south-facing slopes throughout the entire heat budget for the day. A heat surplus accumulates, particularly on the north-facing slopes at an inclination of 5 to 25°. South-facing slopes are generally cooler by up to 4 °C than the north-facing slopes in the lower valley sections. Positive deviations, i.e. heat surpluses, are experienced by the north-facing slopes almost throughout the year, except for the mid-summer months. A balance between these deviations naturally

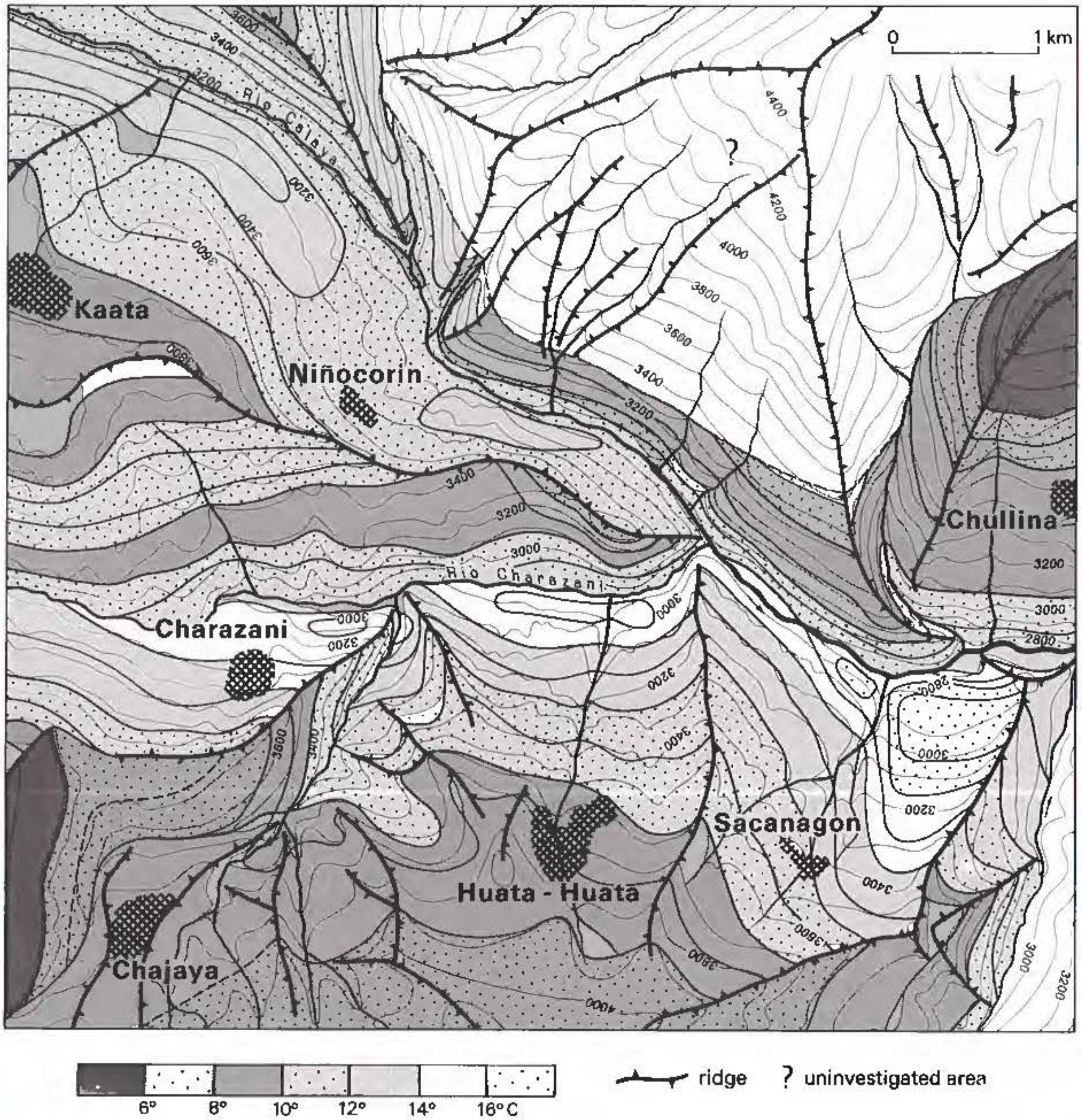

Fig. 11. Map of isotherms of the 50cm-soil-temperatures.

occurs briefly when sun is normal to the earth surface (Fig. 12). The different thermal conditions, with different aspect and inclination, are clearly reflected in the arrangement of the vegetational belts and the cultivation patterns of the crops. Together with measurement of the soil temperature, it was also possible to determine the altitudinal temperature gradient (approximately 0.6 °C/100 m between the lowest and highest points of the area under investigation).

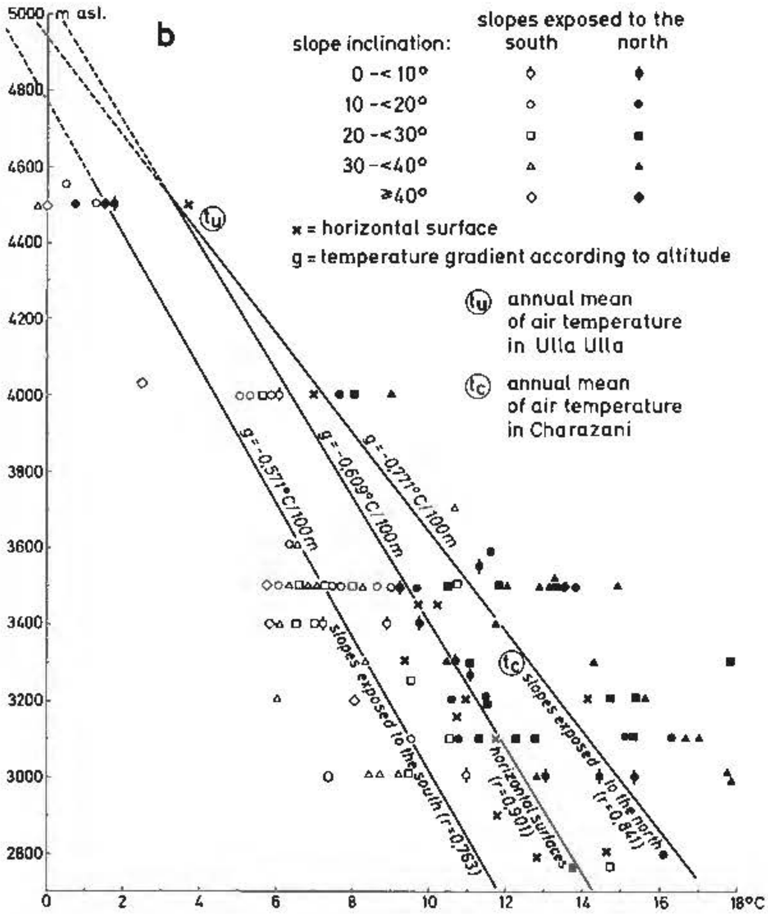

Fig. 12. Regression lines of the 50cm-soil-temperatures.

4. Cultivation Belts

In the lower cultivation belt (Fig. 13), below the central area of settlement, which is almost identical with the dry shrub belt of the valleys and the lower slopes, frost only occurs in valley basins and this only during the dry period of the winter months. Here, mainly grain is grown; since Indian times and, from the colonial era onward, wheat and also legumes, beans and peas (Fig. 14). Tillage is carried out by means of the hook plow which was introduced by the Spaniards. As a result of the gentle relief, particularly on the valley terraces themselves, damage caused by soil erosion is relatively small despite plowing. Breeding of sheep and cattle provides natural manuring in this belt, making a fallow period unnecessary in these warmer parts, where mean temperatures are between 12 and 18 °C. This holds true on the whole for the altitudinal belt up to 3600 m a.s.l. Here, available warmth is still sufficient for plowing under the dung quickly enough after the harvest to replace the nutrients that were extracted with the harvest. Metabolism still takes place in the soil. However, cultivation is not only restricted to the river terraces of the valley bottoms, but can also be found on artificial terraces that were built during early Indian times. By means of this practice the dangers of soil erosion are reduced considerably.

The agrarian system is marked by a strict field system. Although the land is in private hands, it is severely parcelled out due to the proportionate distribution of land on succession. Tillage, harvest and

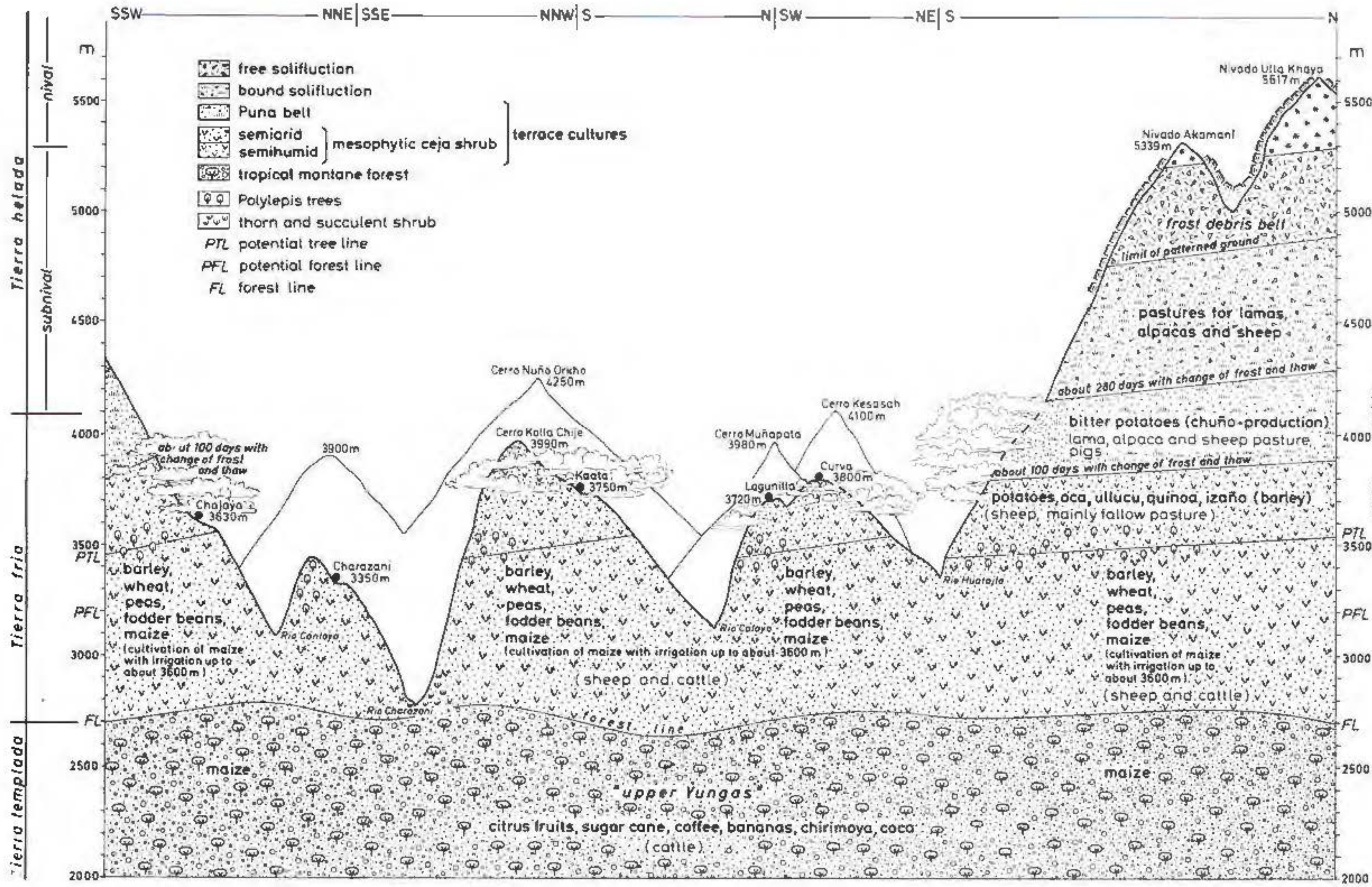

Fig. 13. Agro-ecologic altitudinal belts of the Charazani region.

Fig. 14. Lower cultivation belt with irrigable maize and wheat terraces and groups of eucalyptus trees.

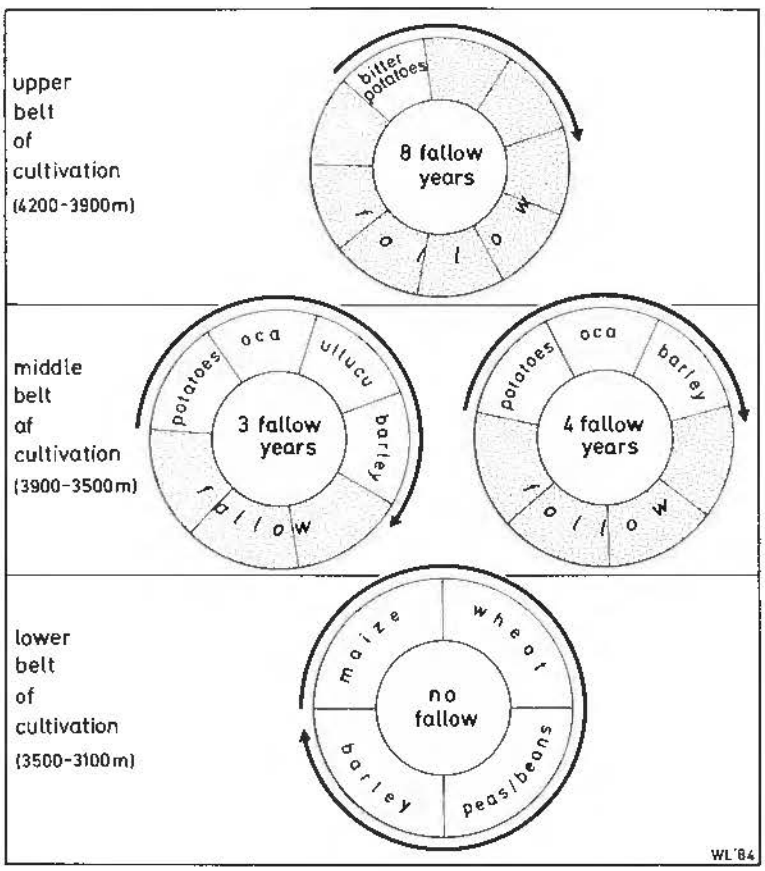

Fig. 15. Crop rotation and fallow times in the Kallawaya region as observed in the village of Kaata (based on MAHNKE, 1982).

Fig. 16. Village of Amarete, 3850 m a.s.l.

Fig. 17. Yard with weaving woman, also drying ground for potatoes.

Fig. 18. Terraced slope near the village of Amarete, tuber plant cultivation belt.

maintenance of the irrigation systems and terrace walls are largely carried out collectively in the form of assistance among neighbours, i.e. on a man-hour by man-hour basis. The field system dictates the rotation of crops: maize, wheat, beans or peas and possibly barley, which is only grown, however, in the drier areas (Fig. 15). Maize is partly irrigated, but does not appear in a purely dry-field cultivation pattern. Irrigation serves the purpose of compensating for precipitation fluctuations and increasing the yield as well as rendering the sowing date independent of the first rain.

In addition to maize, early potatoes and wheat are also included in this irrigated tillage system. Particularly in the areas where irrigated tillage is practiced, there are larger haciendas that were established in colonial times. Therefore, there is good reason for the assumption that the lower cultivation belt in its present form was not part of the old Kallawaya field system. A great portion of the area under cultivation is very likely to have been cleared only in colonial times and cultivated in hacienda operation. Thus one may proceed from the assumption that the established settlements are only partly of colonial origin, gradually developing later into villages. The present settlement structure in this area shows scattered settlements, haciendas and villages existing side by side. Many of the villages did not gain their independence until the agrarian reform on the Fifties, and have enlarged their acreage in order to build up farms of a more profitable size. However, even today, many campesinos are working on the haciendas of reduced size still existing today.

The central and original agrarian area of the Kallawaya Indians is located in the tuberous crop belt, which is identical with the somewhat more humid upper shrub belt of the vegetational zonation. This area is marked by a land-use system strictly adapted to the entire range of microclimatic conditions. This belt lies between 3600 and 3900 m, where the large agricultural villages of the Kallawaya are located (Figs. 16 and 17). Here, the Indian population has always grown the tuberous plants, potatoes, oka and ullucu, on artificially-terraced slopes (Fig. 18) in a strict crop and field rotation system, and also, since the Spanish era, barley as grain – particularly on the dry slope sections. The land is cultivated in a seven-part field

Fig. 19. Fields of bitter potatoes, near the upper limit of agriculture.

system (K'apanas). In each field, each family owns one parcel of land (Sayaña) (MAHNKE, 1982). Since the property can be transferred by way of proportionate distribution, the plots are often very small. Collective tillage and harvest are regulated by a strictly obligatory field system. For the example of the village of Kaata, MAHNKE (1982) has determined potatoes-oka-ullucu-barley as the dominating crop rotation (Fig. 15). This is followed by a three- to four-year fallow, depending only on whether ullucu is involved or not. The fallow areas are used for sheep. In unfavourable localities, permanent fallow areas can also be found, particularly on the steep slopes exposed to the south. The parcel-field-system probably dates back to the Inca agrarian system.

The fields are tilled with the traditional planting stick called taclla; this practice also represents a high degree of ecological adaptation to the existing terrain and climatic conditions. The small parcels of land hardly permit the use of plows. The parcels are determined by the size of the terraces: the steeper the slope, the smaller the terraces. The construction of terraces prevents the water from flowing down the gentle slopes and thus permits optimum utilization of rain water. Soil erosion is avoided to a great extent as well. The removal of the terrace walls and the introduction of plowing would only magnify soil erosion. The planting stick technique on artificial terraces – partly in conjunction with irrigation – constitutes a highly ecological adaptation to the natural conditions, causing only negligible damage to the system.

At an elevation of 3900 m a.s.l. the system of cultivation changes according to the natural vegetation. The grass belt which sets in at this altitude is marked by slightly increased precipitation (approximately 450 mm) and frequent fog. The grassy areas, characterized by *Aciachne pulvinata,* are arranged hexagonally, which is partly attributable to the effects of daily frost particularly during dry periods. The frost limit is clearly marked and is characterized by a sudden concentration of "Frostwechseltage" (days with temperatures alternating above and below zero) for a few days per year at 3900 m and 250 days from 4100 to 4300 m. In humid localities, so-called needle-ice is formed almost every day.

Fig. 20. Conservation of potatoes and oca: water is extracted from the tubers by trampling with bare feet, and potatoes are peeled.

In this area, particularly on sunny slopes, cultivation of bitter potatoes is still possible and even barley can be grown at some places. Potatoes are cultivated on plots owned by the community. Each year, individual plots are allocated to the heads of families (Fig. 19).

According to MAHNKE (1982), the cultivation of bitter potatoes is followed by a fallow period of eight years. This practice must also be regarded as an adaptation to the climatic conditions, particularly to the low temperatures which cause a reduction of the soil's regenerative capacity as a result of retarded soil processes. In this cultivation belt, a special agro-technical phenomenon has developed which is unique in cultural history and which is strictly confined to the marginal tropical highlands of Southern Peru and Bolivia, that is the preservation of tuberous plants with the aid of frost.

The Spanish chronicler CIEZA DE LEON described the so-called chuño production in 1550 only as a drying process. GARCILASSO DE LA VEGA provided a detailed description of the procedure and distinguished three stages of preservation: frosting, pressing out of the water and drying in the sun. Father COBO had differentiated earlier between the production of the common black chuño and the white chuño, which is called tunta in Bolivia. CARL TROLL (1931 and 1943 a) has described in detail the chuño production process which – except for minor differences – corresponds with practices in the Kallawaya area. The potatoes are spread out evenly for several nights on a flat surface with no or only a little vegetation cover, exposing them to frost during the night and to intensive insolation during the day. By means of the freezing process during the night and the thawing process during the day, water is extracted from the product; this process is expedited by trampling with bare feet (Fig. 20). The preservation product is blackened by intensive insolation which impairs its taste. During the production process of the white tunta, however, the potato is not exposed to the sun during the day soaked in water and frozen during the night. Thus, the tasty fruit stays white and is considered the better preservation product.

Apart from the potato, the thickened rhizomes of the wood sorrel species oka are also processed into the preserved product caya. Only seldom is this process carried out with aid of frost. The thick

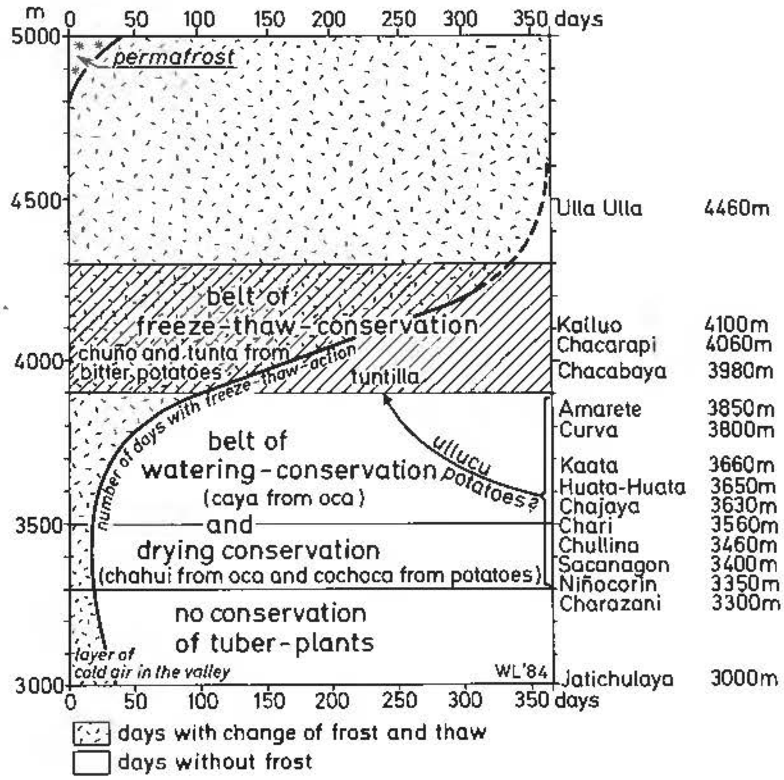

Fig. 21. Conservation of tuber plants and conditions of days with freeze-thaw-action ("Frostwechseltage") in the Kallawaya region.

rhizomes of the oka are generally subjected to a soaking process for several weeks in round basins near the village and then dried. From oka chahui also is produced by simple drying and the so-called tuntilla from papalisa by means of soaking and drying. Nevertheless, the most important preservation products are chuño and caya.

Preservation of the tuberous fruits permits stockpiling of food, which helps to bridge the dry season, but, on the other hand, promotes mobility, since the dried and lighter tuberous fruits may be used as food on trips particularly during the extensive caravan activities. According to TROLL (1931), chuño was also used as travel rations by the Inca during their expeditions. It is important to note that chuño production starts at an altitude of 3900 m because morning frost occurs daily between May and July after the harvest. Inhabitants of villages living below this climatic boundary of chuño production must carry out the preservation of the tuberous fruits grown by them in places above 3900 m. On the other hand, the inhabitants of villages located above 3900 m can preserve their tuberous fruits in the near vicinity of their homes (Fig. 21). It shows the relationship between the altitudinal location of the villages, the preservation methods and the occurrence of frost.

The fallow land in areas where bitter potatoes are grown serves as grazing grounds for lamas, alpacas and sheep and to some extent for pigs; driving of these animals to their grazing grounds is done centrally by each individual village.

A precondition for smooth functioning of the Kallawaya agricultural system is that the inhabitants of the villages have terraced slopes in all altitudinal belts between 3000 and 4300 m. In this way most of the communities can live relatively independently. This large vertical extent of the cultivation areas minimizes harvest risks, as it is quite improbable that the field produce of all altitudinal belts will be affected by negative harvest fluctuations simultaneously.

5. Exchange of Goods

Between the three-tier settlement area of the Kallawaya on the one hand and the higher area of the cattle breeders on the Puna high plateau as well as the lower altitudinal and mountain forest belt of the Yunga on the other, a vertical exchange of goods is practiced, which provides the inhabitants of all altitudinal belts with the vital supplementary goods (Fig. 22). Lama or mule caravans shuttle between the cattle breeders' belt of the Puna high plateau and the Kallawaya area. Caravans come into the Kallawaya region from the Yunga, i.e. from the tropical area. The products are sold on the individual markets and partly also on open fields. W. SCHOOP (1982) has described these activities in detail: the cattle breeders bring down dried meet, fish, wool, cheese and trout; the inhabitants of the tropical mountain forest belt provide citrus fruits, coca, sugar cane, bananas and chirimoya. In the markets of the Kallawaya area, these goods are exchanged by the inhabitants of the cattle breeders' belt and the tropical mountain forest belt for tuberous fruits, legumes and grain from the Kallawaya belt. Money plays only a minor role. Apart from the vertical exchange of goods, long-distance trade connections have in the meantime been established by means of trucks using the only road in the area, thus linking La Paz and also Peru with Charazani. There is a limited amount of traffic across the border to Peru where a much visited market is held every week.

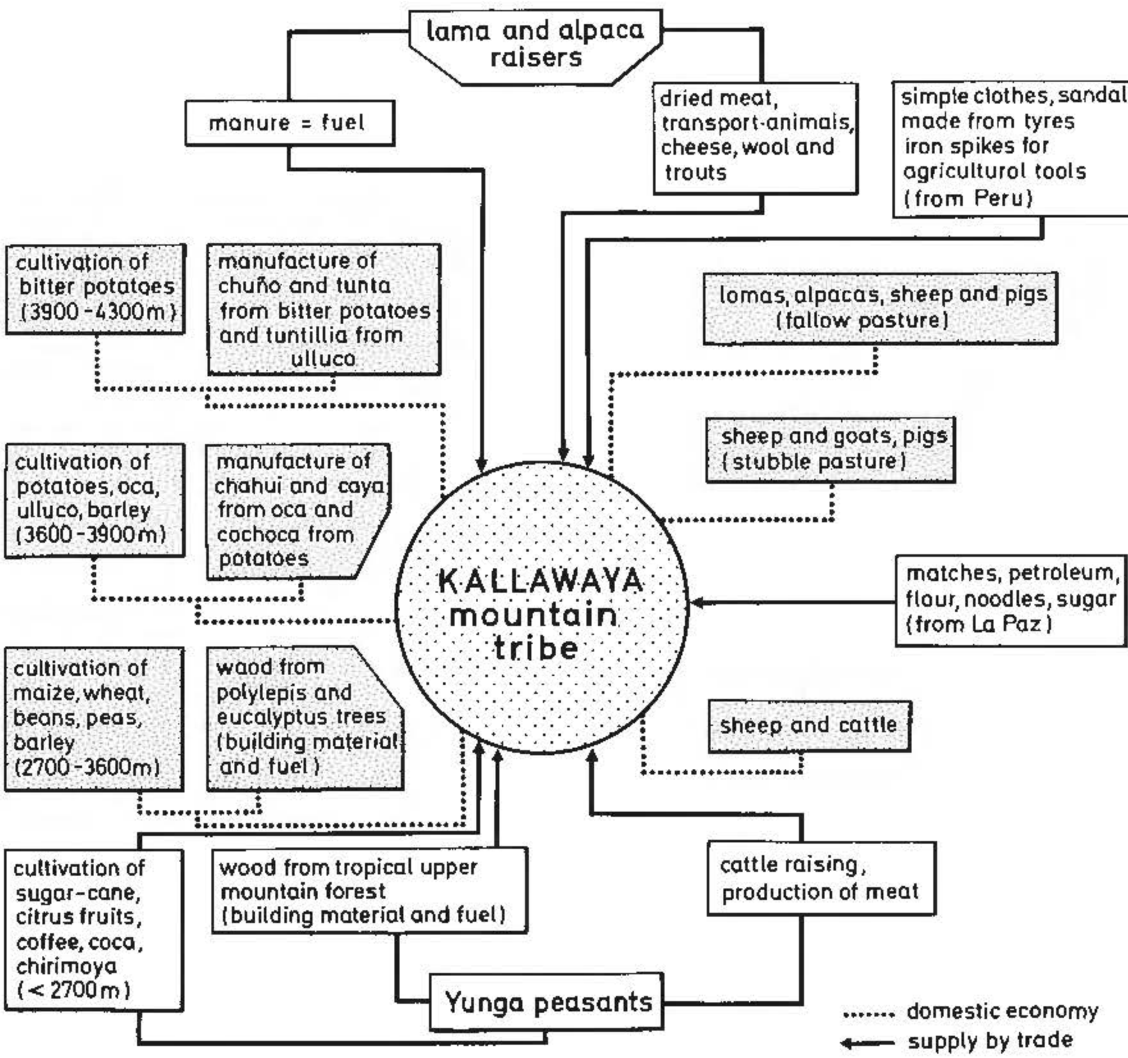

Fig. 22. Providing-system of the Kallawaya people.

6. Summary

The agrarian area occupied by the Kallawaya today still functions as a closed system. Up to the present, the Ketschua-speaking ethnic group in this region has succeeded in maintaining a system of vertical control (MURRA, 1975) deriving advantage from all innovations and amalgamating them as well as subordinating such innovations to their own system. Therefore, the land-use system and the natural potential in this area are still in an approximate state of equilibrium. The imprints of colonial influence are certainly remarkable and relate to the introduction of both large and small livestock from the Old World, i.e. cows, sheep and goats. This also holds for useful plants, weeds and ruderal plant societies, as well as for new forms of farming such as the use of the Spanish hook plow.

Today, however, there is a danger that the socio-economic conditions will be subject to drastic change due to socio-cultural change. External influences on this ethnic group are too strong. Since, at present, the danger of overloading this land-use system – e.g. as a result of overpopulation – does not yet exist, the present system may still be regarded as optimally adapted to the natural potential. The capacity of this region is still sufficient for the present population, since some of the inhabitants are migrating into the larger cities, and the total population might have been even greater in former times. This only means, however, that there is a shift of problem to the larger cities.

7. Summarized Comments

The interaction between the individual factors within the Kallawaya system is shown in Fig. 3. The following phenomena contribute to the close adjustment of the land-use system to the natural potential.

1. The area of cultivation occupied by the Kallawaya – particularly as a result of the altitudinal temperature gradient – can be subdivided into two or three altitudinal belts.
2. The location of the fields and their utilization are closely related to insolation and thus to the thermal conditions on specific slopes, according to aspect as well as to the angle of inclination of the terrain.
3. The agrarian year is determined by the distribution of rainy and dry periods.
4. The location and arrangement of the fields are also governed by the humidity regime of the area. Particular exposures with greater humidity are specifically utilized by the Kallawaya (e.g. locations with fog or dry areas).
5. The different crop rotation and fallow systems in the three altitudinal zones are governed by the thermal and moisture conditions as well as by the resulting state of the soil.
6. The cultivation and preservation of tuberous plants are closely dependent on the altitudinal temperature zonation. The freeze-thaw action during the months of May to August is a precondition for the freeze-thaw method of preservation in the upper land-use belt. In the medium belt only the soaking-drying method of preservation can be applied.
7. The cultivation of grain and tuberous fruits on artificial terraces represents an ecological adaptation to the relief of the terrain. Terraces provide protection against soil erosion and preserve rainwater. The size and form of the terraces are adjusted to the topographic conditions.
8. Tillage with the planting stick and/or the hook plow corresponds to careful cultivation of the thin soils.
9. Irrigation mainly serves the purpose of off-setting fluctuations in the rainy periods – particularly at the time of sowing.
10. The breeding of domestic animals is complementary to the agrarian system.
11. Supplementary goods are procured from other altitudinal belts with the aid of caravans – including protein-rich foods from the cattle-breeders' belt and vitamin-rich foods from the warm tropical region. The Kallawaya land-use belt provides the other region with carbohydrates by exporting tuberous fruits and grain.

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Discussion to the Paper Lauer

Prof. Dr. A. Kessler:

Is not the foggy zone an unfit area for human settlement, because it is unhealthy?

Prof. Dr. W. Lauer:

On the dry slopes of the study area it is only in the fog belt that the water supply is relatively secure. Most of the river sources are situated here. Sometimes water is also collected in cisterns. The site of the villages is partly determined by the relief in the area of glacial mountain terraces and at the lower limit of the glacial frost-débris-belt ("Frostschuttzone") with marked solifluctional humps. Today, this mountain zone is identical with the belt of tuber plant cultivation.

Prof. Dr. W. Haffner:

1. What is the amount of rainfall in the foggy, densely-settled zone?
2. The humidity conditions, or rather the frequency of fogs, may be similar on the slope down to the Red Sea in the densely-settled Yemenite highlands.

Prof. Dr. W. Lauer:

According to the first, still incomplete measurements, with rain-gauges installed for that very purpose, we estimate the annual rainfall at 450 to 550 mm.

Prof. Dr. W. Eriksen:

Since the study area is north of the Tropic of Capricorn, slopes exposed to the south should be more strongly insolated and heated at least during the summer. Is this true, and what consequences can be observed for the agricultural utilization and the altitudinal zonation of these slopes?

Prof. Dr. W. Lauer:

A slight southern position of the sun is recorded between November 3rd and February 8th in the Kallawaya region. These are the days with a vertical position of the sun. During this period the slopes are evenly insolated, but slopes exposed from SE to SW are always steeper because of periglacial denudations within the study area, so that they still show temperature deficiencies even during this season.

Prof. Dr. W. Weischet:

The settlements are almost exclusively found somewhat below the Ceja de la Montaña. Mr. Kessler indicated that the living space just below and within the foggy zone might be unhealthy. Is it not possible that the selection of settlement sites was determined by the existence of reliable sources of water supply in the following context: the Ceja is a climatic altitudinal limit – it possibly has a correlation with pleistocene altitudinal belts of solifluction and slope formation. Solifluction leads to accumulations of loose material on flat slopes. Because of infiltration, ground-water and river sources, the bodies of loose material supply good preconditions for settlements in the concerned semi-arid area. Thus we see today the spatial coincidence of Ceja and settlements; the causes, however, may well be due to other factors dependent on climatology. Mapping of the geomorphological altitudinal zonation is therefore advisable.

Prof. Dr. W. Lauer:

The geomorphology of the area is largely mapped. It can be seen that the villages are situated on flat parts of the slopes at the lower end of late-pleistocene, periglacial débris-streams, which are remarkably rich in sources. The fact that today the belt of tuber-plant cultivation and the fog-belt of the Ceja, for the most part, coincide at these elevations is connected with the post-glacial shift of altitudinal belts, which in this area shows a superposition of the above mentioned phenomena. This is not a single case, however, for in other mountain areas of Latin America similar conditions can be observed, e.g. in Mexico, in Guatemala and in Peru.

Prof. Dr. J. Martens:

From the biological point of view, your study area looks completely degraded, lacking any natural plant cover. Are there actually any larger areas which are covered with original plant societies?

Prof. Dr. W. Lauer:

Within the map section presented, the area has largely been transformed into a terraced agricultural landscape (between 2800 and 3900 m a.s.l.). A secondary vegetation of agricultural weeds has appeared in the fields, which partly originates from the reservoir of the surrounding natural vegetation. Fallows and field balks mostly bear remnants of the natural flora. Permanent fallows and many extremely steep slope sections are largely covered by climax vegetation. Within the mapped transects the last-named areas occupy up to about 20–30% of the area.

Prof. Dr. B. Messerli:

1. Referring to the theoretical insolation: Is this the calculated, effectively possible, or the measured relative length of insolation?
2. Can an increase in soil erosion caused by man be indicated? Have there been negative tendencies in recent times?

Prof. Dr. W. Lauer:

1. The potential insolation for the study area was calculated after GESSLER (1925).
2. Hazard events, especially natural ones, and the ones caused by man, have been partially mapped. However, we cannot yet guess their full scope, especially in recent times, but following the recent slight depopulation of the area, damage should have increased somewhat by natural erosion, since not all areas are still used.

Dr. Yu Xiao-Gan:

Is there any potential for reforestation below 3900 m a.s.l.? If so, by what methods and with what kind of trees?

Prof. Dr. W. Lauer:

Systematic afforestation has not yet taken place. Planting of trees has happened, however, and still happens on a small scale, since the introduction of eucalyptus, cypresses, and pines.

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Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Eco-Climatological Aspects of the Bolivian Puna with Special Reference to Frost Frequency and Moisture Conditions

Wolfgang Eriksen

With 10 Figures

For some decades the altitudinal belts of the paramo and puna regions in the tropical Andes of South America have given rise to intense scientific studies in various fields. Within the natural sciences most attention has been paid to the climatic and biogeographical conditions of these tropical mountain areas because they differ fundamentally from comparable belts in extratropical mountain systems. Moreover they are the basis for the development of well-populated and, at least in parts, highly developed cultural and economic regions.

Early studies made clear that this tropical mountain area cannot be regarded as a homogeneously structured region as far as its climate and vegetation is concerned, but that there is a marked change from equatorial latitudes to the southern margins of the altitudinal belts. This change is characterized on the one hand, in the central tropics, by a negligible annual range of temperature and all-year precipitation and on the other hand, towards the marginal tropics, by a progressively distinctive annual range of temperature and an increasingly seasonal precipitation regime. In addition, there is a decrease of precipitation towards the south and southwest, so that the puna region can be subdivided, from the point of view of moisture and of biogeography, into the "humid puna", the "dry puna" and the "thorn and desert puna" (TROLL, 1968).

Undoubtedly this differentiation finds its clearest expression in the Bolivian Andes, particularly in the Altiplano area. A distinct alternation of dry and humid seasons with a small and spatially differentiated amount of precipitation, a significant annual range of temperature, which decreases however with increasing altitude, and the frequent occurrence of frosts represent the most important macro-climatic characteristics of the comparatively populous puna belt at an altitude between 3300 m and 4500 m[1]. The winter cold period with frequent frosts coincides with the dry season, whereas the moderately warm summer with increased insolation coincides with the rainy season.

From the point of view of plant physiology and distribution, both the natural vegetation (montane grass or shrub semi-desert) and the cultivated plants of this altitudinal belt are highly adapted to the climatic conditions which have been mentioned. As LAUER (1982) expressed it more generally, the identification of the thermal and moisture variations within the puna belt is a basic requirement for ecological differentiation in space and time. The frequency of frosts, the distinctive dry period, the irregular setting in of the rains, as well as their variability in quantity, prove to be the eco-climatic factors which limit the growth of cultivated plants and natural vegetation. In recent years these relationships have been illustrated in several regional studies (e.g. TROLL, 1931, 1943; BECK and ELLENBERG, 1977; SCHRÖDER, 1981; LAUER, 1982; MAHNKE, 1982; BRUSH, 1982).

It is the purpose of the following remarks to examine from regionally limited case studies, what general eco-climatic rules are deducible for the area of the Bolivian "humid" and "dry puna" (in the sense of TROLL) with regard to the frequency of frosts and:

[1] The altitudinal data refer to different authors: 3300 m: RUTHSATZ (1977); 4500 m: HERZOG (1923). As yet no generally accepted upper or lower limits to the puna belt have been defined.

1. its dependence on altitude together with spatial and temporal variation in this;
2. its interaction with the spatially and temporally structured moisture zones;
3. its relevance for the character and the altitudinal structure of agricultural activities.

Fundamental to this study are the long-period meteorological data (esp. FRERE et al., 1975), to which the results of the regional case studies can be related.

The research area extends from Lake Titicaca in the north to the Bolivian-Argentine border in the south and encloses the altitudinal belt between 3300 m and 4500 m (see above), which is occupied by a montane grass or shrub semi-desert.

1. Frost in the Puna Belt of Bolivia

The climatic map "Carta climática de la región andina boliviana" by SHERIFF (1979) shows that one can expect regionally severe winter frosts throughout the Bolivian puna. The mean minimum temperature of the coldest month in the dry-, thorn- and desert puna falls well below $-5\,°C$, at several stations even below $-10\,°C$ and is thus evidently lower than at the high-Andean station of Chacaltaya (5280 m), where

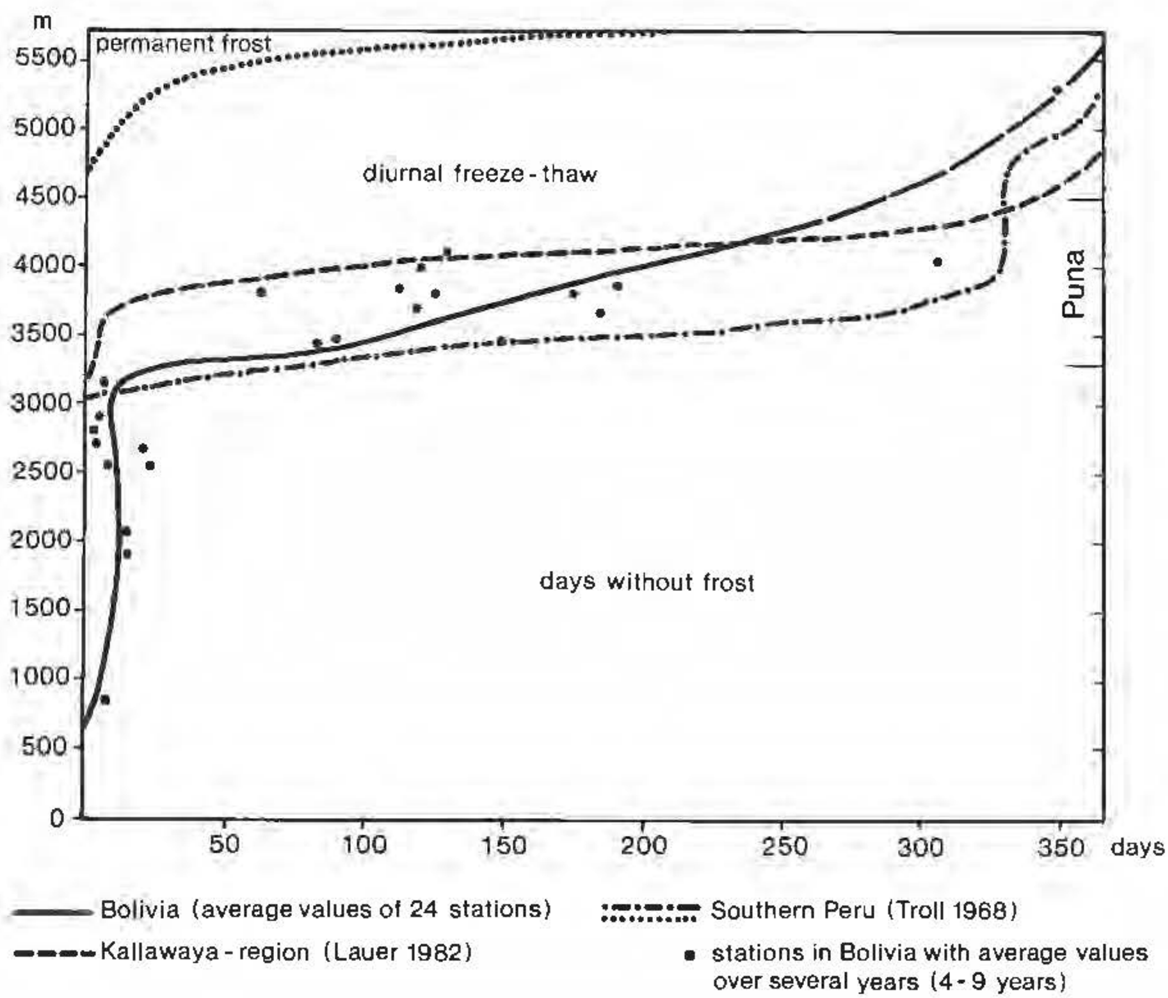

Fig. 1. The dependence of the frequency of diurnal freeze – thaw on altitude.

it reaches only − 6 °C. In the humid puna the winter frost intensity, with temperatures between 0 °C and − 5 °C, is comparatively less severe. Only in the immediate periphery of Lake Titicaca do the mean minima of the coldest month remain above freezing point, correspondingly roughly to conditions in the upper yungas- and valle-region on the eastern flank of the Andes.

Data on frost intensity during the mid-winter season do not indicate much about the ecology, since they do not apply to the vegetative period. On the contrary information on the frequency of night frosts and on the frost-free period during the summer season is of far greater importance for agriculture, particularly since in the puna marked spatial and temporal variations are indicated (BECK and ELLENBERG, 1977).

Since TROLL's investigations in the tropical Andes it has been well known that the occurrence of frost and the frequency of diurnal freeze and thaw primarily depend on the altitude. Corresponding to the high temperatures in the lower regions of the Andes, regular frost – measured at 2 m above the ground – does not occur below an altitude of 3000 m. Above that level, in the "tierra helada", it increases rapidly in frequency, reflecting the seasonal regime of temperature at the fringe of the tropical zone, so that at altitudes of 4000 m nearly half the days of the year experience night frost. Finally at altitudes around 5000 m there are no longer frost-free days as permanent frost sets in (Fig. 1). Thus the puna between about 3300 m and 4500 m is characterized by the extremely wide range from about 25 nights with frost at the lowest to about 300 at the highest altitudes.

To a certain extent these data differ considerably from the findings of TROLL (1968) in southern Peru and of LAUER (1982) in the Kallawaya-region north of Lake Titicaca, although the general trends are similar (Fig. 1). The curve developed by the author is based on 24 Bolivian mountain stations, for which many years' meteorological records are available. It was determined by mean values for different altitudinal belts. It relates also to the occurrence of night frost in several cold-air basins of the southeastern Cordillera (above 700 m) and is dependent at altitudes above 5000 m on the data for the station at Chacaltaya.

The discrepancies between it and the curves of TROLL and LAUER might be caused by the smaller number of stations considered, by some very short periods of measurement (in some cases less than 2 years) and by the local conditions of the relief in the research areas (some measurements being taken on

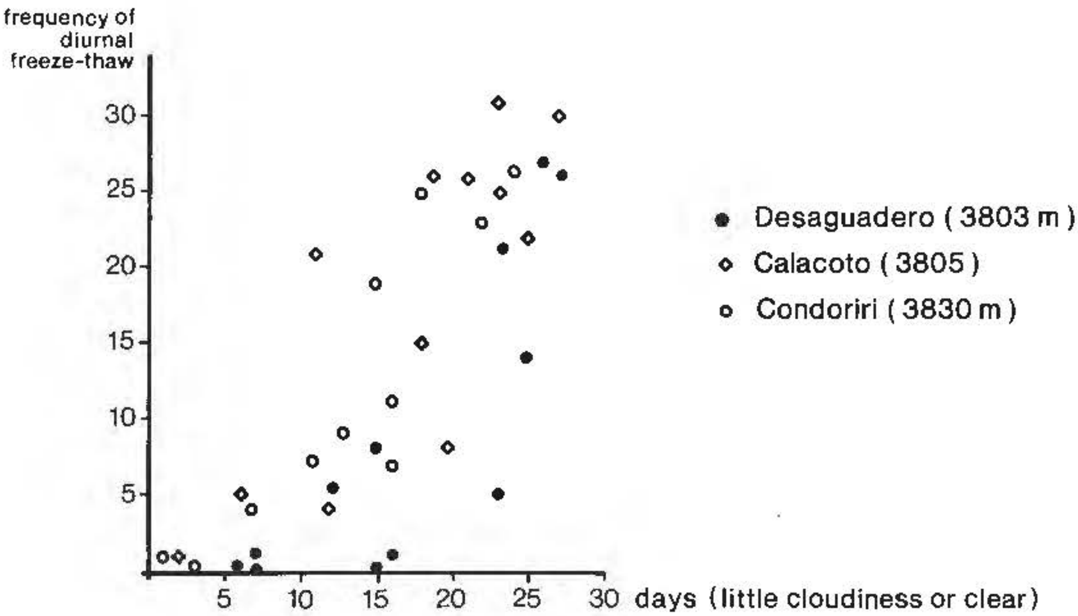

Fig. 2. The relationship between the frequency of diurnal freeze – thaw and cloudiness on the Altiplano (1973).

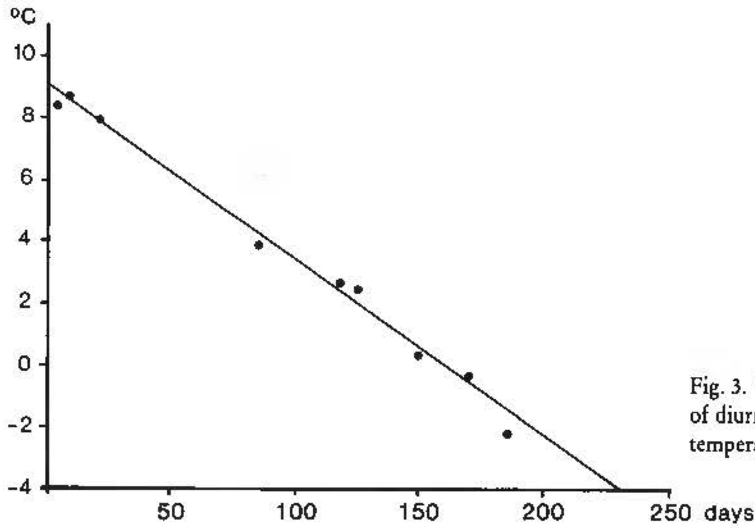

Fig. 3. The relationship between the annual frequency of diurnal freeze – thaw and the mean annual minimum temperature (Bolivia).

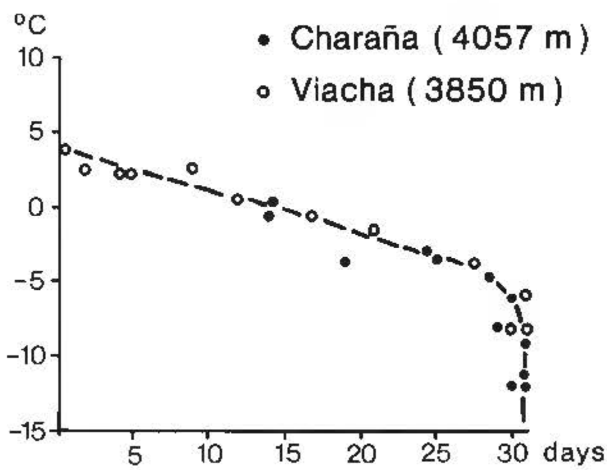

Fig. 4. The dependence of the mean monthly frequency of diurnal freeze – thaw on the mean monthly minimum temperature (Bolivia).

isolated mountain or steep valley sites). Moreover TROLL's curve should reflect the greater dryness (a dry variant) and LAUER's the greater humidity (a humid variant) of the particular research areas concerned.

The curve for the average values is influenced especially by the data for numerous stations on the Altiplano (between 3500 m and 4100 m). With respect to the frequency of frost, it is these data which show that the greatest regional differences can occur at comparable altitudinal levels. Charaña (4057 m) for example has 307 nights with frost, whereas La Paz–El Alto (4105 m) has only 129. These findings illustrate on the one hand the limited usefulness of average values, while on the other hand they prove that the number of nights with frost does not depend solely on the altitude of the station[1].

Besides local influences at the meteorological stations (e.g. the dispersal or accumulation of cold air determined by relief, that is by katabatic slope and mountain winds at night) it is the spatially and temporally variable degree of cloudiness that most influences the frequency of night frosts in the puna

[1] JORDAN (1983) stresses the considerable difference between extremes of temperature measured in and out of the screen in a mountain climate with intense solar radiation.

regions. Indeed the number of days with alternating freeze and thaw evidently increases with the number of days with little cloud, which thus experience more intense radiation loss (Fig. 2). This emphasizes the findings of Bolivian meteorologists who say that 80% of all frosts are caused by radiation loss at night (so-called "heladas blancas") (c.f. FRERE et al., 1975). At the same time this indicates a possible explanation for the extremely high frequency of alternate freezing and thawing (more than 250 days per annum) in the western and southwestern puna, which is very dry and has little cloud, compared with only about 150 days in the humid puna.

It is the radiation loss at night that predominantly determines the diurnal minimum temperature and thus the occurrence of frost. In this connection the close relationship between the occurrence of frost and the mean annual minimum temperature is significant (Fig. 3), so that the latter can be used at least roughly to determine the number of days with alternate freezing and thawing, if direct observations are not available. The same applies to the mean monthly minima (Fig. 4). Only at mean minima of + 4 °C to + 5 °C can frosts in the puna level be expected. With a mean monthly minimum temperature of − 5 °C, frost usually occurs every night.

It is clear that the frost intensity as well as the monthly frequency of frost primarily depends on the mean monthly minumum temperature. Since we are concerned in the marginal tropics with a marked annual range of temperature, there must be, in this connection, a distinct annual variation in the frequency of frost at stations in the Bolivian puna and also a marked contrast between periods during which frosts are frequent and those which have few frosts.

Here again the puna turns out to be a clear transition belt between altitudes above 5000 m with frosts almost daily and altitudes below 3000 m with very few days with frost (Fig. 5). With a decrease in altitude the frequency of frost diminishes and is increasingly restricted to the winter months. At the same time, the frost-free period extends from 0 months at higher altitudes of the puna to about 7 months at pre-puna levels.

The same picture emerges from the mean values for 24 stations for which observations have been collected over many years. Figure 6 shows clearly the rapid vertical increase in the frequency of night frost on the puna as well as the short period of frost risk at altitudes below 3000 m (particularly in frost hollows). In response to the increase in radiation and the consequent overheating of the mountain region (the climatic effect of mass elevation), isolines are raised by about 1500 m during the summer, so that a frost-free "bell" develops, which reaches upwards just into the puna level (up to about 3800 m). This "bell" is ultimately responsible for the fact that at this altitude, especially on the Altiplano, cultivation can still be practised. Nevertheless, the frost-free period is limited to a few (4–5) months and to the lower

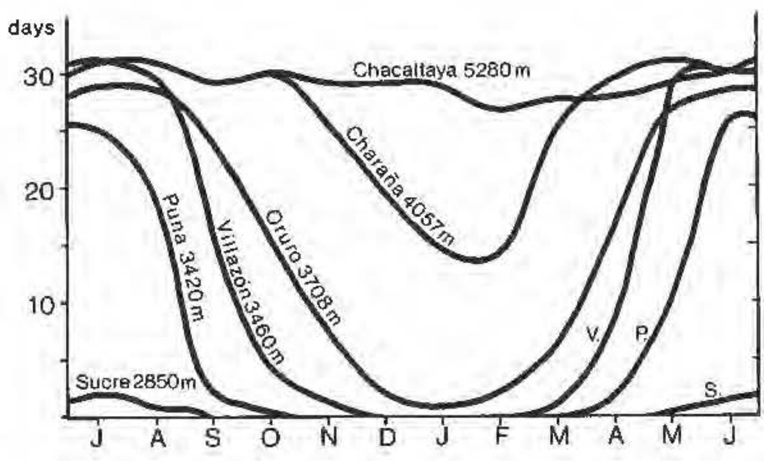

Fig. 5. The monthly frequency of diurnal freeze – thaw at selected stations at different altitudes (Bolivia).

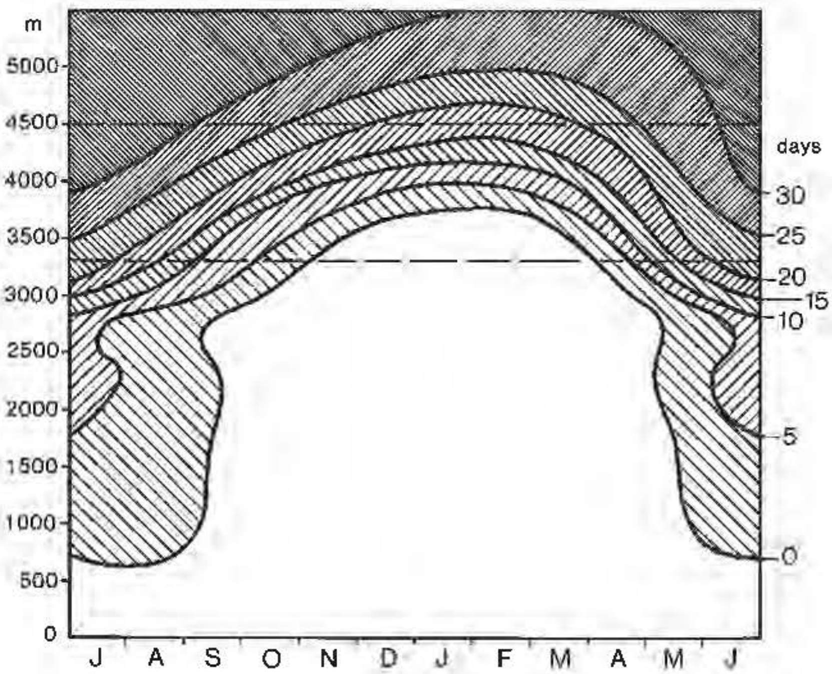

Fig. 6. The dependence of the mean monthly frequency of diurnal freeze – thaw on altitude (Bolivia).

altitudinal levels. It can be extended at most to 6–7 months, provided that the category "1–5 days of freeze and thaw" is included, the "bell" in this case reaching up to 4000 m. The inclusion of the period with a frequency of frost of 1–5 days per month is justified in so far as in such cases it is mostly a matter of relatively moderate night radiation frosts which are recorded only a few hours before sunrise, as the thermoisopleth diagram for Oruro (3706 m) reveals (TROLL, 1959)[1]. From the studies of FURRER and GRAF (1978), at the nearby station Patacamaya (3789 m), it is known that even during the winter (with mean minimum temperatures of approximately − 4.5 °C) frosts up to − 2 °C are registered only in the top layers of the soil (between 5 and 10 cm deep). LAUER (1982) refers particularly to the importance of soil temperature as an ecological factor.

It must be emphasized that the data given so far refer only to air temperature measured at the level of the meteorological screen (1.5–2.0 m above the ground). According to the findings of RUTHSATZ (1977) in the Argentine Puna, over flat terrain an average of 1–2 °C lower minima and thus a correspondingly greater number of days with frost and thaw can be expected in the air layer close to the ground (5 cm) compared with screen values. According to Fig. 4 a reduction of − 2 °C of the mean monthly minimum, measured at 2 m above the ground, would correspond to a rise in the monthly frequency of frost to about 6–7 days.

It stands to reason that the average frost conditions of the puna which have been taken into consideration can not take sufficient heed of the regional and local peculiarities such as inclination, aspect, type of soil and plant cover, and thus the katabatic flow and down-slope accumulation of cold air during the night and the differential insolation and heating of the ground during the day. Concerning this question much research remains to be done, as has been emphasized by BECK and ELLENBERG (1977). Nevertheless the information which has been given so far outlines the thermal conditions and the eco-climatic limits in the puna belt of Bolivia with sufficient exactness.

[1] The discrepancy between TROLL, 1959 (Oruro without night frost during the summer) and Fig. 5 (Oruro with night frost occurring throughout the year) results from the differing lengths of the periods of observations for the climatic data used. In Fig. 5 the mean values of long-period observations have been used.

2. Moisture Conditions in the Puna Belt of Bolivia

As already mentioned, the average precipitation in the puna region decreases from the east to the west and southwest, from more than 500 mm in the humid puna to 300–400 mm in the dry puna and less than 200 mm in the thorn- and desert puna.

All stations have in common a seasonal distribution of precipitation typical of the margins of the tropics, with maxima during the summer and minima during the winter. The summer rainy season begins at most stations with a pronounced increase in the amount of precipitation per month.

Within the puna, however, there are marked differences in the length of the rains (4–5 months in the humid puna, 3–4 months in the dry puna) as well as in the beginning and the end of the rainy season (Nov. or Dec., resp. Feb. or March) (Figs. 7 and 8).

In recent years numerous studies concerning the aridity or humidity of selected areas have shown that the distribution and amount of precipitation are undoubtedly the basis of the moisture status of a region. At the same time it is apparent that only the amount of precipitation not lost by evapotranspiration can be regarded as a water surplus (LAUER and FRANKENBERG, 1978, 1981; SCHMIEDECKEN, 1978). „Zur Bestimmung der Humidität bzw. Aridität eines Raumes kann nur die potentielle Verdunstung herangezogen und dem Niederschlag gegenübergestellt werden" (LAUER and FRANKENBERG, 1978). Without trying to enter into a discussion about different circumstances of evaporation and transpiration and the problems of their measurement and estimation (c.f. ERIKSEN, 1983), potential evapotranspiration in the present study (Fig. 7 and Fig. 8) has been calculated according to the formula by PENMAN (1956), which is generally regarded as satisfactory. The difference between precipitation and potential evapotranspiration determines the water balance, described by LAUER and FRANKENBERG (1981) as the "eco-climatic water balance".

Applying the potential evapotranspiration values (after PENMAN), published by FRERE et al. (1975), the following picture emerges for the moisture conditions of the Bolivian puna. Except for a single month, recorded for the station of El Belén, no fully humid month can be indicated for any station in the puna. Only if the evapotranspiration values are halved do semi-humid and semi-arid months emerge, which without exception coincide with the time of the summer rains. Thus in the humid puna March is still semi-arid, whereas in the dry puna it is already arid. On the whole the relatively humid period in the puna is confined to a few months (2–5) during the summer. Thus the preconditions for cultivation are decisively limited, all the more since the amount and the start of the summer rains vary markedly from year to year (FRERE et al., 1975).

If the moisture conditions of the puna belt are compared with the thermal conditions which have been analysed above, especially with the occurrence of frost, remarkable parallels appear concerning the annual distribution. The time without any or only few frosts (0–1 days with night frost per month) largely coincides with the relatively humid period of the year (Fig. 7 and Fig. 8). It is sometimes shorter and sometimes longer than the rainy season, the shorter humid period in the dry puna coinciding with a shorter period with few frosts on average. In the thorn puna with one semi-arid month, if any, no frost-free month is likely.

The period of October and November proves to be an especially crucial period with regard to the setting-in of the rainy season and the occurrence of late frosts. As for the end of the rains and the occurrence of early frosts, the crucial period is in March and April. Also in this respect the enormous variability of the annual course of the weather and its variability from year to year has to be taken into consideration. Only December, January and February seem to be comparatively safe regarding the availability of water and heat.

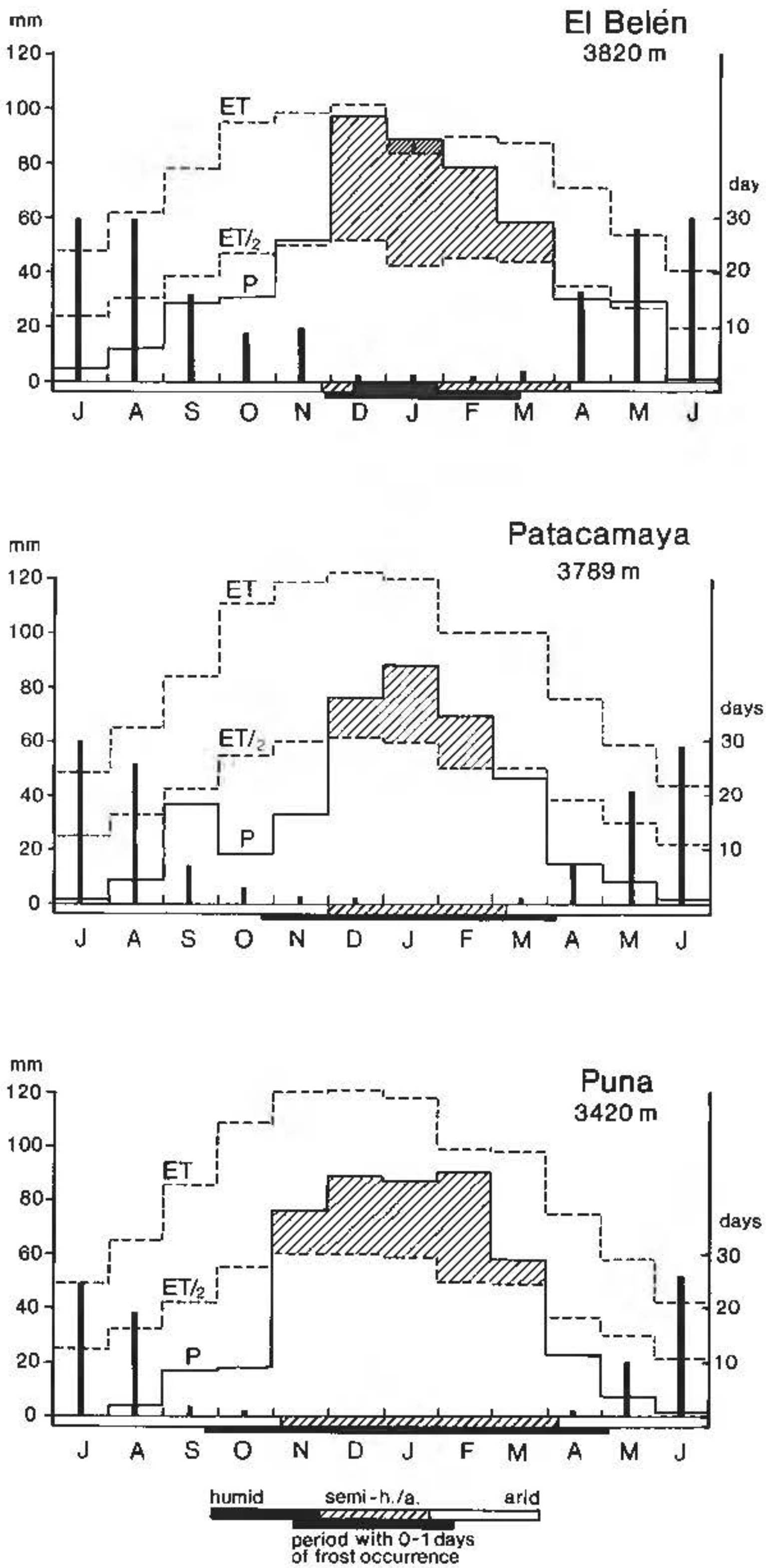

Fig. 7. Monthly precipitation (P), evapotranspiration (ET) and frequency of diurnal freeze – thaw at selected stations in the humid puna (Bolivia).

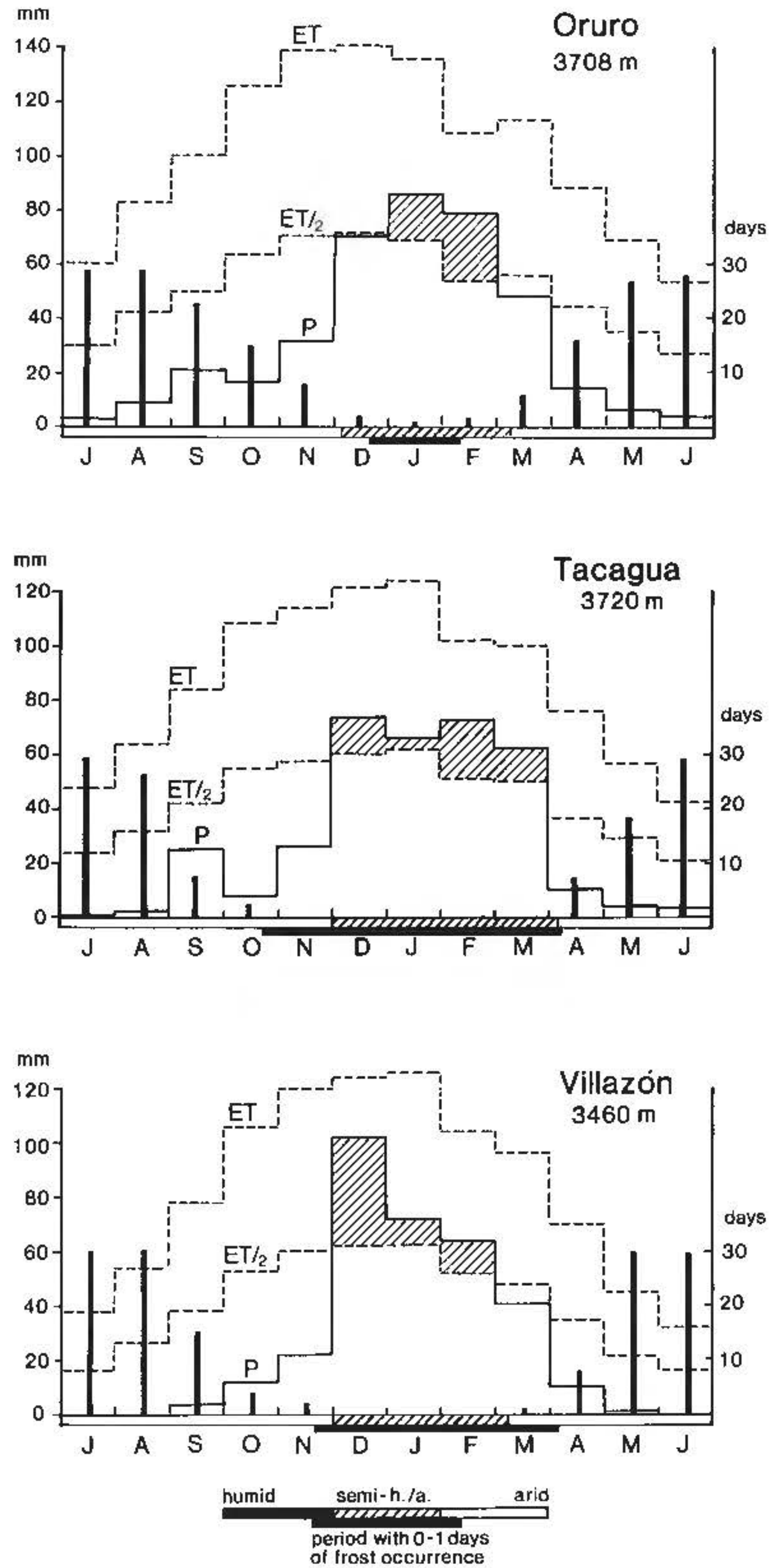

Fig. 8. Monthly precipitation (P), evapotranspiration (ET) and frequency of diurnal freeze – thaw at selected stations in the dry puna (Bolivia).

3. Agricultural Land-Use – the Dependence on the Thermal and Moisture Conditions of the Puna Belt

How is cultivation possible under the limiting eco-climatic conditions in the puna, which have been outlined above? This question – especially in the light of the development of well-populated and advanced civilizations in the Andes – has been widely analysed and discussed (c.f. TROLL, 1931; MONHEIM, 1959; SCHOOP, 1975; SCHRÖDER, 1981; MAHNKE, 1982; LAUER, 1982).

It has long been recognized that over the centuries the Indians of the puna belt have developed pronounced forms of adjustment by which an optimal utilisation of the limited thermal and moisture potential, that is a lessening of the risk of crop failure or financial loss, could be obtained. The most important adjustments to the climatic conditions will be mentioned briefly as follows:

1. In the humid puna intensive cultivation (compared with that in the dry puna), especially in the thermally favourable area close to Lake Titicaca.
2. The distribution of cultivated areas and field crops at different altitudes with different risks.
3. The utilisation of slopes with little danger of frost and with aspects favoured by insolation.
4. The intensification of cultivation by irrigation.
5. Cultivation on terraces which preserve the soils, collect the rain water and make irrigation possible even on steep terrain.
6. The development of a well contrived system of crop rotation and fallow periods.
7. The utilisation of the climatic conditions (frost occurrence) for special methods of preserving tuberous plants (e.g. production of chuño).
8. The cultivation of largely frost-resistant plants which have a short vegetative period.

These different methods of adjustment have frequently been described in the relevant literature (see above) and are widely known. With regard to the eco-climatic explanations which have been made so far only the last point (8) will be dealt with here.

A synopsis of all obtainable data on the distribution of the most important tuberous plants and cereals in the altitudinal belts of the Bolivian Andes (Fig. 9) shows that agriculture can indeed make use of a great variety of cultivated plants, several endemic species being confined to the puna level (Oca, Tarwi, Ulluco).

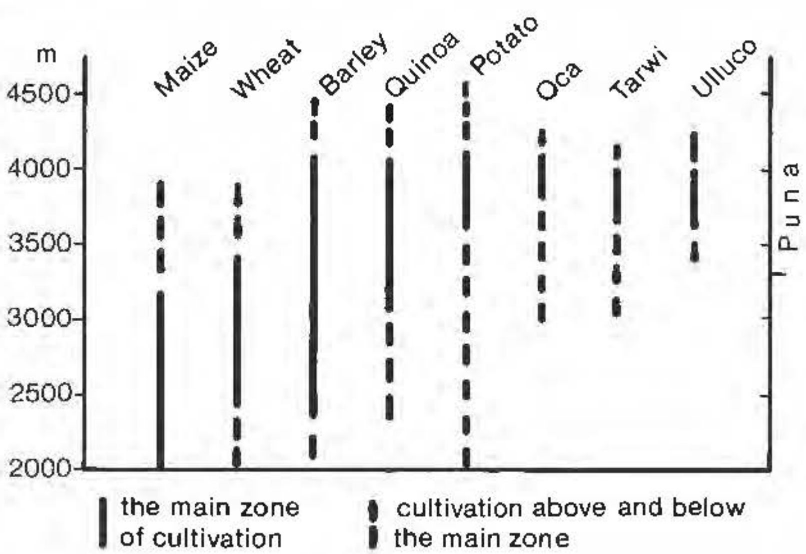

Fig. 9. The altitudinal distribution of important cultivated plants in the Bolivian Cordilleras.

