PL ISSN 0373-6547

POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

INSTYTUT GEOGR
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GEOGRAPHICAL STUDIES
SPECIAL ISSUE No. 2

MONGOLIAN DRY STEPPE GEOSYSTEMS A CASE STUDY OF GURVAN TURUU AREA

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MONGOLIAN DRY STEPPE GEOSYSTEMS A CASE STUDY OF GURVAN TURUU AREA

Results of the Polish-Mongolian
Physico-Geographical Expedition

VOL. III

Edited by
ALICJA BREYMEYER AND KAZIMIERZ KLIMEK

OSSOLINEUM
THE PUBLISHING HOUSE
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WROCŁAW
1983

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Printed in Poland

PL ISSN 0373-6547
ISBN 83-04-01411-4

Zakład Narodowy im. Ossolińskich — Wydawnictwo. Wrocław 1983. Nakład: 900 egz. Objętość: ark. wyd. 10,20, ark. druk. 8,50 + 9 wkl., ark. A_1 - 11. Papier druk. sat. kl. III, 80 g. 70 × 100. Oddano do składania 13 X 1982. Podpisano do druku 8 VI 1983. Druk ukończono w czerwcu 1983. Wrocławska Drukarnia Naukowa. Zam. 1375/82. Cena zł 90.—

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FROM THE EDITORS

In 1976–1980 the Polish-Mongolian Physico-Geographical Expeditions "TRANSMONGOLIA" were working in Mongolia because of co-operation between the Institute of Geography and Spatial Organization of the Polish Academy of Sciences, and the Institute of Geography and Geocryology of the Academy of Sciences of the Mongolian People's Republic. It was the aim of these expeditions to study the resources and qualities of the natural environment of selected regions representing various zones of climate and vegetation in this country, i. e. the mountainous taiga, the forest steppe, the steppe and the semi-desert. The papers in this collection resulted from the research of the dry upland steppes of Central Mongolia, the belt of which attains a width of 250–300 km.

A 10 km long transect, the Gurvan Turuu Transect was chosen for detailed research carried out by many specialists. The name of the transect was derived from the name of a railway station (Ulan Bator–Peking line) where expedition members have lived and worked (Photo 1). Throughout the year data were collected by the Mongolian geographers acting in co-operation with the Polish expedition members during the summer months. Here the meteorological station was situated. The laboratory was provided with basic instruments necessary for climatical, chemical and ecological investigations. Thus it was possible to carry out geological, geomorphological, climatical, hydrogeological, pedological, botanical, zoological and ecological studies in the surroundings of Gurvan Turuu. In this volume of "Geographical Studies"[1] the main results of Polish research are presented under the common title *Mongolian Dry Steppe Geosystems.* The ecological studies led by Alicja Breymeyer were based on earlier investigations of the abiotic elements of the natural environment, directed by Kazimierz Klimek.

The latitudinal Gurvan Turuu Transect cuts across various geological units, which is reflected in the spatial variability of the other components of the natural environment: relief, soils and microclimate

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[1] The results of expeditions to other regions of Mongolia were presented in "Geographical Studies" no. 136 and 137 as well as in other publications.

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(Photo 2A, 2B). This variety is clearly indicated by the plant cover. In the middle part of the transect there occur closed basins seasonally filled with water; whereas on the eastern end, the highest massif, Bayan Ovo is located. The remaining part of the transect covers various steppe formations found in both flat and undulating areas. It may be assumed that a large variety of steppe geosystems being representative of Central Mongolia is included in the examined transect. Some multi-year studies were conducted in areas far larger than the transect. Other field studies took a year only, and they focussed entirely on the transect. Such are the ecological studies the results of which are presented in this volume. It is regretted that they had to be made during only one vegetation season — 1979. Five scientists worked hard in the field during that time, applying many tested methods and examining 10 localities during the whole growing season, i. e. from the very beginnig of June until September. It must be remembered, however, that these were only one-season investigations and that the year to year variations of climate are marked there changing the biotic part of the geosystems.

The editors of the present volume divided the work between themselves according to their specializations, i. e. Kazimierz Klimek prepared chapters I to V, whereas Alicja Breymeyer edited chapters VI to XIII.

The editors will certainly utter the wish of all expedition members expressing their thanks and gratitude to both Academies and Institutes which organized and covered the expenses of the expeditions as well as to our Mongolian colleagues running the Gurvan Turuu station.

Alicja Breymeyer
and
Kazimierz Klimek

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KAZIMIERZ KLIMEK and ZIMEGIN TSERENSODNOM

I. THE ENVIRONMENT OF THE WESTERN PART OF THE MIDDLE-KHALKHASIAN PLAIN

South of the Khentei foreland there extend vast undulating or hummocky steppe areas. This is the western part of the Middle-Khalkhasian Plain which, according to Murzayev (1953), separates the Khentei Mts. from the northern Gobi Plain (Fig. 1). The upland surface of that foreland forms the continental divide between the endoreic area of Central Asia and the Pacific and North Ocean basins. The landscape is determined by two factors: tectonic movements of the earth's crust and past and present climatic conditions.

The Khentei Mts. (2000–2800 m a.s.l.), together with their southern foreland, are a young Neogene-Quaternary upwarp belonging to the Khangai-Khentei (or Mongolian Trans-Baykalian) Palaeozoic fold system (Sonenschein 1973). In the western part of the Middle-Khalkhasian Plain, bordering on the southern Khentei foreland, the geological structure is varied. The rocks in the area exhibit a wide range of lithology and age from Proterozoic to Cretaceous, with numerous granite intrusions and basalt flows cut by a network of faults. Therefore, horsts and tectonic depressions are of frequent occurrence. The largest among them is the Nilghin depression, with a rift valley on the northern end. This valley is being used by the Ulan Bator–Sainshand railway (Dżułyński 1977).

Intersecting fault lines, along which movements of the earth's crust occurred during the Quaternary, and even nowadays, determine the sculpture of the earth's surface in that area. Undulating or hummocky plateaus, several dozen kilometres wide and up to 1500–1600 m a.s.l. high, predominate in the northern part of the region discussed (Photo 3). Flat-floored tectonic basins are found adjacent to the plateaus at 1250–1350 m a.s.l. (Fig. 2). Height differences decrease southwards the Gobi. The closed depressions contain many small salt lakes and solonchaks.

The Middle-Khalkhasian Plain is a riverless area. However, there are found traces of old stream channels which functioned during the

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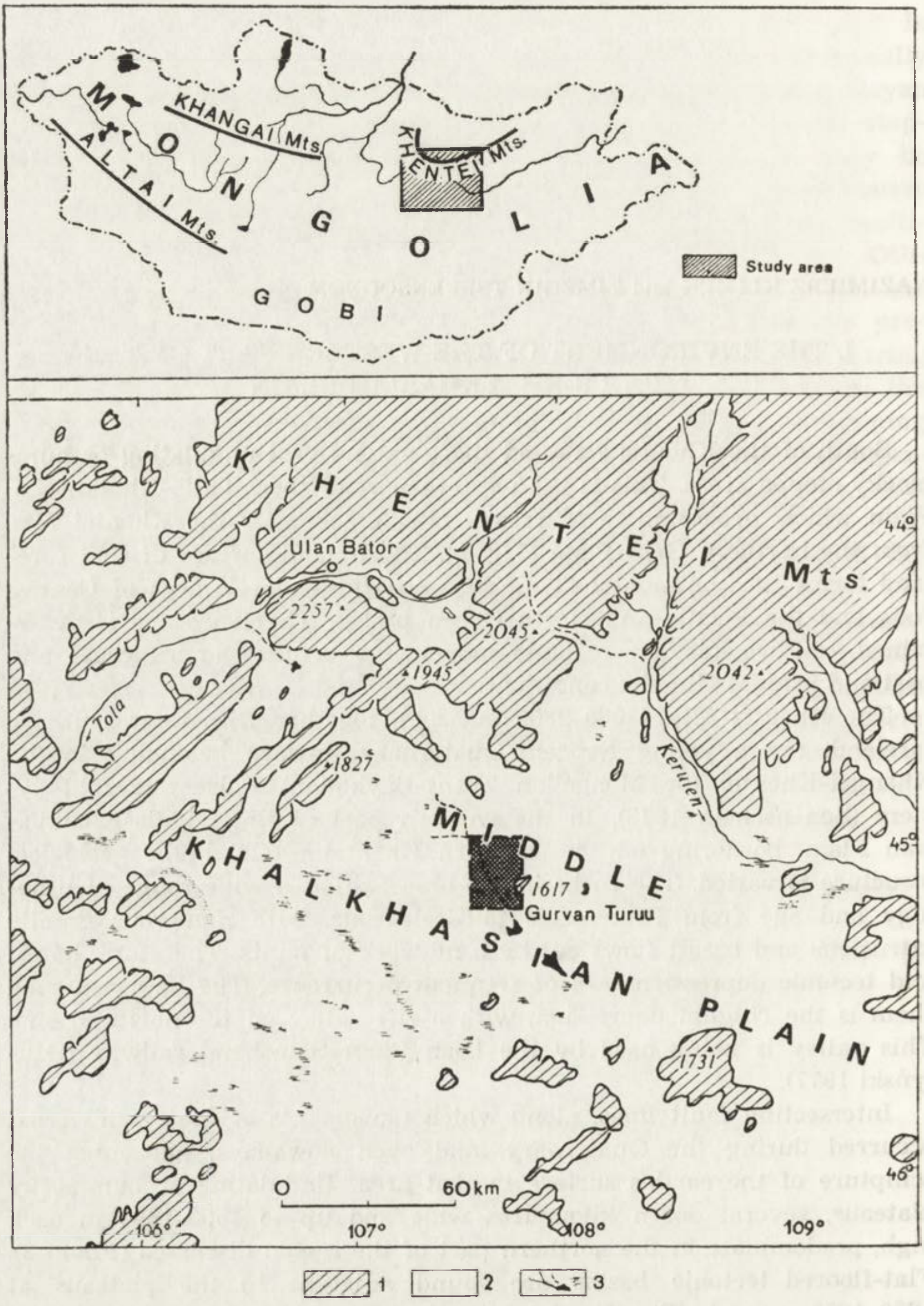

Fig. 1. Main relief features of the southern side of the Khentei Mts. and of the Middle-Khalkhasian Plain, i.e. Tola-Kerulen interfluve

1 — the Khentei Mts. and isolated hills rising above the Middle-Khalkhasian Plain; *2* — undulating and hummocky plains at 1100-1300 m a.s.l.; *3* — rivers and seasonal lakes

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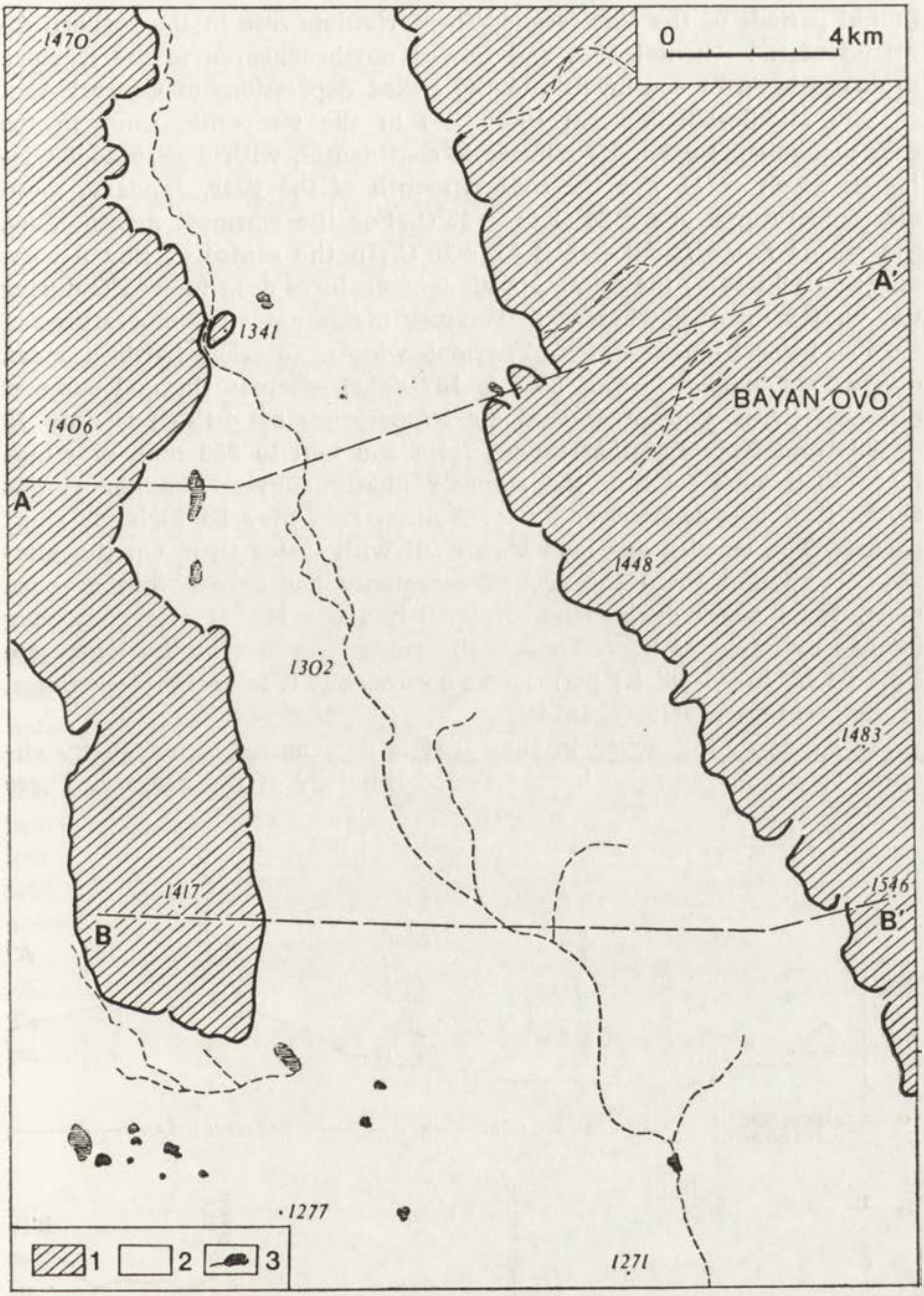

Fig. 2. Main relief features in the Gurvan Turuu

1 — undulating and hummocky upland; *2* — basin and valley floors; *3* — seasonal rivers and lakes; A-A' and B-B' lines of sections humid periods of the Pleistocene. These rivulets rose in the suthern foreland of the Khentei Mts. and flowed northeastwards to the Kerulen drainage basin or southwards to the closed depressions of Central Asia.

The Middle-Khalkhasian Plain lies in the temperate zone, in the east Mongolian region. Its climate is continental, with a very cool winter (Badarch 1971). For the coldest month of the year, January, mean air temperatures are −20°C to −25°C. For the warmest month, July, the means range from +15°C to +20°C. In the centre of Bayan sommone (Olecki 1977) the minimum air temperatures drop to −45°C during the winter months, whereas in summer maximum air temperatures of +36°C have been recorded. Thermal winter duration (with a mean diurnal air temperature of 0°C) is 187 days, whereas thermal summer duration (with a mean diurnal air temperature of +15°C) is only 22 days. Annual precipitation ranges from 200 mm to 250 mm, of which more than 90% falls in the summer month. During summer storms rivers flow occasionally, and stream discharges may be high for short periods. The usually dry lake basins fill with water then. On the Middle-Khalkhasian Plain the ground commonly has only a thin or even none, snow cover during the winter when the sky is clear, allowing intense radiation of heat. Though the study area lies in the temperate zone (φ 46°30'–47°30' N) permafrost occurs, but it is entirely developed in the basin floors (Gravis 1974).

The type of soil cover in that area is determined primarily by climatic conditions but also by the varied lithology of the bedrock. There

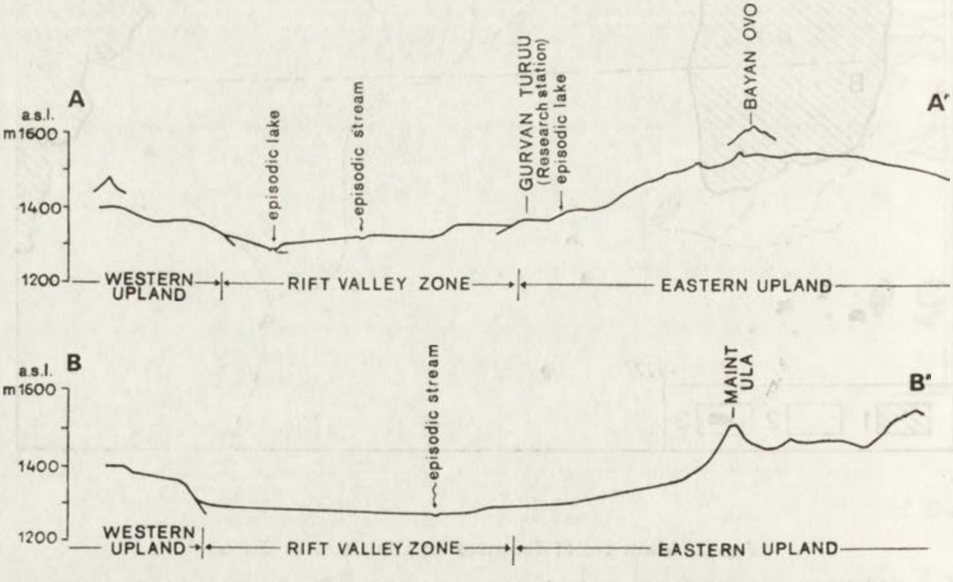

Fig. 3. Latitudinal sections A–A' and B–B' across the Gurvan Turuu area

are typical chestnut soils which in the central part of Mongolia occupy a latitudinal belt 100–150 km wide. They are best developed on the long footslopes of the plateaus. Dark chestnut soils are found on the higher plateau surfaces and mountainous, dark chestnut soils appear northwards towards the Khentei foreland. In the lower parts of the basins there occur soils rich in soluble salts and solonchaks.

