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A NOTE TO THE WEATHERING PROCESSES IN THE EAST NEPAL HIMALAYAS*

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सारांश

क्वाटरनरी समयमा हिमालयको जलवायु–आकारौत्पत्तिक (Climato–morphogenetic) प्रकृयाहरूको अस्थिरता पृथ्वीको जलवायुमा विश्वब्यापी हेरफेरका साथै यी पर्वतहरुको आयतन र आकारमा पर्वत निर्माणात्मक (orogenic) परिवर्तनले गर्दा भएको हो। यस लेखमा पूर्वी नेपाल हिमालयमा ऋतुक्षरण (weathering) प्रकृयाको मुख्य लक्षण माटो उत्पत्ति तथा हिम बिन्यास पत्र (तह) (Glacigenous stratigraphy) संग्रहको उदाहरणको रुपमा संक्षेपमा दिईएकोछ। प्रारंभिक पहाड बिनास र यसरी खण्डित राशको प्रवहनको दर जलवायुको स्थितिद्वारा नियन्त्रित चट्टानहरुको ऋतुक्षरणको तिब्रतामा भर पर्दछ र उच्चतम पर्वत पिण्डको गर्भित शक्ति (Potential energy) संग संवन्धित छ।

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ABSTRACT

The variability of the climato-morphogenetic processes of the Himalaya during the Quaternary was due-in addition to the global climatic variations of the Earth-to the orogenic changes of the volume and shape of these mountains. In this paper the main modellation features of weathering processes in the East Nepal Himalayas on the examples of the soil genesis and glacigenous stratigraphy accumulations are summarized. The rates of the original mountain vault destruction and transport of the disintegrated masses depend on the intensity of the weathering processes of rocks controlled by the climatic conditions, and are a function of the potential energy of the highest mountain massifs.

INTRODUCTION

The extraordinary interest of natural historians in the youngest vault of th Earth, stimulated by observations of unique geological and biological phenomena, leads to ever more intensive recognition of the Himalayan nature and to correlation of these phenomena with further Neoidic mountain ranges.

The variability of the climato-morphogenetic processes of the Himalayas during the Quaternary was due-in addition to the global climatic variations of the Earth-as early as since the Miocene, to the orogenetic changes of the volume and shape of these mountains. The activity of morphogenetic processes continued still in the Holocene, being constantly supported by the permanent uplift of the Himalayan mountain ranges which contributed to the extreme potential energy of the relief. The geologically short time span separating the present time from the Middle Miocene and especially Pleistocene phases of folding permits the problem of the development of the Himalayan relief to be regarded as a rare opportunlty of studying the surface phenomena of folding as the most revolutionary among the known geological events.

The Neoidic orogenic processes in the zone at the contact of the Indian and Asian shields were responsible for the origin of the present-day vault of the Himalayas. The southern foot of this vault lies for example in East Nepal only 150 km from the highest Chomolongma Massif. In a profile of a meridian direction the relative height difference is more than 8500 m. The extreme parts of this climato-vegetation profile showing sharplydelimited vertical succession of biostratigraphically different zones are represented by associations of subtropical mcnsoon forests in a seasonally humid warm climate, and by the abiotic extremely cold high-mountain semidesert.

The division of the rock groups of the Himalayas into the tectonic units composing the relief is the result of nappe thrusts (Jaros & Kalvoda, 1978 a, b) having occurred in two stages-the Miocene and the Quaternary. The dissected character of the mountain reliefs increases according to their tectonic rejuvenation or even tectonic nappe reconstruction of the whole mass of the mountain range.

Regular shifts of dry and cold continental air masses and humid and warm oceanic ones represent the basic rhythm of the seasonal variations of the Himalayan climate. The climatic secondary features then also differ regionally in dependence on the geographical position, the altitude and the arrangement of the high-mountain relief. The position of the Great Himalaya of East Nepal is climatically extreme. The huge barrier of six-to eight-thousand-metres rock massifs is only several hundred kilometers from the bay of Bengal where the main waves of the oceanic summer monsoonal streaming turn toward the Himalayas. The southern slopes of the Great Himalaya of Nepal are characterized by a humid, and its northern slopes by a semi-arid cold, mountain climate with a strictly vertical thermal and pressure stratification. Nevertheless, within the framework of the main climatic zone, local differences in the succession of meteorological elements are considerable. The specific conditions within the mountain range, particularly sudden change of pressure and winds due to the orographic distribution of precipitation frequency, and furthermore the intensity of solar radiation on the slopes, the high thermal amplitudes and the seasonal oscillation of the position of the snow line are important factors controlling the course of the relief-forming and biological processes.

The soils of the Himalayan region are practically unknown from the genetic classification and systematic points of view. The area under consideration is extremely vast, so that a great number of diverse soil types, subtypes and varieties are represented here, which are genetically dependent on the initial substrate, climate, vegetation growths and other significant factors. We therefore have limited ourselves to the investigation of at least the soil development in various climatic zones of the profile across the East Nepal Himalayas, drawn roughly in a meridian direction.

The soil samples taken could have been subjected to most varied methods of examination (e. g. mechanical or chemical analyses, investigation of clay minerals etc.), but for the given purposes we have chosen the method of soil micromorphology which enables direct study of dynamical soil development. The chosen soil samples had been hardened in laboratory and according to the routine procedure, thin sections suitable for micromorphological investigation have been made. Using this method, primary components (quantity, character and variations of soil skeleton) and the secondary ones (nature and forms of the soil plasma and its changes; new formations), as well as various soil fabrics and traces of activity of soil organisms have been distinguished. The diversity of the latter and their abundance in soil thin sections sometimes were surprising.

