

PÁRAMO DE PAPALLACTA

A physiogeographical map 1:50,000 of the area around the Antisana (Eastern Cordillera of Ecuador)*)

With 6 figures, 7 photos and 1 supplement (I)

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Zusammenfassung: Páramo de Papallacta – Eine physiogeographische Karte 1:50 000 im Umfeld des Antisana (Ostkordillere Ecuador)

Mit dieser Karte wird der „Internationalen Hochgebirgsforschung“ ein weiteres Beispiel der Hochgebirgskartographie vorgelegt (LAUER u. RAFIQPOOR 1990). Die Karte stellt wegen ihres detaillierten physiogeographischen Inhalts eine solide Grundlage für die wissenschaftliche Rauminterpretation und Dokumentation der landschaftlichen Elemente und Erscheinungen des untersuchten Hochgebirges dar. Dadurch unterscheidet sie sich von den auf einer minimalen Zeichenlegende beschränkten amtlichen topographischen Karten des Instituto Geográfico Militar (IGM) in Ecuador. Im Bereich des vorliegenden Kartenblattes werden drei große geökologische Raumeinheiten unterschieden und ihre Inhalte hinsichtlich der geologisch-morphologischen, klimatologischen und vor allem der vegetationsgeographischen Ausstattung und der Landnutzung vorgestellt. Abschließend wird die Frage der potentiellen Waldgrenze für das innertropische Arbeitsgebiet in Ecuador mit Blick auf die Waldgrenzproblematik in den tropischen Anden diskutiert.

Summary: Páramo de Papallacta – A physiogeographical map 1:50,000 of the area around the Antisana (Eastern Cordillera of Ecuador)

With this map the authors present to the “International Mountain Research Society” a further example of high mountain cartography (LAUER a. RAFIQPOOR 1990). Due to the specific abundance of physiogeographical details the map provides a solid basis for scientific spatial interpretation. This is also the main feature of the presented map compared with the topographic maps of the Ecuadorian IGM, which are based on a very poor legend. In the study area of this map we distinguish three marked geoecologically different units. We describe the geological, geomorphological, climatological and, with particular emphasis, the phytogeographical features and the land-use types of these sections. Finally we consider the issue of the potential timberline of the equatorial study area in Ecuador, with a focus on the timberline problems in the tropical Andean high mountains.

Resumen: Páramo de Papallacta – un mapa fisiogeográfica 1:50 000 en alrededor del Antisana (Cordillera Oriental del Ecuador)

Con este mapa se presenta a la “Sociedad Internacional de Investigación de Altas Montañas” otro ejemplo de la cartografía de alta montaña (LAUER y. RAFIQPOOR 1990). El mapa presenta, por su minucioso contenido fisiogeográfico, una sólida base para interpretaciones científicas del espacio, para la documentación de elementos paisajísticos y para las representaciones de la alta montaña del área investigada. Es por ello que este mapa se diferencia sustancialmente de los mapas topográficos del Instituto Geográfico Militar (IGM) del Ecuador, construidos en base a leyendas más limitadas. En el mapa aquí presentado se definen tres unidades principales con atributos fisionómicos y geoecológicos bien marcados, con especial énfasis en sus contenidos geológicos, geomorfológicos y climatológicos, resaltando los aspectos fitogeográficos y de uso de la tierra. Finalmente los descripciones geográficas abordan la problemática sobre el límite potencial del bosque en la región equinoccial del Ecuador con un foco sobre el problema del límite del bosque en trop-andino.

1 Introduction

Topographical maps are recordings which represent the earth's surface in a generalized manner. They are produced by land surveyors over a long period of time and have a minimal uniform legend. “Specialised topographic maps of a high standard with a rich, obvious, clear and measurable representation of land” (Louis 1974, 2), and which result from cooperation between

topographers, cartographers and geographers, are very popular as a basis for land development and planning.

The first topographic maps of high mountain regions to meet central European standards were developed for the South American Cordillera from the photogrammetrical data of CARL TROLL and ERWIN HEIN, which was collected on the Andes expedition of the German-Austrian Alps Society in 1928 in the Cordillera Real in Bolivia: “The General Map of the Cordillera Real 1:150,000” (TROLL 1931), “Illampu-Hankouma-Massiv 1:50,000” and “Valley Basin of La Paz 1:15,000” (TROLL a. FINSTERWALDER 1935). KINZL

*) Dedicated to CARL TROLL on the occasion of his 100th birthday

(1942) followed in their footsteps and carried out photogrammetrical work in the Peruvian Andes together with K. HECKLER, A. WERZGER, E. SCHNEIDER and F. EBSTER during the Cordillera Blanca Expedition of the Alps Society: 1932 “Cordillera Blanca 1:100,000”, 1936 “Cordillera Huayhuash 1:50,000”, and later the addition of “Nevado Huascarán 1:25,000”. The “Illampu” map of C. TROLL and RICHARD FINSTERWALDER was revised by RÜDIGER FINSTERWALDER and E. JORDAN in 1989, using aerial photos of the Bolivian Instituto Geográfico Militar (IGM) and a denser aeri-triangulation network, but retaining the original scale. In 1995 RÜDIGER FINSTERWALDER published another topographical map to the scale of 1:50,000. This covered the southern corner of the Cordillera Real (Illimani) and was based on wide-angle photos of the IGM.

In 1990 LAUER and RAFIQPOOR produced a physiogeographic map (Charazani Highlands 1:50,000) to record the results of the field work carried out within the framework of the interdisciplinary Kallawayá Project (Bolivia). This was based on the existing network of IGM maps but included the results of additional field surveys.

2 The Map Representation

The “Páramo de Pappallacta” map (Supplement I) consists of a special detail of the equatorial East Cordillera in Ecuador between the volcano Cayambe (5790 m) in the north and the Nevado Antisana within the coordinates 78 07’30”–78 22’30” W/00 15’00”–00 33’50” S. With this map the Commission for Geographical Research of the Mainz Academy is presenting an example of high mountain cartography. In contrast to the official Ecuadorian maps it contains a wealth of geomorphological and hydrographical features and includes the variations in vegetation and striking geological and geomorphological landscape elements.

For the cartographical surface representation of the map the existing inhomogeneous contour line patterns (partly blueprints) of the IGM were used to create a rough outline, which was complimented by the interpolation of extra contour lines to record the microrelief on plains and gentle slopes. Thus a complete network of contour lines was created. As the plateau-like study area comprises very little harsh rocky relief and steep slopes, the pattern of contour lines, which are 25 m apart, can be applied to the map scale very easily. Specific landform features (e. g. lava streams devoid of vegetation, ice fields) are represented by a change in

contour line colour. Structures of the surface-near solid rock were denoted by fine oblique strokes („*Haarstrichfelszeichnung*”) (see Supplement I). Striking Pleistocene moraines are indicated – with no reference to age – by hachures. Larger relief forms are emphasized by an impressive shading which – along with the contour lines – creates a three-dimensional effect.