The Middle-Khalkhasian Plain lies within the 200 km wide belt of dry steppes which passes northwards into the mountainous steppes (in the Khentei foreland) and into the desert steppes towards the south. However, the formation of the dry Cyperaceous-soddy steppes follows a mosaic pattern. This is related to the local ground and water-soil conditions and slope aspect. Steppes consisting of *Stipa*, *Kolearia* and *Clistogenes* mixed with *Thalictrum*, *Aster* and *Potentilla* and *Caragana* bushes are found on the dark chestnut soils that developed on the undulating and hummocky plateau surfaces. Steppes composed of *Stipa*, *Poa*, *Galium*, *Potentilla* and *Veronica* predominate in the basins. Halophytic plants occupy the basin floors.

For many centuries nomads settled on the Middle-Khalkhasian Plain, an easily accessible area with seasonally abundant fodder. This is indicated by numerous tumuli, ritual "ovo" mounds and the ruins of Buddhist shrines. The settlement was as intensive as in the Khangai Mts. A very old caravan route, passed through the plain, connecting Ulan Bator with Peking, as do a modern railway and highway.

At present the Middle-Khalkhasian Plain is used for pastures. Both the distribution and number of grazing flocks depend on the sources of accessible water. Deep wells dug in the last decades brought about local changes in land use, and even in the distribution of seasonal hamlets. There have been attempts to cultivate the soil but only in small areas and they do not change the original structure of the landscape.

Detailed investigations of the natural environment of the Middle--Khalkhasian Plain were carried out in area situated near to Gurvan Turuu, south of the centre of the Bayan sommone. There natural environment is highly varied within a radius of more than ten kilometres.

DETAILED RESEARCH AREA

A latitudinal section across the surroundings of Gurvan Turuu (Fig. 3) shows the differentiation of the relief of the study area. Its central part is occupied by a nearly meridional broad valley of tectonic origin. In the east and west this valley is framed with upland plateaus (Photo 3–5). In the northern part of the area presented in Figure 1 the valley floor lies at 1340 m a.s.l. It slopes gradually down southwards at an angle of 0.45‰ to 1270 m a.s.l 30 km south of Gurvan Turuu the valley is closed by a tectonic barrier. At its foot occurs the perennial

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Lake Baga Omboy Noor without drainage (1250 m a.s.l.). The broad rift valley is seasonally drained by a river which runs into the above mentioned lake. Moreover, several small periodical lakes and many solonchaks are found there.

The plateaus surrounding the rift valley have distinct scarps and they are dissected by young erosional valleys. Isolated tops rise above the flat upland surface of the Eastern Plateau (1400–1500 m a.s.l.), i.e. the Bayan Ovo (1617 m a.s.l.) and the Maint Ula (1516 m a.s.l.). To the east the plateau extends smoothly down to the adjacent tectonic depression. The Eastern Plateau is somewhat lower and its planed surface reaches 1400–1420 m a.s.l.

The varied relief which, for the most part, reflects the pattern of young tectonic movements, together with the lithology of the rocks and their geochemistry, is responsible for the spatial variability of the remaining components of the natural environment in the area discussed.

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STANISŁAW DŻUŁYŃSKI

II. GEOLOGY OF THE GURVAN TURUU AREA

The chief geologic and physiographic features of the study area are the Graben valley and the flanking uplands which, for convenience, are here indicated as the Eastern and Western Uplands (Fig. 4).

THE EASTERN UPLAND

This upland is comprised of: 1) granites, 2) fine acid intrusives, 3) metamorphic, and 4) volcanic rocks.

The granites include reddish, "normal" granites and light-colored leucogranites. The first are presumably of late Paleozoic age. The second appear to be younger (Triassic?, compare Marinov 1973). Over all parts of the upland, the granites are profoundly weathered. Locally, where these rocks were subject to metasomatic alterations (albitization), two-phase tors are seen to rise above the upland plain (e.g. Gurvan Cochio). Also the aplitic and other dykes cutting the granites are expressed topographically in the form of low ridges (Photo 5). The granites reveal tabular jointing with joint surfaces diping gently towards the south. This accounts for the asymmetry of the valleys incised into the granitic rocks.

The fine, acid intrusives are comprised of near-vertical intrusive bodies of acid rocks such as rhyolites and quartz porphyries. These rocks are genetically related to the leucogranites as evidenced by the similarity in mineralogical composition and transitional contacts between these two types of igneous rocks. The fine-grained acid intrusives, however, show sharp intrusive contacts with the metamorphic rocks and "normal" granites. Due to their resistance, the acid intrusives are expressed in topography in the form of a dissected elevation that runs north-north-west from the Bayan Ovo Mt with a wedge-shaped termination within the metamorphic rocks. The acid intrusives give rise to numerous apophyses that penetrate deep into the metamorphic rocks and granites.

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The metamorphic rocks form the country rock into which the granites were intruded, and consist chiefly of gneisses, amphibolites, quartz, or biotite schists and marbles. These rocks are intensely folded and interlocked with the reddish granites. The metamorphosis occurred presumably during late Paleozoic time and has affected the Lower Paleozoic sedimentary rocks.

The volcanic rocks of the Eastern Upland are exposed in the southeastern part of the mapped area. The most widespread are light-colored, acid and vitreous sub-volcanic rocks commonly showing brecciated or vitreous flow structures. Although these rocks underlie the basalts, their emplacement post-dates the eruption of basaltic lavas, which is regarded as having occurred in the Jurassic period (see below). The acid rocks are seen to cut the basalts in the form of dykes and volcanic necks (one of such necks is the Maint Ula Mt). The top-surfaces of the acid sub-volcanites show grooving and other structures resembling those described from glaciated rock surfaces. These grooves and other structures resulted from the friction exerted by the viscous, acid lava upon the overlying basaltic rocks.

THE WESTERN UPLAND

Only a minute part of this upland is included on the map. Among the rocks exposed there are the metamorphic rocks known from the Eastern Upland. These rocks, together with the overlying and horizontally disposed conglomerates (Permian?) form a flat elevation that borders the central part of the Graben valley. In the north-eastern part of the mapped area, the upland is composed of various volcanic rocks and a folded sequence succession of quartzitic sandstones and phyllites (Cambrian or pre-Cambrian).

THE GRABEN VALLEY

GENERAL GEOLOGY

Apart from Quaternary deposits which will be dealt with later, the rocks involved in the formation of the Graben valley include: 1) basalts, 2) Cretaceous non-marine sediments and, 3) Neogene lake deposits.

Fig. 4. Geology of the Gurvan Turuu area

1 — metamorphic rocks; *2* — leucogranites; *3* — fine acid intrusives; *4* — "normal" granites; *5a* — dykes; *5b* — quartz dykes; *6* — basaltic rocks; *7* — acid volcanic and sub-volcanic rocks; *8* — quartzitic sandstones (Cambrian?); *9* — conglomerates (Permian?); *10* — Cretaceous deposits; *11* — Neogene deposits; *12* — cobble gravels; *13* — sair gravels; *14* — basaltic gravels; *15* — sandy deposits (Holocene?); *16* — fine sandy and silty deposits (Holocene?); *17* — playas deposits; *18* — alluvial fans; *19* — faults lines; *20* — presumed faults; *21* — incised meanders

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The basalts represent a succession of fissure eruptions assigned to Jurassic effusive activity (compare: Marinov 1973). The eruptions resulted in a succession of tabular lava flows. Typically, the lava flows (1–3 m thick) become increasingly vesicular towards their tops. The uppermost parts of such flows show clastic character and, locally, pahoehoe structures. With clastic top parts, the next succeeding lava flow may show load deformations at its base. The vesicles, empty or filled with chalcedony or zeolites, may reveal persistent trends over large areas, pointing to the existence of feeding fissures. One such fissure has been located along the present western margin of the graben. Ashes with volcanic bombs, indicative of central-vent eruptions occur south of the Maint Ula Mt. Sporadically, the tabular lava flows are cut by linear- and ring-dykes of basaltic composition. The non-marine Cretaceous sediments include sandstones intercalated with black fissile shales containing phylopodes and argilaceous sediments with dolomite concretions.

The Neogene deposits are comprised of fresh-water limestones with abundant gastropods and carbonized plant remains (wood-included) oolitic limestone, marls, and gypsum. The last occurs in the form of layers or lens-like bodies. The Neogene sediments contain admixtures of fine quartz particles but are notably devoid of coarse clastics. These deposits were laid down in a low-relief environment; in very shallow, migrating lakes and under much warmer and more humid conditions than those at present.

TECTONICS

The Graben valley is a part of a south-southeast trending tectonic through that can be traced over considerable distances. In the region investigated, the graben coincides roughly with the area occupied by basaltic rocks. Steep gravity faults, topographically well expressed, bound the graben on both sides. They show parallel and *en echelon* patterns, disrupted locally by transverse dislocations controlling the development of erosion valleys. The faulting was associated with rotation and resulted in the appearance of a distinct fault-block topography (Fig. 5). In all instances, the steep fault scarps are facing away from the graben axis and the tilted surfaces of the fault-blocks or "back-slopes" are gently sloping towards the axis. Starting from the most external faults bounding the graben and going towards the center, each successive block is uplifted relative to the tilted surface of the previous one. However, the height of the successive blocks tends to decrease towards the graben center. Consequently, the disturbed planation surfaces of the basaltic rocks are gradually lower towards the central parts of the graben. These central parts are filled with Neogene and Quaternary depo-

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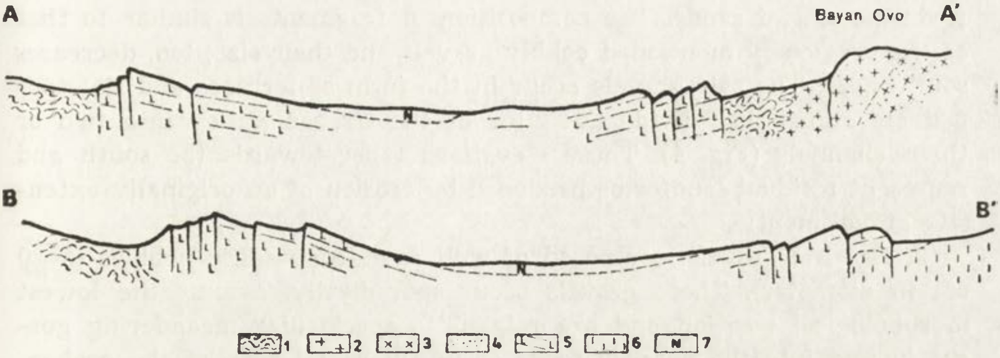

Fig. 5. Geologic sections through graben structure (compare Fig. 4)

1 — metamorphic rocks; 2 — granites; 3 — leucogranites; 4 — acid intrusives; 5 — basalts; 6 — acid volcanic and subvolcanic rocks; 7 — Neogene

sits. The Neogene and, to a certain degree, the Quaternary sediments are also involved in deformations that brought about the appearance of the Graben valley, thus providing evidence as to the very recent age of this structure. However, the graben, which may represent an incipient rift valley, is a rejuvenated tectonic feature and has a long history behind it. Without entering into this subject, which is beyond the scope of the present article, it is necessary to emphasize that, in its basic shape, the Graben valley had been formed during early Pleistocene time and has been subject to further differential movements ever since. These movements resulted in the appearance of transverse elevations that have changed the topography of the graben floor and influenced the deposition of younger Quaternary sediments.

QUATERNARY DEPOSITS

Within the Quaternary deposits of the Graben valley, three series of gravels have been differentiated. No attempt is made here to specify the stratigraphic position of the gravels or to correlate them with similar deposits elsewhere. The gravels in question occur in the following succession from bottom to top:

1. Cobbly gravels, made up of rounded pebbles and boulders of igneous, volcanic, metamorphic and quartzitic rocks, and quartz. The thickness of these gravels attains 4 m. The size of the pebbles ranges from a few to several tens of centimeters, but generally decreases southwards. Locally, the gravels contain boulders up to 4 m in diameter (Photo 6). The cobbly gravels crop out along the scarps of fluvial terraces and on transverse tectonic elevations. Due to the Pleistocene movements, outcrops of the gravels are located at different levels.

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2. Sair gravels [2], made up of sharp-edged rock fragments with varied amounts of sands. The composition of fragments is similar to that of the previously mentioned cobbly gravels and their size, too, decreases southwards. The sair gravels occur in the form of terraces and flat-topped elevations that divide the floor of the Graben valley into two or three channels (Fig. 4). These elevations taper towards the south and represent residual landforms produced by erosion of an originally extensive gravel mantle.

3. Basaltic gravels, composed of well rounded basaltic pebbles (5–20 cm in diameter). These gravels occur sporadically, assume the lowest morphological position and are related to spectacular meandering gorges incised into the basaltic rocks of the marginal zone of the graben.

The cobbly gravels represent the oldest Pleistocene sediments of the study area (Lower Pleistocene?) and were deposited by a large permanent river flowing from the North to the South. These gravels were laid down under more humid and severe climatic conditions than those existing at present. The deposition of the cobbly gravels was followed by erosion but the depressions produced were again filled with fluvial material. This time however, the rock-material was sharp-edged and deposited by intermittent streamlets under climatic conditions more arid than those attending the accumulation of the cobbly gravels.

The deposition of the sair gravels was succeeded by a period of intensive erosion, stimulated not only by increased precipitation but also by tectonic movements. These movements, as well as the increased precipitation, are evidenced by the appearance of deep meandering gorges in the basaltic rocks of the marginal zone of the graben, and by the formation of a large, antecedent meander gorge that cuts the transverse elevation of the Habcal Ovo (Fig. 4).

Significantly, apart from very minor accumulations of basaltic gravels, there are no deposits that can be related to the above mentioned period of erosion. Apparently, vast amounts of rock material and older gravels were carried further to the South, beyond the transverse elevation that rises above the floor of the Graben valley south of the Baga Omboy Noor (this elevation is not indicated on the geologic map). The final uplift of the elevation in question is thus of very recent age (upper Pleistocene?) and postdates the erosive removal of the sair gravels.

The progressing aridity has prevented the infilling of the erosion form that resulted from the previously mentioned period of intensive removal of the sair gravels. The bottoms of fluvial channels and closed depressions are now being covered with a thin mantle of clays and silts deposited from ponding waters and/or by wind action.

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[2] The name “sair” refers to a dry flat-floored valley affected by episodic water flows.

ADAM KOTARBA and BOLESŁAW NOWACZYK

III. THE ORIGIN OF MAIN RELIEF FEATURES

The main features of relief in the vicinity of Gurvan Turuu are controlled by both bedrock lithology and fault lines.

STRUCTURAL-DENUDATION LANDFORMS

In the zone of granite and metamorphic rocks there has developed an extensive denudation planation surface rising to 1500–1540 m a.s.l. This surface is of a pediment type, and as a rule it is covered with a thin veneer of medium- and coarse-grained granite detritus. During the Quaternary, the Paleogene planation surface probably became dissected by a network of broad and long asymmetric valleys. Their floors are now dry and correlate with the two uppermost terrace levels found in the tectonic basin. Thus they indicate the relative age of the dissection. Valley asymmetry is controlled by the southward dip of the joint planes in granite. Hence the south-facing slopes are gentle and the opposite ones are steeply inclined.

The planation surface (Photo 7) is dominated by the residual hill Bayan Ovo which is associated with a rhyolite-granite intrusion. This hill is of erosion-denudation origin. The Gurvan Cochio tors (Photo 8), built of metasomatically altered granite (Dżułyński 1977), rise similarly above the surface, in the manner of small residuals.

Monoclinal ridges of tectonic-denudation origin are typical of the basalt areas. These ridges follow the lines of parallel antithetic faults with N–S trend at both sides of the tectonic basin. The monoclinal ridges have asymmetrical slopes (Photo 9). The fault scarp slopes are steep, whereas the opposite ones are gently inclined. Except for steep cliffs, the slopes are mantled with regolith of different grain sizes and depths, varying from between several and several dozen centimeters. The ridges are separated from each other by closed basins filled with fine-grained sediments which have been created by slopewash from the waste sheets overlying the basalt slopes. Many erosive channels can be traced along the ridges. The channel bottoms pass into the larger valleys crossing the ridges.