In this way it was possible to study soil as a whole (and not as individual details detached from the general picture), and-in some cases-to reveal traces of various processes forming the soil in a certain time succession. On the basis of evaluation of the features determined in soils, the soil under study have been interpreted more accurately, categorized systematically and according to their genesis.

The highest massifs of the Himalayas are ideal model areas, for the study of gradational rhythms and typical relationships between the main relief-forming factors. For the early Tertiary onwards the development of the himalayan relief was controlled by repeated orogenic impulses and climatmorphogenetic processes undergoing secular changes. In view of the Quaternary orogeny of the Himalayas, radical changes in the paleoclimate of the developing vaulted mountain mass may be assumed.

In the altitude zone seasonal oscillation of the snowline (2200-5800 m a. s. l.) evidence has been provided of many small scale forms of modelling due to frost, nivation and periglaciation under semiarid and humid conditions (compare also Fort, 1979). The variability of the climamorphogenetic processes in time and space renders impossible the attempts at correlating the Quaternary stratigraphy of the covering formations with the European mountain ranges. In the Himalayas it is necessary to elaborate local correlation systems, best on the basis of a study of fluvial, fluvio-glacial and glacigenous accumulations in mountain massifs where intense Holocene tectonic movements occur.

MAIN FEATURES OF THE SOILS IN THE EAST NEPAL HIMALAYAS

The height differences of the reliefs between the northern part of the Gangetic plain and the high mountain Himalayan area are responsible for the existence of pronounced climatic zones to which correspond exactly the vertical zoning of vegetation, the fauna and the types of extensive mountain agriculture. In the vegetation profile, the zone of a monsoon sal forest (with Shorea robusta) is developed in the S; in the N there are alpine meadows, the Tibetan steppe and the higher-lying extensive zone of a semiarid glaciated desert. The timberline in East Nepal is determined by temperature and humidity. On the southern slopes of the Great Himalaya at altitudes of 4100–4200 m the local timberline–in relation to the Tibetan highland–also represents the continental forest boundary. Extensive agriculture reaches altitudes of about 4400 m; rice is being cultivated up to 2600 m a. s. l.

In the Himalayas, a three-dimensional arrangement of the vertical zones of climate and vegetation, soil and forest ecological conditions, original types and the general shape of the landscape are characteristic. A further differentiation is controlled by the orographic division and by the influence of the dissection of the reliefs corresponding to meso-climatic local climatic, terrain–and subregional conditions. An instructive example of this dependence may be seen in the difference between the deeply incised consequent and wider subsequent mountain valleys. The canyon valleys mostly of meridian direction are typical by strong wind currents due to the replacement of continental aerial substances by the mountainous ones from the internal Himalayas; this enhances their aridity and maintenance of the xerophilous flora at the bottom on the valley. On shaded slopes, rather humid forests and shrubs grow, while at higher levels solar radiation influences the oscillation of the seasonal snow line. The accumulated dumps of avalanche material very strongly shorten locally the vegetation period, which may lead even to inversion of the vegetation zoning. The variations of plant associations depend on soil conditions affected by weathering processes, ground water and soil-climate. But the vegetation cover influences inversely the formation of soils and the nature and the depth of weathering.

The main features of the vertical climatic zoning in the East Nepal Himalayas may be summarized as follows: below 800 m–a zone with warm tropical climate, between 800–1200 m–a warm subtropical climate, between 1200–2400 m–a mild zone with accool climate, from 2400 to 3600 m–a zone with a moderately cold climate, over 3600 m a subarctic, and over 4800 m an arctic zone. The timberline on southern mountain slopes oscillates between 4100–4200 m, and the snowline between 5600–5800 m; N of the main crest of the Great Himalaya the snowline ranges between 5900–6000 m. The difference between the oceanic monsoon mountain climate S of the Himalayas and the semiarid continental climate in the N is pronounced particularly in comparing the regional distribution of the annual amount of precipitations. The precipitation maxima of up to 3000 mm in Nepal sharply contrast with those in Tibet where they do not exceed 600 mm.

Below we introduce some examples of characteristic micromorphologically elaborated samples of the main soil types (L. Smolikova–J. Kalvoda, in press) in the East Nepal Himalayas (for location see Fig. 1); Braunlehm strongly affected by rubification (Hi-54), Podzol Ranker (Hi-119), strongly developed Pseudogley (Hi-120), Alpine Sod Podzol (Hi-166 together with the Hi--167) and Alpine Ranker (Hi-192). The set of samples obtained here represents an altitude range from 400 m to 3700 m a. s. l. It therefore comprises the soils developed between the zone of a warm tropical and that of a cold subarctic climate.

Sample Hi-54

Sampling site; The foot of the Siwalik 2 km E from the village of Dharan Bazar, 400 m a. s. l.

Position: Lower part of an erosion-denudational slope dipping 5-7° towards SW.

Climate: Seasonally humid monsoon tropical climate with summer temperature over 30_0 C.

Vegetation: Light monsoon deciduous forest with the dominating species Shorea robusta.

Parent material: Coarse-grained slope sediments on mollase sandstones and conglomerates of the Siwalik.