On the map (Supplement I) the ice cap of the Nevado Antisana represents that of the date the aerial photos were taken (18 January 1979). The ice cap of the Antisana appears in clear blue. Glacier tongues and crevices and ice debris near the glacier are accentuated by blue line-shading. Areas with frost debris in the upper subnival belt are – as is usual on detailed geomorphological maps (RAFIQPOOR 1994) – denoted in black. The representation of the hydrographic network corresponds in general to that of the IGM. The hydrographic network denoted in blue and the system of artificially built irrigation channels and trenches were largely verified in field work and differentiated on the map. Moors, swamps, and boggy valley floors are denoted by blue line-shading. The vegetation cover was summarized into formation categories by phytosociological analyses and differentiated according to its spatial distribution and altitudinal zonation. Tropical high montane evergreen forests, ceja-forests (elfin forests) with little variety of species, shrub-like *Polylepis* thickets and xerophytic shrub formations are also represented by different shades of colour. Above the timberline (3,700 m) the grassy páramo (3,800–4,200 m) with its bunch grasslands interspersed with bromelias, is distinguished from the cushion-plant páramo (>4,200 m). The vegetation forms depicted on the map are characterized by a typical categorization of species:

Cushion meadows: *Plantago rigida*, *Distichia muscoides*, *Azorella pedunculata* and *Xenophyllum humile*

Bunch grasses: *Calamagrostis effusa*, *Festuca subulifolia*, *Festuca procera*, *Stipa ichu*

Polylepis forests: *Polylepis incana*, *Hesperomeles heterophylla*, *Gynoxys acostae*, *Escallonia myrtilloides*, *Buddleja latilata*, *Oreopanax floribundus*, *Oreopanax palamophyllum*

Elfin forests: *Tournefortia fuliginosa*, *Vallea stipularis*, *Miconia latifolia*

Xerophytic shrubs: *Mimosa quitensis*, *Byttneria ovata*, *Citharexylum ilicifolium*.

Built-up areas are represented according to their site plan. Their outlines correspond therefore to those at the time of the topographical recordings of the IGM in 1990, as do the names of the villages. Scattered farms and villages had to be generalized, as in the official maps, as the area of the individual farms was too small to be represented by the scale of the map. The road network has been updated since the mid 80s due to the

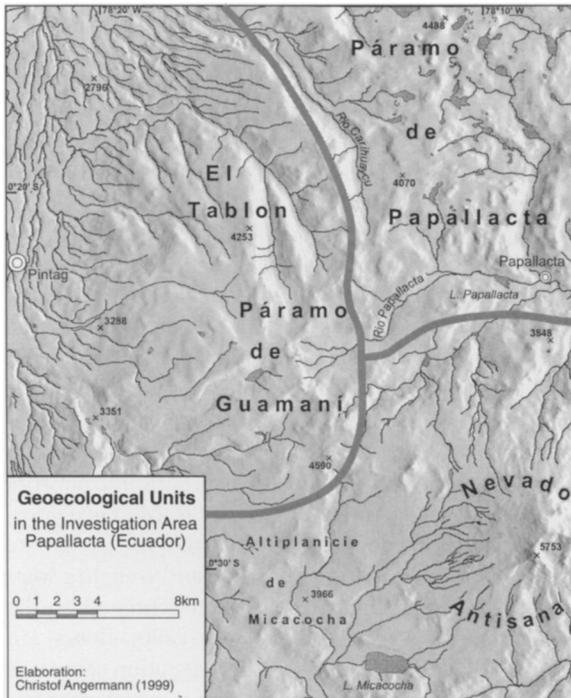


Fig. 1: Geocological main units of the study area "Páramo de Papallacta"

Geoökologische Großeinheiten des Untersuchungsgebietes „Páramo de Papallacta“

expanding infrastructure, and is depicted according to their significance for transport and international trade, and to their passability in the dry and rainy seasons by varying degrees of line-shading. To underline the physiogeographical nature of the map, cultivated vegetation in the agro-economic region is represented in terms of the distribution of anthropozoogenically changed plant communities (substitute communities) in place of natural vegetation.

The cartographic work for the map was carried out in close cooperation with the Department of Cartography at the Geographical Institute of Bonn University, with particular reference to D. GLADENBECK. His artistic expertise transformed the drafts into a work of art. By nurturing the classical tradition of cartography, the publication of this map "presents us with an unparalleled cultural achievement, the value of which demands a greater measure of publicity than has yet been granted" (FINSTERWALDER 1994, 231).

3 The Contents of the Map

The "Páramo de Papallacta" map comprises three geocological units which are typical for the study area,



Photo 1: View from Virgen del Páramo de Papallacta (4000 m) to the northern slope of Antisana and his asymmetric ice shield (Photo: RAFIQPOOR 1998)

Blick vom Virgen del Páramo de Papallacta (4000 m NN) auf die Nordflanke des Vulkans Antisana und seiner asymmetrischen Eiskappe

and which determine the character of the map through their specific physiognomic features (Fig. 1).

(1) *Nevado Antisana* (5753 m): characterized by its recent asymmetric ice cap, recent and historic moraine belt, striking frost debris belt and post-glacial lava streams.

(2) *Páramo de Papallacta* (2,800–4,500 m): marked by a wealth of glacial forms, limited present-day morphodynamic and differentiated vegetation cover.

(3) *Block of El Tablon and Páramo de Guamani* (2,500–4,500 m): featured by glacially deepened valleys in the mountainous area and an agricultural region at the foot of the mountains divided up by numerous small valleys.

3.1 *Nevado Antisana*

The Nevado Antisana (Photo 1) consists of Pliocene andesitic-dazitic volcanic rocks (HALL 1977). It is situated east of the main Andes' ridge on top of a Palaeozoic base, which forms the geological basement of the eastern part of the study area and is only visible to a limited degree. Antisana is one of the quasi-active volcanoes in Ecuador. Its present activity is restricted, however, to active fumaroles, which is why two glaciers to the south (No. 6 and 7, HASTENRATH 1981, 45) are termed "Azufrales" due to the sulphur emissions.

In the post-glacial period lava flowed from various magma chambers on the western and northern slopes of the volcano (HALL 1977, 55–56). Four clear lava streams (Supplement I) developed. One of the most recent occurrences of volcanic activity was in 1773 on the northern forelands of the Antisana. The Papallacta

lava stream (Flujo Potrerillos) flowed and dammed up the lagune of the same name. A further, even larger lava stream (Flujo Antisanilla) began to flow in the north-western approaches of the Antisana. The pale colour of the rock and lack of vegetation cover marks the young age of both lava streams, as the high permeability of the loose surface material has prevented the soil formation process.

The ice cap of the Antisana is slightly elevated to the west (Photo 1, see Supplement I). With the aid of aerial photo interpretation the lowest visible edge of the continuous ice cover was determined there at an altitude of 4,700 m. To the north this is found at 4,450 m, to the south at 4,400 m and to the east at 4,200 m. The asymmetry of the snow line on the Antisana is the result of the luff/lee effect. The luff side of the volcano to the east is constantly supplied with humid air and precipitation from the Amazon basin; the lee side to the west is additionally under the influence of the aridity of the Guayllabamba valley.

Evidence of the recent and Pleistocene ice ages can be traced along the asymmetrical course of the snow line. The recent moraine belt of the Antisana has almost retained its complete form (see Supplement I). Moraines from the late glacial period which extend as low as about 4,400 m on the western slope of the volcano are difficult to recognize as solifluidal processes have led to their misshapening. HASTENRATH (1981, 44) dates them around 10,000–9,000 B.P. in analogy to the MIII moraines of the Mexican volcanoes (HEINE 1975). On the humid eastern slope sharp ridges of moraine deposits stretch to 3,400 to 3,200 m. Morphologically these are attributed to the category of MIII moraines (HASTENRATH 1981, 44). At the outer edges of the Micacocha plateau, at 3,400–3,600 m, certain moraines remain, which date back to before the last glacial occur at the valley mouths towards to inner-Andean basin. These correspond to the mid-Pleistocene MI moraines of HEINE (1995, 10). These developed through plateau glaciation when a shield of ice extended across the Micacocha plateau resulting from a considerable depression in the snow line.