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LANDFORMS DUE TO EXOGENETIC FORCES

On the southern side of the Khentei foreland, a rather dense valley pattern has developed. Under the more humid conditions prevailing during the Pleistocene, one of the rivers which flowed to the south followed the tectonic basin in the vicinity of Gurvan Turuu. Such a drainage direction is documented by the occurrence of six cut-and-fill terraces there. Occasionally remnants of cut terraces can be found. These rocky terrace plains contain fluvial gravel, sand, mud, and clay. The rock-cut bases consist of basalts, sandstones, limestones, marls, clays and gypsum (Dżułyński 1977). The higher terrace levels are formed of gravel and sand. The finest materials, i.e. silt and clay, interbedded with gravels, are disposed in the lowest level (VI), and are modelled by ephemeral rivers which empty into the seasonal lakes. The largest lake, Baga Omboy Noor, is located south of the study area. Silty-clayey deposits are being laid down in these lakes. The occurrence of both seasonal rivers and lakes within the well developed valleys indicates the increasing desiccation of the climate in Central Mongolia. This is also proven by the occurrence of wave-cut benches representing a high stand of Lake Baga Omboy Noor. Distinctive discontinuities in the long profiles of the terrace levels were produced by young tectonic movements. These have clearly affected the tectonic elevation of Khabcal Ovo and the region south of Lake Baga Omboy Noor (Dżułyński 1977).

Rivers have cut through the plateau and the basalt monoclinal ridges and spread gravels and sands at the valley mouths. Analysis of the alluvial fan location in relation to the terrace levels occurring in the tectonic basin indicates that these have been largely formed on the IV terrace surface, and that only some of them occur at the higher terrace levels.

Aeolian features in the form of ellipsoidal mounds with N–S trend, are now stabilized by steppe vegetation. In the lake basins, active lacustrine accumulation is associated with active aeolian processes. In the closed basins, where the slope-derived clay and silt has accumulated during the rainy season, desiccation cracking produces small aggregates corresponding to medium- or fine-sand-size particles. These are being removed by strong winds blowing in March, April and May and moulded into aeolian sheets and mounds, 1–1.5 m high, on the rim of the basin (Borówka and Nowaczyk 1980). The presence of permafrost in the study area is documented by active frost structures and forms (Nowaczyk 1982). In the clayey deposits nonsorted polygons are developing. Furthermore, there occur fine pingos, thufurs and "dovoo" — earth mounds. Fossil ice-wedges and cryoturbations are connected with permafrost in the past.

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CHARACTERISTICS OF SLOPES WITHIN THE GURVAN TURUU TRANSECT

The characteristics of slopes within the transect include the above mentioned relief types. These show distinct differences as far as slope morphology is concerned.

The hill Bayan Ovo rises 245 m from the surrounding flat floors of the dry valleys — sairs. The north-facing hillside of 15–20° has a smooth profile. The narrow and rocky ridge crest is notched by niche headwalls, in the form of cliffs, up to 5 m high. Each of the rocky niches is accompanied by a narrow rocky terrace surface sloped at 5–10°. The benches are strewn with sharp-edged blocks up to 1.5 m in diameter. The blocks form blockfields, 10 m long and 15 m wide. These cliffs resemble frost-riven scarps commonly related to periglacial environments. The corresponding blockfields were produced by macrogelivation. The blockfields have been affected by solifluction giving rise to solifluction lobes, 100 m long and 1.5 m thick. Their features are typical of so-called stone-banked lobes. This complex of landforms is inactive, being connected with the periglacial environment. Only the lower part of the northern side of the Bayan Ovo is a rocky slope, with a waste mantle no more than 20 cm thick. This runs into the footslope of depositional origin, usually 5–10°, formed of proluvial deposits (Fig. 6).

The south-facing side has a stepped appearance because of small cliffs and rocky slopes of above 35° which alternate with rocky floors sloping at c. 20°. Under the attack of granular disintegration, the cliffs produce countless rock particles, i.e. granite grits which cover the rocky floors with a veneer several centimeters thick. These slopes are devoid of loose scree sheets characteristic of the opposite slopes. The block-size particles have rounded edges. The footslopes are rocky floors covered with granite grits up to 20 cm thick. During the summer storms the waste products, resulting primarily from granular weathering, are reworked by rainwaters which pour down the gullies and subsequently form torrential fans. The rocky floor is separated by a concave break, formed either from the vast surface of a typical pediment inclined at 4–5°, or from a *glacis d'érosion* which developed on metamorphic rocks being less resistant than the granites (Fig. 6).

Into the flat and undulating remnants of the Paleogene planation surface, which is cut in granites, broad dry valleys are incised. Only small tors rise above the planation surface. Rocky slopes, to which the genetic term of boulder-controlled slopes is applied in the arid and semi-arid areas of Arizona and Egypt, are very rare in the study area. These rocky slopes are only fragments of the dry valley-sides of 30–36° and are formed of very resistant rocks. Slopes having a convex profile predominate. These bear a 10–20 cm layer of fine-grained waste. The

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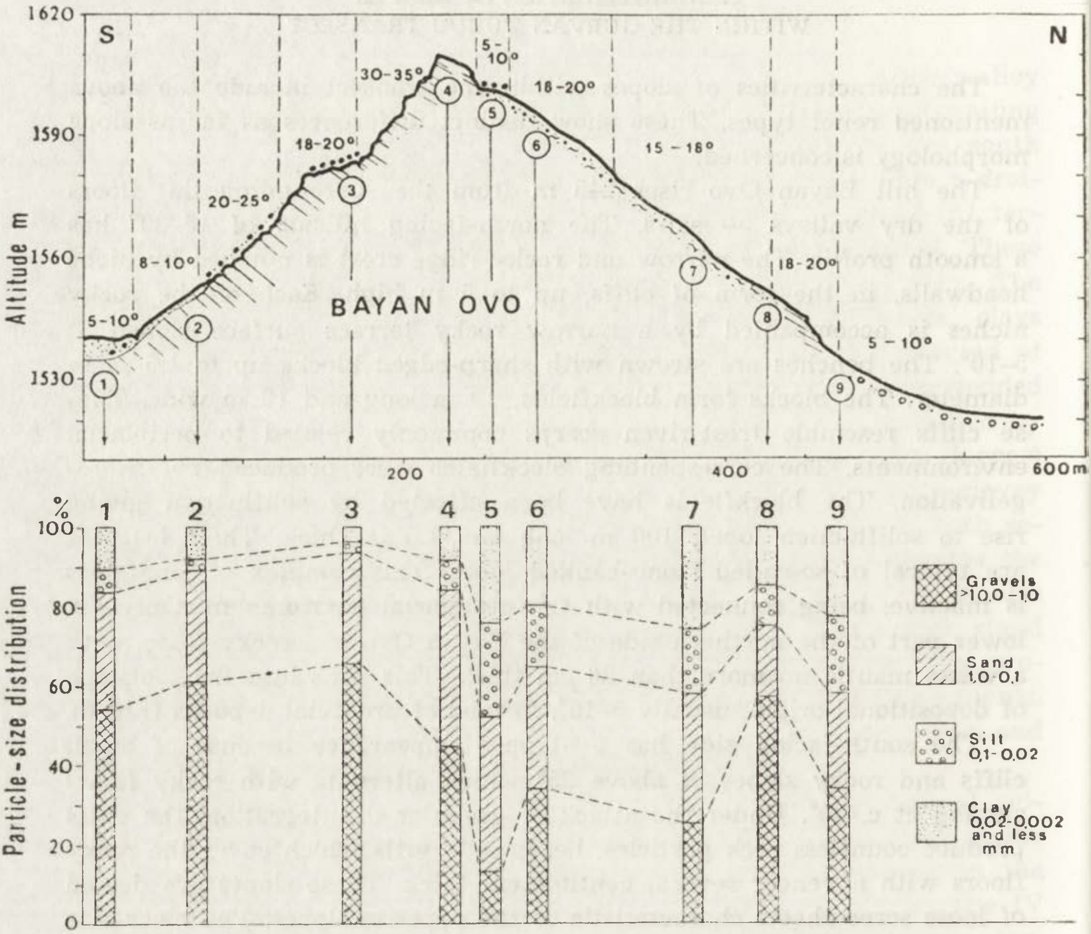

Fig. 6. Slope elements and particle-size distribution of superficial material on the Bayan Ovo Mt.

basin and valley facing hillsides vary highly in inclination downslope from 1° through 3, 5, 8, 10°, up to 18°. The steepest is the slope segment with more small residuals rising out of the waste-mantle. The slopes are interrupted by trough-like valleys. Their floors are frequently dissected by minor dry V-shaped valleys with poorly developed dry channels. Both closed basins and dry valleys contain redeposited waste materials that derived from the slopes either by wash or by splash transport.

Slopes typical of the basalt ridges of tectonic-denudation origin show the following sequence of sections: The monoclinal ridges comprise vertical or even hanging cliffs, at the base of which is a rocky slope of 26–30°. This in turn passes into typical gravitation slope of 18–24° underlain by loose scree. This is the middle debris slope. The lowermost

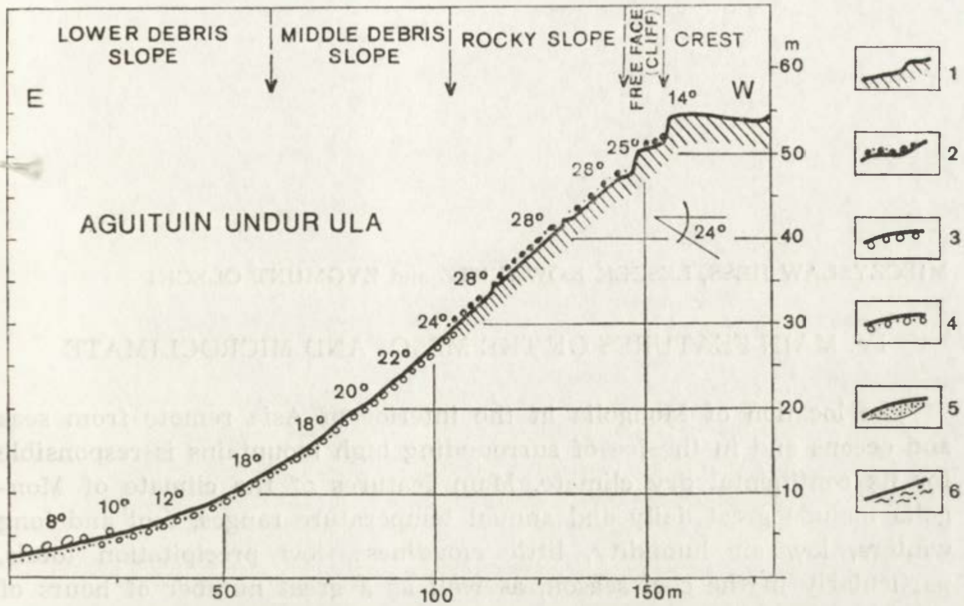

Fig. 7. Elements in basalts slope of the Aguituin Undur Ula

1 — free face; *2* — loose debris mantled rocky slope; *3* — scree slope consist of coarse debris; *4* — debris slope (proluvium); *5* — mudflow/flash flood deposits valley infillings; *6* — solifluction slope

segment is a proluvial slope of 3–12° underlain by fine-grained waste materials that have been washed down from the higher segment. In contrast to the upper slope segments, this piedmont slope is stabilized by steppe vegetation. In general, the monoclinal slopes corresponding to the basalt scarps have a concave profile. The opposite penestructural slopes are gently inclined at 5–10°, with a straight or step-like profile being related to the structure of the basalt lavas (Fig. 7).

The Gurvan Turuu tectonic basin contains thick sequences of alluvial sediments which form serveral terrace sheets. The terrace edges are smooth (up to 5°), and they have slightly concave profiles.

MIECZYSŁAW HESS, LESZEK KOWANETZ and ZYGMUNT OLECKI

IV. MAIN FEATURES OF THE MESO- AND MICROCLIMATE

The location of Mongolia in the interior of Asia remote from seas and oceans and in the lee of surrounding high mountains is responsible for its continental dry climate. Main features of the climate of Mongolia include great daily and annual temperature ranges, cool and long winters, low air humidity, little cloudiness, low precipitation totals, particularly in the cool season, as well as a great number of hours of sunshine throughout the year.

The characteristics of some features of the meso- and microclimate are based on data that have been obtained at Maant ($\varphi = 47^\circ\ 18'$ N, $\lambda = 107^\circ\ 32'$ E, $Hs = 1427$ m a.s.l.) and published in *Climatological Annual...* (1971) for the years 1956–1963, and on our own measurements made at Gurvan Turuu ($\varphi = 47^\circ 03'$N, $\lambda = 107^\circ 38'$E, $Hs = 1370.8$ m a.s.l.) over the period July 1975–August 1978. In July, 1977, the influence of topography and slope aspect upon thermal and humidity conditions was studied in the neighbourhood of the observing station on a hill-top (1616 m a.s.l.), on its northern side (1545 m a.s.l.) and on its southern side (1573 m a.s.l.). The detailed characteristics of these measurement points have been included in an earlier paper (Kowanetz and Olecki 1980).

BASIC ELEMENTS OF THE MESOCLIMATE

DURATION OF SUNSHINE AND SOLAR RADIATION

Throughout Mongolia, including the steppe areas discussed, insolation on a hill-top (1616 m a.s.l), on its northern side (1546 m a.s.l.) and year, and the monthly totals exceed 200 hrs in every month. Even in the winter months, when the days are by a half shorter than in June and July, the duration of sunshine is almost as long as in summer because of scanty cloud cover. In the diurnal cycle insolation is greater in the forenoon. This is particularly visible in the warm season. In the afternoon the intense heating of the land surface and the increased vertical movements of the air cause convectional clouds to develop.

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The great number of hours of sunshine permits entry of solar energy. Throughout the year almost 1450 kWh/m² (125 kcal/cm²) of solar energy in the form of total radiation is received by a horizontal plane at the earth's surface. In the annual cycle the highest values are recorded in May and June, when the monthly totals reach 190–195 kWh/m². The lowest values of 40–50 kWh/m² occur in December and January.

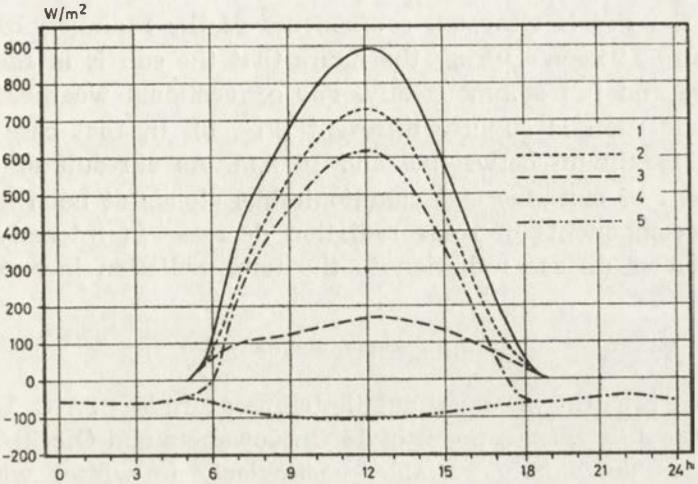

Fig. 8. Intensity of components of the radiation balance at Gurvan Turuu when the sky is clear (15–23 September 1977)

1 — total radiation; *2* — direct radiation on a horizontal surface; *3* — diffuse radiation; *4* — radiation balance; *5* — effective radiation

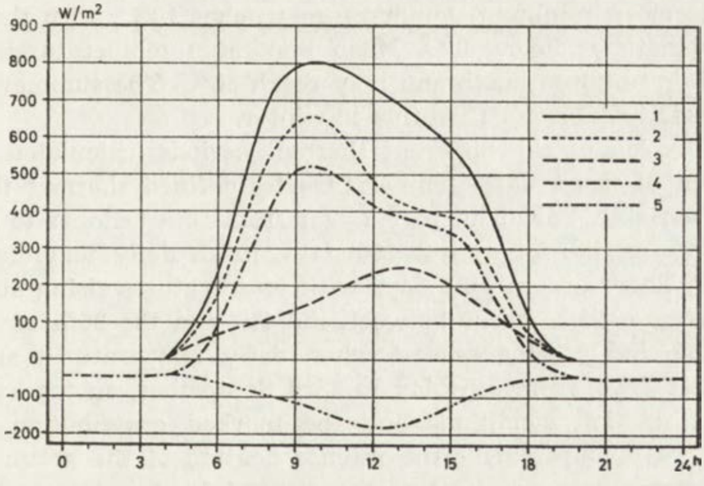

Fig. 9. Intensity of components of the radiation balance at Gurvan Turuu during the convectional type of weather (12–17 July 1977).

For explanation see Fig. 8

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Since the air is clear, owing to low air vapour content and reduced cloud cover, direct sun's radiation is the basic component of the total solar radiation. The exemplary daily cycles of the individual components of radiation balance during clear weather (Fig. 8) indicate that direct radiation accounts for 80% of the total radiation in the forenoon and the afternoon and for about 65% only in the morning and late in the afternoon.

When the sky is clear, all components of the radiation balance are most intense at noon. During the hours that the sun is in the sky, the curves rise and fall symmetrically. For convectional weather the daily cycle of radiation is slightly different (Fig. 9). In that case radiation reaches a maximum between 9 and 10 a.m. As a result of the rapid development of cumulus and cumulonimbus clouds at noon and in the afternoon components of solar radiation decrease in intensity and the contribution of diffuse radiation to the total radiation increases.