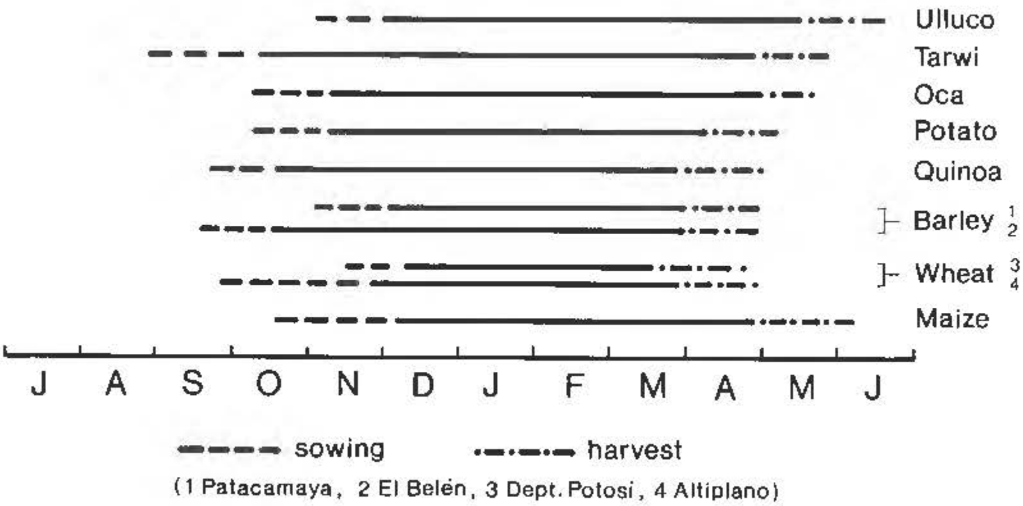

Fig. 10. The times of sowing and harvest for important cultivated plants in the Bolivian puna.

The altitudinal limit of the main cultivation belt is found at 4000 m, an altitude which has previously been regarded as the upper limit to the region without any or with only few frosts in summer. Only by means of an optimal adaptation to local relief (the use of slopes with few frosts, exposed to the sun) and by choosing cultivated plants which are little susceptible to frost (esp. Quinoa, potatoes and barley) can this altitudinal limit be transcended in certain areas (up to 4400–4500 m) (Fig. 9).

Moreover it is important that the comparatively frost resistant species of the high altitudes are sown on an average of 1–2 months earlier in the year and reaped about a month later compared with other species, so that they have a longer growing season with a smaller amount of heat at their disposal (Fig. 10). Nevertheless, both seedtime and harvest are crucial also for these plants, because they coincide with the period of October and November which has been recognized as being eco-climatically precarious (irregular setting-in of the rains with the occurrence of late frosts) and with March and April (rapid increase in night frosts).

Thus cultivation in the Bolivian puna belt remains precarious despite ingenious forms of adjustment to the eco-climatic conditions – including heavy rains and hailstorms during the summer. Unfavourable weather situations at the beginning and at the end of the growing season again and again result in disastrous crop failures or decreases in productivity so that life, which is already hard in this high altitude region, is exposed to further burdens.

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Discussion to the Paper Eriksen

Prof. Dr. W. Lauer:

Have the data, which you used to show the dependence of frequency of frosts on altitude (Fig. 1), been measured in the screen or close to the ground? The difference of both data might have a great influence on the course of the curve in the diagram.

Prof. Dr. W. Eriksen:

The data refer only to air temperature measured at the level of meteorological screens.

Priv.-Doz. Dr. P. Frankenberg:

Is it possible to differentiate the number of days with frost according to the frost intensity?

Prof. Dr. W. Eriksen:

Of course it would be useful to be able to do so. But the necessary data (observations for the various meteorological stations) were not obtainable.

Miss. J. M. Kenworthy M.A.:

Can you tell me whether you have studied the variability of the frost-free period?

Prof. Dr. W. Eriksen:

This was not possible, again because original data for the meteorological stations were not obtainable to illustrate variability, except for precipitation, for which FRERE et al. (1975) give mean monthly and annual values with 80% probability.

Dr. M. Winiger:

a) Is there any correlatiou between the frequency of frost and reduction in the density of plant cover? Is there any information about the degree of plant cover in the vicinity of the various stations?
b) From which altitude upwards does the frequency of repeated freezing and thawing decrease?

Prof. Dr. W. Eriksen:

a) Only a relatively rough assignment of stations to "humid", "dry" and "thorn and desert puna" is possible.
b) From about 5000 m upwards permanent frost sets in so that the frequency of freezing and thawing is reduced correspondingly.

Prof. Dr. B. Ruthsatz:

In the Aguilar region (NW-Argentina), the boundary between the high-Cordilleran and the subnival belt lies at about 4800/4900 m and corresponds to a mean annual temperature of 0 °C, i.e. regular night frosts and some days with continual frost. Here Cordilleran grassland gives way to tufted grassland.

W. Erlenbach:

You mentioned two crucial periods for agriculture. Let me add a third crucial period for plant growth (grass-cover) and thus for livestock production. From the diagram for Patacamaya (Fig. 7) it can be seen that at this station the month of September (climatologically) ought almost to be regarded as sub-humid. This applies to the long period mean value. We can proceed from the fact that sufficient precipitation falls in some Septembers to initiate growth of the grass. Yet this humid period in September lasts for 2–4 weeks only. After that October, and to some extent November, are definitely drier on average and are thus far more likely to show a deficit. The grass dries up after sprouting and taking root (this is confirmed by personal information from the director of the agricultural experimental station at Patacamaya). In such years the regular growth of the grass during the rainy season sets in markedly later, causing considerable hardship for stock farmers on the Altiplano, which is overstocked anyway.

Prof. Dr. W. Eriksen:

These are very interesting remarks which bring out the necessity for more precise analysis of mean monthly values as well as the importance of investigations into the environmental conditions at each locality.

Prof. Dr. W. Weischet:

a) In the diagrams showing annual variation of precipitation and evapotranspiration (Figs. 7 and 8), months with 80–100 mm precipitation are regarded as semi-humid. How has evapotranspiration amount been determined?
b) In the eco-climate of the Bolivian Altiplano, wind, with its characteristic diurnal range, must be an important influencing factor. How has wind been taken into account as a factor in evapotranspiration?

Prof. Dr. W. Eriksen:

Evapotranspiration was determined according to the formula of PENMAN (cf. FRERE et al., 1975). It takes into account the mean wind speed (m/sec) at 2 m above the ground during the period of analysis.

Erdwissenschaftliche Forschung, Bd. XVIII, 211–234
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The Utilization of Natural Resources by a Small Community on the Highlands of Bolivia and Its Effects on Vegetation Cover and Site Conditions

Barbara Ruthsatz and **Ursel Fisel**

With 14 Figures and 3 Tables

1. Introduction

The Highlands of Bolivia have been exploited by man in a variety of ways for thousands of years. They were first settled by hunting tribes around the end of the last glacial period 10 to 12 thousand years ago. The transition to farming and animal domestication may have begun between 4000 and 3000 B.C., culminating between 200 and 800 A.D. in the Tiahuanaco Culture of the Aymara tribes – a stage of development in which the natural resources were being used both cautiously and effectively (LUMBRERAS, 1967; TROLL, 1968; NUÑEZ, 1970; for a detailed bibliography see RUTHSATZ, 1983). The influence of the Inca Empire, developed by the Quechua tribes, was not very intense in southern parts of the Andean Highlands. This was a result of the limited amount of time during which the area was under Inca rule (ca. 1438–1470 A.D.), as well as the apparently similar life-styles of the neighbouring tribes. A much stronger influence with regard to land-use practices resulted from the Spanish conquest of the Highlands. The Spaniards brought in new types of domesticated plants and animals as well as techniques of cultivation which probably spread rapidly throughout the Highlands as a result of their labor-decreasing/yield-increasing effects. But these improvements may not have lasted for long.

It is nevertheless astonishing to see how many of the old practices and customs have been maintained through the centuries.

It is frequently difficult to ascribe their origin to one culture or another. Under similar living conditions in parts of Spain and the Andean Highlands similar farming practices probably evolved: for example the "Zelgen"-system of land-use, grazing of fallow land, and transhumance. After the sharp population decrease at the beginning of the Spanish rule in the Lake Titicaca area (as much as 60%, according to SMITH, 1970, and SÁNCHEZ-ALBORNOZ, 1973), the number of inhabitants in the Highlands gradually began to increase again, and the present-day population density in the Lake Titicaca region presumably corresponds to approximately that existing shortly before the Spanish conquest.

The Andean Highlands stretch from southern Peru to northern Argentina over about 10 degrees of latitude. In Bolivia they reach a width of more than 300 km between the bordering East and West Cordillera. Individual peaks and mountain chains rise up to 5000 m above the 3500–4100 m high plains, subdividing them into several basins, most of which having an internal drainage system.

A marked dry-winter/wet-summer climate, corresponding to the highlands' location in the sub-tropical belt, predominates. Precipitation ranges from over 800 to less than 50 mm per year in a NE-SW-direction. Therefore, all levels of humidity exist, ranging from the subhumid Lake Titicaca area to the permanently arid Atacama Desert. The temperature regime is influenced by both the elevation and the precipitation characteristics. With increasing aridity we find increasing continentality with corresponding higher daily temperature variations as well as the danger of night frost.

Still nowadays, the basis for human life in the Highlands is, apart from a few mining locations the productivity of the plant cover (ELLENBERG, 1979; GUILLET, 1981; BRUSH, 1982), which decreases from northeast to southwest with the aforementioned increasing aridity. Parallel with this goes a decrease in human population density. In all of the zones the subsistence economy is based on farming and animal husbandry. The importance given to each activity varies, and in some areas there is a spatial separation between pastures and farm land. Only in the extremely humid upper elevations of the north and in the semiarid regions of the south it is probable that the population has subsisted entirely upon animal products, which nevertheless were used in trade with neighbouring agricultural communities for other types of food (eg. NACHTIGALL, 1965; WEBSTER, 1973; BROWMAN, 1974).

The long-lasting and ecologically variable land-use practices in the Andean Highlands have led to extensive alterations of the original plant cover as well as its habitats. Because of this, a reconstruction of the natural or original landscape – meaning a landscape without man's influence – is scarcely possible today. Likewise, the historical development of man's influence on the vegetation of the Highlands can only be considered in hypothetical stages (PRESTON, 1974; WENNERGREN and WHITAKER, 1965; RUTHSATZ, 1983). Within the contemporary landscape we can certainly recognize in many places evidence and consequences of past agricultural techniques; e.g. lichen-covered piles of gathered stones, narrow terraces, protecting stone walls, collapsed irrigation canals, vegetation mosaics due to differing land-use pattern in the past. We cannot with certainty, however, put these indicators into a chronological sequence. Without question, soil erosion, which is everywhere, has been caused or at least intensified by overgrazing and farming practices. One can only guess at the size of the area which has irreversibly been degraded this way (TERRAZAS, 1973; DOLLFUS, 1981). It is rather astonishing that the soils in many parts of the Highlands still produce yields without the application of fertilizer or special care. Fields have become larger, terraces are being neglected, steep slopes are planted, heavy soils are plowed with tractors, and the entire landscape is intensively grazed year around (LEBARON et al., 1979).

The investigation of the effects of current agricultural practices on ecosystems is part of the research carried out at the Ecological Institute of the University of La Paz. The Institute was founded as a partner-project with the University of Göttingen in 1978 by the GTZ. The research focuses on the following questions:

1. Will the present land-use pattern led to a gradual decline in production, or is it more or less in equilibrium with the habitat potentials?
2. In case the present system is not in equilibrium with the habitat: what long-term solutions could be recommended?

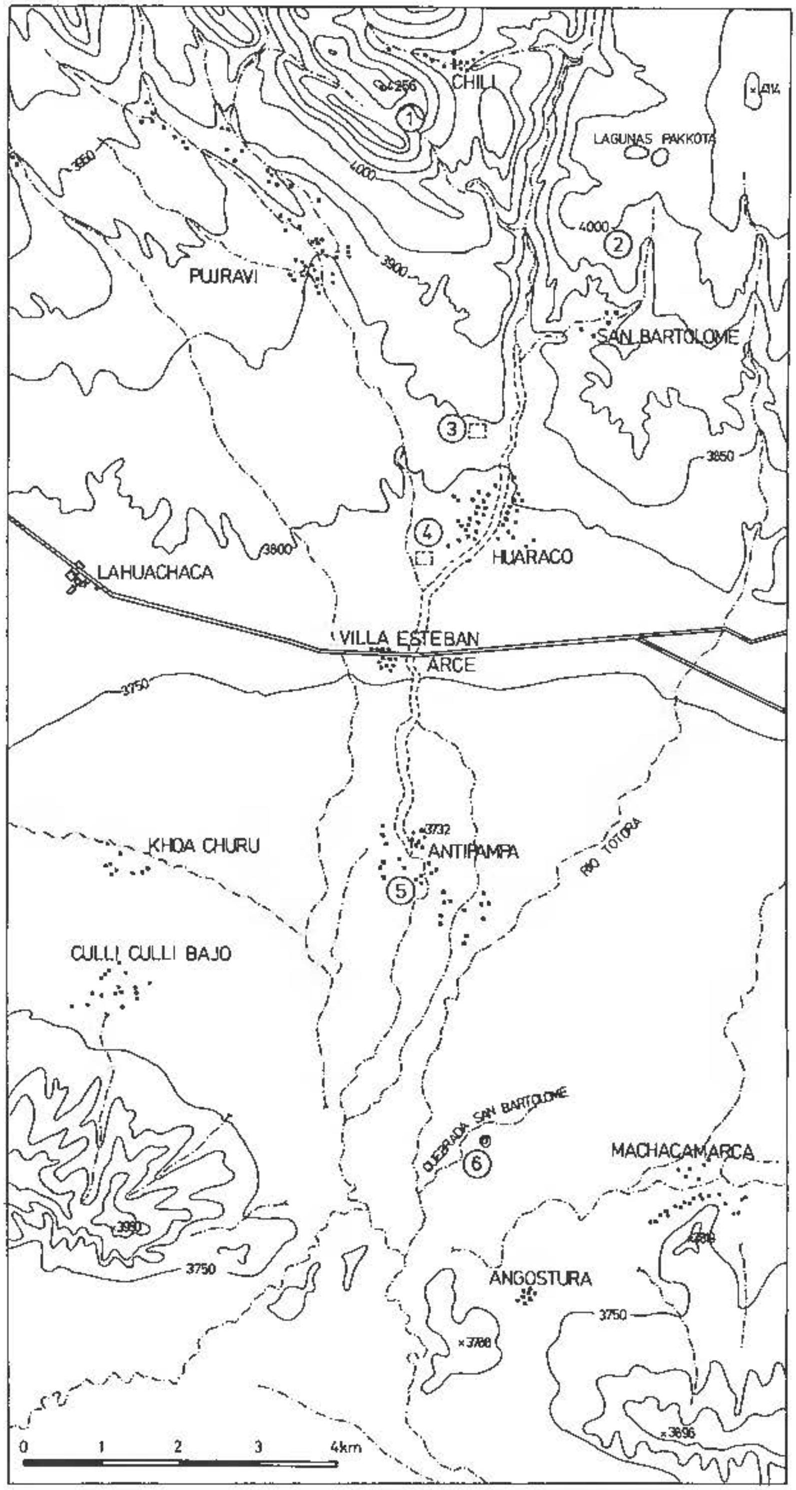
Until now, investigations with similar goals have only been carried out very rarely in the Andean Highlands (MACEWAN, 1969; PRESTON, 1973; BAKER and LITTLE, 1976).

The Ecological Institute selected the small Highland community of Huaraco on the road from La Paz to Oruro southeast from Sica Sica (ca. 17°22′ S, 67°38′ W) as an examplary region for investigation, because an agricultural project of "Bread for the World" had been carried out there for some time, facilitating good contact with the local population*.

The work started by the Ecological Institute concerns the care for a weather station as well as ongoing plant-ecological, zoological and pedological questions. For the most part these are being investigated in sample areas fenced in for long-term research and corresponding to pasture land currently in use.

In the following, we would like to deal in some detail with the general character of the Huaraco-area vegetation, its habitat conditions, and suitable uses of the village region and the connecting plains to the South.

*Institute members and graduate students carried out a very comprehensive study of the Huaraco ecosystems (HANAGARTH and FISEL, 1983). The authors wanted to contribute results based upon botanical-ecological analysis techniques. The research was financially supported by the GTZ and DAAD. Our thanks go especially to J. EWERT from Huaraco for his hospitality and the wealth of information he provided; it also goes to all of the village inhabitants, and to the Ecological Institute, especially Drs. E. GEYGER, S. BECK and W. HANAGARTH. Professor Dr. D. SCHRÖDER, University of Trier, helped to interprete the soil analysis data with respect to long-term fertility improvement measures.



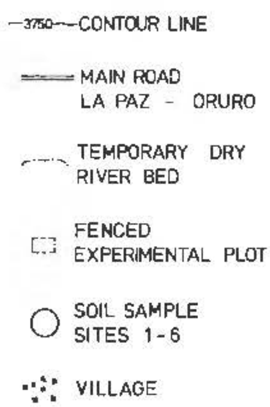


Fig. 1. Survey map of the study area.

2. General Features of the Huaraco Area

The community of Huaraco lies in the semi-arid portion of the Highlands at the foot hills of the East Cordillera. The latter consists at this location chiefly of quartzites, sandstones, arkoses and other palaeozoic strata (Devonian and Silurian). The bordering mountain chains in the north exceed 4500 m only with a few peaks, and descend over hills, small plateaus and gentle slopes of the plains which begin at approx. 3800 m. The more gentle hills are to a great extent covered with tertiary debris of varying thickness. The Huaraco river and some of its tributaries have in some places cut gullies into these sediments. The plains incline gradually towards the broad basin of the Desaguadero and are divided into different old sedimentary terraces, alluvial fans and recent floodplains. Although these are cultivated by the neighbouring communities, they have been drawn into the study area for purposes of comparison (Fig. 1).

The soils on the mountain slopes and in the hill zone are in part very poorly developed or at least rich in unweathered stone material. In some places hard quartzite ridges and sandstone benches have been carved out by erosion. The sandy-stony soils in the debris-covered hill zone become finer on the foot slopes and upper terraces, changing to sandy-silty or clay-rich soils in the plains and finally assuming the character of solonchak near the base of the basin.

The Huaraco river and some springs which appear in the lower part of the plain have water year around, at least in the underground. This fact and the semi-arid climate (Fig. 2), which is still favourable for farming without irrigation, certainly made it possible to settle this landscape quite some time ago. Archaeological investigations in similar regions located nearby (MÉTRAUX 1935/36; IBARRA GRASSO, 1955; PONCE SANGINÉS, 1970) and own discoveries of stone tools, pot sherds, agricultural implements made from stone as well as remains of pre-Inca grave towers ("chulpas") in the community area indicate that an early settlement is very likely. The community of Huaraco together with the bordering plains may therefore be considered as a typical example of the semi-arid portion of the eastern Bolivian Highlands.

The center of Huaraco lies on a terrace of the Huaraco river where the river flows out into the plains. It is a scattered settlement with many individual farms lying at some distance from each other. The presence of the asphalt road from La Paz to Oruro cutting through the area led some time ago to the foundation of the settlement of Villa Esteban Arce along its edge. The inhabitants of Huaraco bought their freedom from the former landowner around 1875 and split the land among themselves. Today about 80 families live here. Altogether there are some 300 people. They live predominantly on farming and livestock, the main trade products being potatoes and sheep meat. Only a few families produce some surplus. A subsistence economy is by and large the rule. Family members who work outside of the community contribute to the support of some families.

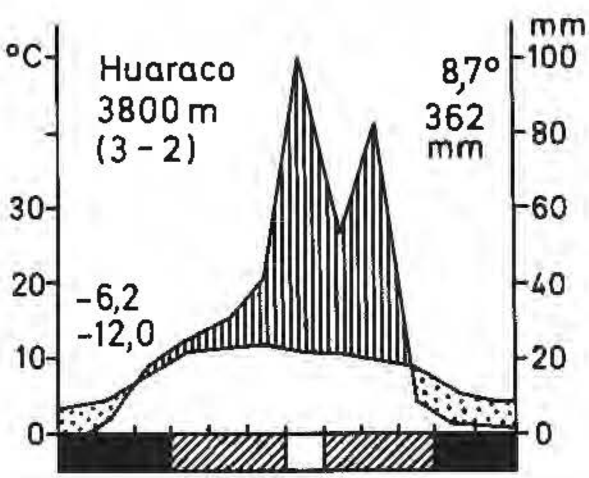


Fig. 2. Diagram of the mean monthly temperature and precipitation values of Huaraco from 1980 to 1982. Source: Ecological Institute, La Paz.

3. Agricultural Practices in the Huaraco Area

3.1. Farming

Many agricultural practices have been maintained by most of the communities of the Highlands which are characteristic for the Aymara people (SORIA LENS, 1954; LOZA BALSA, 1972; PRESTON, 1973; RUBIO Y DURÁN, 1980). Potatoes, barley, and the Andean cereal "Quinoa", are the principal crops.

The potato, today as always, constitutes the major human foodstaple, "sweet" potatoes and the frost-resistant "bitter" potatoes have to be distinguished from each another. 25 different kinds with varying growing requirements, sensitivity to frost, drought, and disease are well-known and put to good use in the study area. Each family converts a portion of the potato harvest into "chuño", meaning that during the coldest months the potatoes are put through a freeze-dry process. In this stage they can be preserved many years.

Potatoes are best grown on light, sandy soils. Heavy clayey soils are apt to mudding and in dry years do not guarantee the necessary water requirements. A good supply of nutrients is important: consequently, potatoes are always planted as the first crop in a newly started crop rotation sequence and manured with sheep dung from the corrals. Above 4000 m only the frost resistant bitter potatoes thrive, which for the most part are converted to chuño.

The largest portion of the cultivated barley serves as feed for cattle. Of the five usable varieties one type without awns is cultivated, the roasted grains of which are eaten. Barley requires more water than potatoes, but is planted at elevations as high as 4200 m.

The traditional Andean cereal "Quinoa" (*Chenopodium quinoa;* six varieties) which is characterized by a special resistance to drought and a moderate salt tolerance, is declining because a much better profit can be gained from potatoes in the local markets.

It is essential for the inhabitants of the area to harvest enough every year, even under adverse weather conditions. The families must have enough food-supply until the next harvest, and enough seeds must remain for the following spring. Cash income for purchases of food-stuffs and seeds usually cannot be earned. For personal consumption, the native tuber plants "Oca"*(Oxalis tuberosus),* "Ullucu" *(Ullucus tuberosus)* and "Isañu" *(Tropaeolum tuberosum)* are frequently cultivated in small quantities. One generally finds all three species growing together in frost-protected slope niches on small fields having good soils. Because of the characteristics of such locations, they cannot be used in a large-scale manner for a common purpose. The cultivation of tuber plants is reported to have sharply declined in the last few years. It is, nevertheless, still of great importance in the fields of the community of Chili, which is located at some distance to the north. Along with Quinoa *(Chenopodium quinoa),* a few rows are occasionally seeded with "Cañihua" *(Chenopodium pallidicaule).* Its fruits are prepared for various foods and a drink. The native lupine *(Lupinus mutabilis),* called "Tarhui", although thriving throughout the Andean Highlands, is not found here, possibly because of the exceptionally rough climate. On the floodplains with their silty-clayey soils, the broad bean, "Haba" *(Vicia faba),* is frequently cultivated on soils with a very low salt content. Peas, onions and other vegetables appear now and then in small frost-protected valleys, on especially good soils, or in a few walled-in house gardens.

Information regarding yields of cultivated plants is very difficult to obtain because of the variable habitat characteristics as well as the highly variable field sizes. For potatoes, yields between 1500 and 4000 kg/ha have been quoted, and for quinoa between 200 and 400 kg/ha. The yields for barley, including the straw, seem to lie between 1500 and 3000 kg/ha, the beans yield about 250–300 kg/ha (FISEL and HANAGARTH, 1983).

The most common sequence of crop rotation usually starts with potato cultivation in the first year, followed by 1–2 years of barley, and a growth period with quinoa. On especially nutrient-rich, sandy soils potatoes will sometimes be cultivated for 2 years. Occasionally quinoa will be seeded in the second year and then followed by barley. At 5 to 10 years – sometimes even longer – fallow period follows, which

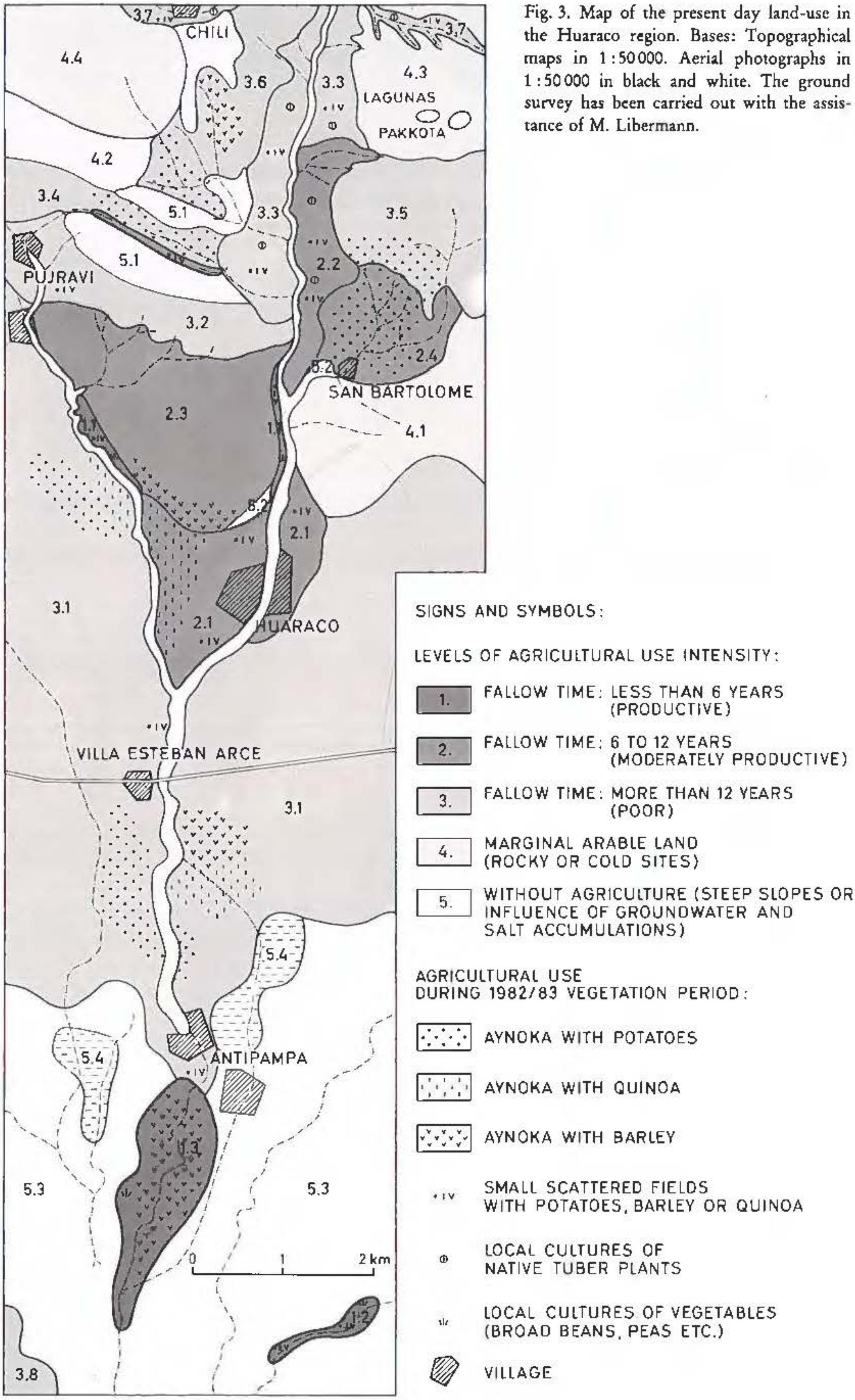


Fig. 3. Map of the present day land-use in the Huaraco region. Bases: Topographical maps in 1:50000. Aerial photographs in 1:50000 in black and white. The ground survey has been carried out with the assistance of M. Libermann.

Legend of Figure 3

Land-use categories:

1. Very intensive use. Fallow period shorter than 6 years.
The farming areas put together in this category present the shortest fallow periods in the entire study area. They concern the lower terraces and sometimes inundated parts of the valleys with fertile soils, poor in stones, where, by individual family-use the highest yields can be obtained.

1.1 Fertile, sandy lower terraces along the Huaraco river and Pujravi river (Figs. 4 and 10), slightly inclinated and partly irrigated through canals, 3780 m. Intensely cultivated by single families. Field sizes up to 0.25 ha. Crops: Potatoes, quinoa, barley, broad beans, peas, onions.

1.2 Ground along the San Bartolomé river with profound, silty to clayey soils, where the salt content of the soil is reduced every year in the rainy season by inundations (Fig. 6), 3720 m. Field sizes up to 0.5 ha. Crops: Barley, broad beans, quinoa, cañihua.

1.3 Sandy sediments of the Huaraco river, to some extent influenced by salty groundwater but with profound fertile soils, 3730 m. Intensely used by single families. Field sizes up to 0.5 ha. Crops: Broad beans, potatoes, quinoa, barley.

2. Intensive use. Fallow period between 6 and 12 years.
Relatively productive farmland can be found on the alluvial sedimentation fan of the Huaraco river, which because of this reason has become the center of the Huaraco village. Parts of the slopes of the corresponding valley are similarly fertile. Normally they are not grazed. The extremely little danger that frosts may occur, permits the cultivation of the native tuber plants on small fields with quite reliable yields up to 3960 m above sea level.

2.1 Sandy stone-rich alluvial fan of the Huaraco river, slightly inclinated to the south (Fig. 7), 3780 to 3810 m. Individually used "sayana"-fields, field sizes up to 0.5 ha. Crops: Barley, potatoes, quinoa.

2.2 West-orientated, dissected slopes of the Huaraco valley (Fig. 10) with 10–15% inclination, including small rock formations, 3840 to 3960 m. Scattered, individually cultivated fields up to 0.5 ha with sandy-silty, often shallow soils. Crops: Barley, native tuber plants, potatoes, quinoa.

2.3 Spurs of the cordillera mountains to the north, covered with tertiary debris. 3820 to 3900 m. Slightly dissected slopes with 5–20% inclination (Figs. 8 and 10). Sandy-silty, stone-rich, often shallow soils. Field sizes up to 0.5 ha. Crops: Productive ground for potatoes; quinoa, barley.

2.4 South orientated slopes, intensively dissected by erosion gullies. 3860 to 3960 m. Profound sandy-silty soils with moderate stone content. Settlement area of the community section of San Bartolomé. The gully formation is probably initiated by human activities. Field sizes up to 1 ha. Crops: Productive ground for potatoes; quinoa.

3. Fallow periods more than 12 years.
Very long-lasting fallow periods are typical for large areas of the community land. Stony soils and frost damage on level plains are the main reasons for the extremely extensive land-use. This also holds true for many shallow sites with rocky outcrops. The continuous overgrazing does not permit here a permanent regeneration of soil fertility.

3.1 Extensive gravel plains and old sedimentation terraces of the Huaraco river, inclinated to the south up to 3%. 3730 to 3840 m. Sandy-silty, mostly profound but stone-rich soils with a southward decreasing amount of skeletic material. Fallow land to some extent older than 20 years, with scattered stonemounds and walls. Field sizes up to 1 ha. Crops: Potatoes, quinoa, barley.

3.2 Moderately steep, southwest-orientated mountain spurs (inclination: 15 to 25%), interrupted by narrow rock ledges, 3850 to 3920 m. Stony shallow soils, which permit only local farming on small fields up to 0.25 ha. Crops: Potatoes, quinoa, barley.

3.3 East- and west-orientated slopes of the Huaraco river in the northern part of the community area. 3860 to 4000 m. Large parts of rocky, extremely shallow or steep sites limit the farming possibilities to few, scattered fields of up to 0.25 ha. Crops: native tuber plants, potatoes, quinoa, barley.

3.4 Southwest-orientated slopes with 5 to 10% inclination at the base of the Janthaloma mountains (Fig. 12) and the neighboring ridge, 3950 to 4050 m. Stony, but profound, sandy-silty soils. Field sizes up to 0.5 ha. Crops: Bitter potatoes, barley.

3.5 Slightly inclinated plain in 3960 to 4000 m. Profound silty to clayey soils with moderate stone content. Field sizes up to 0.5 ha. Because of frequent frost damages only cultivation of bitter potatoes possible.

3.6 Intensively dissected slopes with variable inclination rates (5–30%). 3950 to 4100 m. Rock outcrops and mostly very shallow stony sites are limiting the farming activities to the foot parts of the slopes. Field sizes up to 0.25 ha. Crops: Potatoes, quinoa, barley.

3.7 North- and south-orientated, 10 to 35% inclinated slopes along the tributaries of the Huaraco river. 3950 to 4100 m. Profound, stone-rich, sandy-silty soils. Field sizes up to 0.25 ha. Crops: Potatoes, native tuber plants, quinoa, barley.

3.8 North-orientated spur of the mountain ridge bordering the study area to the south (Figs. 6 and 13), 3750 to 3850 m. North orientated slopes with 15 to 25% inclination. Farmland of the predominantly animal breeding communities of Culli Culli and Antipampa. Stone-rich, shallow, sandy-silty soils. Field sizes up to 0.5 ha. Crops: Potatoes, barley, quinoa.

4. Marginal farming sites.
Shallow and stony soils as well as climatically unfavorable highlands are limiting the farming activities in this land-use category very strongly. But nearly everywhere one can observe stone walls and mounds in decay, which give evidence of former agricultural habits.

4.1 Spurs of the northern mountain chains between 3800 m and 3920 m. Weakly dissected slopes with stony, silty and to some extent clayey soils, which hardly permit any crop cultivation because of their poor nutrient content and water deficiencies. Field sizes up to 0.5 ha with fallow periods of almost 30 years. Crops: Potatoes and dry-resistent quinoa.

4.2 Lower and central slopes of the Janthaloma mountain between 4050 and 4120 m (Fig. 12). Southwest-orientated slopes with 10 to 20% inclination. Stony, but profound soils with silty texture. The small fields of 100 to 200 m^2 size are surrounded by decaying stone walls. They have been mostly abandoned because they are too small and too steep for the usage of the wooden plough pulled by animals. The Andean foot plough is not any more in use at Huaraco.

4.3 Slightly inclinated plain at 4000 m. Two small lakes are situated in a shallow depression, which serve as watering place for the herds during the rainy season. Consequently the whole area shows intensive grazing damage.

4.4 Top crest and upper slopes of the Janthaloma mountain (Fig. 12) with 15–30% inclination, 4120 to 4250 m. Apart from rocky outcrops the soils rich in stones but to some extent of silty texture. Remnants of decaying field terraces indicate former crop cultivation. The change in the farming methods have led to the abandoning of these fields.

5. Pasture land
The areas put together in this land-use category cannot be used for crop production. Rocky outcrops, steep slopes, wet and salt-rich clayey sites permit only the use as grazing land. The moist surroundings of spring areas, however, give raise to very productive grass stands.

5.1 Intensively dissected steep slopes, 3920 to 4000 m. Outcrops of rocks and very shallow soils permit only occasional grazing.

5.2 Short, shallow and stony steep slopes with 30 to 45% inclination along the Huaraco river and one of its tributaries. 3820 to 3940 m. Striking erosion gullies occuring locally might be attributed to heavy grazing activities.

5.3 Vast alluvial plain, exclusively used for grazing, covering the entire southern part of the study area (Fig. 14). 3720 to 3750 m. Silt and clay soils, influenced by salt-rich groundwater. The vegetation cover is composed of short grass and salt plant formations, interrupted by extensive bare ground.

5.4 Productive grazing land on moist spring areas ("canchones") with clayey marsh soils, fenced in by decaying walls of mud bricks.

in good soils near the village is shortened, and lengthened on poor soils at distant locations. Figure 3 represents and explains the different land-use categories of the whole study area. From these categories the suitability of the agricultural land in use can be estimated with regard to its climatic and habitat conditions. The best soils are found on the terraces of the larger rivers or in especially protected niches and slope locations ("k'uchu"). The most frequent and best yields of corresponding cultivated plants, such as the native tuber plants and introduced vegetable types, are obtained here. The required fallow time is usually only 2–4 years. The heavy sandy-loamy soils ("l'aka"), which cover the entire plains of Huaraco, permit especially in dry years very poor yields. They lie fallow 10-20 years on the average. On high altitudes over 4000 m ("k'ollu") only the cultivation of bitter potatoes and barley is possible and, since the fields are relatively far removed, fallow periods of over 20 years are typical.

The most productive grounds are mostly those fields which surround the farms and are designated as "sayanas". These have belonged to the families since time immemorial as indisputable private possessions. Since every family owns "sayanas" between 2 and 6 ha in size, the farms are situated on the best soils, and the villages take on the form of a scattered settlement (SORIA LENS, 1954).

The illustration of the current land use during a vegetation period (Fig. 3) indicated that the potato, barley and quinoa fields mapped lie together in more or less closed blocks. For ages the land-use has been in the form of "Zelge" farming, i.e. with „Flurzwang". Every year the community assembly decides in what part of the community area the fallow ground should be broken for potato cultivation the following year. Since the farmland – as opposed to the pasture land – has remained in private ownership ever since the community bought it up, all the land parcels must be divided up in such a manner that each family in every "Zelge", called "aynoka", possesses a sufficiently large plot. Where this is not the case, there are various possibilities for farmers with little land of their own to farm within the „aynoka". The farmer without much land can, for example, lease a field for the duration of an entire crop rotation (3–4 years) for the price of one sheep. Another possibility is share-farming. The non-owner must undertake the work-intensive preparations for the seeding, i.e. removing the weeds and stones, as well as the plowing. Afterwards, the field is cut in two. The landowner and the leaser do the seeding, farming and harvesting separately. At least 2 "Zelgen" in different parts of the community area are newly farmed each year in order to decrease the risk of an insufficient potato yield.

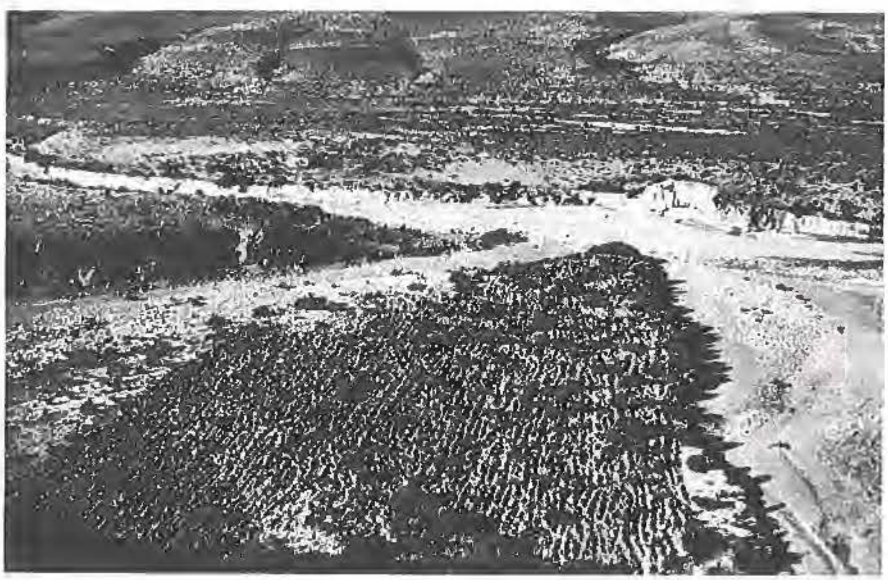


Fig. 4. Recently plowed fallow field (May 1980) in the valley of the Pujravi river, still with some scattered *Baccharis incarum*-shrubs (land-use category 1.1).

Altogether, only about 5% of the entire agriculturally suitable land can be cultivated during one year. Of this, 55% is potatoes, 25% is barley and 20% is quinoa. Whenever the population increases, a decrease in the number of fallow years is usually experienced although the usable land is limited (PRESTON, 1973). Nevertheless, in contrast to many other communities, Huaraco possesses enough land, and frequently 10–15 or more years of fallow can be counted on. The breaking of fallow land occurs in the fall, when the still somewhat moist soils can be worked more easily. A wooden hook-plow, strengthened with an iron tip and pulled by a team of bulls, has been used for plowing since the introduction by the Spaniards. By such a method, the soil is only broken to a depth of about 15 cm and not turned, which certainly has a soil-preserving and erosion-decreasing effect. The original working techniques of the Aymara farmers using shovels or digging sticks is no longer customary in Huaraco. For this reason, the narrow strips of fields surrounded by stone-walls on the steep south-facing slopes on the Cerro Janthaloma have also fallen completely into disuse.

The larger shrubs which are removed during the breaking to fallow land are used as burning material (Fig. 4). Smaller bushes are burned off on the field before the seeding in spring. However, the ashes are only rarely spread over the surface. The seeding of the crops follows between September and December (Fig. 5) depending on the quality of the land, the type of crop and the weather conditions. Only with potatoes, some sheep dung is mixed in. Mineral fertilizers must be paid for in cash, something very few families have.

The field work starts in August with the sowing of broad beans in soils that provide a relatively good water supply during the summer. The quinoa needs also a long vegetation period but is much more resistent to drought, a serious problem in some years. The native tuber plants, including potato, can be planted only when enough moisture has accumulated in the soil after the last dry season, that means not before October or even November. The last to be sown is barley, probably because it has a relatively short vegetation period and is of less importance to the farmers. Thus, it often does not reach maturity. Still, as green plant it serves as good fodder for cows and sheep. Only ripe corn can be stored for a longer period

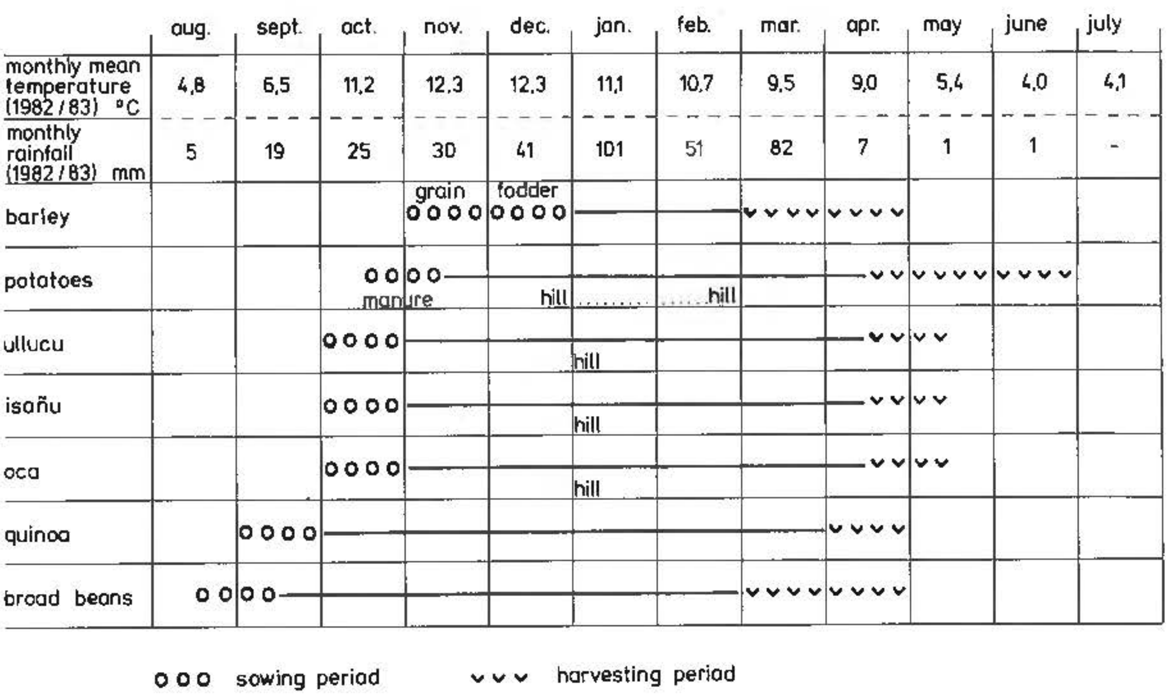


Fig. 5. Range of sowing and harvesting dates of the crop plants cultivated in the Huaraco region ("calendario agricola").

of time. Therefore, it is also needed. The harvest starts with broad beans and barley and ends with potatoes, because their collection requires much time but can be left to the end. Out of all crops the tuber plants need the greatest care since they have also to be hilled at least once during summer.

Fig. 6. Floodplain in the extreme south of the study area (March 1980). Productive farmland-islands along the San Bartolomé river (land-use category 1.2). In the background the Wacani mountain (detail on Fig. 13).

Fig. 7. Tillage of potatoes (November 1981) on the sedimentation terrace of the Huaraco river near the village (land-use category 2.1). In the background to the northeast some farms of Huaraco and the foot slopes of the hill-zone.

3.2. Pasture

Essential for the agricultural economy are sheep and llamas for meat and wool products, and cattle and donkeys as draught and pack animals. Moreover, the animals serve as "living saving accounts" for times of illness, poor yields and festivals. Each family in Huaraco owns 3–5 cows, about 20–50 sheep and a few donkeys. In addition many families have 10–15 llamas. Their importance as pack animals, however, has declined considerably in the vicinity of modern roads. Besides, the successful raising of llamas requires considerable skill and attention, and the community does not own any suitable pasture land for them (such as moist areas in valleys or extensive grasslands in the higher mountains). In the bordering community of Antipampa, however, grazing of domestic animals is much more important on the extensive plains with some moist spring areas. On the extensive short-grass pastures one finds herds of sheep up to 250 head and clearly more llamas than in Huaraco. The "canchones" are a pastureland speciality of this area. In very moist sites tall-grass stands are protected form constant grazing by walls made of mud bricks. They are used as pasture only from March to June. Unfortunately, an increasing number of walls are destroyed and a corresponding increase of unregulated grazing of the "canchones" is to be observed.

Sheep and llamas can be grazed freely, i.e. without rules concerning land-ownership or using-rights, with the exception of the areas designated during the summer to serve as farming "Zelgen". The herds are driven daily from the farmers' houses to the valley pastures and the fallow land and in the evening they return to be locked in corrals. This is usually the task of women and children. During the dry winter months, when fodder is lacking in the vicinity of the village, the herds are driven into farther and higher up grazing regions where small stone huts with nearby corrals are used by the shepherdesses and the herds during the night. Twice a year the sheep are desinfected and at the beginning of the rainy season they are shorn. Sheep are preferred to llamas since they, besides the wool, deliver 15–20 kg mutton per sheep. The mutton is then sold at the market of Lahuachaca, and with this money other foods such as noodles and sugar can be purchased.

The burning of the pasture land before the rainy season begins has not been customary in the community of Huaraco for a long time. The 24th of June is an exception because the burning at the time of solstice has a ritual meaning. Even on this day, however, it has decreased and burning is limited to small, steep slopes. One hardly finds, however, any place, where at the basis of the bunch grasses and scrubs charcoaled remains of plant parts cannot be observed, indicating earlier burnings.

The lack of fodder for the sheep and llama herds as well as the cattle and donkeys during the winter drought determines the condition and size of the herds. The animals must travel over long distances in order to find at this time of the year enough to feed on. Nevertheless, a system of stockpiling of fodder – as has been customary for quite some time in our country – has never been developed in the Andean Highlands. Quite often however the best moist areas generally serve as a reserve in times of emergencies.

4. Effects of Farming and Grazing on the Vegetation Cover and Its Habitats

All moderately suitable habitats, which are not too cold, frost-endangered, shallow, wet or containing too much salt are being cultivated or at least have been cultivated. Except for the river and brook valleys, the source marshes, salty clay-flats, steep slopes and alpine grasslands above 4200–4300 m, the vegetation corresponds more or less to fallow stages of varying ages, which moreover remain under the constant pressure of intense grazing by domestic animals. How the original plant cover may have been composed is not to be deduced from the present situation in the region. Whether or not an open forest of "quishuara" *(Buddleya* spec.) or "queñua" *(Polylepis* spec.) existed here a long time ago remains unknown. It is certainly possible for these trees to grow here today without additional water supply, but they must be protected from grazing animals as long as they are small.

The regularly repeated plowing of fallow land followed by a few years of use before another fallow period must, after hundreds to thousands of years, have led to a certain selection of plant types suited to these conditions. The most successful types of plants under such conditions are those which produce many, easily distributed seeds, which have a moderately long lifespan, which germinate under high light intensity and quickly develop an extensive root network. These characteristics may be found with all common herbs, grasses and even shrubs. On the fresh fallow, therefore, one regularly sees young plants of the predominant dwarf scrubs *Baccharis incarum* and *Tetraglochin strictum*. Since, however, only a small portion of the agricultural land is cultivated at one time and the fallow period can last several decades, other plant types with deviating characteristics can also survive in the region. The diversity of plant species of this landscape, which at first appears rather monotonous, can most likely be traced back more to the richness in micro-habitats, than to the differentiated use of the land.

Additional important selection-factors stem from the continuous and at times very intensive search for food by the domestic animals. The bite of the sheep, llamas and donkeys has predominantly allowed those plants to survive which can regenerate vegetatively, those which due to their chemical composition are poisonous or unpalatable for the animals, those which have developed stabbing shoots (*Adesmia* spec.) or pointy leaves (many grass copses), those that grow so close to the ground that they cannot be bitten (cushion and rosette plants), or those the seeds of which are especially prepared for successful germination having passed the digestive tracks of animals (possibly *Tarasa* spec.). During times of scarce food, nevertheless, almost all plants, even the hardly edible ones, are eaten. Only *Astragalus garbancillo* and other species of *Astragalus* as well as most of the ferns can be regarded as genuinely poisonous; and these alone are being avoided by the grazing animals even in emergencies. Since the herds only remain in the same area for a period of days or weeks, some good grazing grasses and herbs have been able to survive in the region, which then suddenly appear in large quantities on protected fallow land between fields which are actually being cultivated. Many of the better fodder plants can also be found thriving and bearing fruits under the protection of thick or thorny shrubs.

Fig. 8. Potato field with accumulation of eroded soil in the furrows of the lower part. The potato plants are partly damaged by frost (land-use category 2.3). In the background the Janthaloma mountain (detail on Fig. 12).

Besides the pressure or selection which farming and grazing directly exercise on the composition of the plant cover, the abiotic habitat conditions are also clearly influenced by these practices. During the years of cultivation the surface erosion on slope locations can be considerable. Despite the favourable infiltration rates on loose soils, the summer rainstorms lead to the sweeping of fine earths into the furrows and to the lower parts of the fields (Fig. 8), where former stone walls frequently hindered further movement. During the first two fallow years the soil is still not very effectively protected, as the redeveloping plant cover and its root system did not have enough time to become firmly established. The continual trodding of animals produces, on one hand, a compactation of the upper layers, and on the other it damages the soil surface by the sharp hooves of the sheep and donkeys (ELLENBERG, 1981). Llamas do not have the same effect because they are plantigrades. The compactation leads to the accumulation of water on the surface after heavy showers and with just a slight inclination of the slope it results in a quick run-off of the loose soil particels and organic material which has not been incorporated into the soil. The constant grazing of the whole area prevents the development of a complete cover of vegetation and dense rooting of the soil. Such a vegetation cover could be expected without question because of the annual rainfall between 300 and 400 mm. Indeed, it more or less quickly develops on surfaces protected from grazing as the fenced-in experimental plots are beginning to indicate.

Extensive farming and unregulated grazing of domestic animals on the fallow and community lands has led to intense soil erosion in Huaraco as well as everywhere else in the Highlands (LEBARON et al., 1979). The profound fine earth-alluvial soils of the lower plains are probably to a great extent anthropogenic, similar to the "Auen"-soils of Germany. Whether or not the erosion today is at all stronger or weaker than in former times remains unknown. The widely distributed stone heaps, mounds and walls permit the conclusion that soil erosion has been active for a long time. It even appears that the removal of stones is less customary or necessary today than before, as most of the stone piles are thickly covered with slowly growing lichen crusts.

The explanation of this mosaic of cultivated fields, fallow fields of varying ages, bare, stony islands of wasteland and grazing areas, in a way that the suitable uses of the habitats could be made clear by the respective plant covers, was one of the goals strived for by the botanical-ecological investigations around Huaraco. Phytosociological results according to the BRAUN-BLANQUET-method from fallow land as old as possible, from pasture land and from shallow rocky sites in the whole study area as well as from several series of succession stages on fallow fields are the basis for a simplified overview of the most important vegetation types in the Huaraco region (Table 1 and Fig. 9). A comprehensive cartographic representation of the vegetation cover is in preparation (FISEL und RUTHSATZ).

The analysis of the fallow vegetation of those sites more or less suitable for cultivation between the upper limit of farming at approx. 4200 m and the habitats which are too wet and/or salty provided a clearly differentiated mosaic of plant communities according to elevation, depth of soil and soil texture (Table 1). Most probably the difference between habitats would appear more clearly if older stages of fallow fields (more than 20 years) had been available for the phytosociologically analysed plots and if the succession stages would not have been influenced by the year-round intensive grazing. The plant species groups with very wide ecological amplitudes, as for example those of *Baccharis incarum*, *Stipa ichu* or *Parastrephia lepidophylla*, appear in almost the entire region and may be considered as indicators of the uniformation of the sites as a result of strong overgrazing. In Fig. 9 we have tried to make the vegetation and habitat gradients visible. The illustration includes, in addition to the farming sites, the vegetation types of the Andine grazing zone as well as azonal grazing communities at wet and/or salty habitats, distinguished by their characteristical species composition. The constant grazing has severely altered these areas. Most of the shrubs, many hard-leaved grasses as well as low-growing herbs and cushion plants (eg. *Anthobryum triandrum*, *Verbena minima* etc.) may therefore be favoured indirectly.

In order to obtain a general idea of soil nutrient supply of the main land-use categories and the way in which they are presently influenced by agriculture and grazing, soil samples were taken along an elevation gradient in 6 habitats on fallow land of varying ages. The fine earths (Ø less than 2 mm) were then

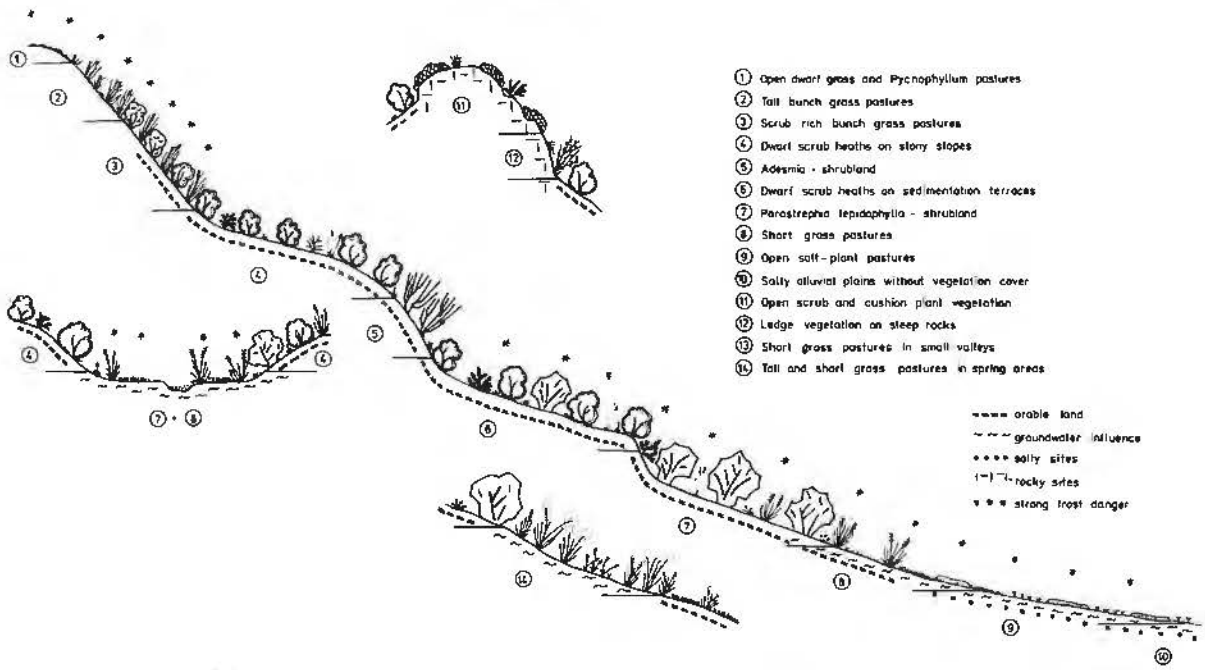


Fig. 9. Main plant communities in the Huaraco region, more or less influenced by agricultural and grazing activities. Common and typical plant species of the vegetation units:

1. Open dwarf grass and *Pycnophyllum*-pastures in the Andine belt. Outside the investigation area on hill tops and plains above 4500 m.

   Pycnophyllum tetrastichum Remy
   P. molle Remy
   Nototriche div. spec.
   Arenaria pycnophylloides Pax.
   Werneria denticulata Blake
   Calamagrostis minima (Pilger) Tovar
   Poa aequigluma Tovar
   Festuca magellanica Lam.
   Agrostis haenkiana Hitchc.
   and other

2. Tall bunch grass pastures in the Andine belt. Outside the investigation area above 4200 m.

   Festuca humilior Nees et Meyen
   Poa asperifolia Hack.
   Stipa hans-meyeri Pilger
   Festuca andicola HBK.
   Scirpus rigidus Boeck.
   Luzula racemosa Desv.
   Lepidium meyeni (Wedd.) Thell.
   Lupinus conicus C.P. Sm.
   Werneria apiculata Sch. Bip.
   Englerocharis peruviana Muschler a.o.

3. Scrub-rich bunch grass pastures in the sub-Andine belt. List of plant species: see Tab. 1, vegetation units A and B.

4. Dwarf scrub heaths in the foot hill zone. List of plant species: see Tab. 1, vegetation unit D.

5. *Adesmia*-shrubland on steep south-orientated slopes. List of plant species: see Tab. 1, vegetation unit C.

6. Dwarf scrub heaths on old stony sedimentation terraces. List of plant species: see Tab. 1, vegetation unit E.

7. *Parastrephia lepidophylla*-shrubland on young sedimentation terraces and alluvial plains. List of plant species: see Tab. 1, vegetation units F and G.

8. Short grass pastures on the alluvial plain (compare Tab. 1, vegetation units H and I).

   Festuca dolichophylla Presl
   Muhlenbergia fastigiata (Presl) Henr.
   Azorella diapensioides A. Gray
   Senecio humillimus Sch. Bip.
   Trifolium amabile HBK.
   Astragalus micranthellus Wedd.
   Plantago orbignyana Steinh. ex Decne
   Hypochoeris taraxacoides (Meyen et Walp.) Ball.
   Conyza artemisiaefolia Meyen et Walp.
   C. obtusa HBK.
   Hordeum muticum Presl
   Ophioglossum nudicaule L.
   Spergularia andina Rohrb.
   Tarasa tenella (Cav.) Krap.

9. Open salt-plant pastures on the alluvial plain.

   Distichlis humilis Phil.
   Anthobryum triandrum (Remy) Surgis
   Atriplex herzogii Standl.
   Salicornia pulvinata R.E.Fr.
   Baccharis acaulis (Wedd.) Cabr.
   B. juncea Desf.
   Lepidium spec.
   Plantago spec.

cont. Fig. 9.

10. Salty alluvial clay plains, nearly without vegetation cover.

11. Open scrub and cushion plant vegetation on shallow rocky sites.
Azorella compacta Phil.
Stipa hans-meyeri Pilg.
Muehlenbeckia vulcanica (Benth.) Endl.
Hieracium cfr. *eriospaerophorum* Zahn
Silene mandonii (Rohrb.) Bocq.
Stebia spec.
Oreomyrrhis andicola (Lag.) Hook. f.
Belloa cfr. *argentea* (Wedd.) Cabr.
Lobivia spec.
Ephedra americana var. *rupestris* (Benth.) Stapf

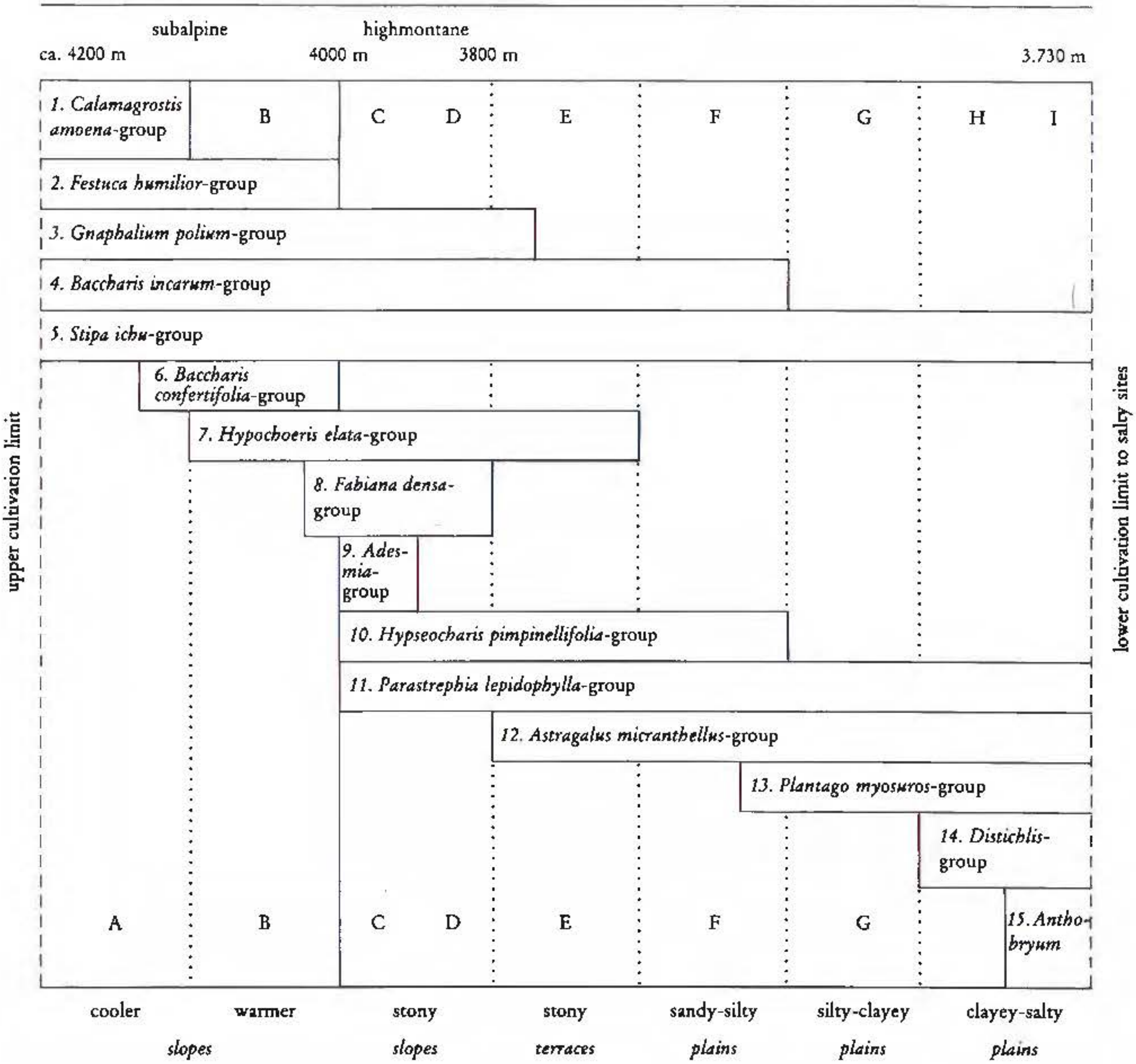
12. Ledge vegetation on steep rocks.
Calceolaria parvifolia Wedd.
Achyrocline ramosissima Britton ex Rusby
Eupatorium azangaroense Sch. Bip. ex Wedd.
Gerardia spec.
Chersodoma candida Phil.
Hedeoma mandoniana Wedd.
Asplenium fragile Presl
Pellaea ternifolia (Cav.) Link
Thelypteris spec.
Woodsia montevidensis (Spreng.) Hieron.
Notholaena nivea (Poir.) Desv.
Wahlenbergia linarioides (Lam.) A.DC.
Bartsia meyeniana Benth.
Bowlesia tropaeolifolia Gill. et Hook.
Crocopsis fulgens Pax.
Peperomia peruviana (Miq.) Dahlst.

13. Short grass pastures in small valleys of the foot hill zone.
Festuca dolichophylla Presl
Muhlenbergia fastigiata (Presl) Henr.
Hordeum muticum Presl
Hypochoeris taraxacoides (Meyen et Walp.) Baker
Lachemilla pinnata (R. et P.) Rothm.
Trifolium amabile HBK.
Plantago tomentosa Lam.

14. Tall and short grass pastures of percolared spring areas ("canchones").
Festuca dolichophylla Presl
Calamagrostis orbignyana (Wedd.) Pilg.
Carex spec.
Hordeum muticum Presl
Muhlenbergia fastigiata (Presl) Henr.
Trifolium amabile HBK.
Azorella diapensioides A. Gray
Lachemilla pinnata (R. et P.) Rothm.
Hypochoeris echegaray Hieron.
Taraxacum officinale Wiggers s. l.
Geranium sessiliflorum Cav.
Eleocharis spec.
Hypsela reniformis (HBK.) Presl
Ranunculus cymbalaria Pursh
Castilleja fissifolia L.f.
Poa glaberrima Tovar
Cotula mexicana (DC.) Cabr.

Fig. 10. Valley of the Huaraco river, looking southward (March 1983), with fertile grounds on the bottom (land-use category 1.1) and relatively productive fields protected from strong frosts on both slopes (land-use categories 2.2 and 2.3). In the background to the right vast flood plains.

Table 1. Characteristic groups of plant species on grazed fallow fields between 4200 and 3700 m in the Highland community of Huaraco and the adjacent plain to the south. A–I: Vegetation and site types. 1–15: Typical species groups.

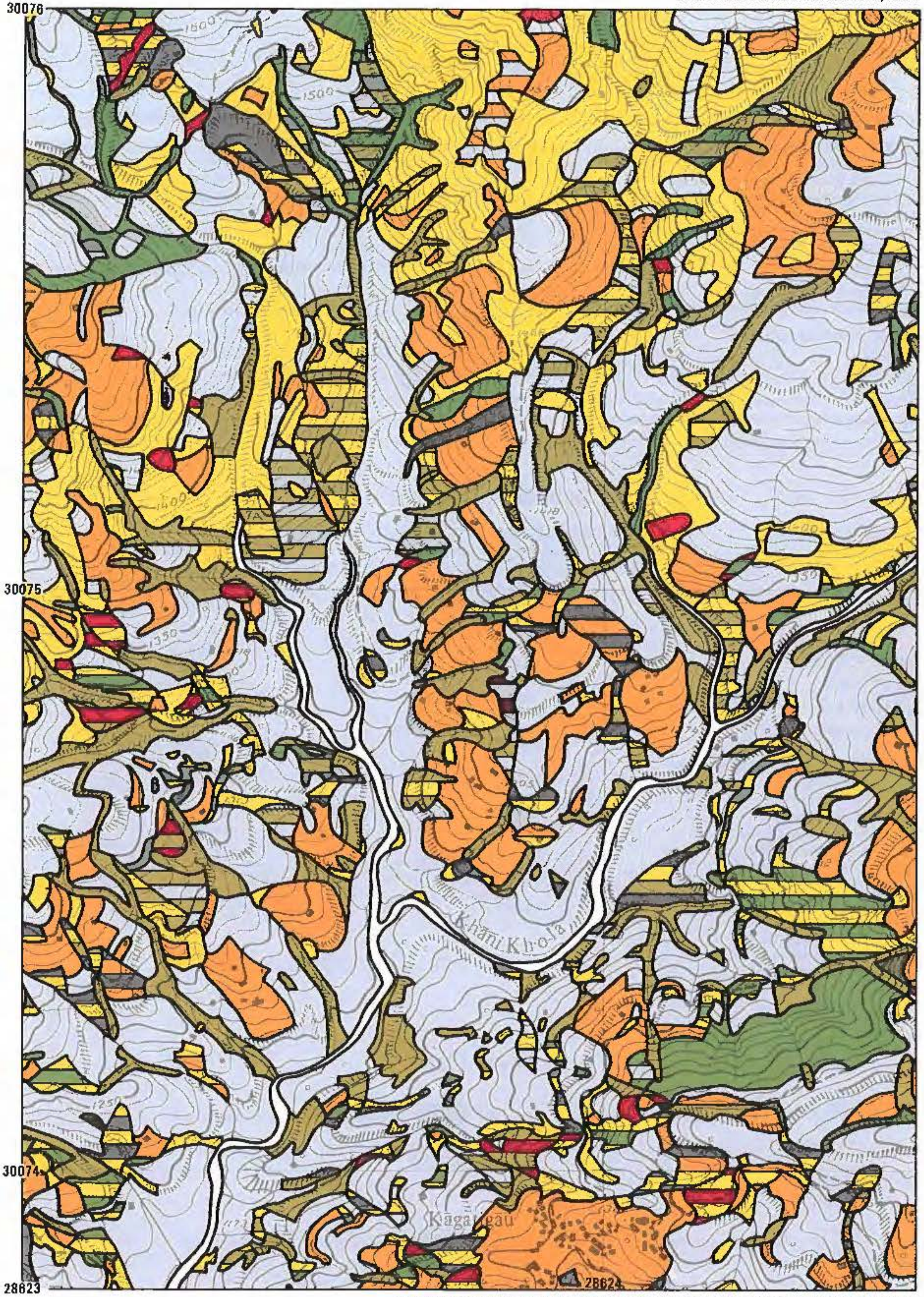


1. *Calamagrostis amoena* (Pilg.) Pilg., *Parastrephia phyllicaeformis* (Meyen) Cabr., *Werneria apiculata* Sch. Bip., *Scirpus rigidus* Boeck, *Arenaria pycnophylloides* Pax., *Gentiana gayi* Griseb., *Lepidium meyeni* (Wedd.) Thell., *Nototriche* spec., *Perezia pygmaea* Wedd., *Crocopsis fulgens* Pax u. a.

2. *Festuca humilior* Nees et Meyen, *Wahlenbergia peruviana* A. Gray, *Relbunium hirsutum* (R. et P.) K. Schum., *Sisyrinchium* spec., *Luzula racemosa* Desv., *Poa gymnantha* Pilg., *Calamagrostis recta* (HBK.) Trin. ex Steud., *Stipa hans-meyeri* Pilg., *Luzilia violacea* Wedd., *Baccharis alpina* HBK., *Stipa brachyphylla* Hitchc., *Belloa virescens* (Wedd.) Cabr., *Gomphrena meyeniana* Walp., *Englerocharis peruviana* Muschler u. a.

3. *Hypochoeris meyeniana* (Walp.) Griseb., *Gnaphalium polium* Wedd., *Relbunium croceum* (R. et P.) Schum., *Cerastium subspicatum* Wedd., *Quinchamalium chilense* Lam., *Paronychia* div. spec., *Silene mandonii* (Rohrb.) Bocq., *Bartsia meyeniana* Benth., *Belloa subspicata* Wedd., *Bidens andicola* HBK., *Senecio spinosus?*, *Calceolaria parvifolia* Wedd. u. a.

4. *Pentacaena polycnemoides* (Schlecht.) Walp. non Bartl., *Baccharis incarum* Wedd., *Tetraglochin strictum* Poepp., *Conyza deserticola* Phil., *Muhlenbergia peruviana* (Beauv.) Steud., *Plantago sericea* R. et P., *Galinsoga calva* Rusby, *Tagetes multiflora* HBK.