Description of the soil profile: 10 cm thick humous horizon A immediately overlying the ruddy-brown sandy loam of the horizon B--the sampling site of a 60 cm thick sample; the parent material consists of coarse-grained sand, sandstone and conglomerate horizons; pebbles of diameters not exceeding 6 cm.

Micromorphology: The brown-red matrix consists of a braunlehm plasma. It is distinguished by complete decomposition of colloidal substances to which belong particularly hydrates of silicates of iron and aluminium uniformly diffusionally dissolved. The aggregates of the braunlehm plasma display a very dense structure due to a low amount of micropores; their walls are smooth, bounded polyhedrally or subpolyhedrally and are penetrated by narrow sharply broken fissures. In addition to these forms, aggregates of rounded outlines are also represented abundantly, which are deep-red in colour and have a more favourable inner structure. They are products of rubification during which amorphous iron hydroxides passed through crystallization into goethite and hematite, so that the brown colour changed to red. The amorphous substances here are flocculated, the groundmass contains abundant cracks (which is responsible for fine agregation), small SiO_2 crystals and concretions which in incident light are light--red. All the aggregates are separated from each other by a high proportion of interaggregate spaces produced by diverse volume changes of the soil material.

The soil microskeleton consists particulauly of quartz grains, muscovite and fragments of sandstone being represented to a lesser extent; the latter are strongly corroded. Large braunlehm concretions are abundant; they are of dark sepia brown colour, circular or elliptical in outline with a pronounced concentric structure and smooth faces. In the soil material not affected by rubification these concretions are brown or black in incident light. Some mineral grains and fragments are rimmed with thin dark Mn compounds separated out. Large fragments of coalified wood are abundant; they show a well preserved tissue structure.

The soil substance is almost non-humous. In thin sections, among the traces of organisms activity, numerous root channels may be seen which are irregularly branched and in some places finely rimmed with ferric hydroxides (during decomposition of plant remains a small amount of O_2 is released which binds the iron compounds). The earthworm tubes are smooth, finely coated locally with humous substances. Some fragments of decayed wood contain many feeding cavities with droppings of moss mites (Oribatei); they are oval and reddish in colour due to deposition of substances rich in lignine.

On the basis of the above mentioned features the soil of the sample Hi-54 may be classified genetically as Braunlehm strongly affected by rubification.

Sample Hi-119

Sampling site: The Lesser Himalaya at the northern periphery of the Sekaha village, 1600 m a. s. l.

Position: An agricultural field with terraces on a denudational slope dipping up to 15.

Climate: Subtropical monsoon mountain climate with summer temperatures of over 20^0 C and precipitations of up to 2000 mm.

Vegetation: In the surroundings of the village, monsoon very light deciduous mountain forest; around the sampling site, grass.

Parent material: Muscovite–biotite schists and biotite gneisses of the Himalayan tectonic Tinjure unit.

Description of the soil profile; The humous subhorizon A_1 is very shallow being only 3 cm thick. Then the subhorizon A_2 follows consisting of grey sandy clay overlying a bed of 70 cm thick loamy sands and fine debris of the horizon C. The total thickness of the exposure of the weathered mantle attains 150–200 cm; the sample was taken at the contact of the subhorizons A_1 and A_2.

Micromorphology: The flaky groundmass consists of two components markedly differing in colour–light–grey portions and those which are humous and light–brown. The former portions correspond to the subhorizon A_2, the humous ones to the subhonizon A_1. The humus here is a raw humus and a moder; in some places excrements of earthworms occur. The humus is usually present around the mineral constituents. The structure is loose characterized by a high proportion of micro–and macropores and bv slight aggregation. The soil is sandy to skeleton-like. The primary constituents are mostly quartz, biotite, muscovite, augites, hornblende, feldspars and fragments of micaschists and phyllites. All these are fresh, devoid of any traces of rather strong weathering; fragments of coalified wood are abundant.

On the basis of the main micromorphological features, mixing of the subhorizon A_1 with the strongly bleached subhorizon A_2 (with regard to the steep slope of the sampling site) and also because of the slight degree of weathering and the absence of horizon (B), the soil of sample Hi–119 may be assigned to the most acid one among the group of Rankers, i. e. a Podzol Ranker.

Sample Hi–120

Sampling site: The Lesser Himalaya, 6 km SE of village Num, 1950 m a. s. l.

Position: Denudational watershed–ridge with loamy-clayey slope detritus; the thickness of the weathered mantle is 5–6 m.

Climate: Mild warm monsoon mountain climate with precipitations of over 3000 mm per year, and summer temperatures of over 20^0 C; this zone represents the most humid mountainous area of East Nepal.

Vegetation; Very light humid monsoon evergreen mountain forest.

Parent material: Micaschists and biotite gneisses of the Lesser Himalayan tectonic Tinjure unit, which do not outcrop on the ridge because of intensive processes of prevailingly chemical weathering.

Description of the soil profile: A humous horizon consisting of well developed subhorizons A_e, A_f, and A_h; it is 30 cm thick, then the subhorizon gA^3 follows (light-grey sandy loam) and a strongly developed subhorizon g^B consisting of deep brown, and along roots grey-marbled clayey loam. The weathered rocks uncovered up to a depth of 6 m (horizons g_1, g_2, g_3 and g^C) are composed mostly of finely sandy loams up to strongly clayey loams with an admixture of sand. The sample has been taken from the horizon g^B at a depth of 40 cm.