In the mid-Pleistocene the snow line underwent a striking depression of over 1,000 m (V. D. HAMMEN 1981, 126 a. 142). HEINE (1998, 32) assumes that at the last glacial maximum (LGM) the temperature in Ecuador sank by about 5°C which, under equatorial climatic conditions with a temperature gradient of about 0.5°C/100 m, would justify a snow line depression of at least 1,000 m in the LGM. One can assume that in the mid-Pleistocene – with even lower temperatures – a considerably greater depression of the snow line occurred.

The frost debris belt is only to be found in continuous form in the subnival zone of the Antisana (see Supplement I). The volcanic rocks are only slightly weathered and these, together with the glacial deposits, are so monotonous that an effective sorting of material at the subnival belt does not occur. Areas with frost debris are limited at the subnival belt around the Antisana, as the

plateau-like topography of the region prevents much extension into the subnival frost debris zone. Small frost debris fields, rubble and rockfall cones are therefore mainly restricted to steep slope sections and ridges above 4,500 m.

The differentiated hydrographic network around the Antisana consists of a tributary system of one single river, the Río Amazonas. The meltwater from the western and southern slopes including the drainage basin of the Laguna Micacocha is carried by the Río Antisana to the Río Napo, the upper course of the Río Amazonas. The streams on the northern and eastern slopes first flow into the Río Papallacta/Río Quijos, join together in the Río Coca and finally flow also into the Río Napo.

The Altiplanicie de Micacocha (see Supplement I) with an average altitude of 4,100–4,400 m is part of a volcanic ridge, which runs perpendicular to the inner-Andean basin and is divided into two sections by a shallow watershed running SSW–NNE. The section of the plateau east of the watershed comprises a deposit plain for volcanic and glacial primary matter from the Antisana. The western part belongs to the foreland of the V. Sincholagua, which is located within the drainage basin of the Río Guayllabamba. North of this plateau the eastern Cordillera narrows into a ridge-like watershed which, around the Cerro Puntas, forms the division between the drainage systems of the Atlantic and the Pacific. Glacial erosion has led to the evolution of glacial troughs as U-shaped valleys in the high plateau. Some of these contain large, elongated trough lakes such as the Laguna Micacocha, others are swamps. On the Micacocha plateau a high degree of anthropogenic devastation (fires, cattle grazing) has caused the grass páramo zone to extend to much lower altitudes. This would also explain why no forest mosaics (*Polylepis*, *Gynaxys*, *Escallonia*, *Hesperomeles*) are to be found here in the belt, in which they occur in the other units within the study area. They reappear on the slopes toward the inner-Andean basin at an altitude of about 3,800–3,700 m.

The vegetation cover around the volcanic massif is more or less continuous up to the lower boundary of the frost debris belt (MEYER 1907, 333). On the western slope its high grasses disappear at an altitude of about 4,200 m upwards. Herbs, particularly cushion plants, predominate, together with scale leafed (e. g. *Loricaria ilinissae*) and wool-leafed (e. g. *Diplostephium rupestre*) shrubs. In the lower subnival belt (4,200–4,600 m) the vegetation cover gradually becomes sparser. In the frost debris belt (>4,600 m) only a few “specialists” from the plant cushion páramo survive. The edaphic variety of the localities – whether influenced mainly by glacial or

volcanic occurrences – influences the spatial differentiation of the plant species considerably.

3.2 *Páramo de Papallacta*

Páramo de Papallacta (see Fig. 1 and Supplement I) is part of the volcanically marked Cerro Puntas range, of which the Caldera tertiary formation around the Laguna Nunalviro is partly covered by the northern edge of the map. This unit reveals a rich differentiation in physio-geographical terms. It is marked by a plateau-like structure with average heights of around 4,100–4,300 m. Smooth slopes, numerous lakes, boggy cirques, hanging troughs, roches moutonnées, lateral and end moraines dominate the young glacial landscape of the *Páramo de Papallacta*. Several quaternary lava streams have evolved from the tertiary volcanic rock base of the Cerro Puntas, witnessing young tectonic activity (TORRES 1982).

150,000–180,000 B. P., the Flujo Sigsichupa lava stream emerged north of the Laguna Nunalviro. The obsidian which emerged with it has left its mark on the landscape and cultural history. In the stone age man used it to make tools (SALAZAR 1985) and it has been of considerable commercial value. Moraine sediments, which surround the Quebrada Mullumica at about 3,600 m are beyond the reach of this lava stream. These are allocated to the MI/MII phase by HEINE (1995, 11).

One lava stream which is significant for the history of the ice age (Flujo Andesito Paluguillo, TORRES 1982) is situated near the upper left-hand edge of the map (Supplement I). Its outline is hardly recognizable today due to infra-structural development and land use. A MI moraine which rises 154 m above the valley floor of the Rio Carihuaycu and ends at 3,400 m (HEINE 1995, 10) covers the upper section of this lava stream.

On the eastern slope of the mountain range older moraine complexes from the MI phase can be detected at 2,800 m in the Papallacta valley (see Supplement I). Between 2,800 and 4,100 m at least six other moraine complexes can be found in the direction of the Cordillera, which HEINE (1995, 11) classified with the 14C method, attributing them to the glaciation phases MII (pre-Wisconsin) to MVII (little ice age). Ground, lateral and end moraines are covered by tephra layers and fossil soil horizons which reveal various degrees of weathering.

The hygrothermic east-west climatic variation affects the phytogeographical proportions considerably. The more humid eastern slope of the main ridge of the Papallacta inclines more steeply than the drier western side towards the inner-Andean basin. This results in a closer succession of different geoecological altitudinal zones to the east of the mountain range with an asymmetric arrangement of the zones in terms of vegetation on the eastern and western slopes of the *Páramo de Papallacta*. To record the vegetation cover of the study

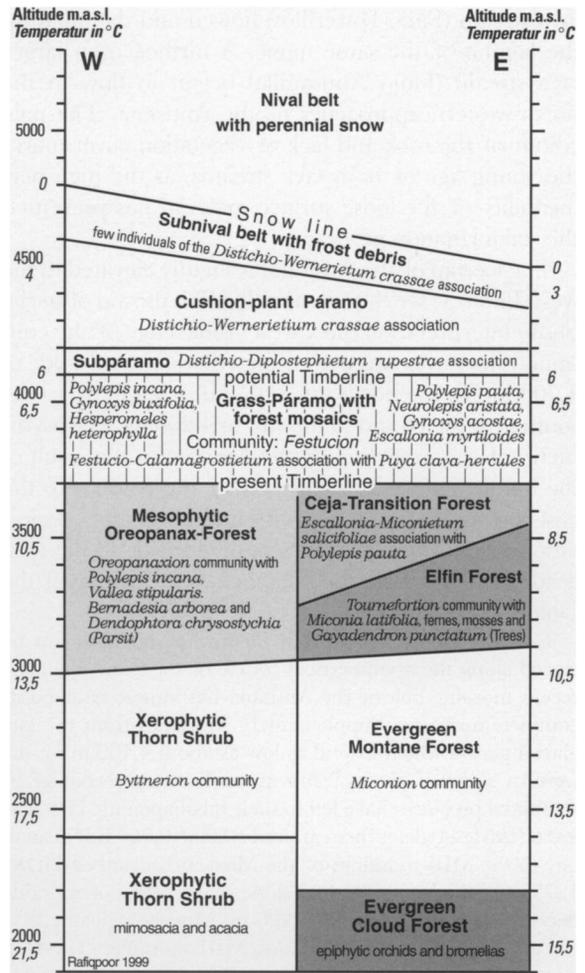


Fig. 2: Asymmetric arrangement of the altitudinal zonation of vegetation on the western and eastern slopes of the *Páramo de Papallacta*, eastern cordillera of Ecuador. The moist zones are differentiated according to the intensity of cloud and fog

Asymmetrischer Aufbau der Höhenstufen der Vegetation an den West- und Ostabdachungen des *Páramo de Papallacta*, Ostkordillere Ecuador. Die Kondensationsstufen sind je nach Intensität von Wolken und Nebel durch unterschiedliche Rasterstufen hervorgehoben

area phytosociological records were made according to BRAUN-BLANQUET's method (1964) and the plant communities mapped out according to SEIBERT and MENCHOFER (1991/1992). On the basis of phytosociological analyses it was possible to determine a pattern of the asymmetric vertical arrangement of the vegetation zones on both slopes based on vegetation associations (Fig. 2).