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Land-Use Kathmandu - Kakani Area, Nepal

Geomorphic Damages

HYDROGRAPHY

A) CLASSIFICATION OF NATURAL STREAMS
- small or for other reasons not classifiable
- bed with latent erosion (bed in strong bedrock)
- bed in balance (balanced alternation of erosion and accumulation)
- bed with erosion
- bed with accumulation or rearrangements
- presumed bed condition (in inaccessible areas)

B) ARTIFICIAL STREAMS
- irrigation canal causing recent erosion
- canal diverting water into a damaged area

C) OTHER HYDROGRAPHIC ELEMENTS
- spring
- wet area
- lake, pond
- well
- reservoir

DEPOSITION

A) DEPOSITIONS OF SLIDES
- a) as a compact mass
- b) as boulders:
  - – fresh
  - – partially weathered
  - – partially overgrown
- c) as a debris flow:
  - – fresh
  - – partially overgrown

B) OTHER ELEMENTS OF DEPOSITION

boulders, weathered in situ:
- – fresh
- – partially weathered
- – partially overgrown

MAN-MADE ELEMENTS

A) DESTRUCTIONS

slope cutting
- a) in clastic material
- b) in highly weathered bedrock
- c) in hardly weathered bedrock
- d) in a, b or c with vegetation

- man-made badland (intended terrace construction)
- cattle steps
- defile, sunken path
- gravel pit

B) CONSTRUCTIONS
- check dam
- lateral construction

} constructions in rivers

- construction on terraces or roads
- Trisuli Road

EROSION

A) RILL AND GULLY EROSION
- rillwash
- gully active
- badland active (gullying, slope failure etc.)
- badland less than 5 meter deep
- area with rillwash
- gully inactive
- badland inactive
- badland more than 5 meter deep

B) MASS MOVEMENT ALONG CREEKS AND RIVERS

scarp of a slide or a slump caused by lateral corrasion
- a) in clastic material
- b) in highly weathered bedrock
- c) in hardly weathered bedrock
- d) in a, b or c with vegetation

scarp of a slide or a slump caused by vertical cutting
- a) in clastic material
- b) in highly weathered bedrock
- c) in hardly weathered bedrock
- d) in a, b or c with vegetation

C) MASS MOVEMENT ON OPEN SLOPES

scarp of a slide or a slump
- a) in clastic material
- b) in highly weathered bedrock
- c) in hardly weathered bedrock
- d) in a, b or c with vegetation

scarp of a planar slide
- a) in clastic material without vegetation
- b) in clastic material partially with vegetation
- c) in clastic material with vegetation
- d) on bedrock

groups of planar slides
- a) in clastic material without vegetation
- b) in clastic material partially with vegetation
- c) in clastic material with vegetation
- d) on bedrock

confirmed slow mass movement
- a) undefined
- b) shallow (less than 2 m)
- c) deep (more than 2 m)

presumed slow mass movement
- a) undefined
- b) shallow (less than 2 m)
- c) deep (more than 2 m)

rock wall
- a) fresh and continuous
- b) interrupted by slopes covered with vegetation

D) OTHER ELEMENTS OF EROSION
- tensile crack
- damaged irrigable terrace
- damaged non-irrigable terrace
- damaged vegetal cover

0 200 400 m

Land-Use

- Irrigable terraces
- Non–irrigable terraces
- Idle terraces

} Terraced land

- Shrubland (heigh less than 3 m)
- Deciduous or coniferous forest

} Woodland

- Pasture and grassland
- Barren land
- Mosaic of different land-use types
- Streams ,roads and industrial area

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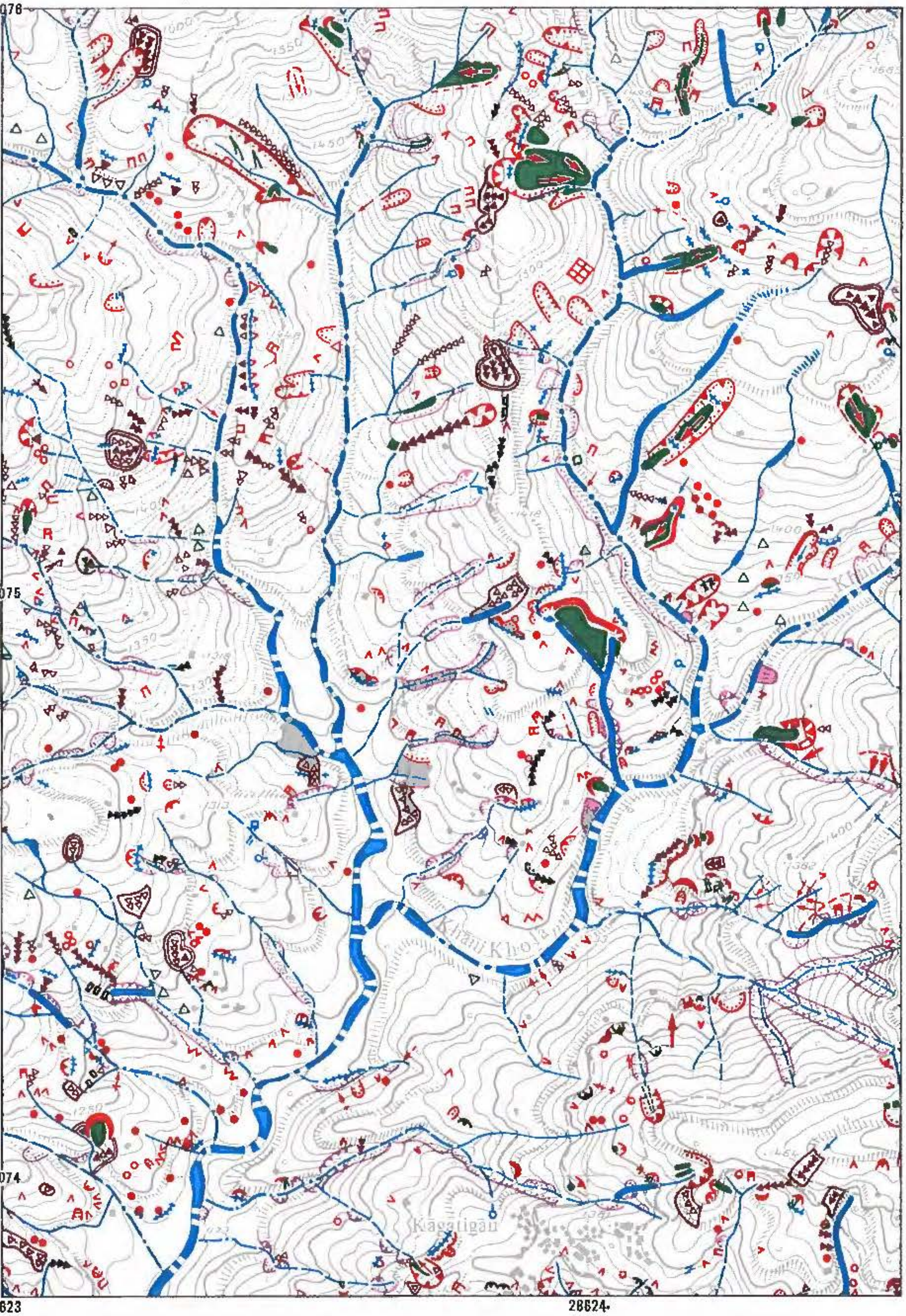

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Geomorphic Damages Kathmandu–Kakani Area, Nepal

Fig. 11. 7 to 10 year old fallow field with *Stipa ichu* and *Baccharis incarum* plants, north of the main road from La Paz to Oruro (land-use category 2.3). The former furrows of the field are still perceptible. In the background the Cielo Pata mountain south of Sica Sica.

cont. Table 1.

5. *Stipa ichu* (R. et P.) Kunth, *Stipa imconspicua* Presl, *Trifolium amabile* HBK., *Agrostis gelida* Trin., *Stipa depauperata* Pilg., *Heterosperma nana* Nutt. et Sherff, *Gamochaeta erythractis* (Wedd.) Cabr., *Facelis plumosa* (Wedd.) Sch. Bip., *Gnaphalium* cf. *calviceps*, *Cyperus andinus* Palla ex Kükenth., *Oenothera punae* O. Ktze., *Festuca orthophylla* Pilg.
6. *Baccharis papillosa* Rusby, *Hieracium* cf. *eriosphaerophorum* Zahn, *Azorella compacta* Phil., *Cheilanthus pruinata* Kaulf., *Poa asperiflora* Hack., *Hedeoma mandoniana* Wedd., *Silene* aff. *genovevae* Bocq., *Eupatorium azangaroense* Sch. Bip. ex Wedd., *Calandrinia acaulis* HBK., *Gerardia* spec.
7. *Adesmia vicina* MacBride, *Bromus unioloides* HBK., *Hypochoeris elata* (Wedd.) Griseb., *Bidens pseudocosmos* Sherff, *Sisyrinchium* spec., *Verbena microphylla* HBK. u. a.
8. *Fabiana densa* Remy, *Poa buchtienii* Hack., *Eragrostis* cf. *lugens* Nees, *Stipa mucronata* HBK., *Mutisia orbignyana* Wedd., *M. ledifolia* Decne. ex Wedd., *Zephyranthes* spec., *Lobivia* div. spec.
9. *Adesmia miraflorensis* Remy, *Opuntia* spec., *Clematis millifoliata* Eichl., *Chaptalia similis* R. E. Fries.
10. *Erodium cicutarium* (L.) L'Hérit. ex Ait., *Hypseocharis pimpinellifolia* Remy, *Baccharis incarum*-Verjüngung, *Aristida asplundii* Henrard, *Crassula* spec.
11. *Parastrephia lepidophylla* (Wedd.) Cabr., *Oxalis bisfracta* Turcz, *Bouteloua simplex* Lag., *Schkuhria multiflora* Hook. et Arn., *Astragalus garbancillo* Cav., *Conyza artemisiaefolia* Meyen et Walp., *Tarasa* cf. *tenella* (Cav.) Krapovickas, *Festuca dolichophylla* Presl.
12. *Gnaphalium badium* Wedd., *Junellia minima* (Meyen) Moldenke, *Astragalus micranthellus* Wedd., *Muhlenbergia fastigiata* (Presl) Henr., *Ophioglossum nudicaule* (Metf.) Clausen, *Gilia laciniata* R. et P.
13. *Plantago myosuros* Lam., *Plagiobotrys congestus* (Wedd.) J. M. Johnst., *Spergularia andina* Rohrb.
14. *Distichlis humilis* Phil.
15. *Atriplex herzogii* Standl., *Anthobryum triandrum* (Remy) Surgis.

Table 2. Chemical soil characteristics* of six agricultural sites in the Huaraco area between 4200 m and 3700 m above sea level. The figures are mean values of four different old fallow stages. The chemical analysis have been carried out according to standard methods by the "Landes-Lehr- und Versuchsanstalt, Trier", under the direction of Dr. Walter. Site locations: Fig. 1.

sample sites	m above sea level	depth cm	C %	N %	C/N	pH (KCl)	P_2O_5 **	K_2O **	Mg **	Na **	Cl **	SO_4 **	Bor ppm
1	*Chili:* andine grass belt (4180m)	0–15	1.40	0.09	22.6	5.1	3	11	8	3.2	1.8	0.1	0.4
		15–30	1.60	0.10	18.1	5.1	2	6	8	2.7	1.5	0.1	0.8
2	*Pakkota:* plateau of the hills (4000 m)	0–15	1.17	0.11	11.0	5.2	3	35	10	1.4	1.2	2.0	0.9
		15–30	0.69	0.09	5.5	5.5	2	22	13	1.7	0.6	2.1	0.9
3a	*Huaraco:* hill tops (3850 m)	0–15	0.68	0.10	7.2	5.6	3	26	17	0.5	1.8	0.2	1.3
		15–30	0.38	0.06	7.0	5.6	2	19	18	0.8	1.8	0.1	1.0
3b	*Huaraco:* depression between hills (3850 m)	0–15	1.05	0.15	7.3	5.6	2	30	31	1.2	1.8	0.2	1.7
		15–30	0.75	0.11	7.2	5.5	1	30	40	3.7	1.8	0.1	2.1
4	*Huaraco:* stony sediment-plain (3800 m)	0–15	1.27	0.11	11.4	5.3	4	38	18	0.9	1.8	0.3	0.7
		15–30	0.54	0.07	7.8	5.7	2	18	23	1.4	1.3	0.2	0.8
5	*Antipampa:* alluvial plain (3750 m)	0–15	0.51	0.06	8.9	7.1	7	27	28	27.0	7.1	15.5	4.4
		15–30	0.52	0.05	10.7	7.7	9	18	36	40.4	9.7	13.5	8.7
6	*Antipampa:* alluvial plain (3720 m)	0–15	0.57	0.07	8.6	7.5	9	32	28	27.7	7.1	16.7	4.9
		15–30	0.46	0.05	8.7	7.6	16	26	29	116.6	13.0	16.8	20.4

* Analytical methods: Total C = Wet oxydation with $K_2Cr_2O_7$ followed by a colorimetric determination. Total N = Kjeldahl. pH = in n/10 KCl. Exchangeable P and K = Extraction with Ca-lactate and colorimetric determination as molybdate/vanadate-P complex. Exchangable Mg = Extraction with $CaCl_2$ and colorimetric determination as Mg-titane yellow complex. Exchangable Na = Extraction with n/10 HCl and determination of the Na-content in a flame-photometer. Cl = Extraction with water and titration with $AgNO_3$ against K_2CrO_4 as an indicator. SO_4 = Extraction with 1% NaCl, precipitation with 10% $BaCl_2$ and determination of the turbidness with a photometer or by weighting the precipitate. Bor = Extraction with hot water and colorimetric determination with carmine.

** mg/100 g.

analysed with regard to their nutrient content. The average values drawn from two to four samples are compiled in Tables 2 and 3.

Apart from the soils of the lower floodplains (sites 5 and 6), which are influenced by salty groundwater, the pH-values in the hill soils and those at their bases are between 5 and 6, or relatively favourable. With the exception of the Andean grass belt at 4180 m above sea level, where the breakdown of the organic substance is limited by climatic factors, the carbon and nitrogen content is extremely low and the C/N-ratios are usually very narrow. The nitrogen level could therefore certainly be an important minimum factor. At least as deficient is phosphorus, a fact which is generally known (COCHRANE, 1973; SALM, 1983). On the other hand, the base content of the soils is relatively favourable with the exception of Calcium. This fact is in connection with the potassium of great meaning for the cultivation of potatoes. All in all, the portion of exchangeable bases is altogether not very high (40 to 60%).

The question pertaining to the effectiveness of the fallow years in regard to the lasting production capacity of the farm soils remains unanswered. Usually the following advantages have been ascribed to the fallow periods:

Table 3. Exchangeable bases* of six agricultural sites in the Huaraco study area. The figures are mean values of four different old fallow stages. Location of the sample sites: Fig. 1.

sample sites m above sea level		depth cm	K	mval/100 g dry soil: Na	Ca	Mg	T-value	S-value	% V-value
1	*Chili:* andine grass belt (4180 m)	0–15	0.16	0.50	1.88	0.49	12.40	3.03	24.2
		15–30	0.01	0.95	1.67	0.69	16.06	3.32	22.5
2	*Pakkota:* plateau of the hills (4000 m)	0–15	0.94	0.76	2.46	0.80	8.40	4.97	59.5
		15–30	0.61	0.69	3.44	1.06	8.15	5.80	72.8
3 a	*Huaraco:* hill tops (3850 m)	0–15	0.50	0.88	3.37	2.36	17.70	7.10	40.5
		15–30	0.46	0.57	4.85	2.98	21.55	8.85	42.1
3 b	*Huaraco:* depression between hills (3850 m)	0–15	0.62	0.53	2.74	1.34	9.13	5.23	56.9
		15–30	0.36	0.64	3.42	1.69	10.59	6.10	57.5
4	*Huaraco:* stony sediment-plain (3800 m)	0–15	0.82	0.67	2.87	1.37	12.50	5.72	47.1
		15–30	0.32	0.75	4.38	1.90	13.60	7.35	55.9
5	*Antipampa:* alluvial plain (3750 m)	0–15	0.63	2.02	4.57	2.19	12.41	9.42	81.2
		15–30	0.33	2.64	4.95	2.95	14.78	10.86	77.5
6	*Antipampa:* alluvial plain (3720 m)	0–15	0.69	2.24	9.04	2.55	31.75	14.53	47.5
		15–30	0.53	8.40	6.89	1.81	29.70	17.64	54.3

* Analytical methods: Extraction with 5% $BaCl_2$. Determination of K, Na and Ca in the extract with a flame-photometer and of Mg with an AAS. T-value = Total exchange capacity of cations in mval. S-value = Sum of the analyzed cations in mval. V-value = % of S-value from the T-value.

1. Enrichment of organic material in the soil, and consequently the improvement of water-holding capacity and soil structure, as well as enhanced supply of mineral nitrogen.
2. Storing of precipitation in the soil profile.
3. Mobilization of mineral nutrients from deeper soil layers by deep-rooted plants and weathering processes.
4. Dying-out of the long-lived stages of plant pathogens.

All of these processes are conceivable; however, none of them has actually been proven. Comparative soil analyses of fallow lands of varying ages (RUTHSATZ, unpublished) indicate a tendency towards a certain degree of enrichment with organic material and therefore a possibility of short-term improvement in the N-supply in freshly broken ground. Since the fallow lands are, however, continuously and intensively grazed, the plant cover can neither above nor below ground strongly develop, so that the nitrogen replenishing effect cannot be too great and, above all, cannot be effective over a long-term period.

The storage of precipitation input during the fallow years likewise could not be too effective, since the constant grazing and damage to the vegetation subsequently leads to instinct compactation and, after heavy rain storms, to the loss of topsoil, such that the overland flow is considerable (SALM, 1983). Moreover, only one or two rainy seasons would be necessary to fill the soil to its maximum water-holding capacity, as most of the soils can only take up and maintain small amounts through the dry season. Regarding long-lived stages of parasites, e.g. Nematodes, up until now no positive evidences have been recorded. Nevertheless, the farmers of the Highlands consider the fallow a soil-fertility measure.

Fig. 12. Southeast facing slopes of the Janthaloma mountain (March 1980). The trend to abandon the farmland with increasing hight and inclination of the slope is obvious (land-use categories from below to above: 3.4; 4.2; 4.4). On the upper slope very old field terraces are still visible.

5. Suggestions for the Improvement of the Land-Use

The greatest problem for the long-lasting productivity of the soils on the semi-arid Highlands is the intense soil-erosion as a consequence of the present land-use methods. To limit these, while guaranteeing the growing population better yields without large investments is not a simple task. A number of scientists have already tried to come to terms with this (PRESTON, 1973, 1974; BECK und ELLENBERG, 1977; LEBARON et al., 1979; ELLENBERG, 1981; TAPIA, 1982). Above all, it would not be easy to motivate the extremely tradition-bound Highland peoples to change their life-styles, since they have already had less than encouraging experiences with similar proposals. For the community of Huaraco and comparable regions in the semi-arid portion of the Highlands, the following reforms may promise some success:

5.1. Separation of Intensely Used Farmland and Public, Unregulated Pasture Land

Grazing should be regulated according to the various habitats in the community area in order to achieve a lasting performance as well as to reduce soil erosion. If the fallow years are to have a soil-improving effect, then the resting fields should not be overgrazed year round. Grazing compacts the upper layers of the soil, it makes it difficult for the water to infiltrate, it regularly wounds the soil surface and consequently creates starting points for water erosion, and it hinders the vegetation from covering the soil surface and densely rooting the soil. Overgrazing can limit the enrichment of organic material and the improvement of living conditions for the soil organisms. The unhampered grazing of all community lands including the fallow areas is one of the principal causes for the ubiquitous soil erosion and the deficient production capabilities of the pasture lands. The herd sizes and grazing rights were regulated by the old Aymara and Inca cultures as well as under the government of the Spanish land owners (MURRA, 1965; MONHEIM, 1966). At that time there was already erosion damage, but probably not to the degree observed today.

Fig. 13. Southeast facing slope of the Wacani mountain (October 1982) in the very south of the study area with 5 to 7 and more than 15 year old fallow land. The walls and mounds of gathered stones are defining the property limits (land-use category 3.8).

To compensate for the necessary restriction of the grazing on fallow land, especially during the dry season, new solutions must be found. Conceivable enhancement efforts could include:

1. Cultivation of alfalfa on the better farmland during the fallow period.
2. Preservation of the more productive grassland for dry-season grazing or fodder harvesting.
3. If possible, irrigation of alfalfa and productive grassland.
4. Selection, breeding and cultivation of indigenous fodder plants on the fallow land instead of unregulated succession development.

5.2. Improvement of Farming Techniques

A community which does not possess extensive and productive pasture land, but, on the other hand, owns relatively frost-protected, moderately fertile agricultural ground should concentrate on improving the latter. Ways in which this can be done include the following:

1. Increasing the organic fertilization (manuring) and moderate mineral fertilization, especially with phosphorus.
2. Including the cultivation of legumes (e.g. Lupine) with the usual crop rotation sequence.
3. In as much as it is possible, occasional watering of the fields in the valley grounds.
4. Construction or repair of agricultural terraces and supporting walls on slope locations.
5. No expanding or combining of fields.
6. Maintenance of habitat-specific plant varieties within crop plants.
7. Maintenance of the traditional soil-preserving ploughing method.
8. Consistent measures against the most important plant diseases and pathogens.

The most important goal of all these measures should be the lasting improvement of the fertility of the farmland through reduction of erosion and favouring of the humus accumulation of the soils. Suitable

Fig. 14. Vast flood plain near Antipampa with short grass pastures for sheep and llamas (land-use category 5.3). The small cushions of *Anthobryum triandrum* indicate the influence of salt-rich groundwater (March 1980).

rotation crops ("Zwischenfrüchte") and sufficient mineral fertilization to compensate for losses could eventually lead to a sharp decrease in the number of fallow years required, or even render them superfluous as well as allow the farming to be limited to the most favourable habitats.

Summary

The Highlands of Bolivia have been exploited by man in a variety of ways for thousands of years. The chosen community of Huaraco is situated south to Sica Sica near the main road from La Paz to Oruro. It makes a good example for the semi-arid portion of the Highland. The study area ranges from high mountains of 4500 m in elevation down to the vast flood plain in the central valley of the Desaguadero river at 3730 m above sea level. As many others, the village of Huaraco is located just where the first hills rise from the plain beside a small temporary dry river. The summer rains (350 to 400 mm/year) are quite irregular but still allow farming without irrigation. The people live on potatoes, barley and the Andean cereal "quinoa" as well as some native tuber plants. The farming methods are still based on old Aymara traditions, to some extent modified by the Spaniards. Their characteristics are: Cultivation in common "Zelgen", crop rotation of 3 to 4 years, followed by 7 to 15 and more years of fallow, and tilling of the fields with primitive wooden, hooked plows, pulled by bulls. Besides farming the breeding of sheep and some llamas is necessary. The herds are grazing without any restriction on native pastures and fallow land all the year round.

The objectives of the investigation were to analyse the interrelations between site conditions, vegetation cover, the aptitude for usage alternatives and actual land-use as well as their reactions on soils and plants. For that purpose the following measurements were carried out:

1. Description and classification of the more frequent plant communities.
2. Analysis of the interdependency between vegetation mosaics and site conditions.
3. Investigation of the farming and breeding customs of the local population.
4. Compilation of the usual "calendario agricola" of the crop plants.
5. Chemical analysis of soil samples from typical farming areas with respect to their nutrient content.
6. Mapping of the actual land-use categories and their interpretation for the use-aptitudes of the different sites.

The results demonstrate that, besides dry and frost periods, especially P- and N-deficiencies in the soil are a main minimum-factor for crop yields. The unregulated and year-round intensive grazing of fallow and pasture land blocks a sufficient regeneration of the vegetation cover and of soil fertility. As a consequence many sites are degraded in a probably irreversal way by heavy soil erosion.

This process could be at least restrained by some changes in the farming and grazing habits. To that end a list of proposals is presented.

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Discussion to the Paper Ruthsatz

Prof. Dr. W. Lauer:

Which are the areas of origin of the secondary vegetation mapped out by you?

Prof. Dr. B. Ruthsatz:

Most of the plant species now frequent on fields and fallow land are indigenous of the Bolivian highlands. The few neophytic species from other continents, such as *Brassica rapa, Poa annua, Capsella bursa-pastoris* etc. from Europe are restricted to disturbed or cultivated areas. Many of the weeds from arable fields are natives of temporary dry river beds and flat plains, inundated during the summer, when erosion especially by water and sometimes by wind disturbs the vegetation cover. These weeds disappear more or less rapidly after cultivation stops. We neither know how the original vegetation was composed, nor can we estimate the pasture pressure by the wild camelids and rodents. But one can observe some phenomena, which perhaps in oue way or another are informative:

1. Plants and plant communities on mountain slopes climb several ten meters higher on old fallow land than on undisturbed sites. This means that plants of the actual vegetation may be native to similar sites but at 50–100 m lower in altitude.
2. From vegetation changes in areas which have occasionally been protected from grazing and browsing by domestic animals during several years, one can deduce that especially grasses and herbs are suffering from pasture activities favouring indirectly dwarf shrubs and cushion plants. The invasion of herbaceous vegetation in nonpastured areas is the more obvious the more fertile – in terms of nutrients and water – the sites are. This is correct at least for the first succession stages (15–30 years). Perhaps several of the woody pasture-resistant species are natives from shallow and dry slope sites and invaded the heavily browsed plains only at the expense of the better fodder plants.

Prof. Dr. E. Löffler:

What is the origin of soil oversalting, and is it connected with the groundwater level? If so, would the irrigation of the valley floors lead to a rising of the groundwater level and thus to an increasing danger of soil oversalting?

Prof. Dr. B. Ruthsatz:

The salt content of the soils on the lower flood plain in the surroundings of Antipampa is the result of the contact to salty groundwater ascending in the clayey material. During rainy summers the salt content in the upper layers declines, but during the dry season salt crusts can be formed on the surface.

The Huaraco river carries too little water to be used for the irrigation of large areas. But some probably pre-Spanish canals prove the restricted application of field watering for yield improvement. The upper part of the valley has water without high salt concentrations, that can be used to some extent.

Prof. Dr. P. Höllermann:

Which are the criteria for distinguishing between high montane and sub-Andean in the study area?

Prof. Dr. B. Ruthsatz:

The limit between the oreal (high montane) and the sub-Andean vegetation belt ranges from about 4000 m to 4200 m. It corresponds more or less to the upper limit of the agricultural activities and can be clearly defined floristically (see Table 1). Several shrub species just end here at their upper distribution limit, as f.e. *Fabiana densa*. Others reach here their lower limit like some bunch grasses, f.e. *Festuca humilior*.

Dr. C. Schubert:

In this paper, as in others presented during the past 2 days, I have heard repeatedly workers use the terms "winter" and "summer" for tropical regions. I would like to propose that we finally refrain from using these terms in the tropics because they make no sense. There are no seasons in the sense of the temperature regions in the tropics.

Prof. Dr. B. Ruthsatz:

"Winter" in the extra-tropics refers to a cold and less sunny season, when most of the plant species interrupt their growing period. „Summer", on the contrary, means the season with optimal vegetative and generative development for most of the plants because of high temperatures and light intensities as well as good water supply. In the Andean Highlands of Bolivia very marked wet and dry seasons exist from November to April and May to October, respectively. Although the dry period is the more sunny one, it is also the colder one because of regularly occuring intense night frosts. The rhythm of plant growth is in great part regulated by mean and threshold temperatures. With very few exceptions all plant species of the highlands interrupt their growing period during the dry and cold season. Many of them do so before the soil is really dry only reacting to temperature. Therefore, I think it reasonable to use the terms „summer" for the growing and "winter" for the resting period as well in the subtropical Andean Highlands south to the Titicaca Lake.

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Tropical Glacier and Climate Variations

Stefan Hastenrath

With 10 Figures

Abstract

The glaciers in the high mountain regions of the tropics are extremely sensitive, albeit complex indicators of long-term climatic change. Historical evidence of glacier variations is limited to the four most recent decades for New Guinea; sources extend to the end of the last century for East Africa and the Northern Andes; but for the equatorial Andes documentation covers half a millenium. A monotonic recession since the beginning of records is borne out for New Guinea, East Africa, and the Northern Andes; for the equatorial Andes there are indications for the ice retreat to have started in the first half of the 19th century.

A central task in climate reconstruction is the inference of the climatic forcing which has brought about the glacier response. A sensitivity analysis shows that glaciers are particularly responsive even to small changes in surface albedo and cloudiness, less to temperature variations, and least to changes in solid precipitation.

The following two independent approaches are being used to construct climatic history from field observations on tropical glaciers:

a) Analyses of microparticle content, oxygen isotope ratios, and gross beta activity performed on ice cores retrieved from the Quelccaya Ice Cap, Peru, and Lewis Glacier, Mount Kenya, offer the prospect of a net balance chronology.
b) For Lewis Glacier, Mount Kenya, measurements of current net balance, kinematics, and morphology, serve as input to numerical modelling of the ice dynamics, geared at simulating the observed long-term glacier behavior. An abrupt precipitation decrease in the latter part of the 19th, and temperature change in the course of the 20th century are identified as the climatic forcings of the continuing glacier recession.

1. Introduction

An abundance of geomorphic evidence attests to a formerly much larger ice extent in various mountain regions of the tropics, including some that are presently not glaciated, such as the Central American Cordilleras, the Ethiopian highlands, Borneo, and Hawaii. The Pleistocene to early Holocene glaciations are the subject of other contributions to this symposium. At present, glaciers near the Equator still exist in three regions of the World: East Africa, New Guinea, and the South American Andes. Tropical glaciers are extremely sensitive – albeit complex – indicators of climate variations. The translations of glacier observations into climatic history remains a fundamental task.

In the following, I will first review the recent glacier variations in the tropics, and then I will sketch two independent approaches that are being developed to infer a climatic history from glacier observations. The present written version of the symposium lecture is intended as a source of reference. It draws on the numerous original publications listed in the bibliography.

2. Tropical Glacier Inventory and Recent Glacier Variations

International efforts directed at global environmental monitoring and the physical causes of long-term climatic change have recognized the study of glaciers as a task of high priority (UNESCO, 1970; World Meteorological Organization, 1980; World Meteorological Organization-ICSU, 1975, pp. 7, 11, 60; International Association of Hydrological Sciences – UNESCO, 1977; Temporary Technical Secretariat for World Glacier Inventory of IUGG-ICSI-UNESCO, 1977; United Nations Environment Programme, 1979; United Nations Environment Programme – World Meteorological Organization, 1982). For the low latitudes, inventories of existing glaciers and systematic compilations of fluctuations in ice extent are just being initiated (International Association of Hydrological Sciences-UNESCO, 1977; Temporary Technical Secretariat for World Glacier Inventory of IUGG-ICSI-UNESCO, 1977; United Nations Environment Programme – World Meteorological Organization, 1982; HOPE et al., 1976).

The modern ice distribution in the Ecuadorian Andes and on Kilimanjaro, Mount Kenya, and in the Ruwenzori in East Africa has been assessed from field observations and the evaluation of air photographs and topographic maps. On this basis, I provided the Ecuador, Tanzania, Kenya, Uganda, and Zaire contributions to the World Glacier Inventory, at the request of the Temporary Technical Secretariat for World Glacier Inventory of IUGG-ICSI-UNESCO. Based on a variety of historical sources and observations in the terrain I reconstructed the secular glacier variations since the 1500's for the Ecuadorian Andes, and since the latter part of the 19th century for East Africa. In accordance with a request by the Permanent Secretariat for Glacier Fluctuations of IUGG-ICSI-UNESCO, I contributed pertinent results for publication (HASTENRATH, 1977). For the Ecuadorian Andes, the modern ice extent, glacier variations in historical times, and evidence on pleistocene and early holocene glaciations are presented in a recent book (HASTENRATH, 1981 a). A monograph on the glaciers of equatorial East Africa is in preparation (HASTENRATH, 1983). Recent ice extent and glacier variations in New Guinea are described in HOPE et al. (1976). Glacier inventories for various regions of the tropical Andes are also being compiled under the auspices of the Temporary Technical Secretariat for World Glacier Inventory of IUGG-ICSI-UNESCO.

At the three presently glaciated mountains of East Africa, Kilimanjaro, Ruwenzori, and Mount Kenya, a drastic and monotonic ice recession is documented from the earliest observations in the latter part of the 19th century to the present (HASTENRATH, 1975, 1983). A detailed reconstruction of terminus history was possible for Mount Kenya, where a relatively abundant historical documentation is available, as well as an excellent topographic base map at scale 1 : 5 000 (Forschungsunternehmen Nepal-Himalaya, 1967). Lewis Glacier in particular is now the ice body with the most complete historical documentation in all of the tropics.

The ice-capped Mount Carstensz (Jaya) in Western New Guinea (HOPE et al., 1976) was first sighted in 1623, but this report was disbelieved until around 1900. The peak region was first reached in 1912, and visits since then have remained rare (HOPE et al., 1976). A drastic and monotonic ice retreat is borne out from the 1930's to the 1970's.

The existence of snow and ice in the equatorial Andes was known since the 1500's and historical accounts extend over more than four centuries (HASTENRATH, 1981 a). The earliest sources are the municipal and church records from the era of Spanish colonization. These indicate a much larger ice extent than at present. The French Academicians BOUGUER and LA CONDAMINE worked in Ecuador in the mid 1700's, with the aim of measuring the first three degrees of the meridian. Their books are not only classics in geodesy, but they also contain useful observations on ice conditions, indicating a much lower ice equilibrium line than at present. Alexander VON HUMBOLDT visited the country at the beginning of the

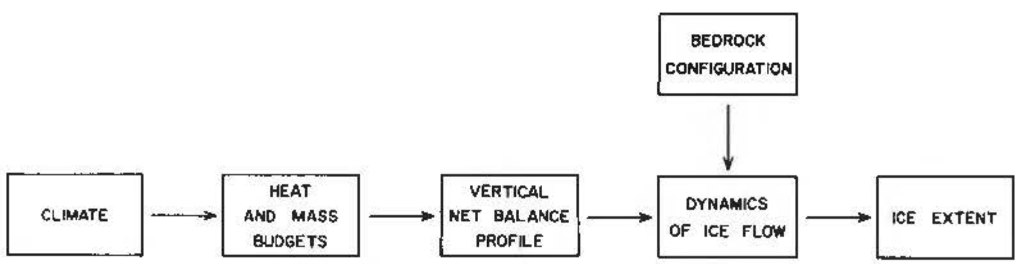

Fig. 1. Causality chain of climatic forcing and glacier response.

19th century. His observations also indicate an abundance of snow and ice. It is not until the middle of the 19th century that a drastic upward shift of the ice equilibrium level sets in; the recession continuing to the present.

In summary, a drastic and monotonic ice retreat continuing from the 19th century to the present is documented for East Africa and the Ecuadorian Andes, while observations for New Guinea only start in the 1930's. The reconstruction of a climate history from glacier observations is the task that lies ahead.

3. Climatic Forcing and Terminus Response

One approach to inferring the (unknown) climatic variations from the (well documented) glacier behavior is through computer simulation of climate, net balance, and ice dynamics. A causality chain is illustrated in Fig. 1. Climate controls the mass and heat budgets, which are reflected in the vertical net balance profile. The vertical net balance profile and the bedrock configuration in essence determine the ice dynamics, which lead to variations in ice extent. The intent is to reconstruct the climatic forcing from the glacier response. The regional input to the computer simulation includes

(a) the record of terminus positions;
(b) bedrock configuration;
(c) modern mass budget conditions.

From this information, the climatic variations are to be reconstructed that caused the observed terminus behavior. A glacier of maximum extent is created, as indicated by moraines. Then a retreat is simulated in such a way that the various observed terminus positions are reproduced. This then allows quantitative inference on the history of the climatic forcing.

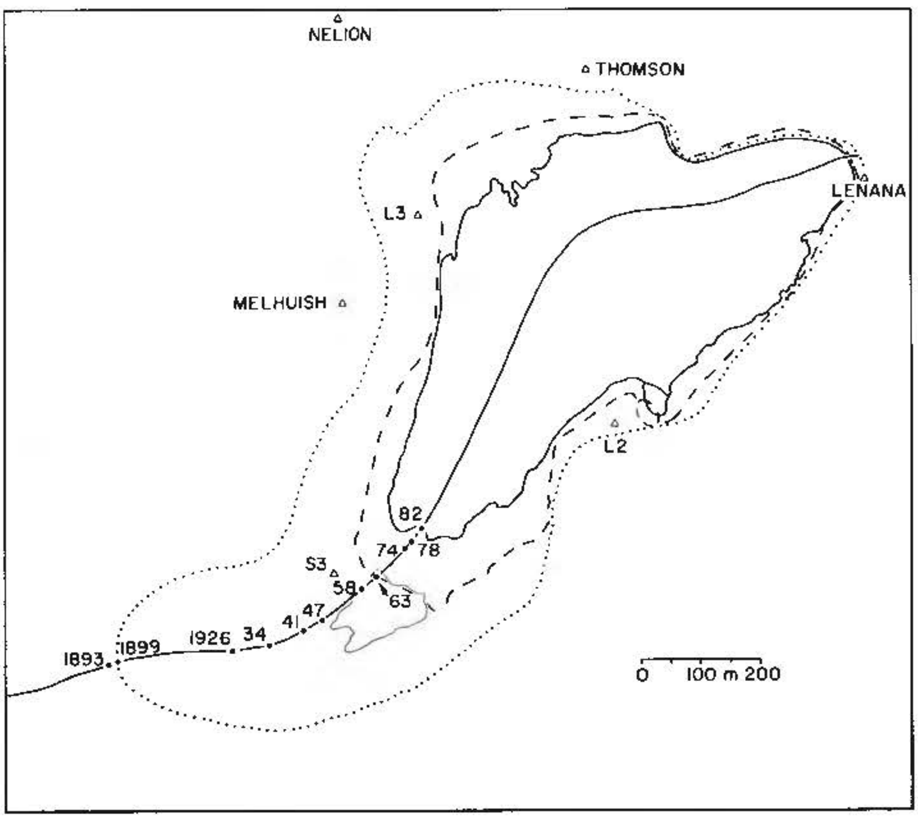

Fig. 2. Map of the terminus and area variations of Lewis Glacier since the turn of the century. Scale 1 : 12 500.

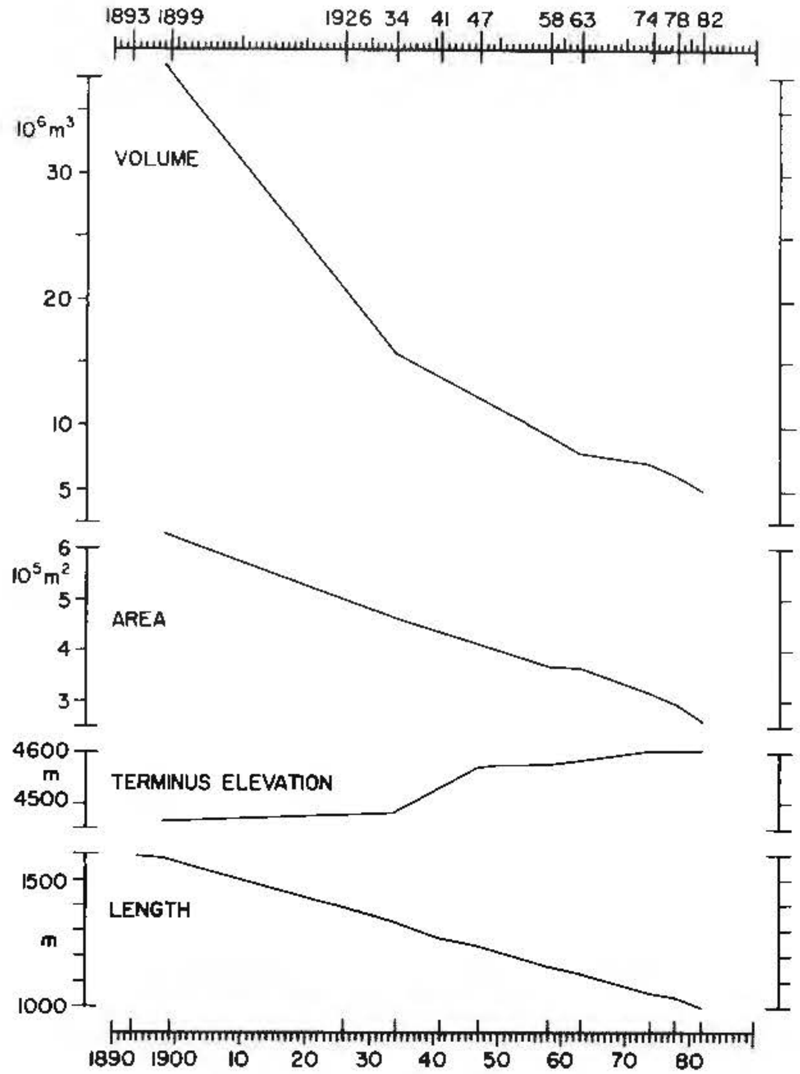

Fig. 3. Secular variation of Lewis Glacier 1899–1982. Volume in 10^6 m^3; area in 10^5 m^2; length of the glacier and elevation of terminus in m.

Lewis Glacier on Mount Kenya is the glacier with the most comprehensive historical documentation of long-term variations in all of the tropics. My reconstruction of Lewis Glacier variations since the turn of the century based on a variety of historical sources (TROLL und WIEN, 1949; CHARNLEY, 1959; Forschungsunternehmen Nepal-Himalaya, 1967; HASTENRATH, 1975, 1981 b, 1983) is illustrated in Figs. 2 and 3. It is the largest ice body on Mount Kenya, its catchment is well defined, and it is comparatively accessible. Based on these considerations, Lewis Glacier was chosen for a study of cryosphere-climate relations including the quantitative reconstruction of the climatic forcing from the observed glacier response. Basic to this effort is a multi-annual field investigation of glacier morphology, kinematics, and heat and mass budgets. A pilot project was undertaken during my affiliation with the University of Nairobi in 1973–74. A more comprehensive and continuous field program materialized since December 1977. This encompassed observations throughout the year and intensive field expeditions. The tasks of this field program are as follows.

Aero-photogrammetric mappings of the glacier at scale 1 : 2 500 were accomplished in February 1974 (CAUKWELL and HASTENRATH, 1977), in February 1978 (HASTENRATH and CAUKWELL, 1979), and in

February and March 1982 (CAUKWELL and HASTENRATH, 1982). These mappings document a glacier average decrease in ice thickness over the four year interval 1974–78 of about 4 m, which corresponds to a volume loss of the order of 11×10^3 m^3. Over the four year interval 1978–82, the ice thickness decreased further by 3.6 m and the volume by 1.067×10^3 m^3. These mappings further reveal changes in the crevasse pattern: while longitudinal crevasse orientation prevails in the lower, and transverse alignment in the upper glacier, the transition between these two regimes is gradually being displaced glacier upward (HASTENRATH and KRUSS, 1979, 1982; KRUSS and HASTENRATH, 1983). Ice thickness and bedrock topography were determined by the seismic and gravimetric techniques and through numerical modelling (BHATT, HASTENRATH and KRUSS, 1980). On this basis, the total ice volume for the February 1978 datum is estimated at about 10^7 m^3.

An array of stakes was installed on the glacier for purposes of net balance measurements and determination of surface ice flow velocity through repeated surveys of these poles. The stations in the lower glacier consist of various 2 m long wooden stakes that are linked together, while single 4 m long bamboo poles are used in the upper glacier. The network was repeatedly refurbished since 1978 with a major overhaul during the 1981/82 expedition.

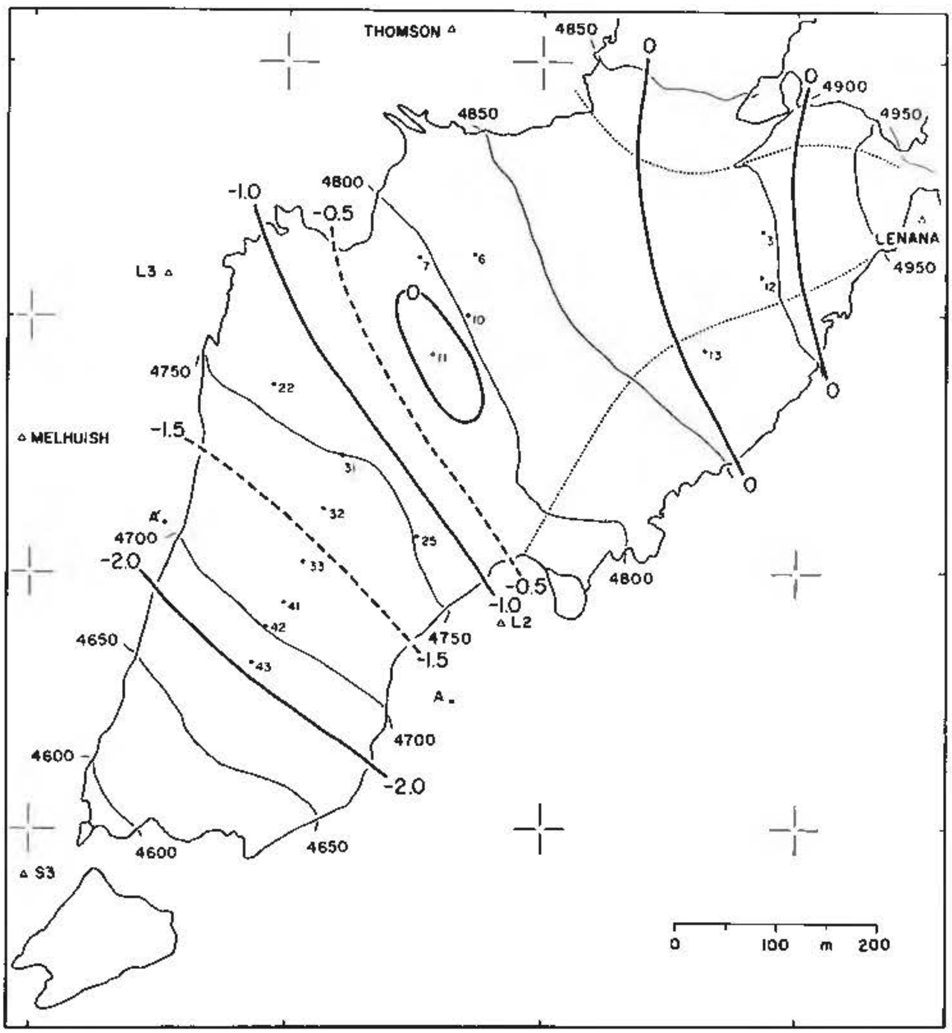

Fig. 4. Map of net balance averaged for the budget years 1978/79, 1979/80, 1980/81, and 1981/82, in m of liquid water equivalent.

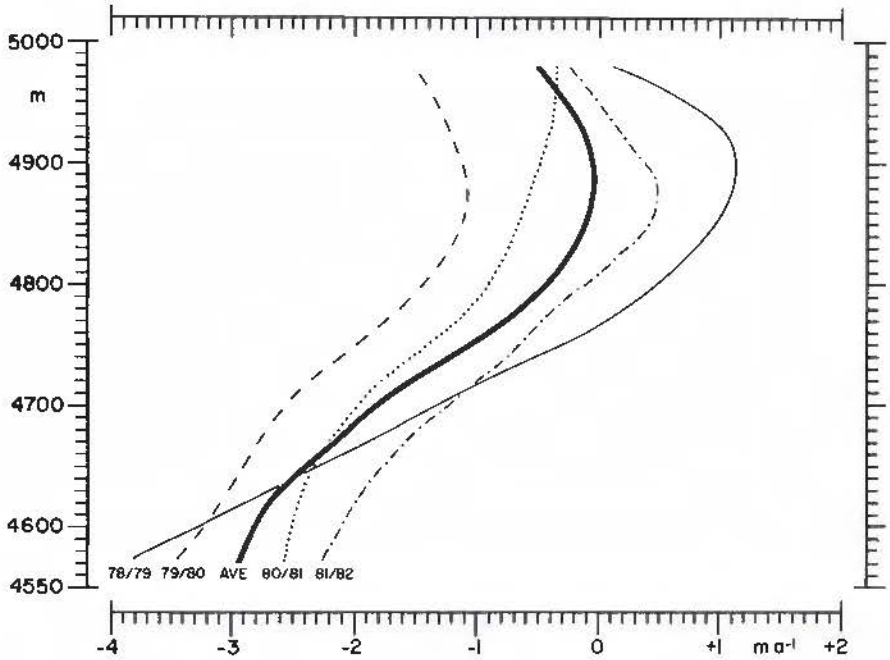

Fig. 5. Vertical net balance profiles, in m of liquid water equivalent, for the budget years 1978/79 (thin solid), 1979/80 (broken), 1980/81 (dotted), 1981/82 (dash-dotted), and the four-years combined (heavy solid line).

Readings at the stake network are converted into liquid water equivalent net balance under consideration of densities representative of various portions of the glacier, as obtained from ice pit investigations. The latter are complemented by climatic ice core studies (THOMPSON and HASTENRATH, 1981). The net balance pattern for the four year period 1978–1982 is shown in the map Fig. 4. Small positive values are found in the upper glacier, while large negative values are characteristic of the ablation zone in the lower glacier. Planimetering of the map yields for the glacier as a whole a deficit of 1.007×10^3 m^3 of liquid water equivalent over the four year period 1978–82. Based on individual annual maps comparable to the four-year map Fig. 4, vertical net balance profiles are constructed such as displayed in Fig. 5. The profiles reveal pronounced interannual variations in the net balance conditions, which parallel those of precipitation, as monitored by the gauges we installed in January 1978. Thus the abundant precipitation year 1978/79 shows the largest positive net balance in the upper glacier, and for the glacier as a whole mass equilibrium is almost reached. By contrast, during the extreme drought year 1979/80 net balance was negative everywhere, that is the entire glacier behaved as ablation area; the mass deficit for the glacier as a whole was accordingly large. The budget years 1980/81 and 1981/82 show intermediate conditions. The four-year average profile is also plotted in Fig. 5 for comparison.

Our observations show that the interannual variability of net balance is considerably larger than that of precipitation. It is realized that precipitation variations are typically associated with changes in cloudiness and in albedo of the glacier surface. The latter two factors strongly affect net radiation and thus the surface heat budget, which is in turn intimately linked with the mass budget. Thus precipitation changes appear greatly magnified in the net balance conditions. Quantitative relationships are being developed empirically and through heat and mass budget calculations. In conjunction with our radiation measurements (HASTENRATH and PATNAIK, 1980), the intended installation of a sunshine counter would be useful in this effort.

The annual mean heat and mass budgets of Lewis Glacier are schematically summarized in Figs. 6 and 7. In Fig. 6 the downward directed shortwave radiation SW↓ results from the radiation geometry and a representative cloudiness of 6 tenths. The upward directed shortwave flux SW↑ is then commensurate with a representative surface albedo of 57 percent. Cloudiness, temperature, and humidity control the net longwave radiation LW↑↓. The sensible heat flux Q_s amounts to a heat input to the glacier. The resultant heat gain allows large melting rates, but a substantial portion of the heat input is spent on the energetically more expensive sublimation. In the mass budget scheme Fig. 7, solid precipitation is available from gauge measurements. Melting and sublimation rates are consistent with the energy budget scheme Fig. 6, as well

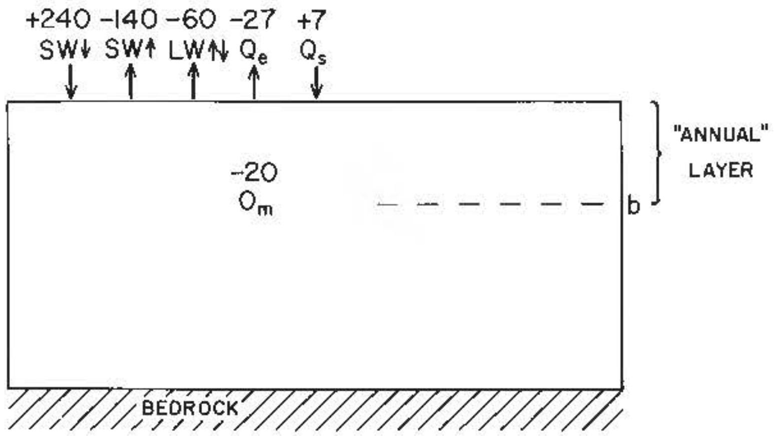

Fig. 6. Scheme of average annual heat budget of Lewis Glacier.
SW↓ downward directed shortwave radiation
SW↑ upward directed shortwave radiation
LW↑↓ net longwave radiation
Q_e latent heat flux at glacier-air interface
Q_s sensible heat flux at glacier-air interface
Q_m heat used in melting throughout a column except at base
(A glacier average albedo of 57 percent, and cloudiness of about 6 tenths are adopted. Numbers are in $W \cdot m^{-2}$.)

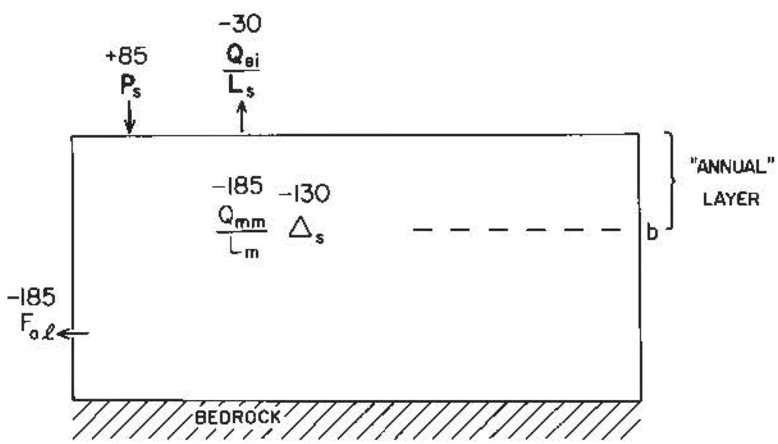

Fig. 7. Scheme of average annual mass budget of Lewis Glacier, commensurate with heat budget illustrated in Fig. 6.
P_s solid precipitation
Q_{ei}/L_s sublimation
Q_{ei}/L_e melting
Δ_s net balance
F_0 water discharge
(Numbers are in cm of liquid water equivalent or g $H_2O \cdot cm^{-2}$ = 10 $kg \cdot m^{-2}$)
($F_{o\ell}$ = 1.850 $kg \cdot m^{-2}$ corresponds to 17 $\ell \cdot s^{-1}$.)

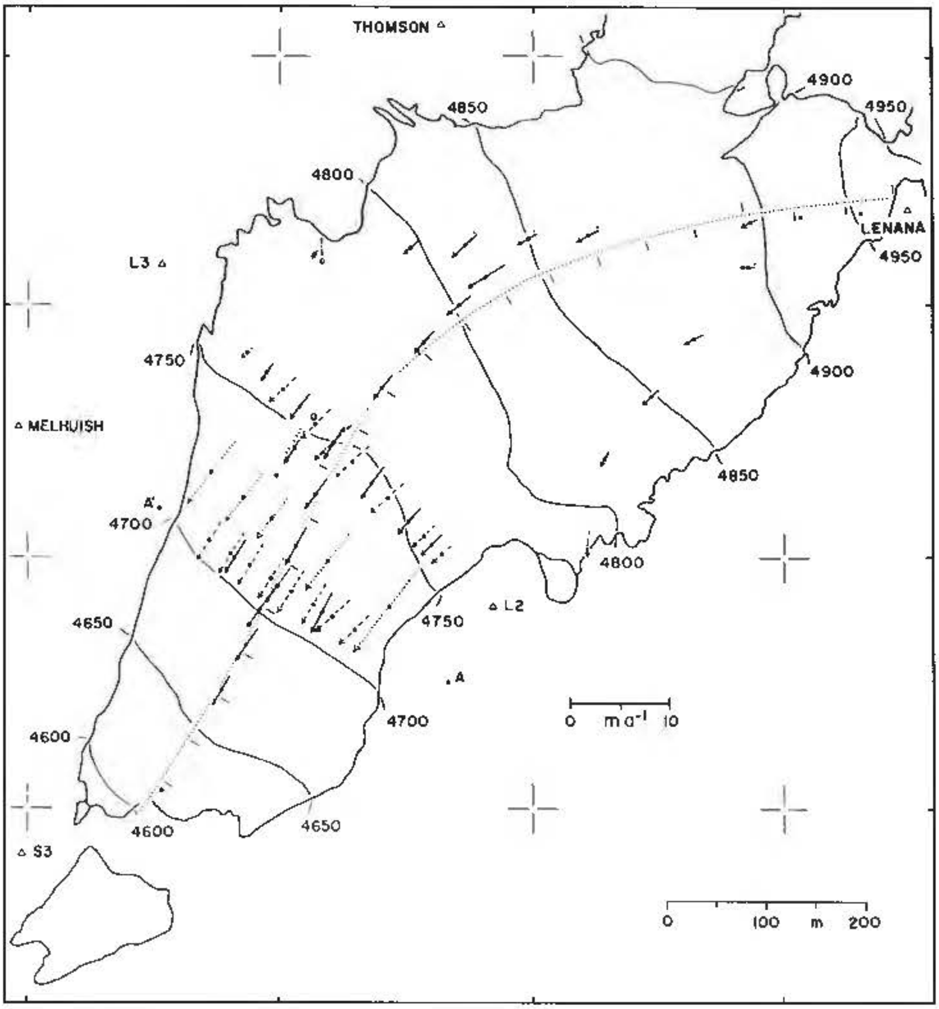

Fig. 8. Surface velocities measured at various epochs during the 20th century. Dots indicate the location of targets, and arrows the direction and magnitude of motion. Velocity scale in $m \cdot a^{-1}$ is ten times the horizontal scale in m (i.e. $10\ m \cdot a^{-1}$ would be represented as a 100 m arrow). Dotted, dash-dotted, broken, and solid arrows refer to measurements in 1934 (TROLL und WIEN, 1949), in 1957 (CHARNLEY, 1959), in 1973–74, and during 1978–80, respectively. Solid arrows with small dot at right-hand side of tail denote measurements limited to January-February 1978. Open circle and dot indicate the 1958 and 1974 locations of a meteorological shelter and its remnants. The corresponding motion vector, shown by solid line shaft with perpendicular short barbs to the right, is plotted at the midpoint of this distance. The dotted line represents the modeled central line, with tick marks at 50 m intervals indicating longitudinal distance. 1978 height contours in m are entered as thin solid lines. Scale 1 : 7 500. (From HASTENRATH and KRUSS, 1982.)

as with the water discharge measured at the exit of Lewis Tarn. Losses through melting and sublimation far exceed the mass gain by solid precipitation. The deficit is manifested in the continuing mass decrease of the glacier, as borne out by the repeated aero-photogrammetric mappings and the net balance stake network discussed above.

Repeated surveys of the aforementioned stakes yield estimates of surface ice flow velocity. Values obtained for the 1978–80 interval are plotted in the map Fig. 8, along with measurements for various earlier epochs. The observations from various epochs are consistent in both spatial pattern and general magnitude, although a gradual slowdown of surface flow is indicated. The secular variation of ice flow velocity along the central line is illustrated in Fig. 9, which combines field observations with the results of

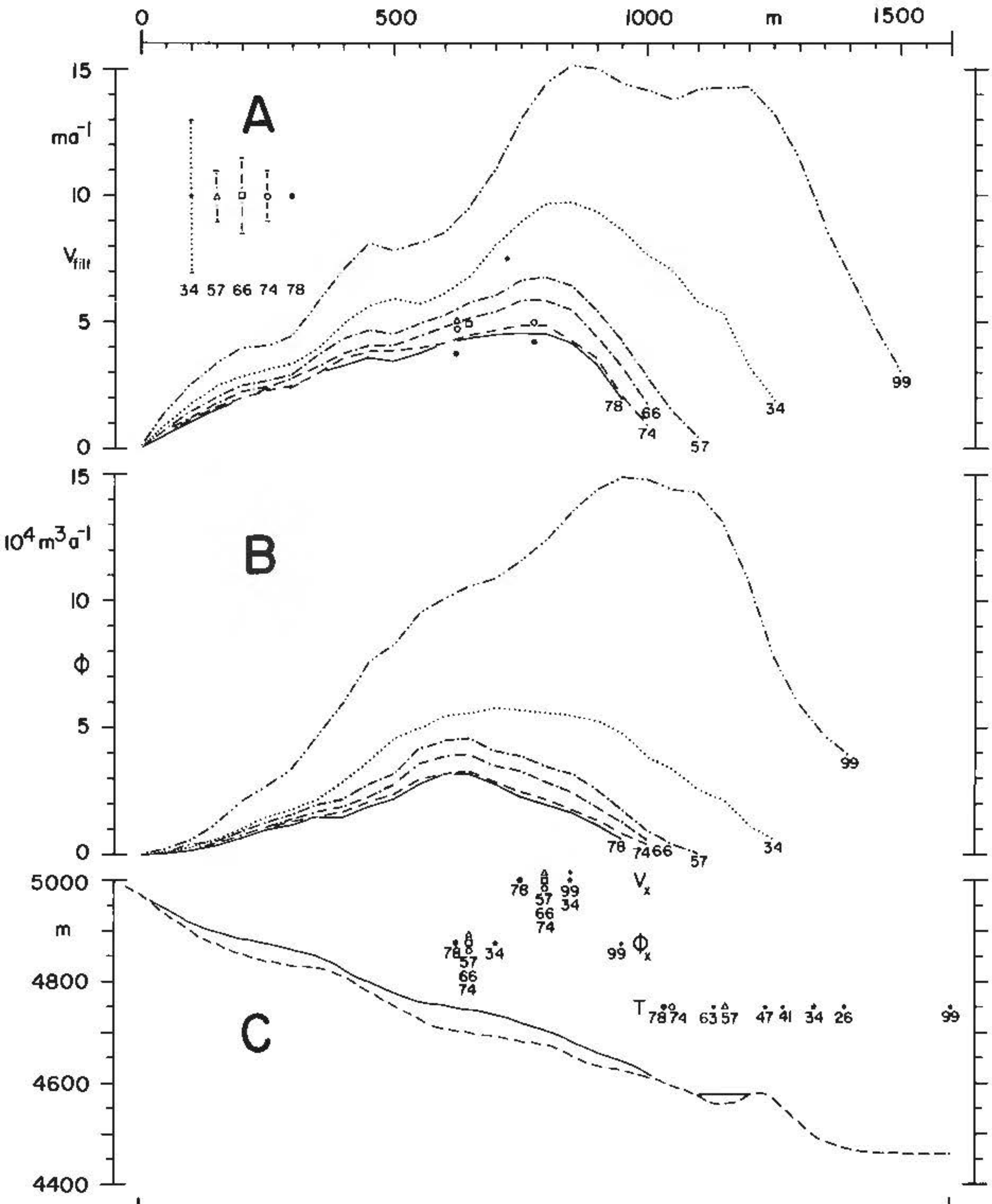

Fig. 9. Secular variation of surface velocity and mass flux along central line. Modeled longitudinal profiles are shown of filtered velocity V_{filt}, and filtered mass flux ϕ, for various epochs as follows: 1899 (double dot-dashed), 1934 (dotted), 1957 (dash-dotted), 1966 (double dash-dotted), 1974 (broken), 1978 (solid line). In the graph of V_{filt}, observed velocities are entered as asterisk for 1934, triangle for 1957, square for 1958 to 1974 mean displacement rate (labelled 1966), open circle for 1974, and large dot for 1978–80 (labelled 1978). Vertical lines to the left indicate the estimated uncertainties of measurements. In the bottom part, bedrock topography is depicted as broken, and tarn and 1978 ice surface topography by solid line. Modeled maxima of surface velocity V_x and mass flux ϕ_x are denoted by the aforementioned symbols for the 1899, 1934, 1957, 1966, 1974, and 1978 epochs. The observed terminus positions T are furthermore indicated by small dots for the additional epochs 1926, 1941, 1947, and 1963. (From HASTENRATH and KRUSS, 1982.)

numerical modelling. Figure 9 shows a monotonic decrease of velocity and a gradual displacement of the velocity maximum glacier upward, since the beginning of the century.

The reconstruction of terminus positions for various epochs since the end of the 19th century along with study of recent morphology, mass and heat budget, and kinematics, serve as a basis for the quantitative reconstruction of climate variations through numerical modelling (KRUSS, 1981, 1983, 1984). On this basis the following major forcings emerge as causes of the continued glacier recession since the 19th century: (i) a precipitation decrease of the order of 150 mm a^{-1}, concomitant with a small decrease of cloudiness and surface albedo, during the last two decades of the 19th century; and (ii) a temperature increase of a few tenths of °C during the 20th century, concentrated in the 1920's. The drastic precipitation decrease in the latter part of the last century is also reflected in a drastic drop of the water level of East African lakes.

The climatic forcings responsible for the conspicuous and well documented glacier response are as a rule too small to be ascertained by conventional sensing techniques. The Lewis Glacier study thus points the way for the quantitative assessment of climate variations from glacier observations. The Lewis Glacier field program is now being continued in the mode of long-term monitoring of net balance, precipitation, and kinematics.

4. Ice Cores

Extraordinary climatic records have been reconstructed from ice cores in the polar regions. Indicators evaluated include microparticle concentration, total beta radioactivity, and oxygen isotope ratios. Application of climatic ice core techniques to the tropics is novel. In the tropics, particular difficulties must be considered, that are not encountered in the well-established polar glaciology. Aside from logistic considerations, the following criteria guide the choice of an ice body for coring and paleoclimatic studies in the tropics:

(i) the ice cap should be at very high elevations and thus low temperature to preclude significant melting and percolation;
(ii) for an extended ice plateau with gentle topography, the effects of flow dynamics on stratigraphy are summarized;
(iii) location in the outer tropics allows same seasonality in the stratigraphy;
(iv) the thickness and net balance are limiting factors for the length of the climatic record to be expected.

These conditions are ideally met for the Quelccaya Ice Cap. This vast ice plateau in the Eastern Andes of Peru (Fig. 10) is the object of a multi-annual field program conducted since 1974. The central objective is the retrieval of ice cores for microparticle and isotope analysis and climate reconstruction. The study of the present climate, heat and mass budget is an important component of the project, inasmuch as this should put paleoclimatic interpretations on a firm footing. Reference is made to the various publications stemming from this project (MERCER et al., 1975; THOMPSON and DANSGAARD, 1975; HASTENRATH, 1978; THOMPSON et al., 1979; HASTENRATH and KOCI, 1981).

The ice stratigraphy at Quelccaya is characterized by a conspicuous annual layering, the June/July dry season being marked by an ice horizon and concentration of microparticles and total beta radioactivity. The annual net balance is obtained from the mass contained between annual horizons. On the Quelccaya summit plateau net balance is essentially equal to precipitation, because virtually no energy is available for ablation. This is a direct consequence of the large surface albedo (HASTENRATH, 1978). The few years' net balance series obtained for the Quelccaya summit compares well with precipitation at stations outside the ice cap. Thus, the microparticle and beta profiles offer a good prospect for establishing a net balance or precipitation chronology for Quelccaya.

Regarding the oxygen isotope ratios, the Quelccaya cores offer a surprise when compared to the classical records from the Arctic and Antarctic, where they were interpreted in terms of a temperature

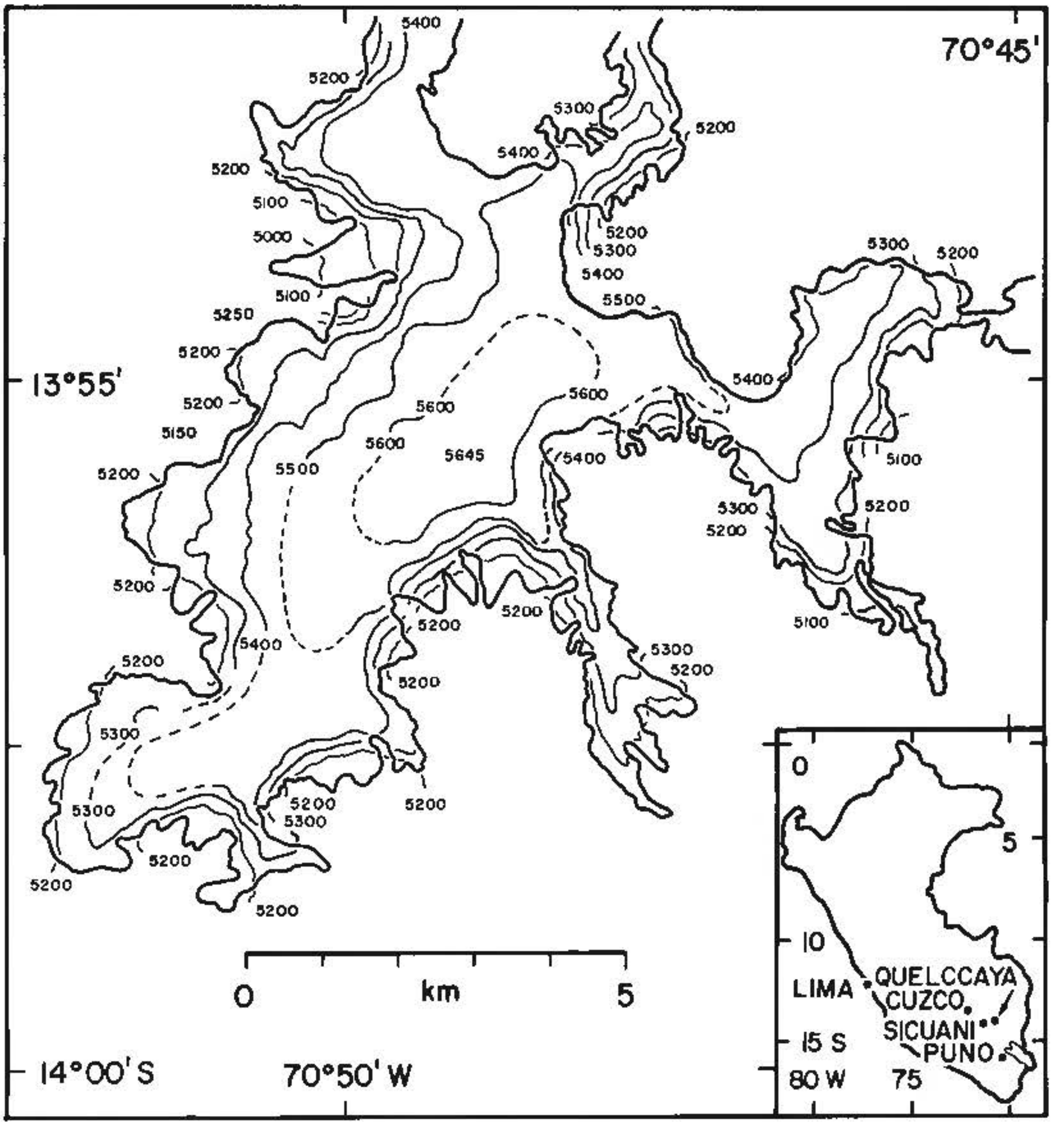

Fig. 10. Map of Quelccaya Ice Cap and orientation map of Peru.

history. Thus at Quelccaya the annual range of δ-values is as large as that in the polar regions from the last ice age to the present; and the least negative values occur at the coldest time of year – again contrary to the polar experience. The results indicate the need for a revision of isotope "thermometry" for application in the tropics.

In brief, the Quelccaya cores show the potential for a net balance and precipitation chronology based on the identification of annual horizons from ice layers, microparticle concentration, and total beta radioactivity. A temperature history similar to the polar regions is unlikely, but this may be of subordinate importance for the tropics. The theoretical foundation still needs to be created for the evaluation of oxygen isotope ratios in terms of climate. A drilling to bedrock as intended for the near future is expected to yield a record of about half a millenium or more for the Eastern Peruvian Andes.

Elsewhere in the tropics, the prospects for climatic ice core studies appear more limited, as melting and percolation at lower elevations contaminate the ice profile. These complications were also recognized at Lewis Glacier on Mount Kenya (Thompson and Hastenrath, 1981). The summit ice fields of Kilimanjaro appear most nearly suitable for climatic ice core studies in East Africa.

5. Concluding Remarks

In all three glaciated high mountain regions under the Equator, ice has been receding monotonically since the 19th century. The onset of the glacier recession differs between the three regions, being around the middle of the 1800's in the Ecuadorian Andes and around 1880 in East Africa. The inferred onset of retreat of the New Guinea glaciers is around the mid 1800's (ALLISON and KRUSS, 1977). In all three regions the ice retreat is continuing to the present.

While the glacier retreat is drastic and generally well observed, the climatic changes that caused it are not known. Two independent approaches are being developed to quantitatively infer a climate history from glacier observations. The application of ice core techniques is novel for the tropics, but offers good prospects for a few locations at very high elevations. The numerical simulation of the causality chain climate – net balance – ice dynamcis terminus translates the observed glacier response into the unknown climatic forcing. A detailed terminus history is essential. Inasmuch as the climatic forcings responsible for the conspicuous and well documented glacier response are as a rule too small to be ascertained from conventional sensing techniques, this methodology merits attention for long-term environmental monitoring.