Micromorphology: The flocculated groundmass consists of deep rust-brown portions rimmed with broad stripes of light-gray markedly bleached substance. This characteristically marbled coarse-grained soil substance of a compact structure is distinguished by many rather narrow or wider fissures responsible for the polyhedral form of the aggregates. The soil skeleton is mostly sandy consisting for the greater part of fragments of sericitic micaschists, micas, quartz, augites, hornblende and feldspars. Only feldspars display traces of rather intense weathering. In the horizon g^B, biological activity disappears irrespective of brought in fragments of wood densely penetrated by bright red minute oval droppings of moss mites. The stage of calcification is very advanced, as the rusty rims are shifted deep into soil elements. Evidence of this is furnished by almost complete replacement of brown relics by a material of rusty colour. The pores and fine crack's within these portions are mostly coated with red up to black manganese limonite. The grey zones of adequate width are grey or in places grey-white. Roots extend in all directions within these zones. Within brown-coloured relics of the soil mass, fragments of Braunlehm Teilplasma remained preserved.

Among the micromorphological features, the extreme amount of pseudogley concretions and their perfect development are incontestably the most conspicuous. The intensity of their formation has attained such a degree that even individual coating zones may be seen in them. In this case, this fact belongs to very noteworthy statements. The colours of these zones are different-black, black-brown, rusty up to rusty-orange. They are finely wavy and carry parallel-arranged micropores.

From the typological point of view, a strongly developed Pseudogley is involved, derived most probably from clayed Podzol on a slightly dissoluble substrate. As to relation to habitat, this soil is the typical one occurring under the forest cover in a pronounced humid area and on a suitable rather flat part of the relief.

SAMPLES Hi-166 AND Hi-167

Sampling site: The Great Himalaya, lower part of the Barun valley 3 km SE of the Yangle locality, 3200 m a. s. l.

Position: Surface of a coarse-sandy and gravelly 20-25 m thick fluvioglacial accumulation cut by downward river erosion.

Climate: Cool monsoon mountain climate with summer temperature over 15° C with mean annual precipitations of 2500 mm.

Vegetation: Monsoon evergreen mountain forest, locally with birch (Betula utilis).

Parent material: Fluvioglacial sediments are underlain by solid granulites and paragneisses of Great-Himalayan crystalline sequences; Quaternary accumulations consist of debris of strongly weathered migmatites, gneisses and granites.

Description of the soil profile: The soil profile is composed of horizon A_1, A_2 and B and a parent substrate (horizon C) consisting of strongly sandy loams and loamy sand of the surface of the fluvioglacial accumulation. The sample Hi-166 was taken from horizon A_2 at a depth of 30-40 cm, the sample Hi-167 from horizon B at a depth of 60-70 cm.

Micromorphology: Sample Hi-166, light-brown-grey slightly humous groundmass is flocculated and is characterized by a loose structure rich in voids. The grain sizes of the primary components correspond to coarse-grained sand and rock debris. The primary constituents are mostly fragments of leucocratic granites, migmatites, quartzites and paragneisses, grains of quartz, orthoclase, plagioclases, augites, hornblende, biotite and muscevite. Only dark minerals and feldspar are slightly weathered; the solid soil constituent is fresh throughout. Humus is represented in the form of coprogenic moder and raw humus. However, the coprogenic elements are disintegrated throughout, in contrast to those which became brown and remained entire plant remains. Only numerous minute red coloured and oval-shaped droppings of small arthropods predominantly mose mites (Oribatei) accumulated in small piles occuring in fragments of decayed wood.

Hi-167 The brown groundmass of the horizon B of the same soil displays similar grain sizes, and petrological and mineralogical compositions of the soil skeleton. But it differs in that each grain is uniformly coated with sepia-brown humus substances; these coatings are disintegrated into isolated irregular small fields, so that the surface of the grains is mostly uncovered. The characteristic feature of this horizon is the fact that due to the above-mentioned coatings of the grains, a slight connection arises on the contacts of the grains, whereas the intergranular spaces are quite empty. This is to a great extent responsible for the loose structure which differs from the dense structure of the horizon B in Podzola developed in forest of healthier growths. The coatings are poor in ferric compounds and clay minerals. Very slight chemical weathering is evidenced by the absence of mineral products of weathering and by the presence of fresh or only slightly weathered primary elements; in contrast a great amount of the loosened soil skeleton testifies to strong mechanical weathering.

The loose character of the soil fabric is undoubtedly a result of periodic drying of the soil or perhaps biological activity, surfaces exposed to wind and negligible formation of clay, and therefore also shift of clay in the alpine zone under grass and shrubs. Under such conditions when mechanical loosening markedly exceeds the degree of physical weathering, there appears a distinct tendency for formation of a thicker horizon A_1 at the expense of horizon A_2 and B. Large amplitudes of day-and seasonal temperatures are responsible for strong drying manifesting itself by field-like disintegration of cementing humus.

On the basis of the above-mentioned features, the soil under consideration (sample Hi-167) corresponding to the climatic stage in the alpine zone may be identified as alpine Sod Podzol.

SAMPLE Hi-192

Sampling site: The Great Himalaya, the middle part of the Barun valley at an altitude of 3500 m a. s. l. at the Yangle localily.

Position: Moderately inclined platform of Holocene fluvioglacial sediments.