The vegetation formations of the cushion-plant and grass páramo depicted on the map (Supplement I)



Photo 2: Cushion-plants *Xenophyllum humile*, *Xenophyllum crassum* and *Plantago rigida* in Páramo de Papallacta at 4330 m a.s.l. Small shrubs (*Diplostegium rupestre*) and *Lycopodium crassum* are also present (Photo: RAFIQPOOR 1987)

Polsterpflanzen *Xenophyllum humile*, *Xenophyllum crassum* und *Plantago rigida* im Páramo de Papallacta bei 4330 m ü. NN. In den Polsterzwischenräumen gedeihen kleine Sträucher aus *Diplostegium rupestre* und *Lycopodium Crassum*

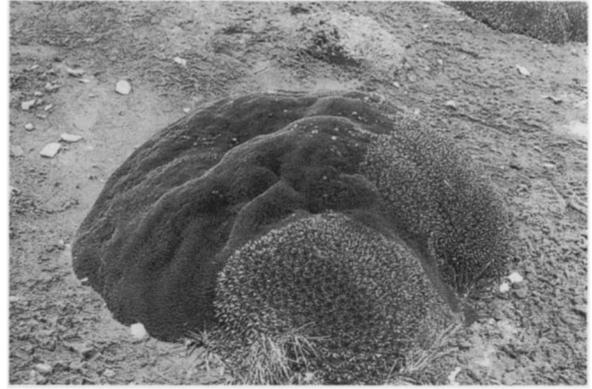


Photo 3: Initial phase of patterned ground as a consequence of needle ice formation in the vicinity of a combined cushion plant: *Xenophyllum humile* (left) and *Plantago rigida* (bottom) in Páramo de Papallacta at 4300 m a.s.l. (Photo: RAFIQPOOR 1987)

Leichte Strukturierung des Oberbodens infolge der Kammeiswirkung im Umfeld eines zusammengewachsenen Riesenpolsters aus *Xenophyllum humilis* (dunklere, obere Hälfte) und *Plantago rigida* im Páramo de Papallacta (4300 m ü. NN)

stretch from the east to the west of the mountain range without divergence of species, forming a unified cover over the entire ridge region. Beneath the grass páramo a striking asymmetry occurs to the east and west of the Cordillera, both in the vertical zonation and the composition of species within each zone. These differences were expressed on the map through a differentiation of symbol and colour.

The uppermost vegetation formation of this unit, the cushion-plant páramo, comprises the belt above 4,200 m (Photo 2). It is characterised by a *Distichio-Wernerietum crassae* association, which consists of a thick carpet of cushion-plants (*Xenophyllum humile*, *Xenophyllum crassum*, *Werneria pygmaea*, *Distichia muscoides*, *Plantago rigida*). The woolly dwarf shrubs (*Diplostegium rupestre*), along with the pink colored *Lycopodium crassum*, moss and lichen, fill in the gaps between the cushion plants. The authors' own field studies show that at the lower boundary of the subnival belt (4,200 m) ground frost occurs at night – particularly under cloud-free weather conditions. It is not severe enough, however, to permeate the soil, but merely triggers the formation of needle ice in localities devoid of vegetation. The needle ice loosens the top soil and structures it when the needle ice disintegrates at sunrise (Photo 3). True microforms of the patterned ground (stripe patterns, stone polygones, stone stripe patterns etc.) only occur above 4,500 m and then only rarely.

Below 4,200 m a narrow transition zone occurs, where the vegetation is dominated by the association *Festucio-Diplostegietum rupestrae*. Numerous dwarf shrubs thrive (*Loricaria lil-nissae*, *Chuirea jussieu*, *Baccharis arbutifolia*, *Valeriana adscendens*, *V. microphylla*, *Diplostegium rupestre*, *D. ericoides*, *Festuca subulifolia*). In edaphically humid localities *Lycopodium crassum*, *Distichia muscoides*, *Plantago rigida*, *Diplostegium rupestre* and *Isoetes andicola*

occur. *Aciachne pulvinata* cushion plants thrive in drier localities. This belt with a breadth of about 100 m forms a striking, floristically diverse ecotone between the cushion-plant and grass páramo, which can be termed as virtual sub-páramo, since the floristically very uniform biom of the grass páramo beneath evolved through the anthropogenic devastation of a former continuous “ceja low forest” formation (LEGAARD 1992).

The “ceja low forest” is a transition forest, which has evolved from the elfin forests, comprises few species and is of low shrub-like growth. It occurs at the upper edge of the ceja de la montaña and reaches a maximum height of 10 m. In this context VARESCHI (1980) speaks of a strongly impoverished facies of a “high Andean low forest” (*chirivital*) at the upper limit of the elfin forests in Venezuela. The *chirivital* of the Cordillera eastern slope, however, is richer in species than the higher *Polylepis* shrubs.

The grass páramo (Photo 4) extends between 4,100 and 3,700 m. Floristically it can be divided into two sections. Between 4,100 and 3,800 m the tussock grass *Festucetum subulifoliae* association and *Calamagrostis intermedia* dominate both slopes; *Bromelias* are also found here and there (*Puya clava-herculis*). Below 3,800 m the *Festucetum procerae* association and *Calamagrostis effusa* predominate. On both slopes shrub-like, low-growing, forest mosaics of *Polylepis*, *Gynoxys*, *Hesperomelis*, *Escallonia* are scattered over the grass páramo. These mark the potential timberline at 4,100 m (see Fig. 2). The floristic variations in the distribution of *Polylepis* are such that on the eastern slope *Polylepis pauti* occurs together with *Neurolepis aristata*, whereas *Polylepis incana* is restricted to the western slope (Photo 5). These forest mosaics become denser on the eastern slope and form the so-called ceja transition forests (Photo 6).



Photo 4: Tussock-grass-formation with *Festuca procera*, *Calamagrostis effusa* and *Puya clava-hercules* in 3800 m a. s. l. on the western slope of the Paso de Papallacta (Photo: RAFIQPOOR 1994)

Büschelgras-Formation aus *Festuca procera*, *Calamagrostis effusa* und *Puya clava-hercules* in 3800 m ü. NN am Westabhang des Paso de Papallacta



Photo 5: *Polylepis incana* remainder in 3700 m in grass-páramo on the western slope of the Paso de Papallacta. The very rapid growth of *Polylepis incana* shrubs after the *Polylepis* forest was damaged by fire and road construction in 1987 is remarkable (Photo: RAFIQPOOR 1998)

Polylepis incana-Bestand in 3700 m im Graspáramo des Westabhangs des Paso de Papallacta. Bemerkenswert ist die rasche Verjüngung des abgebrannten und durch Straßenbau im Jahr 1987 zerstörten *Polylepis*-Waldes

Floristically they are dominated by the *Escallonia-Miconietum salicifoliae* association, of which *Miconia salicifolia*, *Escallonia myrtilloides* and *Gynoxys acostae* are the most common. Lower down are the true hygrophilic elfin forests of ceja de la montaña which consist to a large extent of Boraginacea (*Tournefortia fuliginosa*) and Melastomatacea (*Miconia latifolia*). These are denoted by colour and symbol at the eastern edge of the map around the town of Papallacta (see Supplement I).