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Discussion to the Paper Hastenrath

Prof. Dr. A. Kessler:

How much is the annual mean of the net allwave radiation (Gesamtstrahlungsbilanz)?

Prof. Dr. S. Hastenrath:

1. For the highest part of the Quelccaya ice plateau in South Peru SWLW↑↓ is about zero.
2. For the Lewis Glacier of Mount Kenya the annual mean of SWLW↑↓ is about 40 Wm^{-2}.

Miss J. M. Kenworthy M.A.:

Have you found it possible, from the model you have developed, to estimate how long it would take for the Lewis Glacier to disappear, given that the present range of climatic conditions continue?

Prof. Dr. S. Hastenrath:

We have modelled the past history of the Lewis Glacier, and have predicted velocity (and men's) changes for the *near* future only. From the smaller and higher residual glacier, man economy becomes increasingly more favourable. Our monitoring shows a decrease in volume of about 12 percent over the four-year-interval 1978–82. Accordingly I am looking foreward to a walk on the ice of Lewis Glacier at the beginning of the next millenium.

Prof. Dr. W. Weischet:

1. How high is the mean accumulation of snow-cover on the Quelccaya ice-plateau?
2. With all reservations concerning the transferability of results from Peru to East-Africa, the deeper layers of the Quelccaya-ice could give direct hints at the drastic diminuation of annual precipitation during the last two decades of the 19th century, which till now had to be calculated from the lowering of the lake-level.

Prof. Dr. S. Hastenrath:

1. About 3 m of snow.
2. No. The drastic decline of precipitation from 1880 to 1900 concerns East-Africa in particular, and possibly the east coasts of the lower latitudes.
   Reference: KRAUS, E. B. (1955): Secular changes of east-coast rainfall regimes. Quat. J. Roy. Met. Soc., Vol. 81, No. 349, 430–439.

Dra. M. L. Salgado-Labouriau:

The retreat of glaciers that you have observed in the tropical zone occurs also in higher latitudes, including arctic and antarctic ice?

Prof. Dr. S. Hastenrath:

During much of this century the recession of tropical glaciers was paralleled by ice retreat in the mid-latitudes. However, since the 1970's there are indications for glacier advance in the mid-latitudes (Alps, Himalayas), while the glaciers of East-Africa and South America continue to retreat. For New Guinea ice recession is indicated at least for the early 1970's, the most recent observations available for that area.

Dr. H. Kienholz:

You have shown the velocity-distribution for the surface of the Lewis Glacier. What about the vertical velocity-distribution?

Prof. Dr. S. Hastenrath:

The theory of glacier dynamics makes it possible to calculate the velocity of flow within the interior of a glacier from observations at the surface. The velocity rises from the middle of a glacier to its sides, but declines approaching its ground. The vertical component is directed downward in the upper glacier, upward in the glacier-tongue. For the Lewis Glacier the internal velocity-distribution is shown in a longitudinal section (compare: KRUSS and HASTENRATH, 1983).

M. D. Rafiqpoor:

1. In his Book "Geologie von Ecuador" Mr. SAUER reports moraine-levels at 800 m above sea-level and explains them tectonically. Do you share his opinion and do you know similar examples from Peru and Bolivia?
   Reference: SAUER, W. (1971): Geologie von Ecuador. Beiträge zur regionalen Geologie der Erde, Bd. 11. Berlin/Stuttgart.
2. How do you explain the asymmetric construction of the glacier-tongues (lower on the eastern slope, higher on the western slope) at the Ecuadorian vulcanoes?

Prof. Dr. S. Hastenrath:

1. SAUER's interpretations are entirely based on stratigraphy, but not on surface-morphology, and his observations are confined to lower regions. He doesn't attempt to compare his scheme with the older-one of MEYER. Revision is indispensable!
2. Humidity was supplied from the Amazone-Region.

Erdwissenschaftliche Forschung, Bd. XVIII, 249–259
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Pleistocene and Present Day Glaciations in the High Mountains of New Guinea

Ernst Löffler

With 6 Figures

Summary

The Pleistocene glacial history of New Guinea may date back to about 700 000 ± 100 000 yrs. BP when lava erupted under ice on Mt. Giluwe. At 290 000–300 000 yrs. BP Mt Giluwe was again covered by ice and this glacial event may have been synchronous with glaciations in other parts of the world.

The onset of the last glaciation is not known but the maximum extent of glaciation was reached between 18 500 and 16 000 yrs. BP when nearly 2000 km² were covered by ice and the snowline lay at approximately 3600 m with only minor variations due to local climatic conditions or as in one case due to tectonic uplift.

From 15 000 yrs. BP the glaciers retreated rather rapidly to completely disappear by about 9000 yrs. BP. These dates are consistent over the entire island and also with evidence of climatic change in Australia where conditions changed from arid to less arid.

The reconstruction of the climate during the last glaciation is complicated by conflicting geomorphological and palynological evidence. While the extent of the glaciation indicates a lowering of the snowline by some 1000 m corresponding to a temperature depression in the order of 5–6 °C the depression of the forest/grassland boundary seems to have been nearly twice as much. It is argued that this extraordinarily large depression in the forest boundary could be due to local conditions and not to a general temperature depression of 10 °C.

From about 5000 yrs. BP some glaciers in the highest areas formed again and survived to the present day where some 7–8 km² are covered by glacial ice. The ice retreat in recent times is broadly synchronous with world wide glacier fluctuations.

Although neither Pleistocene nor present day glaciations are of any direct consequence to man in New Guinea the glaciation has created topographic and resulting edaphic and ecological conditions for the occurrence of valley floor grasslands well below the timber line and through burning man has extended these grasslands to cover large areas of formerly forested terrain.

1. Introduction

Although the presence of glacial ice on the island of New Guinea has been known since the 17th century when the ice capped summit of Mt. Carstensz was sighted by the great Dutch explorer, research into the glacial history started relatively late. Early this century a British exploring party reached the ice of the Carstensz glacier and in 1936 a Dutch expedition undertook the first scientific work on glacial geomorphology in the Carstensz Mts. DOZY, the geologist of the expedition, mapped the extent of the present and Pleistocene glaciation and claimed that valley glaciers descended to surprisingly low altitudes, in one case to 2000 m (DOZY, 1938). Recent glaciers were marked by cairns.

Despite of several other mountaineering expeditions it was not until the 1970's that a second scientific expedition visited the area and provided more detailed information not only about the Pleistocene and recent glaciations but also the associated vegetation changes (HOPE et al., 1976). Because of the great difficulties of access and for political reasons no further work has been possible.

In Papua New Guinea, the eastern part of the island, formerly under Australian administration and until the First World War partly under German rule, no work was done until the sixties when members of Australian Universities and Research Institutions such as CSIRO worked in the area. The time between 1965 and 1975 undoubtedly was the great time of research in Papua New Guinea as this work was generously supported by the Australian Administration and Universities.

The following account represents a review of the state of knowledge on Pleistocene and recent glaciations and some ideas on how Pleistocene glacial features have influenced man's access to the mountain areas and how man has modified the high mountain vegetation.

2. Pre-Würm Glaciations

Evidence for glaciations pre-dating the last are always difficult to find in areas where glaciation was restricted to cirque and valley glaciations, and New Guinea is no exception. So far only two areas have been discovered where there is clear evidence for older glaciations. In West Irian weathered moraine material was found outside the limits of the last glaciation by DOW (1968) and by HOPE and PETERSON (1975) on the Kemabu Plateau north of the Jaya Mountains, but no dating was possible.

My own work which was entirely restricted to the eastern part of the island has shown that on Mt. Giluwe eruptions of lava were intermittent with certainly one, possibly two periods of ice cover. Dating of lavas associated with palagonitic breccias has shown that at 290000 yrs. BP much of the present summit area was covered by ice. This data is supported by another finding which shows moraine material sandwiched between two lava flows the one underlying the moraine being 319000 years old, the one overlying the moraine having an age of 290000 yrs. BP (LÖFFLER, 1976; LÖFFLER et al., 1980).

A second site with palagonitic breccia was found near the main peak but dating of the associated lavas has been poor and given a spread of ages between 750000 and 880000 years.

Therefore there can be no doubt that the New Guinea Mountains experienced earlier glaciations relatively early in the Pleistocene and consequently must have reached altitudes similar to the present ones. The 290000 years date is synchronous with dates from other parts of the world such as Hawaii, Kilimanjaro, New Zealand and also agrees well with the oxygen isotope dates of SHACKLETON and OPDYKE (1973), and we can assume that the glaciation represents the third last glaciation.

3. Last Glaciation

No evidence for the second last glaciation has been found and it is not known how much the earlier glaciations had modified the mountain terrain, however the traces of the last glaciation are exceptionally well preserved and obvious even to the casual observer. Most striking is the sharp contrast in valley cross sections between the V shaped fluvially formed valleys below and the broad U shaped valleys above the limits of glaciation. Terminal and lateral moraines are up to 100 m, in the Carstensz area up to 200 m high and are exceptionally well preserved, a feature typical for tropical mountains and probably due to the diurnal regime of melting with relatively constant rates of discharge even during times of glacial retreat and the relatively minor effect of periglacial solifluction.

The total area covered by ice amounted to some 2000 km^2 of which nearly three quarters are situated in Irian Jaya (Fig. 1). In Irian Jaya there existed a nearly continuous ice field from Mts. Idenburg and Carstensz (Mt. Jaya) in the west to the Star Mountains (Jayawijaya Ranges) in the east (DOZY, 1938; VERSTAPPEN, 1964; HOPE and PETERSON, 1975). Most extensive was the glaciation in the Carstensz area where huge moraines, up to 200 m high were deposited on the Kemabu Plateau to the north at 3400 m altitude while on the southern fall the moraines descended down as far as 2300 m as already claimed by DOZY.

The Pleistocene snowline was at 3600–3700 m. This was slightly higher than on the mountains further east and may be due to the "continental" position of the Carstensz mountains during the low sea level stand when the Torres Strait and Arafura Sea were dry land.

While the western New Guinea Mountains contained the largest and most spectacular expressions of glaciation the eastern New Guinea Mountains being more accessible are better known and more intensi-

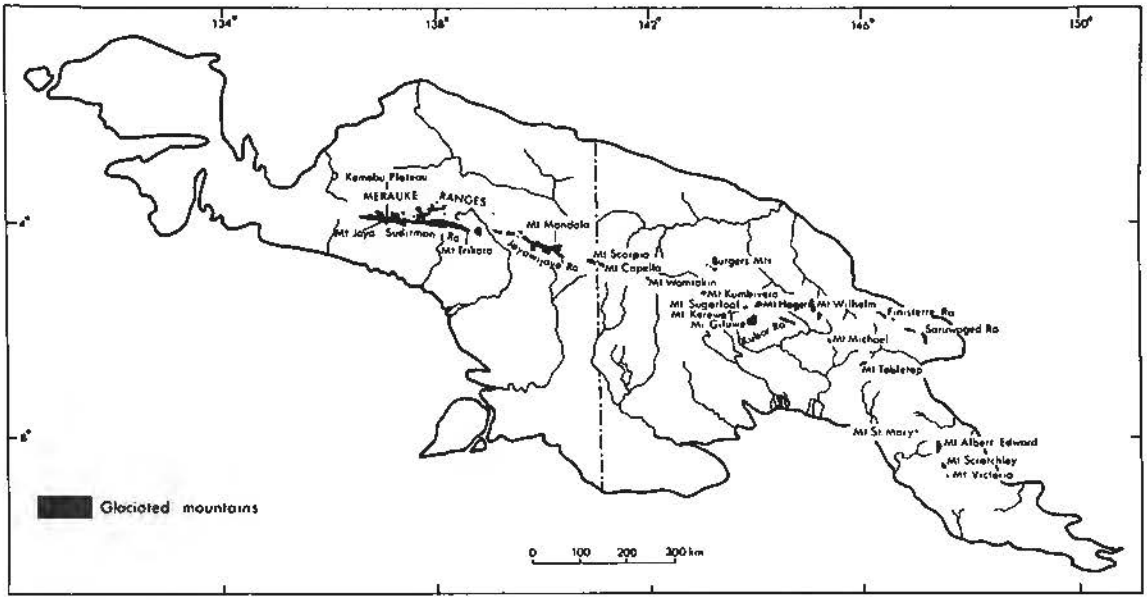

Fig. 1. Generalized map of the distribution of Pleistocene glaciers in New Guinea.

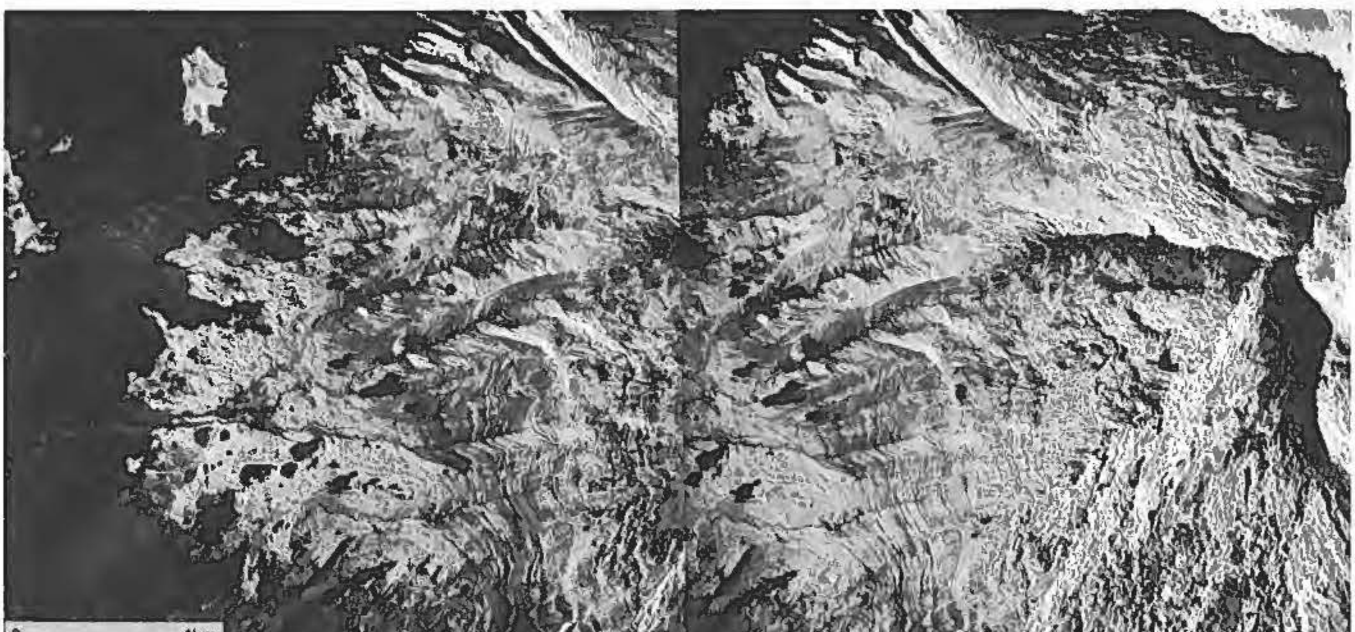

Fig. 2. Stereopair of western side of Mt. Giluwe, a Pleistocene volcano that was covered by an extensive ice cap during the last glaciation. The broad moraine of the main glaciation and the numerous recessional moraines are exceptionally well preserved. Some of the small recessional moraines overtop the moraine of the main glaciation.

vely studied. The two most interesting and best researched mountains are Mt. Wilhelm and Mt. Giluwe with 4509 and 4368 m the higest and second highest mountains in East New Guinea (Fig. 1).

Mt. Giluwe has already been mentioned as the site where evidence for older glaciations has been found. It is also the mountain most extensively glaciated with an ice cap type of glaciation covering some 190 km^2. Terminal moraines are again well preserved and form a nearly continuous belt around the summit area of the broad dome shaped volcano (Fig. 2) (LÖFFLER, 1972). They extend down to an altitude of 3100–3200 m with several tongues descending further down deeply incised valleys to about 2750 m. The snow line during the maximum extent was at 3550 m.

While Mt. Giluwe experienced an ice cap glaciation with a more or less continuous thick ice cap from which only short valley glaciers extended further down, Mt. Wilhelm being a much more dissected mountain was covered by an alpine type glaciation with long and thick valley glaciers emerging from deeply excavated cirques which today are filled with lakes and form a spectacular mountain scenery. Although some 200 m higher than Giluwe the area available for snow accumulation was smaller and the ice covered area only about half that of Mt. Giluwe.

There is a certain asymmetry in the distribution of cirques as already pointed out by REINER (1960) who undertook the first survey of the glacial morphology of the mountain. However this asymmetry is not restricted to the cirque distribution but is also apparent in slope profiles with smoother and gentler east-facing slopes and more irregular and steeper west facing slopes (Fig. 3).

This asymmetry is similar even though not as pronounced as the north-south asymmetry of mountains in subtropical latitudes where the difference in the sun insolation favours glacial action on north facing slopes and periglacial solifluction on south facing slopes. A similar explanation can be sought for the asymmetry of Mt. Wilhelm however the difference in sun insolation is caused by the daily changes in cloud cover whereby easterly facing slopes receive more insolation than westerly facing slopes due to the rapidly increasing cloud cover during the day, a phenomena already noticed by TROLL.

Fig. 3. Mt. Wilhelm, with asymmetric summit ridge. Smooth slope is facing east, irregular slope is facing west.

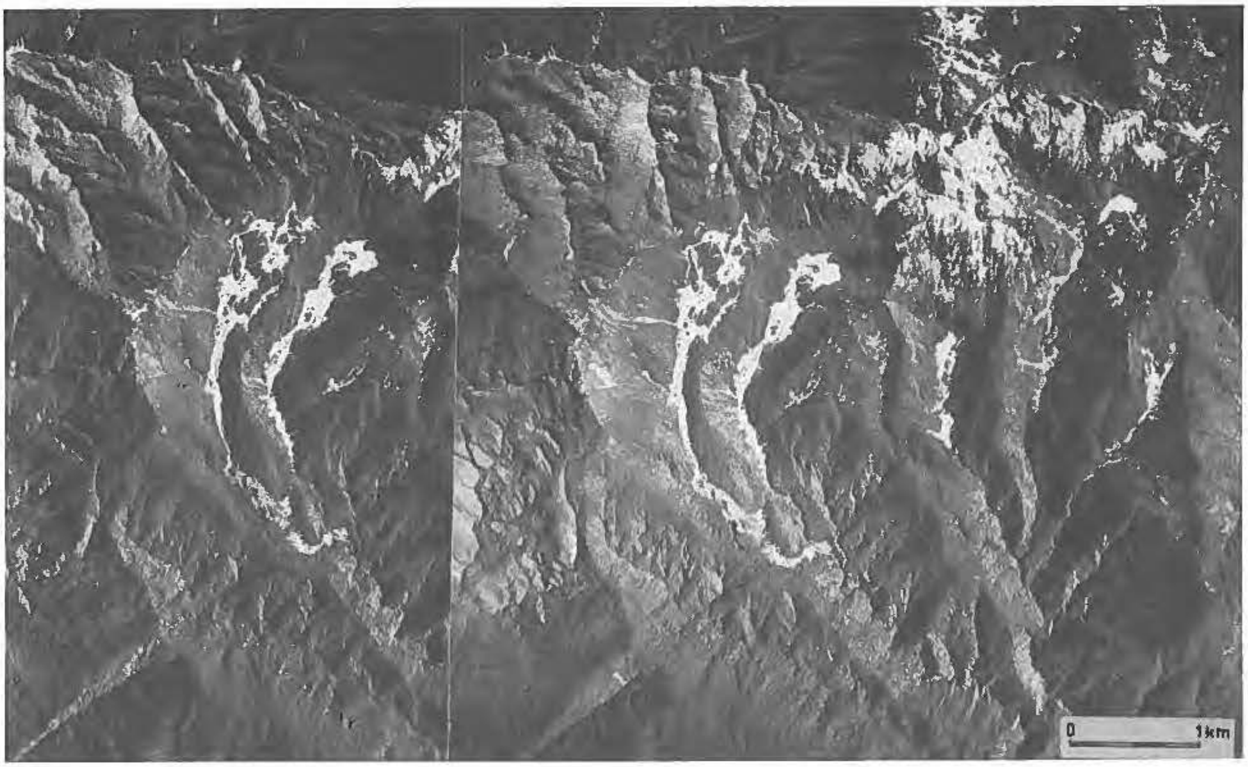

Fig. 4. Stereopair of Mt. Digini, Kubor Range. The contrast between the formerly glaciated and non glaciated terrain is particularly obvious in the valley cross sections. The contrast is further accentuated by the grassland covering the floors of the glaciated valleys.

One difficulty with this explanation for New Guinea is that this kind of asymmetry is only present on Mt. Wilhelm. Two factors could account for this. The asymmetry can only develop where a deeply dissected terrain is present and secondly no prominent rock structures such as bedding in limestone, layering in lavas or foliation in schist must be present otherwise they override the climatic geomorphic factors.

It is interesting to note that a certain asymmetry in the distribution of plants has been observed by SMITH (1977) with altitudinal limits being some 200 m higher on east facing slopes.

Apart from the two mountains there are several other isolated mountain areas that experienced glacial ice cover (LÖFFLER, 1972). The largest of these is Mt. Albert Edward, an extensive summit surface in the eastern part of the central ranges. Despite of the modest summit height of 3980 m the plateau area was extensively glaciated with some 90 km^2 being under ice. The oldest deglaciation date is 12 000 yrs. BP.

The other relatively large area of glaciation was on the Saruwaged Mountains on the northern coastal ranges where a limestone plateau was covered by an ice cap measuring some 80 km^2. Surprisingly the snow line on this mountain which at present is the wettest area is some 100 to 200 m higher than elsewhere in New Guinea and the reason for this must be sought in the extraordinarily high rates of uplift of these mountains. This is manifested in a series of raised coral terraces along the northern coast (CHAPPELL, 1974).

The ice cover on all other mountains of New Guinea was considerably smaller mostly extending only over a few square km. However with great regularity all mountains extending into the Pleistocene snowline which was at 3600 m ± 50 were glaciated and the contrast between the glaciated and non-glaciated terrain is always pronounced (Fig. 4). This contrast is further accentuated by a contrast in vegetation. The U shaped glacial valley floors are always covered with grassland while the V shaped valleys below are always forest covered. This close correlation between former ice cover and present day extent of grassland is not simply the result of climatically controlled altitudinal zonation since the lower limits of these grasslands vary considerably with the extent of the glaciers.

The presence of grasslands in these glacial valleys is probably primarily due to the high degree of wetness. Frost may be an additional factor but the sharp boundary between grassland and forest at the change of valley profile indicates that cold air drainage is not the main factor since it would also affect the V shaped valleys at least at their upper margin where they meet the U shaped valley section. The occurrence of these valley floor grasslands well below the natural timber line has undoubtedly permitted easier access to these mountains for primitive man and through burning and felling he has extended these grasslands from the valley floors to the adjacent slopes. Comparison between mountains with relatively easy access and close to populated areas and those of greater remoteness (Fig. 4) shows that man induced extension of the grasslands is much more advanced on the former (LÖFFLER, 1979).

The reconstruction of the climate during the last glaciation is complicated by conflicting geomorphological and palynological evidence (WALKER and FLENLEY, 1979; LÖFFLER, 1980). The Pleistocene snowline was at 3600 m ± 50 and the present snowline is some 1000 to 1100 m higher indicating a Pleistocene snowline depression of this magnitude. This would correspond to a temperature depression of 5–6 °C assuming precipitation was not drastically different to the present. There is no evidence for such a difference in precipitation at least as far as the mountain areas are concerned and the low snowline itself would not be explicable under low precipitation rates.

Palynological evidence from some sites especially from Sirunki (WALKER and FLENLEY, 1979; FLENLEY, 1984) however suggest that the temperature depression was of the order of 10 °C calculated from a depression of the timber line of over 1500 m.

My own work in the Lake Trist area, however, shows that there was no dramatic change in vegetation around a small lake basin at 2000 m altitude. Although the pollen data do not permit such a fine resolution as the Sirunki data they indicate that during the last 32 000 years the vegetation around the lake was dominated by *Nothofagus* forest. There is some change in sedimentation from strongly organic to less organic, and there is also some change in the pollen spectrum with an increase in pollen from aquatic plants up the sequence, reflecting a change in the hydrological regime of the small karst basin. This change may have been caused by a change in precipitation, however the continued presence of *Nothofagus* montane forest around the small basin indicates continuously high rates of precipitation. The total absence of pollen of "alpine" and "subalpine" plants, however, clearly shows that in this area the altitudinal vegetation zones were not depressed by the same amount as at Sirunki. The exceptionally large depression of the forest/grassland boundary at Sirunki may reflect the basin position of Sirunki where excessive wetness and frost may have prevented forest growth. Similar basins exist today some 1000 m below the timber line as for instance the Neon Basin below Mt. Albert Edward (PAIJMANS and LÖFFLER, 1972).

4. Deglaciation

Although there is rough agreement in the dates of deglaciation across New Guinea there is considerable variation in detail.

From about 15 000 yrs. BP the glaciers retreated rather rapidly and by 11 000 yrs. BP most New Guinea mountains were ice free and by 9000 yrs. BP even those that have a present day ice cover. The recession did not proceed continuously but was interrupted by numerous readvances. The number of recessional moraines varies from mountain to mountain as a result of local orographic and climatic conditions. Most numerous are the recessional moraines on the eastern slopes of Mt. Giluwe where over 20 single moraines can be distinguished (Fig. 2). Dates of peat bogs behind these moraines have given minimum dates of 13 050 ± 750 yrs. BP for the second oldest group of moraines, 11 250 ± 550 yrs. BP for the second youngest group and 9980 ± 280 yrs. BP for a peat bog near the main peak at 4160 m. These dates show that by 13 000 yrs. BP the ice had already receeded considerably from its maximum extent and that by 10 000 yrs. BP the mountain was free of ice and no further ice developed. The rate of ice retreat was in the order of 1 m/yr.

The deglaciation dates from Mt. Wilhelm are in good agreement with the Giluwe dates. There are only few recessional moraines present and this may reflect the completely different nature of the glaciers. On Giluwe the broad exposed and probably not very thick ice cap reacted relatively quickly to small climatic changes while valley glaciers on Mt. Wilhelm were thick and partly protected from insolation by steep sided ridges towering above the ice and consequently were much less likely to react to small climatic oszillations. The retreat on Mt. Wilhelm was therefore more uniform reflecting the general change to warmer conditions. According to the palynological work of HOPE (1976) the glaciers retreated rapidly from about 14 000 yrs. BP and by 11 000 yrs. BP most of the mountain massif was free of ice except for a small glacier probably around the main summit above 4000 m. By 9000 yrs. BP the deglaciation was complete. This slight difference between Mt. Wilhelm and Mt. Giluwe is probably due to their difference in summit height and summit morphology.

The only deglaciation date not fitting into the general trend was reported by PETERSON and HOPE (1972) from the Carstensz area where a date of 10 300 yrs. BP was obtained for moraine material at the surprisingly low altitude of 1750 m. The initial interpretation was that this extraordinary glacial advance was caused by sudden influx of moist air following the flooding of the Arafura Sea and Torres Strait during the post glacial rise in sea level. In view of the fact that in the humid tropics precipitation is usually not the limiting factor for glacial development this explanation is unlikely and it has not been upheld by the authors.

Fig. 5. Oblique aerial photograph of the Carstensz glaciers with Carstensz and Meren glaciers in the foreground and the Northwall Firn in the background. (Photograph by Australian Universities Expeditions to Irian Jaya).

Fig. 6. Mt. Wilhelm with periglacial scree at 4350–4450 m. Note the dense cover or tussock grass in the foreground indicating that periglacial activity can not be very efficient even at this altitude.

According to pollen-analytical work of HOPE (1976) the time between 7000 and 5000 yrs. BP was one of higher temperatures than today and all New Guinea mountains were free of ice. Ice redeveloped again after 5000 yrs. BP in the Carstensz Mts. and the other presently glaciated peaks and by 3500 yrs. BP a glacier advanced in the Carstensz area down to 4200 m. There were some further glacier oszillations at 3000–2400 yrs. BP, after 2400 yrs. BP and at 1500–1350 yrs. BP in the same area but the presently non glaciated mountains remained free of ice.

Present day glaciation is restricted to Mt. Carstensz where about 7 km^2 are under ice and to three isolated peaks Mt. Juliane, Mt. Wilhelmina and Idenburg Top (Fig. 5). Glaciers have been retreating rapidly over the last 35 years and the rates measured by PETERSON et al. (1973) are of the order of 33 m/yr. and 16 m/yr. for the two main glacier tongues of Carstensz. Air photo evidence shows that the ice on all other New Guinea mountains has also retreated and in two cases completely disappeared. The ice retreat in New Guinea is therefore broadly synchronous with world wide glacier fluctuations and is probably due to a slight rise in temperature since precipitation does not appear to be a limiting factor for glacier development in this area.

5. Periglacial Processes

The relative geomorphic stability of the high mountains of New Guinea is surprising in view of the generally high rate of processes in the lower altitudinal zones (LÖFFLER, 1977). There are several reasons for this. Most important are the diurnal regime of melting as already mentioned in connection with the well developed moraines, the relative insignificance of periglacial solifluction, and the protective cover of the dense root mat of the upper montane forest or peat layer of high altitude grasslands.

Despite systematic investigations no evidence for periglacial solifluction has been found outside the areas formerly covered by ice, and one must assume that periglacial solifluction did not have a significant erosional impact during and after the glaciation.

This fact, however, is hardly surprising if one studies the present day periglacial processes and their altitudinal distribution. Periglacial solifluction is an important process only above 4350 m (LÖFFLER, 1975), and even here it is only a surficial process affecting a soil horizon of some 10 cm (Fig. 6). With the present day snowline at 4600–4650 m this means that the periglacial altitudinal belt is compressed to a mere 250–300 m and the reason for this must be sought in the exceptionally uniform climate of the New Guinea mountains with a small range of diurnal temperature variations and the virtual absence of any seasonal temperature changes (HNATIUK et al., 1976).

During the Pleistocene the ice caps and glaciers extended well below the climatic snowline especially where larger ice masses were developed. If we assume a similar uniformity in climate and thus a similarly narrow altitudinal belt of periglacial activity then most of the terrain that was climatically suitable for periglacial activity, namely the belt of diurnal frost and thaw, was covered by glacial ice.

Once the ice retreated, the formerly glaciated terrain became subject to periglacial solifluction processes, however, since the temperature rose rather rapidly the period during which this occurred was too short to affect the low lying moraines to any significant degree. Once a vegetation cover had developed surface erosion was reduced even more since both the upper montane forest as well as the dense grass cover with its thick root mat stabilize the slopes.

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Discussion to the Paper Löffler

Dr. C. Schubert

The asymmetry you mentioned on Mt. Wilhelm is very similar to the one found in the Sierra Nevada de Mérida. Here, the western side has a much better-developed glacial complex than the eastern side.

Prof. Dr. E. Löffler:

It is not surprising that the east-west asymmetry is found in other parts of the tropical high mountains for the same reasons as I explained and as in fact already noted by TROLL. However, compared to the marked north-south asymmetry of the subtropical high mountains it will always be a relatively minor feature and it will only develop where prominent rock structures are not interfering.

Prof. Dr. W. Klaer:

1. What is the reason for the moraine of the last glacial period below the field station on Mt. Wilhelm being still so incredibly well preserved, while in the Alps it would correspond more to the type of the 1850-moraine?
2. How did the snowline-depressions of the Pleistocene glacial period effect the lower sections of the mountain?
3. How can the "moraine steps" at Mt. Giluwe be explained?

Prof. Dr. E. Löffler:

1. The excellent preservation of the moraines of the last glacial period is mainly due to two factors. Firstly, to the daily rhythm of melting of the glaciers even in times of their retreat. For the same reason, fluvioglacial sediments are mostly lacking. Secondly, to the small effect of periglacial solifluction, which must be explained by the extreme uniformity of the climate and thus the extremely narrow altitudinal range of the zone of periglacial processes. In addition to this the areas suited for periglacial processes, i.e. the areas with daily freeze-thaw action, were largely covered with ice during the glacial period. A periglacial zone hardly existed during this period. Thus, no indications of older periglacial forms can be found outside the area which was once covered by glaciers. The thick mossy or upper montane forest, which mostly covers the moraines today, also contributes to their good preservation.
2. The snowline-depression of about 1000–1100 m first of all effected a depression of the vegetation belts in lower sections; there is, however, no agreement concerning its extent, as can be learnt from the paper of Dr. FLENLEY. I think that the amount for the grassland depression and the snowline depression is roughly the same while FLENLEY and also WALKER and HOPE report a substantially higher figure based on pollenanalytic results. It is still unknown how this depression effected the lower belts. From the geomorphological point of view, however, it can be stated with some certainty that the depression of altitudinal zones did not result in a considerable change of geomorphological processes.
   This is quite obvious, since even today a differentiation of geomorphological processes according to altitudinal zones does hardly exist, except for the periglacial and glacial zones.
3. I would not use the term "moraine steps". As can be seen from the aerial photograph (and even better from the stereopair, Fig. 2) the small moraines represent low ridges, 0.5–2.0 m high that follow the general shape of the broad plateau area like reversed contour lines bending downwards in valleys and depressions and upwards on ridges and spurs. For this reason alone they can not be related to the structure of the basalts as might seem from the aerial photo at first sight. Their moraine character is also obvious in the field. My explanation for the multitude of moraines on Mt. Giluwe lies in the particular topographic situation of the Mt. Giluwe volcano as compared to the other mountains of New Guinea in particular since these moraines are only present on this mountain. On Mt. Giluwe they occur mainly on the broad and open eastern and western slopes and are

largely lacking in the deeper glacial valleys that extend to the south and north. Therefore I think that the moraines are related to the ice cap situation. We do not know how thick the ice cap was but the glacier depositing the moraine of the main glaciation must have been considerably thicker than the glacier that was responsible for the small moraines. I assume that with the general warming up at the end of the last glacial period the ice cap first lost its thickness without much altitudinal retreat. It then reacted quite sensitively to small climatic oscillations and even managed to overtop the main moraine without causing much erosion. The valley glaciers being much thicker than the ice cap reacted much more slowly to small climatic changes and therefore reflect the general trend to warmer conditions.

Dr. C. Schubert:

Concerning the small moraines within the large end moraine, could they also be explained by rapid glacier retreat with very short stationary periods?

Prof. Dr. E. Löffler:

The small moraines within and partly overtopping the moraine of the main glaciation have intrigued me too and I have mentioned already that their development must be linked with the particular ice cap conditions on the broad western and eastern slopes of the volcano. Your suggestion that the small moraines could be explained by rapid glacier retreat with very short stationary periods does not account for the overtopping of the main moraine and the C^{14} dates indicate that retreat was not all that rapid.

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Late Quaternary Changes of Vegetation and Climate in the Malesian Mountains

John R. Flenley

With 4 Figures and 1 Table

The Malesian floristic region, as defined by GOOD (1947) consists mainly of South-east Asia and New Guinea. We shall be concerned here only with New Guinea, Borneo and Sumatra, since this is where most of the research has been carried out. Malesia differs from the other major equatorial regions, Africa and South America, in consisting of separate islands. During the Pleistocene, however, these would mostly have been amalgamated into two main land masses, the Sunda platform and the Sahul shelf.

Many, but not all, of the mountains of Malesia are volcanic. In New Guinea the mountains rise to over 5000 m. Research has chiefly been carried out on the lower mountains of eastern New Guinea, however. The main interest in New Guinea has been in fluctuations of the altitudinal forest limit. The mountains are generally forested today up to c. 3600 m, except where forest clearance by man has occurred. Above the forest is the "tropicalpine" vegetation, rich in taxa of temperate affinities. This gives way at c. 4500 m to bare ground, and permanent snow occurs above about 4700 m. There are also boundaries within the forest, especially that between the lower montane forests, dominated by Fagaceae, especially species of *Nothofagus*, *Lithocarpus* and *Castanopsis*, and the mixed mountain and subalpine forests, which tend to be dominated by Gymnosperms such as *Papuacedrus*, *Podocarpus*, *Phyllocladus*, *Dacrycarpus* (FLENLEY, 1969; WALKER and FLENLEY, 1979).

The palynological technique for vegetational reconstruction relies heavily on modern pollen rain studies. The pollen spectra collected on the New Guinea mountains (FLENLEY, 1973) suggest a fairly direct relationship between vegetation and modern pollen rain. For example, samples from "beech" *(Nothofagus)* forest are dominated by *Nothofagus* pollen; samples from "oak" forest by *Lithocarpus/Castanopsis* pollen. There is one exception to this; samples from above the forest limit contain significant quantities of forest pollen. They are recognisable, however, by the high values for Gramineae and/or the presence of "alpine" taxa. These include *Astelia*, *Drapetes*, *Oreomyrrhis* and some *Plantago* spp., none of which occur below 3000 m.

Lake Inim, in a tectonic basin at 2550 m, is about 1000 m below the forest limit (FLENLEY, 1972; WALKER and FLENLEY, 1979). It has a large surrounding swamp, but inflow streams are few and small. The surrounding *Nothofagus* forest is being actively cleared for cultivation of sweet potato. The pollen diagram from this site shows dominance by *Nothofagus* during the latter part of the time represented, until very recent forest clearance. The earlier phase represented, however, has high values for Gramineae and *Astelia*, and forest pollen drops to 50%. It is difficult to avoid the conclusion that the forest limit was depressed by at least 1000 m. The end of this phase is between 8000 and 12000 B.P. The inversions in the radiocarbon dates here could result from various causes. One possibility is that a lowering of water level led to erosion and redeposition of sediment at this time.

The nearby Sirunki Swamp, at 2500 m, is a very much larger tectonic basin and has major inflow streams, so that pollen could be derived from a much greater range of altitudes. The site extends beyond the range of C^{14} dating, but the part so far published (WALKER and FLENLEY, 1979) covers the last c. 33000 years. This is a pollen influx diagram (i.e. in grains/cm^2/annum). In the earlier half of this record there is a great abundance of *Astelia* and Gramineae pollen, but there is an interesting peak of forest pollen between 28000 and 25000 B.P. The forest revives between 14000 and 13000 B.P., but has disappeared again by 12 500 B.P. Forest development began again about 9000 B.P. and a closed forest resulted. From 5000 B.P. forest starts to decline, however. This decline is much earlier than at Inim, and is therefore diachronous. It is almost certainly the result of forest clearance by man. The decline in all pollen influx from c. 3000 B.P. is perhaps related to overgrowth of the lake by swamp, reducing inwash of material.

From Draepi at 1900 m we also have evidence of early forest clearance, from at least 5100 B.P. (POWELL et al., 1975).

Analogous results have been obtained from the group of sites on Mt. Wilhelm (HOPE, 1976). At Imbuka bog (3550 m) a replacement of unforested by forested conditions was dated at approximately 9000 B.P. By 8500 B.P. the forest limit had reached even to Brass Tarn at 3910 m, which is above its present level. It declined again about 5000 B.P., perhaps either as a result of climatic change or because of burning by hunting parties. There is no agriculture at this altitude. The tree line never reached the summit bog.

The overall sequence during the last 30 000 years in the New Guinea mountains may thus be summarized as shown in Fig. 1. The forest limit, apart from a brief excursion, was below 2500 m (perhaps around 2200 m) until 14 000 B.P. The chief rise in forest limit occurred about 9000 B.P. It is particularly interesting that there is no evidence for the existence of the mixed-mountain and sub-alpine forests until c. 9000 B.P. It has been suggested that these survived as rare individuals of the constituent taxa around the forest limit during the Pleistocene (WALKER and FLENLEY, 1979). Perhaps the Pleistocene climate was in some way less suitable for them: possibly too dry.

The mountains of Western Malesia are lower, and only from Mt. Kinabalu (4000 m), in Borneo, do we have evidence of glaciation. The summit plateau of this granite mountain is glacially smoothed and there are other glacial features (KOOPMANS and STAUFFER, 1968).

A small pool on the summit plateau is perhaps the result of glacial plucking adjacent to a fault. The basal organic sediment from this pool gave a radiocarbon date of 9186 ± 120 B.P. (FLENLEY and MORLEY,

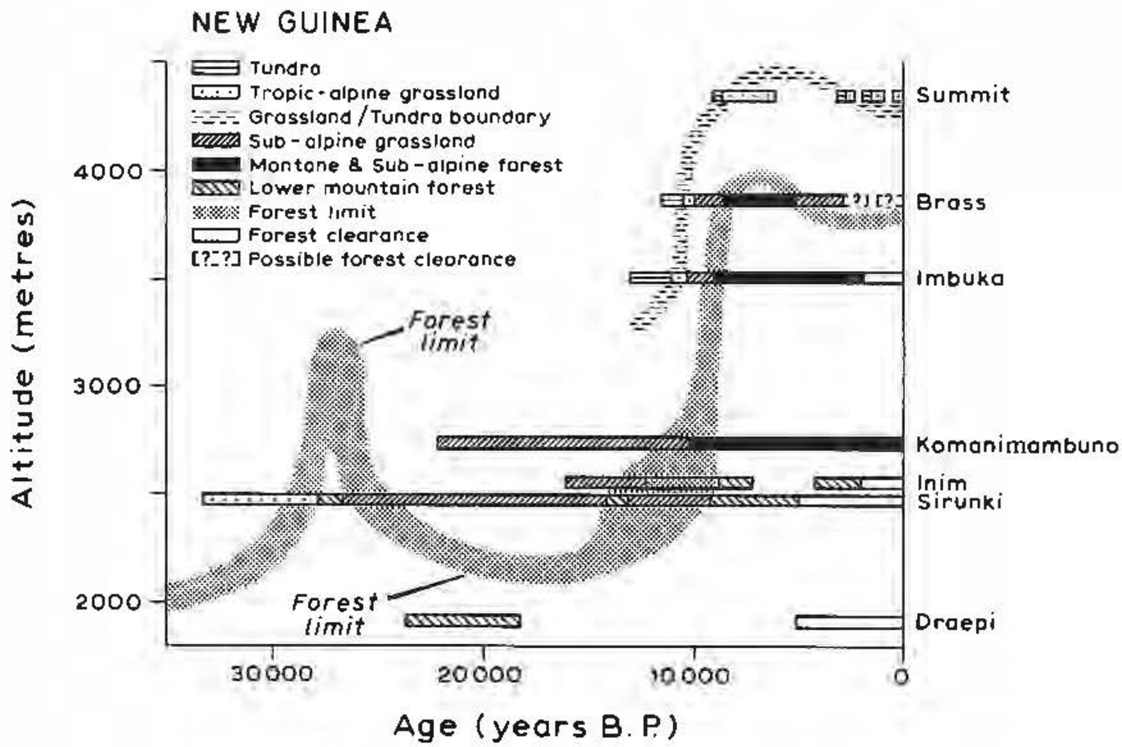

Fig. 1. Summary diagram of Late Quaternary vegetational changes in the New Guinea Highlands (after: FLENLEY, 1979).

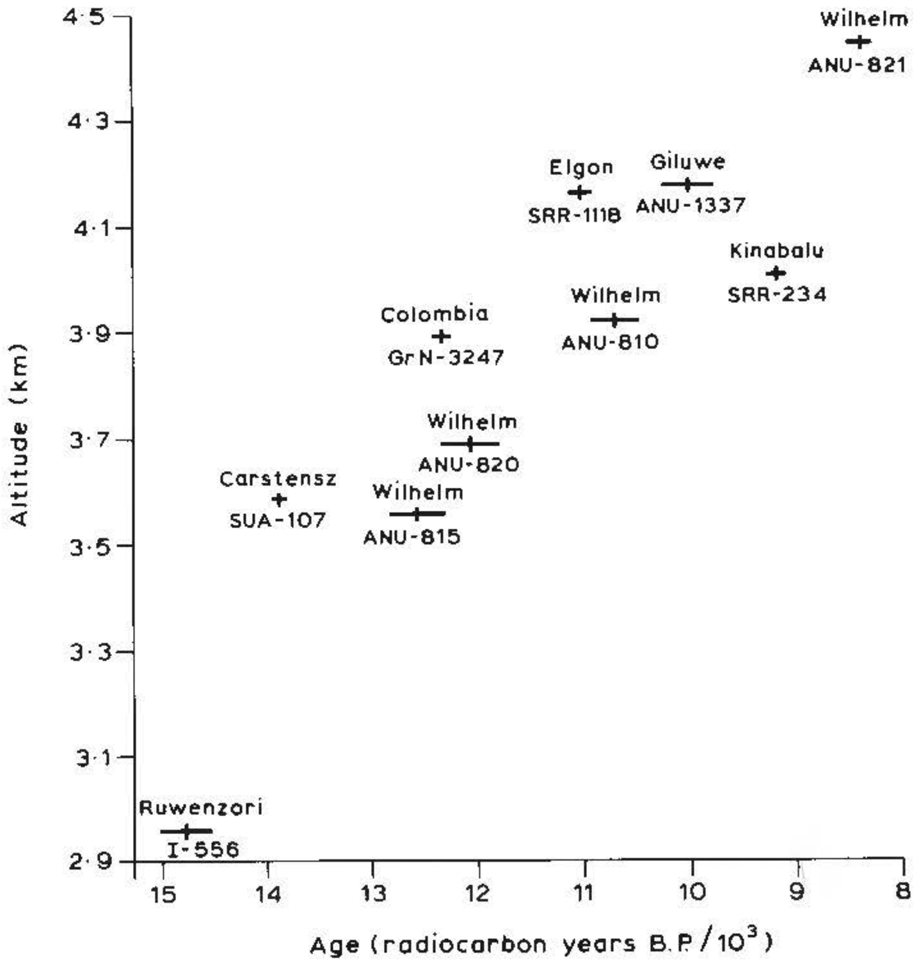

Fig. 2. Minimum ages for deglaciation of some equatorial mountains (after: FLENLEY and MORLEY, 1978).

1978). This provides a minimum age for deglaciation of the plateau. The date is not altogether out of line with some from other tropical mountains at various altitudes (Fig. 2). So far we have no pollen evidence from Borneo, although it seems an appropriate area for study.

The Sumatran mountains form a chain, chiefly volcanic, with a rift valley running longitudinally through it (VAN BEMMELEN, 1949; VERSTAPPEN, 1973). The result is that there are numerous sites suitable for pollen analysis (MORLEY, FLENLEY and KARDIN, 1973). The principal areas studied, by the group centred at Hull, U. K., are those near Mt. Kerinci and those near Lake Toba.

The Sumatran mountains bear a vegetation which, where undisturbed, may be zoned approximately as shown in Table 1 (MORLEY, 1982). The forest types of particular interest to us are the Sub-montane forest, c. 1000 – c. 1400 m, Montane forest I, c. 1400 – c. 1800 m, Montane forest II, c. 1800 – c. 2400 m and Ericoid forest, 2800–3000 m. Characteristic taxa include *Celtis* sp. for Sub-montane forest, and for Montane forest II, *Dacrycarpus imbricatus* and *Symingtonia*. There are no taxa absolutely characteristic of Montane forest I, but it tends to be rich in *Quercus* and *Lithocarpus* species.

A limited number of surface samples suggests that the modern pollen rain is rather similar in distribution to its parent vegetation types, although there is some tendency, as in New Guinea, for pollen types to be carried to higher altitudes (e.g. *Celtis*).

Table 1. Altitudinal Zonation of Vegetation in Sumatra (after MORLEY, 1982).

Vegetation type	Structural characteristics	Altitudinal range	Orographic Zone (VAN STEENIS, 1965, 1972)	Rain Forest Formation (GRUBB, 1974; WHITMORE, 1975)
Ericaceous scrub	low microphyll shrubs with herbs	3000 m – 3600 m	Sub-Alpine Zone	Upper Montane Rain Forest Formation
Ericoid forest	closed, low mossy microphyll forest	c. 2800 m – 3000 m		
Gleichenia scrub	Gleicheniaceae with low microphyll trees and shrubs	c. 2400 m – c. 2800 m		
Montane forest II	closed, high-stemmes floristically little-diverse mossy mesophyll forest, lianes rare, ground flora rich	c. 1800 m – c. 2400 m	Montane Zone	Lower Montane Rain Forest Formation
Montane forest I	closed, high-stemmed, floristically diverse mesophyll forest, mosses and lianes common, buttresses and emergents rare, ground flora rich	c. 1400 m – c. 1800 m		
Sub-montane forest	closed, high-stemmed, floristically diverse mesophyll forest, emergents and lianes common, buttresses present, little moss, poor ground flora	c. 1000 m – c. 1400 m	Sub-Montane Zone	

Lake Padang at 950 m is a small tectonic lake with a surrounding swamp about 300 m × 1 km (MORLEY, 1982). The site is surrounded by hills up to 1250 m. The pollen record extends back to about 10 000 B.P. and shows an early phase in which *Dacrycarpus imbricatus* and *Symingtonia populnea* occur in small quantities. It is not suggested that these were growing next to the lake, but they could have been on the surrounding hills. Sub-montane taxa are absent, so the vegetation around the lake was probably similar to Montane forest I. A change to present-day forest types occurred about 8600 B.P. From about 4000 B.P. there is evidence of forest disturbance, indicated especially by abundance of *Trema* pollen. According to MORLEY, an altitudinal shift of c. 350 m would explain the change at 8600 B.P.

The record is extended by studies at Lake di-Atas (1535 m). The site is a swamp in a narrow side-arm of this tectonic lake in the rift valley. The pollen record extends back to 31 000 B.P. The early part is all dominated by Gymnosperms, including *Dacrycarpus imbricatus*. There is even a peak of Gramineae and herbs at c. 21 000 to c. 18 000 B.P. Carbon dates in this part of the core are inverted, suggesting disturbance of the deposits. One possibility is a lowered water level, leading to erosion of marginal sediments. Perhaps the climate was drier and/or colder, either of which would be compatible with the peak of Gramineae. There is a gradual change to forest of modern type indicated from about 12 000 B.P., and the Gymnosperms disappear completely by about 7000 B.P. Disturbance is suggested (especially at another site in the same area) from c. 6000 B.P., by peaks of *Trema*, and, much later, Gramineae (J. C. NEWSOME, pers. comm.).

From the Lake Toba area we have evidence from two craters at 1400 m on the Toba plateau. Pea Sim-sim crater (MALONEY, 1980) has a record extending back to ca. 18 000 B.P. Before ca. 12 000 B.P. it shows presence of Gymnosperms (including *Dacrycarpus*), and *Symingtonia* in some quantity. About 17 000 B.P. there is a peak of herbs reminiscent of that found at Lake di-Atas during the Gymnosperm phase there. Forest disturbance is evidenced continuously from c. 7000 B.P. Sipinggan crater has a 12 000 year record which substantially confirms what is found in the same period at Pea Sim-sim (MALONEY, 1981).

The tentative conclusions to be drawn from this Sumatran work seem to be:

a) The Sub-montane/Montane forest boundary was depressed by c. 350 m (1400–1050 m) prior to 8600 B.P.
b) The Montane forest I/II boundary was depressed by c. 400 m (1800 m–1400 m) prior to c. 12 000 B.P.
c) The Sub-alpine/Alpine zone boundary was depressed by c. 1000 m (2400 m–1400 m) around 17 000 B.P. for a limited period.

If we combine these results with those for New Guinea (Fig. 3), we find a remarkably consistent series of events. Late Pleistocene vegetation zones were everywhere depressed and/or compressed. The gradual change to present vegetation took place everywhere between 14 000 and 8600 B.P., and especially between 12 000 and 9 000 B.P. The forests established by 8000 B.P. began to be disturbed as early as 7000 B.P., especially around 1400 m altitude. By 4000 B.P. forest clearance was common between 950 m and 2500 m.

The compression of zones in the Late Pleistocene is perhaps expressible in terms of mean annual temperature. The present lapse rate of c. 0.6 °C per 100 m conforms with the sea surface temperature,

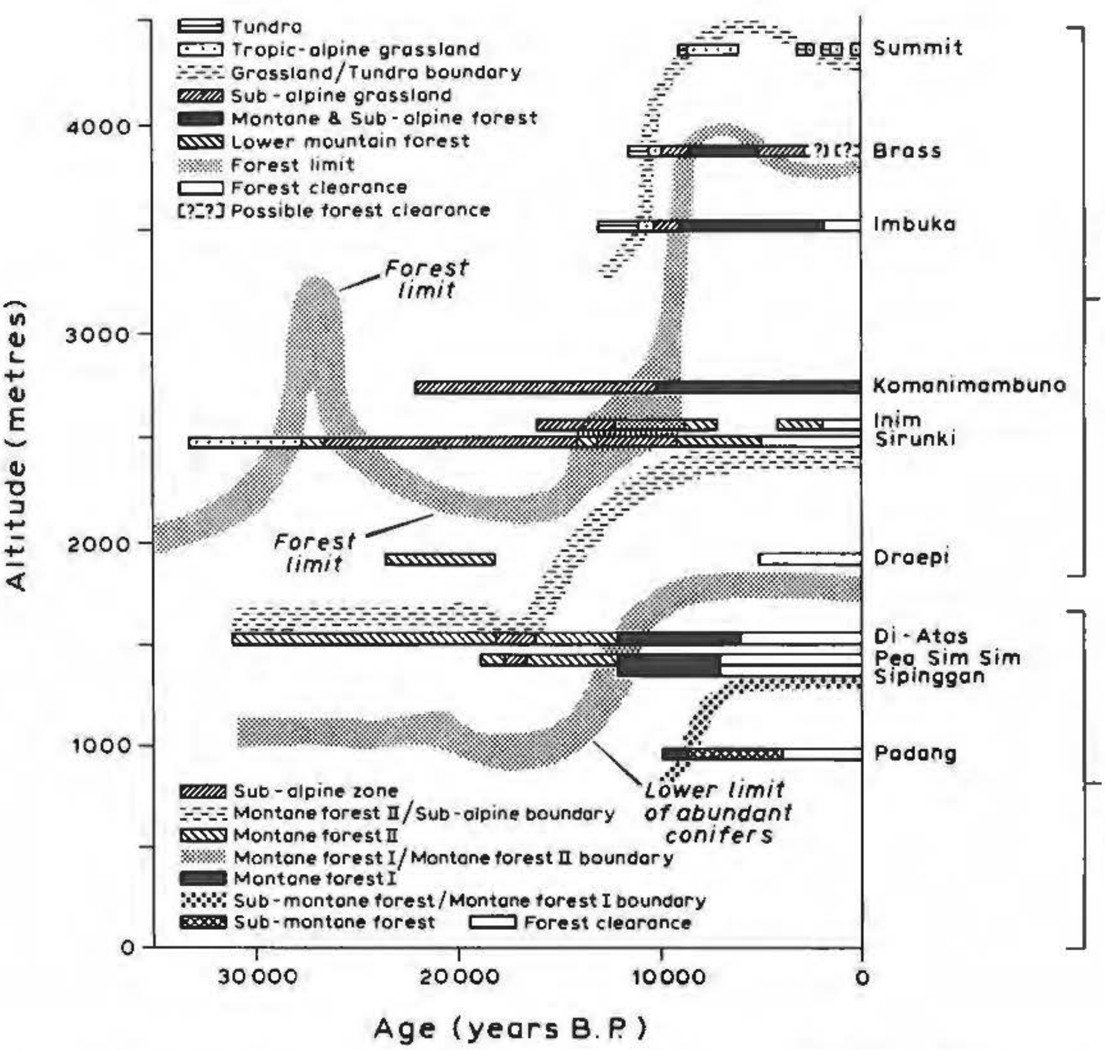

Fig. 3. Combined summary diagram showing Late Quaternary vegetational changes in the New Guinea Highlands and Sumatra.

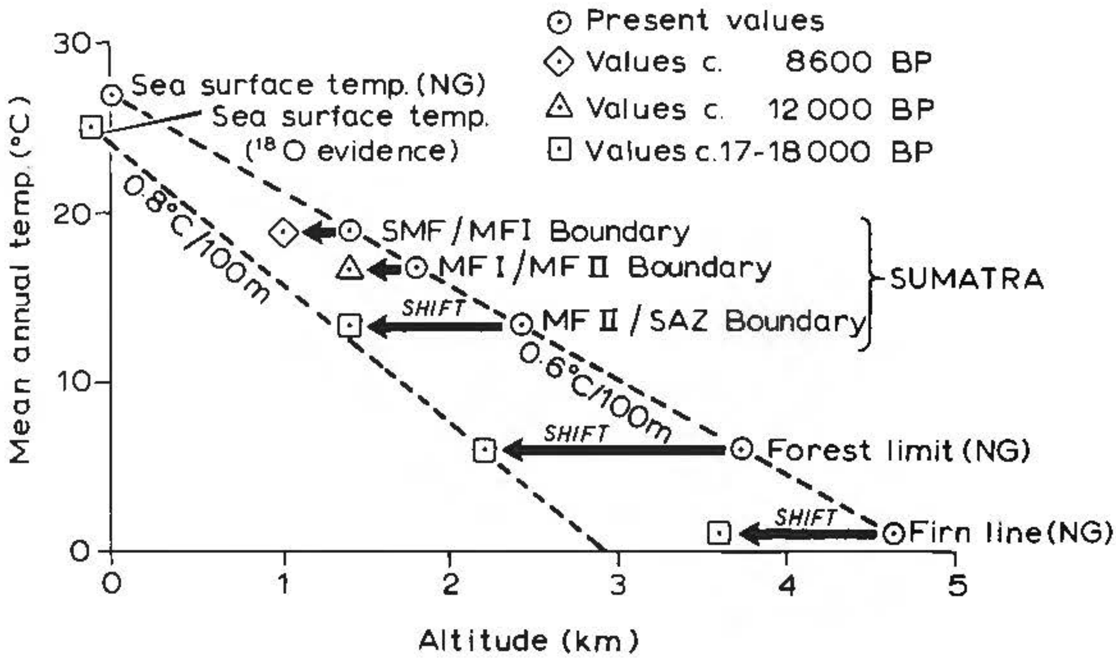

Fig. 4. The relationship between mean annual temperature and altitude in South-East Asia at present and in the Late Quaternary, the latter as judged from palynological evidence. Abbreviations refer to the altitudinal zonation given in Table 1 and Fig. 3.

vegetation zone boundaries and the snow line. At c. 18 000 B.P. the sea surface temperature of New Guinea and Sumatra was only c. 2 °C lower than at present (CLIMAP, 1976), and the surface perhaps 100 m lower. The depressions of the various vegetation zone boundaries are shown on Fig. 4, assuming that these are determined by mean annual temperature and that their temperature requirements remained the same in the past. Including also the marine temperatures, we now have three points for 17 000–18 000 B.P. These fall almost on a straight line which corresponds to a lapse rate of c. 0.8 °C per 100 m. This steeper lapse rate is nearer to the dry adiabatic lapse rate and therefore implies a drier atmosphere. This would be consistent with the relatively small depression of the snow line, which was perhaps kept high by low precipitation.

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Discussion to the Paper Flenley

Priv. Doz. Dr. P. Frankenberg:

You showed a synthetic diagram in which one saw a peak of the upper timberline at about 30 000–28 000 B.P. for New Guinea. This could mean the Stillfried B-Interglacial, documented by ice-core analysis in Greenland and the Antarctis by DANSGAARD et al. This did obviously not appear in Sumatra. What could be the reason for these differences of upper timberline development in New Guinea and Sumatra?

Prof. Dr. J. R. Flenley:

I think there are three possible reasons. Firstly, our Sumatra data is from a much lower altitude and concerns changes within the forest, rather than the timberline. At this altitude the changes could have been relatively minor.

Secondly, our pollen diagram is estimated to go back to c. 31 000 B.P., but this is based on a single carbon date and the diagram could start only after 28 000 B.P.

Thirdly, our pollen samples are widely spaced in this part of the core, so it is possible, if unlikely, that a 2 000 year event could be missed.

Dr. C. Schubert:

I am very happy with the temperature gradient you derive from your palynological data (0.8 °C/100 m). We have found a very similar glacial gradient for the Dominican Republic, based on different data, namely CLIMAP sea-level tempeature estimates, elevation of glacial erosional and sedimentary features, and the "Massenerhebungseffekt".

Prof. Dr. J. R. Flenley:

Since preparing the paper I have heard that new estimates for the Pleistocene sea surface temperatures in the S.E. Asian region are somewhat lower. Thus the value of 0.8 °C per 100 m for the lapse rate may now be too high.

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The Pleistocene and Recent Extent of the Glaciers of the Sierra Nevada de Mérida, Venezuela

Carlos Schubert

With 5 Figures and 1 Table

Abstract

The Sierra Nevada de Mérida and its northern branch, the Sierra de Santo Domingo, were affected by the Mérida Glaciation during the Late Pleistocene; this glaciation culminated at about 18 000 years B.P. and ended at about 13 000 years B.P., based on radiocarbon dating and comparison with the Cordillera Oriental of Colombia. The Mérida Glaciation was characterized by at least two main glacial advances: a possible early one which reached 2600 to 2800 m elevation, and a well documented late advance, which reached 3000 to 3500 m. This glaciation gave rise to a typical Alpine glacial topography and large glacial sedimentary deposits in the form of morainic complexes. A reconstruction of the Pleistocene glaciers suggests that the great late glacier system of these two mountain ranges occupied an area of less than 197 km^2; at present, only remnants of this system remain in the Sierra Nevada de Mérida, occupying an area of less than 3 km^2. This implies an areal glacier retreat of 98.5% with respect to the Late Pleistocene. The Holocene glaciers probably experienced small neoglacial advances; during the last 100 years, a spectacular glacier retreat has been documented, based on photographs, maps, and paintings. In the Sierra de Santo Domingo, a small firn field existed at least until 1922. The Pico Espejo Glacier, inexistent today, still existed in 1936. It is estimated that between 1885 and 1972, the glaciers of Pico Bolívar (5002 m) retreated vertically at a rate of the order of 6 m/year.

Zusammenfassung

Die Sierra Nevada de Mérida und ihr nördlicher Ausläufer, die Sierra de Santo Domingo, wurden im Spätpleistozän von der Mérida-Vergletscherung modelliert; diese Vergletscherung erreichte ihren Höhepunkt um die 18 000 Jahre vor heute und endete um die 13 000 Jahre vor heute. Die Mérida-Vergletscherung kennzeichnete sich durch mindestens zwei Hauptgletschervorstöße: ein möglicher früherer, der bis zu 2600 bis 2800 m Höhe vorstieß, und ein gut belegter späterer, der bis zu 3000 bis 3500 m vorstieß. Diese Vergletscherung hat eine typische alpine Glazialmorphologie und mächtige glaziale Sedimentablagerungen erzeugt. Eine Rekonstruktion der pleistozänen Gletscher deutet auf eine Gesamtfläche des großen Spätglazialsystems, das in diesen beiden Sierras existierte, von weniger als 197 km^2; heute bleiben nur noch Reste dieses Systems in der Sierra Nevada de Mérida, mit einer Gesamtfläche von weniger als 3 km^2. Dieses deutet auf ein Gletscherrückgangsareal von 98,5% im Vergleich mit dem Spätpleistozän. Die holozänen Gletscher hatten wahrscheinlich kleine neoglaziale Vorstöße; in den letzten 100 Jahren ist ein spektakulärer Rückzug der Gletscher belegt worden, hauptsächlich durch Photographien, Karten und Gemälde. In der Sierra de Santo Domingo gab es ein kleines Firnfeld bis mindestens 1922. Der Pico Espejo Gletscher, der heute ganz verschwunden ist, war noch 1936 bekannt. Es ist angedeutet, daß die Gletscher des Pico Bolívar (5002 m) zwischen 1885 und 1972 eine vertikale Rückganggeschwindigkeit von ungefähr 6 m/Jahr hatten.

Resumen

La Sierra Nevada de Mérida y su ramal norte, la Sierra de Santo Domingo, fueron afectadas por la Glaciación Mérida durante el Pleistoceno Tardío; esta glaciación culminó hace aproximadamente 18 000 años A.P. y terminó hace aproximadamente 13 000 años A.P. basado en datos radiocarbónicos y comparaciones con la Cordillera Oriental de Colombia. La Glaciación Mérida se caracterizó por un posible avance glacial antiguo hasta elevaciones de 2600 a 2800 m y un avance final bien documentado hasta elevaciones de 3000 a 3500 m. Esta glaciación originó una topografía glacial alpina y grandes depósitos sedimentarios glaciales en forma de complejos morrénicos. Una reconstucción de los glaciares pleistocenos sugiere que el gran sistema glacial tardío de estas dos sierran ocupaba un área menor a 197 km^2; actualmente quedan remanentes de este sistema en la Sierra Nevada de Mérida, ocupando un área menor a 3 km^2. Esto implica un retroceso glacial holoceno del 98,5% en área con respecto al Pleistoceno Tardío. Los glaciares holocenos probablemente sufrieron pequeños avances neoglaciales; durante los últimos 100 años, se ha documentado un retroceso espectacular de los glaciares, con base en fotografías, mapas y pinturas. En la Sierra de Santo Domingo existía una pequeña capa de nieve perenne hasta por lo menos 1922. El glaciar de Pico Espejo, actualmente inexistente, todavía existía en 1936. Se estima que entre 1885 y 1972, los glaciares de Pico Bolívar (5002 m) retrocedieron verticalmente con una velocidad del orden de los 6 m/año.

1. Introduction

The Sierra Nevada de Mérida and the Sierra de Santo Domingo (Fig. 1) are the most important massifs of the Venezuelan Andes; they have an area above an elevation of 3000 m above sea level of approximately 850 km^2. The maximum elevation is 5002 m (Pico Bolívar) in the Sierra Nevada de Mérida and 4609 m (Pico Mucuñuque) in the Sierra de Santo Domingo.

Just as most of the high mountain systems, both in temperate and tropical regions, the Sierra Nevada de Mérida and the Sierra de Santo Domingo, and other ranges of the Venezuelan Andes, were affected by Quaternary glaciations. These have been described in detail in the northwestern flank of the Sierra de Santo Domingo, in the Pico Bolívar area, in Páramo de La Culata, in Páramo de Piedras Blancas, and in

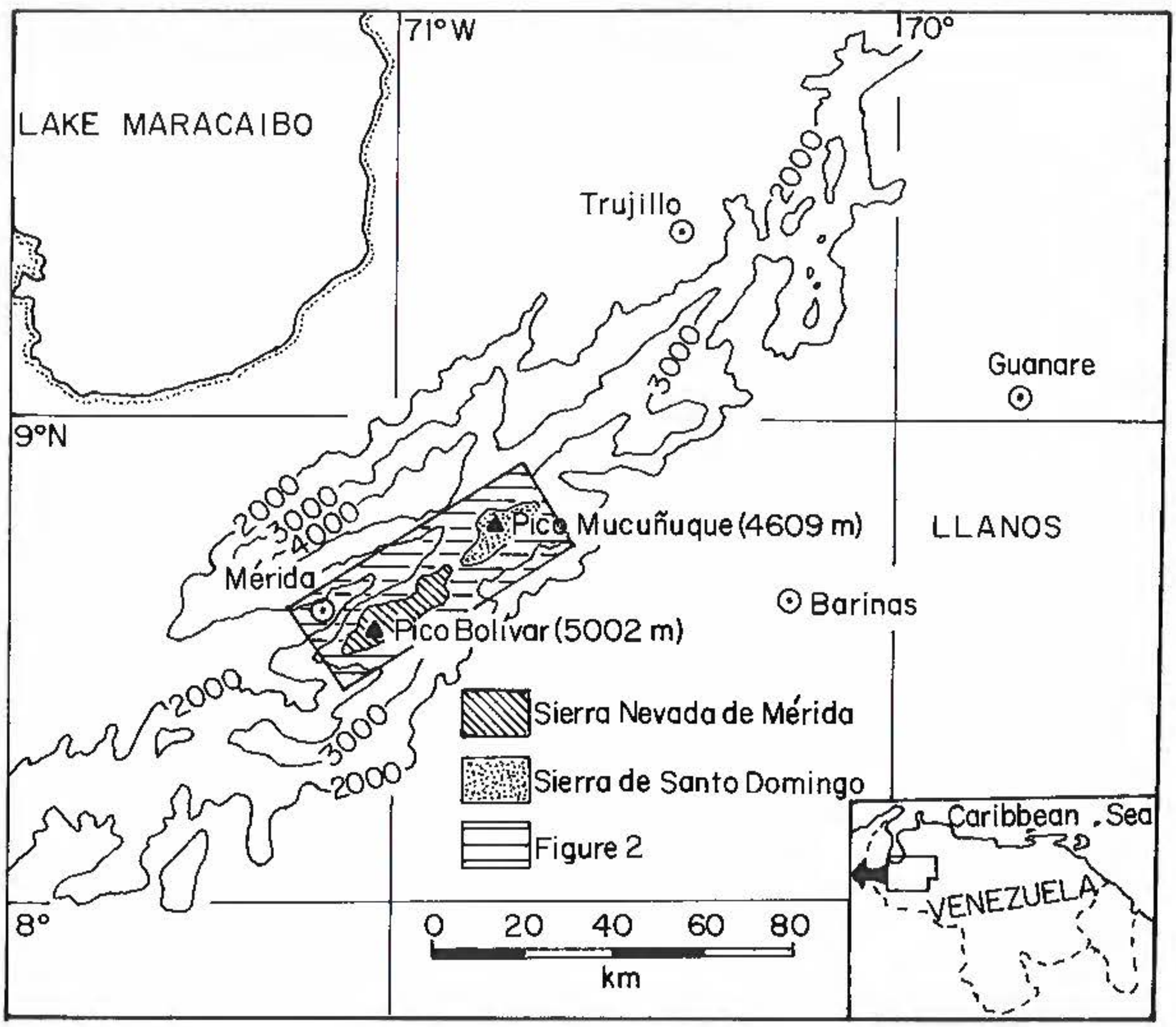

Fig. 1. Index map.

Páramo El Batallón (SCHUBERT, 1970, 1972, 1975, 1982; SCHUBERT and VALASTRO, 1974). Based on these studies, the Mérida Glaciation was defined (SCHUBERT, 1974), which comprises the last glacial advance of the Pleistocene. This advance has been approximately dated as Late Pleistocene (18 000 to 13 000 years B.P.), based on radiocarbon dating of organic-rich sediments, and stratigraphic and palynological comparisons with the Cordillera Oriental of Colombia (SALGADO-LABOURIAU et al., 1977; VAN DER HAMMEN, 1974; VAN DER HAMMEN et al., 1981). The Mérida Glaciation was characterized by a possible glacial advance to elevations of 2600 to 2800 m, and a well documented late advance to elevations of 3000 to 3500 m.

Only remnants of morainic sediments remain in some valleys from the older glacial advance (Chama, Mucujún, and Santo Domingo river valleys), in the form of isolated outcrops of a diamicton, a conglomerate without bedding, with grain-sizes ranging between sand and boulders. The latter show little fluvial action (poor rounding), are frequently faceted, and rarely striated. Another indirect evidence of the existence of this older glacial advance is the presence of possible fossil periglacial sediments (formed principally by solifluxion) in the Aracay river valley, at an elevation of 1600 to 1800 m, much below the present and Pleistocene elevation (3600 and 2400 m, respectively) at which this type of sediment forms and formed, due to the action of frequent daily freezing and thawing of the soil.

The final advance of the glaciers of the Mérida Glaciation is represented by spectacular morainic complexes above approximately 3000 m, by evidence of glacial erosion (glacial valleys, roche moutonnées, whaleback forms, rock steps, glacial channels). In addition, striae and grooves of glacial origin are frequently found on the outcrops of basement rocks in the glacial valleys. The moraines consist of long horse-shoe shaped ridges, which close the glacial valleys; several superimposed moraines are frequently found, which indicate multiple glacial advances. The morainic sediments contain all the classic evidence of Alpine glacial sedimentation (FLINT, 1971, p. 182): a great variety of grain-size (clay to boulders), little or no bedding (except in sediments left in open channels through the moraines by post-glacial streams), glacial abrasion of pebbles and boulders (facets, polygonal clasts, striae), and an oriented internal fabric which reflects the flow direction of the glaciers (SCHUBERT, 1979).

In the high parts of the glacial valleys, evidence of the Holocene glacier retreat and small re-advances is found in small recessional moraines. Of these glaciers, only remnants still exist in the Sierra Nevada de Mérida, with a total area of less than 3 km^2 (SCHUBERT, 1980). It has been estimated that the total area covered by glaciers during the final advance of the Mérida Glaciation, in the Venezuelan Andes, was approximately 600 km^2. This implies that the areal decrease during the Holocene was approximately of the order of 99%.