Climate: Cool monsoon mountain climate with summer temperatures of over 15° C and mean annual precipitations of about 2500 mm.

Vegetation: The surface of the platform is covered with grass while the surroundings subalpine coniferous mountain forest is covered with Abies spectabilis and rhododendrons.

Parent material: The clastic material of the fluvio-glacial terrace consists mostly of gneisses and migmatitic rocks of the Great-Himalayan crystalline sequences; the accumulation is underlain by paragneisses.

Description of the soil profile: A humous horizon with well developed subhorizons A_e, A_f, and A_h, immediately overlies the horizon C whose surface portions are composed of gray andy loams passing from the 110 cm depth downward into coarse sands, gravels and blocks of the fluvioglacial terrace. The sample was taken from a depth of 20–30 cm.

Micromorphology: Completely flocculated brown humous groundmass displays high aggregation; the aggregates are irregular, their structure being slightly loose. They contain abundant pore spaces. The aggregates, in addition to primary elements, are composed of coprogenic elements of small soil animals or their fragments. Excrements of enchytraeids are relatively abundant; these worms feeding on a material soft humous throughout which has already been affected by activity of microorganisms). Their excrements are darker than the surrounding soil subatance from which they are separated by narrow cracks. These excrements are minute, polyhedral in shape, lying particularly in narrow conducting paths between ramnants of leaves. Their slight chemical decomposition is due to microflora. Plant debris which became brown is abundant. Extremely numerous are spores of imperfect fungi (Deuteromycetes–Moniliales–Dematiaceae). The inactive soil material is not sorted; as to grain size, silt-sized grains occur which probably were released by micromechanical action, further more sand and skeleton are present; among fragments, quartzite and various crystalline rocks dominate; of minerals, quartz orthoclase, plagioclases, biotite, muscovite, augites and hornblende occur. All these components are very slightly weathered, and the very low proportion of clayey cementing substances corresponds to this fact. The humus here is a raw a coprogenic moder. This highly loose earthy soil rich in minerals does not display any traces of wetting.

Typologically, this profile including horizons A and C corresponds to an alpine Ranker which represents a climax stage of high-mountain areas.

Micromorphologically, the soil samples derived from the East Nepal Himalaya (for details see Smolikova, Kalvods in press) may be generally assigned to four main groups:

1. Bolus-like silicate soils among which original Braunlehm types as well as

Rotlehm types (rubified Braunlehm and earthy or earthified Rotlehm) have been stated. They originate in a plain relief with a luxuriant vegetation cover of the tropical and subtropical zones.

2. Illimerized soils represented particularly by clayed Podzols occur on mixed substrates under a forest cover. The characteristic feature of these soils is the release of the colloidal clay inclusive of ferric compounds and their concentration in joints and macropores. In rather humid terrains these soils show a pronounced tendency to develop toward soils of the Podzol catena.

3. Pseudogley soils (initial stages up to strongly developed Pseudogleys) in which occasional wetting by precipitation water (supported by an only slightly permeable basement) provokes reduction phenomena, occur on a silicate substrate. They appear on rather flat parts of the relief under a forest.

4. Rankers (humous silicate soils) are represented by a series beginning with the simplest Proto-Ranker through a mull Ranker, alpine Ranker up to a Podzol Ranker. A skeleton-weathered silicate substrate carries a sharply bounded horizon A. The dissected mountain relief hinders the development to higher developmental stages, so that on the respective habitats these soil represent the most widespread climax. In the set of samples studied, these Rankers form a varied group of high-mountain soils.

The correlation of the soil types described with the vertical climatic zones reveals the types of weathering. With increasing altitude a. d. l., the biological activity and intensity of chemical weathering decrease (although they by far do not die out); they are gradually replaced by the mechanical disintegration of the soil skeleton and by cryogenic weathering. An instructive example of this is the locality of samples Hi-166 and Hi-167, which were taken at an altitude of 3200 m, where – in contrast to the compact structure of the soil in lower climatic-vegetation zones–a loose structure is apparent and where the brown coatings of mineral grains are poor in ferric compounds and clay minerals.

On the Quaternary sediments in the close foreland of glaciers, Alpine raw Proto-Rankers markedly dominate and the formation of humus ceases here. The extraglacial cold morphogenetic zone with marked predominance of selective mechanical weathering and of cryogenic processes is represented primarily by a glaciated alpine-type mountain type.

GLACIGENOUS ACCUMULATIONS IN THE CHOMOLONGMA AND MAKALU REGION

The intensive destruction of the crystalline masses under a semi-arid extremely cold climate in the Great Himalaya led to the development of the recent relief on the rocks of the Pleistocene mountain vault. Steep walls devoid of permanent snow and ice covers, deeply fissured by ice action and exfoliation processes, are subject to corrosion, and dark rock layers and dykes are selectively carved out. The detailed modellation of the relief fully depends on the extreme climatic conditions. Block disintegration of rocks in situ is taking place continuously; after detachment of the block they are rapidly displaced down slope, parts of the walls often break off along the surface, this being the result of the gravitational instability of peaks and crests. Desquamation and exfoliation surfaces appear as high as at the firn line and below it; in the extremely cold climatic conditions a varied set of gelivation and congelifraction microforms is developed. But in the first place, the large peak sculptures are significant for the recognition on the Great Himalayan mountain vault development. These sculptures are evidenced in vertical sections by the differentiation of partial geological units.