AIR AND SOIL TEMPERATURES

In the study area the mean annual air temperature is −2.7°C. The warmest month is July with a mean of 16°C (Kowanetz and Olecki 1980). Air temperatures are highly variable, particularly in winter when mean minimum temperatures drop to −30°C, and the absolute minima even fall below −45°C. Mean maximum temperature is then −15°C, but the absolute maximum may be about 0°C. Thus the mean amplitudes are 15°C in winter, with the extreme range reaching 45°C.

Air temperatures show less variation in summer. In the warmest month the mean minimum temperature reaches 10°C, with the absolute minima sometimes below 0°C. Mean maximum temperatures are over 20°C, and an absolute maximum may reach 36°C. The summer temperature range is 4–5°C lower than that in winter.

The duration of the different thermal periods (calculated from the intersection of mean daily temperature by defined thermal thresholds) is highly variable. For about half a year from 10th October to mid-April on the average, i.e. for almost 190 days, mean daily temperatures are below 0°C. There are only 22 days with temperatures rising above 15°C, on the average, these occur between the 4th and the 26th of July. The duration of the growing season, when daily temperatures are 5°C or more, is 141 days, from 5th May to 23rd September, on the average.

Good insolation conditions and the marked contribution of direct radiation are favourable for the intense heating of the ground surface. Its mean temperatures are between −24°C in January and 20°C in July. Extreme temperatures of the ground surface may range from nearly −35°C in winter to more than 40°C in summer.

One of the essential problems connected with the thermal conditions of the soil in this area is the distribution of the 0°C isotherm, which makes it possible to define the approximate duration and depth of frost penetration into the soil. In the study area ground surface freezing begins in October and reaches a depth of 3.5 m at the turn of March and April. The period with soil temperature below 0°C lasts from mid-October to mid-April on the ground surface, and from mid-January to mid-June at a depth of 3 m. In places, however, the thermal relationships of the soil can have more contrast. Since the study area is on the southern fringe of continuous permafrost, perenially frozen ground occurs in patches there at a shallow depth of about 1.5 m.

AIR HUMIDITY

The steppe areas of central Mongolia are characterized by low air humidity. Its mean annual value is 70%. In the annual cycle two maxima are recorded: a winter maximum in December, when humidity reaches 80%, and a smaller one in July, with humidity values not greatly exceeding 70%.

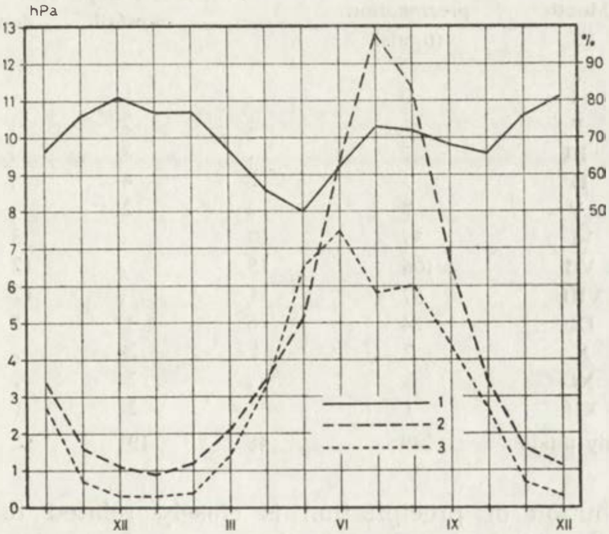

Fig. 10. Annual march of relative humidity (*1*), of water vapour pressure (*2*), and of saturation deficit (*3*) at Maint

The winter relative humidity maximum is due to low air temperatures prevailing in this season, whereas the summer maximum is associated with the penetration of humid air, mainly in July.

Air humidity is lowest in spring and autumn (50–60%). The very low values (1–2%) of relative humidity occurring particularly at noon and early in the afternoon, are worthy of notice. Figure 10 shows the annual march of air humidity.

CLOUDINESS AND PRECIPITATION

In the study area the mean annual cloudiness is only 37%. Throughout the yeaar the clouds are covering the greatest areas in spring and summer. The maximum, exceeding 50%, occurs in June and July, with low-lying clouds predominating largely of the convectional type (almost 40% of the cloud cover in July). In contrast to the summer, winter clouds are of the high and intermediate types; low-lying clouds are observed very rarely. In the daily cycle cloudiness is greatest in the morning and in the afternoon. Cloud cover is reflected in the occurrence of clear and cloudy days. On the average there are more than 120 clear days in a year. The greatest number of them is recorded in the cool season. There are only 40 cloudy days in a year with a maximum in summer.

Table 1. Mean monthly totals of atmospheric precipitation (in mm) and number of days with rain, snowfall and dew at Maant

Month	Atmospheric precipitation (totals)	Number of days with rain	Number of days with snowfall	Number of days with dew
I	0	.	1	.
II	1	.	2	.
III	2	.	3	.
IV	7	2	4	.
V	7	3	2	.
VI	39	10	.	3
VII	106	15	.	12
VIII	57	11	.	12
IX	24	6	1	5
X	2	1	2	.
XI	3	.	2	.
XII	1	.	2	.
Yearly totals	249	48	19	32

The distribution of precipitation is closely related to the annual cycle of cloudiness. On the average, there are only 67 days with precipitation, and they are concentrated in summer half-year (Tab. 1). The frequency of days with rain is greatest in July, followed by August and June. Soild forms of precipitation are recorded from September to May. From November through March only snowfall occurs.

The small number of days with snowfall and low precipitation totals in winter account for a very thin snow cover. Its mean depth reaches 3 cm, being 14 cm at a maximum.

The distribution of monthly precipitation totals also differs widely (Tab. 1). These vary from 1 mm in winter to above 100 mm in July.

Table 2. Intensity of atmospheric precipitation at Gurvan Turuu during the period 6th–30th July, 1977

Date July 1977	Precipitation [mm]	Duration of precipitation [min]	Intensity [mm/h]
6/7	25.3	1630	0.9
8	0.4	27	0.9
11	1.2	90	0.8
19	0.2	17	0.7
20	12.7	330	2.3
21	0.7	70	0.6
21	12.2	170	4,3
22/23	36,4	1605	1.4
23	0.9	100	0.5
23	0.6	15	2.4
26	0.7	50	0.8
27	3.2	245	0.8
30	0.6	5	7.2

Almost 45% of the annual total of 249 mm falls in July, and more than 90% is recorded over the period June–September, with only 9% in the remaining eight months.

In the summer months an important role is played by short and fairly frequent intense rainfalls associated with cumulonimbus clouds (Tab. 2). Continued rainfalls lasting for 1–2 days are rare.

In areas having a dry climate the occurrence of dew is of great importance. In the study area dew may occur from June to September (Tab. 1), and on the average, occurs 32 days per year.

WIND

In the study area, the prevailing winds are from the north-west and north (60% of all winds recorded in a year). In winter low speed winds are generally recorded. 50% of them are included in the 0–1 m/s interval, 40% are calms, and the speed of almost 90% of the winds observed is less than 5 m/s. In summer, calms decrease in number and the speed of winds increases. The frequency of winds velocities of 0–1 m/s drops below 20%, whereas winds with velocities of over 5 m/s occur in 40%, and those with velocities greater than 10 m/s are almost 10%.

THE CLIMATE OF THE AIR LAYER NEAR THE GROUND

The physical features of the air show striking differences in the air layers near the ground surface. Here the most active exchange of heat between the soil and the atmosphere takes place. Related to the

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low wind speeds in these layers is the stagnation of the air, its enrichment in atmospheric moisture, as well as the production of great vertical temperature gradients.

CHARACTERISTICS OF THE DISTRIBUTION OF TEMPERATURE AND HUMIDITY

The greatest differences in the thermal stratification of the air layer near the ground and in the upper part of the soil are observed during clear weather, when the ground surface becomes extremely heated because of intense solar radiation. Differences diminish during cloudy weather. The vertical distribution of temperatures is presented by taking its mean values when it was not very cloudy as for example over the period from the 15th to 23rd August, 1977.

With this type of weather the greatest differences in temperature are recorded in the basal air layer (Fig. 11). During the daylight hours

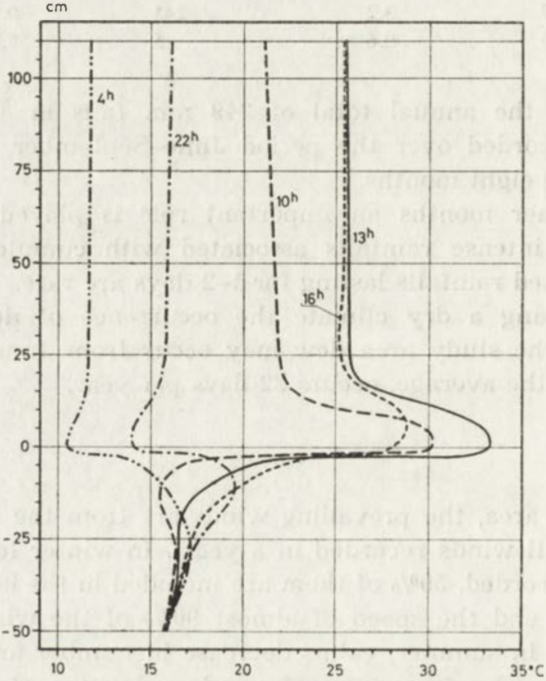

Fig. 11. Distribution of mean temperatures in the air layers near the ground and in the soil for selected time limits at Gurvan Turuu during clear weather

the intensity of solar radiation is greatest and the ground surface becomes intensely heated. Air layers lying close to the ground are cooler up to the height of 20 cm, and a drop of temperature with increasing height is particularly great here. In this layer the vertical temperature gradients are 0.4°C per 1 cm of elevation. During the night hours heat is conducted from the ground surface into the overlying 20 cm air layer and temperatures increase on the average by 0.6–0.8°C per 1 cm there. In the higher air layers temperature changes with increasing height are not great during the day, and night hours.

The thermal activity of the soil is greatest in its upper part, i.e. to a depth of 20 cm. During the daylight hours, temperatures are falling here considerably, while at night they tend to increase with depth (Fig. 11). Soil temperatures are less varied in the deeper layers.

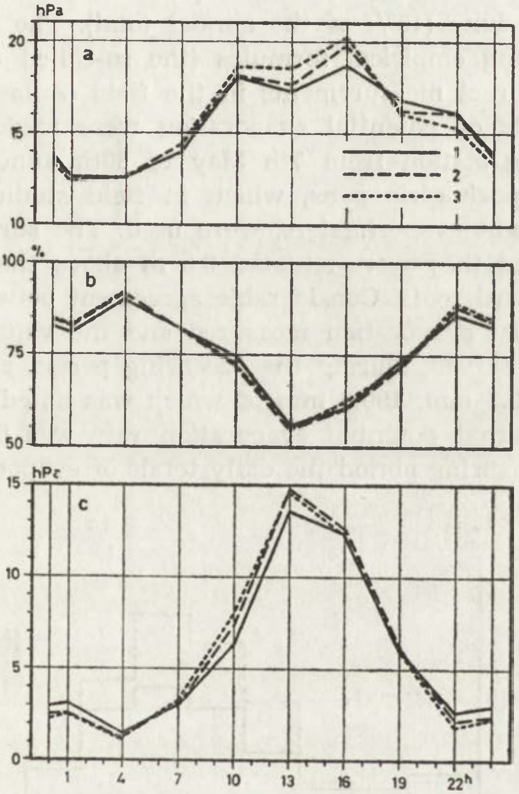

Fig. 12. Daily march of water vapour pressure (*a*), of the relative humidity (*b*), and of saturation deficit (*c*) at Gurvan Turuu during clear weather

1 — at a height of 150 cm, *2* — 50 cm, *3* — 20 cm above the ground surface

The plant cover is another important control of soil temperatures in the upper soil layer. In the study area at noon the temperatures of grass covered soil are from 8°C (at a depth of 5 cm) to about 3°C (at a depth of 20 cm) lower than the temperatures of bare soil. The basal air is characterized by the greatest water vapour content. Its amount decreases with increasing height above the ground surface. Figure 12

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shows the daily cycle of the indicators of air humidity. It appears that contrasts between the particular levels are greater during the day hours. At night the humidity is uniform throughout the vertical profile of the air layer near the ground.

POTENTIAL EVAPORATION

In the steppe zone of central Mongolia potential evaporation varies from between 700 and 800 mm per year. Annually, its highest values are recorded from May to September (80% of the annual total), with a maximum in June (19% of the annual total). The above data were obtained by using empirical formulas (the so-called complex method) and not from direct measurements in the field (Zubienok 1976).

Measurements of potential evaporation were made at the Gurvan Turuu observing station from 7th May to 30th June. For these measurements evaporimetric pans, which in field studies safely replace the Wilde's weight evaporimeters, were used. The surface of the pans was 200 cm² and they were situated 0.5 m above the ground surface, under louvre-board roofs. Considerable agreement between the monthly totals of potential evaporation measured and the values calculated for the area was observed. During the observing period potential evaporation reached 372.7 mm, 190.9 mm of which was noted in May. On the average, the diurnal potential evaporation rate was 6.8 mm. In spite of the short measuring period the daily totals of evaporation were highly variable. The maximum diurnal potential evaporation rate exceeded 16 mm, while its minimum value was 1 mm. The daily totals of potential evaporation were highest under clear skies, when air temperatures were high, the saturation deficit was particularly large and the wind blew at high speeds. During the day hours (8–20 h) evaporation accounted for 73.5% of the diurnal evaporation rate on the average (hydrological days 8–8 h). The maximum rate of evaporation recorded

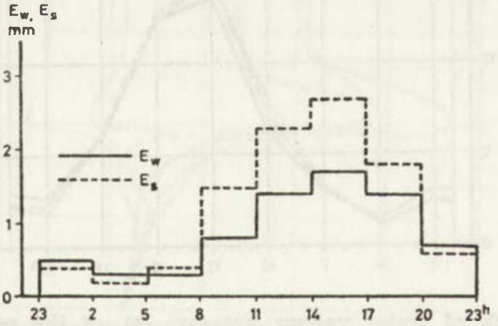

Fig. 13. Daily march of potential evaporation under a roof (E_w) and in the open air (E_s) at Gurvan Turuu over period 16–23 June 1978

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during the day hours was 89% of the daily sum, its minimum was 50%. Clear and windy days were marked by the greatest contribution of evaporation recorded during the day hours to the diurnal evaporation.

During the studies of the daily cycle of potential evaporation, an evaporimeter without a lid was also used. The highest values of potential evaporation were recorded between 14 and 17 hrs and between 11 and 14 hrs (Fig. 13). The higher potential evaporation totals that were obtained from the uncovered evaporimeter (E_s) during the day hours probably result from the heating of both pan and contained water by the direct radiation. At night and in the morning the potential evaporation totals E_s were lower than the E_w values. This should by explained by a considerable input of condensation water into the uncovered pan.

THE INFLUENCE OF THE TOPOGRAPHY UPON VARIATIONS IN AIR TEMPERATURE AND HUMIDITY

In the study area, during the periods of little cloudiness, the mean daily air temperatures differ only slightly. The difference between the mean daily air temperature at Gurvan Turuu (1371 m a.s.l.) and the summit of the Bayan Ovo (1616 m a.s.l.) is 1°C, which corresponds to a mean vertical temperature gradient of 0.4°C/100 m. The movement of the mean hourly air temperatures reveals the close influence of the topography (Fig. 14). At night and in the morning the occurrence of temperature inversions is observed. These are caused by the considerable cooling of the plains. Both summit and slopes of the Bayan Ovo are

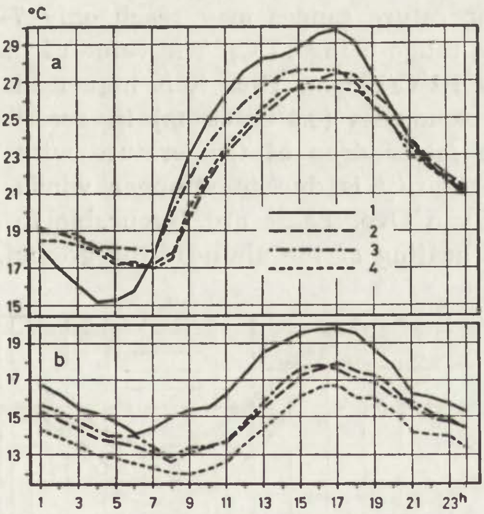

Fig. 14. Daily march of air temperatures during the period of little cloudiness, 12–17 July 1977 (*a*) and when the sky is clouded, 19–23 July 1977 (*b*)

1 — the Gurvan Turuu station; 2 — north-facing slope; 3 — south-facing slope; 4 — summit area

2–3°C warmer than Gurvan Turuu. At noon the summit of the Bayan Ovo is about 2–3°C cooler than Gurvan Turuu. Furthermore, the greatest contrasts between the northern and southern slopes (up to 2°C) are observed then, because a greater amount of solar radiation is received by the southern slope.