2. The Pleistocene Glaciers of the Sierra Nevada de Mérida

A detailed study of aerial photographs of Mission A-34 (Cartografía Nacional, Caracas, 1952, Nos. 176–190, 285A–299A, 317A–333A, 609A–626A, 969–982, and 995–999), and field study of some relevant regions (Sierra de Santo Domingo, Pico Bolívar, Mucuchíes-Mucubají region) revealed abundant evidence of former and present-day glacial activity, related to the Late Pleistocene Mérida Glaciation (Fig. 2), and permitted the reconstruction of the glacial geography during that glaciation.

Fig. 2 A shows the glacial morphology of the Sierra Nevada de Mérida and the Sierra de Santo Domingo. This morphology consists of erosional and sedimentary features. The glacial erosional features are located at the highest elevations and consist of arêtes, which form the crests of the ranges; cirques, which generally are round depressions with very steep walls and one or several rock steps below their outlet; roche moutonnés and whaleback forms, which indicate the direction of glacier flow; glacial valleys, which reach down to elevations of approximately 3500 m; and numerous striated and grooved rock surfaces on all of the former features. The sedimentary features consist of lateral and end moraines, which close the glacial valley outlets, in some cases damming the river which drains them; recessional

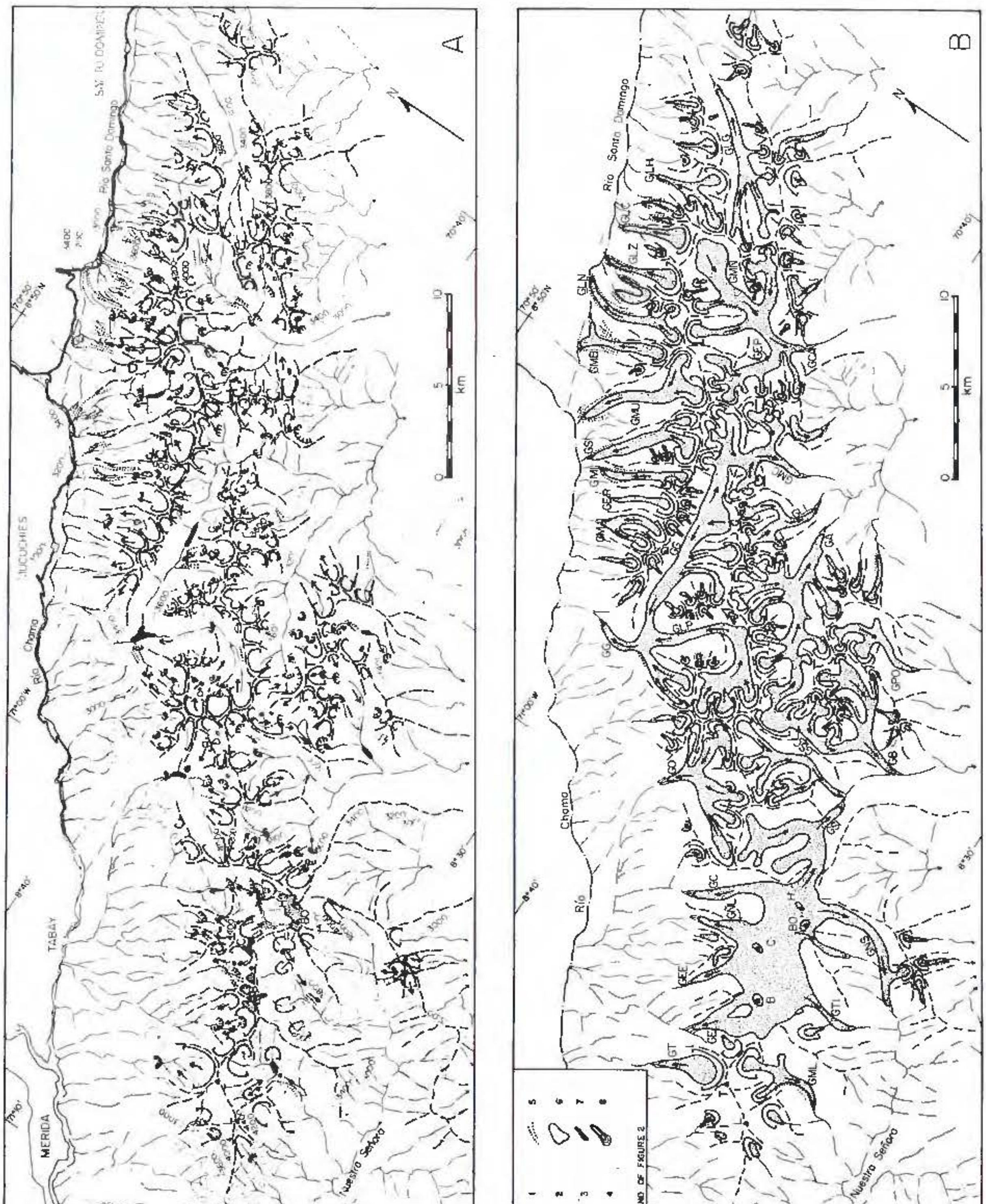

Fig. 2. *A:* Glacial geomorphological map of the Sierra Nevada de Mérida and the Sierra de Santo Domingo. Legend: 1. arête; 2. cirque; 3. rock step; 4. oriented feature (roche moutonnée, striae, grooves, whaleback form); 5. moraine; 6. glacier; 7. peat bog; 8. glacial lake; B. Pico Bolívar; B0: Pico Bonpland; C: Pico La Concha; H. Pico Humboldt; L. Pico El León; T. Pico El Toro.
B: Reconstruction of the Late Pleistocene glaciers of the last advance of the Mérida Glaciation in the Sierra Nevada de Mérida and the Sierra de Santo Domingo. The arrows indicate the direction of glacier flow. The glacier nomenclature corresponds to that of Table 1.

moraines within the glacial valleys and cirques; and peat bogs at different levels within the glacial and morainic valleys, in part produced by desiccation of former glacial lakes. Glacial lakes are found very frequently filling the bottoms of the cirques; the largest is Laguna Santo Cristo (1.5 km long and 0.75 km wide) in the Páramo of the same name, approximately 17.5 km south of Mucuchíes. The arrows in Fig. 2 A indicate the probable flow direction of the ancient glaciers, based principally on the presence of roche moutonnées and glacial striae and grooves on the walls and floors of the glacial valleys.

One of the most prominent features on Fig. 2 A is the concentration of moraines in the region situated between Mucuchíes and Santo Domingo, on the northwestern flank of the Sierra de Santo Domingo. In no other region of the map there are morainic complexes of equal magnitude, except the recessional moraines in the high parts of the glacial valleys. From the topography (Fig. 2 A), it can be deduced that the region between Mucuchíes and Santo Domingo is relatively flatter when compared with the other flanks of the Sierras, both to the northwest (Chama river valley) and to the southeast (Barinas piedmont). This region corresponds to the Páramos de Mucuchíes and Mucubají, a small *altiplano* on which great morainic sedimentary masses were deposited during the last advance of the Mérida Glaciation; later fluvial

Table 1. Nomenclature of the Pleistocene glaciers of the Sierra Nevada de Mérida and the Sierra de Santo Domingo.

Symbol (Fig. 2)	Name	Area (km^2)
GT	El Toro	5.7
GE	Espejo	
GEE	El Encierro	
GÑL	Ño León	
GC	Coromoto	49.3
GNS	Nuestra Señora	
GTI	Timoncito	
GSI	Sinigüis	
GML	Media Luna	
GG	Gavidia	
GLP	Las Piñuelas	32.6
GMC	Micarache	
GA	Arenoso	
GSC	Santo Cristo	26.4
GB	Bizcochito	
GCA	Canaguá	
GEP	El Potrero	17.3
GMÑ	Mucuñuque	
GM	Misteque	2.9
GEL	El Royal	
GMI	Michurao	1.7
GS	Saisay	4.8
GMU	Mucuchache	
GMB	Mucubají	3.4
GLN	La Negra	2.5
GLZ	Los Zerpa	
GLC	La Carbonera	
GLH	La Honda	2.9
GLG	Los Granates	6.0
GLL	Las Lajas	4.7
GPO	Los Pozones	3.4
GO	El Oro	6.9
Total area (minimum)		170.5

Area measured with planimeter

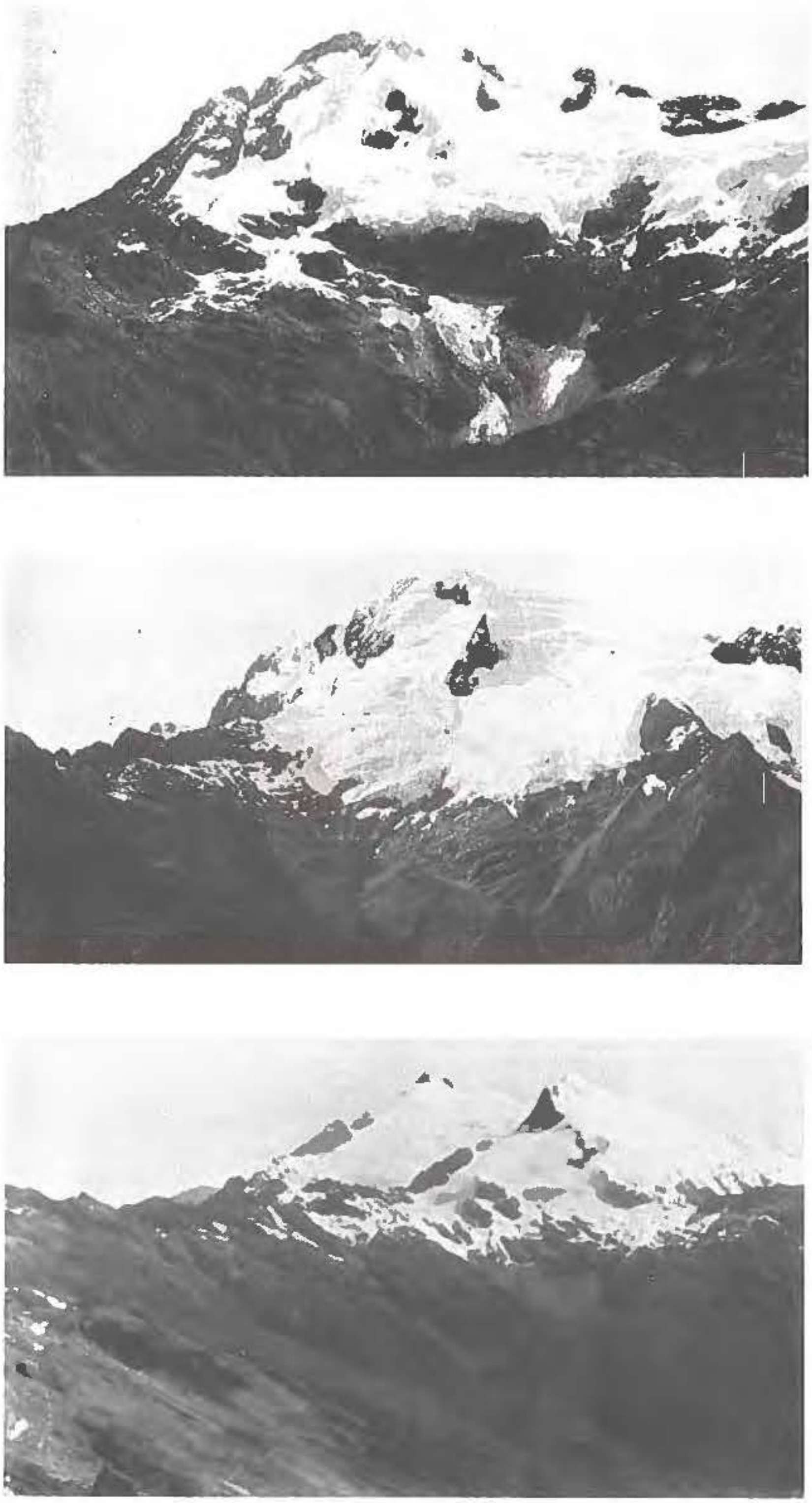

Fig. 3. Photographic evidence of glacier retreat during the last 60 years.
Above: The western Pico Bolívar glaciers in 1910 (left) and 1962 (right).
Middle: The western Pico Humboldt glaciers in 1910 (left) and 1972 (right).
Notice the possible neoglacial moraines below the glacier termini.

cont. Fig. 3.

Below: Southern Pico Bonpland glaciers in 1910 (left) and 1972 (right).
Sources of the photographs: JAHN (1912), HERRERA (1973), and the author.

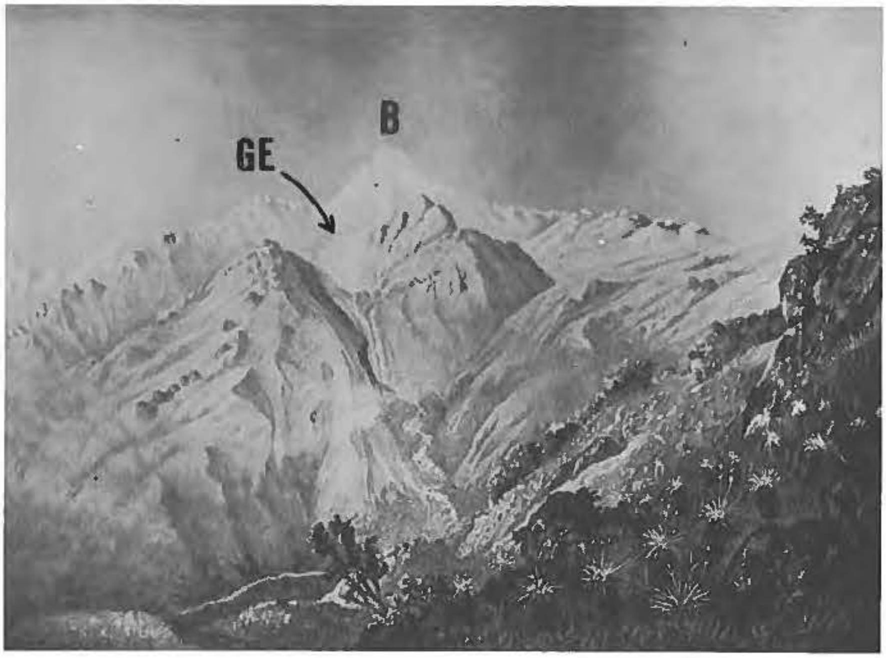

Fig. 4. Painting by Anton GOERING (1962), done between 1864 and 1874, clearly showing the Pico Espejo Glacier (GE) filling the western cirque below Pico Bolívar (B). This glacier is non-existent today.

and periglacial erosion during the Holocene has not been able to significantly remove these moraines, mainly due to the low slope values. At the same time, this region is situated in the transition zone between the humid climate of the Barinas piedmont (Santo Domingo river valley) and the dry climate of the high Chama river valley and the Páramo de Piedras Blancas (FLOHN, 1968; SCHUBERT, 1975), which suggests a slower weathering and erosion. On the rest of the flanks of the Sierras, erosion has been very effective, as indicated by the great erosional power of the rivers and the great alluvial accumulation on the Barinas piedmont.

An attempt to reconstruct the extent of the glaciers during the last important advance of the Mérida Glaciation (approximately between 18 000 and 13 000 years B.P.) is made in Fig. 2 B. This reconstruction is based on the data of Fig. 2 A. Table 1 shows the nomenclature of these glaciers and the area occupied by the most important of them. The arrows in this figure indicate the direction of glacier flow. The total area covered by the glaciers during this advance was approximately 197 km^2. Compared with the area occupied by glaciers at present (somewhat less than 3 km^2), it can be estimated that the Holocene glacier retreat in the Sierra Nevada de Mérida and Sierra de Santo Domingo was approximately 98.5%.

3. Contemporary Glacier Retreat

The Holocene glacier retreat documented in the preceding section continues today, as is suggested by photographic (Fig. 3) and pictographic (Fig. 4) comparison, and the observations made by different explorers during the last 100 years (SCHUBERT, 1980). In the Pico Bolívar massif, a vertical upward migration of the snowline, of approximately 100 to 150 m, has been observed since 1910. Timoncito Glacier has retreated in a spectacular manner during the last 20 years; the recently abandoned zone is characterized by outcrops of basement rocks, polished, striated, and covered by glacial debris. Retreat was so rapid that no moraines could accumulate. Vegetation, which is generally very sparse at this elevation (4700 m), has not been able to invade this zone yet, which testifies to its recent subaerial exposure. Another evidence of the rapid glacier retreat can be found in the reports by SIEVERS (1886; 1888, p. 188), BLUMENTHAL (1923), and JAHN (1925), who mention the existence, at least until 1922, of a small firn field below Pico Mucuñuque in the Sierra de Santo Domingo (significantly, at that time this mountain range was called Sierra Nevada de Santo Domingo). These authors also mention the existence of perpetual snow on Pico El Toro and Pico El León, of the Sierra Nevada de Mérida; at present, neither peak supports perpetual snow. The retreat of the snowline estimated by various authors is shown in Fig. 5. The accuracy of these data is probably quite variable, because the elevations were measured by different methods. However, the data suggest a clear and rapid retreat of the order of 6 m/year.

The Late Holocene glacier retreat documented here parallels a similar retreat observed elsewhere in northern South America. In the Sierra Nevada de Santa Marta (northern Columbia), WOOD (1970) documented that at least one third of the ice present in 1939 had disappeared by 1969, with glaciers on the southern flank being more affected by ablation (mean glacier termini in 1969 were at 4700 m on the north flank and 5000 m in the south flank). In the Sierra de Perijá, no glacier has survived the Holocene retreat due to its low elevation (3750 m; SCHUBERT, 1976). In the Sierra Nevada del Cocuy (Cordillera Oriental of Colombia), VAN DER HAMMEN et al. (1981) observed a marked glacier retreat from a possible neoglacial (or "Little Ice Age") moraine to the present glacier limit of about 4800 m. Similarly, in the Cordillera Central of Colombia, HERD (1977, p. 58) recorded a significant glacier retreat from a neoglacial moraine and an upward migration of the snowline by about 200 m in approximately the last 500 years. Finally, HASTENRATH (1981) documented in detail the spectacular glacier retreat in the Ecuadorian Andes during the last few centuries. The snowline retreated upward from about 4650 m in the late 18th century, to 4800 m in about 1900, to somewhat less than 5000 m in 1975. HASTENRATH (1981, Table 4) calculated an approximately 90% decrease in glacier-covered area between the probable last glacial maximum and present conditions.

In human terms, this spectacular glacier retreat means a progressive loss of one of the principal water sources of the high tropical mountains (see, for example, JORDAN, 1978). At the same time, the climatic-ecological belts progressively move upward and expand vertically, increasing the area of human exploitation and consequent environmental effects.

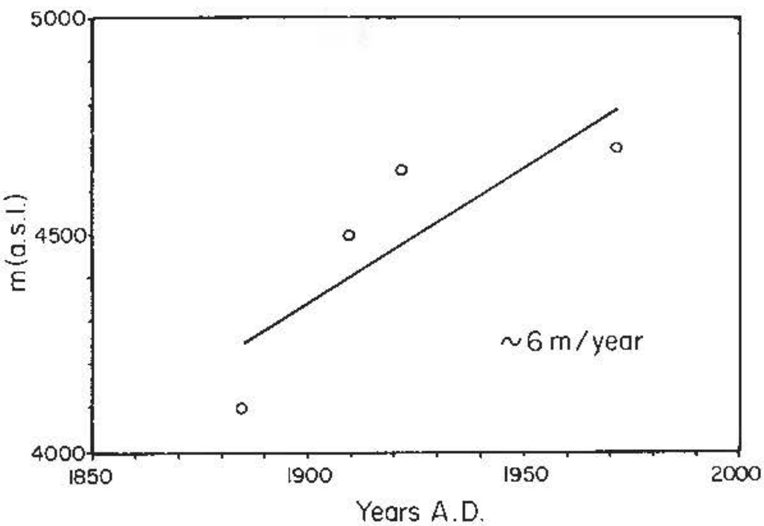

Fig. 5. Vertical retreat of the snowline in the Sierra Nevada de Mérida, after SIEVERS (1886), JAHN (1925), BLUMENTHAL (1923), and SCHUBERT (1980). A regression analysis ($r^2 = 0.69$) suggests a vertical retreat velocity of the order of 6 m/year.

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Late-Quaternary Palynological Studies in the Venezuelan Andes

Maria Lea Salgado-Labouriau

With 12 Figures and 2 Tables

The high elevations of the Venezuelan Andes and the steepness of its mountains cause a number of altitudinal belts of vegetation that ranges from savannas and deciduous forests, at about 200 m elevation, to a sequence of montane forests and finally, to "páramo" vegetation. The páramo region, at elevations between 2800 and 4700 m, is covered by an open plant formation, generally formed by a low stratum of cushion-, rosette- and tussock-form herbs, mainly Gramineae, Compositae, Rosaceae. Scattered through this low stratum are small shrubs and tall rosettes of which the species of *Espeletia* (Compositae) are, to the human eye, the most conspicuous feature of the páramos. Rivers, creeks and small lakes are abundant and usually bordered by bogs. Peat formation is common and constitutes, together with the glacial lakes, good environments for pollen and spore accumulation and preservation.

At present glaciers are limited to the highest peaks (above 4700 m) but geological evidence has shown that the glaciation at the end of the Pleistocene reached elevations between 3000 and 3500 m (SCHUBERT, 1974 and 1984). The moraines of this glaciation are covered today by páramo vegetation and montane forest.

The Mérida Andes, where mountains reach their highest elevations in Venezuela, were chosen to start the palynological investigation (Fig. 1). It is based in the analysis of pollen grains, pteridophyte spores and algal remains. An outline of the results is presented here, including unpublished data.

1. Modern Pollen and Spore Deposition

The study of pollen, spores and algal remains that are being deposited at present in the páramo belt by modern vegetation (SALGADO-LABOURIAU, 1979) made possible the characterization of assemblages from the transition zone between páramo and forest, the páramo proper, and the superpáramo (subdivisions according to CUATRECASAS, 1957). It was also possible to determine the local, the regional and the long-distance types, as well as the dispersion power of the most abundant types. The results point out that:

1. Compositae and Gramineae are the main source of pollen in the páramos;
2. pollen of the Caryophyllaceae and the genera *Polylepis*, *Acaena*, *Geranium* and *Montia* also occur in modern sediments and are indicators of páramo condition in the past;
3. the pollen assemblages that are being deposited at present change according to the altitude making possible the distinction of subpáramo, páramo, páramo proper and superpáramo samples;
4. the long distance pollen types belong to the arboreal genera *Podocarpus*, *Alnus* and *Hedyosmum*, all from the humid montane forest; their pollen may reach the highest elevations in the superpáramo. Nevertheless, their frequency decreases with the increase in altitude. Also are long-distance types the spores of the forest Cyatheaceae.

These results and those from the Colombian Andes by GRABANDT (1980) enabled the intepretation of assemblages from old sediments.

2. Late-Pleistocene Gallery Forest

In the Motatán river basin there are several fluvial terraces (or mesas) that have been geologically described and radiocarbon dated (SCHUBERT and VALASTRO, 1980). A landslide occurred in one of them (at 2490 m elevation) displaying a stratigraphic section of about 200 m height (Fig. 2) in which organic layers were separated by layers of sandy conglomerate. Fragments of trees were embedded in these sediments allowing an accurate radiocarbon dating. A whole trunk was identified as a Myrtaceae, *Eugenia* or *Myrcia* (SCHUBERT and VALASTRO, 1980).

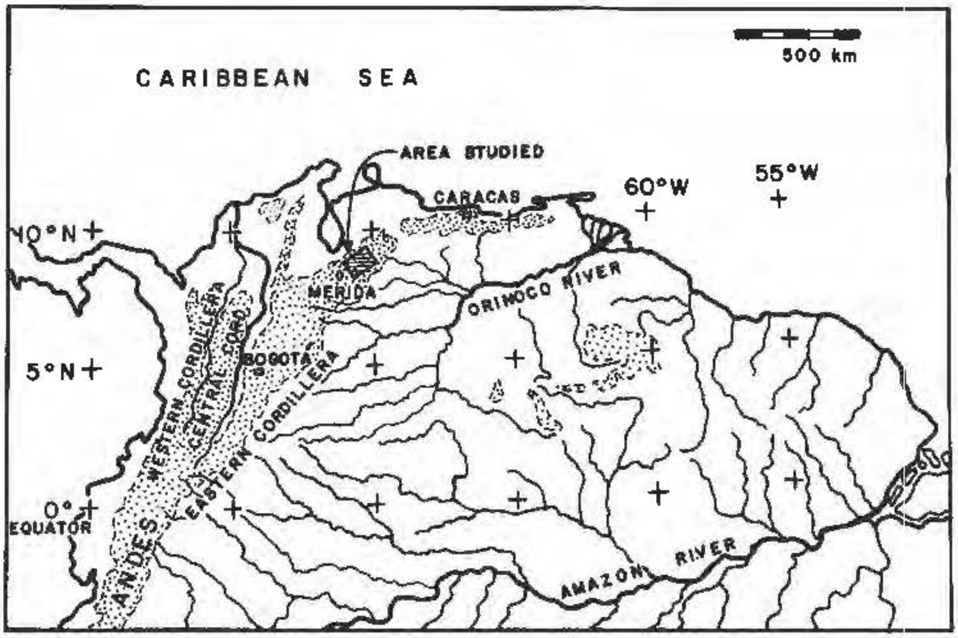

Fig. 1. Map of South America showing the Northern Andes and the area studied in this article.

Fig. 2. Landslide of the terrace in the Tuñame river, a tributaire of the Motatan river in the Mérida Andes (Venezuela).

The pollen analysis of the organic layers from this terrace (Tuñame river) is in progress. Due to problems in the identification of a few types the complete analysis is not yet concluded. Nevertheless, the preliminary results allow some conclusions (Fig. 3).

All the levels in the Tuñame deposits are dominated by pollen of *Alnus*, followed by a large frequency of pollen of *Podocarpus*. The presence of *Alnus* pollen dates the terrace as of Pleistocene age. It has been well established in the stratigraphy of Venezuela that the first occurence of this pollen type indicates the Lower Pleistocene. *Alnus*, a Northern temperate genus, is thought to have migrated to South America after the uplift of the Panamá isthmus in the Late Tertiary (VAN DER HAMMEN, 1974), and has reached Venezuela in the beginning of the Pleistocene.

Arboreal pollen, besides *Podocarpus* and *Alnus*, is not abundant but occurs throughout the Tuñame deposit. The most common taxa are *Ilex*, *Hedyosmum*, *Juglans*, *Alchornea*, *Myrica*, *Escalonia*, *Weinmania*, *Valea* and the families Myrtaceae and Melastomataceae. The low frequency of Myrtaceae pollen (below 2.5%) in levels where their macrofossils are found shows that Myrtaceae pollen is under-represented in sediments. The sum of the grains from the genera quoted above constitutes the majority of the pollen in all levels and points out the existence of a rain forest at that time. The Tuñame sediments also contain spores of humid forest ferns, such as *Lindsaea* and the tree-ferns *Alsophila* and *Cyathea*, that may reach a very large amount in some levels. The presence of rain forest ferns, together with arboreal pollen, reinforces the interpretation that the site was occupied by a humid gallery forest between >50 000 and 33 700 B.P. This interval of time is included within the last glacial event, and the moraines formed by its glaciers are found at 3000–3300 m elevation in this region (SCHUBERT and VALASTRO, 1980). The altitudi-

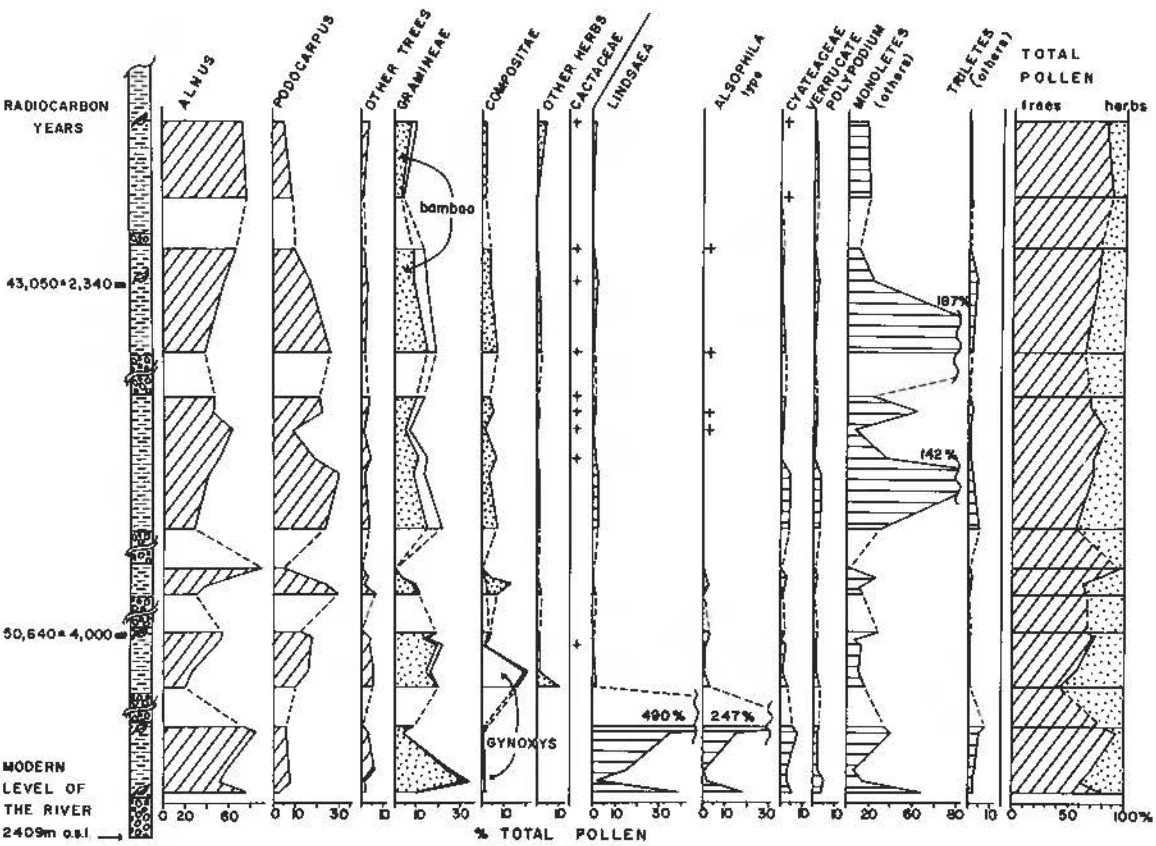

Fig. 3. Pollen und spore diagram of selected types from the Tuñame terrace, based on SALGADO-LABOURIAU, unpublished data.

nal position of the moraines indicates that the gallery forest, by modern standards, was too close to the snowline, and the páramo belt would have been altitudinally compressed in the 500 m between the snowline and the forest at that time.

The forest pollen and spore assemblages of Tuñame are associated in some levels with a large frequency of pollen of Compositae and/or Gramineae (Fig. 3). Since the plants of both these families grow mainly in open vegetation, it was necessary to study the pollen morphology of their Northern Andes species to verify which grasses and composites had grown in the Tuñame gallery forest.

The study of Compositae pollen (SALGADO-LABOURIAU, 1982) has shown that the Compositae maxima in the Tuñame deposits were due to the genus *Gynoxys*. It was probably *G. meridensis* (Fig. 4), a shrub or small tree that grows at present in the upper limit of the cloud forest and also in the *Polylepis* dwarf forest of the páramo. *Gynoxys* would therefore be part of the forest.

The genera of Gramineae cannot be identified by qualitative morphological features of their pollen. Nevertheless, size distribution of grass pollen from modern ecosystems follows a continuous sequence from very small (about 20 μm) to large grains (over 40 μm diameter). The species that are at the two tails of the size distribution are significantly different. This can be well seen, for example, for the Brazilian savanna grasses (CAMPOS and SALGADO-LABOURIAU, 1962) and North European grasses (ANDERSEN, 1978).

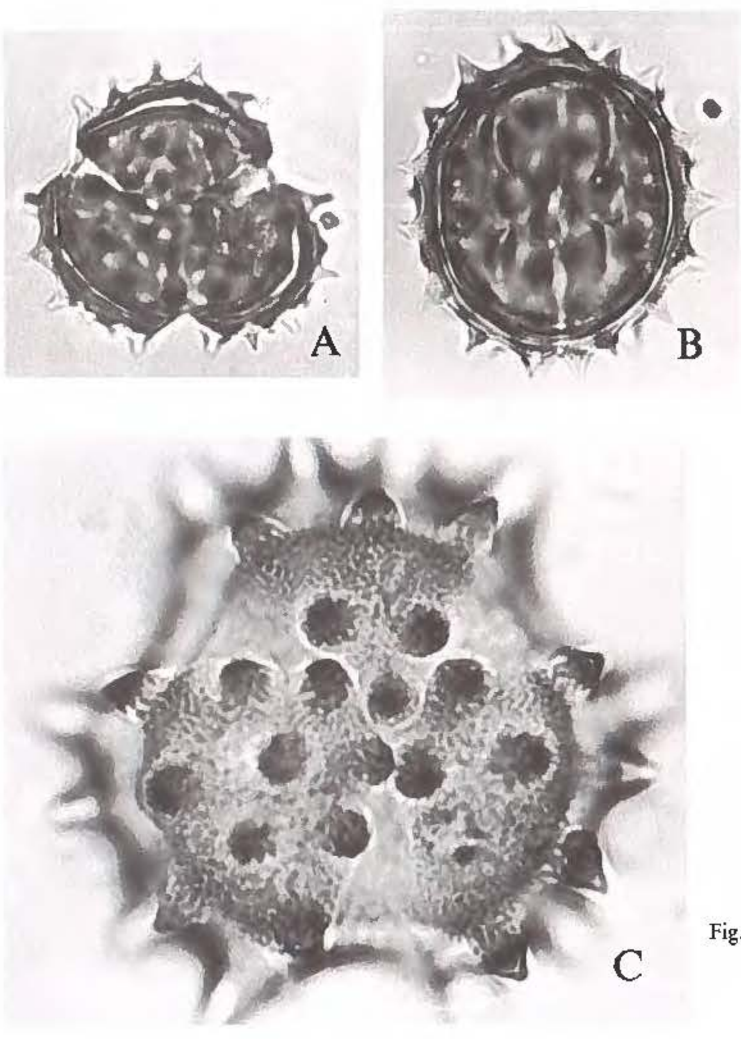

Fig. 4. Modern pollen grains, light microscope:
A – Gynoxys meridana Cuatr., in polar view;
B – idem, equatorial view;
C – *G. violacea* Sch. Bip., polar view.

Most of the grass pollen in the Tuñame sediments are over 40 µm in diameter and the grain surface is smooth. Therefore, a statistical study of the Andean grasses was undertaken to verify which are the montane grasses that have large grains with smooth surface. The results (Fig. 5) show that pollen grains above 40 µm in diameter belong to the genera *Bromus, Trisetum, Heleria, Festuca* and to the subfamily Bambusoideae, cultivated grasses not included (SALGADO-LABOURIAU and RINALDI, unpublished data). It

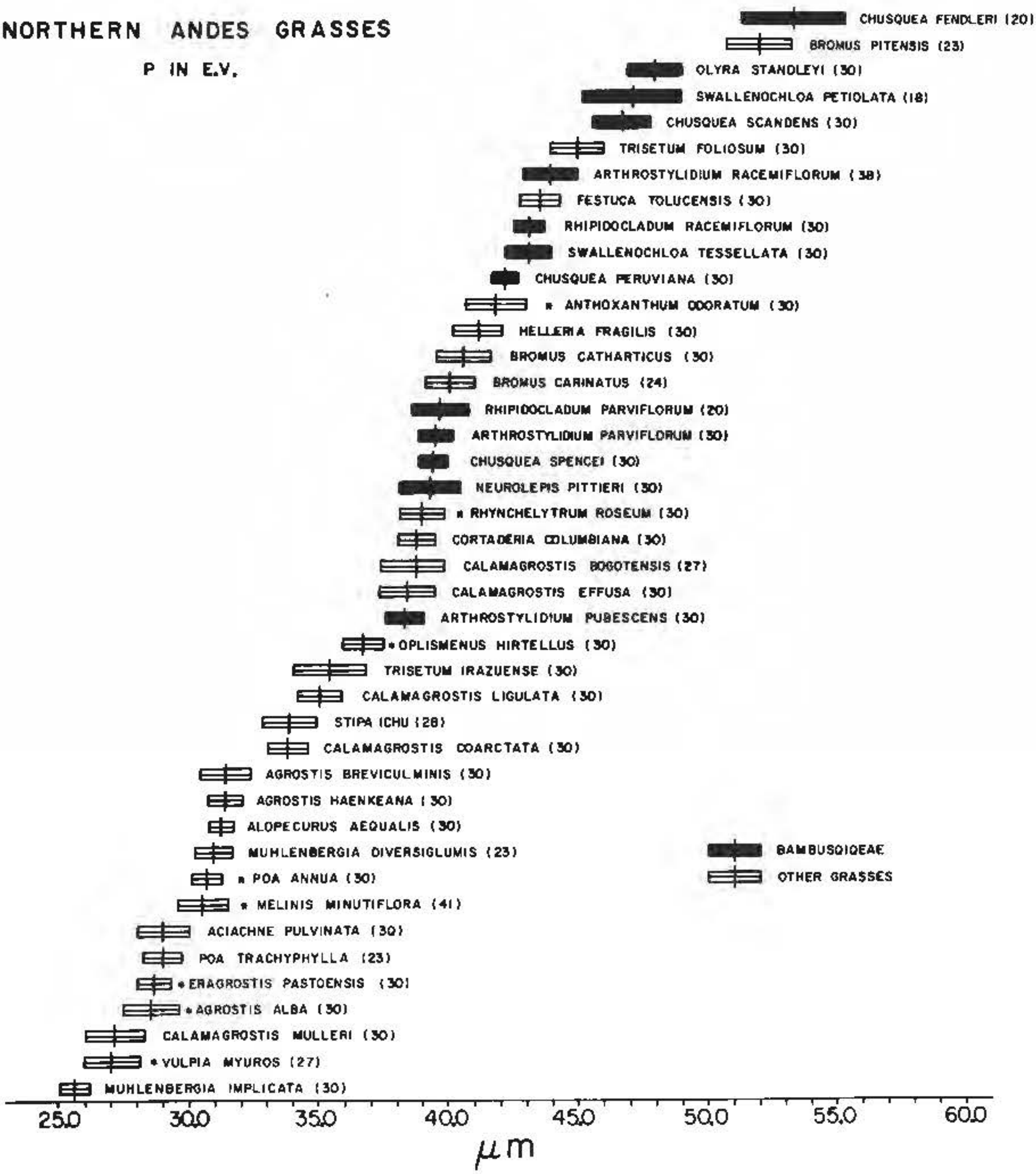

Fig. 5. Size distribution of grass pollen from the Northern Andes. An asterisk before the name of the species indicates introduced or cultivated grasses. *Rhipidocladum racemiflorum* and *Arthrostylidium racemiflorum* are two different specimens of the same species (*R. racemiflorum* McClure); *R. parviflorum* and *A. parviflorum* are specimens of *R. parviflorum* McClure. Observe that the grains with polar diameter below 37 µm do not include bamboos; all of them belong to species that occur in the páramo belt.

was also found that most of the bamboo pollen grains are psilate (smooth surface), whereas the other genera present coarsely granulated grains. These results indicate that the grass pollen found in the Tuñame sediment is most probably bamboo pollen. It is well known that bamboos are mainly forest elements; the herbaceous species flowering almost continuously throughout the year; the woody bamboos, although usually monocarpic or blooming at long and irregular year periods (CALDERÓN and SODERSTROM, 1980), always flower abundantly. This irregular blooming probably could explain the high frequency of grass pollen found in some levels of Tuñame that may reach more than 20% of the total pollen whereas it is scarce in levels immediately above or below them (Fig. 3).

The analysis of the pollen and spore assemblages from the Tuñame terrace points out that between 50 640 and 33 700 radiocarbon years B.P. the site was not occupied by páramo vegetation nor by a grassland of a cold tropical climate, even though it is only a few hundred meters below well preserved moraines. It had a humid gallery forest that could have been a forest refuge area during the Mérida glaciation.

3. Late-Quaternary Climatic Oscillations and Post-Glacial Vegetational Succession

The Páramo of Mucubaji (3500–3700 m elevation) was covered by glaciers during the Late-Pleistocene glaciation and high moraines were formed confining a deep glacial valley. Paleoecological data show that glaciers have retreated from the Mucubaji valley at 12 650 ± 130 B.P. (SALGADO-LABOURIAU, SCHUBERT and VALASTRO, 1977). Superpáramo vegetation started to establish at that time in the glacial valley. The first plants to reach the newly deglaciated soil belong to the families Gramineae, Portulaceae and Compositae (Fig. 6). In the beginning *Montia*-type pollen, probably *Montia (Mona) meridensis* (Fig. 7), was the most abundant, but it decreased shortly after. *M. meridensis* is a small unconspicuous herb of humid soils; at present it is more frequent in bogs above 4000 m elevation. It produces very little pollen which suggests the plants were very abundant at that time.

Gramineae and Compositae pollen is scarce in the beginning. At about 12 400 B.P. the Caryophyllaceae arrived at the site, followed by *Lycopodium* (foveolate type). Only at about 12 000 B.P. these taxa attained

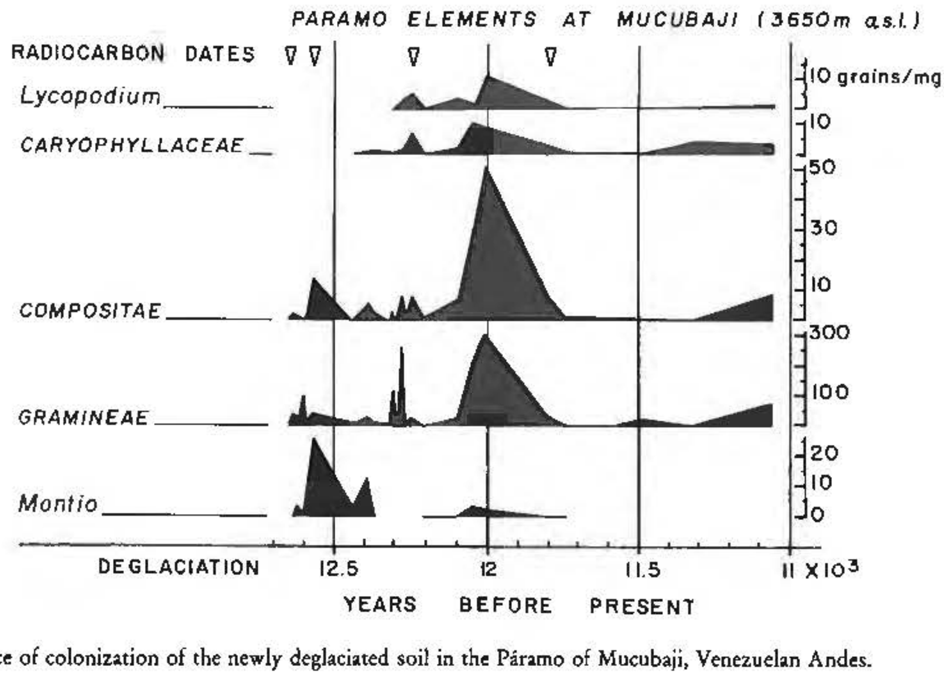

Fig. 6. Sequence of colonization of the newly deglaciated soil in the Páramo of Mucubaji, Venezuelan Andes.

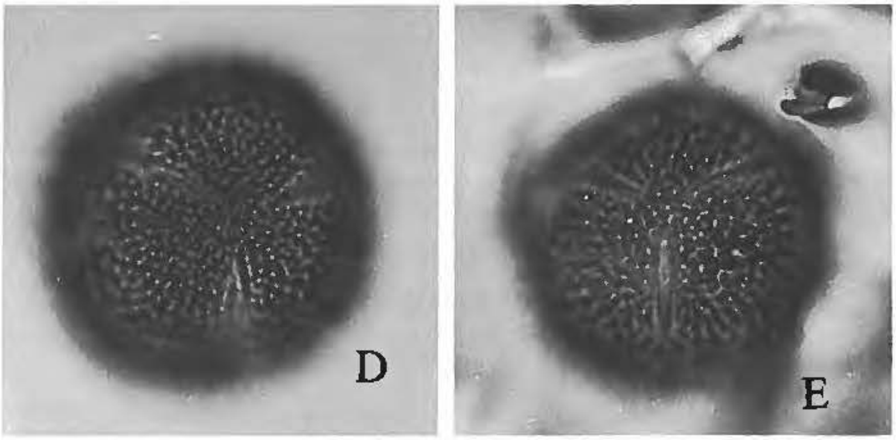

Fig. 7. Pollen grains of *Montia meridensis* Friedrich in polar view:
D – modern grain;
E – fossil grain from the Mucubaji terrace, level SD-42, about 12 500 years before present.

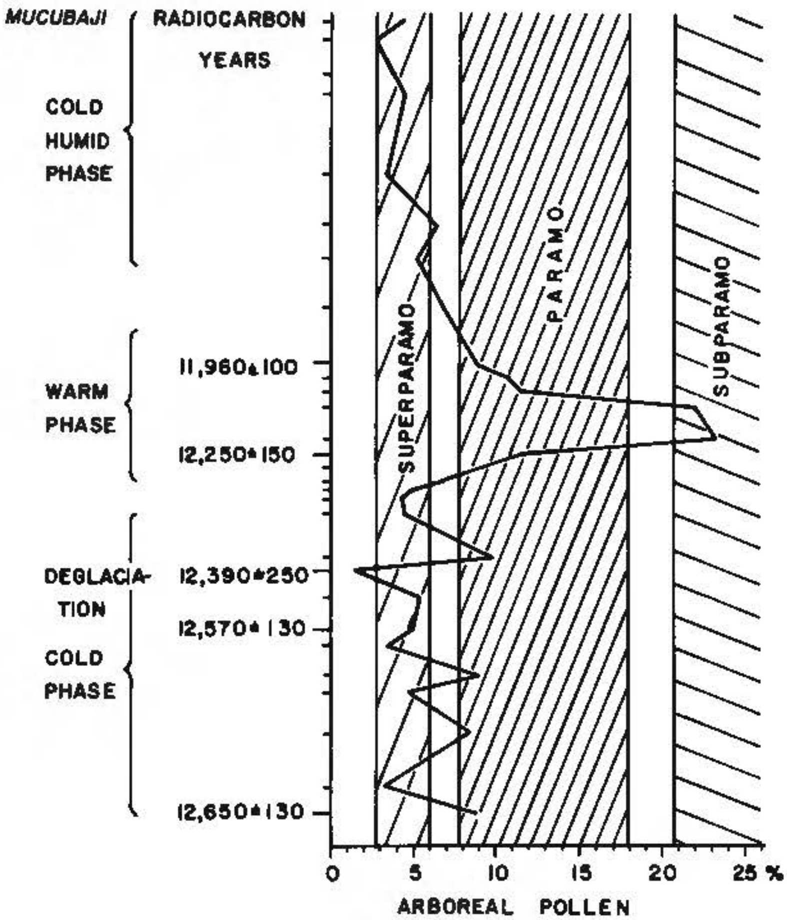

Fig. 8. Oscillation of the tree line at the end of the Pleistocene. The curve represents the total percentage of tree pollen per level in the Mucubaji terrace. It is plotted against the percentage of modern tree pollen that is being deposited in the páramos according to the altitude. Based on SALGADO-LABOURIAU, SCHUBERT and VALASTRO (1977) and SALGADO-LABOURIAU (1979).

Table 1. Late-Quaternary climatic oscillations in the Mérida andes.

Radiocarbon year before present (*interpolated dates)	Vegetation and climate at 3500 to 4000 m elevation
0 (present)	humid páramo. Humid and cold montane climate: average temperature 5.3 °C; absolute minimum −9 °C; absolute maximum + 22 °C, in 24 hours cycles; average precipitation 1084 mm per year
2520 to 5270	vegetation and climate similar to present
6150	scarce páramo vegetation; climate cooler and drier than present (La Culata dry phase)
6240 to 7530	vegetation and climate similar to present
ca. 11 000* to ca. 11 700*	humid superpáramo vegetation; climate cooler than present, average temperature probably 2–3 °C below present; humid (Mucubaji cold humid phase)
11 960 to 12 250	humid páramo vegetation; climate similar to present (Mucubaji warm phase)
ca. 12 280* to 12 650	superpáramo with scarce vegetation. Climate colder and drier than present, average temperature c. 2.9 °C deglaciation
Before 12 650	Mérida glaciation

Based on SALGADO-LABOURIAU and SCHUBERT (1976); SALGADO-LABOURIAU, SCHUBERT and VALASTRO (1977).

their maximum frequency to decrease again shortly after (11 960 B.P.) when a cold phase started. The same sequence of colonization of the newly deglaciated soil was found at another site, in the Páramo de Piedras Blancas at 4000 m elevation (RULL and SALGADO-LABOURIAU, unpublished data).

In the Sierra Nevada de Santa Marta (Colombia) the pollen analysis of a peat core in a glacial valley at 4760 m elevation shows a similar sequence. The glacier has a retreat at about 1700 A.D. when *Montia*, Cyperaceae and Compositae occupied the site. They were followed by *Plantago* and finally by *Lycopodium*, Caryophyllaceae, Cruciferae *(Draba)* and Scrophulariaceae (VAN DER HAMMEN, 1979).

The results from these three sites suggest that Fig. 6 represents general pattern of colonization in new deglaciated soils from the páramos: *Montia* and a few Compositae (together with Gramineae or Cyperaceae) are the first to establish, and they are followed later by *Lycopodium* and Caryophyllaceae with a few other elements that varies according to the mountain.

The pollen assemblages in Mucubaji from 12 650 to 12 280 B.P. are similar to those of modern superpáramo assemblages. Nevertheless, pollen frequency is lower in the old sediments indicating a scarce vegetation spread over almost bare soil. At 12 250 B.P. the pollen assemblage is abundant, and new elements have reached the valley (SALGADO-LABOURIAU, SCHUBERT and VALASTRO, 1977). Long-distance tree pollen which was scarce after deglaciation increases in this phase reaching values similar to those of modern páramo (Fig. 8). The abundance of páramo elements and the uplift of the forest indicate that a warm interval took place at that time. This phase is correlated with the Guantiva Interstadial of Colombia (GONZALEZ, VAN DER HAMMEN and FLINT, 1965). Shortly after the temperature must have decreased again because the forest has retreated to lower elevations (Fig. 8). The site gradually returned to superpáramo conditions, and a cold and humid interval began after 11 960 B.P.

Table 1 shows the climatic oscillations from the end of the Pleistocene to modern time at the Páramos of Mucubaji and La Culata based in the pollen analysis of sediments from fluvio-glacial terraces. Three cold phases with different degrees of humidity were detected: > 12 650–12 280 (relatively dry); 11 700–11 000 (humid); and 6150 B.P. (dry) (SALGADO-LABOURIAU, SCHUBERT and VALASTRO, 1977; SALGADO-LABOURIAU and SCHUBERT, 1976).

The main retreat of the last glaciation ice sheet at about 13 000 B.P. in the Venezuelan and Colombian Andes shows that the soils in the páramo belt are recent when compared with the montane forest belt. Below 3000 m elevation the soil has not been continuously destroyed by the readvances of the glaciers during the Pleistocene.

4. The Polylepis Forest

The small trees of *Polylepis sericea*, 4 to 6 m tall, grow above the montane forest in the Venezuelan Andes. They are found in the ecotone páramo-forest, between 2400 and 3000 m elevation, and along streams, in gallery forests that penetrate into the páramo. They also form small clusters of trees or woodlands enclaved in the páramos from 3200 a 4200 m elevation, usually in rocky slopes (Fig. 9) or along rivers. Sometimes they are the only trees; in other instances they are associated with small trees of the genus *Gynoxys* and with several types of shrubs (SALGADO-LABOURIAU, 1979, and literature within). The reduced size of these dwarf forests and their anomalous distribution is illustrated in Figs. 10 and 11.

Recently, the genus *Polylepis* was reviewed by B. B. SIMPSON (1979) and reduced to 15 species. As well as *P. sericea*, the other fourteen species have a similar distribution, and occur in the highest parts of the Andean mountains, from Northern Chile and Argentina to Colombia, with many species reaching 4000 to 5200 m elevation. According to the species, they are found in rocky slopes, valley bottoms or along rivers. Rare as an isolated tree, the *Polylepis* species form small woodlands surrounded by open plant

Fig. 9. Páramo landscape: La Aguada Station, Mérida, Venezuela, at 3400 m elevation. Arrow indicates a dwarf *Polylepis* forest at the background.

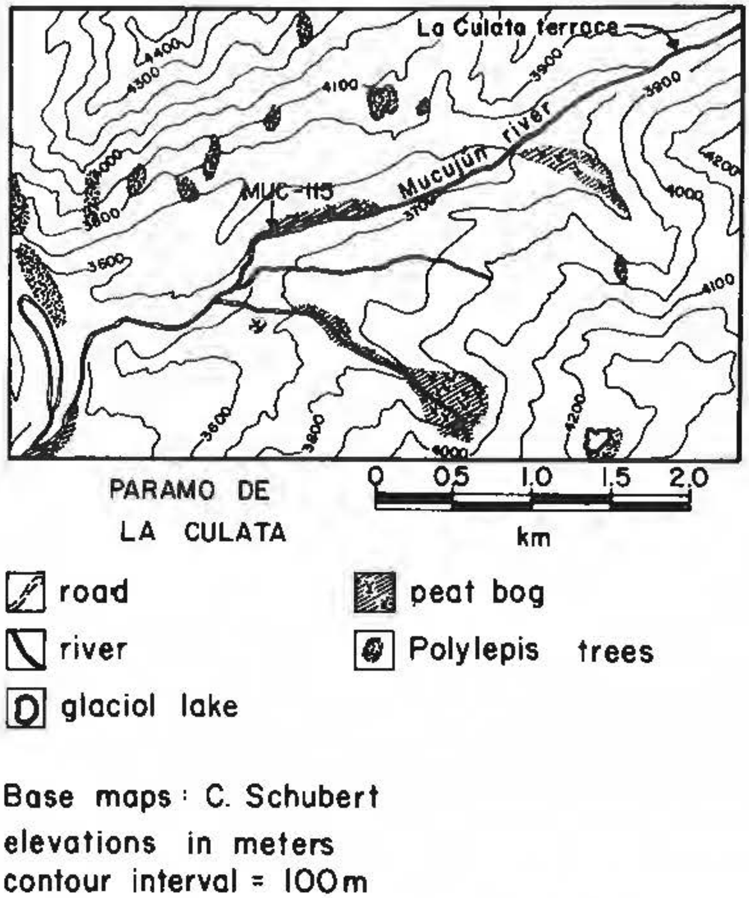

Fig. 10. Map of the Páramo of La Culata indicating the modern occurrence of the *Polylepis* dwarf forests.

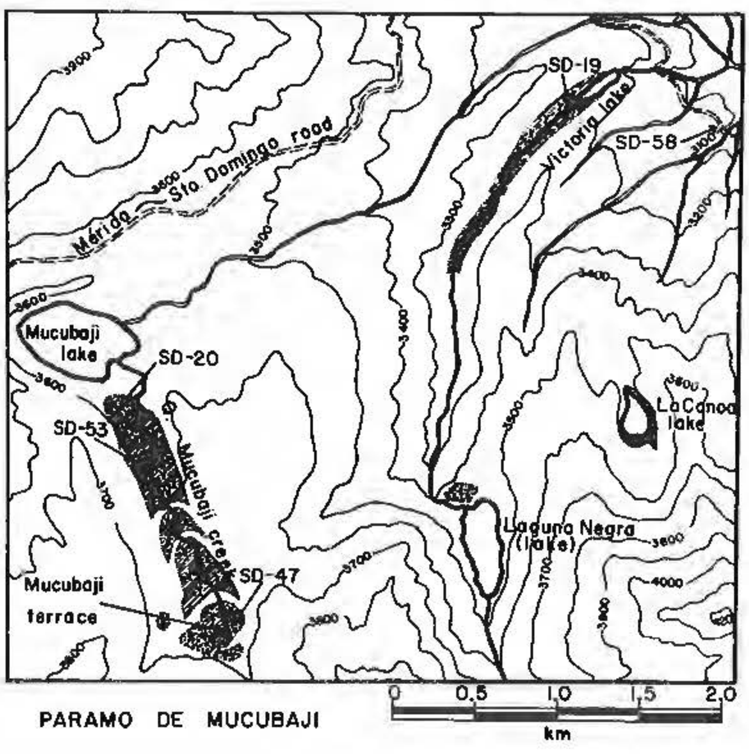

Fig. 11. Map of the Páramo of Mucubaji indicating the small areas occupied by *Polylepis* trees at present.

formations, as páramos and punas. These dwarf forests are specialized type of vegetation restricted to certain areas in the cold belt of the Andes.

The use of *Polylepis* as firewood and fence in these otherwise treeless regions, is drastically reducing its member (HUECK, 1972). The pollen analysis of a core in a bog close to the Laguna Victoria (3250 m elevation), in the Venezuelan Andes (SALGADO-LABOURIAU and SCHUBERT, 1977) has shown the existence of a *Polylepis* woodland around this small glacial lake in the last millenia, up to modern times. Nevertheless, at present the lake is surrounded by a recent plantation of exotic coniferous, and no *Polylepis* remains in the site.

The ability to grow above the montane forest in soils which freeze almost every night, and the distribution in dwarf woodlands is still a problem to ecologists and physiologists. WALTER and MEDINA (1969) suggested it is mainly due to favorable soil temperature. There is very little information about the development and microclimatic conditions for all the species of *Polylepis*, and the problem can only be solved by ecological and physiological investigation on this genus.

Recently, ELLENBERG (1979) reaffirmed his early theory that the *Polylepis* dwarf forests in the Altiplano of Peru and surrounding regions are remnants of a continuous evergreen woodland above the present montane forest. *Polylepis* is supposed to be one of the dominants in this woodland and would have declined by man interference clearing trees for pasture, timber and firewood, and also by domestic animals destroying the seedlings. Other authors (HUECK, 1972; SIMPSON, 1979; among others) oppose ELLENBERG's view, although recognizing that these small woodlands could have been larger than today.

In the last 30 years pollen analysis data have been accumulated for the Northern Andes in Colombia (VAN DER HAMMEN, 1974, 1979). They have shown that *Polylepis*-type of pollen started to be found in the Pliocene of the high plain of Bogotá and has been a constant element in the Quaternary high altitude

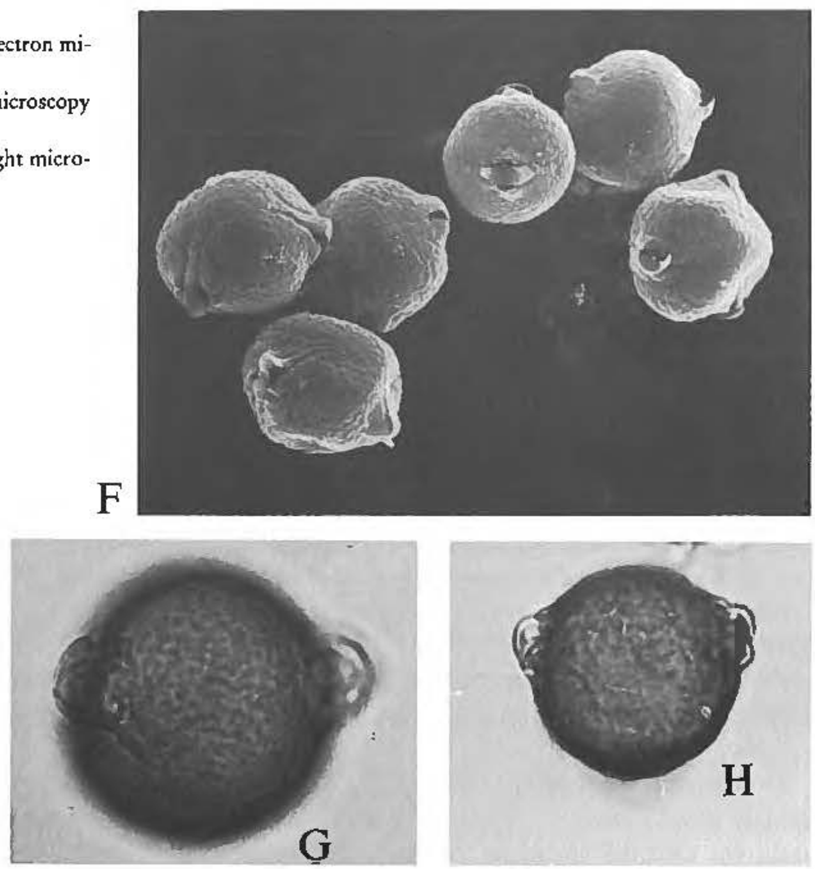

Fig. 12. Modern pollen grains:
F – *Polylepis incana* H. B. K., scanning electron microscopy photograph, x 700;
G – *Polylepis sericea* Wedd., light microscopy photograph, obj. x 40/1.0;
H – *Acaena cylindrostachya* R. & Pav., light microscopy photograph, objective x 40/1.0.

Table 2. Modern pollen grains of the genera *Acaena*, *Margyricarpus* and *Polylepis*, Measurements of the equatorial diameter in polar view.

	Collector	Average ($\bar{x}$)	95% Confidence Interval ($x \pm t \cdot s_{\bar{x}}$)
Margyricarpus pinnatus (Lam.) Ktze.	Asplund 6902	23.95	23.23–24.67
Acaena argentea R. & Pav.	Vareschi 5712	27.32	26.66–27.98
A. elongata L.	Badillo 913	28.40	27.37–29.43
A. cylindrostachya R. & Pav.	Baruch s/n	28.73	28.26–29.20
A. cylindrostachya R. & Pav.	Lasser & Adams 4489	28.92	28.28–29.56
Polylepis racemosa R. & Pav.	Hodge 6221	30.70	29.79–31.61
P. lanuginosa H. B. K. (*P. lehmanii* Hieron.)	M. Giler 2773	32.84	31.64–34.04
P. besseri Hieron.	B. Vuilleumier 468	33.32	32.54–34.10
P. australis Bitter	Schreiter 9814	33.52	32.82–34.22
P. incana H. B. K.	B. Simpson 8554 D	34.85	33.64–36.06
P. ciliata Maguire, Isotype	W. H. Camp E-2000	35.74	34.84–36.61
P. sericea Wedd.	Cuatrecasas 28145	36.21	34.89–37.53
P. sericea Wedd. (*P. quindiensis* (Cuatr.)	Cuatrecasas 23257	38.18	37.02–39.34
P. sericea Wedd.	Aristeguieta 7886	38.63	37.27–39.99
P. multijuga Pilg.	Hutchinson 6463	38.99	37.93–40.05
P. tomentella Wedd.	F. Schlegel 4815	39.28	37.58–40.98
P. quadrijuga Bitter (*P. boyacensis* Cuatr.)	Cuatrecasas 27834	41.22	40.16–42.28

sediments up to the Holocene. Toward the end of the Pleistocene it reached a marked maximum that is better observed in the sediments from Lake Fúquene (VAN GEEL and VAN DER HAMMEN, 1973). It declines at 20 600 radiocarbon years B.P. and disappears from the region after about 10 000 B.P. (VAN DER HAMMEN, 1974, Fig. 6). The pollen analysis of Quaternary sediments from several sites of the Colombian Andes (VAN DER HAMMEN, 1974, 1979, and literature therein) shows small maxima and minima of *Polylepis*-type probably indicating expansions and contractions of local *Polylepis* populations but, except for the Fúquene maximum, they do not indicate large forests because their percentage is always much smaller than the pollen sum.

It is difficult to distinguish between the pollen grains of *Polylepis* and those of the genus *Acaena*, which includes small shrubs and herbs of the páramo (VAN DER HAMMEN and GONZALEZ, 1960; HEUSSER, 1971; SALGADO-LABOURIAU, 1979; SIMPSON, 1979) (Fig. 12). Separation for several modern species was attempted using scanning electron microscopy (SMIT, 1978) and grain size (SALGADO-LABOURIAU, 1979). Table 2 presents pollen grain measurements of ten species of *Polylepis* compared with the andean species of *Margyricarpus* and *Acaena*. This table indicates that all the modern species of *Polylepis* studied have pollen grains significantly larger than those of the other two genera. Although both criteria of separation may be applied for recent sediments, they have to be used with care for old deposits. Nevertheless, if all the grains belonging to the Polylepis-type and found in Quaternary sediments are assigned to the genus *Polylepis*, they still do not reach the high frequency that allows the assumption of a continuous *Polylepis* belt above the cloud forest nor an evergreen woodland in which it was one of the dominants.

ELLENBERG's hypothesis that *Polylepis* "declined" in Perú by human interference cannot be applied to Venezuela. *Poylepis*-type of pollen is not abundant in post-glacial sediments from the Páramos of la Culata, Mucubaji, Laguna Victoria and Piedras Blancas (SALGADO-LABOURIAU and SCHUBERT, 1976, 1977; SALGADO-LABOURIAU, SCHUBERT and VALASTRO, 1977; RULL and SALGADO-LABOURIAU, unpublished).

Human settlements are unknown in the highest parts of the Venezuelan Andes prior to the arrival of the Spanish in XVI century. The region which is covered today by páramo vegetation was only used in short visits for religions purposes and probably as mountain paths to reach other low mountain regions

(WAGNER, 1967, 1979). Population was fairly large only after the Spanish invasion. Moreover, the pre-Colombian inhabitants of Venezuela had no herds of domestic animals, and European cattle was introduced in 1570 (WAGNER, 1967, 1979). Agriculture was practiced at elevations below 2000 m (ZUCCHI, 1973; WAGNER, 1973) which does not include the páramo region. Any change in the pollen assemblages from post-glacial páramo sediments prior to the last four hundred years are not caused by human interference. Any expansion or contraction of local *Polylepis* population or other montane vegetations would be climatically controlled, except for the possibility of pathogenic agents interfering in a specific plant, as suggested by M. B. DAVIS (1977).

Because of the absence or at least infrequent presence of man during post-glacial times, as well as the lack of domesticated animals during most of the Holocene, the Venezuelan páramos present a climatic model for the interpretation of other regions such as those of Perú and Equador where men and their large herds of camelidians (FLORES, 1979) had an important role for millenia in the modifications of plant communities.

Acknowledgments

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Summary

The results of the palynological studies of sediments from five different sites in the highest part of the Northern Andean mountains are discussed, and compared with modern assemblages.

The analysis from a fluvial terrace at 2490 m elevation shows that a humid gallery forest existed from 50 640 to 33 710 B.P. The pollen assemblages in all levels are dominated by *Alnus*, followed by *Podocarpus*, and spores of forest ferns; bamboo pollen is frequent in some levels. Glaciers have extended to 3000–3500 m elevation in the region. The Northern Andes was in a glacial period during the time, and the Tuñame gallery forest could have been a forest refuge area.

Information from 3500–4000 m elevation (in the páramo belt) shows that glaciers have retreated from Mucubaji valley at 12 650 B.P., and páramo vegetation started to establish at the region. The first elements to reach the newly deglaciated valley were *Montia*, and a few Compositae and Gramineae. Shortly after they were followed by Caryophyllaceae and *Lycopodium*. The other paramo elements started after. The same sequence is found in post-glacial sediments from Piedras Blancas at 4000 m elevation and in a Holocenic glacier retreat at 4760 m, in Colombia. These results indicate that the Mucubaji sequence represents the general pattern of colonization of newly deglaciated soils in the Northern Andes.

At altitudes from 3500 to 4000 m three cold phases with different degrees of humidity were detected during post-glacial time:

1. > 12 650–12 280 B.P. (relatively dry);
2. 11 700–11 000 B.P. (humid);
3. 6150 B.P. (dry).

A warm phase occurred from 12 250 to 11 900 B.P.

The paleoecological data suggest that the *Polylepis* dwarf forest could have been somewhat larger in some phases during the Quaternary, but they do not support the hypothesis of a continuous evergreen woodland above the present montane forest. Expansions and contractions of the local *Polylepis* populatins are mainly climatic controlled.

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Discussion to the Paper Salgado-Labouriau

Prof. Dr. W. Lauer:

Which interpretations of the *Polylepis*-problem result from your studies in Venezuela?

Dra. M. L. Salgado-Labouriau:

The results we have at present show that *Polylepsis* has not formed large extensions of forest at post-glacial times in Venezuela. *Polylepis* trees had probably grown as small woodlands isolated one from the other.

Prof. Dr. J. R. Flenley:

What was the change in temperature between the Mucubaji phase and the succeeding cold phase?

Dra. M. L. Salgado-Labouriau:

Mucubaji warm phase, characterized by a rapid upward displacement of the vegetational belt, possibly had an average annual temperature about the same as today (5.3 °C; average minimum of 1.9 °C; average maximum of 10.8 °C). The succeeding cold phase, with a retreat of the forest belt, perhaps was 2–3 °C below today average; but we need more sites to be sure.

Prof. Dr. B. Messerli:

The time of deglaciation was described with a radiocarbon data of about 12 500 B.P.
My questions are: When began the deglaciation, approximately, following your pollen diagrams?
Did the deglaciation begin at nearly the same time all over the Andes or were significant differences in time?

Dra. M. L. Salgado-Labouriau:

At 12 650 radiocarbon years B.P., the first pollen grains started to be deposited in peat sediments from Mucubaji. Before this date, only sand was found. Therefore, we believe deglaciation occurred shortly before 12 650 B.P., in this glacial valley. At present we have no other site analysed at this elevation (3650 m) to compare. Another site at higher elevation (4000 m) that is now beeing analysed shows a later date for the beginning of pollen deposition. The phases found in Mucubaji sediments are similar to those for the Columbian Andes (see VAN DER HAMMEN and collaborators); but there are not enough data for the Andes in general to answer the second question.

Miss J. M. Kenworthy, M. A.:

Can any participant in the discussion explain to me what is behind the assumption of a steeper lapse-rate in the past – throughout the equatorial zone, when the laws of physics and local topography must have at all times been relevant?

Dr. C. Schubert:

Concerning lapse-rates: lapse-rates may vary significantly from low elevations to higher elevations. So, it might be useful to subdivide lapse-rates into elevation segments.

Erdwissenschaftliche Forschung, Bd. XVIII, 295–306
Franz Steiner Verlag Wiesbaden GmbH · Stuttgart (1984)

Ecological Diversity and Human Settlements in the Tropical Northern Andes

Los Pueblos del Sur: A Pilot Project of Integral Analysis in the Cordillera de Mérida

Maximina Monasterio and Guillermo Sarmiento

With 10 Figures

1. Ecological Diversity in the Venezuelan Andes

Starting at the Colombian border, the main Andean belt in Venezuela extends for 450 km to northwest direction (Fig. 1). All along its length the cordillera has an average width of nearly 100 km. This huge continuous massif appears deeply dissected by large structural valleys that give rise to systems of parallel chains. Most of the population is concentrated along these valleys, particularly in the middle and upper parts. Here, a rich and diversified agriculture occupies the terraces and alluvial fans. Thus along the Bocono, Motatan, Chama and Mocoties rivers, stand Bocono, Valera, Timotes, Mucuchies, Merida, Tovar, Bailadores and other minor urban centres. Beyond these main valleys, most slopes and secondary valleys remain sparsely populated.

In the central part of the Venezuelan Andes, in Merida, the Chama-Mocoties valleys separate the Cordillera de la Culata, to the north, from the Sierra Nevada de Merida to the south. Our study area, Los Pueblos del Sur, occupies both slopes of the Sierra Nevada (Figures 1 and 2) to the northwest, that drains into the Chama river towards the Lake of Maracaibo, and to the southeast that is draind by several rivers descending to the Llanos, which is then collected by the Apure, one of the major tributaries of the Orinoco.

Los Pueblos del Sur are thus bordered on the northwest by the Chama and Mocoties valleys; the highest peaks of the Sierra Nevada: Humbolt, Bonpland and Bolivar, reaching 5000 m, close the region to the north; while a large transversal range, el Batallon, acts as its natural southern frontier. Towards the llanos, the only natural limit that imposes itself is one of human occupation, since settlements are restricted to the slopes above 1000 m. The whole lower slopes remain almost completely unoccupied. The area thus defined has a total surface of about 300 000 ha (Fig. 2).