The areas and volume of the accumulation forms of the Himalayan relief are substantially smaller than those of the destructional ones. The most widespread accumulations are slope sediments, especially block elluvia and deluvia, talus cones and polygenetic foothills detritus. The block elluvia of the mountain walls consist of an autochthonous material of the rocky surfaces affected by frost action on their plates and ledges. The gravitationally disintegrated blocks of the rocky crest towers also belong here; they represent the main components of rockfalls and stone avalanches. On the erosional denudational slopes of gneisses and migmatites and their connecting ridges, the block deluvia form continuous fields also bordering the base of the isolated outcrops of rocks. The wall foot is often covered with hundreds of metres high talus cones and accumulated detritus. These are developed below the firn line only, as the slope sediment series of glacier accumulation areas coincide with the formations of Recent ice mass moraines. On the sides of the main glacier valleys, polygenetic detritus accumulations were piled up after the retreat or disappearance of slope and hanging firn fields. In these accumualatoins, sub-Recent to Recent angular slope block material prevails, mixed with basal moraines. In the valleys, the slope sediments link up with glacigenic accumulations, overlapping them locally. The shapes of the torrent fans and talus cones rapidly vary due to permanent gravitational differentiation of weathering products and to the intensive transport of detritus from walls.

In the East Nepal Himalayas (Chomolongma and Makalu Massifs) five main moraine types in the glacigenous deposits corresponding to the partial stages of mountain glaciation are developed. On the base of the spatial relationship of the moraines to the recent relief and glaciers, to their mutual position, lithology, weathering and degrees of wear of detritus, small-scale modellation and sometimes also relation to the vegetation cover, probable ages of these moraine types have deen determined (Kalvoda, 1978, 1979)

Moraine type	Mountain glaciation stage	Estimate of oldest age (in years)
glacier masses	Recent	10^1
Lingten	Recent oscillation	10^2
Khumbu	sub-Recent	10^3
Changri	Late Holocene	10^4
Dusa	Late Pleistocene	5.10^4–10^5

The names of the moraine types have been chosen according to the typical localities of the area mapped; their developmental succession and the character of their shapes are typical of the whole Mahalangur Himal zone. The Recent moraine type of glacial masses comprising the surficial, inner, basal, middle and marginal moraines transported by glaciers is an indicator of the huge destruction of the rocky relief.

Short incontinuous morainic walls of the Recent oscillation of the Lingten type extend between the margins of glacier tongues and the inner slopes of the moraine of the sub-Recent Khumbu type. They are 10–20 m high, in places covered with the detritus of the higher moraines; they often contain layers of dead ice. The moraines of this Recent oscillation are composed of angular, fresh, slightly weathered block material of granitoid and catametamorphic rocks. These moraines are best developed on the left side of the Khumbu glacier near the Lingten (outside the Chomolongma area also on the Barun glacier); they are lacking in the front of the Imja valley glaciers which are today advancing slightly.

At the foot of the Chomolongma the sub-Recent moraines of the Khumbu type are the most noteworthy glacigenous formations. Geomorphological analysis permits only an estimate of their age as of up to a thousand years at most. The sub-Recent moraines of the Khumbu type constitute the continuous border of the glacier tongues sides, overtopping them by 80–120 m and in the foreland forming a closure adjacent to the glacier front. The decrease of the ice masses of the sub-Recent type up to their recent volume testifies rather to an increased aridity than to a warmer climate. The moraine walls of the Khumbu type are markedly asymmetrical, displaying on their outer side lichen-covered oscillation ridges, and on their inner sides denuded detritus; the inner slopes dip at angles of up to 50° and the material covering them is angular, practically non-weathered, often slipping and collapsing. Along the Khumbu glacier tongue these sub-Recent moraines are composed almost throughout of granite detritus; in the glaciers of the Imja valley dark gneisses and migmatites predominate.

The Holocene moraines of the Changri type have been preserved W of the Chomolongma between the glaciers Changri and Changri Nup, at the foot of the eastern Lobuche crests and in the vicinity of the Nuptse and Lhotse Nup glaciers in the Imja valley. The sub-Recent glacigenous accumulation of the Khumbu type are separated from them by longitudinal depressions, partly filled with fluvioglacial sediments. The Changri type moraines arose by transgression taking place after the marked retread of the Late Pleistocene glaciers. The moderately undulated and flat moraine ridges of the Changri type rest 40–50 m above the Recent glacier tongues, being almost continuously covered with mosses and lichens. On their outer slopes which dip up to 30°, detritus is often detached or sliding.

The oldest glacigenous accumulations are represented by the huge lateral moraines of the Late Pleistocene Dusa type in the lower parts of the Khumbu, Imja, Barun and Ngochumba valleys. These deposits plunge beneath the Changri and Khumbu moraines. The frontal moraines of the Dusa type rest 6–10 km in front of the present day glacier snouts, being cut by erouding melt water. The lateral moraines of the Dusa type attain relative heights of up to 200 m; they adjoint the valley slopes. Their inner surfaces dip up to 35°, being generally consolidated by grass, mosses and lichens. In the moraine detritus of the Dusa type paragneisses and migmatites of the Great Himalayan crystalline masses prevail but granites are also represented locally. Of the above-described glacigenous accumulations, the material of the Late Pleistocene moraines is worn to the extreme, and gravel lumps and blocks are coated by a weathering crust up to 2 cm thick. The volume emplacement and shapes of these accumulations sugge t that they are remnants of the strongest Himalayan glaciation.