During the periods of little cloudiness, the highest air temperatures are recorded in the plains (30.5°C) and on the south-facing slopes (28.2°C). The distribution of minima reflects the inversive stratification of temperatures with increasing height, ranging from 14.5°C at Gurvan Turuu to 17°C on the south-facing slope of the Bayan Ovo massif. On its summit the minimum air temperatures are on the average 0.6°C lower than those on the southern slope. The daily air temperature range decreases with increasing altitude. The mesoclimatic conditions are most extreme at Gurvan Turuu, i.e. in the plain. When the cloudiness is little the mean daily air temperature range reaches 16°C there (the absolute range being 26.1°C). At the same time the mean daily air temperature range is c. 11°C in the summit areas (the absolute range being 20.7°C).

Under cloudy skies the thermal contrasts being controlled by topography and slope aspect are all much smaller (Fig. 14). For example the daily air temperature ranges may reach only 7–9°C under cloudy skies (the absolute range being 17°C). The value of the mean air temperature gradient is 1.1°C/100 m. Thus it is higher than that during the periods of little cloudiness (0.4°C/100 m) in accordance with greater differences and a faster drop of temperature with increasing height. Probably, this regularity is due to stronger winds prevailing on the summit of the Bayan Ovo. These are favourable to persistent flow of air which retards heating of the air near the ground. When the sky is

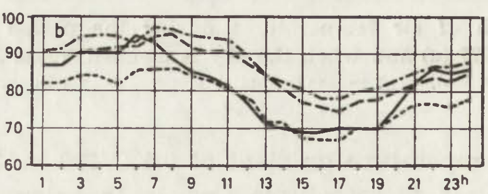

Fig. 15. Daily march of relative air humidity during the period of little cloudiness, 12–17 July (*a*), and when the sky is clouded, 19–23 July 1977 (*b*). For explanation see Fig. 14

clouded the drop of air temperature with increasing altitude is recorded throughout the day and night. When the cloudiness is little the above process occurs only during the day hours (inversion at night).

Analyses of the air humidity conditions reveal that during periods of little cloudiness the contrasts between relative humidity values are clearly related to topography and slope aspect (Fig. 15). At night in cold air the atmospheric moisture reaches 80% over the plains, whereas in the forenoon and in the afternoon the lowest values of 30–40% are recorded there. During the cloudy weather the spatial variability of the air humidity is not great. At times of little cloudiness and cloudy skies the values of relative humidity are about 10% lower on the summit of Bayan Ovo as compared with slopes. This is the effect of greater wind speeds in the upper parts of the mountain massif.

CONCLUSION

Because of limited volume we have concentrated here only on the characteristics of selected features of the mesoclimate and on some problems concerning the differentiation of temperature and humidity in the air layers near the ground, leaving out a more detailed analysis of the processes that are responsible for this differentiation. A broader discussion of these problems, together with abundant graphic and numerical materials, has been included in earlier publications (Kowanetz and Olecki 1980; Hess *et al.* 1980).

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WOJCIECH CHEŁMICKI

V. WATER CIRCULATION

The steppe areas of central Mongolia are characterized by a great precipitation deficit in relation to potential evaporation. This deficit is estimated at about 760 mm per year (*The Global...* 1974), and it results in a considerable deficiency of water which is accessible by plants; this is revealed in, among other things, a short growing season.

DISTRIBUTION OF WATER PHENOMENA

The area under investigation is characterized by a lack of perennial streams (Fig. 16). The only periodic stream is found within the tectonic depression. Every year, during the period of summer precipitation, the stream channel carries small amounts of water (c. 5–10 l/s). The water level is not of a permanent character, because in some places all the water infiltrates into the sandy-gravelly alluvial deposits, only to reappear after dozens or several hundred metres. The stream is fed mainly by shallow lying groundwater. Feeding of the stream by surface run-off waters occurs only occasionally.

Episodic streams — running only during and immediately after rainfalls of exceptionally great intensities — occur mainly within the valleys which dissect the Eastern Plateau. Their pattern is determined by clearly formed dry channels with recent traces of erosion and sedimentation. Episodic water also flows down the short V-shaped valleys which dissect the slopes of basalt fault scarps. This occurs mostly in the eastern margin of the tectonic depression.

Depressions of periodic lakes are a typical element of the scenery; they occupy floors of endoreic depressions lined with deluvial silty deposits. Every year the depressions of periodic lakes are being filled with water after the first significant summer rain.

Episodic lakes fill with water only after exceptional heavy rainfalls. In 1976–1978 most of the episodic lakes filled with water only once, and they existed only for a few days.

In the steppe area of Mongolia, groundwater commonly occurs (Ivanov 1958; Marinov and Popov 1963; Kuznetsov 1968, 1973; Kartavin

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and Marinov 1976). In the study area groundwater is found: 1) in the fissured intrusive rocks, mainly granites forming the Eastern Plateau; 2) in effusive rocks, mainly mushy basalts which crop out within the fault scarps of the tectonic depression and constitute the substratum of younger deposits which fill the central part of depression (cf. Dżułyński, chapter II); 3) in Quaternary deposits, mainly in alluvia and proluvia which fill the bottoms of valleys and basins.

Because of their small depth (0.5–3 m), waters which occur in the Quaternary deposits are easily accessible and, owing to sunken wells (Fig. 16), are used for watering the herds that graze in the steppe. Unfortunately, these waters can easily be polluted with organic elements contained in the animals excrements which cover the ground surface, and are carried into the soil with infiltrating rain-water (Chełmicki

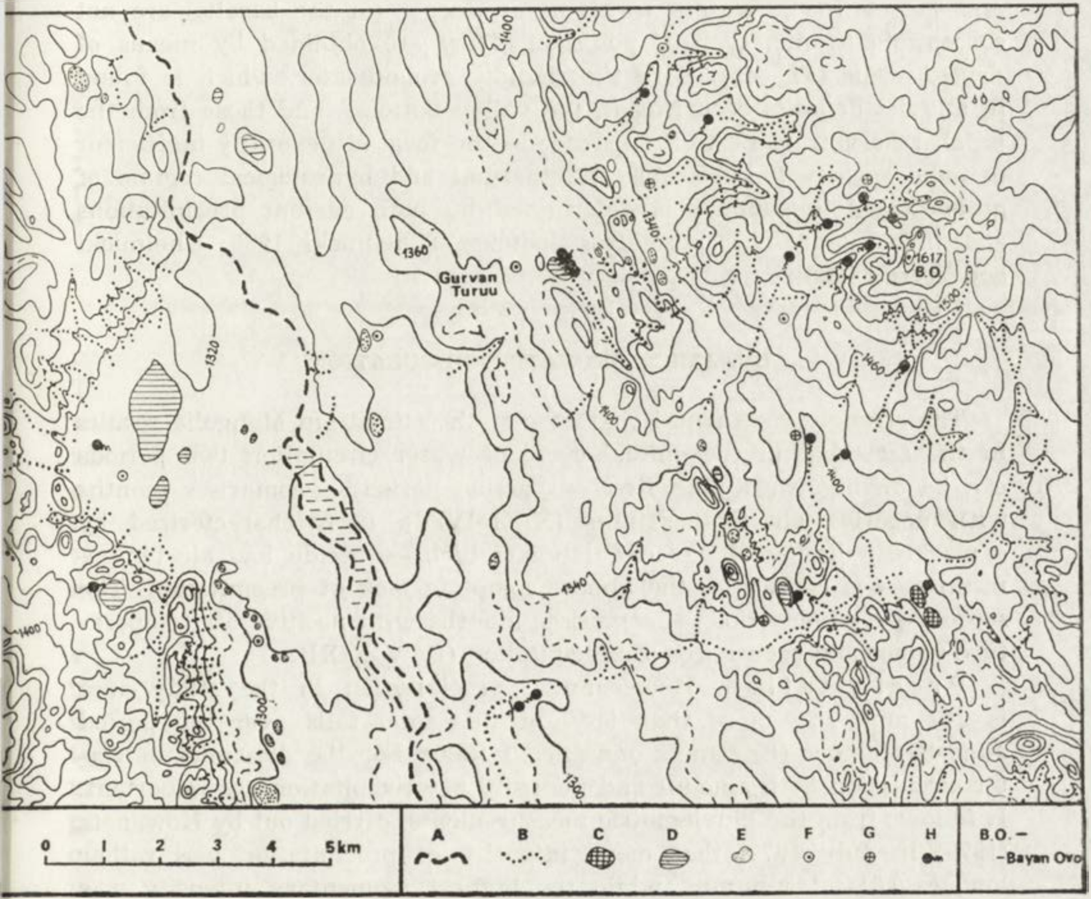

Fig. 16. Distribution of the surface water phenomena near Gurvan Turuu

A — seasonal streams; *B* — episodic streams; *C* — permanent lakes; *D* — seasonal lakes; *E* — episodic lakes; *F* — deep drilling wells; *G* — shallow sunken wells; *H* — seasonal springs

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Table 3. Characteristics of the run-off plots

Feature	Experimental plot "on the lake"	 "Bayan Ovo"
Area	81.25 m²	81.25 m²
Slope inclination	12°	14°
Exposure	NE	NNW
Altitude above sea level	1378 m	1550 m
Type of substratum	fine earth waste on basaltic substratum	fine earth sandy waste on granitic substratum
Thickness of the soil	0–80 cm	above 100 cm
Infiltration capacity of the soil on the plot	2.7 mm/min	2.9 mm/min

and Tserev 1980). Waters which occur deeper (in the basalts) are not susceptible to this type of pollution. They are obtained by means of drilled wells (Fig. 16). Both the shallow groundwater, which is found in alluvial deposits occurring in the valley bottoms, and those from the basalt reservoir, come to the surface in the form of generally inefficient periodic springs (0.1–0.5 l/s). The thermal and hydrological régime of groundwater in summer is determined by both current precipitations and thawing of local permafrost patches (Chełmicki 1980; Chełmicki and Tserev 1980).

DYNAMICS OF WATER CIRCULATION

The strongly continental character of the climate in Mongolia results in the fact that in the annual cycle of water circulation two periods can be distinguished. The first — passive period — comprises months with negative air temperatures (X/XI–IV/V). It is characterized by a markedly limited water circulation, which — beside low air temperatures — is caused by the almost complete lack of precipitation. The second — active period — comprises months with positive air temperature values and occurrence of precipitation (IV/V–X/XI).

Precipitation. Mean annual precipitation in the study area is 249 mm, and more than 90% of this total falls over the period June–September (Kowanetz and Olecki 1980). For the dynamics of water circulation both amount and intensity of precipitation are important. It follows from the pluviometric measurements, carried out by Kowanetz (1979) in July 1977, that mean intensity of precipitation was rather low, c. 0.01–0.1 mm/min, while the highest momentary intensity was 0.6 mm/min. Of all the precipitation recorded at Gurvan Turuu in 1976–1978, hail was characterized by the highest mean intensity (Table 4). The highest mean intensity of rainfall was 0.37 mm/min. Precipita-

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tion of such intensity is recorded only sporadically, probably once in several years.

Infiltration. The permeability of superficial deposits was measured by means of a Burger cylinder infiltrometer. The measurement runs were continued until a constant percolation rate was achieved. This rate, i.e. the infiltration capacity, is expressed in mm/min. A similar method of ground permeability evaluation was applied by Słupik in the Khangai (1975, 1980).

Table 4. Selected characteristic results obtained from measurements of surface run-off on experimental plots in 1976–1978

Date	Experimental plot			
	"on the lake"		"Bayan Ovo"	
	precipitation mm/h	run-off mm	precipitation mm/h	run-off mm
22 July 1976	13.7/0.5	0.06	14.0/0.5	0.08
6–7 July 1977	24.8/27	0.02	17.0/27	0.28
21 July 1977	12.2/3	0.07	19.3/3	0.05
22–23 July 1977	37.5/27	0.10	41.3/27	0.03
13 June 1978	37.0/1.5	12.30	—	—
9 July 1978	17.5/0.2 (hail)	0.01	—	—

The measurements were made within a transect that included the main structural-morphological units found in the vicinity of Gurvan Turuu. This transect reflected the physiographical differentiation of the whole territory. The map showing the permeability of the soil layer at depths of 0–10 cm was drawn on the basis of measurements carried out at 32 sites (Fig. 17). The boundaries of areas being characterized by similar values of infiltration capacity were drawn by using both the geomorphological map of the transect (Kotarba 1978) and the soil map (Kowalkowski *et al.* 1979).

The infiltration capacity of superficial deposits in the study area varies from 0 to more than 10 mm/min. Practically impermeable are the silty deposits in the floors of endoreic depressions that are situated within and at the margin of the basalt zone. Slight permeability is typical of aeolian silts occurring in the areas surrounding the lake. This is favourable for the periodic filling of the lake basin with water supplied by precipitation and run-off from the immediate environment of the lake. In addition, several patches of weakly permeable grounds were discovered; they occupied the floors of endoreic depressions.

Within the transect, deposits with an infiltration capacity of 1–3 mm/min are predominant. These occur mainly on the slopes and ridges, composed of Quaternary gravels, Jurassic basalts and metamorphic rocks (cf. Dżułyński, chapter II), in the western and central parts of the transect. In the western section of the transect medium-thick and thick chestnut and dark chestnut soils tend to prevail (Kowalkowski *et al.* 1979); their permeability being 1.2–1.4 mm/min. The soils developed on the gravelly deposits of the dry sair valley are characterized by a higher permeability of 3.1 mm/min. Greatest permeability within this valley was recorded on soils which formed on the patch of fluvioaeolian sands: 9.3 mm/min. The permeability of deposits which occur on the basalt slopes of the fault scarps is less varied.

The permeability of thick soils which occur on the slightly inclined slopes is only 1.8 mm/min, whereas the shallow soils developed on the more abrupt slopes and ridges are slightly more permeable (2.2–3.1 mm/min). This is due to the higher content of skeletal particles derived from the shallow-lying bedrock. The basalt outcrops tend to absorb certain amounts of water, particularly in places where the upper parts of lava flows have a cavernous sponge-like structure. In the depressions which separate the parallel ridges the permeability of the soils is lower (1.6 mm/min) because of the higher content of small particles.

The permeability of soils which developed on the metamorphic rocks approximates that of the soils formed on the basalts: 1.6–1.8 mm/min. Contrary to the basalt area, however, the valley deposits of the metamorphic zone are characterized by a higher permeability than those on slopes and ridges (2.1 mm/min). This should be ascribed to the coarse grain structure of waste formed during the process of granular disintegration (Kotarba 1978).

In the granitoid massif of the Bayan Ovo, the ground permeability varies greatly. Outcrops of impermeable solid rock are common there. The permeability of soils developed on plains of fluvial accumulation is 1.4–2.3 mm/min, on inactive solifluction tongues is 2.9 mm/min, and on pediments is 4.3 mm/min. Because of the coarseness of deposits, measurements were not made on the torrential cones and tongues of proluvial accumulation to which permeablities of more than 5 mm/min were ascribed.

The map of soil permeability presents a very simple picture. Among the factors controlling the permeability of soil there are vegetation and soil fauna. The *Caragana* shrubs facilitate the formation of aeolian mounds with very good permeability. Conditions facilitating infiltration prevail in holes of field-voles (*Microtus*) and *Marmota marmota*. Low permeability resulting from compaction is typical of grounds situated along roads.

The infiltration depth of precipitation in typical medium-thick (40 cm) chestnut soil is illustrated in Figure 18.

As follows from the everyday measurements of the soil moisture (May–August 1978), the infiltration depth of the first spring rain of 36.2 mm was c. 30 cm. The infiltration depth of precipitation recorded

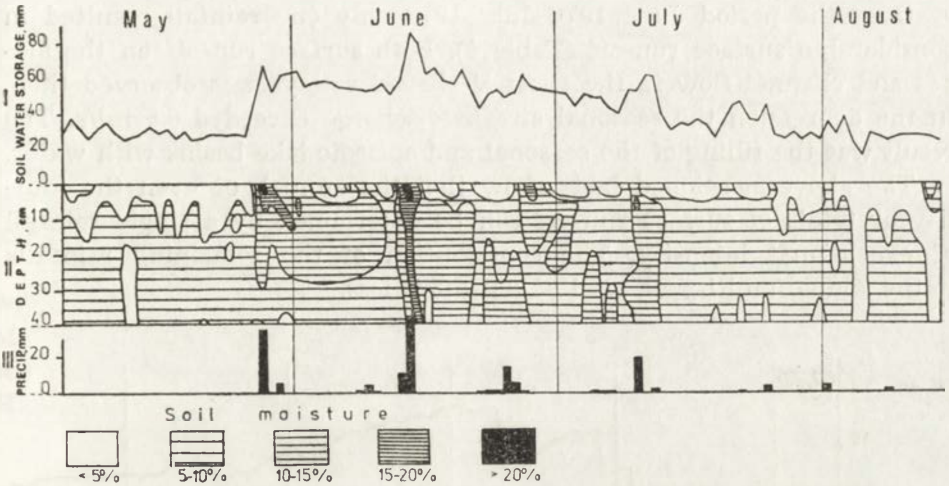

Fig. 18. Storage of the soil water and hydrochronoisopletes of the chestnut soil of the steppe in relation to precipitation in the period between 5 May and 13 August 1978

in the last ten days of June (the maximum daily amount of which reached 14.1 mm) exceeded slightly 20 cm. The infiltration depth of precipitation of several millimetres is only 5 cm; it depends on air temperatures and humidity and the development of vegetation. Rains associated with soil moisture movement through the whole soil profile occurred in mid June. Their total was as much as 52.8 mm, i. e. more than 20% of the mean annual value.