3.3 Block of El Tablon and Páramo de Guamaní

This unit comprises about the entire western half of the map and has its emphasis in the agricultural region on the western slope of the mountain range (see Fig. 1 and Supplement I). The highest elevations of the unit are in the Páramo de Guamaní (4,189 m), with its young glacial characteristics such as a few glacial lakes. Also the lowest point of the study area is situated in the north-western corner of this unit, more or less at the foot of the Ilaló volcano, at an altitude of 2,500 m a. s. l. The hydrographic network is exclusively connected with the inner-Andean basin and forms part of the drainage basin of the Río Guayllabamba.

The mountain block out of Plio-Pleistocene andesitic-dazitic volcanic rocks (TORRES 1982) is dominated by glacially deepened asymmetric valleys (e. g. Río Encañada) and NNW–SSE directed ridges (e. g. Filo de Tablarumi). These are witnesses of large-scale tectonic activity. The northern flank of the andesitic lava stream of the tertiary Nuñurcu volcano (3,748 m) (see Supplement I) is covered by MI moraines (HEINE 1995, 10) at the mouth of the Encañada valley (TORRES 1982).

The agrarian economic region is subdivided by numerous Quebradas and fluvial channels which run more or less N–S. This lively topography is based on the liability to erosion of Cangahua, an aeolic-volcanic sediment, which spreads across the entire study area, is >100 m thick in the Quito basin, and narrows to a thickness of only a few metres on the ridges of the Cordillera.



Photo 6: Ceja-transition forest of *Miconia salicifolia* (coniferous type trees), *Escallonia myrtilloides* and fern at 3700 m a.s.l., eastern slope of Paso de Papallacta (Photo: RAFIQPOOR 1998)

Ceja-Übergangswald aus *Miconia salicifolia* (coniferenartige Bäume), *Escallonia myrtilloides* und Farne im Vordergrund als Unterwuchs in 3700 m ü. NN, Ostabdachung des Paso de Papallacta

Altitude m.a.s.l.	Thermal Belt (Annual mean)	Soil	Vegetation	Land-Use Type	
				main culti- vation fruit	secondary fruit
> 4200	< 5 °C	brown Humic glei partly Bog soils	Cushion Plant Páramo "Páramo propiamente dicho" Association: <i>Distichio-Wernerietum</i> with <i>Xenophyllum humile</i> , <i>Werneria pygmaea</i> , <i>Xenophyllum crassum</i> , <i>Lycopodium crassum</i>	Uncultivated land	
4100-4200	<i>tierra helada</i> 6 - 5 °C	brown Cambisols with leaf mold acidic humus	Subpáramo (Dwarf shrub transition zone) Association: <i>Festucio-Diplostephietum</i> with <i>Loricaria ilinense</i> , <i>Diplostephium rupestre</i> , <i>Baccharis arbutifolia</i> and <i>Festuca subulifolia</i>	Pasture land	
3700-4100	8 - 6 °C <i>tierra fría II</i>	black, humic Andosols	Grass-Páramo Community: <i>Festucion</i> Association: <i>Festucietum subulifoliae</i> (>3800m), Association: <i>Festucietum procerae</i> (<3800m) with <i>Calamagrostis effusa</i> , <i>Calamagrostis intermedia</i> , <i>Puya clava-herculis</i> , <i>Satureja tomentosa</i> Forest mosaics Community: <i>Polylepton</i> Association: <i>Polyleptum incanae</i> with <i>Polylepis incana</i> , <i>Cynoxys acostae</i> , <i>Cynoxys halli</i> , <i>Saracha quitensis</i> , <i>Hesperomelis heterophylla</i>	Pasture land	
3100-3700	11 - 9 °C	brown, humic forest soils	„Ceja-Wald” (fog belt) Community: <i>Oreopanaxion</i> with <i>Oreopanax floribundus</i> , <i>Oreopanax palamophyllum</i> , <i>Vallea stipularis</i> , <i>Barnadesia arborea</i>	Tuber plants	Potatoes, barley, oca, onion fodderbeans Pasture, partly as forest pasture
2800-3100	14 - 11 °C <i>tierra fría I</i>	deep profiled lessiveted Cambisols	Transition Zone of xerophytic community (<i>Byttnerion</i>) to mesophytic community (<i>Oreopanaxion</i>) with <i>Baccharis latifolia</i> .	Potatoes	Maize, beans, fodderbeans Pasture, partly as forest pasture
2400-2800	17 - 14 °C		Xerophytic Shrub Formation Community: <i>Byttnerion</i> Association: <i>Durantaetum triacanthae</i> with <i>Durandra triacantha</i> , <i>Citharexylum ilicifolium</i> , <i>Dalea coerolea</i> , <i>Croton wagneri</i>	Maize, beans	Wheat, potatoes, beans, fruits
< 2400	<i>tierra templada</i> > 17 °C		Xerophytic Shrub Formation Mimosacia, Acacia		Citrus fruits, avocados, chirimoyas, alfalfas

Fig. 3: Altitudinal zonation of vegetation and land-use types on the western slope of the Paso de Papallacta
Höhenstufen der Vegetation und Landnutzung am Westabhang des Paso de Papallacta

Cangahua generally has a compensating effect on the landforms, resulting in a very smooth relief on the Cordillera slopes, particularly in areas with a continuous vegetation cover. Different soil types have arisen from the Cangahua cover, according to altitude and topoclimate, resulting in the development of a rich agrarian landscape. The zone above 3,600 m is characterized by a 1–2 metre-thick layer of absorbent, black andosol, on which vegetables and tuber plants are cultivated right up to the upper cultivation limit (3,800 m). Below 3,600 m maize, peas, fodder beans and potatoes are cultivated on light brown cambisoles (Fig. 3). Near towns and villages horticulture is common in the high valley of Quito, where flowers, particularly roses, are now cultivated in greenhouses for export.

Particularly at higher altitudes (2,800–3,400 m) the agricultural landscape is characterized by the predominance of villages, haciendas and farms (see Supplement I). Within this unit the upper boundary of the more “densely populated” region (relative density of villages and farms) strangely follows the cloud condensation level, which rises from 2,800 m in the south (Pintag) to 3,100 m in the north (El Tablon). Cattle farms penetrate the more mountainous regions. A certainty of precipitation throughout the year within the condensation zone provides the population with drinking and irrigation water. The dense network of irrigation channels in

the cultivated landscape is evidence of this (see Supplement I).