The Holocene to Recent fluvioglacial sediments occur below the lower boundary of the semi-arid modellation zone. For 2–3 km above this line, only narrow stripes of these sediments overlap between the lateral moraine of the Changri and Khumbu types.

Lacustrine sediments occur on flat banks and bottoms of moraine-damned lakes. Blown sand are deposited in depressions between morainic walls at slope bases and in erosional hills in the form of flat or undulated covers. Their thicknesses do not exceed 2 m, their areas are of the order of tens of square metres, their surfaces are undulated by ripple-marks often smoothed by the impact of storms. In the Barun and Khumbu valleys light angular wind blown sands prevail, derived from granitoid rocks; in the Imja valley they are characterized by their grey-black tint and platelets of sericitized micas. Of periglacial forms many primary ones of polygonal soils with patterns of a diameter of the metre order and thufur fields were found by the present author at altitudes of 4600-5200 m.

Study of the geological processes in the Great Himalaya shows the unique character of its dynamics and rhythms. The youngest stage of the Himalayan orogeny began in the Late Pliocene, culminated in the Late Pleistocene, dying out at the present time. During this phase, the Tibetan Highland and the Transhimalaya were uplifted (Wager, 1937, Hagen, 1969) as well as the folded mountain ranges of the Tibetan Himalaya, the Neogene displacements were reactivated, and relief nappes arose in the Great Himalaya. At the same time, the intermountain tectonic depressions decame more marked, and the Siwalik molasses were folded. The original total thickness of the sandstone facies attains almost 3000 m, in conglomerate facies 3500 m. The sedimentary filling of the Himalayan foredeep rests on a dissected and buried relief of the Gondwana crystalline sequences; its thickness in the Indus-Gangetic plain therefore varies between 1800-9000 m.

In the Pleistocene, the Great Himalaya became an important boundary between the seasonal oceanic climate of Indan and the continental semi-arid Tibetan territory. From the analysis of geomorphological data the Quaternary vaulting of the main crest of the Great Himalaya and its spurs by 4000 m (Bordet, 1961) in the Mahalangur Himal by up to 5000-6000 m may be estimated. The lowest boundary of the evidenced reach of the Pleistocene glaciers in Nepal lies at an altitude of 3000-3200 m; the recent glaciers extend to 4000-4100 m a.s.l. The dissection and the extreme relief amplitudes of the Great Himalaya are responsible for the strictly vertical zoning of its climate. This feature of these mountains is emphasized by the rising degree of continental climate from S to N and from E to W, by the mesoclimate of slopes depending on their different exposures to solar radiation, by their biogenic facies of flora and fauna, and the intensity of climato-morphogenic pro-

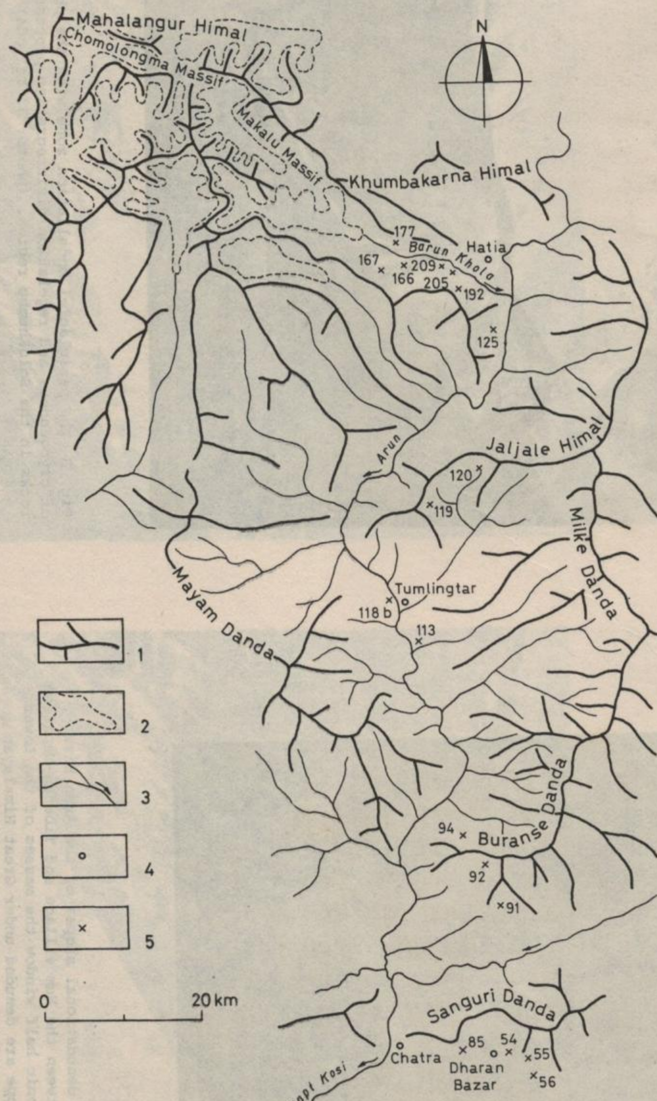

Fig. 1 Orographical scheme of the Chomolongma and Makalu Massifs - Sapt Koshi lowland section in the East Nepal Himalayas with the location of the introduced examples of the micromorphologically elaborated soil samples. Explanation : 1. ridges 2. glaciers 3. rivers 4. villages 5. localities of the selected set of micropedologically elaborated soil samples.