Considerable thickness of the soil, together with intensive evaporation and transpiration, creates conditions for limited infiltration of rainwater into the rocky substratum. Groundwater alimentation, through the infiltration of precipitation, takes place mainly in the summit areas, especially in the areas built of porous basalts.

Surface run-off. The estimations of the surface run-off rates near Gurvan Turuu were based on the knowledge of both atmospheric precipitation and ground permeability as well as on the results of measurements made on two plots bounded by a plastic foil (Table 3 and 4).

The comparison of precipitation amounts and intensities and of the soil permeability revealed that, in the greater part of the area, the probability of run-off occurrence is small. Only in places where weakly permeable and impermeable silts are found, can run-off be observed to occur after each precipitation of at least several millimeters. The observations on the plots proved that even high precipitation resulted in very slight run-off (Table 4). This was also confirmed by observations of waste displacement on the slopes (Kotarba 1980).

Over the period June 1976–July 1978 only one rainfall resulted in considerable surface run-off (Table 4). Both surface run-off on the slopes and channel flow in the short V-shaped valleys was observed then. In the depression the seasonal stream discharge exceeded 0.5 m^3/s. The result was the filling of the seasonal and episodic lake basins with water.

The above-mentioned facts show that the annual, or even the multi-year totals of surface run-off can be determined by a single rainfall of exceptional intensity. The contribution of the remaining rainfalls to the annual/multi-year total of run-off is less.

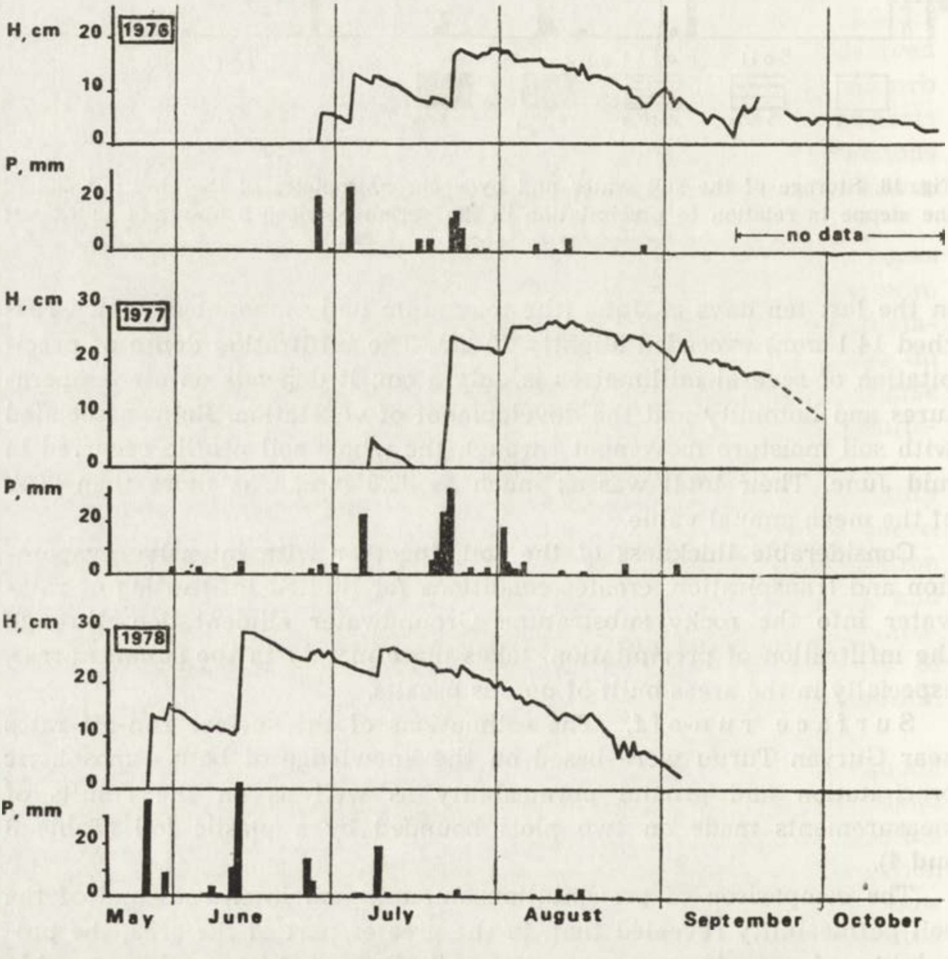

Fig. 19. Course of water-level (*H*) of a periodic steppe lake in relation to atmospheric precipitation (*P*) in 1976–1978

Evaporation. The estimations of the evaporation rates from the water surface in summer are based on diurnal observations of the seasonal lake water-level near Gurvan Turuu from June, 1976 until

September, 1978 (Fig. 19). Having assumed the lack of water percolation into the lake bottom (this was confirmed by measurements of infiltration) and taken into account the seasonal feeding of the lake by springs with a total mean discharge of 0.5 l/s, it was found that the daily evaporation rate from the lake surface in summer was on the average 5–6 mm, and 20 mm at most. Thus the monthly total of evaporation reached 150–180 mm and was similar to results obtained from measurements of evaporation from pans (Kowanetz 1979).

The estimation of evaporation rates from the soil surface, together with transpiration, can be made on the basis of analyses of the course of water storage in the soil (Fig. 18). It appeared that the average losses of soil moisture per day caused by evapotranspiration were 3–7 mm. Maximum daily values of evapotranspiration reached 23 mm.

BOGUMIŁ WICIK

VI. GEOCHEMICAL PROPERTIES OF LANDSCAPES

The landscape-geochemical studies were conducted within the framework of two expeditions: TRANSMONGOLIA '79 and TRANSMONGOLIA '80. During three stays at the Gurvan Turuu Physico-Geographical Research Station, observations were collected both on the spot (over 200 excavations and shallow drillings) and *en route.* In addition, a preliminary survey was made of the basic chemical features of waters, soils and weathered materials in the immediate and surrounding vicinities of the station. The landscape-chemical mapping was conducted by the method suggested by both Glazovskaya (1964) and Pelerman (1975). The cartographic survey of the analyzed landscape features was made on the strength of topographic maps (1:100 000), serial photographs and satellite surveys.

On the surveyed region there occur two tectonically conditioned surface groups, that is autonomous eluvial groups and accumulative groups subordinated to the former (Fig. 20, Table 5). Such a division on the southern Khentei borders was already marked by the beginning of Mesozoic. The tectonically depressed units are filled with a series of neoeluvial sediments. It is here that, from the beginning of Mesozoic, took place the processes of accumulation and metamorphism of ding eluvial units (*Geological Map*... 1971; Kleiner 1979). Low tectonic both soild and dissolved substances that are furnished from the surroun- stability of this region accounts for the poorly evolved transit zone of substances. In the episodes of tectonic movements, changes occurred in the position of watersheds; this gave rise to local (mainly in the zone of tectonic contacts) transformations of the subordinated accumulative surface fragments into autonomous eluvial ones. Tertiary tectonic transformations formed the two groups of the earlier existing landscape units, and led to the deformation of their original topographic surface and to the changes in a number of hydrological and geochemical features (Dżułyński 1977; Wicik 1980). Reactivation of the old tectonic lines favoured the displacement of solutions and, as a result, the introduction into the circulation of new chemical elements and compounds. The tec-

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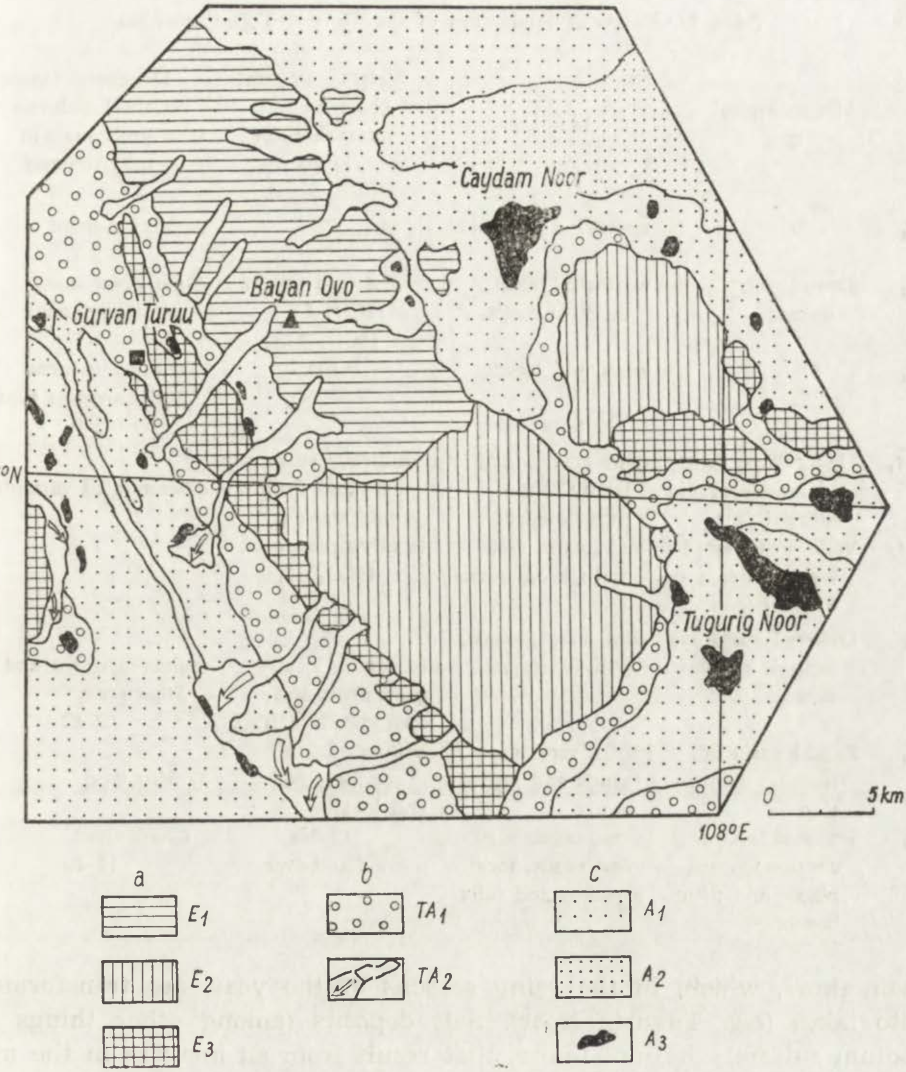

Fig. 20. Sets of landscapes

a — eluvial; b — transit and accumulation; c — accumulative. For explanation of symbols see Table 5

tonic lines at present constitute a migration system of waters; they form also the borders of the hydrogeological units (Wicik 1982). The accumulative landscapes are supplied by both the autochtonic, transferred from the eluvial units, and the allochtonic waters. Since the geological and morphological landscape features bring about differences in hydrostatic pressures (the borders of the accumulative units are raised in relation to the surface of their bottom), then, subartesian water is found (*Hydrogeological Map...* 1968). Equalization of pressure (5–10 m) occurs in the lowest surface parts where continuous wet places are

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Table 5. Groups of landscapes of the Gurvan Turuu environs

	Morphological unit	Lithology	Waters category, chemism and mineralization in g/l	Dominant steppe variants; richness in green mass in q/ha/summer
E_1	Denudation uplands	weathered granitoids	fissure waters HCO_3–Ca HCO_3–Mg 0.1–0.5	multicomponent 5–7
E_2		weathered acid eruptive rocks		*Stipa* grass and multicomponent 5–7
E_3		weathered basalts		multicomponent and *Caragana* type 5–9
TA_1	Under-slope deluvial surfaces and alluvial fans	sand gravels and loamy sands with boulders	sporadically surface waters and shallow ground waters, locally permafrost HCO_3 –Na 0.5–1.0	differentiated variants 7–9
TA_2	Valleys of sporadic watercourse and alluvial fans	sand loams, deluvial-alluvial series		
A_1	Lowered parts of tectonic depression	sand loams, sands, gravels, clays	subartesian, locally permafrost and sporadically surface waters SO_4–Na and locally Cl–Na 1–5 and over	multicomponent and *Stipa* grass 7–12
A_2	Raised parts of tectonic depression	loams, very fine sands and gravel sands		*Tschiya* type
A_3	Seasonal lakes and continuous wet places and their borders	loams, clays, very fine sands, locally gypsums and salts		(*Deris* type) 12–20

maintained, which, in the rainy seasons of the year, are transformed into lakes (e.g. Tugurig Noor). Salt deposits (among other things of sodium sulfate salts) are found, that result from an increase in the mineralization and the chemical change of waters that circulate.

The climatic conditions prevailing at present in this region of Asia account for a generally small quantity of precipitation (about 240 mm), and for the exclusion of a part of soil-ground waters from the annual hydrological cycle and their retention in the islets of the permafrost (Chełmicki and Tserev 1980).

Closely associated with the hydrological component of the geosystems under study is the production of the plant mass. This parameter should be taken into account when attempting to divide the analyzed surface. To this end a schematic map of plant communities (Fig. 21) was drawn and information was collected on the above-ground production of pastures in summer (Table 5). The map was based on a report found at the site intended for the pasture users (*Pastoral resources*... 1954). This

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report permitted the fodder value of the respective landscape units to be valuated for the nomadic grazing economy.

The comparison of the two above shown maps and the assessment of resources permits a general conclusion to be drawn, that the pastures of the accumulative landscapes are, on the whole, richer in the green plant mass. The largest quantities of the latter are produced in the superaqual both continually and seasonally variants of these landscapes.

For the immediate vicinity of the Gurvan Turuu Research Station a more detailed cartographic survey has been elaborated (Fig. 22, Ta-

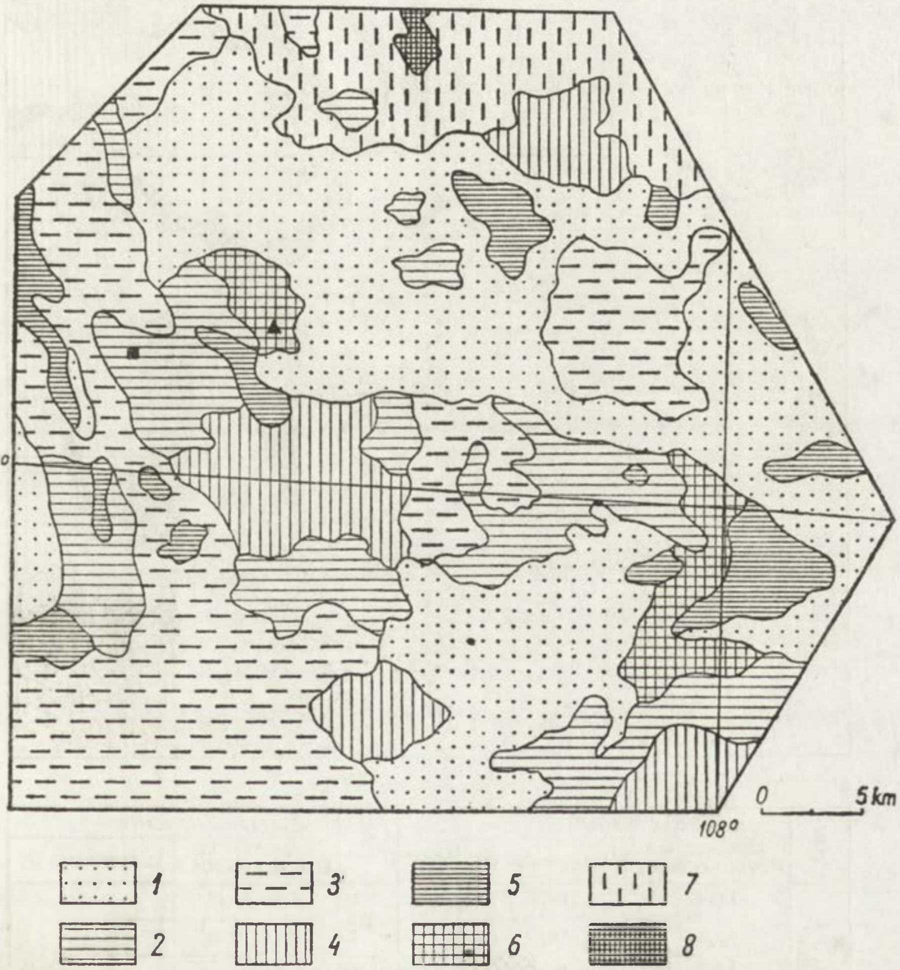

Fig. 21. Schematic map of plant communities. Dominant and accompanying genera (according to *Pastoral resources...* 1954)

1 — multicomponent steppe with *Caragana* admixture; 2 — *Caragana* (*Koeleria*, *Cleistogenes*); 3 — Stipa (*Koeleria*, *Caragana*); 4 — *Agropyrum* (*Carex*, *Cleistogenes*), 5 — *Lasiagrostis* (*Carex*, *Agropyrum*); 6 — *Cleistogenes* (*Stipa*, *Artemisia*); 7 — *Koeleria* (*Artemisia*, *Agropyrum*); 8 — ploughland (spring crop)