Recent observations have revealed that on the western slope of the mountain range the cultivation boundary for vegetables and tuber plants is gradually increasing in altitude. In the lower Carihuaycu valley, for instance, the cultivation of tuber plants has extended upwards from 3,600 to 3,800 m within the last fifteen years (1985–1999). This also applies to the páramo landscapes around the basin of Cayambe north of Quito. It is not yet clear whether this is due to a general climatic warming, or the high population rate in the high Andean valleys, or a reaction to the market prices for basic foodstuffs near the urbanized area around Quito. Certainly the huge greenhouse cultivation sector in the high Quito and Cayambe basins competes with the cultivation of food crops, as the international demand for flowers ensures high profits as “cash crop”. Thus the cultivation areas for food crops are being forced out of the ideal cultivation zone. Today 3,800 m – with slight fluctuations – is considered to be the upper limit for arable farming within the study area. Above 3,800 m crop cultivation is restricted thermically by an average annual temperature of 7 °C. Pasture farming, however, penetrates to a much higher altitude.

On the western slope of the mountain range below the páramo two phytogeographical altitudinal zones can be identified. Immediately below the grass páramo with its *Polylepis incana* forest mosaics, at an altitude of

about 3,700 m, are the mesophytic ceja forests of the *Oreopanax* group in which the *Aralicea* (*Oreopanax floribundus*, *O. palamophyllus*) together with *Vallea stipularis* and *Barnadesia arborea* predominate. These forests follow the asymmetrical course of the condensation zone between Pintag (2,800–3,700 m) and El Tablon (3,000–3,700 m) (see Supplement I). At the foot of the mountain range these give way to a dry shrub formation of the *Byttnerion* group. The dry shrub formation has been largely destroyed by anthropogenic land use. Remains of these forests can only be found today on steep slopes in the Quebradas which are unsuitable for agriculture or inaccessible.

4 The timberline in the Ecuadorian eastern Cordillera as an example for the inner tropics

The polylepis shrubs in Papallacta regions either reach right down to the ceja forests at 3,700 m or occur as isolated mosaics in the grass páramo, where they extend up to an altitude of 4,100 m. We assume that the “park landscape” of tussock grass and forest mosaics between 3,700 and 4,100 m used to be a continuous low-forest formation (*Polylepis*-woodland) before the influence of man (see Fig. 2). There are many indications of this. In the Pleistocene the timberline, páramo boundary and snow line were continually inconsistent (Fig. 4). In the dry, cold glacial maximum of the last ice age (LGM about 18,000 B. P.) all the geoecological altitudinal zones lay about 1,000 m lower than today due to the striking fall in temperature of about 5°C (v. D. HAMMEN 1981; HEINE 1998, 32). During the post-glacial climatic optimum (7,000–3,000 B. P.) these shifted about 400 m higher than today, a fact which is supported by palynological studies in Columbia. (v. D. HAMMEN a. CLEEF 1986, 190: “In the first place, the altitudinal forest limit in the period from 7,000 to ca. 3,000 B. P. was obviously higher than today, and locally may even have extended to altitudes 300–400 m higher”). LAUER (1986, 1988) has referred many times to quarternary research findings (HANSEN; WRIGHT a. BRADBURY 1984; MARKGRAF a. D’ANTONI 1978 etc.) which allow for the conclusion that remains of the *Polylepis*-woodland above the present continuous timberline at high altitudes in the Andes are evidence of the timberline during the post-glacial climatic optimum (8,000–3,000 B.P.). Since then the ceja forests have retreated by an altitudinal zone of about 100 m, which now forms a low shrub transition zone – the true sub-páramo (s. Fig. 2).

The potential upper timberline at 4,100 m is of climatic origin. From a hygric point of view the vegetation

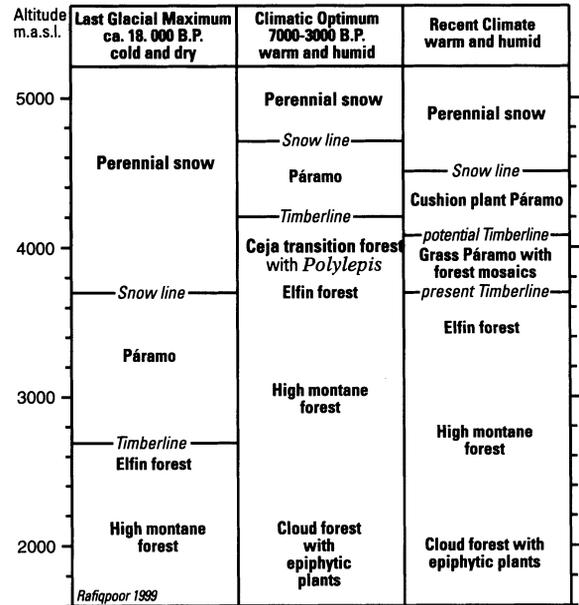


Fig. 4: Vertical variation of timberline, páramo limit and snowline since Last Glacial Maximum in the inner tropics of Ecuador

Wandel der Höhengrenzen des Waldes, des Páramo und des ewigen Eises seit dem Höhepunkt der letzten Eiszeit in den inneren Tropen Ecuadors

formations in the higher regions indicated on the map (cushion and grass páramo) are humid the whole year round. At an altitude of 3,900–4,100 m a condensation level is usually reached which allows for the favourable hygric conditions. After evaluating field studies and records of the soil temperature at a depth of 50 cm over many years, the annual mean temperature at the present upper limit of the continuous ceja transition forests in the study area (3,700 m) is 7.5°C. It has been proposed that a temperature of 5.5–7.5°C constitutes the critical thermic threshold value for an upper timberline (KÖRNER 1998, 455). Soil temperature measurements in the inner tropics in the Papallacta region suggest that this would correspond to an altitude of about 4,100 m (6°C). It is significant that this boundary correlates with the sites of the highest occurrence of *Polylepis* and thus corresponds to the potential timberline.

Historical sources, particularly documents about land ownership and court decisions on land-use rights from the 16th century provide information on the anthropogenic devastation of the *Polylepis*-woodlands. They testify that the entire Quito basin used to be covered by dense forests. “The geographical relationships, communal records and a few old court-case

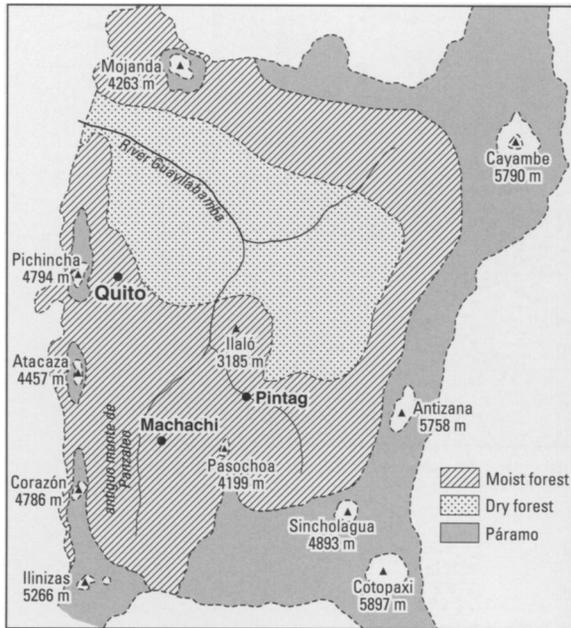


Fig. 5: Distribution of former vegetation cover in Guayllabamba Valley (var. after NISTRÍ 1998)