Fig. 2 Structural - denudational slopes of the Arun river antecedent valley between the Num village and Tibetan-Nepalese border. In this tectonic half window the masses of the Lower Himalayan Tinjore nappe are denuded under Great Himalayan crystalline rocks of the Barun nappe. (photo: J. Kalvoda).

Fig. 3 The periglacial modellation zone with the phenomena of cryogennous and regelation disintegration processes of rocks in the SoloKhumbu region. (photo: J. Kalvoda)

Fig. 4 The Khumbu glacier foreland with the Late Pleistocene moraines of the Dusha type between 4200-4400 m a.s.l. (photo: J. Kalvoda)

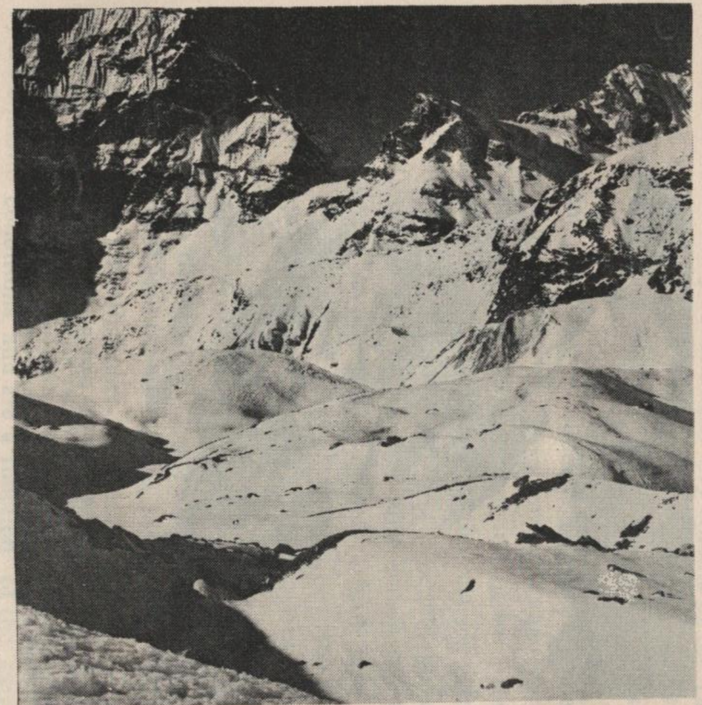

Fig. 5 The system of the glacigenous and fluvioglacial sediments in the foreland of the Barun glacier. (photo: J. Kalvoda)

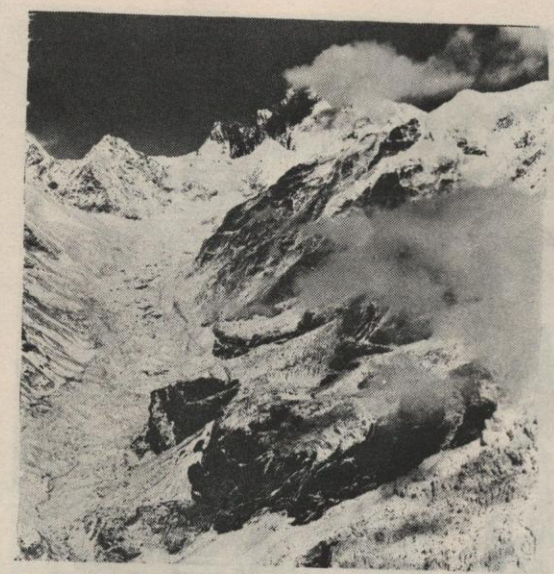

Fig. 6 The south-western frontal part of the Chomolongma Massif (8848 m in the right) relief nappe. In the foreland confluences of the ice streams and holoceneous moraines of the Barun glacier are seen. (photo: J. Kalvoda)

Fig. 7 Strongly tectonically dissected Alpine relief of the crystalline Great Himalayan range south of the Mahalangur Himal. In the background towers the Makalu Massif (8475 m) (photo: J. Kalvoda)

cesses. The Quaternary continental dry climate of the Tibetan Himalaya was not favourable to a major development of mountain glaciers; its secular uplift only maintained the mountain ranges within a cold climatic zone for a fairly long time.

The recent relief of the Mahalangur Himal is markedly polygenetic. The main modellation features of its development in the Quaternary are in addition to orogenic impulses, the extensive destruction of the palaeoreliefs under the conditions of secular altitude oscillation of the sharply vertically dissected climato–morphogenetic zones. The highest relief levels undergo glacigenic and cryogenic destruction of all types, whose outset falls within the Middle Pleistocene. The alpine–modelled peaks of the Great Himalaya form part of the Pleistocene and later shapes of the mountain vault which has not yet been strongly disturbed by gradation processes. Rendering more precise the dating of the mountain glaciation stages are specific glaciological and geomorphological tasks connected with the investigation of recent modellation processes and climatic conditions. In addition to the revision of the data on the absence older than the Middle Pleistocene glacigenous accumulations at the Chomolongma and Makalu foothills, it is necessany to perform a stratigraphic correlation of the accumulation forms in East Nepal. The rates of the original mountain vault destruction and transport of the disintegrated masses depend on the intensity of the weathering of rocks controlled by the climatic conditions, and are a function of the extreme potential energy of the highest mountain massifs.

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