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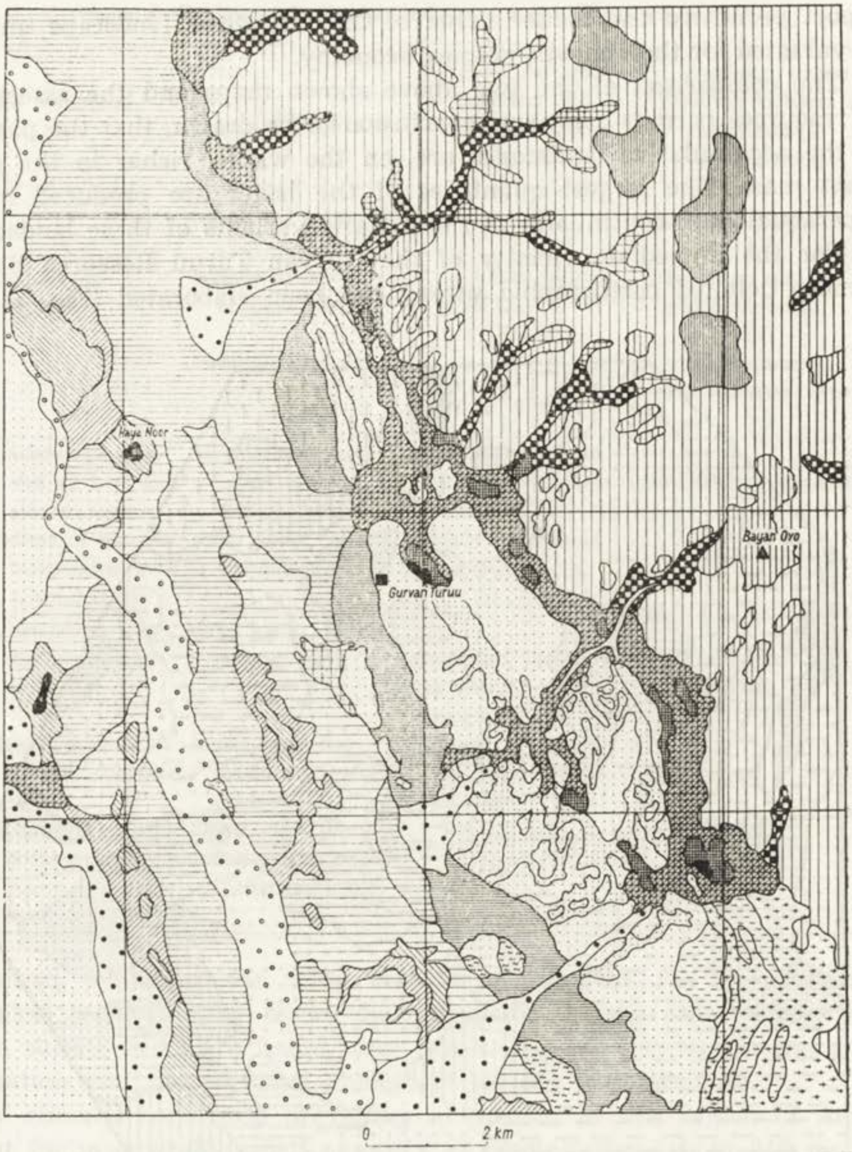

CLASS	LANDSCAPE SUBTYPE			
	AUTONOMOUS AND RELATIVELY AUTONOM. (I)		SUBORDINATED (II)	
GRANITOID ORTHOELUVIA AND NEOELUVIA	A_{I1}	▒	A_{II1}	▦
	A_{I2}	▥	A_{II2}	▦
	A_{I3}	▥	A_{II3}	▩
			A_{II4}	▓
			A_{II5}	█
NEOELUVIA	E_{I1}	▤	E_{II1}	▨
	E_{I2}	▤	E_{II2}	▨
	E_{I3}	▤	E_{II3}	●

CLASS		LANDSCAPE SUBTYPE			
		AUTONOMOUS AND RELATIVELY AUTONOM. (I)		SUBORDINATED (II)	
ORTHOELUVIA	OF BASALTS	B_I	⁘		
		$B_{I/II}$	⁘		
	OF ACID VOLCANIC ROCKS	C_I	⁘		
		$C_{I/II}$	⁘		
PARA-ELUVIA		$D_{I/II}$	⁘		
MIXED				F_{II}	•
		H_I	∘		

Fig. 22. Map of geochemical landscape of the Gurvan Turuu environs
For explanation of symbols see Table 6

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ble 6). The regions with an arid (here cryoarid) type of climate have been defined by Glazovskaya (1964) as surface-eluvial landscapes (or eluvial landscapes of a shortened profile). Under conditions of the Mongolia's dry steppe under analysis, this type of landscape is dominant but not unique. Other types of landscapes are also encountered locally which constitute chain links in the exchange of substances between the above mentioned landscape groups, i.e. autonomous eluvial and accumulative subordinated to the latter.

The regions constructed of Trias-Jurassic granitoids and Jurassic basalts as well as acid eruptive rocks are comprised by the class of ortho-eluvial landscapes. The common feature of the weathered material of these rocks is their richness in both the primary- (ortho-) and secondary- (neo-) alumino-silicates. The lithological and morphological variants of these landscape-subclasses are obvious, the scale, however, of the cartographic survey (Fig. 20) does not permit their full graphical documentation. The landscapes of the granitoid regions *A* have a distinctly delineated morphological structure. The fragments of watersheds are covered by the formations of a high filtration coefficient, poor in secondary clay minerals; in this connection these formations are predisposed to a seasonal leaching of the whole soil profile (mainly in July when the rainfall amounts here to about 100 mm — *cf.* Olecki 1977). The soils have in the upper horizons a slightly acid reaction, and in the lower ones — usually a neutral reaction. The question arises, whether in these conditions the soils persist that have the features typical of the chestnut soil. These surfaces have been numbered among the autonomous eluvial landscapes of the full profile (A_1 according to the Glazovskaya's terminology). The majority of the surfaces covered by the weathered granitoids possess the features of a relatively autonomous landscape (A_{I_3}). Gentle slopes (only locally exceeding 3°) favour the slight surface displacement of solutions and weathered material at present. There occur here the soils counted among the chestnut soils; in their profiles two genetic series have been found that are separated, at the depth of about 30–40 cm, by the carbonate horizon [3]. In the case of the occurrence of stones in the profile their lower surfaces are frequently covered by a hard carbonate shell of a depth of up to 2 mm, now and then cracked and torn. These landscapes are referred to as "eluvial with a shortened profile".

The subtypes of subordinated landscapes form a fairly extended sequence. The upper parts of valleys to which penetrate — from the

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[3] Many soil experts stress the characteristic farinose form of carbonates amassed here. It seems, however, that the farinose nature should not be regarded as a diagnostic feature of these particular soils because, among other things, in cold climates (in the cryoarid climate of Mongolia too) the various concretions of the new formations disintegrate when freezing.

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Table 6. Geochemical landscape of the Gurvan Turuu environs

Landscape symbol and name	Lithological fractions	Type of soil, water régime	Water chemism and mineralization in g/l	Soil chemism Carbonates	 Sulfates	 Chlorides
$A\mathrm{I}_1$ Eluvial with full profile	stony gravels, gravels, sands	sporadically leached	prevailing HCO_3–Ca up to 0.2	none to the traces in B_{Ca} depth of 20–40 cm		
$A\mathrm{I}_3$ Eluvial with shortened profile	loamy sands, stony loams	surface leached				
$A\mathrm{I}_2$ Rock outcrops						
$A\mathrm{II}_1$ Permafrost-transeluvial	gravels and loamy sands, loams	permafrost-evaporative with intrasoil outflow	prevailing HCO_3–Ca 0.2–0.5	in A_1 only		
$A\mathrm{II}_2$ Permafrost-transaccumulative	sandy loams and loamy gravels	permafrost-evaporative with poor intrasoil outflow		present throughout the profile but maximum in A_1		
$A\mathrm{II}_3$ Transaccumulative	loams, sands and gravels	surface leached, sporadically washed on	prevailing HCO_3–Ca about 0.5	throughout the profile	traces throughout the profile	
$A\mathrm{II}_4$ Accumulative-eluvial	heavy loams with cover of sands and loamy gravels, and locally humic fine sands	locally variable	HCO_3–Na 0.5–1.0	throughout the profile or below the eolian series	traces throughout the profile	
$A\mathrm{II}_5$ Eluvial-accumulative-permafrost	heavy loams and clays	permafrost-evaporative and evaporative, locally seasonally inundated		present throughout the profile but maximum in A_1		
$E\mathrm{I}_1$ Eluvial with shortened profile	sandy-stony gravels with loamy interbeddings	surface	locally variable HCO_3–Na HCO_3–Ca HCO_3–Mg	present throughout the profile or sometimes below A_1	traces throughout the profile	
$E\mathrm{I}_2$ Eluvial with shortened profile	loamy sands and loams with gravel interbeddings	leached			traces throughout the profile, locally increased quantities below A_1	

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$E\mathrm{I}_3$	Eluvial with shortened profile	loamy sands and loams with gravel interbeddings, clays at the depth of 2–3 m	prevailing surface leached	0.3–1.0	usually negligible quantities throughout the profile, locally gypsum
$E\mathrm{II}_1$	Periodically superaqual	loamy sands and loams with gravel interbeddings, clays at the depth of 1–2 m	prevailing evaporative	SO_4–Na CL–Na (only in the West) HCO_3–Ca (at points) 1.0–3.0 locally up to over 5.0	present sometimes in large quantities throughout the profile, accumulation horizons of the respective salts occur at different depths
$E\mathrm{II}_2$	Superaqual	very fine sands, sandy loams, clays	evaporative		
$E\mathrm{II}_3$	Subaqual	loams, clays	evaporative and inundated		present throughout the profile, locally precipitations of crystalline mirabilite and gypsum
$B\mathrm{I}$	Basalt rock outcrops and weathered stones			mainly HCO_3–Ca and HCO_3–Mg up to 0.5	mostly carbonates present below A_1; sulfates and chlorides locally only
$B\mathrm{I/II}$	Stony-fine-sand and fine-sand weathered basalts				
$C\mathrm{I}$	Rock outcrops and stony weathered waste of acid eruptive rocks				
$C\mathrm{I/II}$	Stony-gravel and sandy weathered waste of acid eruptive rocks				
$D\mathrm{I/II}$	Limestone and sandstone outcrops with carbonate binder				
$F\mathrm{II}$	Transit surfaces of precipitation waters and of deluvial accumulation				
$H\mathrm{I}$	Trans-superaqual landscape (sporadically). Details in the paper				

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watershed surfaces — slightly mineralized soil-ground waters, are taken up by the permafrost-transeluvial landscapes A_{II_1}). The exudative type of the water economy of these places accounts for the formation of soils wherein the horizons A_1 are being enriched with carbonate, sulfates and chlorides, while the horizons immediately above the permafrost as well as the frozen layers are deprived of these components. Of similar features are the surfaces located outside the granitoid landscapes but remaining under the influence of the poorly mineralized allochtonic waters. In the parts of valleys, in which the waters occur of somewhat higher mineralization and having a tendency to stagnate in the ground, there occur the permafrost-transaccumulative landscapes (A_{II_2}). In their total balance of matter the accumulation is marked of the substances supplied with soil solutions.

These parts of the valleys in which there are no conditions for the groundwater retention (no permafrost) and which are predisposed to episodic flow of surface waters, have been referred to as "transaccumulative" (A_{II_3}). A part of the substances carried with the surface flow is accumulated here, while the rest is carried away outside the borders of the landscape unit.

The lowest step of this cascade arrangement in the system of subordinated landscape units constitute the accumulative-alluvial surfaces (A_{II_4}). They have always constituted the place of accumulation of matter both solid and dissolved. In the under-slope parts of these units, within the deluvial series, there occur highly limy horizons of a depth sometimes exceeding 0.5 m. Location of the surface and the layered arrangement of the material, which is mainly associated with its deluvial origin, account for the hydrological features of this unit. In the gravel-sand interbedding at the depth of 2–3 m lenses of frozen ground were encountered along with capillary-saturated series. The location of this subtype landscape in the frontier zone of basalts and granitoids accounts for the heterogeneity of mineralogical features of the material accumulated here, while its form and spatial orientation — for the fact that it plays the role of a settling pond for material transported by air (prevailing winds from north-west). Since the non-carbonate humic horizons are subjected to deflation (and locally to rain wash as well), then the material accumulated in this way, for the most part very-fine sand, is noncarbonate and rich in humus. The depth of this type eolic-soil series sometimes exceeds 1.5 m.

Patches of permafrost eluvial-accumulative landscapes (A_{II_5}) take up, for most part, the lowest topographically places within this morphological unit. Hence, by the ground flow and, sporadically, by the surface flow, a part of the substance is carried off to the landscapes of the neoeluvial class.

The tectonic depression with neoeluvial landscapes is filled by se-

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diments of a considerable lithological differentiation. The beginning of their accumulation is associated here with the Cretaceous period. Three subtypes have been distinguished here of autonomous landscapes with a shortened eluvial profile. In the E_{I_1} subtype the depth of the gravel or gravel-sand cover-series comes up to about 3.0 m. Its upper part contains appreciable admixture of basalt material, while in the lower one — the granite and gneiss fragments prevail. The bottom of these formations rests on basalts, and, locally, on limestones. The upper soil horizons usually possess the mechanical composition of loam sands. In the subhumic horizons loam rolls of 10 cm in diameter were found. The loamy nature of the upper part of the soil favours the maintenance of the seasonal, suspended capillary moisture.

In the E_{I_2} subtype of the autonomous landscape the loam-sandy neoeluvia are of a depth exceeding 6 m. The type of the granulation and the presence of a few buried horizons with humus content, indicate the cyclic character of accumulation; the shallow leached soils in illuvial horizons contain 5–15% $CaCO_3$.

In the eluvial autonomous landscapes E_{I_3} there occur, at the depth of 2.5–3.0 m from the surface, dark grey (blackish) clays that contain 3–5.5% organic substance. The depth of this limnic series of sediments exceeds 3 m. It is covered by a series of sand-loamy and gravel formations. The bottom parts of the cover series are locally saturated with water or frozen. The presence of gypsum has been found in these landscapes.

The functioning of the subordinated neoeluvial landscapes is distinctly affected by the hydrological factor: they are supplied by ground and surface waters. For the most part these are permafrost landscapes.

In the periodically superaqual landscapes E_{II_1} the soil-weathering series remains sporadically in the state of capillary saturation. There is no permafrost within the soil profile. The upper soil series are usually formed of loamy and fine sands with gravel interbeddings. At the depth of 1.0–2.0 m there occur clays sometimes with ice crystals. The soil surface is often covered by salt efflorescences.

In the superadual landscapes E_{II_2} the lower horizons of soils remain within the range of a continuous capillary ascension of water. In the soils usually occur the reduction (gley) processes with H_2S. There is no compact soil cover. The surface is subjected to intense deflation. Among the tufts of halophile vegetation salt efflorescence is found.

The subaqual landscapes E_{II_3} function in summer as lakes, while in the drier seasons they are, in the majority of cases, transformed in the deflation bowls. The lake bowls are located in sediments of a heavy mechanical composition. The chemism of waters and the mineralogical composition of sediments are associated with the local hydrogeological conditions. On the borderline of these landscape units, patches of permafrost persist along with degraded forms resulting from the frost expansion of grounds.

The surfaces built of basalts and acid eruptive rocks (landscape subtypes *B* and *C*) can be regarded as systems having limited matter exchange with their environment. There occur here short slopes as well as numerous hollows with no outflow that constitute local bases of accumulation. The exchange with surrounding units occurs chiefly by air (deflation, blowing on, supply by rainfall). Surface drainage becomes pronounced solely on the borders of these units; slopes and alluvial fans are formed here.

The landscape of the paraeluvial class ($D_{I/II}$) take up small areas. They are linked with limestone and sandstone outcrops having a carbon cement.

The subordinated landscapes F_{II} include sets of mainly Pleistocene as well as accumulated in modern times alluvial fans (Klimek and Niedziałkowska 1977). Locally, in the front parts of the fans, there occur patches of soils with features resembling those of takyrs.

The subtype of the autonomous landscape H_I occurs in the depression of sporadic water course. There occurs here a discontinuous alluvial series composed of sand, gravel-sand or very fine-sand. The lower horizons of soils are for the most part capillarily saturated. A relatively low mineralization of ground waters results from the hydrological link of the valley with the source Sante Bulak (type of a seepage with an outflow of about 5 l/s). The source is located about 20 km to the north-west of the Haya Noor Lake.

In the present paper an outline is presented of the structure and functioning of the landscapes of a definite fragment of Mongolia's dry steppes. As analysis of the material collected permits, among other things, the following general conclusions to be drawn:

1. Degree of interdependences as well as complexity of connections between the respective components of the physico-geographic environment result here, to a large extent, from the palaeogeographic features of the region.

2. Geochemical studies enabled the determination of spatial arrangement of the landscape units as well as their functioning and interrelations.

3. The picture obtained of the natural circulation of substances in the landscape has an effect upon the existing and potential productivity of the geosystems under study.

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ALOJZY KOWALKOWSKI

VII. SOIL MOSAICS

Geological and orographical complexity of the Gurvan Turuu region causes the mosaics of the granulation and the depth of the weathered covers constituting the soil parent-rocks. These soils were explored and mapped out in the years 1977–1978.