Verbreitung der ursprünglichen Vegetation im Guayllabamba-Tal

documents, which were written in Quito, provide very interesting information about the vegetation cover of this sub-region before its total destruction following the introduction of cattle farming and extensive land use” (NISTRÍ 1998, 27). On the basis of the historical documents NISTRÍ (1998, 103) drafted a map of the “Antiguos Paisajes Forestales” for the Quito basin (Fig. 5). These documents contain references to the use of *Poly-lepis*-woodlands for coal production. In addition to this the traditional use of shifting cultivation in the forest and grassland of the páramo is a well known fact, which has undoubtedly added to the degradation of the forests. Fires are still often observed in the páramo, particularly in the dry season. Fires lead to the growth of younger bunch grass which is favourable for grazing. At the upper cultivation limit at about 3,800 m páramo vegetation is also burnt to obtain cultivation area. The ash is worked into the soil to provide it with nutrients. The landscape of the grass páramo testifies to the fires with its various shades of green in close proximity to each other, giving the impression of a patchwork quilt. Also blackened trees at the edges of the forests in the grass páramo are evidence of fires. This usually gives way to a belt of *Cortaderia nitida* (Photo 7) which, as a pioneer plant in the succession chain, is able to utilize the nutritional conditions following fires (LÆGAARD



Photo 7: *Gynoxys* mixed forest in grass-páramo with damages caused by fire. Fresh *Cortaderia nitida* grass hem round the forest at 3900 m a. s. l. on the western slope of the Paso de Papallacta (Photo: RAFIQPOOR 1998)

Gynoxys-Mischwald im Graspáramo mit Brandspuren und *Cortaderia nitida*-Saum in 3900 m ü. NN am Westabhang des Papallacta-Passes

1992, 154). This particularly supports the theory that the characteristic flora of the grass páramo, with its uniform composition of species, could only have emerged through fire (LÆGAARD 1992). The grass páramo is the secondary formation of an altitudinal zone (up to 4,100 m) in which continuous forests used to thrive, which have disintegrated to form scattered mosaics through anthropogenic influence (fires, grazing).

5 The Problem of the Timberline in the Andes

The timberline issue in the tropical Andes of South America is closely related to the “*Polylepis* problem”. Reports of the occurrence of *Polylepis* in the higher

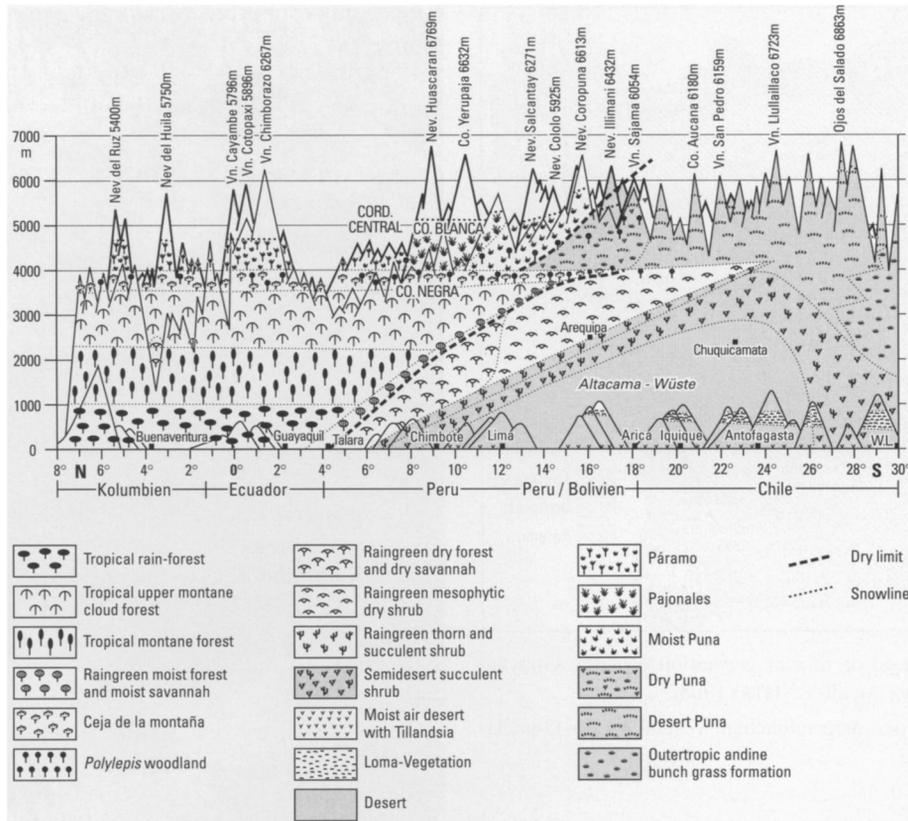


Fig. 6: Altitudinal zonation of vegetation on the western slope of the Andes (from LAUER 1988)

Höhenstufen der Vegetation an der Westabdachung der Anden

regions of the Andes existed as far back as the 18th century: RUIZ u. PAVON (1794), HUMBOLDT u. BONPLAND (1807), WEDDEL (1861), PHILIPPI (1891), HIERONYMUS (1874). The scientific study of the question of the timberline in the tropical Andes began with WEBERBAUER (1911, 1945), HERZOG (1931) and TROLL (1948). WALTER a. MEDINA (1969) investigated the ecological growth conditions of the *Polylepis* forests in Venezuela. KOEPCKE (1961), RAUH (1956), ELLENBERG (1958, 1979), LAUER (1979, 1986), JORDAN (1980/83), BRAUN (1988), KESSLER (1995) etc. have approached the question of the *Polylepis* as evidence of the upper timberline from a synecological, phytomorphological, paleobotanical, climatic and taxonomic-ecological point of view. As early as 1958 ELLENBERG made the hypothetical statement, that continuous *Polylepis* forests used to be widespread in parts of the Andes up to an altitude of about 4,500 m, and were destroyed by felling, fire and grazing. Shortly before he died he added, "Today the assumption of ELLENBERG (1979) can be considered certain, that widespread areas of the Puna, Jalca and Páramo below the upper boundary of tree-growth in the South American Andes, marked by *Polylepis* and

Espeletia species, are potential forest regions." (ELLENBERG 1996, 21). Studies by HENSEN (1993) and KESSLER (1995) support ELLENBERG's theory, particularly on the basis of the modern international pro-forest conception (BALSLEV a. LUTEYN 1992; VERWEIJ a. KOK 1992; VERWEIJ a. BUDDE 1992; LÆGAARD 1992).

In the discussion of the timberline in the tropical mountains of South America, the eastern and western slopes of the meridionally aligned Andes chain should be viewed separately in accordance with the respective climatic conditions.

The vegetation of the eastern slope of the tropical Andes is characterised by an obvious sequence of altitudinal zones between the equator and the Tropic of Capricorn. In the inner tropics (Venezuela, Columbia, Ecuador) *Polylepis* forests occur in the "Chirivital" and grass páramo zones, between 3,500 and 4,100 m. Along the eastern slope the upper boundary of the elfin forests with their wealth of species, gradually dips from the equator, beyond the Tropic of Capricorn to southern Bolivia: Ecuador 3,700 m, Yungas of Bolivia 3,400 m, southern Bolivia around 3,000 m (GEROLD 1987, 2–3). The upper limit of the *Polylepis* forests

remains more or less constant at $4,100 \pm 100$ m. Thus between the northern Andes and the Tropic of Capricorn these two upper limits diverge. The *Polylepis* forests, which used to be continuous, have largely disappeared under the pressure of a growing population and made way for arable farming and grazing. They have been decimated to a minimum, particularly in the densely populated northern (Venezuela, Columbia, Ecuador) and central Andes (Peru, Bolivia). Extensive grassland (Grass Páramo, Pajonales, Jalca) has now replaced them. Only a few inaccessible mountainous locations still bear the original vegetation cover.