Due to the wide altitudinal range in this section of the Andes (500 to 5000 m), together with the diversity of rainfall regimes, almost every type of tropical mountain environment can be encountered (Fig. 3). Under each major climatic type a particular altitudinal zonation of vegetation and land-use belts may be found (Sarmiento et al., 1971; Monasterio, 1980) (Figures 4 and 5). The constitutive elements of this zonation, as well as the precise altitudinal limits between them, vary in function of rainfall amount and its annual distribution. Thus, in the driest slopes facing the Chama valley, the vegetation sequence begins with a cactus shrub and ends with a dry type of paramo that already appears at 2500 m. In the moister areas of this same inner slope, most of the mountain side is covered by cloud forests (Fig. 6) that rise to 3300 or more meters, and that still remain mostly untouched because this area belong to the Sierra Nevada National Park. Above the cloud forest a wet type of paramo occurs, that is replaced higher on the slope by the Desert Paramo (Fig. 7), then by the periglacial desert and finally, above 4700 m, by the nival zone.

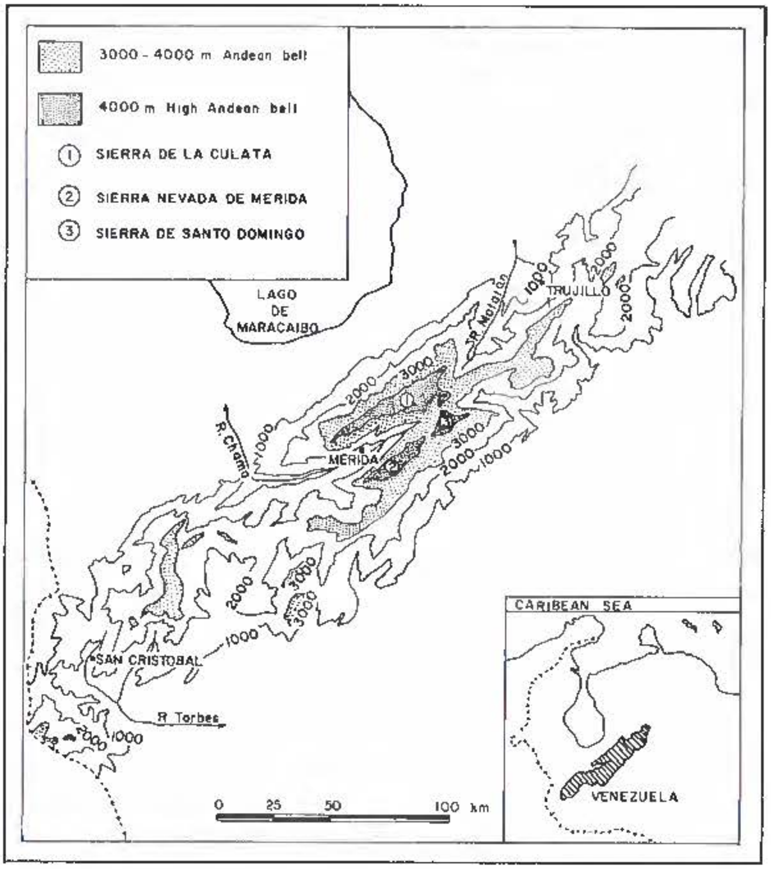

Fig. 1. Surface corresponding to different altitudinal levels in the Cordillera de Mérida, Venezuela.

Another sharp climatic contrast appears between the two slopes of this Andean chain (Fig. 8). The NW inner slope that drains into the Chama and Mocoties rivers, has a typical bimodal rainfall regime with two peaks of rainfall (April-May and September-October), while the SE outer slope, looking towards the llanos, shows an unimodal distribution, with a single annual peak in the midyear months and an accentuated drought from December to March (MONASTERIO and REYES, 1980).

Geology is another important factor which plays a major role in environmental diversity. Several geologic formations outcrop in this area, characterized as most mountain regions by a moving geological history (SCHUBERT, 1980). The main contrast in habitat condition for vegetation and cultures arise from

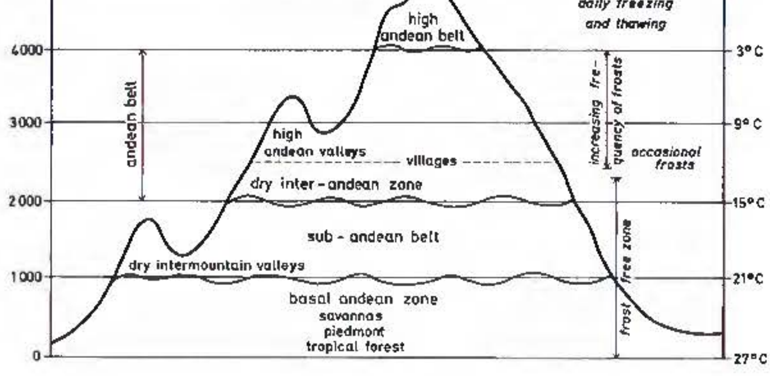

Fig. 3. Idealized profile of altitudinal zonation in the Cordillera de Mérida. The human population, distributed in "islands", is primarily in the two valley zones of Andean and sub-Andean belts (after MONASTERIO, 1980).

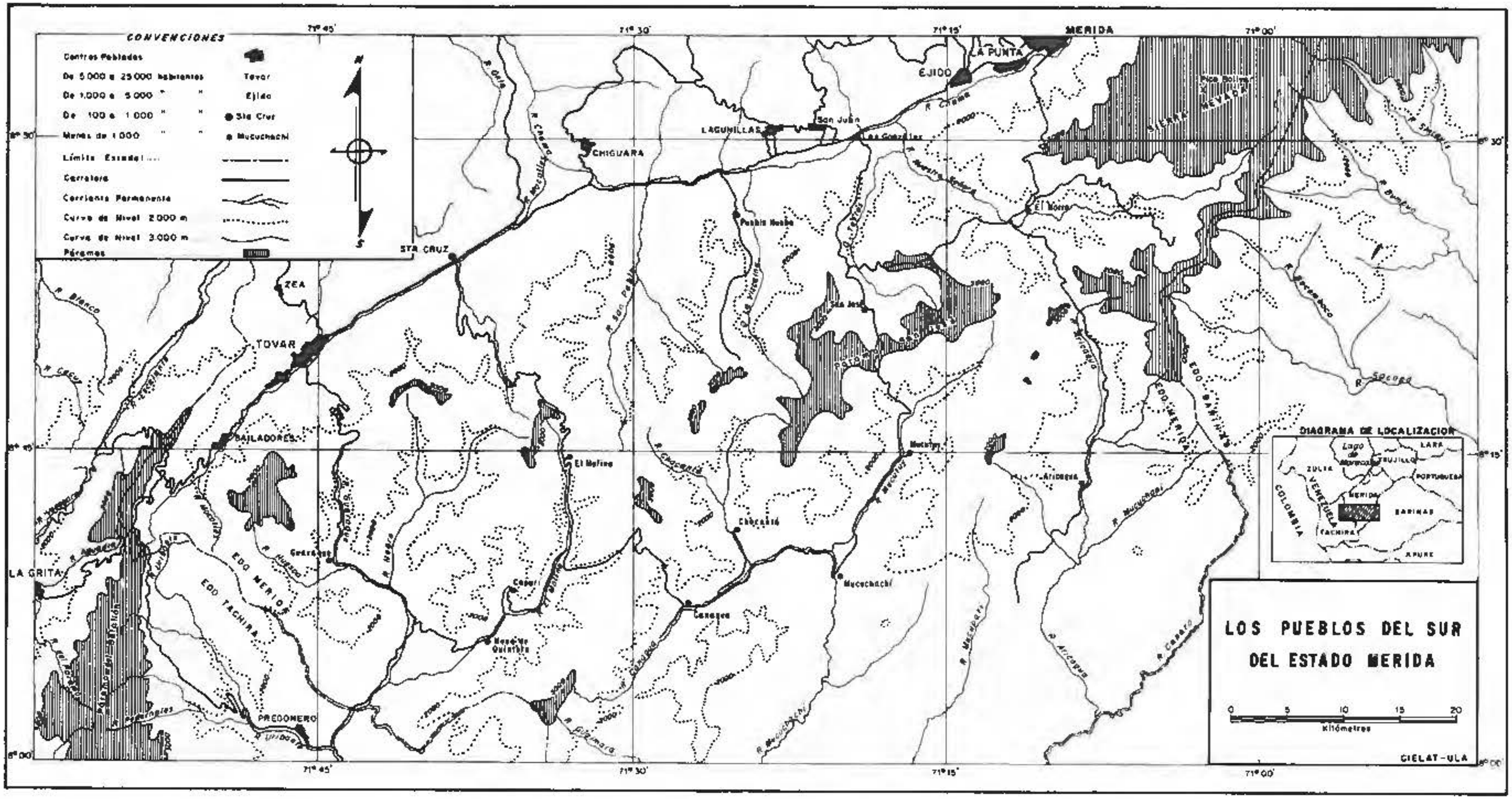

Fig. 2. Area of Los Pueblos des Sur de Mérida.

the occurence of three quite different rock types: metamorphic rocks, mostly gneisses and schists, giving rise to a massive relief; hard sedimentary rocks, like conglomerates and sandstones, that produce a contrasted faulted relief of crests and monoclines; while softer sedimentary rocks, such as shales and limestones, produce a gentler topography where deeper soils may develop. In this way, lithological influences through its effect on structure and differential erosion, the kind of surface modelling, the degree of soil development and hence the possibilities of land utilization (MESSER, MONASTERIO and SARMIENTO, 1982).

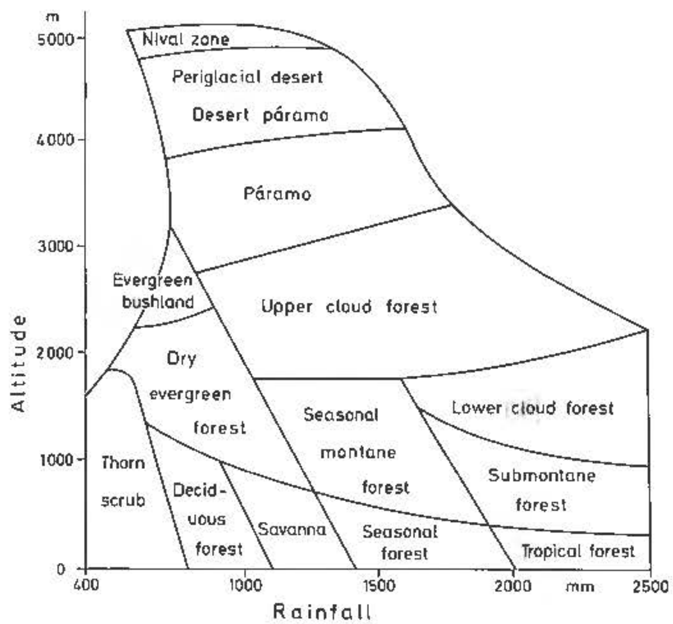

Fig. 4. Wide diversity of primary ecosystems existing in the northern tropical Andes (Cordillera de Mérida), according to altitudinal and rainfall gradients.

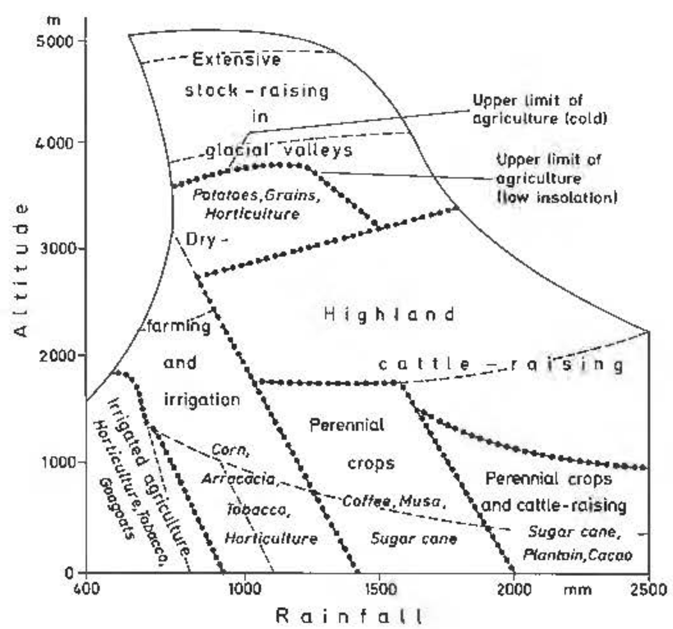

Fig. 5. Main land-use patterns in correlation with primary ecosystems existing in the Cordillera de Mérida (compared with Fig. 4). Thus, in the cloud-forest area, we have cattle raising for milk and meat production, the seasonal montane forest corresponds to perennial crops, mainly coffee, etc.

2. General Outlook and Some Key Methodological Premises

The primordial aim of this project, already in progress, is an ecological and socioeconomic study of the Pueblos del Sur in the Cordillera de Merida (see Fig. 2). This should provide a basic contribution to the establishment of developmental policies in harmony with the natural environment having their main focus on the stabilization of the local population and the improvement of their living conditions.

The Pueblos del Sur constitutes an area of striking regional individuality resulting from both eco-geographic factors and the historical development of its economy. Until very recently this area was relatively isolated from the macroregional context, even considering the isolation patterns characteristic of the high Andean valleys. Modernization is just beginning and most of the area remains as a marginal zone of traditional agriculture. However, public works are already in progress: roads, electricity, irrigation, etc. They will certainly lead to a dramatic change in all aspects of rural life. For this reason it becomes still more urgent to undertake an integral study that might lead to further knowledge of the overall regional picture of its agricultural systems, the local technologies and their ecological rationality. It is also important to study the possible alternatives created by better access to regional and national markets, the intensification of land use, and new pressures upon natural resources.

Furthermore, this region shows a diversity of temperature and other agroclimatic conditions given by the extension of its altitudinal belts. These range from the tropical lowlands in the Andean piedmont to the coldest paramos bordering the snowcovered peaks. The diversification of agroeconomic activities

Fig. 6. A view of the cloud-forest at 3000 m, in the Pueblos del Sur.

Fig. 7. A view of the Desert Páramo ecosystem with *Espeletia timotensis* at 4200 m in the Cordillera de Mérida. Snowfall is frequent at this altitude.

made possible by this rich variety of natural environments the relative persistance of production and conservation, and of local cultivars, render particularly interesting. It is especially important to analyze and characterize these systems or to define the conditions under replacement by socially more productive forms could be envisaged.

It is also worth emphasizing that, even if the traditional practices of management have allowed a relative equilibrium of the local environments and ecosystems, the strong slopes prevailing everywhere in this high mountain area, together with the climatic stresses to which it is normally subjected, determine the potential fragility of most natural and secondary ecosystems. Every technological innovation and infrastructural work has to be based on a thorough knowledge of the dynamics of the ecological units.

One of the most important elements considered in this project refers to the human resources of the region. Its peasants, heirs of aboriginal and hispanic traditions, remain warmly attached to the land. In spite of their isolation, they were open to trade both during the colonial and the republican periods. Any developmental programme must therefore take into account local traditions and feelings, avoiding the mechanical extrapolation of experiences and results coming from completely different socio-cultural backgrounds. High priority will be given to promote policies whose main objective is the well-being of the local peasantry and the maintenance of a long-term natural and social equilibrium.

To cope with the forementioned premises, it becomes absolutely necessary to implement methodologies ad hoc, adapted to the tropical mountains of Latin America. A multidisciplinary approach is essential, where the various personal and institutional participants can integrate their viewpoints and abilities in a process of mutual learning and gradual self-correction leading to the improvement of the whole team. Many methodologies are supposed to use an integral approach to regional problems as a basis for agricultural planning and rural development, but apparently none of them are entirely satisfactory nor have they resulted in direct application to all real situations. In our case, the existing agricultural systems, as well as the environmental conditions and the natural ecosystems, suggest the need for a global systemic approach rooted in a solid understanding of the physico-natural and socio-historical factors. From these factors may be derived the most rational alternatives to improve land-use and increase land and human productivity. We will try to set out, and to test in practice, certain methodological principles that could be applied by a small multidisciplinary and interinstitutional team. These principles could be adapted to the previous knowledge and to the working conditions of the tropical Andean environments. The two institutions already engaged in this project are the FONAIAP (National Organization for Agricultural Research), and the CIELAT (Center for Ecological Research of the Los Andes University).

One of the major interests of the project may lie in its possible value for future programmes of regional analysis on a large scale, by demonstrating an integrated approach, focused towards a clearly established practical goal. Quite often the programmes of rural development or regional planning, in Latin America and elsewhere, have neglected the ecological processes and constraints, either by lack of pertinent information or by straightness of vision, thus imposing a heavy handicap to the success of the project. On the other hand, regional analysis undertaken on sounder ecological basis have suffered from a distinctly academic bias. Scale problems are also evident, many studies are designed on such an excessively small scale that makes them useless for regional planning in mountain areas.

3. Patterns of Settlement and Land-Use

According to the figures of the last available National Census (1971) the total population of the Pueblos del Sur was approaching 40 000. In this essentially rural area, a dual pattern of human settlement appears: an archipelago of small villages together with a sparse population of isolated farms. There are about 30 villages, that in the humid areas always lie in valleys between 1200 and 1800 m. In the drier zone, where valley bottoms are excessively dry, most settlements stand on slopes between 1600 and 2800 m. In any case they range from small groups of a few houses to villages of a few hundred inhabitants.

Human occupation in the Pueblos del Sur follows divergent historical patterns according to agricultural possibilities given by the ecological conditions. On dry slopes, wheat (Fig. 9), seconded by other temperate-zone grains, constituted the major market crops. During most of the colonial period, and in spite of the non-existence of carriage roads, this area exported wheat not only to regional markets in the Andes

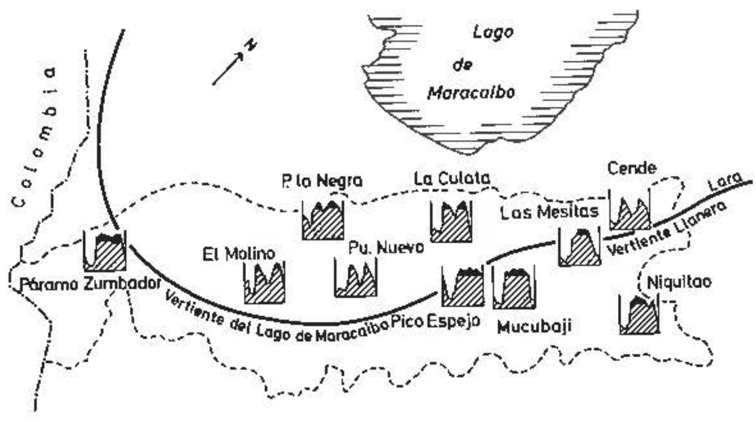

Fig. 8. Diversity of rainfall patterns in the Venezuelan Andes. Northwestern slopes show a bimodal rainfall distribution, while southeastern slopes show the typical unimodal tropical regime, with a dry season from January to March.

Fig. 9. Ancient wheat village at 2700 m in the Cordillera de Mérida. the wheat system is relictual and persists on dry slopes. There is a clear trend towards diversification and market crops beginning in alluvial fans.

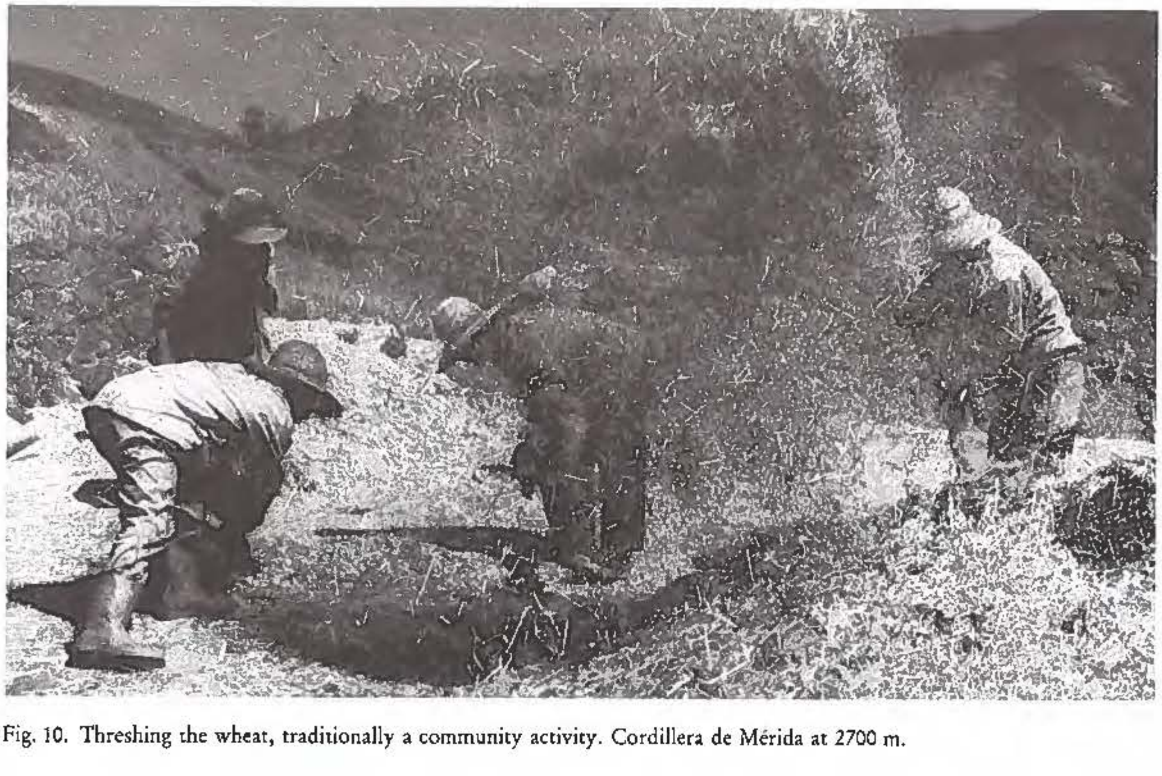

Fig. 10. Threshing the wheat, traditionally a community activity. Cordillera de Mérida at 2700 m.

but even to Maracaibo and through this port to other regions. In the last decades of the nineteenth century, this wheat cycle was replaced by the coffee cycle. Coffee is cultivated in the Seasonal Montane Forest. Nowadays, wheat appears as a relictual crop directed mostly to self consumption (Fig. 10). During many periods, smallholders maintained a subsistence agriculture on these dry slopes, but recently modernization has progressed slowly through a diversified agriculture oriented to regional and local markets. Maize, blackbeans, arracacia, garlic, carrots, stand among the principal crops.

The southeastern slopes, as well as the moister inner slopes draining into the Mocoties, were colonized much later than the drier areas that already maintained aboriginal populations before the Spanish conquest. Until coffee cultivation and export came to play a significant role in the last decade of the century, most of these humid slopes remained sparsely populated. The coffee cycle persisted until the world crisis of 1930 that, together with the oil boom, induced dramatic changes in the whole Venezuelan society. Nowadays coffee production, complemented by subsistence crops, is regaining importance, but a new boom in horticulture results from ease of access to the national market and modernization. Most of the fertile alluvial soils are dedicated to a variety of crops like potatoes, onions, garlic, carrots, and many other vegetables, i.e. market gardening.

We have to recall here the fact that the Andes was not only but still remains, a major area of coffee production in Venezuela. However because of its unique agroecological conditions given by its mountain climates within a predominantly tropical warm country, the high andean valleys represent the sole area where many temperate crops become possible. In this way, this mountain areas, in spite of adverse slope conditions, become the necessary complement to the tropical agriculture of the warm lowlands.

Finally, a recent trend clearly apparent in the Pueblos del Sur, as in many other highlands in Venezuela, is the tremendous expansion of cattle raising on lands gained from the mountain forest. This upwards extension of rangelands not only changes the whole economic picture of the region, but also is subjecting the high ranges to new pressures of unpredictable consequences. Thus, the development of large hydroelectric projects points out the incompatibility between stockraising in the catchment areas and large dams and water reservoirs in the middle and low basins.

4. Some Objectives of this Research Project

a) Delimitation, characterization and mapping of the regional ecological units.
b) Identification and evaluation of the physical and biotic factors conditioning or limiting the use of natural resources in each ecological unit.
c) Inventory of the agricultural systems by ecological units.
d) Farm typology definition, characterization and analysis of agricultural systems.
e) Understanding of the regional agrarian systems on the basis of the existing agricultural systems and their interrelationships.
f) Analysis of the interrelationships between ecological factors, and agroeconomic structure and use of natural resources.
g) Identification of socioeconomic factors affecting or promoting the efficient utilization of natural resources in this region.
h) Analysis of the impact of past and present land-use practices on the stability of the ecosystems.
i) Consideration of the local technological traditions and their ecological and economic rationality.
j) Evaluation of possible impacts of new agronomic technologies on the agricultural systems, agroecosystems and natural ecosystems.
k) Analysis of the ecological, economic and social consequences of various infrastructural works undertaken in the last years: roads, irrigation systems, education and health-care centers, etc.
l) Discussion of methodological principles applicable to the agroecological zonification and agroeconomic analysis of tropical mountain regions.

5. Some Final Remarks on Methodology

During the last two or three decades, the problems posed by developmental urgencies in many regions, particularly in the underdeveloped countries, initiated the search for appropriate methodologies that could afford a rapid and efficient gathering of relevant information to sustain governmental or private actions. Though many useful tools were increasingly available, especially in the field of remote sensing, a lot of unsolved problems remained in this multidimensional research area.

The actual knowledge on climates, morphodynamics, soils, ecosystems and many human and social aspects, is so fragmentary that even guiding principles, not to speak of hard facts of scientific laws, are difficult to support or extrapolate. Obviously the underdevelopment also has a scientific dimension. This lack of hard facts and quantitative data is still more dramatic in tropical or in mountainous regions. Probably, the mountain regions of tropical countries accumulate the most handicaps.

It is our intention in this project to start with a quite restricted goal, taking into account the sea of ignorance around us. Our aim is to analyze a few aspects in a particularly restricted area that by its near location to our daily activities could be carried out by a small team having some previous experience both in the area and in the general ecological, agricultural and socioeconomic problems.

Two rather divergent types of approach have been followed in regional land and resources inventories. One is multi-sectorial approach, where specialists analyze each component of the natural and social environment. Once the sectorial aspects have been accomplished more or less independently, all this information is added in some way to produce an a posteriori synthesis. These seems to have been the methodological guiding principles in some ambitious and successful programmes carried on in various countries. Perhaps the best example might be the RADAM BRASIL program of inventory of natural resources in the huge Amazonian region of that country.

The second alternative is to start with a synthetic viewpoint, delimiting units resulting either from physico-natural conditions or from social pressures. That is, to have a first reading of the landscapes to be used later in the analysis and characterizatiou of factors and processes. The leading thread towards a synthesis has been land forms in the CSIRO methodology (CHRISTIAN and STEWART, 1963); natural vegetation in many European mappings; surface dynamics in the ecographic approach of Strasbourg (TRICART and KILIAN, 1979); or the global landscape as a product of environment and people in their actual and past actions in some geographic approaches (BERTRAND, 1970).

This approximation to integral regional analysis through an initial synthetic lecture of the landscape continued by a further analysis leading to a new synthesis, seems more adequate to small projects involving a reduced multidisciplinary team and limited resources. On the other hand, it may be argued that this synthetic approach would be more adequate than the multisectorial one, in mountain regions where all factors physical, biotical and social, are strongly linked with each other.

The system we propose to follow is one of successive approximations through interdisciplinary discussion of the conclusions obtained during each stage of the research work. It may be started with a preliminary delimitation of homogeneous landscape units through both interpretation of remote imagery and field work. Then each unit is sampled in its natural parameters and in its agroeconomic organization. The sampling may lead to some reinterpretation of units and may suggest the consideration of some previously neglected factors or processes. The zonification is thus improved and further data collection is suggested. Within this process, various kinds of information are pooled, from field data to imagery interpretation, from available statistics to questionnaires submitted to rural producers or other qualified informers, from various laboratory data to a collective discussion with landowners in their villages.

In this way, the art of regional ecological analysis, taking the word ecology in its wider and wiser sense, may be developed through a gradual process of learning and giving, what we hope would lead to a deeper understanding of this fascinating world of the Tropical Andes.

Acknowledgements

We thank Dr. LAUER and Dr. MESSERLI for their kindly invitation to attend the Symposium: "Man and Environment of Tropical High Mountains".

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Discussion to the Paper Monasterio

Dra. M. L. Salgado-Labouriau:

I find your project very interesting. I would like to ask if the rural settlements in the area have remained fairly stable or if they have expanded in the last 50 years.

Prof. Dra. M. Monasterio:

According to the various populations censuses (the last one in 1981), the total rural population in the Pueblos del Sur remained fairly stable during the last 50 years in spite of the large migration to other regions of the country. Various processes of internal displacement are also apparent, such as the seasonal or permanent migration from the relictual wheat system to the more dynamic coffee system or even to the expanding cattle raising areas in the Cloud Forest belt. These migratory currents were compensated by the high rates of population growth and the improved health conditions.

Prof. Dr. B. Ruthsatz:

Is there some knowledge about symbiosis between species of *Espeletia* and fungi, such as some type of mycorrhiza that could improve the uptake of mineral nutrients?

Prof. Dra. M. Monasterio:

Preliminary observations suggest the occurence of mycorrhiza in several species of *Espeletia*. This may obviously constitute a great selective advantage for species colonizing páramo environments where nutrient supply may be critical.
Specialists interested in a more systematic approach to this relevant problem are certainly needed.

Prof. Dr. W. Eriksen:

In what concerns your first map, why there are no páramos southward from Peru, at least on the eastern, more humid, Andean slopes?

Prof. Dr. M. Monasterio:

In our map (not published), we show the páramos extending from 11 °N, in the Sierra Nevada de Santa Marta (Colombia) to 8 °S in northern Peru. These limits frame the páramos in equatorial or mostly equatorial areas – where they occur as islands conforming a continental archipelago. Southwards from 8 °S, the high tropical moutain appears as a more continuous area, drier and less equatorial. Even if the eastern slopes are wetter, as in the case with the Peruvian Jalca zone, we prefer to relate these systems to the punas. Both types of formations: punas and páramos occur inside wide humidity gradients, therefore we do not emphasize this aspect as a basis for their ecological distribution. There are quite dry páramos, with 600 mm of rainfall, in the Cordillera de Mérida.

Then, to represent the continental extension of punas and páramos, we rely more on the particular features, structural and functional, of both types of ecosystems, as well as on the actual or potential land-use patterns.

Prof. Dr. F. Klötzli:

The parallelisms between Andean and East African Páramo vegetation are well known. But less thought has been given to special adaptations of typical Páramo organisms (e.g. *Espeletia, Senecio, Lobelia*). There must be a special reproduction or regeneration strategy, because in certain cases (as in Ethiopia with *Lobelia thynchopetralum*) such organisms are more or less growing solely under extreme solifluction conditions. Are details known from Venezuela concerning their regeneration?

Prof. Dra. M. Monasterio:

In the Cordillera de Mérida, all species of *Espeletia* growing in the Desert Páramo (that is above 4000 m), reproduce only sexually. We undertook a detailed analysis of their reproductive cycles and annual phenodynamics using permanent plots along a period of seven years (1976–1983). Some forms of vegetative regeneration by means of basal stems have been observed in species of *Espeletia* that occur at lower elevations (3000-3800 m).

Given that the solid surface maintains the most extreme habitat conditions in the Desert Páramo (daily frost cycles), with the related phenomena of solifluction and cryoreptation, it seems that all species of *Espeletia* have avoided a concentration of their biomass in the lowest, most unfavourable layers, exhibited by the contrary one upright life form and very sparce distribution pattern, in a similar way to that showed by the high-altitude Ethiopian Lobelias. Other characteristic features of the reproductive patterns of these species are presently under analysis and will be the subject of a coming publication.

Prof. Dr. W. Lauer:

Which climatic conditions characterize the individual páramo-types mentioned by you?

Prof. Dr. M. Monasterio:

In the Andes of Mérida it is possible to fix at about 4000 m the lower limit of undoubted periglacial features. This level marks the boundary between two clearcut ecological zones: the Andean belt, downwards, and the High Andean belt, towards the summits. The Desert Páramo corresponds with the periglacial belt of low latitude mountains where frost action and daily cycles of freeze-thaw promote specific geomorphogenetical processes and soil movements of deep ecological consequences. This climatic effects are reinforced by the open nature of the vegetation cover, giant rosettes of *Espeletia*, that leaves large areas of bare ground, favouring thus the rapid cooling and heating of the soil surface that lead to daily cycles of freeze and thaw along most of the years. Below 4000 m, the Desert Páramo is replaced by various páramo formations characterized by a continuous vegetation cover. Frosts in this belt are either mostly seasonal phenomena or they occur sporadically.

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Zur klimaökologischen Stellung der Gattung *Araucaria*

Winfried Golte

Mit 7 Abbildungen

Unter den heute lebenden Coniferengattungen ist *Araucaria* eine der phylogenetisch ältesten, wenn nicht *die* älteste überhaupt (vgl. FLORIN, 1963). Früheste, noch spärliche Funde stammen aus der späten Trias, doch schon vom unteren Jura an ergeben die fossilen Nachweise ein zwar disjunktes, jedoch – über die langen Zeiträume hinweg – bis ins Tertiär hinein bemerkenswert konsistentes und stetiges Verbreitungsbild, dem sich auch die lebenden Vorkommen zwanglos anfügen (Abb. 1). Araukarien beherrschen – zusammen mit Podocarpaceen – vom Jura an die südhemisphärische Coniferenflora. Mit der Verbreitung ihrer gegenwärtig 19 Arten erscheint die Gattung als rein südhemisphärisch, sie war jedoch entweder selbst oder mit einem ihr sehr nahestehenden Genus im Mesozoikum auch auf der Nordhalbkugel verbreitet. Das hohe Alter der Gattung wird durch die Tatsache unterstrichen, daß sich noch deren lebende Vertreter in ihren vegetativen Organen durch eine Anhäufung primitiver Merkmale auszeichnen. Im Habitus zeigen Araukarien, namentlich *A. heterophylla* (= *excelsa*) von der Insel Norfolk auffallende Übereinstimmungen mit den sog. Urconiferen (Sammelgattung *Walchia*) des Jungpaläozoikums. Auch im Feinbau des Holzes (Xylotomie) vertreten die Araukarien (und die Schwestergattung *Agathis*) einen Urtypus, wie er in den Gymnospermenhölzern jener Zeit auftritt und bei keiner anderen lebenden Coniferenfamilie mehr erhalten ist (GREGUSS, 1955).

Angesichts dieser Befunde liegt es nahe, die heutige Verbreitung der Gattung *Araucaria* einmal im Hinblick auf die zugrundeliegenden Gesetzmäßigkeiten zu untersuchen und die Frage zu stellen, wieweit diese Ausdruck vorzeitlicher Verbreitungsverhältnisse sind. Damit sollen Gedanken weitergeführt werden, die ich in früheren Arbeiten zur Coniferenflora der Südhalbkugel (GOLTE, 1978 a) und in einem ökologischen Vergleich der beiden in Südamerika heimischen Araukarien (GOLTE, 1978 b) niedergelegt habe. Da die Ergebnisse der letztgenannten Arbeit in besonderer Weise Ausgangspunkt der nachfolgenden Betrachtungen sind, müssen sie hier zunächst kurz resümiert werden.

1. Ökologischer Vergleich von *Araucaria angustifolia* und *A. araucana* in Südamerika

A. angustifolia (Abb. 2) hat ein recht großes Verbreitungsgebiet im südlichen Brasilien und dem angrenzenden argentinischen Territorium Misiones. 2000 km davon entfernt, in den chilenisch-argentinischen Anden, befindet sich das viel kleinere Areal von *A. araucana*. Der ökologische Vergleich beider Arten drängt sich vor allem deshalb auf, weil sie in der Systematik einander sehr nahe stehen[1], die klimatischen Bedingungen in ihren Verbreitungsgebieten aber auf den ersten Blick gegensätzlich zu sein scheinen. *A. angustifolia* gedeiht am äquatorwärtigen Rand der Subtropen bei – jedenfalls im größten Teil des Areals – überwiegenden Sommerniederschlägen. Umgekehrt befindet sich das Areal von *A. araucana*

[1] Beide Arten bilden innerhalb der Gattung die Sektion *Colymbea*, die sich von den anderen Sektionen vor allem durch die relativ großen Nadelblätter und Zapfen (und Samen), sowie hypogäische Keimung unterscheidet.

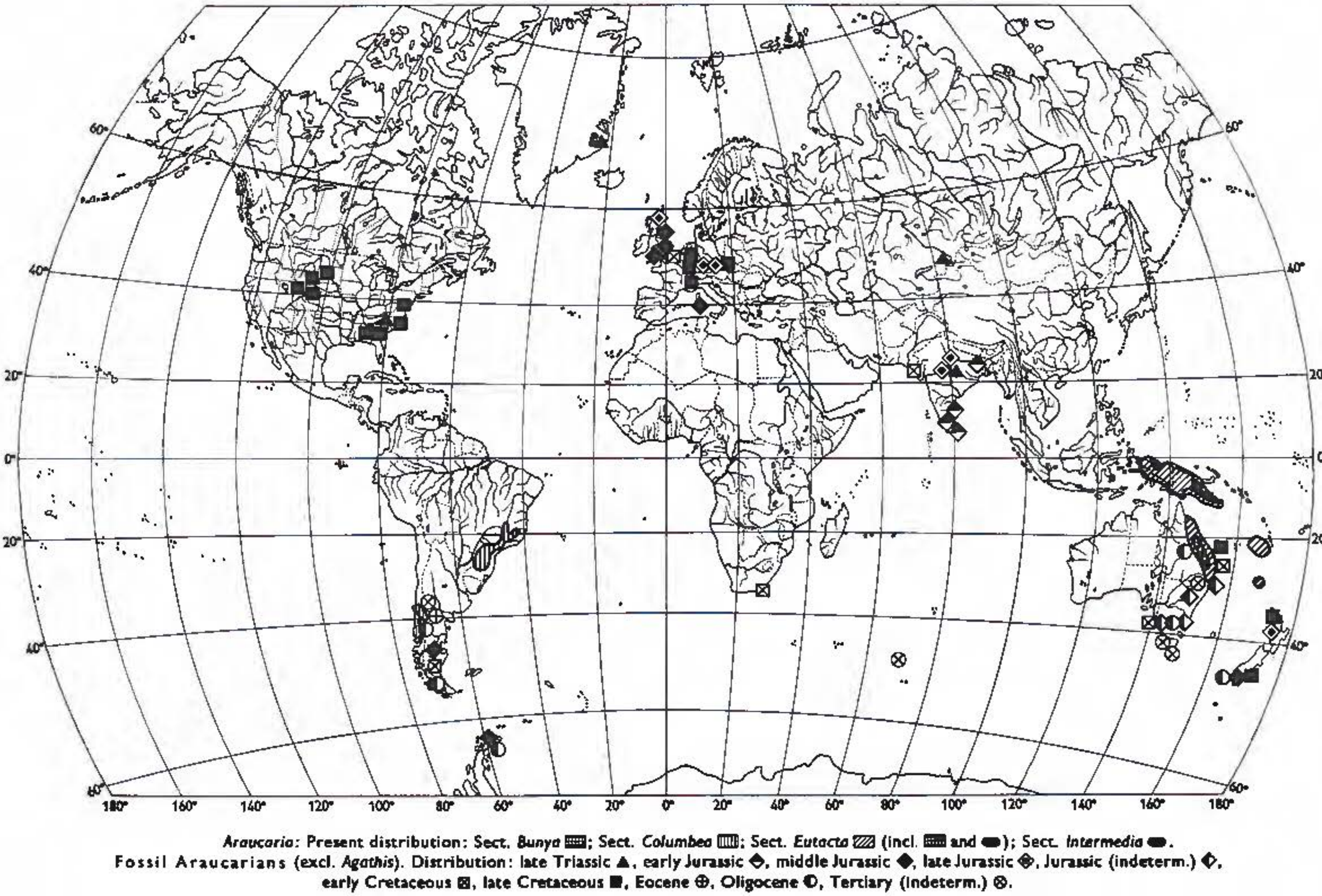

Abb. 1. Heutige und frühere Verbreitung der Gattung *Araucaria;* aus: FLORIN, 1963. (Present and past distribution of *Araucaria;* from: FLORIN, 1963).

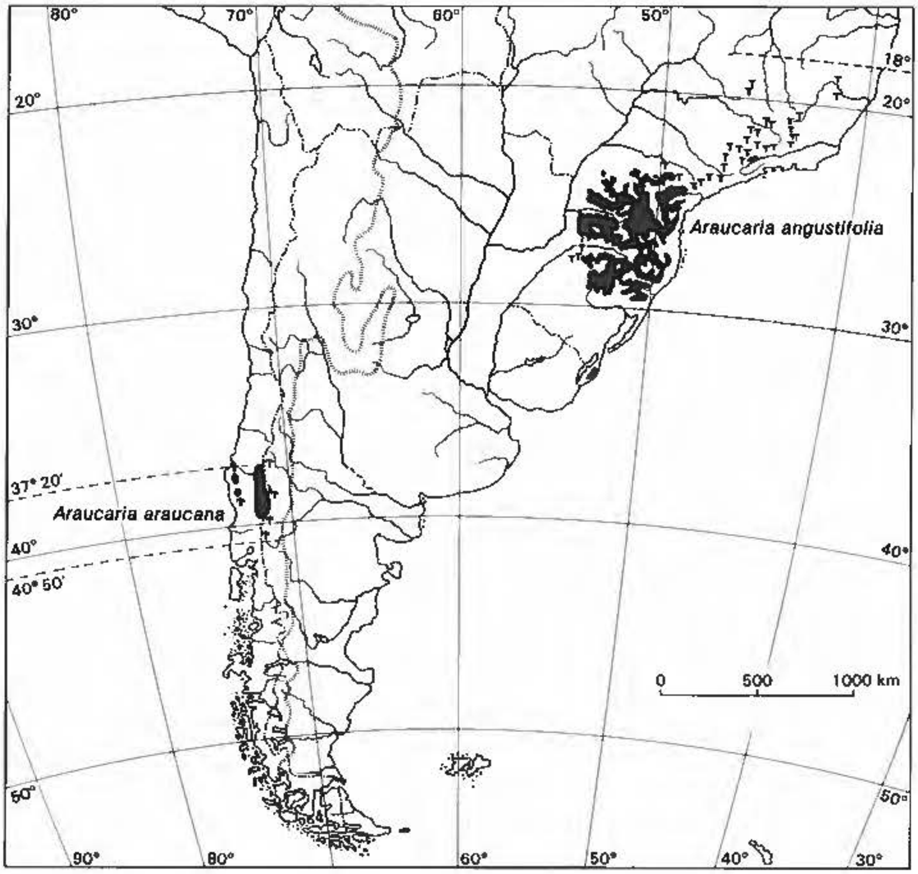

Abb. 2. Die Verbreitung von *Araucaria angustifolia* und *A. araucana* in Südamerika; aus: GOLTE, 1978 b. Kleinere Vorkommen sind durch Baumsymbole dargestellt.

(Distribution of *Araucaria angustifolia* and *A. araucana* in South America; from: GOLTE, 1978 b. Smaller occurences are represented by tree symbols).

am polwärtigen Rand der Subtropen im Übergangsbereich zur außertropischen Westwindzone, d. h. in einem Gebiet mit überwiegenden Winterniederschlägen.

Sehen wir uns zunächst die Verhältnisse bei *A. angustifolia* genauer an. Ihr Areal scheint die Grenze der Tropen (v. WISSMANN, 1948) geradezu zu „verhüllen", d. h. es liegt in einem Gebiet, das in sich tropische und außertropische Züge des Klimas vereinigt. Tropische und außertropische Zirkulation treten hier in Wechselwirkung.

Dies zeigt sich zunächst bei den Niederschlägen. Um deren jahreszeitlichen Gang zum Ausdruck zu bringen, habe ich in einem Meridionalschnitt längs durch das Areal den prozentualen Anteil der monatlichen Niederschläge an der jeweiligen Jahressumme dargestellt (Abb. 3). Wir sehen, daß sich innerhalb der Araukarienregion als Folge der Beteiligung von tropischer und außertropischer Zirkulation eine Umkehrung der jahreszeitlichen Niederschlagsverteilung vollzieht. Im Sommerhalbjahr kommt es, und zwar mit polwärts abnehmender Häufigkeit und Intensität, zu ergiebigen Niederschlägen vorwiegend konvektiven Typs, während im Winterhalbjahr, und zwar mit äquatorwärts abnehmender Häufigkeit und Intensität, außertropische Zyklonalniederschläge auftreten. Im Winter wird das vom atlantischen Subtropenhoch geprägte stabile Wetter immer wieder – etwa allwöchentlich – von instabilem Wetter mit Niederschlägen abgelöst, die den Durchzug einer Kaltfront begleiten. Diese Kaltfronten setzen auch bei den winterlichen

Temperaturen einen außertropischen Akzent (Abb. 4). Generell ist festzustellen, daß *A. angustifolia* nur dort vorkommt, wo die Mitteltemperatur mindestens eines Wintermonats 13 °C nicht übersteigt. Dazu kommt aber auch eine gewisse Häufigkeit von Frösten und sogar Schneefällen. Winterliche Niederschläge, Frost- und Schneefallhäufigkeit sind am größten im südlichen Teil der Araukarienregion. Und von diesen Bedingungen ist es nur noch ein Schritt zu den Verhältnissen, unter denen *A. araucana* in den Südanden gedeiht.

Das Diagramm der dort gelegenen Station Lonquimay (Abb. 5) zeigt ein ausgeprägtes Wintermaximum der Niederschläge, die in dem obersten Waldgürtel, in dem die Art auftritt, großenteils als Schnee fallen und zu einer mächtigen – bis über 2 m hohen – Schneedecke führen. Der Schnee hat nun verschiedene ökologische Konsequenzen. Erstens schützt er den Boden vor der Einwirkung der – gelegentlich sogar unter – 20 °C reichenden – tiefen Lufttemperaturen, so daß es zu keiner ausgeprägten Bodengefrornis, mithin auch zu keiner Sistierung der Assimilationstätigkeit kommen kann. Zweitens führt der Schnee zu einer Speicherung des Winterniederschlags und – da er erst im Frühsommer (Dezember/Januar) völlig abtaut – damit zu einer Annäherung des Optimums der Bodenfeuchte an das thermische Optimum.

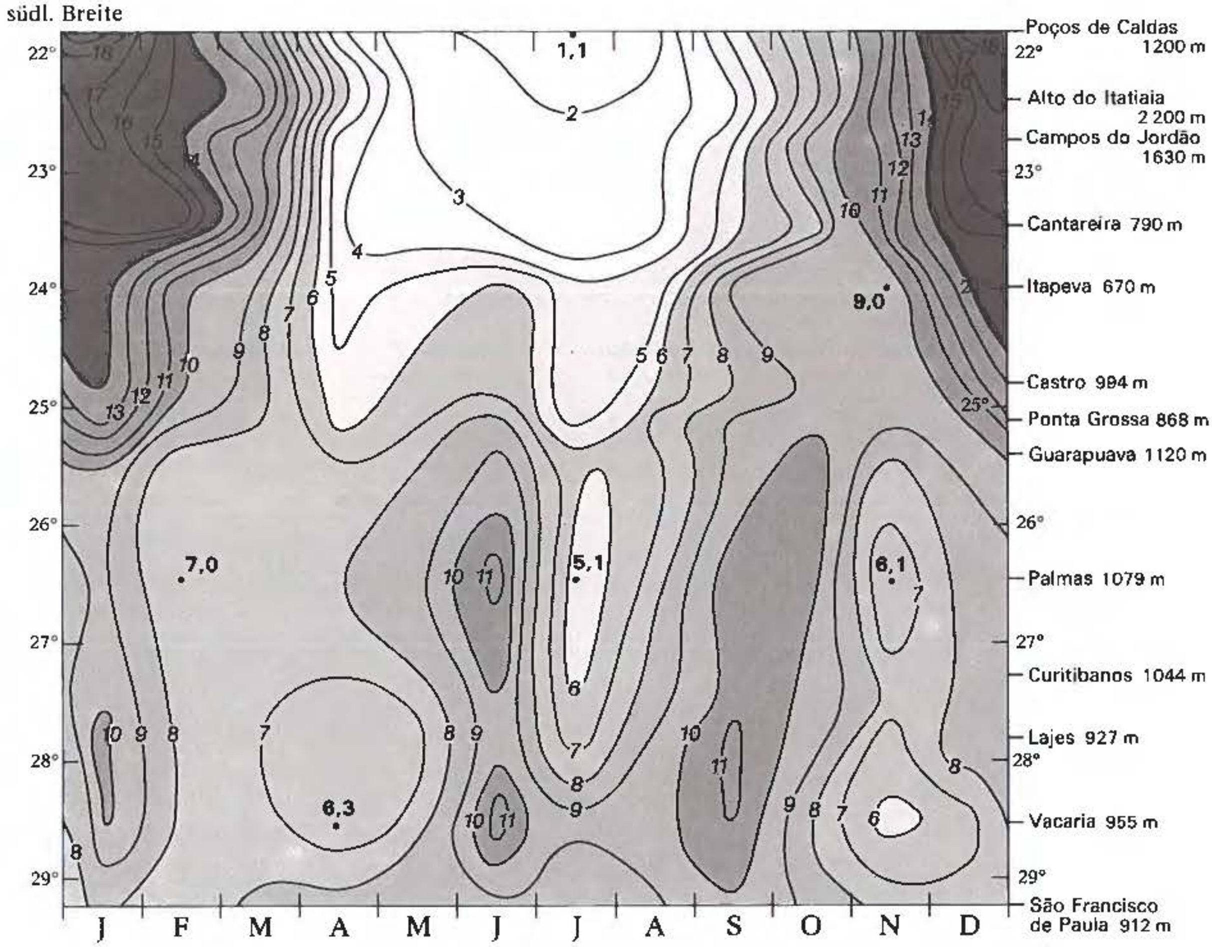

Abb. 3. Die jahreszeitliche Verteilung des Niederschlages in der Araukarienregion Südbrasiliens, dargestellt in Prozent der Jahressumme entlang eines Stationenschnittes zwischen 22° und 29° s. Br.; aus: GOLTE, 1978 b.

(The seasonal distribution of precipitation in the Araucaria region of Southern Brazil, presented as percentages of the annual total along a cross section of stations between 22° and 29° South; from: GOLTE, 1978 b).

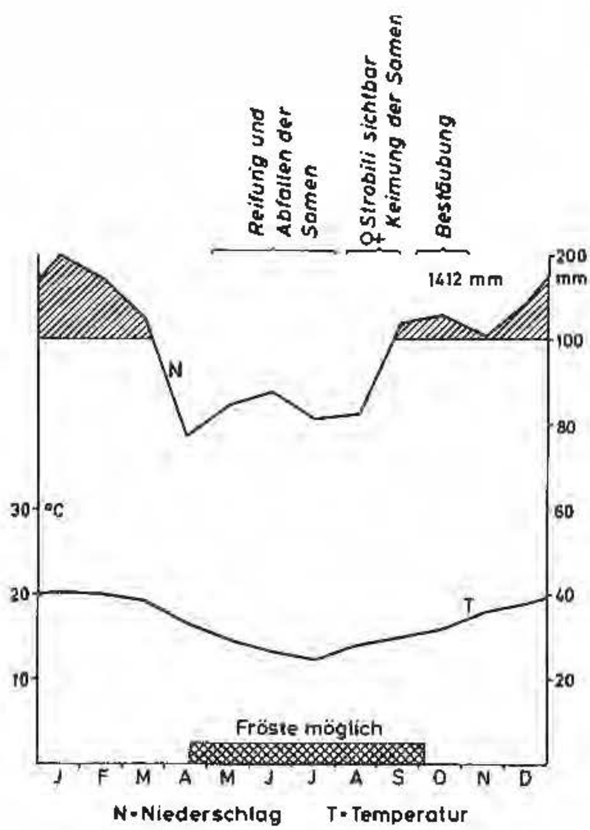

Abb. 4. Jahreszeitlicher Gang des Klimas (Station Curitiba, 25°26′ s. Br., 49°14′ w. L.; 959 m) und reproduktiver Zyklus bei *Araucaria angustifolia* (die angegebenen Zeiten gelten etwa für den mittleren Abschnitt des Verbreitungsgebietes); aus: GOLTE, 1978 b.

(Seasonal Course of the climate (station Curitiba, 25°26′ s, 49°14′ w; 949 m) and reproductive cycle of *Araucaria angustifolia* (the periods indicated apply approximately to the central section of the distribution area); from: GOLTE, 1978 b).

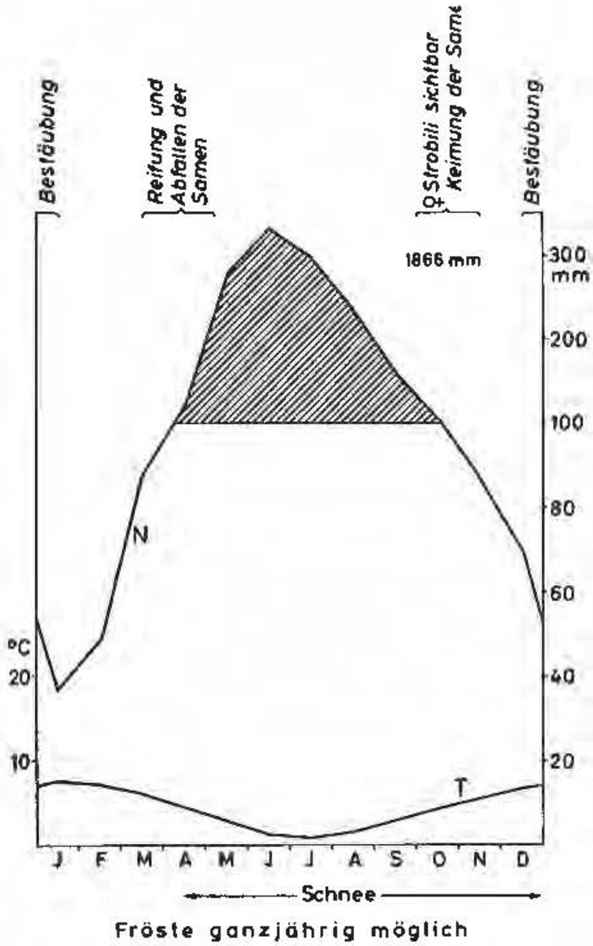

Abb. 5. Jahreszeitlicher Gang des Klimas (Station Lonquimay, 38°26′ s. Br., 71°15′ w. L.; 900 m) und reproduktiver Zyklus bei *Araucaria araucana;* aus GOLTE, 1978 b.

(Seasonal course of the climate (Station Lonquimay, 38°26′ s, 71°25′ w, 900 m) and reproductive cycle of *Araucaria araucana;* from: GOLTE, 1978 b).

Ähnlich wie das Areal von *A. angustifolia* in Südbrasilien die Tropengrenze gleichsam verhüllt, so verhüllt *A. araucana* mit ihrem Verbreitungsgebiet eine andere wichtige Klimagrenze, nämlich die zwischen der subtropischen Hochdruckzone und der außertropischen Westwindzone. Im Winterhalbjahr unterliegt die südandine Araukarie ganz dem zyklonalen Geschehen der Westwinddrift, während im Sommerhalbjahr zyklonale und antizyklonale Witterung einander abwechseln. Es fällt auf, daß der Niederschlagsgang (Wintermaximum) bei *A. araucana* die genaue Umkehrung dessen (Sommermaximum) darstellt, was wir im nördlichen Teil des Areals von *A. angustifolia* vorfinden. Wir haben aber gesehen, daß durch die Speicherung des Winterniederschlags in einer mächtigen Schneedecke bei *A. araucana* eine starke Annäherung an das Sommermaximum bei *A. angustifolia* zustandekommt. Daß die jahreszeitliche Umkehrung letztlich für die ganzjährig – wenn auch mit schwankender Intensität – wachsenden Araukarien von untergeordneter Bedeutung ist, können wir auch daraus schließen, daß sie sich bereits innerhalb des Verbreitungsgebietes von *A. angustifolia* abzeichnet, so daß im südlichsten Brasilien Verhältnisse herrschen, die denen bei *A. araucana* stark angenähert sind.

Der ökologische Vergleich der beiden südamerikanischen Arten zeigt also, daß die Araukarien einem ganz bestimmten jahreszeitlichen Niederschlagsgang angepaßt sind. Die Jahressummen der Niederschläge (1500–über 3000 mm) sind recht hoch, aber durchaus ungleichmäßig über das Jahr verteilt. Mehr oder weniger niederschlagsreiche Jahreszeiten wechseln mit solchen, die – ohne daß es dabei zu echter periodischer, d. h. regelmäßig einen Monat oder gar länger anhaltender Regenlosigkeit käme – eine Häufung trockener, von Strahlungswetter bestimmter Abschnitte aufweisen. Nur im Ausnahmefall einzelner Jahre – dies ist allerdings charakteristisch – kann dieses jahreszeitliche Nachlassen der Niederschläge das Ausmaß einer Dürre (drought) annehmen. Die Jahresschwankungen der Temperatur sind in den Verbreitungsgebieten beider Araukarien verhältnismäßig gering (6–8 °C), so daß von daher ein ganzjähriges Wachstum möglich ist. Andererseits sind diese wenn auch geringen jahreszeitlichen Schwankungen der Temperatur für die Araukarien offensichtlich von Bedeutung, wie übrigens klar auch aus der Verbreitung von *A. angustifolia* abzulesen ist (vgl. GOLTE, 1978 b).

Die Frage ist nun, welche Anpassungen der Bäume sich hinter der Bindung an die skizzierten Klimaverhältnisse verbergen. Zunächst einmal sind die Araukarien vermöge ihrer ausgeprägten Hartlaubigkeit (Sclerophyllie) auf eine gewisse Verschlechterung der hygrischen Bedingungen, wie sie ja mit dem jahreszeitlich gehäuften Auftreten von Strahlungswitterung und der Verringerung der Niederschläge verbunden ist, eingestellt. Die Tatsache, daß sie mit ihren schirmförmigen Kronen im ausgewachsenen Zustand stets aus dem übrigen Kronendach herausragen und ihre assimilierenden Organe den möglichen hohen Sättigungsdefiziten geradezu exponieren, zeigt auch, daß sie die jahreszeitliche Trockenheit in gewissem Umfang brauchen. Es ist auch sehr auffällig, daß die Bäume nur dann Zapfen und Samen hervorbringen, wenn sie in dieser Weise der Sonne ausgesetzt sind. Und hier, in der Samenbildung, liegt nun, wie mir scheint, eine sehr bedeutsame Anpassung an eine jahreszeitliche Verschlechterung der hygrischen Bedingungen vor.

Diese Anpassung ist nur zu verstehen, wenn man bedenkt, daß die Gymnospermie, das Hervorbringen von (frei auf den Fruchtblättern liegenden) Samenanlagen, phylogenetisch eine Fortentwicklung des Generationswechsels der Pteridophyten darstellt. Bei den Farngewächsen durchläuft bekanntlich die Ontogenie noch zwei selbständige Generationen, eine geschlechtliche (Gametophyt) und eine ungeschlechtliche (Sporophyt). Das, was uns als Samenpflanze entgegentritt, ist der Sporophyt, der den einst selbständigen Gametophyten unter mehr oder weniger starker Reduktion gleichsam in seine Obhut genommen hat. Der für die Araukarien – und nicht nur für diese – entscheidende Umstand besteht demnach darin, daß die Megaspore im Megasporangium am Sporophyten verbleibt und sich hier die Entwicklung des Gametophyten von der Keimung bis hin zur Hervorbringung des Embryos, d. h. des neuen Sporophyten, vollzieht. Wenn auf diese Weise in der Samenbildung die geschlechtliche Generation gleichsam aufgehoben wird, dann deshalb, weil diese zu ihrer Entwicklung auf gleichmäßig hohe Feuchtigkeit und für die Verschmelzung der Gameten auf freies Wasser angewiesen ist. Der ökologische Sinn der Gymnospermie besteht also in der Überbrückung der für einen selbständigen Gametophyten zu ungünstigen oder zumindest risikoreichen trockenen Jahreszeit.

Diese ökologische Funktion der Samenbildung läßt sich deutlich an der Entwicklungsperiodizität der beiden Araukarien ablesen. Wir sehen bei *A. angustifolia* (Abb. 4), daß sich Reifung und Abfallen der Samen im Übergang zu der für das Wachstum ungünstigen, d. h. verhältnismäßig trockenen Jahreszeit, vollziehen. Etwa Mai bis Juli zerfallen die Zapfen. Die Samen keimen in der Regel schon 1–4 Monate später, und zwar in Zusammenhang mit dem Wiederansteigen der Niederschläge. Das Ruhestadium der Araukariensamen ist also relativ kurz und es läßt sich auch nicht lange ausdehnen, weil nämlich schon nach wenigen Monaten ein rascher Abfall der Keimfähigkeit eintritt. Dieser verhältnismäßig rasche Abfall der Keimkraft der Samen gilt nun für alle Araukarien (vgl. NTIMA, 1968), und er ist umso schneller, je höher die Temperaturen sind. Versuche von forstlicher Seite haben gezeigt, daß durch die Aufbewahrung der Samen im Kühlschrank dieser Abfall der Keimkraft merklich hinausgezögert werden kann. Daraus wird auch die Bedeutung der Tatsache verständlich, daß bei *A. angustifolia* die Samen zu einer Zeit fallen, in der zugleich die Temperaturen relativ niedrig sind und mit einer gewissen Häufigkeit Fröste auftreten.

Sehr aufschlußreich ist in dieser Hinsicht der Vergleich mit *A. araucana* (Fig. 5). Deren Samen reifen und zerfallen zwischen März und Ende Mai, d. h. gegen Ende der niederschlagsarmen Jahreszeit, und sie fallen – da Ende April/Anfang Mai die Schneefälle einsetzen – in eine Art natürlichen Kühlschrank, in dem sie ihre Keimfähigkeit regelmäßig über etwa ein halbes Jahr bis zum Beginn der Schneeschmelze und damit der Hauptwachstumszeit erhalten.

2. Die Araukarien Australasiens

Nur in Form eines kurzen Überblicks kann im folgenden gezeigt werden, daß die beim klimaökologischen Vergleich der beiden südamerikanischen Species erkannten Gesetzmäßigkeiten – mutatis mutandis – auch für die übrigen 17, in Australasien heimischen Araukarien (Fig. 1), gelten. Eine eingehende Darlegung und Begründung der diesbezüglichen Befunde mit Ausbreitung des umfangreichen in der botanischen, klimatologischen, geographischen, boden- und forstkundlichen Literatur verstreuten Belegmaterials wird an anderer Stelle vorgelegt werden. Insbesondere muß bei den folgenden Ausführungen auf eine nähere Interpretation der klimaökologischen Beziehungen und die – dabei unerläßliche – Einbeziehung der bodenkundlichen Gegebenheiten verzichtet werden. Die 17 weiteren *Araucaria*-Arten verteilen sich auf Ostaustralien und Neuguinea (zus. 3), die Norfolk-Insel (1) und Neu-Kaledonien (13). Sie werden drei weiteren Sektionen der Gattung zugeordnet[2].

2.1. Ostaustralien

Unter jenen 17 Arten ist es die ostaustralische *A. bidwillii*, die sowohl im Habitus, als auch ökologisch die größte Ähnlichkeit mit den beiden südamerikanischen Araukarien hat. Sie hat eine sehr begrenzte Verbreitung mit dem Schwerpunkt im gebirgigen südöstlichen Queensland (Hinterland von Brisbane, bei etwa 27° s. Br.), wo sie in Höhen zwischen 150 m und über 1000 m feuchte Talgründe (in tieferen Lagen) und Hänge (höhere Lagen) bevorzugt (vgl. MCARTHUR, 1949; NTIMA, 1968). Dazu gesellen sich zwei kleinere Reliktvorkommen weiter nördlich, über die bisher wenig bekannt ist.

Ebenso wie das Areal von *A. angustifolia* ist auch dasjenige von *A. bidwillii* schwerpunktmäßig in ausgesprochen subtropischer Position unmittelbar an der Tropengrenze (vgl. v. WISSMANN, 1948) angesiedelt. Entsprechend greifen auch hier tropische und außertropische Zirkulation ineinander. Die reichlichsten und zuverlässigsten Niederschläge fallen zur Zeit des weitesten südlichen Ausgreifens der ITC in den Sommermonaten (Januar–März), während im übrigen Teil des Jahres häufiger trockene Phasen eingeschaltet sind, die aber nur ausnahmsweise die Form einer Dürre annehmen. Ähnlich wie in Südbrasilien setzen winterliche Kaltlufteinbrüche in SE-Queensland einen außertropischen Akzent. Von Neusüdwales her reicht ein „Kältestreifen" mit wirksamen Frösten und (seltenen) Schneefällen gerade noch in das Verbreitungsgebiet von *A. bidwillii* hinein (vgl. GENTILLI, 1955). An ihren tiefstgelegenen Standorten sind Fröste noch relativ selten, doch treten in den höher gelegenen Vorkommen bis zu etwa 30 Frostwechsel-

[2] Zur Einteilung der Gattung in Sektionen vgl. NTIMA (1968), der freilich die ostaustralische *A. bidwillii* entgegen der von WILDE & EAMES (1952) vorgeschlagenen Revision noch gemeinsam mit den südamerikanischen Arten in die Sekt. *Colymbea* stellt. Sie wird seither in der monotypischen Sektion *Bunya* geführt. Alle weiteren Arten – ausgenommen *A. hunsteinii* von Neuguinea – sind in der Sekt. *Eutacta* zusammengefaßt, die sich durch relativ kleine Blätter (pfriemenförmig u. gebogen, Folgeform z. T. schuppenartig) und Zapfen, sowie epigäische Keimung von den Sekt. *Colymbea* und *Bunya* unterscheidet. Eine Mittelstellung nimmt die in eine eigene Sekt. *Intermedia* gestellte *A. hunsteinii (= klinkii)* ein.

tage im Jahr auf (NTIMA, 1968). Tatsächlich besitzt die Art eine ausgeprägte Frostresistenz. Erst bei unter – 6 °C können Schädigungen auftreten.

Es ist gewiß kein Zufall, daß auch das viel größere Areal von *A. cunninghamii* im subtropischen SE-Queensland und dem angrenzenden Neusüdwales einen ausgesprochenen Schwerpunkt hat, von wo es über die „Passatküste" des nördlichen Queensland (GENTILLI, 1955) bis in das westliche Neuguinea sich fortsetzt. Allein in Ostaustralien erstreckt sich das Vorkommen dieser Art über etwa 20 Breitengrade (31°–12° s. Br.; vgl. WEBB & TRACEY, 1967). Zusammen mit dem Verbreitungsgebiet in Neuguinea, das nahe an den Äquator heranreicht, ergibt sich eine Erstreckung des Areals über mehr als 30 Breitengrade. Es liegt nahe, hinter dieser erstaunlichen meridionalen Verbreitung eine besonders breite physiologische Valenz der Art zu vermuten, doch deutet alles darauf hin, daß hier im Zusammenspiel von Klima und Relief innerhalb des Areals tatsächlich so einheitliche Wachstumsbedingungen zustandekommen, daß von „relativer Standortkonstanz" (im Sinne von H. & E. WALTER) gesprochen werden kann. Infolge seiner Lage auf dem südlichen Ast des südostasiatisch-australischen Monsungebietes weist der gesamte Raum ein Sommermaximum (Dezember–März) der Niederschläge auf, dessen Ausprägung im Mittelabschnitt des Areals, der Passatküste zwischen Bundaberg (25° s. Br.) und Cooktown (15° 28′ s. Br.), am stärksten ist und sich sowohl gegen den polwärtigen Rand (außertropische Westwindzone), als auch gegen den äquatorwärtigen Rand (äquatoriale Westwindzone) zugunsten gleichmäßiger verteilter Niederschlagsregime abschwächt. Im Winterhalbjahr herrscht Hochdruckeinfluß vor. Das Niederschlagsminimum fällt in Queensland in die Monate August (Südabschnitt) bzw. September (Nordabschnitt). Es kommt aber auch hier nicht zu länger anhaltender periodischer Regenlosigkeit. Vielmehr treten mit einer gewissen Regelmäßigkeit Niederschläge auf, die teils orographisch bedingt sind (in Queensland polwärts abnehmend), teils von den zwischen den wandernden Antizyklonen durch die gegenläufigen Winde unter Einbeziehung außertropischer Luftmassen entstehenden Kaltfronten herrühren. Nur unperiodisch, d. h. in extremen Jahren treten im küstennahen östlichen Queensland während der Wintermonate (April–November) ausgesprochene Dürren auf.

2.2. Neuguinea

Das Vorkommen von Araukarien im Zentralgebirge von Neuguinea muß in engem Zusammenhang mit demjenigen in Queensland gesehen werden. Bis zum Beginn des Pliozäns und – durch Trockenfallen der nur etwa 50 m tiefen Torresstraße – noch während der Kaltzeiten des Pleistozäns war eine Landverbindung gegeben. Auch klimatisch stehen, wie im vorigen Abschnitt für *A. cunninghamii* bereits herausgestellt wurde, beide Gebiete in engem Zusammenhang (vgl. FITZPATRICK et al., 1966). Neben der letztgenannten Art, die nicht nur im östlichen Teil der Insel (Papua New Guinea), sondern auch bis in den äußersten Westen des indonesischen Teils (Irian Jaya) vorkommt, gedeiht dort noch – allerdings beschränkt auf Papua New Guinea – *A. hunsteinii*. Die Vorkommen beider Arten in Papua New Guinea hat GRAY (1973) kartographisch zusammengestellt. Dabei zeigt sich, daß die beiden Arten, mögen sie auch großräumig gesehen den gleichen Einflüssen unterliegen, standörtlich deutlich divergieren. *A. cunninghamii* wächst zwischen 600 m und 2800 m (zumeist 900–2200 m) vornehmlich auf steilen Hängen und Rücken, während *A. hunsteinii* in durchschnittlich etwas tieferen Lagen, zwischen 550 m und 2100 m (zumeist 750–1500 m), vorzugsweise in Tälern verbreitet ist. Trotz dieser Unterschiede, die hier nicht näher erörtert werden können, ist offensichtlich, daß beide Arten mit ihren Vorkommen die Stufe des Übergangs vom Tieflandsregenwald in den Bergwald besiedeln (vgl. GRAY, 1975). Entsprechend treten in den Araukarienbeständen als Begleiter Elemente aus beiden Höhenstufen auf. Es liegt demnach hier in der Vertikalen ein ähnliches „Verhüllen" der Warmtropengrenze vor, wie wir es im Falle der südbrasilianischen *A. angustifolia* und auch bei *A. bidwillii* bereits in der Horizontalen konstatiert haben. Daß es sich tatsächlich um ein analoges Verhalten handelt, ist schon daraus zu schließen, daß *A. cunninghamii* als einzelne Art innerhalb ihres von der warmgemäßigten Zone bis in die inneren Tropen reichenden Areals

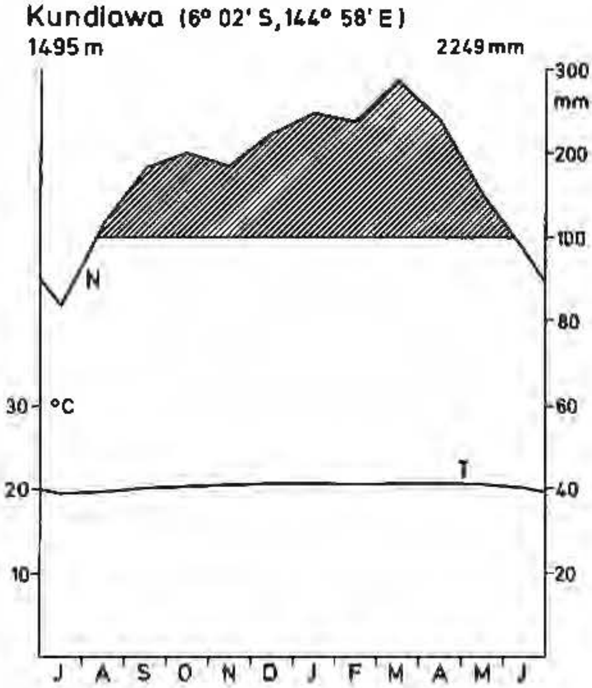

Abb. 6. Klimadiagramm von Kundiawa (Verbreitungsgebiet von *Araucaria cunninghamii*), Neuguinea.

(Course of the climate of Kundiawa (distribution area of *Araucaria cunninghamii*), New Guinea).