On the western side of the Andes, between southern Ecuador and northern Chile, is the earth's most arid desert – the Atacama (Fig. 6). As a result the humid evergreen forests on the slopes of the Andes gradually peter out at about 7° south. From about 1,500 m a mesophytic shrub-forest formation emerges instead, the lower limit of which gradually rises to about 4,100 m, in connection with a reduction in tree height towards the Tropic of Capricorn. The *Polylepis* woodlands are found at the upper edge of this mesophytic shrub-forest formation and extend in places up to 4,500 m. Their optimum, however, seems to be at 4,200 m (KOEPCKE 1961, 174). Along with the *Polylepis* woodland the shrub-forest (mesophytic shrub belt) also peters out at higher altitudes in the vicinity of the arid axis of the Andes at about 24° south.

The arid axis crosses the Andes mountain range from NW (Antofagasta, northern Chile) to SE (Mendoza, Argentina). In climatic terms it is a region with ephemeral summer and winter precipitation, its most central region being hardly touched by any precipitation regime, even in the central highlands (e. g. in the Lullaillaco region). Moving away from the arid axis in both directions – towards the equator and the south pole – precipitation increases in the form of tropical summer rains and extra-tropical winter rains respectively.

On the western slope of the Andes the mesophytic shrub belt with its clear upper and lower limits, coincides climatically with a foggy belt (condensation zone) (TROLL 1955; LAUER 1986; 1988). Volcanoes are located on top of the edge of the Peruvian-Bolivian Altiplano (e. g. El Misti, Parinacota, Pumarape), some of which reach further into the centre of the plain (Sajama). Around these volcanoes a more humid condensation zone is only to be found above 4,300 m. Under these climatically and edaphically favourable conditions a circle of *Polylepis* woodlands has formed which, at the part with the largest "Massenerhebung" in the Andes (Sajama volcano), is the highest occurrence of trees worldwide (5,100 m). Due to the extreme aridity the *Polylepis* are of one particular species (*Polylepis tarapacana*) which has adapted to arid conditions. The population is not very dense and has a maximum

height of 3–4 m and the specimens are more shrub than tree.

The entire arid axis region on the Altiplano forms a forest-free corridor. The aridity of the Andean arid axis stretches to the puna area of southern Bolivia, at least as far as Lake Titicaca. It causes extreme aridity, particularly around the Salars of Uyuni and Coipasa (Salt Puna). The vegetation of the thorn and succulent puna in the southern Altiplano mainly consists of low-growing bushes (*Adesmia*, *Tetraglochin*, *Parastrephia lepidophylla*) and bunch grass (*Festuca ichu*, *Festuca dolichophylla*). This part of the Altiplano was never forested.

6 Conclusion

On the humid eastern slope of the Andes a complete sequence of altitudinal zones exists with regard to vegetation, from rain forests to the super páramo in the sub-nival zone. On the arid western slope a mesophytic shrub forest has only developed in the condensation zone above the Atacama desert. A ring-shaped *Polylepis* belt occurs around the numerous volcanoes in the western Cordillera and Altiplano, corresponding also with the condensation zone. The upper timberline on the volcanoes of the Altiplano, which reaches 5,100 m a. s. l. is a unique phenomenon. The ELLENBERG theory that the grassy highlands (Páramo, Pajonales, Jalca) form a potential forest zone is true for the humid eastern Cordillera and for the humid sections of the western Cordillera (e. g. the mesophytic shrub forest in the condensation zone). The dry puna formation forms no potential forest zone due to the extreme aridity on the northern edge of the Andean arid axis.

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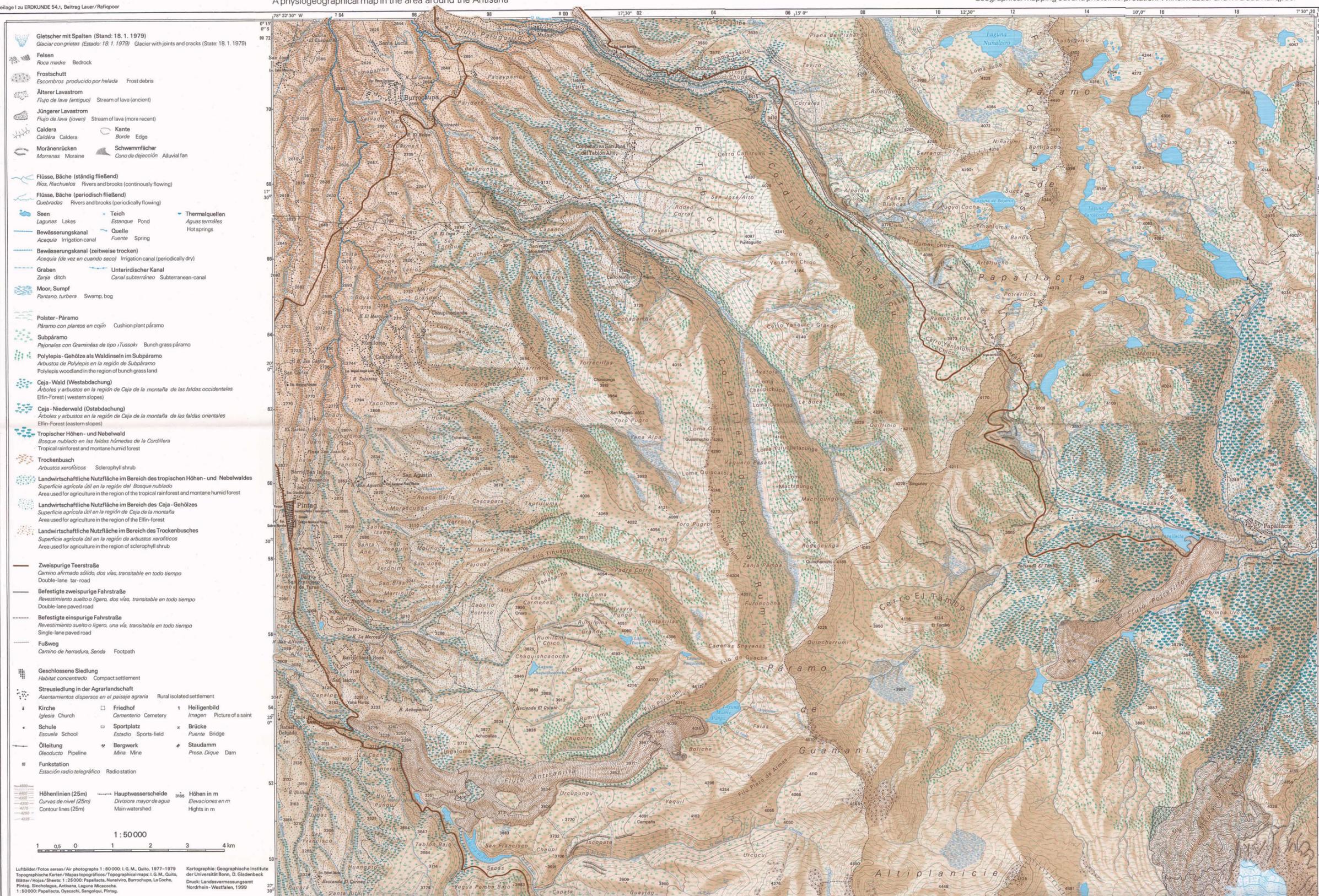
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Sources

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- Aerial photos 1:60,000 of the Mission *Proyecto Carta Nacional* del Instituto Geográfico Militar, Quito-Ecuador.
- Our own field studies in 1985, 1987, 1988, 1994, 1998, 1999

Beilage 1 zu ERDKUNDE 54.1, Beitrag Lauer/Rafiqpoor



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