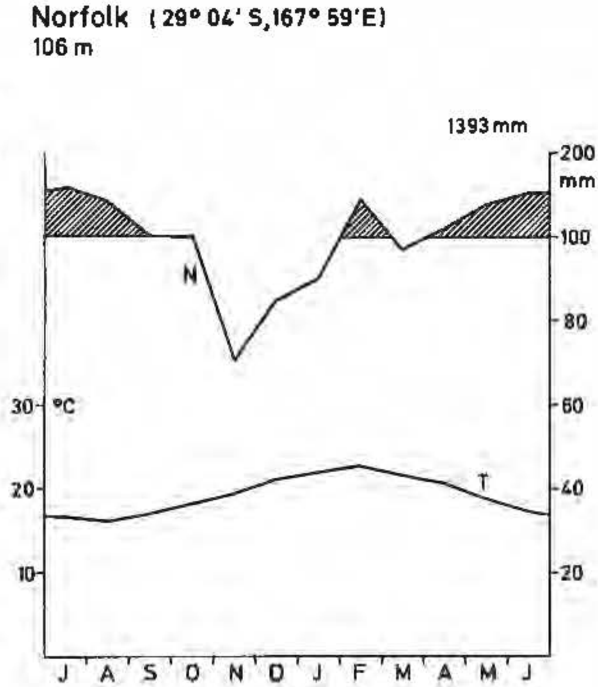

Abb. 7. Klimadiagramm von Norfolk Island (Verbreitungsgebiet von *Araucaria heterophylla (= excelsa)*).

(Course of the climate of Norfolk Island, distribution areas of *Araucaria heterophylla (= excelsa)*).

beide Verbreitungstendenzen erkennen läßt. Die Bestände von *A. cunninghamii* und *A. hunsteinii* reichen gerade in die Höhenstufe hinein, in der Frostwechsel auftreten. Bodenfröste setzen – abhängig von der Topographie – bei etwa 1500 m ein, und ab 2000 m sind leichte Fröste eine regelmäßige Erscheinung (Brown & Powell, 1974). Dabei ist hinsichtlich der im Vergleich etwas tiefer liegenden Vorkommen von *A. hunsteinii* zu berücksichtigen, daß diese gerade die für Ansammlung von Kaltluft besonders empfänglichen Tal- und Beckenlagen besiedelt.

Die Bedeutung einer akzentuierten nächtlichen Abkühlung für die Araukarien muß auch hier in einem Zusammenhang mit dem gesamten jahreszeitlichen Witterungsablauf gesehen werden (Abb. 6). Die Frostwechsel treten in mittleren Höhen nur während der Saison des SE-Passats (Mai–Oktober) auf, die in großen Teilen des Zentralgebirges – bei scharf ausgeprägten orographischen Effekten – eine „Trockenzeit" ist. Freilich ist diese auch hier nur als eine Zeit verminderter Häufigkeit und Intensität der Regenfälle zu verstehen. Die Hauptniederschläge fallen in der Zeit des indonesisch-australischen NW-Monsuns (Dezember–März). In dieser Zeit starker konvektiver Aktivität wird die Niederschlagsverteilung nur schwach von der Orographie beeinflußt. In Zeiten stabiler SE-Strömung jedoch besteht in weiten Teilen des Hochlandes eine Tendenz zu Wolkenarmut und Strahlungswetter, wodurch bei Tage die potentielle Evapotranspiration kräftig ansteigen und bei Nacht die Temperatur unter den Gefrierpunkt absinken kann. Bezeichnenderweise – unter dem Gesichtspunkt des Vergleichs mit anderen Araukariengebieten – können diese Phänomene in einzelnen Jahren extreme Ausmaße annehmen, so beispielsweise 1940 oder 1941 und 1972, als im Hochland Neuguineas über Wochen und Monate Dürre und scharfe Fröste bis in Höhen unter 2000 m verzeichnet wurden (vgl. Brown & Powell, 1974).

Wenn die Araukarien im Zentralgebirge Neuguineas – trotz der etwa bei den südamerikanischen Arten noch wesentlich stärker ausgeprägten Frostverträglichkeit – nicht in noch höhere Lagen aufsteigen, so dürfte das vor allem damit zusammenhängen, daß sie andererseits auf strahlungsreiche, trocken-warme Witterungsabschnitte angewiesen sind, Luftfeuchtigkeit und Bewölkungsgrad aber gerade mit Annäherung an das Kondensationsniveau aufwärts sprunghaft zunehmen.

2.3. *Norfolk Island*

Die 34 km² große, bei 29° s. Br. und 168° ö. L. vor der Ostküste Australiens gelegene Insel (höchster Punkt 330 m) war zum Zeitpunkt der Entdeckung durch James Cook (1774) noch vollständig von einem immergrünen Regenwald bedeckt, in den *A. heterophylla (= excelsa)* – die bei uns bekannte „Zimmertanne" – als beherrschendes Element in mehr oder weniger dichten Beständen eingestreut war. Norfolk liegt nach den Kriterien H. v. WISSMANNs (1948) noch im Randbereich der Tropen, doch zeigen schon die Mittelwerte des wärmsten und des kältesten Monats (Fig. 7: Februar 22,8 °C, August 16,1 °C) und erst recht die absoluten Extrema (31,7 °C bzw. 7,8 °C) der Temperatur – gemessen in 17 m Seehöhe –, daß das Klima subtropisch genannt werden muß. Dies kommt auch im jahreszeitlichen Gang der Niederschläge zum Ausdruck, der sich dadurch auszeichnet, daß die Winterregen hier reichlicher und zuverlässiger sind als die Sommerregen (vgl. SCHOTT, 1938). Die Sommerregen entsprechen dem tropischen Regime des SW-Pazifiks, während die Winterregen im Gefolge außertropischer Wanderdepressionen niedergehen.

2.4. *Neu-Kaledonien*

Nirgendwo auf der Erde findet sich auf engstem Raum eine solche Ansammlung archaischer Gewächse wie auf Neu-Kaledonien. Dazu gehören auch die nicht weniger als 13 Vertreter der Gattung *Araucaria*, die in der Gymnospermenflora der Insel von D. J. DE LAUBENFELS (1972) beschrieben werden. Dieser Reichtum an altertümlichen endemischen Pflanzen hat – abgesehen von der Inselnatur als solcher und ihrem Gebirgscharakter (größte Höhe 1634 m) – vor allem klimatische und geologisch-pedologische Ursachen. Die letzteren beziehen sich auf die Serpentinmassive, die weite Teile, besonders im südlichen Drittel der Insel (in dem auch die Araukarien ihre Hauptverbreitung haben) einnehmen. Mit ihrer extremen Kieselsäure- und Basenarmut (völliges Fehlen von Quarz, Feldspäten und Feldspatvertretern) bilden diese hier wie auch anderswo auf der Erde günstige Substrate für Coniferen (vgl. GOLTE, 1978 a). Tatsächlich sind alle neu-kaledonischen *Araucaria*-Arten – mit einer Ausnahme – auf Serpentingebiete beschränkt. Auf die verschiedenen Arten kann hier nicht näher eingegangen werden (vgl. u. a. VIROT, 1956; DE LAUBENFELS, 1972). Die meisten von ihnen sind Bestandteile der Berg- und Nebelwälder (oberhalb von etwa 300 m) auf den Serpentinmassiven. Besonders bemerkenswert – und mit den extremen Eigenschaften des ultrabasischen Gesteins zu erklären – ist allerdings, daß einzelne Arten (*A. muelleri, A. biramulata, A. rulei*) hier am Tropenrand auch noch im Tiefland heimisch sind.

Ein Baum des Tieflandes schließlich ist auch die eigenartige *A. columnaris (= cookii*; „pin colonnaire"), die einzige nicht auf Serpentin gedeihende Araukarie Neu-Kaledoniens. Sie steht *A. heterophylla* von der Norfolk-Insel nahe und wächst – bei etwa 2000–3000 mm Jahresniederschlag – auf Korallenkalken im Küstenbereich des südlichen Neu-Kaledonien sowie der nahegelegenen Loyalty-Inseln und der Ile des Pins.

Entsprechend seiner Lage nahe dem Wendekreis lassen sich in Neu-Kaledonien bereits deutlich eine wärmere (Mitte Oktober–Mitte April) und eine kühlere Jahreszeit (Mitte April–Mitte Oktober) unterscheiden (die Jahresschwankung beträgt etwa 6 °C). Während des ganzen Jahres, verstärkt aber im Südwinter, unterliegt die Insel dem Einfluß des SE-Passats. Die Hauptniederschläge fallen, verbunden mit veränderlichen, teilweise stürmischen Winden, im Sommer und entsprechen dem von der Südwärtswanderung der ITC bestimmten tropischen Regime (vgl. FAIVRE et al., 1955). Sie sind im Norden der Insel reichlicher als im Süden. Tropische Zyklonen können gelegentlich schwere Regenfälle bringen. Ab April/

Mai gerät Neu-Kaledonien mit dem Rückzug der ITC zunehmend unter antizyklonalen Einfluß. Die winterliche Situation (Juni–August) ist durch wandernde Hochdruckzellen gekennzeichnet, zwischen denen wärmere Luftmassen aus NE und Polarluft aus S bis W gegeneinander geführt werden. Der Durchzug dieser Kaltfronten ist mit mäßigen Niederschlägen verbunden, die den Süden der Insel stärker befeuchten als den Norden.

SARLIN (1954) hat am Beispiel von Nouméa gezeigt, daß sich die Niederschläge in Neu-Kaledonien durch beträchtliche Variabilität auszeichnen. Grundsätzlich ist in allen Monaten des Jahres Trockenheit möglich. Allerdings waren von 564 Beobachtungsmonaten (= 47 Jahren) nur 8 absolut regenlos, wovon wiederum nur die Monate September bis Dezember betroffen waren, die auch mit relativ größter Häufigkeit „trocken" sein können. Insgesamt zeigen der jahreszeitliche Witterungsablauf und die räumliche Niederschlagsverteilung deutlich, daß Neu-Kaledonien im Übergangsbereich der tropischen und der außertropischen Zirkulation liegt, deren Wechselwirkung offenbar das ganze Jahr über Häufigkeit und Menge der Niederschläge beeinflußt, dabei aber eine hohe Niederschlagsvariabilität zur Folge hat.

3. Schlußfolgerungen

Die knappe Übersicht der Araukarienvorkommen Australasiens zeigt in Übereinstimmung mit den beim Vergleich der südamerikanischen Arten gewonnenen Erkenntnissen, daß die Gattung ungeachtet der bei ihren 19 Arten zum Ausdruck kommenden Spielbreite an ganz bestimmte Klimaverhältnisse gebunden ist, die sich aus einer synoptischen und jahreszeitlichen Wechselwirkung der tropisch-subtropischen Zirkulation (ITC und Passat) einerseits und der außertropischen Zirkulation (Westwinddrift) andererseits ergeben. Der verbreitungsmäßige Schwerpunkt liegt eindeutig in den Subtropen, und zwar in den Sattelgebieten zwischen den subtropischen Hochdruckzellen als den Bereichen intensivster Wechselwirkung der tropischen und der außertropischen Zirkulation. In diesen Gebieten ist der subtropische Hochdruckgürtel quasi-permanent durchbrochen, so daß ganzjährige, wenn auch deutlich schwankende Niederschläge möglich sind. Dynamisch-klimatologisch entsprechen diese Feuchtebrücken im Trockengürtel den quasistationären Höhentrögen, in denen die ektropische Westwinddrift weit gegen den Äquator vorstößt bzw. ihn sogar überschreitet (vgl. FLOHN, 1971). Auf diese nicht nur für die Araukarien, sondern auch für die Verbreitung zahlreicher anderer Reliktconiferen entscheidenden Zusammenhänge habe ich bereits in der erwähnten früheren Arbeit (GOLTE, 1978 a) hingewiesen. Am Beispiel der beiden südamerikanischen *Araucaria*-Arten konnte gezeigt werden, in welcher Weise die Bäume mit dem xeromorphen Bau ihrer assimilierenden Organe (Sclerophyllie) und der Art ihrer Reproduktion (Gymnospermie) auf den jahreszeitlichen Gang der Wachstumsbedingungen eingestellt sind.

Wie nun sind Verbreitung und standörtliches Verhalten der Araukarien über die bloße Feststellung der Zusammenhänge hinaus zu erklären? Wie wenig zweckmäßig es wäre, die Verbreitungsverhältnisse und ökologischen Beziehungen lediglich aus dem gegenwärtigen Verhalten zu beurteilen, zeigt eine einfache Rechnung. Das gesamte Quartär, wenn man es einmal grob auf 2 Millionen Jahre veranschlagt, macht gerade 1% der mehr oder weniger überschaubaren Verbreitungsgeschichte der Gattung *Araucaria* aus. Alles spricht dafür, daß die noch heute erkennbare verbreitungsmäßige und ökologische Spielbreite, die sich deutlich an bestimmten dynamischen Klimagrenzen orientiert, Ausdruck eines weit in die Vergangenheit zurückreichenden, genetisch festgelegten Potentials ist. Die ohne Zweifel noch lückenhafte und teilweise schwer deutbare Verbreitungsgeschichte der Gattung (vgl. Abb. 1; u. FLORIN, 1963) läßt gleichwohl bestimmte Tendenzen erkennen, die dann zu erklären sind, wenn man von einer weitgehenden Konstanz dieser Spielbreite ausgeht.

Betrachten wir einmal nur das südhemisphärische Vorkommen beiderseits des Pazifiks! Legen wir die gegenwärtige Position der Kontinente zugrunde, dann finden wir die jurassischen Vorkommen zwischen etwa 30° (Ostaustralien) und 63° s. Br. (Westantarktis). Im Falle Australiens ist aber wegen der Kontinentalverschiebung in Wirklichkeit eine polnähere Lage anzunehmen. In der Kreidezeit fand offenbar eine geringfügige äquatorwärtige Verschiebung des Verbreitungsgebietes statt. Im frühen Tertiär scheint zunächst ein ebenso geringfügiger polwärtiger Rückzug erfolgt zu sein, bevor im Jungtertiär und Quartär das Areal sich auf seine heutige Position in Richtung auf den Äquator verschob.

Wir finden also die Gattung *Araucaria* im Mesozoikum und Alttertiär eindeutig in mittleren Breiten (vermutlich bis in die Nähe des Polarkreises), während die niederen Breiten in auffälliger Weise gemieden wurden. Diese (wohl kaum durch Lücken im Fossilbestand bloß vorgetäuschte) Tatsache deutet darauf hin, daß das Klima niederer Breiten in jener Zeit anders ausgesehen haben muß als heute. Auch andere Indizien machen es unwahrscheinlich, daß ein äquatorialer Regengürtel in einer der heutigen ähnlichen Form existierte. Entsprechend dürften auch transäquatoriale Feuchtebrücken – die etwa für *Araucaria* oder ihre Stammformen „gangbar" gewesen sein könnten – nur zeitlich und räumlich sehr begrenzt bestanden haben – ein Umstand, der das von FLORIN (1963) als nicht gesichert betrachtete bihemisphärische Vorkommen der Gattung zu einem interessanten, aber schwer lösbaren Problem der Florengeschichte macht. Aufschlußreich ist in dieser Hinsicht das Beispiel Vorderindiens, das im älteren Mesozoikum zum Verband der Südkontinente (zwischen Antarktis und SE-Afrika) gehörte. Hier befand sich von der späten Trias bis wahrscheinlich in die frühe Kreidezeit eines der alten Verbreitungsgebiete von *Araucaria*. Dann driftete – wie ein Floß – Indien im Laufe der Kreide in die Nähe seiner heutigen Position. Dabei mußte es den Äquatorialbereich queren – mit der Folge, daß die Gattung hier ausstarb.

Das Klima der Mittelbreiten, in denen die Araukarien, hauptsächlich in Faltengebirgszonen entlang den Kontinentalrändern, gediehen, muß in der Zeit des eisfreien (akryogenen) Zustandes der Erde recht warm gewesen sein, aber eben nicht tropisch, wie so oft behauptet wird. Es war – nach dem heutigen Verhalten dieser Gattung zu urteilen – ein Mischtyp, der tropische und außertropische Merkmale in sich vereinigte, nicht nur im Sinne eines jahreszeitlichen Alternierens, sondern auch im synoptischen Sinne.

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Diskussion zum Beitrag Golte

Dra. M. L. Salgado-Labouriau:

The map of distribution of *Araucaria* (present and fossil) do not indicate the presence of this genus in Africa in the Cenozoic and Mesozoic (Exept for one occurence in South Africa Tertiary). How do you explain it?

Dr. W. Golte:

Das weitgehende – wohl kaum durch lückenhaften Fundbestand bloß vorgetäuschte – Fehlen von *Araucaria* in Afrika dürfte m. E. u. a. damit zusammenhängen, daß dieses im ehemaligen Zusammenhang der Südkontinente (Gondwana) stets eine relativ äquatornahe (Binnen-)Lage einnahm und daher (s. meine obigen Ausführungen) verhältnismäßig trockene Klimabedingungen aufwies.

Priv.-Doz. Dr. P. Frankenberg:

Sie haben sehr deutlich aufgezeigt, daß sich die *Araucaria* in ihrem Verbreitungsgebiet an den Übergangsbereich Tropen/Außertropen orientiert. Dieser hat sich ja in den letzten Jahrtausenden seit dem Kältemaximum verschoben. Hat sich damit auch das Gattungsareal von *Araucaria* verlagert?

Dr. W. Golte:

Von großräumigen Verschiebungen der Araukarienareale während des Holozäns ist mir aus der Literatur nichts bekannt. Vielleicht sind die von HUECK in Südbrasilien festgestellten Verschiebungstendenzen im Mosaik Subtropischer Feuchtwald – Araukarienwald – Campograsland als Ergebnis von Klimaänderungen zu deuten.

Prof. Dr. W. Haffner:

Araucarien sind in fast allen frostfreien oder doch sehr wintermilden Gebieten der Erde als Zierbäume verbreitet. Wie steht es mit der Samenreife außerhalb des natürlichen Verbreitungsgebietes? Sollten Araucarien nur im heutigen Verbreitungsgebiet Samen bilden, wäre dies ein eindeutiger Beleg für die von Ihnen herausgestellten besonderen Klimaansprüche.

Dr. W. Golte:

Ich habe vielerorts außerhalb der natürlichen Vorkommen angepflanzte Araukarien beobachtet, die z. T. auch Samen hervorbrachten. Stets jedoch fiel auf, daß keinerlei natürliche Verjüngung stattfindet – ein Phänomen, das ja auch für den größten Teil unserer Nadelholzforsten gilt, in denen die „Konkurrenz" künstlich ausgeschaltet ist.

Prof. Dr. B. Ruthsatz:

Ich möchte zu bedenken geben, daß man das aktuelle Verbreitungsgebiet der *Araucaria*-Arten nicht als ihr potentiell mögliches ansehen darf, weil dabei sicher die Konkurrenz von Laubbäumen eine große Rolle spielt. Viele unserer Nadelbäume sind sehr konkurrenzschwache Arten, die auf Extremstandorte abgedrängt werden von den Konkurrenten.

Prof. Dr. F. Klötzli:

Wenn wir das von Frau RUTHSATZ angefangene Strategie- und Konkurrenzdenken noch etwas ausweiten, so sehen wir, daß sich im *Araucaria*-Areal ganz ähnliche Beziehungen ergeben, wie z. B. zwischen Fagaceen und Pinaceen auf der nördlichen Halbkugel. Auch auf der südlichen Halbkugel erscheint z. B. *Araucaria araucana* auf speziellen edaphisch geprägten Standorten, wo *Nothofagus* deutlich an Vitalität verliert, im Bereich des Lago Conguillo z. B. auf grusigen jungen Lavaböden. Ich frage mich nun, wie die Beziehungen im *A. angustifolia*-Areal beschaffen sind. Konzentrieren sich die Araucarien auch dort auf Spezial-Standorte? Haben Sie entsprechende Bodenanalysen?

Prof. Dr. W. Weischet:

Als Information zu den Diskussionsbemerkungen von Frau RUTHSATZ und Herrn KLÖTZLI scheint es mir bemerkenswert, daß die singuläre Verbreitung der Araucarien tatsächlich mit singulären dynamisch-klimatologischen Bedingungen zusammenfällt. Ähnliche klimatologische Situationen gibt es m. E. sonstwo in der allgemeinen Zirkulation nicht.

Dr. W. Golte:

Das Argument der „Konkurrenzschwäche" wird immer wieder zur Erklärung von Coniferenstandorten angeführt. Ich habe mich aber in meinem Beitrag zu zeigen bemüht, daß die Areale der Araukarien mit ganz bestimmten klimatischen Bedingungen und deren räumlicher Ausdehnung in Zusammenhang stehen. Insofern freue ich mich über die Bestätigung durch Herrn WEISCHET, daß es sich tatsächlich um singuläre dynamisch-klimatische Verhältnisse handelt. Im übrigen bin ich der Auffassung, daß die Araukarien (und andere Nadelhölzer) auch heute noch im Pflanzenkleid der Erde genau jenen Platz besetzt halten, der ihnen nach ihrer Stellung in der Phylogenie und der Entwicklung in der anorganischen Welt zukommt. Der Begriff „Extremstandorte", der in diesem Zusammenhang von Frau RUTHSATZ verwendet wird, ist m. E. Ausdruck eines „angiospermozentrischen" pflanzengeographischen Weltbildes. Auf Standorten mit derartigen physikalisch-chemischen Eigenschaften sind offensichtlich seit ihrer Entstehung (Oberkarbon) die Coniferen zu Hause. Wie sollte man sich etwa das über mehr als 30 Breitengrade reichende Areal von *Araucaria cunninghamii* als das einer „konkurrenzschwachen" Conifere noch gut 100 Millionen Jahre seit der explosionsartigen Ausbreitung und Differenzierung der Angiospermen erklären? Gerade für Ostaustralien und Neuguinea konnte durch verschiedene Arbeiten (WEBB & TRACEY, 1967; HAVEL, 1971) festgestellt werden, daß die dortigen Araukarien unter bestimmten ökologischen Bedingungen „normale" Komponenten des voll entwickelten Regenwaldes sind und sich entsprechend regenerieren. Gleiches gilt nach eigenen Erfahrungen für die südamerikanischen Araukarienwälder. Dort habe ich zwar Bodenanalysen gemacht (wiedergegeben in: GOLTE, 1978 b), jedoch nicht speziell unter dem Gesichtspunkt des Vergleichs mit Nachbarstandorten. Eine überragende Rolle spielt der Wasserhaushalt der Böden, hinsichtlich *A. angustifolia* ist durch die Arbeiten von K. HUECK bekannt, daß innerhalb des Areals gewisse standörtliche Verschiebungen stattfinden, im Zuge derer der subtropische Feuchtwald in tieferen Lagen den Araukarienwald „unterwandert", während dieser seinerseits sich auf Kosten der Höhengrasländer (Campos) ausdehnt. Diese Verschiebungen tragen aber höchstwahrscheinlich klimatischen Veränderungen Rechnung.

Prof. Dr. U. Schweinfurth:

Zur Verbreitung von *Araucaria hunsteinii:* Sie kommt auch im früheren Kaiser-Wilhelm-Land (= ‚New Guinea') vor, nicht nur in ‚Papua'. Die Station Kundiawa wäre zu ersetzen vielleicht durch Station Bulolo-Wau, wo *A. hunsteinii* verbreitet vorkommt.

Dr. W. Golte:

Hinsichtlich Punkt 1 (*A. hunsteinii* im früheren Kaiser-Wilhelm-Land) muß ich natürlich zustimmen. Zu Punkt 2: Die Station Kundiawa habe ich gewählt, weil sie von GRAY (1973) unter denjenigen genannt wird, die sich in enger Nachbarschaft zu Araukarienbeständen (innerhalb von höchstens 2 km Entfernung), in diesem Falle *A. cunninghamii*, befinden.

Prof. Dr. W. Lauer:

Inwieweit haben ausgebildete, wenn auch kürzere Trockenzeiten generell eine Bedeutung für den Samenabfall der Araukarien-Früchte? Nach den von Ihnen für Neuguinea gezeigten Diagrammen scheint hier die kurze Trockenzeit von großer Bedeutung zu sein für den Lebensrhythmus der Araukarien.

Dr. W. Golte:

Xerochastische Bewegungen (Trockenspalten) spielen bei Coniferen generell für die Freisetzung der Samen eine große Rolle. Sie sind uns von *Pinus*-Zapfen in besonderer Weise vertraut. Bei *Araucaria*, deren Samen durch die Verwachsung von Deck- und Samenschuppe vollständig mit einer festen Schale umhüllt sind, erfolgt diese Freisetzung durch Zerblättern des Zapfens, d. h. durch Abfallen der Schuppenkomplexe von dessen spindelförmiger Achse. Nach eigenen Erfahrungen genügt bei vorzeitig gepflückten Zapfen schon die geringste nachfolgende Austrocknung, um diese zum Zerfallen zu bringen. Auch etwa in Neuguinea findet die Freisetzung der Samen (in der Regel September bis November, standörtlich variierend) in Zusammenhang mit der Jahreszeit statt, in der gehäuft trockene Phasen auftreten. Darin kommt sicher die Synchronisierung des physiologischen Geschehens mit dem hygrischen Jahresgang zum Ausdruck; allerdings ist zu berücksichtigen, daß es sich zugleich um endogen gesteuerte Vorgänge handelt.

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Vertical Distribution of Palaearctic and Oriental Faunal Components in the Nepal Himalayas[1]

Jochen Martens

With 14 Figures

From the viewpoint of biology, the geographical position of the Himalayas is significant in several respects:

1. The Himalayas separate the uplands of Central Asia from the Indian Subcontinent, thereby forming an effective barrier between two large areas of Asia, which are quite different climatically: cold High Asia and tropical South and South-east Asia.
2. The Himalayas themselves enforce the contrast. Exchange of air between the two regions is difficult and the Himalayas create their own climate, when during the South-west monsoon orographic precipitation occurs on the southern flanks, though it is greatly reduced on the northern slopes. This striking function as a climatic barrier holds true only for the central parts of the mountains, that is approximately the areas of Kumaon, Nepal, Sikkim and Bhutan. In the western Himalayas, the aridity of Central Asia extends across to the southern slopes, while in the eastern parts rainstorms, though declining in amount and frequency, reach as far as South-east Tibet (SCHWEINFURTH, 1957; TROLL, 1967).

This sharp climatic separation by the Central Himalayas is of great importance biologically and in many respects influences the distribution of plants and animals of the mountain chain. The Himalayas are regarded as a region of contact between the two great biogeographic realms which meet and intermesh in various ways. The criteria for classification differ somewhat for phytogeography and zoogeography, but both show that the Himalayas are a meeting place for florae and faunae of different origins and ecological requirements. All areas north of the Central Himalayas belong to the Palaearctic realm as do the highest parts of the southern flanks occupied by animals. The lower and lowest altitudes of the southern flanks are associated with the Oriental realm. The border between the two regions is, however, not striking and abrupt, but forms over vast distances a transition area, which comprises varying combinations of representatives of each of the areas in question. This holds especially true for the eastern Himalayas. In the Central parts, it is easier to delimit the boundaries due to the sharp contrast in climate and vegetation between northern and southern slopes.

Within the general terms Palaearctic and Oriental, however, we find a great variety of plant and animal groups according to their differing geographical origin. We must take into account that the Himalayan fauna is predominantly one which invaded the Himalayas at the time of or after the uplift of the mountain chain during the Tertiary and that the Himalayan fauna has only partially undergone an evolution of its own. As we might expect, recent distributions reflect the route by which individual species or species groups migrated into the Himalayas and can be deduced from the habitat or forest community to which each species is adapted.

[1] Results of the Himalaya Expeditions of J. MARTENS since 1969. Senckenbergiana biol., 65 (1/2), 1984. – J. M. sponsored by Deutscher Akademischer Austauschdienst and Deutsche Forschungsgemeinschaft.

As the Himalayas are predominantly forest covered, at least on the southern slopes and in many areas of the Inner Valleys, it is analysis of the forest vegetation that will provide the first indications of the origin and vertical distribution of the exceedingly rich fauna. For Himalayan faunae, we can distinguish three main areas of origin, as far as the Palaearctic is concerned. In each different climatic conditions prevail and the flora and fauna have undergone different development during the Pleistocene.

1. **Species of the High Steppe and of the Mountains above Timberline.**
   Predominantly these are adapted to cold temperate climates at high altitudes and are always found in open habitats: in the rock and rubble zone with sparse vegetation, on the high mountain steppes and naturally above the timberline, not usually below 4000 m, but upwards to the limits of animal life near to 6000 m and locally even higher (SWAN, 1961). In Nepal, the species in question have reached the Himalayas from Tibet and most do not extend southwards further than the northern slopes. Only a few reach the uppermost parts of the southern flanks (Central Asian species).
2. **Species of the Xerophilic Forests, which penetrate into the Central Himalayas from the West.**
   These species belong to the West Asian fauna and correspond largely to the Mediterranean subregion of the Palaearctic. They are adapted to relatively dry forest habitats, much less exposed to the monsoon. The forest habitats in question reach into the Central Himalayas as a narrow belt, mainly to North-west Dhaulagiri and also, though with fewer typical species, as far as North Annapurna and North Manaslu (West Asian Himalayan species).
3. **Species of the Moist Forests of the Subalpine Belt.**
   These have reached Nepal mainly from the east from various areas of western China. They are distributed mainly in a narrow belt extending westward along the southern slopes of the Himalayas. The species concerned are not well adapted to high precipitation rates typical of the Eastern and Central Himalayas, but they tolerate them, and so we find them in both the eastern and wetter and in the western and drier forest types. Vertically, they are found from the temperate *Rhododendron*-Coniferous zone to the timberline, that is from about 2800 to 4200 m. The zoogeographic relationships of this species group are clearly indicated by the fact that closely related species are found in northern parts of the Palaearctic, while areas in which Himalayan species are found point far into northern regions (West Chinese Himalayan species).

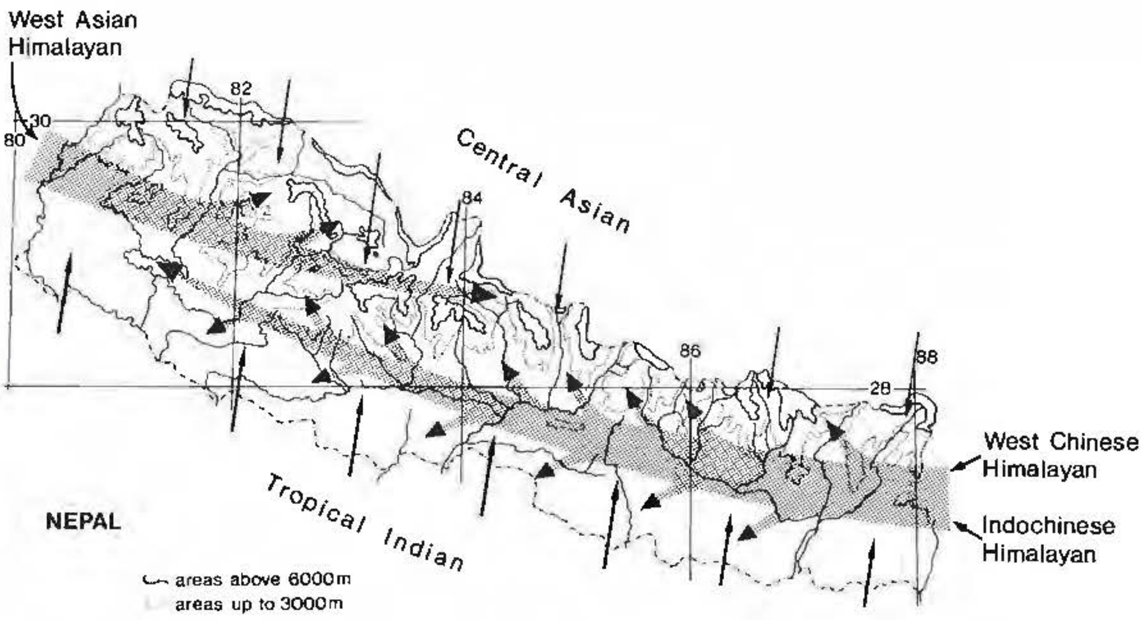

Fig. 1. Map of Nepal indicating main immigration routes of faunal components into the Central Himalayas.

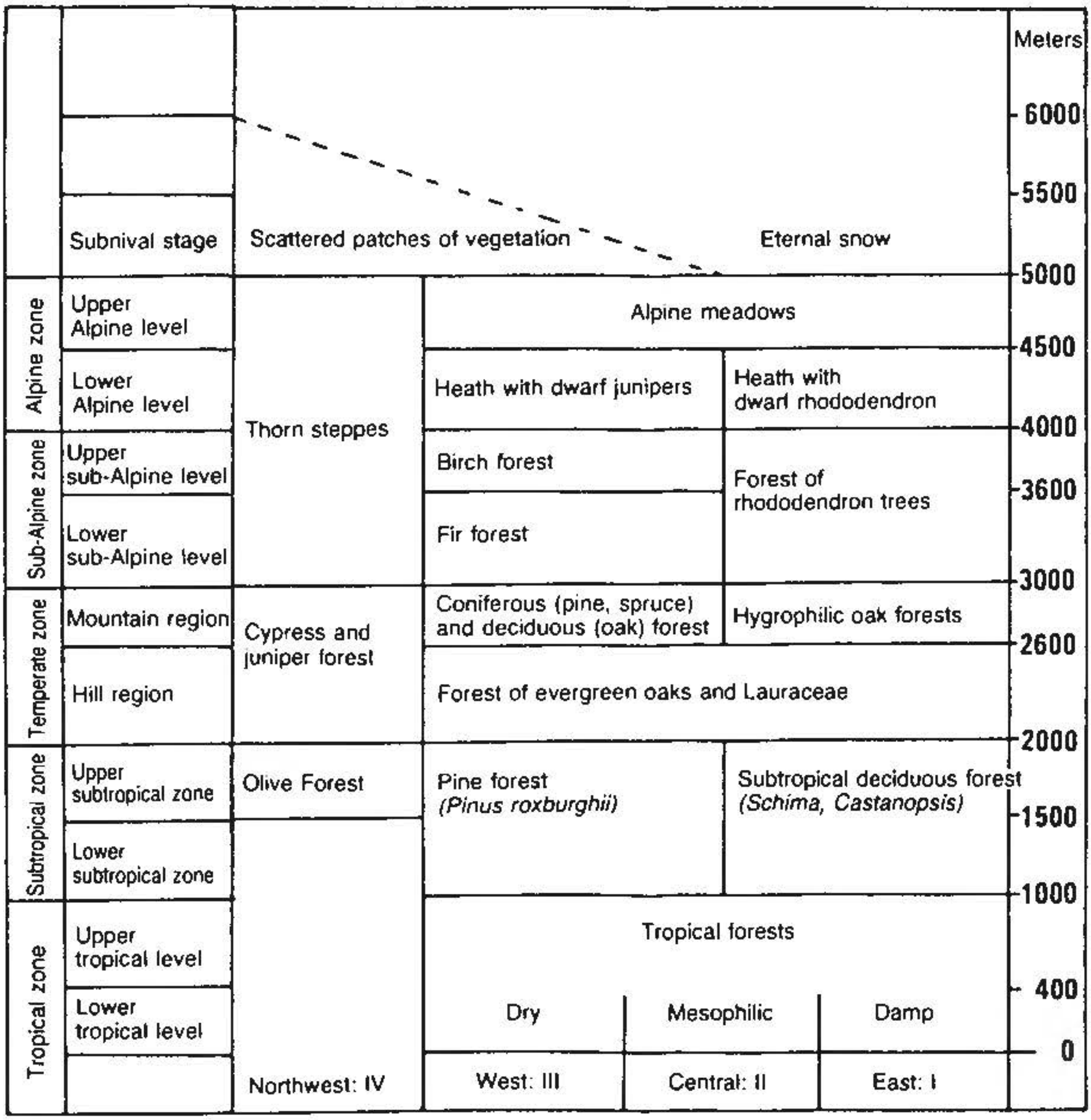

Fig. 2. The vegetation belts with the most important plant communities in Nepal. The Roman numerals at the bottom of the Table indicate the floral regions of Nepal (after: DOBREMEZ, 1972).

The Oriental faunal elements belong to two major groups:

4. Tropical/Subtropical Oriental Species of Southeastern Origin from the Indochinese Subregion, mainly Burma and Indochina.

Those species migrated in high numbers westward along the southern slopes of the Himalayas. Their diversity is greatly reduced from east to west in response to the diminishing monsoon rainfall. Within the zone of *Castanopsis-Quercus*-laurel forest and partly within the tree *Rhododendron* belt (2000–3500 m), they are distributed in a great variety of genera and families, and, only in the subalpine coniferous forest, are they greatly reduced in numbers (Indochinese Himalayan species).

5. Tropical Oriental Species, broadly distributed in the Indian Peninsula.
These reach the southern Himalayan mountains from the south and along deeply cut river valleys, may penetrate right into the main mountain chain. Their vertical distribution rarely exceeds 2000 m, and is in many cases much less (Tropical Indian species or Peninsular Indianspecies).

Thus, the Himalayan faunal elements, though emphasized by various authors, are not an independent group confined to the Himalayas, but are a mixture of species groups which invaded the Himalayas from various directions. Himalayan palaeo-endemics, with no closely related species outside the Himalayas, are rare but neo-endemics, especially among arthropods, currently occur (MARTENS, 1979 and 1981 b).

To be able to assess individual components in the fauna, we have to know first their environmental limits, then their region of origin, their recent distributional extent and the history of their establishment in the Himalayas. The ecological limits of the animal groups – in so far as the forest fauna is concerned – are, on the other, dependent on the vertical zonation of the vegetation and very often follow the climatic gradient. Frequently, there are far-reaching correspondences between the zonal gradation of the vegetation and its faunal communities.

First let us glance at a classification of the vegetation belts, as proposed by DOBREMEZ (1972) in a simplified diagram for Nepal (Fig. 2). From a mainly zoological point of view, it provides sufficient information and from it we can see that on the southern slopes tropical forests prevail to an altitude of

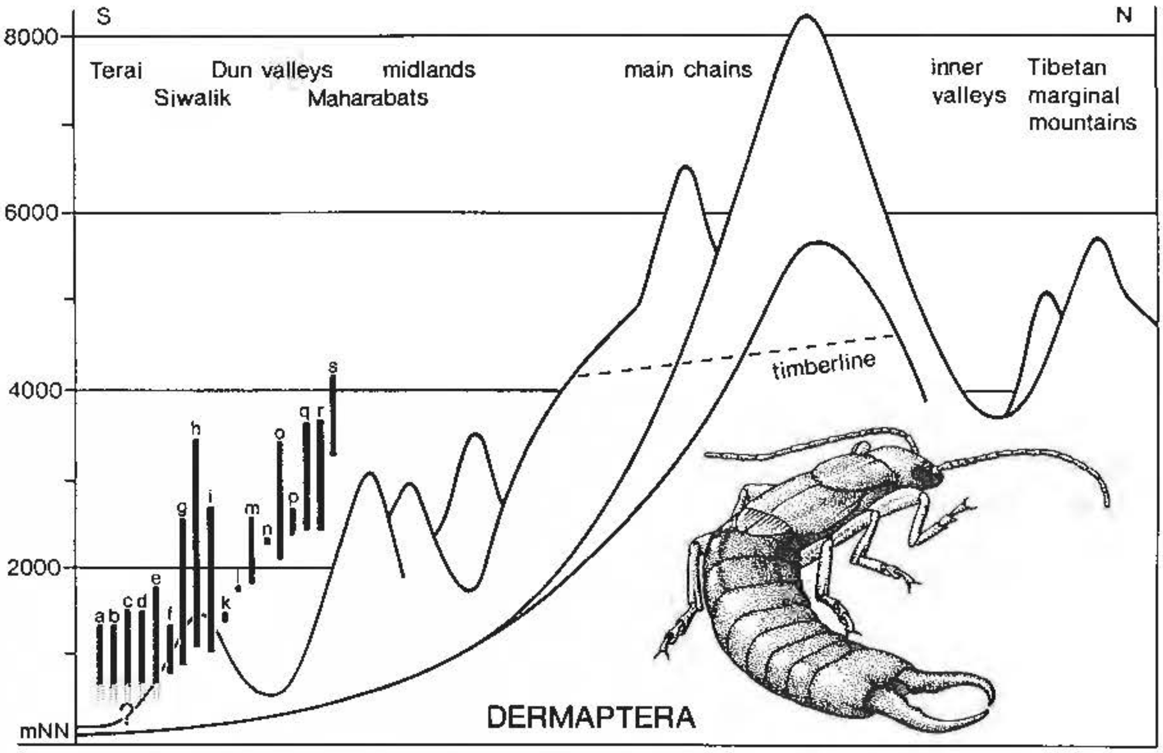

Fig. 3. Vertical distribution of 18 earwig species (after the collections of J. MARTENS; combined after: BRINDLE, 1974 and 1983). Stippled parts of the columns: distribution in the lower parts unknown. – a) *Labidura riparia* (600–1350 m), b) *Nala lividipes* (600–1350 m), c) *Forcipula trispinosa* (600–1500 m), d) *Diplatys transversalis* (600–1500 m), e) *Eudohrnia metallica* (600–1770 m), f) *Forcipula borellii* (700–1300 m), g) *Forcipula decolyi* (800–2250 m), h) *Forficula beelzebub* (1100–3450 m), i) *Aborolabis nepalensis* (1000–2700 m), k) *Diplatys rileyi* (1350–1450 m), l) *Nala nepalensis* (1750–1800 m), m) *Eparchus oberthuri* (1800–2600 m), n) *Diplatys rufescens* (2250–2300 m), o) *Allodahlia martensi* (2100–3400 m), p) *Allodahlia macropyga* (2350–2700 m), q) *Forficula schlagintweiti* (2400–3650 m), r) *Anechura stoliczkae* (2400–3700 m), s) *Forficula beebei* (3250–4200 m).

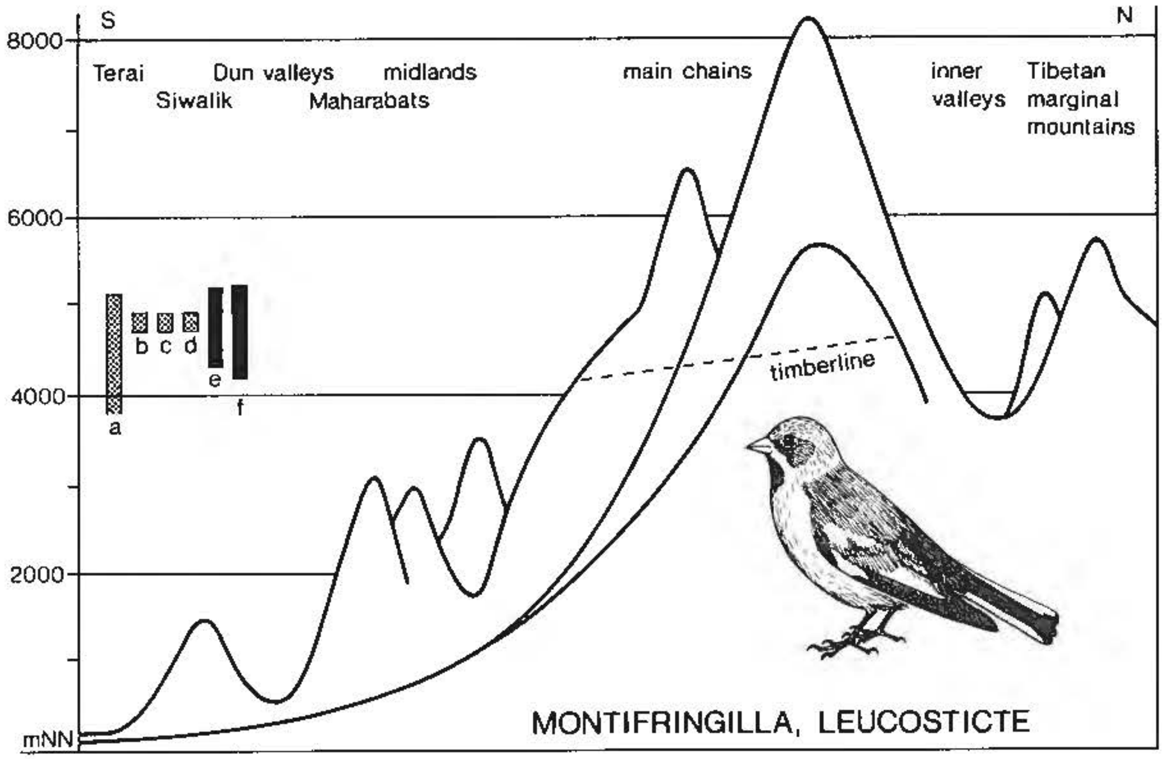

Fig. 4. Vertical distribution of snowfinches (after: DIESSELHORST, 1968; FLEMING et al., 1980; pers. obs.). Stippled columns: species restricted to dry Tibetan mountain steppe habitats. – a) *Montifringilla adamsi* (3900–5200 m), b) *M. taczanowskii* (4750–4900 m), c) *M. ruficollis* (4750–4900 m), d) *M. blanfordi* (4750–4900 m), e) *Leucosticte nemoricola* (4300–5190 m), f) *L. brandti* (4200–5200 m).

1000 m, which receive reduced rainfall from east to west. Transition areas with strongly changing vegetation between eastern and western parts of the Central Himalayas are the Arun valley in East Nepal and the Dhaulagiri area in West-central Nepal. This belt is almost exclusively inhabited by Oriental Indian species. Above it, we find subtropical montane forest, where – mainly in the western parts – *Pinus roxburghii* prevails, a species adapted to soils which dry quickly after rainfall. At altitudes up to 2000 m, the tropical influence is steadily reduced and between 1000 and 2000 m are found the greatest number of Indochinese species.

Of particular significance is the vegetation between 2000 and 3000 m and locally even higher. This belt receives more convective-type precipitation and the high altitude causes a cooler climate. Plant species and genera occur which belong to the temperate zone and which are known for example from the European flora, like *Quercus*. With regard to the fauna and flora, we call this belt the Himalayan West Chinese. The arthropod fauna especially contains many neo-endemic species.

In the belt between approximately 3000 and 4000 m are found the *Rhododendron*-Coniferous forests, in the drier western parts mainly fir and birch forest. The timberline is near to 4000 m, locally higher, meeting the scrub formation subject to Central Asian influence. Strikingly divergent is a region, north of Dhaulagiri, Annapurna and other West Nepal parts of the main mountain chains, which is forestless except for a few lower parts. The high altitude and dryness bring about strong similarities with Tibetan plateau conditions and it is actually from Tibet that the region has been colonized by plants and animals.

This rough floristic differentiation can provide the zoologist with but a guideline, since individual animal species are only broadly associated with plant communities typical of their geographical origin. On the contrary, in the Himalayas, many separate evolutionary trends have succeeded. We can identify

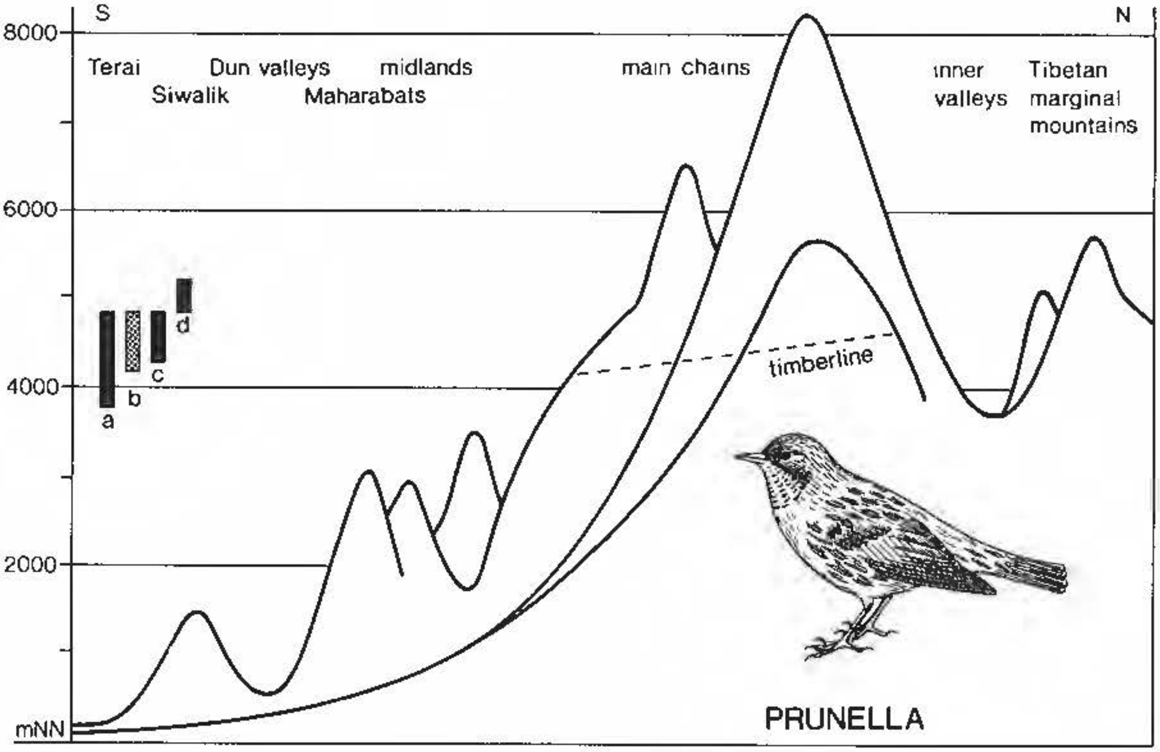

Fig. 5. Vertical distribution of hedgesparrows (after: DIESSELHORST, 1968; FLEMING et al., 1980; pers. obs.). Stippled column: species confined to dry Tibetan mountain steppe habitats. – a) *Prunella strophiata* (3800–4800 m), b) *P. fulvescens* (4200–4800 m), c) *P. rubicilloides* (4300–4800 m), d) *P. collaris* (4800–5200 m).

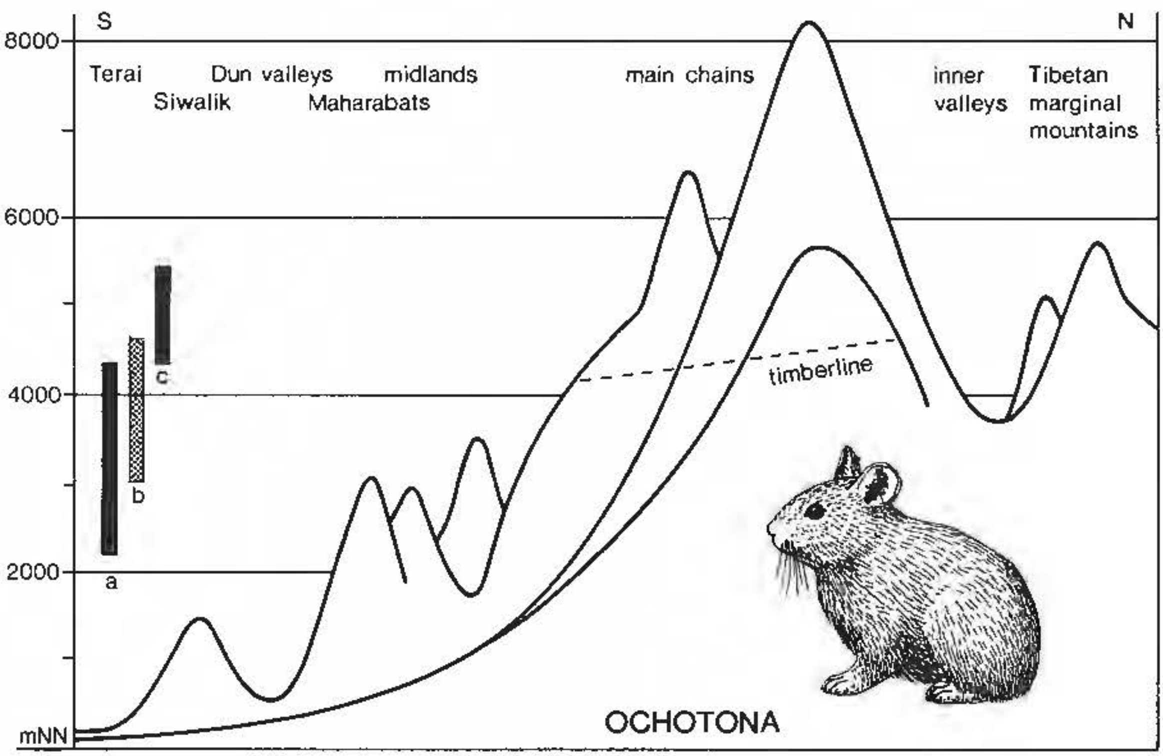

Fig. 6. Vertical distribution of pikas (after: ABE, 1971; KAWAMICHI, 1971; MITCHELL and PUNZO, 1975; pers. obs.). Stippled column: species restricted to dry Tibetan mountain steppe habitats. – a) *Ochotona roylei* (2200–4300 m), b) *O. thibetana* (3050–4600 m), c) *O. macrotis* (4300–5400 m).

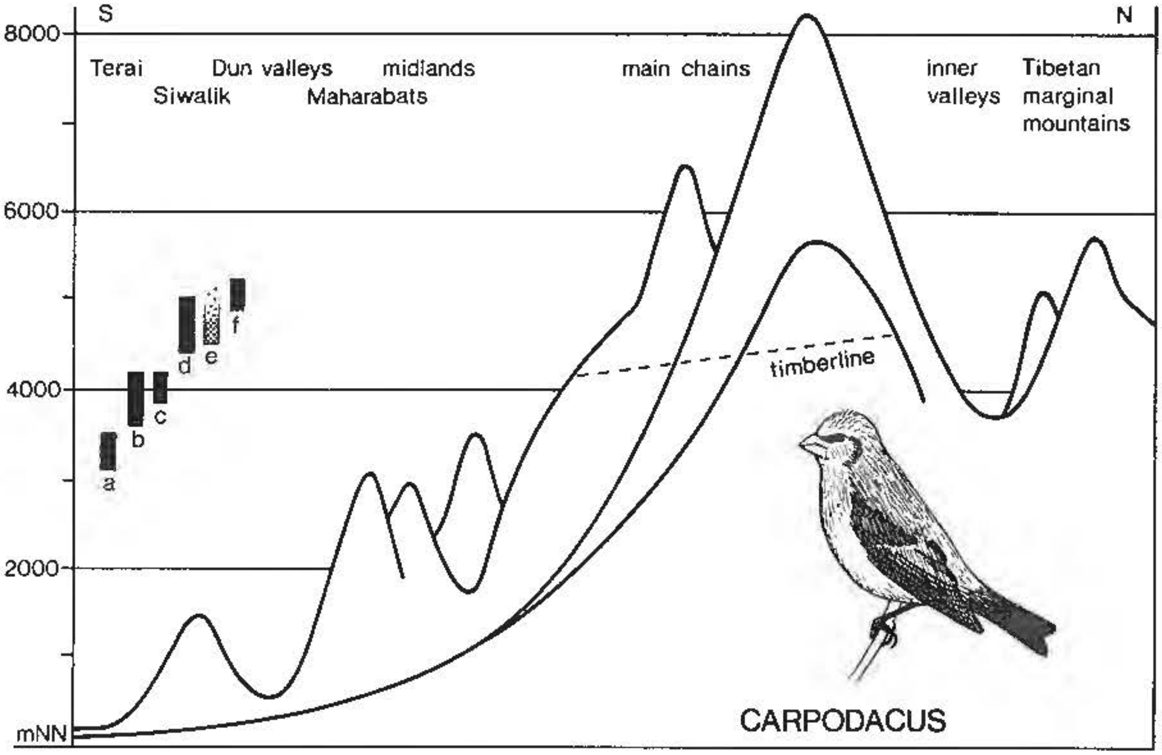

Fig. 7. Vertical distribution of rosefinches (after: DIESSELHORST, 1968; FLEMING et al., 1980; pers. obs.). Stippled column: species restricted to dry Tibetan mountain steppe habitats, upper limit unknown. – a) *Carpodacus erythrinus* (3100–3700 m), b) *C. pulcherrimus* (3600–4200 m), c) *C. thura* (3800–4200 m), d) *C. rubicilla* (4350–5000 m), e) *C. rubicilloides* (4450 to about 5000 m), f) *C. puniceus* (4800–5200 m).

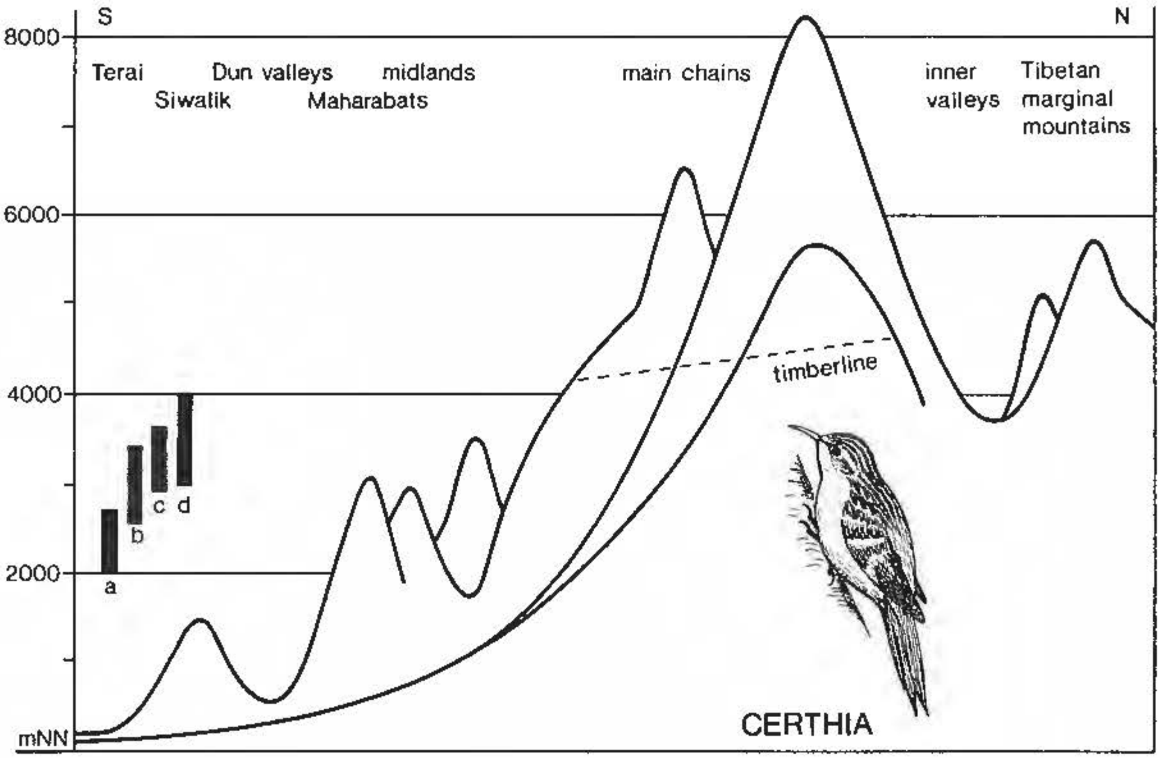

Fig. 8. Vertical distribution of treecreepers (after: DIESSELHORST, 1968; FLEMING et al., 1980; MARTENS, 1981 a). – a) *Certhia discolor* (2000–2700 m), b) *C. nipalensis* (2550–3400 m), c) *C. himalayana* (2900–3650 m), d) *C. familiaris* (3000–4000 m).

secondary adaptations to tropical, subtropical and cold-temperate altitudinal belts, which hardly conform to the area of origin of the species, genus or even family in question. This holds especially true for those animal groups, which after colonization of the Himalayas underwent heavy fragmentation of their populations and finally speciation into many neo-endemics now inhabiting small areas only. Such circumstances prevail for the small arthropods of the forest soils and litter. The vertical distribution of these closely related species is clearly graduated, covering altogether a wide range of altitude and climatic conditions (cf. Fig. 12).

Looking at a few examples, we shall try to identify the different types of vertical distribution in the Nepal Himalayas and to emphasize special developments.

Earwigs (Insecta: Dermaptera; Fig. 3): The only group of insects the vertical distribution of which is relatively well known. As many as 36 species have so far been listed. The vertical distribution of 18 of these is given in the figure. Species of Oriental origin and Indian affinities ascend up to about 1500 m, those of Palaearctic origin are found from 2000 to 4200 m and nearly all belong to the family Forficulidae (Forficulinae), "and the five species which occur at the highest altitudes all belong to the genera *Anechura*, *Allodahlia*, and *Forficula*" (BRINDLE, 1983). In the Central Himalayas all species but one – regardless of their zoogeographic affinities – are confined to the monsoon-influenced southern slopes. An exception is *Forficula beelzebub*, penetrating to the dry areas north of the main chain. Normally, the vertical belts are less than 2000 m broad, and *F. beelzebub*, covering 2500 m, is the only euryoecean species occupying a large variety of habitats. About half of the Nepal species, often endemics with small areas, are known in a few localities only. In such cases, their vertical distribution seems to be very limited, but detailed information is still lacking.

A more detailed classification of the patterns of vertical distribution starts with the Central Asian Palaearctic elements. They penetrate with few species only to the southern slopes.

Snowfinches (Aves: Ploceidae; Fig. 4): The genera *Montifringilla* and *Leucosticte* are mainly Palaearctic, *Leucosticte* extending to North America. Tibet is believed to be the centre of development of *Montifringilla*. Four species reach the northern flanks in Nepal in Tibetan mountain steppe habitats. Both the *Leucosticte* species are found also on the highest parts of the southern slopes (e.g. in Khumbu) and one of them, *nemoricola*, is a common winter visitor locally down to 2100 m (pers. obs.).

Hedgesparrows (Aves: Prunellidae; Fig. 5): Three of the four *Prunella* species of Nepal also breed on the northern slopes (one breeding only there), concentrated vertically between 4000 and 5000 m. None of the species penetrates from its lower limits into the forest belt, *strophiata* however inhabits tall willow bushes (down to 3800 m). *Rubeculoides* and *fulvescens* may occur side by side.

Pikas (Mammalia: Lagomorpha: Ochotonidae; Fig. 6): The species of the genus *Ochotona* are found only in the Northern Hemisphere, in the Southeast Palaearctic mainly at high altitudes and nearly exclusively outside forests and above the timberline. One species, however, *roylei*, has succeeded in adapting itself to the monsoon-influenced southern flanks, down to 2300 m in the subtropical zone. *Thibetana* inhabits dry northern areas. Beside *Alticola* voles, pikas are the only mammals settling permanently altitudes up to nearly 6000 m in the Himalayas.

Rosefinches (Aves: Fringillidae; Fig. 7): *Carpodacus* is a genus rich in species mainly in the Palaearctic realm of the Old World with the most important concentration of species in South-west China, in the Himalayas and in areas adjoining them to the north. Eleven species breed in Nepal. The distribution of several species is similar to that of *Ochotona:* they penetrate from Central Asia to Nepal (Fig. 7 b, d, e, f) and are confined to high altitudes but not only on the northern slopes. Others are Himalayan West Chinese (7 c) or are largely distributed in North Asia (7 a). Only two of the species presented here (*erythrinus*, 7 a; *thura*, 7 c) are confined to the forest belt and only *thura* inhabits the dense forests proper. None of the Nepal species has breeding colonies below 3000 m.

Treecreepers (Aves: Certhiidae; Fig. 8): In Asia, all the species of the genus *Certhia*, except one, inhabit the Palaearctic realm and thus occupy only the upper forest belt. The four species in question

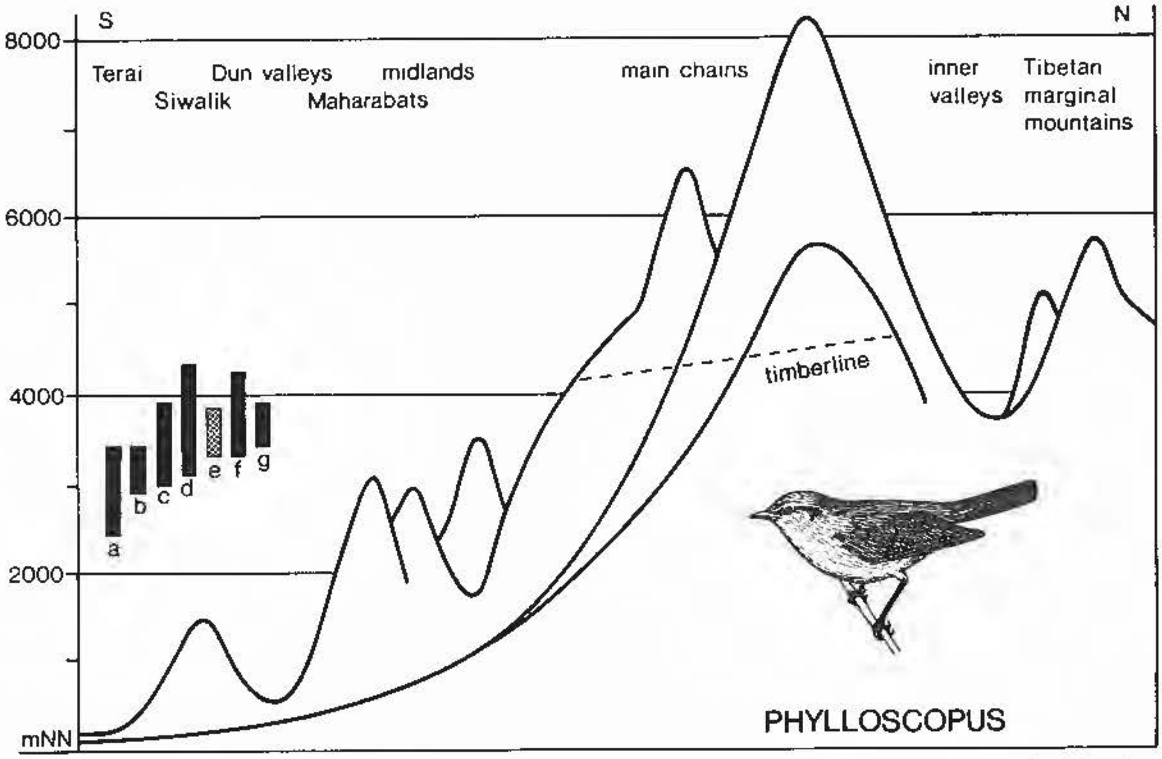

Fig. 9. Vertical distribution of leafwarblers (after: DIESSELHORST, 1968; FLEMING et al., 1980; MARTENS, 1980). Stippled column: species largely restricted to dry West Himalayan forests north of the main chain. – a) *Phylloscopus reguloides* (2400–3400 m), b) *P. maculipennis* (2900–3400 m), c) *P. proregulus* (3000–3900 m), d) *P. affinis* (3150–4300 m), e) *P. inornatus* (3300–3800 m), f) *P. trochiloides* (3300–4200 m), g) *P. pulcher* (3400–3900 m).

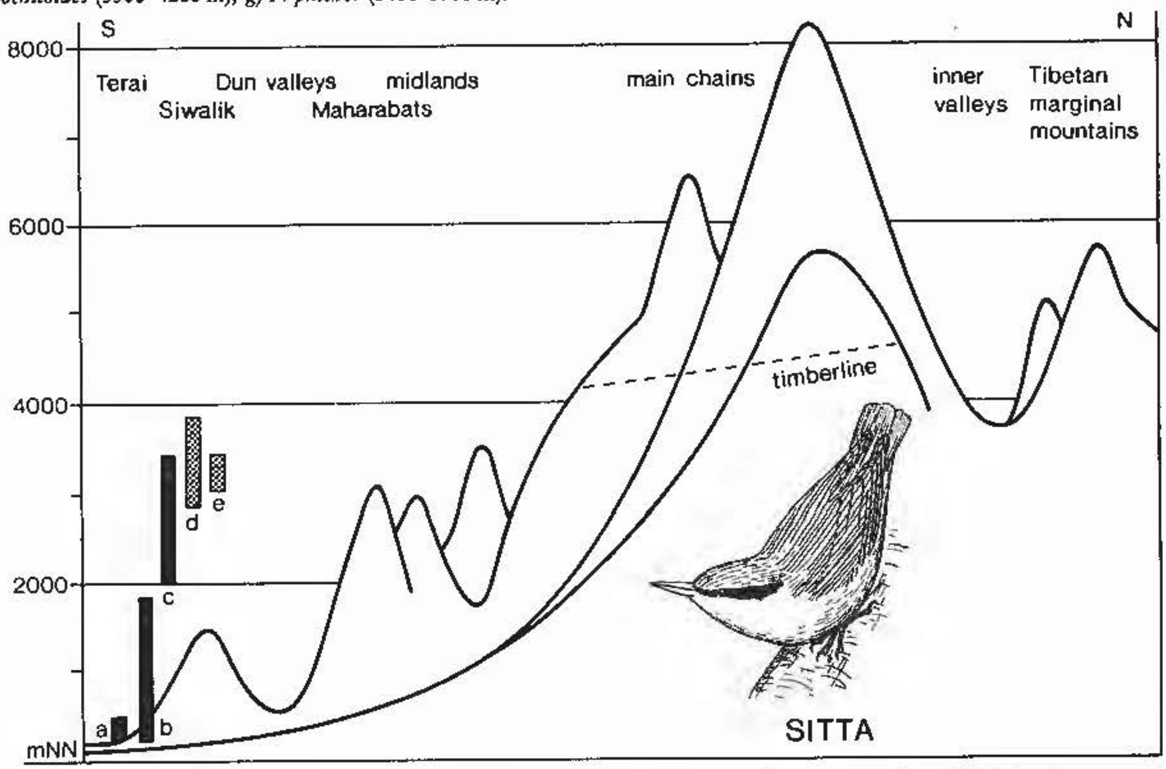

Fig. 10. Vertical distribution of nuthatches (after: DIESSELHORST, 1968; FLEMING et al., 1980; pers. obs.). Stippled columns: species restricted to dry West Himalayan forests north of the main chain. – a) *Sitta frontalis* (150–400 m), b) *S. castanea* (150–1800 m), c) *S. himalayensis* (2000–3400 m), d) *S. leucopsis* (2800–3800 m), e) *S. cashmirensis* (3050–3500 m).

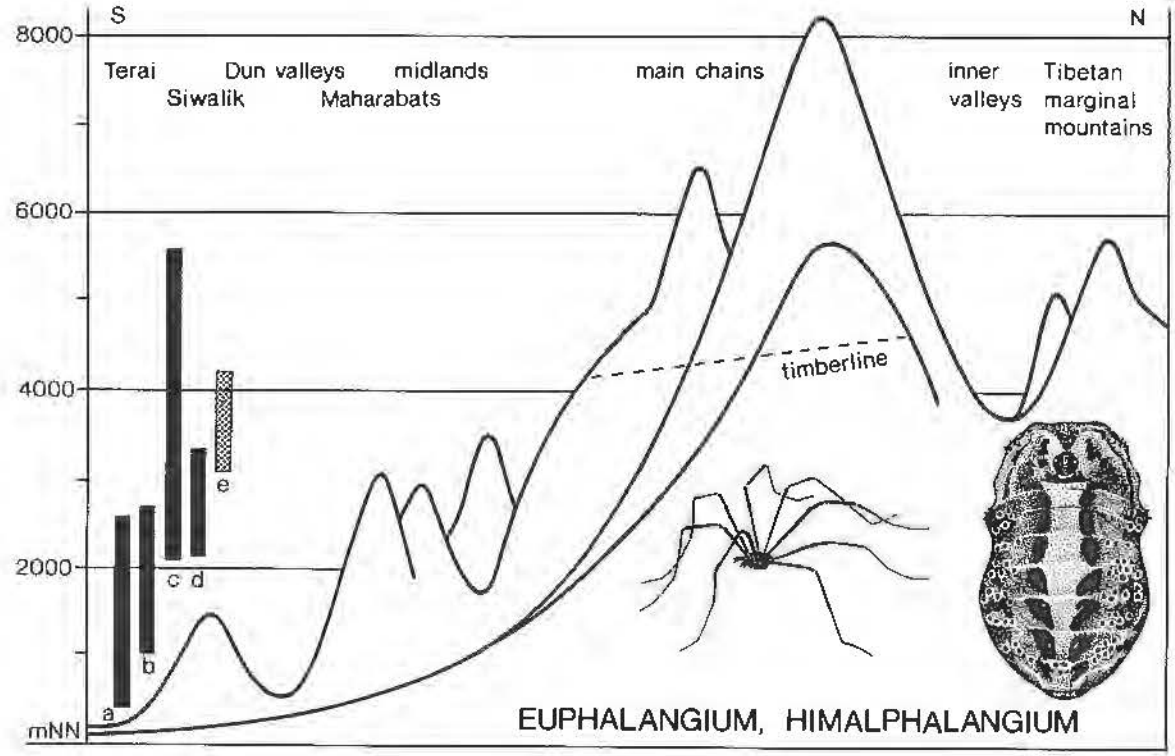

Fig. 11. Vertical distribution of harvestspiders (Phalangiinae) (after: MARTENS, 1973). Stippled column: species largely restricted to dry areas: forests and mountain steppe north of the main chain. – a) *Euphalangium nepalicum* (300–2600 m), b) *Himalphalangium nepalense* (1000–2700 m), c) *H. palpale* (2100–5550 m), d) *H. suzukii* (2150–3350 m), e) *H. dolpoense* (3100–4200 m).

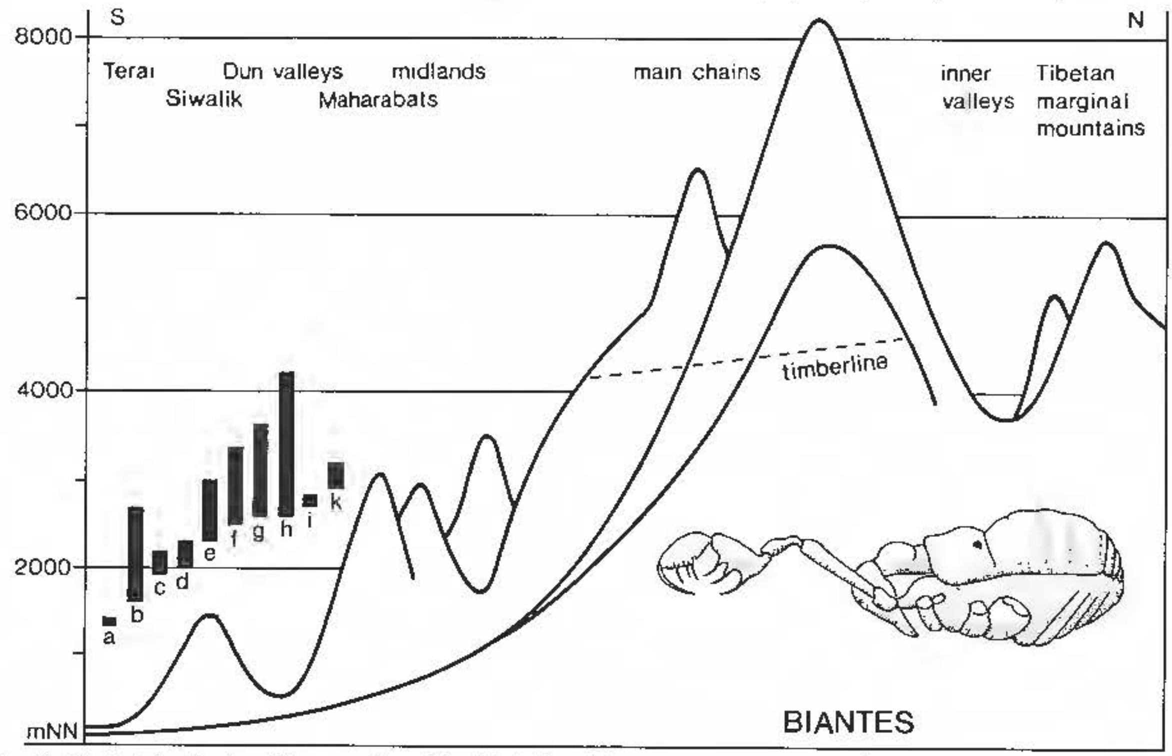

Fig. 12. Vertical distribution of harvestspiders (Biantidae) (after: MARTENS, 1978). – a) *Biantes brevis* (1300–1400 m), b) *B. newar* (1600–2700 m), c) *B. gandaki* (1900–2200 m), d) *B. gandakoides* (2000–2300 m), e) *B. thamang* (2300–3000 m), f) *B. dilatatus* (2500–3350 m), g) *B. thakkhali* (2600–3640 m), h) *B. pernepalicus* (2600–4250 m), i) *B. annapurnae* (2600–2850 m), k) *B. sherpa* (2900–3200 m).

reached the Himalayas of Nepal from different areas: from west (*himalayana*, 8 c), the east (*discolor*, 8 a) or, apparently, from east and west (*familiaris*, 8 d). *Nipalensis* is endemic to the Himalayas. Only *discolor* is confined to subtropical (i.e. to temperate) forest types, and occurs also in the Indochinese subregion, thus avoiding the tropical forest belt of the Himalayas. Each species inhabits a different altitudinal belt and forest formations, but vertical distributions overlap broadly. Two, or exceptionally three species may occur sympatrically. In the lower forest zone up to 2000 m, the ecological niche maintained by the treecreepers remains unoccupied (MARTENS, 1981 a).

Leafwarblers (Aves: Sylviidae; Fig. 9): The genus *Phylloscopus*, comprising about thirty species, is largely distributed in the Palaearctic and almost confined to this region. The heaviest concentration of species is in the Himalayas, and only few survive in the Indochinese subregion. In Nepal, only one species (*reguloides*, 9 a) descends to subtropical forest types, but it originated in West China and thus has adapted to a temperate climate. One species (*inornatus*, 9 e) reaches Nepal from the west inhabiting only dry forest types of western origin, the limit to its eastern distribution being in South Dolpo (North-west Dhaulagiri), perhaps further east in Thakkhola (Kali Gandaki Valley between Dhaulagiri and Annapurna).

Examples of genera of Palaearctic origin, penetrating into the Oriental Realm within the Himalayas with species restricted to low altitudes.

Nuthatches (Aves: Sittidae; Fig. 10): Nearly the whole forest belt is inhabited by *Sitta* species, but two are found only in the North-west in the dry forests of West Himalayan character as far east as North-west Dhaulagiri (*leucopsis*, 10 d; *cashmirensis*, 10 e). Two are restricted to the foothills (*frontalis*, 10 a; *castanea*, 10 b). Curiously enough, large areas, densely forested especially in the Inner Valleys (f.e. Thakkhola, Manang), are void of nuthatches; *himalayensis* avoids habitats not influenced by the monsoon; *leucopsis* and *cashmirensis* – though conditions are favourable for them – have not discovered the "hidden" Inner Valleys, separated by vast inhospitable areas from their easternmost breeding areas: These are the regions above the timberline to the north and wet areas to the south.

Harvestspiders (Arachnida: Opiliones: Phalangiidae; Fig. 11): The genera *Himalphalangium* and *Euphalangium*, both Phalangiinae, originate from the Palaearctic. *Himalphalangium* radiated in the Central Himalayas, now inhabiting the area and South Tibet with endemic species. One species lives mainly in the dry areas on the northern flanks (*dolpoense*, 11 e), others have adapted to a different extent to the forests of the lower subtropical zones and do not avoid the monsoon influence. Their adaptation consists of the biological peculiarity that embryonic and postembryonic development of the low altitude species takes place during the coldest part of the year, that is during the winter and pre-monsoon seasons.

Himalayan fauna of Oriental origin. These are throughout species relating to genera from India and Indochina, which entered the Himalayas mainly from the south, south-east and east.

Harvestspiders (Arachnida: Opiliones: Biantidae; Fig. 12): The family Biantidae is distributed in both Indias, though known only locally until recently, and also in Africa south of the Sahara. The genus *Biantes* consists of numerous species in the Himalayas, and, from Nepal only, as many as 18 species are described. We can be sure that the individual species developed within or at least near to their present distribution areas. Most surprisingly, a relatively large number of species have adapted to a temperate climate in the upper forest zone and one species (*pernepalicus*, 12 h) is even found above the (artificial) timberline. This case can be quoted as an illustration of how an originally tropical genus may reach – including the phenomena of speciation – up to altitudes forming part of the Palaearctic realm.

Sunbirds (Aves: Nectariniidae; Fig. 13): The genus *Aethopyga* is mainly Indochinese in distribution and of tropical origin. As for the Biantidae, purely tropical species exist beside others adapted to temperate montane forests (*nipalensis*, 13 c), and one is exclusively restricted to the Palaearctic *Rhododendron*-Conifer forest zone up to the timberline and is, in addition, endemic to the Himalayas (*ignicauda*, 13 d).

Shrews (Mammalia: Soricidae; Fig. 14): The genus *Suncus* is largely distributed in the Oriental realm, and the two Himalayan species (*etruscus*, *murinus*) invaded the area from the south. The musk shrew

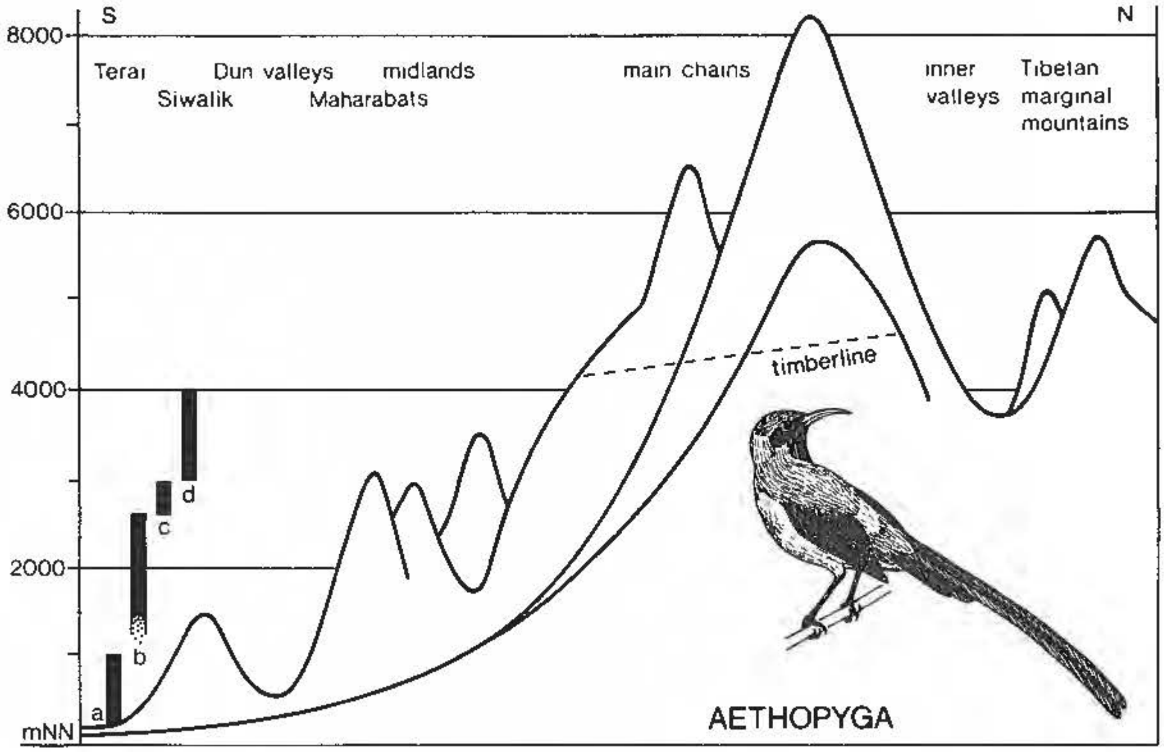

Fig. 13. Vertical distribution of sunbirds (after: DIESSELHORST, 1968; ALI and RIPLEY, 1972; FLEMING et al., 1980; pers. obs.). – a) *Aethopyga siparaja* (250–1000 m), b) *Ae. saturata* (1500–2600 m), c) *Ae. nipalensis* (2600–3000 m), d) *Ae. ignicauda* (3000–4000 m).

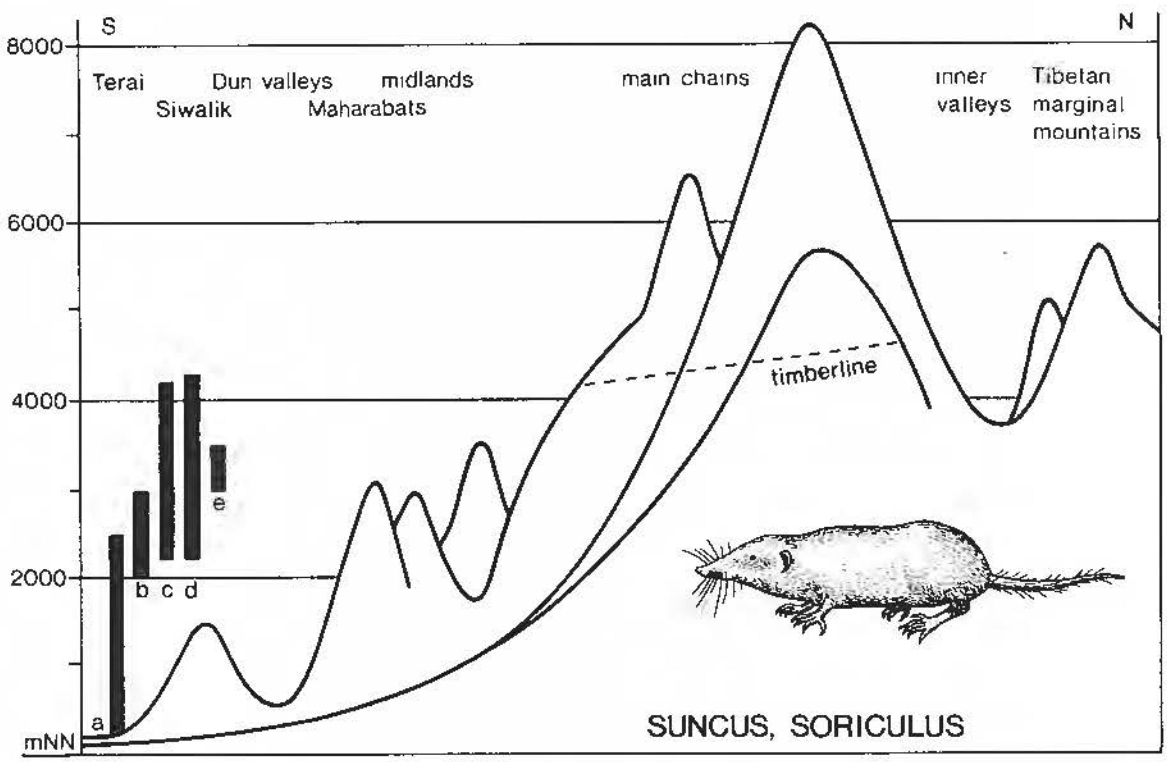

Fig. 14. Vertical distribution of shrews (after: ABE, 1971; GRUBER, 1969; MITCHELL, 1977; pers. obs.). – a) *Suncus murinus* (150–2750 m), b) *Soriculus leucopsis* (2000–3000 m), c) *S. nigrescens* (2200–4200 m), d) *S. caudatus* (2200–4300 m), e) *S. baileyi* (3000–3400 m).

(*Suncus murinus*, 14 a), though living frequently with human settlements, normally occurs upwards to 2000 m, rarely higher (recorded in Nepal to 2750 m), and it is evidently confined to the tropical/subtropical belt. *Soriculus* has mainly Indochinese and west Chinese affinities and, in consequence, inhabits the temperate forest zone with a tendency to reach altitudes even above the timberline (*nigrescens*, 14 c; *caudatus*, 14 d).

Discussion

The vertical distribution of no group of the Himalayan fauna is as yet satisfactorily known – not to mention the local variations reflecting exposure and vegetational differences within small distance. Comparatively sound is the information on birds, small mammals (excepting bats), a few soil dwelling arthropods (Carabidae: *Carabus;* Dermaptera; Opiliones), and butterflies (Lepidoptera: Rhopalocera). Moreover, as the diversity of the fauna is enormous, cataloguing will take many more years. Thus the examples given rely on the taxa mentioned elsewhere and which I have observed myself during Himalayan expeditions (six since 1969).

The examples show that vertical distributions are well defined and that they depend on the climatic conditions in the areas from where immigration into the Himalayas has taken place. The present vertical distribution is in agreement with the ecological adaptations acquired by the species/genera in their areas of origin. In the secondary Himalayan areas, however, adaptations to warmer or colder altitudinal belts have occurred quite frequently.

In comparison with the large vertical span of 6000 m inhabited by living beings, the vertical belts for individual species must be considered narrow. Often they cover hardly more than 1000 m and seem to be even smaller for endemics with limited areas. According to recent findings, this holds especially true for small arthropods of the forest litter and soil. Marked vertical gradation of closely related species is the rule and the species swarm covers a great variety of altitudes and climatic conditions – regardless of their faunal origin. Only a few species, not to mention ubiquitous ones with very large area spans, occupy belts of 2000 m or more. In several cases, we can recognize the reasons for such extensive belts:

a) The habitat may change little in essential detail at the different altitudes. This holds true for running water, which offers apparently similar conditions at different altitudes at least for several birds: Brown Dipper *(Cinclus pallasii)* and White-capped Redstart *(Chaimarornis leucocephala)*, each confined to the borders of mountain streams and occupying a very large extent of at least 4000 m (DIESSELHORST, 1968; pers. obs.).

b) The vertical zone may be colonized by two subspecies, which replace one another altitudinally. This holds true for the Jungle Crow *Corvus macrorhynchus)*, comprising in Nepal the subspecies *C. m. culminatus* up to about 2000 m, and *C. m. intermedius* up to timberline.
   In the case of the Stonechat *(Saxicola torquata)*, the subspecies *S. t. indica* penetrates into the lower Himalayas from North India up to 2500 m. The Tibetan subspecies *S. t. przewalskii* descends from the Tibetan plateau to the Inner Valleys to the northern rim of the Main Chain, down to 3800 m. However, they do not meet and there is a belt of about 1500 m void of Stonechats (ALI and RIPLEY, 1973; MARTENS, 1972).

c) Habiats may be extended vertically by human activity. Frogs of still waters in the lowlands penetrate to the artificial rice terraces of the foothills and higher (DUBOIS, 1980).

d) Species associated directly with human settlements may reach even to the inhospitable northern slopes of the sparsely settled Main Chain – which could be impossible to sustain without human support. Good examples are the Tree Sparrow *(Passer montanus)* and the Cinnamon Tree Sparrow *(P. rutilans)*, which colonize even the highest villages in Dolpo, up to 4300 m.
   Also the human flea *(Pulex irritans)* extends its area to the highest villages – a species living not permanent on men but during the adult stage (SMIT, 1974).

The data presented here can provide only a rough idea of the multitude of phenomena relating to vertical distribution in the vast Himalayan mountain chain. At present, we are occupied in collecting data in the field. Until now, we have understood only a few main factors acting on and limiting vertical distributions. But we are quite ignorant of how to explain which ecological factors and environmental peculiarities act on the fine structure of the vertical distributions.

Summary

a) The Himalayan fauna is to be understood as adapted to different climatic belts and vegetation zones.
b) Both climatic belts and vegetation zones are largely in accordance with the areas of origin outside the Himalayas of the various faunal elements.
c) The Himalayan fauna is mainly an immigration fauna. We distinguish five main centers of origin and thus five categories of Himalayan fauna, three of which fall into the Palaearctic (Central Asian, Himalayan West Asian, Himalayan West Chinese) and two in the Oriental realm (Himalayan Indochinese, Peninsular Indian).
d) Though the Palaearctic elements are more differentiated than the Oriental ones, they are represented by a greater number of species.
e) Vegetation belts and climatic zones provide only guidelines to our understanding of the faunal distribution. After immigration a large variety of special adaptations have occurred, mainly the colonization of vertical belts not matching areas of origin (tropical, subtropical, temperate). Speciation has played a major role in such special ecological adaptations.

Acknowledgment

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Discussion to the Paper Martens

Priv.-Doz. Dr. P. Frankenberg:

Are any faunistic elements of the cold tropics to be found in the Himalaya?

Prof. Dr. J. Martens:

Yes, in the sense that groups of tropical, in our case of oriental origin, have adapted themselves to altitudes, which belong to the cold-temperate, palaearctic area of influence. Numbering among these groups are for example daddy-long-legs (harvestmen, Opiliones) of the families Biantidae and Assamiidae, which are to be found in few species even above 4000 m, that is to say clearly above the forest-line. Close relatives are living in lower altitude in (sub)tropical areas. The same is true for the Laughingthrushes (Timaliidae).

Priv.-Doz. Dr. P. Frankenberg:

Do breeding areas coincide with feeding areas in the bird's territories?

Prof. Dr. J. Martens:

This is quite variable. Many small birds defend territories, in which their nests are located and where at the same time food is searched. Other species, e.g. vultures in the high mountains, show very low (breeding-)settlement densities. They remove far from the breeding-place and may meet at the food-source, e.g. at a carcass, with others of their kind. Between these two extremes are many transitions, additionally modified by the extreme conditions in high mountains. Heavy snows during the monsoon may force non-breeding partners down into lower belts, e.g. *Grandala coelicolor*, a mountain thrush adapted to high altitude.

Prof. Dr. W. Haffner:

Can you quote examples of faunistic elements which are typical not only for the humid, cloudy *Rhododendron*-fir forest but also for the dry zones?

Prof. Dr. J. Martens:

Among the titmice (Paridae) *Parus rubidiventris* and *P. ater* settle in both biotopes, though more densely in areas where conifers dominate. Within the dry areas, both species live in the deep-cut valleys (Thakkhola), as well as on the northern flanks as far as they are covered with woodland (southern Dolpo, Manang). Among the small mammals the fieldmouse *Apodemus gurkha* and the shrew *Soriculus nigrescens* are spread respectively, as well as the daddy-long-legs of the Phalangiidae family. Generally, this type of distribution doesn't occur frequently; it demands high ecologic plasticism.

Prof. Dr. W. Haffner:

In Nepal there are also plant species with broad altitudinal belts, e.g. *Rhododendron arboreum*, a species which is to be found between 1200 m and 3500 m. Numbering among these, above all, are many species whose distribution was favoured by man.

Prof. Dr. J. Martens:

Culture plants are certainly favoured by man in the whole vertical zone, depending on climatic tolerance. Indirect supports of distribution, if new ecologic niches are created, do certainly occur. They may be less important, however, since it can be expected that climatic factors exercise an influence on vertical limitation. Certain species of some families are selectively favoured by pasturing, since they are shunned by the animals, e.g. *Primula* (Primulaceae) and *Arisaema* (Araceae). Particular, very adaptable adventive-plants spread along road borders, e.g. *Eupatorium* (Compositae).

Prof. Dr. B. Ruthsatz:

Are the examples of distribution which you demonstrated tied to the original plant societies in their areas? In how far do they tolerate a disturbance of biotopes by man, or can they even survive in anthropogenic substitutional societies?

Prof. Dr. J. Martens:

The dependence on primary vegetation is always especially high, if the species in question – independent of the altitudinal belt – settle on wood biotops. Slight interferences, e.g. moderate clearing without complete deforestation, are mostly tolerated. It is always fatal, if shading of the forest ground is strongly reduced and insolation increases. Soil-dwelling forms with high demands on constant air humidity and balanced temperature ranges do mostly not succeed in compensating the accompanying stress. Substitutional societies are only suitable to a limited number of species, mainly those, which are able to settle a larger spectrum of biotopes, anyway.

Dr. W. Golte:

In how far do the differences in exposition exercise an influence on the large vertical distribution of some species?

Prof. Dr. J. Martens:

The most marked differences are to be found on the southern resp. northern side of the main mountain chain in dependance on monsoon rains. The local variances of precipitation have their effect on the distribution of species. However, the influence of locally restricted differences in exposition haven't so far been judged; the data needed are still too sparse.

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The Position of Fagaceae and Myrtaceae on the Pacific Mountains

Frank Klötzli*

With 15 Figures and 2 Tables

1. Introduction

In almost all areas of the southern hemisphere, subtropical and tropical zones, Myrtaceae may take the role as dominant tree species, especially in middle and higher altitudes and even from the timberline. And also in the northern hemisphere, certain genera may dominate (e.g. *Syzygium, Eugenia, Tristania* etc. in evergreen broadleafed ["laurel"] forests.). But with preference on mountains in the specific area Myrtaceae may furnish the leading tree species, thereby often competing with Fagaceae of the genera *Quercus, Lithocarpus, Castanopsis* and *Nothofagus* (or then also with Pinaceae/Podocarpaceae, e.g. *Dacrydium, Phyllocladus, Papuacedrus,* etc.).

Leading Myrtaceae species are often recruited from the genera *Eucalyptus* (Australia, from northern Queensland to southern Tasmania, New Guinea, etc.) or *Metrosideros* (e.g. New Zealand, Tahiti, Hawaii, etc.), and on special sites (bog, subalpine belt) also *Leptospermum*.

On the other hand, Fagaceae play a decisive role in the more temperate areas, but also in montane and subalpine forests (compare the conditions in Indonesia, SE-Australia, incl. Tasmania, New Guinea, New Caledonia, New Zealand, but also between the Himalayas and Japan under subtropical conditions).

Between these two areas, dominating Myrtaceae under more tropical conditions, Fagaceae under more subtropical and temperate conditions, there is a large transition zone, where Fagaceae and Myrtaceae may be under heavy competition, thereby also meeting representatives of other dominating families, e.g. Podocarpaceae (incl. *Dacrydium*) on indomalaysian mountains (e.g. Kinabalu), Mimosaceae (*Acacia*, e.g. Tasmanian coastal heath) in eastern Australia.

On the northern boundaries of such areas, there are many relictic[1] sites of Fagaceae, a topic to be treated in this paper.

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* Work of this type can only be achieved with the help of numerous colleagues. Therefore, I owe special thanks to the following "antipodial" botanists and ecologists, going from Australia to South America: Dr. R. K. Crowden, Hobart, Tasmania; Dr. J. M. Veillon, ORSTOM, Nouméa, Nouvelle Calédonie; Mr. St. Chambers, Waitakaruru, New Zealand (N), Dr. P. Wardle and Mr. R. Allen, Christchurch, New Zealand (S), Monsieur D. Drakni, Directeur ORSTOM, Papeete, Tahiti; Prof. Dr. C. Ramirez, Valdivia, Chile; Prof. Dr. R. J. C. León, Buenos Aires, Argentina. I am also very grateful for their hospitality and their conscientious preparation of all excursions and many fruitful discussions, in Europe especially also to my friend and teacher Prof. Dr. H. Ellenberg.
To finance this trip I got a grant from the Swiss Federal Institute of Technology. My coworker and friend Mrs. Anna Holström has done a good deal of all the evaluations. And the graphs have been drawn by Mrs. Erika Wohlmann. To all these institutions, persons and many other colleagues in the more subtropical and tropical parts of the area of *Nothofagus* I owe my heartfelt thanks, last, but not least also to my family that had to bear the consequences of such trips around the world.

[1] Not all of them, however, are true relictic stands, i.e. remnants of a former large area of distribution (compare Fig. 1, e.g. *Nothofagus moorei, Nf. cunninghamii*). Some stands would have to be called more correctly "special sites" or are part of an extrazonal pattern.
Similar relictic site conditions for nemoral broadleafed forests are also detectable in the southern Taiga (e.g. Scandinavia; KLÖTZLI, 1975).

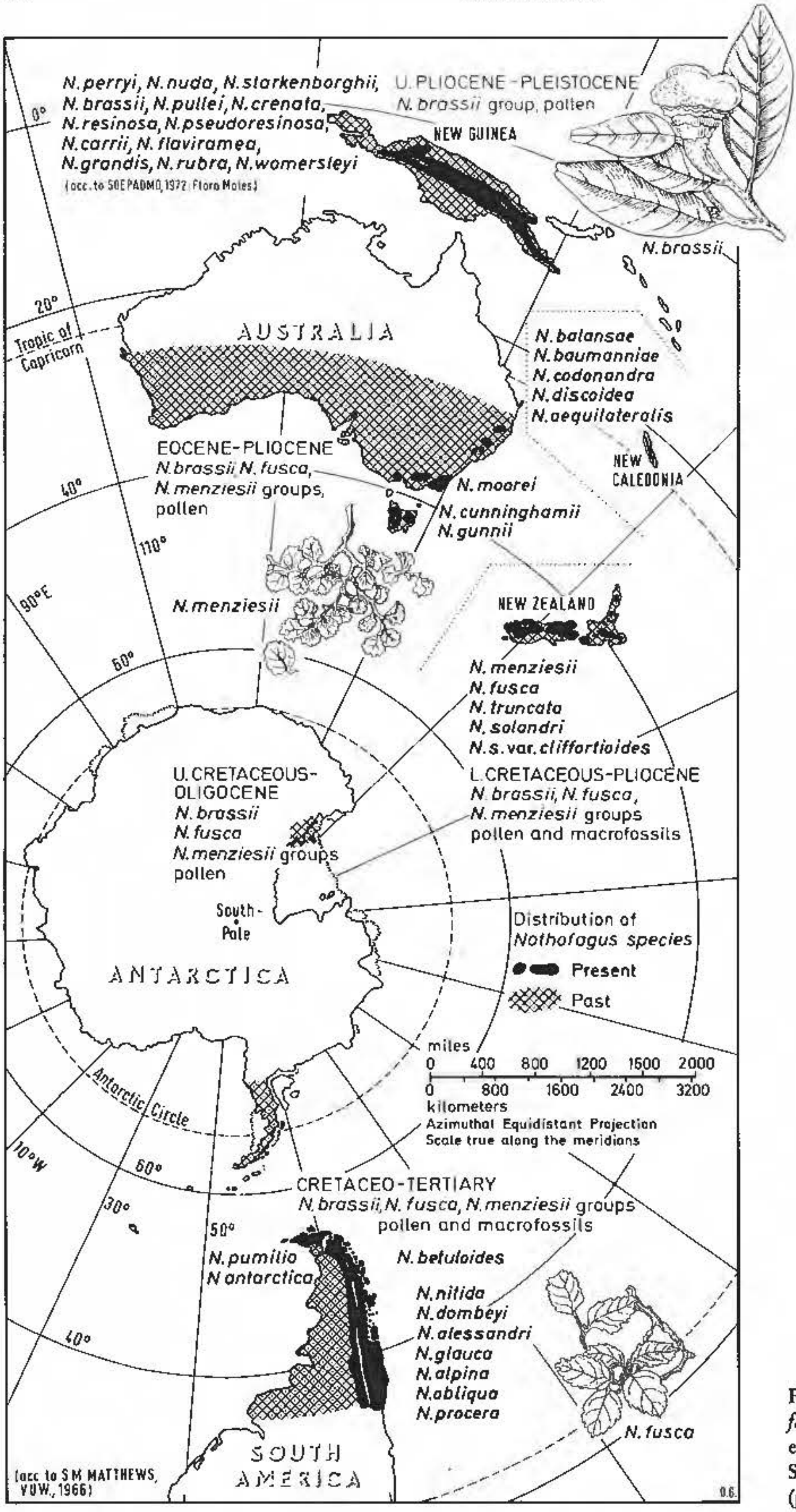

Fig. 1. Distribution of *Nothofagus* (s.l.) in the reach of former eastern Gondwana, compiled by S. M. MATTHEWS, N.Z., 1966 (part of display).

In these latitudes only *Nothofagus* s.l. (incl. *Trisyngyne*) is a representative of this family, but with many species having only very restrictive areas (compare e.g. Chapter 2.1.1., *Nothofagus moorei*; for New Guinea endemites see: ASH, 1982, *Nothofagus nuda, Nothofagus womersleyi*). Often they occupy very distinct patches in a multigenera forest, be it in Australia, the pacific area or in South America, thereby showing every aspect of relict species, sometimes due to difficulties of migration or because of dieback of unknown cause (see CARTLEDGE et al., 1975, in ASH, 1982).

2. Relictic Situations of Fagaceae in the Area of the Myrtaceae

In this transition zone, two distinct groups of relictic sites may be differentiated, namely those with and those without fire protection; i.e. in one case relictic sites are surrounded by vegetation which is regularly influenced by fire, and for the other group of sites this is not the case, vegetation all around being of a non-fire influenced type. In all regions, *Nothofagus* is highly fire-sensitive, therefore endemites may be endangered in fire-exposed areas because of insufficient regeneration (compare also: ASH, 1982).

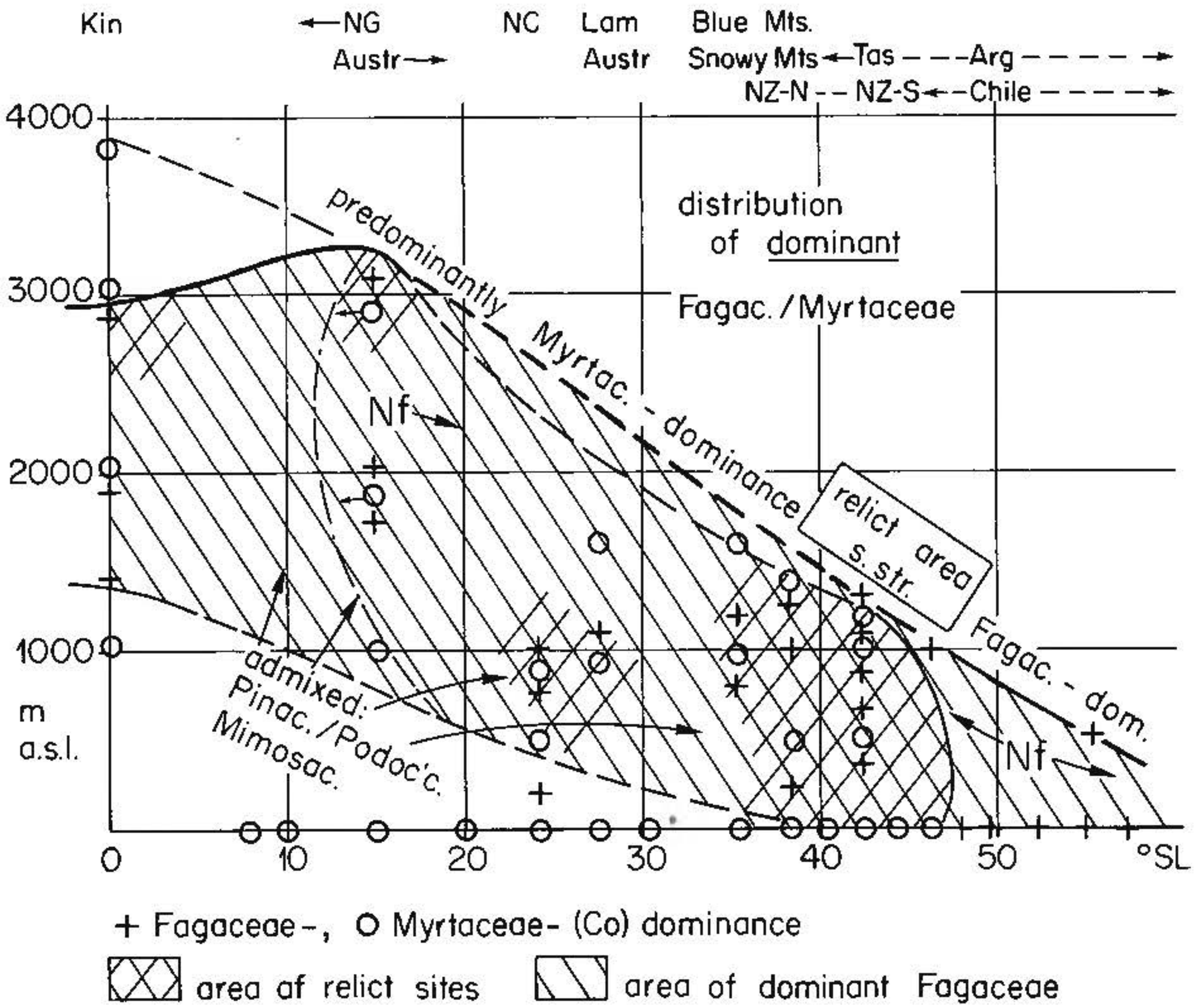

Fig. 2. Area of Myrtaceae and Fagaceae (only where dominant or codominant) in the southern hemisphere, showing zone of intense competition where boundaries overlap in their southern parts, i.e. area of so-called "relictic stands".

2.1. Relictic Sites without Fire Protection

In this group of sites, an eventual fire would not be prevented from spreading. According to ASH (1982) there is "no simple explanation for their topographic distribution". But most cases may be attributed to one of the six following types.

A good deal of topo- and orographic positions are possible, e.g. hill tops, ravine slopes, basin sites, but also flat sites.

2.1.1. Hill Tops

The summits (about 1000–1200 m a.s.l.) of round hills in the area of the Lamington National Park, south of Brisbane, Queensland, Australia, are often colonised by fragments of *Nothofagus moorei* forests. They are covering just the tops ($\Delta h \approx 10$ m!) and mostly monospecific in their tree layer, but also their shrub and herb layer is rather poor in species (dominant species are *Tasmannia* and *Doryphora* as a shrub and *Blechnum wattsii* and other ferns, some monocots e.g. *Dianella,* and also Hydrocotyle species, and occasionally *Dawsonia* moss).

Adjacent to these relicts of a former continuous carpet of *Nothofagus* rain forests, are as a rule different types of subtropical montane rain forest with dominating *Ficus wattsoniana, Agryrodendron trifoliolosum, Geissois benthamii, Pseudoweinmannia lasiocarpa* and admixed *Araucaria cunninghamii* and *Cryptocarya* species, carrying some climbers *(Calamus, Derris involuta)* and epiphytes *(Platycerium, Adiantum,* Orchids). The lower strata are governed by tree ferns (*Cyathea,* sometimes penetrating *Nothofagus* stands) and palms or ferns, Commelinaceae, Iridaceae, Cyperaceae and Poaceae, respectively (compare also WEBB, 1968, "Notophyll evergreen vineforest" and "Microphyll fern forest").

For similar conditions in lower altitudes in New Guinea, where *Nothofagus* escapes competition on hill tops, see ASH (1982; there also: DAWSON, 1966, for New Caledonia).

2.1.2. Ravine Slopes

On Mt. Do (about 1000 m a.s.l.) but also on other mountains of eastern New Caledonia, e.g. near Rivière Bleue, at about 200–300 m a.s.l.; there are many relict(-like) woodlands and forests with dominant endemic *Nothofagus* species which are on rather steep slopes of ravines (*Nothofagus aequilateralis, Nf. balansae* etc.; details on distribution see BAUMANN-BODENHEIM, 1983). They may be mono- to polyspecific, carrying a wealth of endemic species in all strata. Besides Fagaceae, also *Alphitonia novaecaledoniae, Myodocarpus fraxinifolius, Agathis ovalis* and many other broadleafed species (Table 1) may be prevalent. Some climbers, e.g. *Freycinetia, Smilax,* may be conspicuous, and quite a number of typical species of a true understorey, Cordyline, *Cyathea vieillardi,* palms *(Actinoquintia, Basolinia, Clinosperma),* but mostly young trees are dominating. An occasional herb layer is governed by ferns (e.g. *Blechnum, Schizaea, Sphaenomeros, Trichomanes, Elaphoglossis,* etc.) and tussocks of *Schoenus tendo.*

There is no chance for these Nothofagus species to grow on the adjacent plateaux (heavy metal soils, serpentine and peridotite), because dense heath (Table 2) or low bush with occasional stands of *Araucaria balansa* prevents any regeneration of more demanding species. Also, Myrtaceae are confined to the richer sites of the valleys and foothills *(Melaleuca leucadendron)* or occasionally admixed in the ravines (*Syzygium, Eugenia,* etc.).

In northern New Zealand, the situation is less evident, as the less steep slopes are cultivated. But also in this case, *Nothofagus truncata* is dominant with some *Phyllocladus trichomanoides, Agathis australis, Beilschmiedia tawa, Knightia excelsa,* overgrown with *Metrosideros* climbers and fern epiphytes, and a

Table 1. Tropical montane rainforest on Mt. Do/New Caledonia. List of genera in the tree layer (partly regeneration). (species names in brackets where verifiable)

Nothofagus (codonandra[x]*)*	(± dom.)	*Hibbertia*	[Dilleniac.]
Araucaria (bernieri and *muelleri)*	[Araucariac.]	*Ixora*	[Rubiac.]
Austrobuxus	[Buxac.]	*Myodocarpus (fraxinifolius*[+]*)*	[Araliac.]
Baloghia	[Euphorbiac.]	*Podocarpus (silvestris*[+]*)*	[Podoc'c.]
Baccariella	[Sapotac.]	*Pittosporum*	[Pittosporac.]
Balanops[°]	[Balanopsidac.]	*Psychotria*	[Rubiac.]
Cupaniopsis	[Sapindac.]	*Rapanea*	[Myrsinac.]
Caryophyllus	[Myrtac.]	*Rauwolfia*	[Apocynac.]
Casearia	[Flacourtiac.]	*Scaevola*	[Goodeniac.]
Dysoxylon	[Meliac.]	*Salacia*	[Hippocrateac.]
Dutaillyea	[Rutac.]	*Styphelia*	[Epacridac.]
Guettarda	[Rubiac.]	[x] upper	montane belt
Gastrolepis	[Icacinac.]	° middle	
		[+] lower	
in lower altitudes also:			
Nothofagus (aequilateralis[+]*)*	(± dom.)	*Guioa (glauca)*	[Sapindac.]
Alphitonia (novae-caledonica)	(co-dom.) [Rhamnac.]	*Geissois*	[Cunoiac.]
Agathis (moorei[°]*)*	[Araucariac.]	*Garcinia*	[Guttiferae]
Albizia (granularis)	[Mimosac.]	*Hugonia (penicillanterus)*	[Linac.]
Bocquillonia	[Euphorbiac.]	*Ochrothallus*	[Sapotac.]
Citronella (sarmentosa)	[Icacinac.]	*Schefflera*	[Araliac.]
Elaeocarpus	[Elaeocarpac.]	*Stenocarpus (tenellus)*	[Proteac.]
Euroschinus	[Anacardiac.]	*Syzygium (austrocaledonicum)*	[Myrtac.]
Eugenia	[Myrtac.]	*Tristaniopsis*	[Myrtac.]
Gardenia	[Rubiac.]		

Table 2. Tropical montane heath on Mt. Do/New Caledonia. List of genera in the shrub layer (S.) and field layer (F.), the only tree being *Araucaria balansa* [Araucariac.] at 1000 m a.s.l. (species names in brackets where verifiable).

S. *Dracophyllum*	[Epacridac.]	F. *Costularia (arundinacea)*	[Cyperac.]
Polyscias	[Araliac.]	*Caladenia*	[Orchidac.]
Rapanea	[Myrsinac.]	*Eriaxis (rigida)*	[Orchidac.]
Scaevola (beckii)	[Goodeniac.]	*Baeckia (ericoides)*	[Myrtac.]
Symplocos	[Symplocac.]	*Fistula*	[Caesalpiniac.]
Wickstroemia	[Thymelaeac.]	*Gleichenia*	[Gleicheniac.]
Epiphytes		*Lycopodium*	[Lycopodiac.]
Nepenthes (vieillardii)	[Nepenthac.]	*Schizaea*	[Schizaeac.]
Dendrobium (oppositifolium)	[Orchidac.]	*Thelymitra*	[Orchidac.]
		and carpets of *Cladonia* lichens	

(in lower altitudes [300 m] serpentine scrub with less ericoids and more sclerophyllous species and conifers as e.g. *Dacrydium araucarioides* [Podocarpac.] and *Agathis ovata* [Araucariac.])

According to the plantgeographical (chlorological) analysis of Baumann-Bodenheim (1956) both stands of Table 1 and 2 may be interpreted as typically montane, with a tendency to middle-montane. The same time a considerable amount of possible distribution types of (sub-)tropical plant species are present, including extreme new-caledonian endemics in both cases, forest and heath.

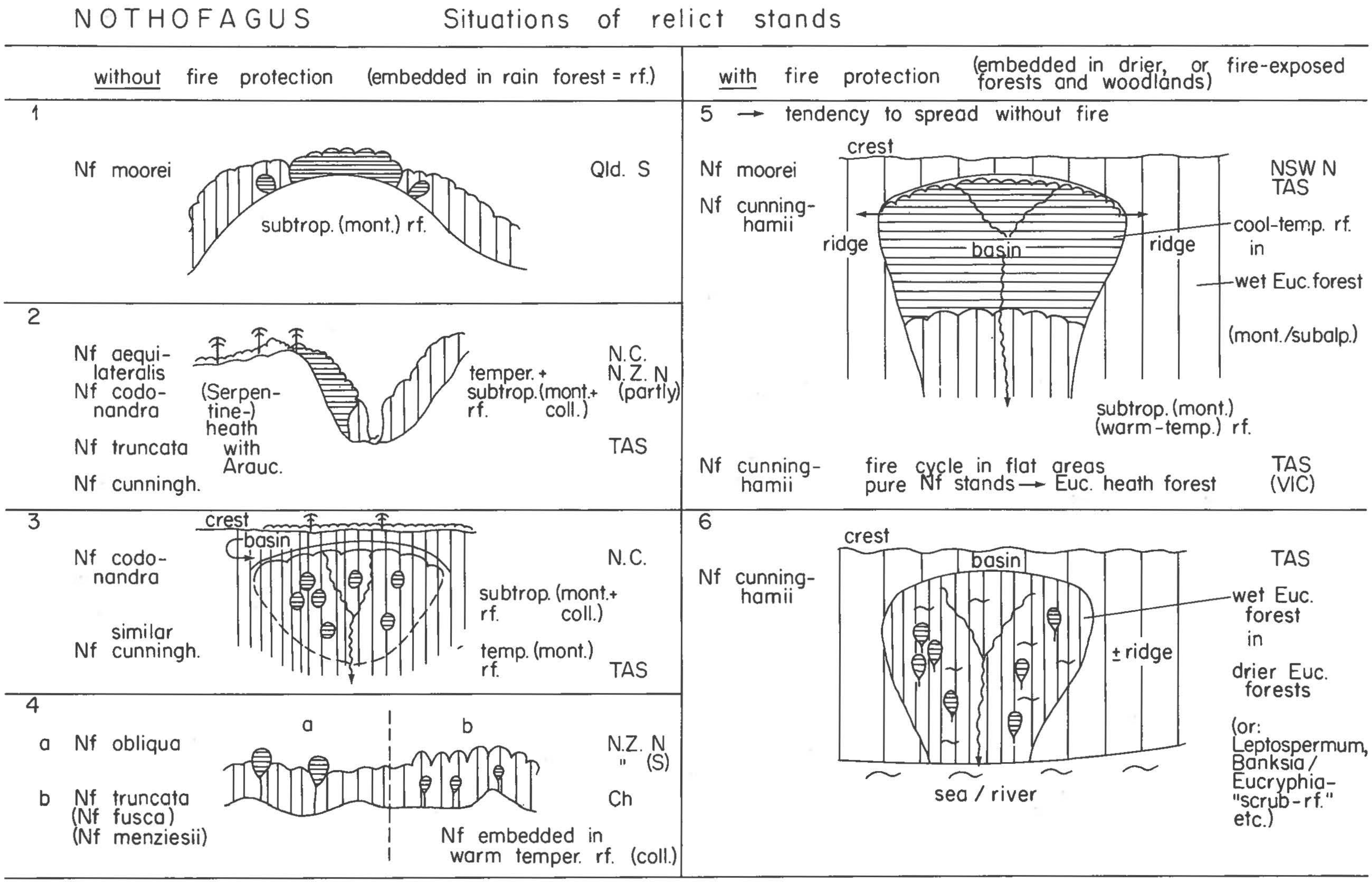

Fig. 3. Situation of "relictic stands" in the widest sense ("special sites") (compare also views in: KLÖTZLI, 1975).

dense undergrowth of some *Cyathea medullata*, some bushes *(Cyathodes, Olearia, Myrsine)* and *Pteridium* herds.

Under less steep conditions, the Fagaceae have apparently no advantage any more with their stabilising root system and capacity of sprouting from fallen trunks, and they are overgrown by Podocarpaceae (*Podocarpus, Dacrydocarpus* etc.) and/or Myrtaceae *(Metrosideros)*, at the utmost forming subdominant understorey groups. In many areas, this type of forest is indicated by the hedge row species or some trees left in the pastures. Sometimes, also *Agathis australis* may prevail under these conditions admixed with the same species as above, especially *Beilschmiedia, Dysoxylon, Pseudowintera, Weinmannia racemosa* and *Podocarpus* species and a great number of shrubs (e.g. Coromandel Peninsula 400 m; compare e.g.: WARDLE, 1970; KUSCHEL, 1975).

2.1.3. Basin Sites with Isle-like Domes

Also Mt. Do and some other mountains in New Caledonia (Dividing range) have relict(-like) forests in moist basins (≈ 900 m, 30–40%/W) on steeper slopes with dome- or crest-like convex parts in the same basins. Under these conditions, *Nothofagus codonandra* is mostly codominant or just present with single stems surrounded by montane rain forest species (*Actinoquintia* as high palm, *Cyathea* as tree fern, *Pandanus* and many tree species as e.g. *Meryta coriacea, Beauprea, Elaeocarpus, Tapaeinosperma, Falcatifolius, Myodocarpus, Phellina, Guettarda*, etc., in the moister parts especially *Planchonella, Podocarpus silvestris, Austrocedrus, Oxera* etc.) (for further details see also: DAWSON, 1966, in ASH, 1982).

Nothofagus is probably prevented from colonising the more concave parts of these basins because of difficulties in seed-installation (fungus attack, see also GADEKAR, 1975, for similar conditions with *Fagus silvatica* in C-Europe). Also from New Guinea ERIKSON (pers. comm.) reports to have seen a similar pattern.

2.1.4. Climax Woodland on Flat Sites

In middle Chile, *Nothofagus obliqua*, sometimes *Nothofagus dombeyi*, may be found as protruding stems in climax forests with a great number of laurophyll ("Notophyll") trees and *Podocarpus (Pc.)*, e.g. *Aextoxicum punctatum, Laurelia philippiana, L. sempervirens*, many climbers, fern epiphytes, often hard-leafed ("microphyll") shrubs, *Chusquea* bamboo and mesic herbs (e.g. near Lake Puyehue, 40–50 m a.s.l.) or then with *Pc. andinus, Austrocedrus chilensis, Lomatia hirsuta, Drimys winteri, Maytenus boaria* and many shrubs (e.g. near Cunco at 350–450 m a.s.l.). Near the coast similar forests occur in the montane belt with a physiognomy quite near to the *Podocarpus*-forests of New Zealand, often with *Weinmannia trichosperma, Laurelia philippina, Podocarpus nubigenus, Dasyphyllum, Saxegothea conspicua* and *Nothofagus obliqua* as dominants, normally with many climbers, fern-epiphytes, Bamboo, shrubs and mesic herbs (e.g. Cord. Pelada, 650 m; compare e.g.: OBERDORFER, 1960; HUECK, 1966; KLÖTZLI, 1983).

Regeneration is rather scarce, showing that *Nothofagus* is more or less on an outpost and not a fully emancipated species like dominant "colleagues" of them in the montane and subalpine temperate rainforests with dominant *Nothofagus dombeyi, Nothofagus betuloides* or *Nothofagus nitida* (compare lit. cit.) or in transitions from colline to montane temperate deciduous forests (with *Nothofagus procera* or *Nothofagus pumilio*), or then to colline, cool-temperate broadleafed ("laurel") forests with *Nothofagus obliqua, Persea, Laurelia*, etc. (e.g. to the north of Puerto Montt).

These forests are hard to ignite, therefore, do not need any fire protection to guarantee their existence (human influence excluded!) and the codominance of Fagaceae.

Fig. 4. Australia E, Queensland S, Lamington National Park: View on complex of wet *Eucalyptus*-forests, subtropical montane rain forest, and, background, on small hills with *Nothofagus moorei* (up to 1100 m).

Fig. 5. id.: *Nothofagus moorei* stand on Mt. Hobwee, 1100 m.

Especially in northern, but also on the westcoast of southern New Zealand, Fagaceae (*Nothofagus fusca, Nothofagus solandri, Nothofagus menziesii,* sometimes *Nothofagus truncata*) are never amongst the single highstemmed trees as the *Podocarpus.* They form, as a rule, an understorey, often dense, and are dominated or overgrown by *Podocarpus (Podocarpus ferrugineus, Pc. dacrydioides, Pc. spicata, Pc. totara, Pc. hallii, Dacrydocarpus cupressinus)* and sometimes *Metrosideros.* The understory is quite rich in ericoid and small leafed shrubs, in luxuriously growing herbs and ferns, but regeneration of *Nothofagus* may be quite satisfactory (for further details see e.g.: WARDLE, 1970; KUSCHEL, 1975; KLÖTZLI, 1983).

Withouth *Podocarpus* and *Nothofagus,* but with similar physiognomy, and dominating *Metrosideros, Weinmannia* and tree ferns, *Freycinetia,* ericoid shrubs, *Blechnum* and other ferns, such forests are in all warm-temperate and tropical montane areas of the Pacific (N.Z., Tahiti, Hawaii, and other pacific isles; see e.g.: KUSCHEL, 1975; PAPY, 1948 and 1954/55; MUELLER-DOMBOIS, 1983).

2.2. *Relictic Sites with Fire Protection*

Under this heading, little fire-endangered sites are collected or then – mostly – sites englobed by fire-influenced forests.

Fire protection in these relict stands is given by edaphic support, i.e. by moister soil, generally in basins or also flat sites. There is no chance of regeneration of the leading species outside of these fire-protected areas, because any young plant would be destroyed by the annual fire, which, on the other hand, does not prevent Myrtaceae from growing in dense fire adapted stands (details e.g. in: GILL et al., 1981; for Australia see also: KEAST, 1981).

2.2.1. Basin Sites

Especially in Tasmania (JACKSON, in SPECHT et al., 1974; JACKSON, 1981; WILLIAMS, 1974) but also along the eastern Australian Great Dividing range, *Nothofagus* relict stands are surrounded by often mono-specific *Eucalyptus* stands, where *Nothofagus* is only a "guest" tree in the understorey, if presence is possible.

In Tasmania, such stands occur on the south eastern coast (e.g. Signal Hill) where *Eucalyptus* (e.g. *E. obliqua, E. delegatensis*) are dominant with an often dense layer of ericoid and small-leafed shrubs – sclerophyll and "laurophyll" – and also tree ferns, *Nothofagus cunninghamii,* up to 15 m tall only, and *Atherospermum moschatum,* up to 25 tall, both being confined to rather moist seepage basins, and regenerating freely in a fern-rich herb layer with *Blechnum wattsii, Polystichum proliferum* and some monocots, e.g. *Dianella.*

But similar stands with similar shrubs and dominating ferns may also occur at higher altitudes, including the mainland, where also *Eucalyptus* is absolutely dominating the bordering areas, the transition zone being barely around 50 m wide, with e.g.:

1. *Euc. subcrenulata, E. delegatensis, E. coccifera, E. urnigera* in Tasmania on Mt. Field (at 600 m up to 1100 m), with *Nothofagus cunninghamii* and shrubs of the neighbouring forests, with Epacridaceae, Proteaceae and Asteraceae, all mostly needle-leafed or sclerophyll; also *Phyllocladus aspleniifolius* and *Anodopetalum biglandulosum* being mostly present.
2. *Euc. viminalis,* partly surrounded by *E. fastigiata, E. obliqua, E. pauciflora,* depending on altitudes, aspect and moisture (see also: WEBB, 1968; TURNER, 1976), in New South Wales on Barrington tops (at about 1000 m a.s.l.) with *Nothofagus moorei* and sclero- to laurophyll species as e.g. *Doryphora* and *Trochocarpus,* and predominance of ferns *(Blechnum, Polystichum).*

Other similar sites are treated in chapters 2.2.2. and 2.2.3. Furthermore, also *Eucalyptus oreades,* fire-sensitive, may survive under similar conditions.

Fig. 6. Nouvelle Calédonie, Mt. Do., ca. 1000 m: *Araucaria* in heath, to the right touching edge of slope carrying stands of *Nothofagus aequilateralis.*

Fig. 7. New Zealand N, Waitakaruru, ca. 60 km E of Auckland, ca. 150 m: Stand of *Nothofagus truncata* on slope leading to rivulet.

Fig. 8. Nouvelle Calédonie, Mt. Do., ca. 900 m, S-slope: Moist basin with (sub-)tropical montane rain forest, containing small stands of *Nothofagus codonandra* on small crests.

Fig. 9. New Zealand S, N-part of west coast: Temperate rain forest (climax) with *Dacrydocarpus cupressoides* and some *Nothofagus cliffortoides* in the lower tree layer. – In the Valdivian rain forest similarly *Nothofagus obliqua* may be conspicuous in the upper tree layer.

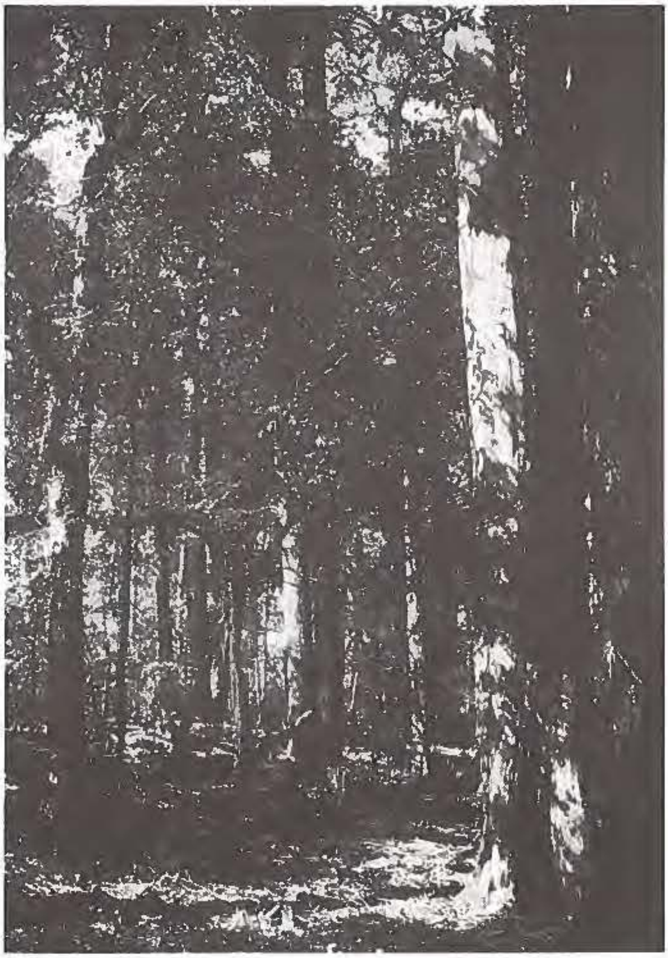

Fig. 10. Australia E, New South Wales N, Barrington Tops, ca. 1000 m: *Nothofagus moorei* stand in moist basin, surrounded by montane moist *Eucalyptus*-forests.

In these areas, *Nothofagus* may penetrate into surrounding natural, nutrient-poor heath sites, where even *Eucalyptus* and *Phyllocladus* show reduced vitality and grow there as small park-like trees under very light conditions, together with typical heath endemites (e.g. *Richea pandanifolia*, many ericoid Epacridaceae and sclerophyll Proteaceae, dominating, *Gahnia*, *Sphagnum*, *Hepaticae* and lichens), and menaced by occasional fires (for causes leading or characterising heath, see also: TRACEY and WEBB, 1969).

From New Guinea similar conditions are announced by ASH (1982), for *Nf. starkenborghii*, on peat for *Nf. rubra* (compare also other chapters in: GRESSITT, 1982).

2.2.2. Very Moist Basins

In very moist basins, *Nothofagus* species grow on rather crest-like domes, often on boulders (compare 2.1.3.), which are as a rule situated near the area, or near rivulets or streams. Again, these sites are surrounded by non-Fagaceae woodlands and drier forests (e.g. *Euc. pulchella*, *E. amygdalina* on triassic sandstone), on the Tasmanian southeastern coast by *E. delegatensis*/*E. obliqua* (often on jurassic dolerite), in the southwestern moist wilderness area, on soils of very low fertility, at about 300–400 m a.s.l., by "Scrub Rainforest" with *Eucryphia lucida* stands including *Anopterus glandulosus*, *Anodopetalum*, an

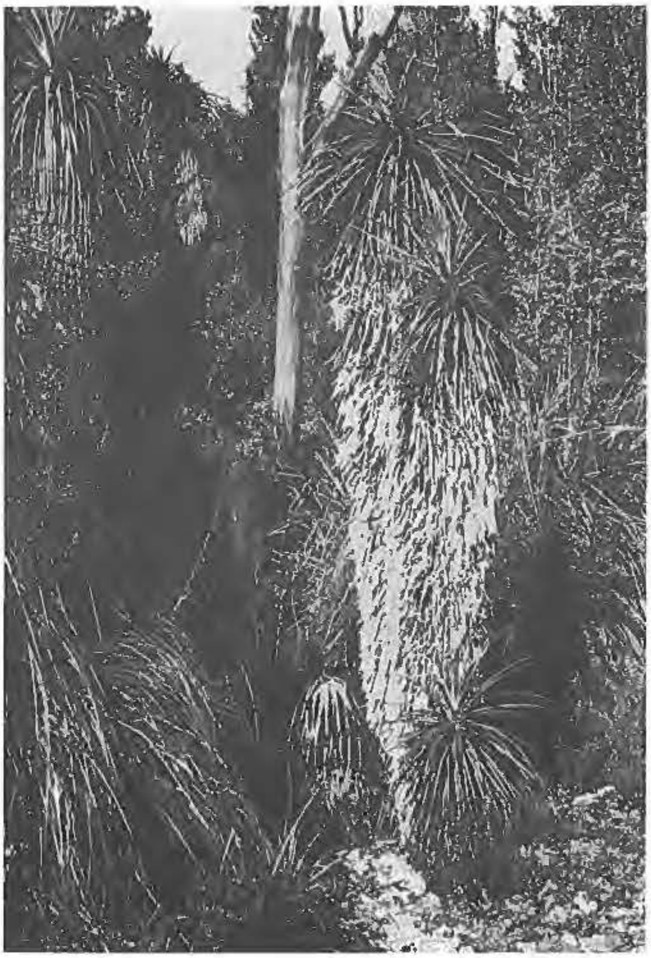

Fig. 11. Australia, Tasmania, Mt. Field, ca. 600 m: Heath woodland adjacent to basin with *Nothofagus cunninghamii*, surrounded by moist montane *Eucalyptus*-forests, still carrying some stems of *Nothofagus cunninghamii*, *Phyllocladus* and *Eucalyptus*.

Acacia, many ericoids and a variety of ferns forming a dense scrub of a "Krummholz-like" type, or then even by heath thickets with *Banksia* and *Lepidospermum*. Under such conditions, fire-sensitive *Nothofagus* avoids the drier ridges, and for *Eucalyptus* there is often too little light (JACKSON, 1981).

2.2.3. Moister Flat Sites

As in boreal coniferous forests, showing at fire-induced (birch-)pine-spruce cycle, also in Tasmania, the composition of forests on moister flat sites is ruled by frequence and intensity of fires, but also by nutrient regime (compare e.g.: JACKSON et al., 1981; "ecological drift": WALTER, 1968, pp. 267 ff.).

Therefore, pure or mixed *Eucalyptus-Nothofagus cunninghamii*-forest (with e.g. *Eucalyptus regnans*, up to 100 m tall, Ø 3–5 m(!), *E. obliqua* etc., on precambrian metamorphes) with tree ferns *(Dicksonia antarctica)* and a laurophyllous understorey *(Zieria arborea, Monotoca glauca, M. elliptica, Atherospermum moschatum, Anopteris glandulosa)* with many ferns (*Blechnum*, *Polystichum*, compare 2.2.1.) occur on moist flats around Mt. Field (e.g. near and on the Styx River) or then similarly in Victoria (SE-slopes), moist enough to secure the existence of *Nothofagus cunninghamii* – dominated stands in regions with annual fires (compare also: WEBB, 1968, "nanophyll mossy forest"; HOWARD, 1973; HOWARD and ASHTON, 1973).

Fig. 12. Australia, Tasmania, on Styx River, ca. 150 m: Moist flats with *Eucalyptus regnans* (up to nearly 100 m tall, here not visible) and tall *Nothofagus cunninghamii;* luxuriant tree ferns *(Dicksonia antarctica)* in foreground.

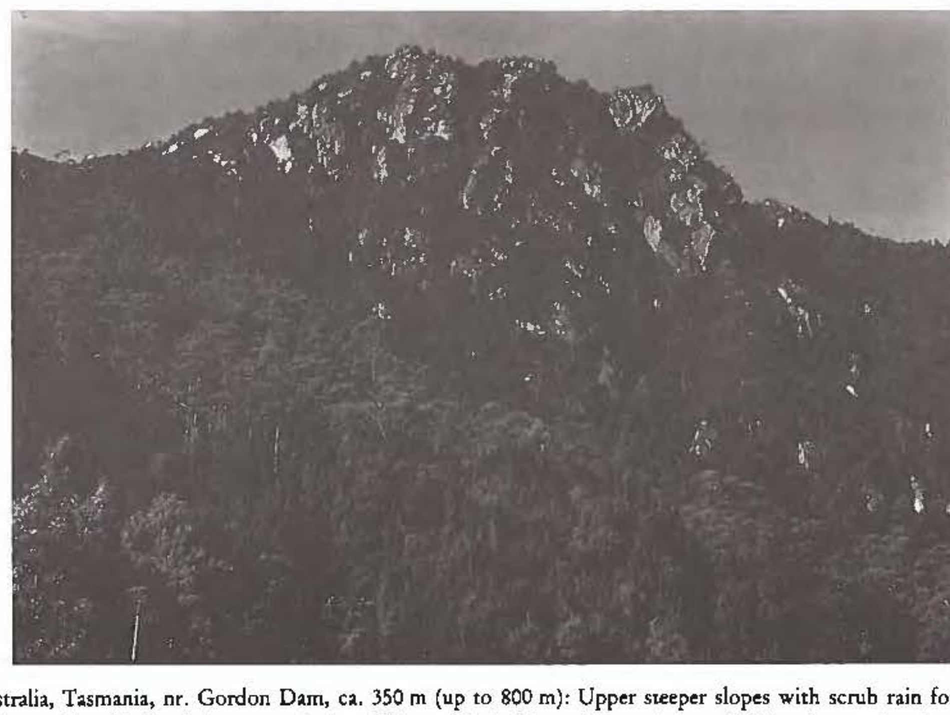

Fig. 13. Australia, Tasmania, nr. Gordon Dam, ca. 350 m (up to 800 m): Upper steeper slopes with scrub rain forest, on moist boulder basins partly with *Nothofagus cunninghamii/Eucryphia lucida,* on lower slopes with *Eucalytpus, Acacia mucronata* and different *Leptospermum* species.

Fig. 14. Australia, Tasmania, nr. Gordon Dam, ca. 350 m: Scrub rain forest with *Phebalium squamosum* [Rutaceae], *Acacia mucronata, Leptospermum* and *Epacris* (different species), and also *Anodopetalum biglandulosum*.

3. Considerations on the General Strategy of Fagaceae and Myrtaceae

Considering the above-mentioned site conditions, and now tracing the situation from "the other side", dominance of Myrtaceae has to be expected under the following conditions:

1. Less temperate but favourably at least subtropical to tropical climates at lower altitudes, also from the colline to the subalpine belts (E-Australia, Indonesia etc.).
2. In drier climates under the influence of regular fires (drier sites in the whole area).
3. At a given suitable temperature, or then even below optimum temperature, under more stress-rich conditions, as e.g.:
   - more pronounced mechanical factors (river, unstable slopes, browsing)
   - high water table
   - drought-exposed sites
   - nutrient-deficient (heath) sites inducing more open and consequently mostly more fire incidents and less shade to the detriment of shade-tolerant Fagaceae. An advantage is certainly given by an internal ability to spourt from roots (suckers), the base of stems, and by the fact that seed and seedling are fire-adapted.

Fig. 15. Australia, Tasmania, nr. Gordon Dam, ca. 350 m: Interior of scrub rain forest, on rather steep slopes, with dom. *Anodopetalum* (Photo: Australian Botanical Congress, slide series, 1981).

Under human influence, Myrtaceae, therefore, tend to increase their special area by taking over sites of less adapted families (on the other hand: for die-back compare: MUELLER-DOMBOIS, 1983; CARTLEDGE et al., 1975).

Fagaceae on the other hand, especially *Nothofagus*, are much less fire-adapted, and in the area of the Myrtaceae confined to less temperate (colder), moister and richer sites, or then, under conditions where neighbouring species tend to have more difficulties to establish as young trees or hold themselves on exposed sites due to mechanical factors. As a rule, they are very shade-tolerant under their parent trees or in canopy gaps of mixed forests (see: ASH, 1982; SCHULZE, 1982, p. 658). But under the extremely shady conditions of closed rain-forests, they are inclined to colonise more open areas, where seeds of often very low viability may also be deposited more readily. On the other hand, out of the area of the Myrtaceae, Fagaceae are capable to colonise all sites, from dry to moist, rich to poor, the colline to the subalpine belt (compare also: ASH, 1982).

Comparing both families, they both show maximum adaptation to the prevailing conditions under subtropical and temperate climates, respectively, and give way to other families, when regeneration is difficult under very shady conditions and/or production too slow under more tropical conditions.

Summary

1. On many mountains in the whole Pacific area Fagaceae (F.) and Myrtaceae (M.) play an essential role as dominant arborescent organisms (compare e.g. Kinabalu/Sabah, Malaysia, volcanic mountains in Tahiti, eastern Australia, New Guinea, New Caledonia, southern Andes etc.).
2. As a rule, M. reach the timberline and other higher altitudes in the tropical zone (incl. Podocarpaceae); in the more marginal areas towards the southern temperate zone rather F. are dominating (compare F. in SE-Australia, New Zealand, southern South America etc.).

3. In the transitional zone towards the temperate zones, these F. appear in ± relictic situations:

a) without fire protection
   1. hill tops in the subtrop.-montane rain forest (e.g. S-Queensland);
   2. ravine slopes in (sub-)tropical montane rain forest, surrounded by heath woodland (containing *Araucaria*, New Caledonia; New Zealand);
   3. basin sites with isle-like domes in subtropical rainforest (New Caledonia);
   4. flat sites protected by climax woodlands with leading dominants (middle Chile) or in the auxiliary stand (N- and partly S-New Zealand), within the area of colline to submontane warm-temperate rain forests or then transition to temperate deciduous forests or laurophyllous forests.

b) with fire protection (little fire endangered stands in fire influenced forests)
   1. basin sites with montane to subalpine warm to cool-temperate *Eucalyptus-Nothofagus*-rain forest surrounded by wet *Eucalyptus*-forests of high diversity (Tasmania, SE-Australia);
   2. very moist basins but on small isle-like crests in the vicinity of rivers or the sea, in colline to montane wet *Eucalyptus*-forests, surrounded by dry *Eucalyptus*-forests, *Eucryphia*-stands or then *Banksia/Leptospermum*-thickets (Tasmania);
   3. moister, flat sites as final stages of the *Eucalyptus/Nothofagus*-fire cycle, surrounded by wet *Eucalyptus*- or heather forests (Tasmania, SE-Australia (Victoria)), mostly in the montane belts.

4. The general strategy of both families is accentuated by the fact, that M. are starting to dominate where they are sponsored by higher temperatures, especially in their production, or then when M. as frequent pyrophytes have certain advantages (coppicing, viability of seed etc.), or are submitted to higher mechanical stress. Under humau influence the area of the M. is mostly widened to the detriment of the F.

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Discussion to the Paper Klötzli

Dr. W. Golte:

1. How is the ecological relation of the deciduous *Nothofagus gunnii* to the *Eucalytpus* species (e.g. *E. coccifera*) in Tasmania?
2. How do you interprete the paleoclimatic and paleoecological development of Australia considering the fact that *Nothofagus* has played – mainly in the South – a dominant role dnring most of the Tertiary there?

Prof. Dr. F. Klötzli:

1. As far as I have experienced *Nothofagus gunnii*,it is usually forming a shrub layer under e.g. *Eucalyptus coccifera* at an altitude of about 900–1100 m a.s.l. (e.g. Mt. Field), sometimes up to the timberline, but always protected from fire.
2. Being not a paleobotanist I can only state that *Nothofagus* had a far greater area in the tertiary age dne to less warm-temperate to tropical conditions. Later the old Gondwane area was split up into more relict-like isles and the conterminous areas in New Zealand and southern South America, the Myrtaceae taking over the old, now warmer Fagaceae areas.

Prof. Dr. E. Löffler:

Your observations concerning the preferred supine position of *Nothofagus* correlate very well with my interpretations of aerial studies on New Guinea. My question refers to a phenomenon which I observed in extended *Nothofagus*-forests. Within the forest there appear roundish gaps which indicate a dying out of the forest. Do you have an explanation for this phenomenon?

Prof. Dr. F. Klötzli:

Possible explanations are: mechanical damages (wind, biting by herbivors) or/and locally superannuated groups of trees.

Prof. Dr. W. Eriksen:

Do you observe a comparable extension of Myrtaceaes in *Nothofagus*-areas in South America, e.g. after burnings?

Prof. Dr. F. Klötzli:

After burnings only Myrtaceae bushes which need much light (e.g. *Myrceugenia*, *Myrceugenella*) can extend more.

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