METHODS

The soil mosaics have been mapped out in the 1:5000 scale by plotting the contours of the elementary soil areas with the aid of drillings to a depth of 150 cm. In the most typical elementary soil areas the soil profile has been described and the samples were taken from the horizons and beds for the purpose of laboratory analyses. The mechanical composition of the less than 0.1 mm fraction was areometrically determined by the Bouyoucos method modified by Prószyński, while that of the greater than 0.1 mm fraction — on sieves. The specific mass was determined by the pycnometric method. In 100 cm^3 samples of intact structure volumetric mass was determined. In the same samples the maximal capillary water capacity (CWC) as well as the field water capacity (FWC) were determined. Wilting moisture capacity (WM) was calculated from the product of the maximum hygroscopicity determined by the Nikolayev method, and the 1.34 index characteristic of the Mongolia's dry steppes (Andronikov and Shershukova 1978). The total soil porosity (TP) was calculated from the value of both the specific mass and the volumetric mass. The biologically useful water (WA) was computed from the difference between the field water capacity and the wilting moisture capacity while the air capacity (AC) — from the difference between the total porosity and the field water capacity. The soil reaction was determined potentiometrically by using glass and calomel electrodes, the $CaCO_3$ content — by the Scheibler volumetric method, the organic carbon — by the Tyurin method, and total nitrogen — by the Kjeldahl procedure.

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SOIL COVER BASIC STRUCTURES

The soil mosaics on the transect in question can be classified, depending upon the relief and geological structure, into three basic structure types: accumulative, denudational-accumulative and expositional (Kowalkowski *et al.* 1980c).

The soil cover of the transect's western part, on the flat terraces of the great tectonic depression (see chapter II and III) is little differentiated and has an accumulative structure. It is dominated by farinose, carbonate chestnut soils, typical of dry steppes, with pronounced features of fluvial-eolic accumulation upon the surface of depressed places.

The transect middle part situated on the edge of the depression, on the basalt covers and having diversified relief, is of the denudational-accumulative type of the soil cover structure. The essential landscape-shaping role in the soil cover structure has been played by the zonal chestnut soils with islets of intrazonal shallow permafrost solonchaks and deep permafrost chestnut solonchak-like soils.

The transect eastern part in the Bayan Ovo massif, on the edge of granitoid eastern plateau, has a structure corresponding to the denudational-expositional type with the vertical zonality of soils (Photo 10).

An increase with the height occurs, typical of the mountainous terrains, in the humus content in soil (Kowalkowski and Lomborinchen 1975; Kowalkowski 1980; Skiba 1980). In higher positions, screened against insolation, there are islets of relic chernozem (Kowalkowski 1981). Poorly developed chestnut lithosols occupy uplands and ridges. The soil mosaics are illustrated in the map (Fig. 23).

RELICT NATURE OF SOILS

The existing Mongolia's soil cover includes numerous features of the ancient humid cold climate (Dorzhgotov 1973; Kowalkowski and Lomborinchen 1975; Nogina *et al.* 1977; Nogina 1978b) as well as of dry continental climate with monsoonlike precipitation distribution. Numerous retardative soil properties have frequently a decisive effect upon the composition of plant communities (Vipper *et al.* 1976; Bannikova and Khudyakov 1976), the latter being better adjusted to the recent climate conditions than to the relic soil conditions, modified by the existing plant cover (Kowalkowski *et al.* 1980b; Kowalkowski 1981). The relict nature of soils on the transect is testified by the chestnut cover having the mean depth of 40–55 cm as well as by the underlying carbonate horizon, the carbonates having a fine crystalline farinose form.

The chestnut cover shows not only the uniform chestnut colouring typical of the dry steppe zones but also fairly homogeneous granulation, quite apart from the diverse mechanical composition of the underlying

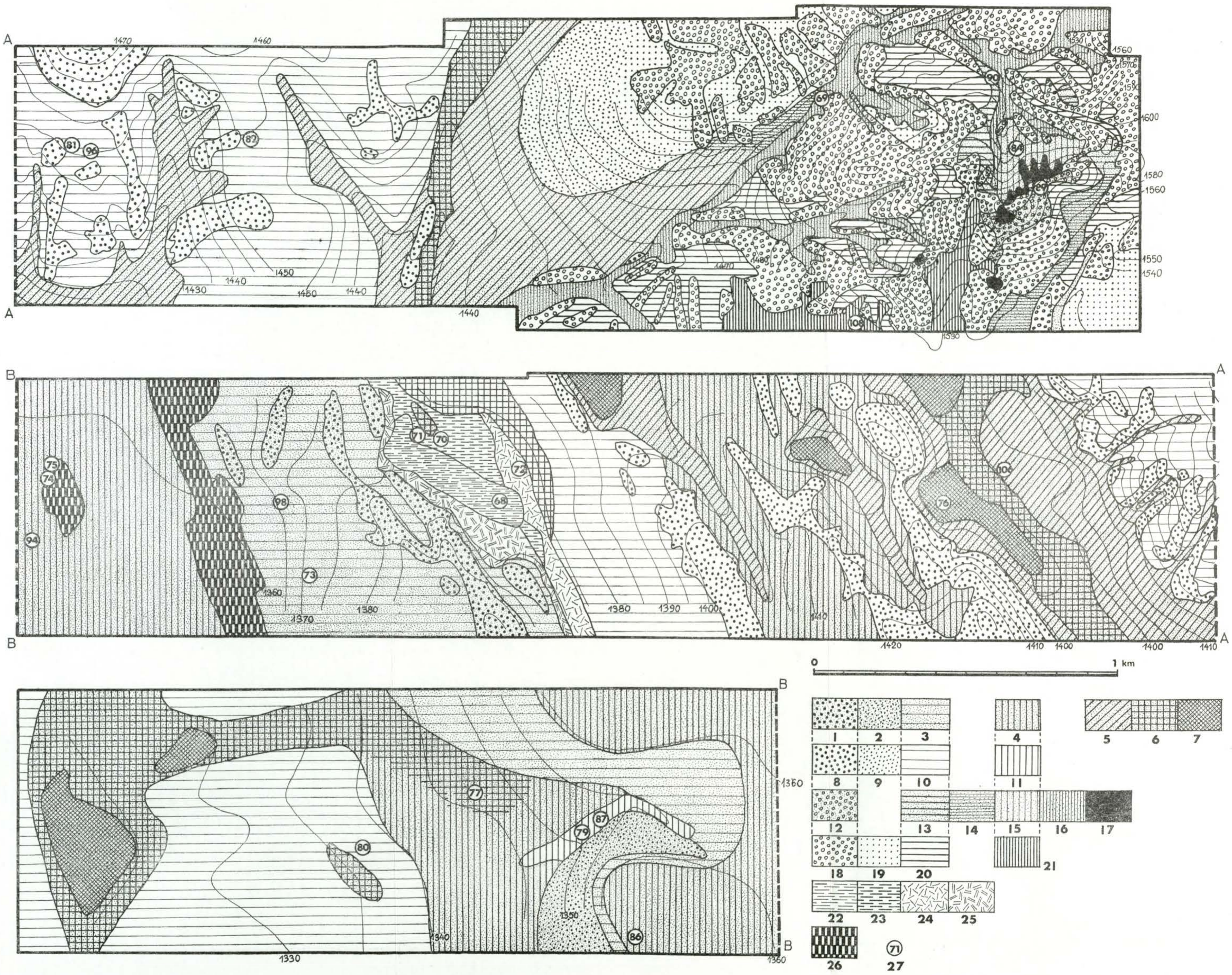

Fig. 23. Soils of the Gurvan Turuu transect

Zonal soils: *1* — denudated, stony dark chestnut soils; *2* — denudated, shallow dark chestnut soils; *3* — farinose-carbonate dark chestnuts of medium thickness; *4* — thick farinose-carbonate dark chestnut soils; *5* — thick and very thick, farinose-carbonate, deluvial dark chestnut soils; *6* — periodically permafrost-dark chestnut soils; *7* — deep permafrost dark chestnut solonchak-like gleys; *8* — denudated, stony chestnut soils; *9* — shallow, denudated farinose-carbonate chestnut soils; *10* — farinose-carbonate chestnuts of medium thickness; *11* — thick farinose-carbonate chestnut soils. Mountain soils; *12* — denudated, stony non-carbonate dark chestnut soils; *13* — farinose-carbonate dark chestnuts of medium thickness; *14* — deluvial, farinose-carbonate dark chestnuts of medium thickness; *15* — thick, farinose-carbonate dark chestnut soils; *16* — deluvial, very thick dark chestnut soils; *17* — stony non-carbonate chernozems; *18* — denudated, stony chestnut soils; *19* — shallow, farinose-carbonate chestnut soils; *20* — farinose-carbonate chestnuts of medium thickness; *21* — deluvial, very thick dark chestnut soils. Intrazonal soils: *22* — shallow permafrost tacyric solonchaks; *23* — shallow permafrost turf-meadow solonchaks; *24* — shallow permafrost turf-sedge solonchaks; *25* — semi-desert permafrost solonchaks; *26* — anthropogenic soils; *27* — described soil profiles

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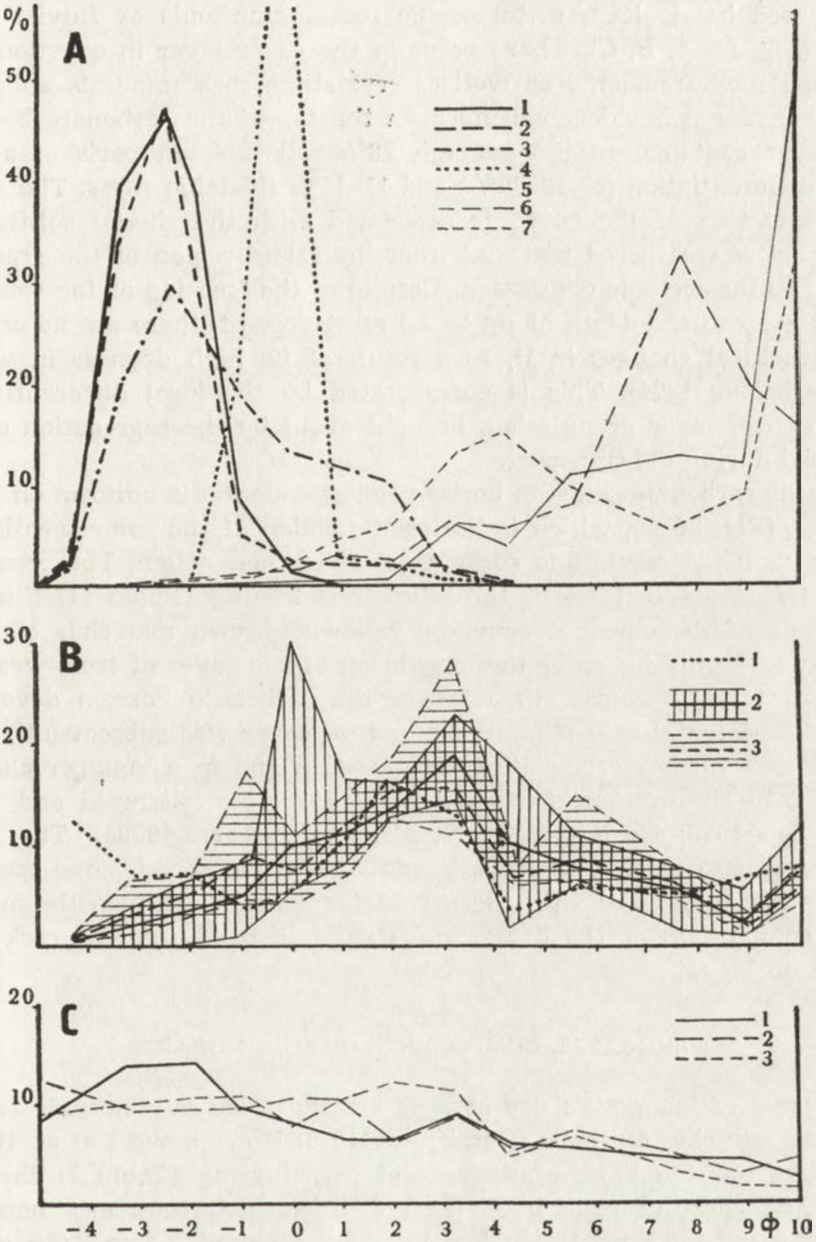

Fig. 24. Grain size curves of soils on the Gurvan Turuu transect

A — deflation covers (*1–4*) and fluvial sediments (*5–7*): *1* — in tectonic depression on terrace III (profile 077); *2* — in tectonic depression on terrace III (profile 085); *3* — on metamorphic rocks (profile 081); *4*, *5* — on tacyric solonchak (profile 068); *6* — in tectonic depression on terrace III (profile 077); *7* — in tectonic depression (profile 076). *B* — chestnut cover-layer: *1* — layer richer in skeletal parts; *2* — cover on basalts, mean from 8 samples, and maximal variations; *3* — cover on metamorphic rocks, mean from 4 samples, and maximal variations. *C* — coarse grained substrate in carbonate horizon: *1* — on basalts (8 samples); *2* — on granite rocks (3 samples); *3* — on metamorphic rocks (3 samples)

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weathered basalt lava, metamorphic rocks, granitoids or fluvial black clays (Fig. 24 *A*, *B*, *C*). There occur in the cover layer in question well rounded rock fragments as well as crystalline rock minerals and, now and then, large boulders resting upon the top of the carbonate horizon; the layer contains, on the average, 20% soil skeleton parts of a high local differentiation (of 16–32%) and 11–15% floatable parts. The chestnut formation of the cover is associated with the fluvial solifluction transport of weathered material from the raised region of the granitoid massif to the tectonic depression. Despite of the freezing of the weathered material to the depth of up to 3.5 m at present, there are no cryogenic structural changes in it, as a result of its high dryness in winter (Tumerbaatar 1974). This is corroborated by the local differentiations in the cover-layer granulation, brought about by the segregation of the material during the transport.

In the carbonate skeleton horizon the granulation is uniform on a large area (Fig. 24 *C*), which indicates the action of the same weathering factor upon the crystalline rocks apart from their origin. The occurrence in the clay substrates of the relict frost fissures (Photo 11) filled by materials of the chestnut cover or yellowish-brown materials of cryogenic weathering indicates the overthrust of the cover of frost-weathered material of a moist climate over the carbonate horizon developed in the continental arid climate. The above cover was subsequently subjected to a further cryogenic transformation and in a younger climatic facies into chestnut soils (Kowalkowski 1975; Kowalkowski and Lomborinchen 1975; Nogina 1978b; Kowalkowski *et al.* 1980a). The latest climatic phase is characterized by deflation covers and slope creeping of weathered material with the granulation dependent upon the mechanical composition of the cover, and the depth of the parent rock (Fig. 24, Photo 12, 13).

PRINCIPAL COMPONENTS OF SOIL MOSAICS

Typical of Mongolia's dry steppes are the zonal automorphic farinose-carbonate chestnut soils (Dorzhgotov 1976; Kowalkowski *et al.* 1980c). Although, on the basis of differences in colouring (Table 7) chestnut and dark chestnut soils have been distinguished, they are, however, characterized by a relatively low humus content of 2.1 to 3.0% in the humus horizon of a depth of 8 to 26 cm. These features correspond to the criteria of the chestnut and light chestnut soils (Nogina *et al.* 1977) or to the meadow-chestnut ones turning into steppes (Dorzhgotov 1976; Andronikov and Shershukova 1978). Dark coloured lower part of the humus A_k horizon common on large areas of chestnut soils testifies to the relict nature of the meadow-chestnut soils (Dorzhgotov 1976; Nogina *et al.* 1977; Nogina 1978b; Undral 1978; Dorzhgotov and Kowalkow-

Table 7. Characteristics of some soil-properties in A humus horizon

Profile	Thickness in cm	Colour according to Munsell	pH in KCl	$CaCO_3$ [%]	C_{org} [%]	Humus [%]	N_{total} [%]	C:N
73	10	7.5YR 4/4	8.3	0	1.57	2.70	0.15	10
74	20	5YR 4/3	8.0	0	1.17	2,02	0.14	8
75	16	7.5YR 4/3	8.0	0	1.20	2.07	0.18	7
080	8	10YR 3/3	8.5	0	1.73	2.98	0.15	11
081	26	10YR 4/4-6	7.8	0	1.25	2.16	0.12	10
076	10	7.5Y 5/2	7.2	0.6	2.17	3.74	0.19	11
077	5	7.5Y 4/2-3	6.8	0	1.47	2.53	0.20	7
068	15	2.5Y 5/1	9.6	20.1	1.35	2.32	0.09	16
070	20	2.5Y 3-4/2	8.9	12.0	0.89	1.53	0.09	10
071	34	7.5Y 3/4	8.4	4.9	2.13	3.67	0.20	10
072	35	2.5Y 3/2	8.1	12.8	5.32	9.17	0,51	10
084	37	7.5YR 3/3-4	6.4	0	2.88	4.96	0.32	9
088	30	10YR 3/2	6.4	0	4.04	6.96	0.31	13
069	105	10YR 3/2	9.4	0.1	2.81	4.84	0.22	13
087	190	7.5YR 3/3	5.1	0	1.70	2.93	0.21	8
090	110	10YR 3/3	6.0	0	3.15	5.43	0.33	10

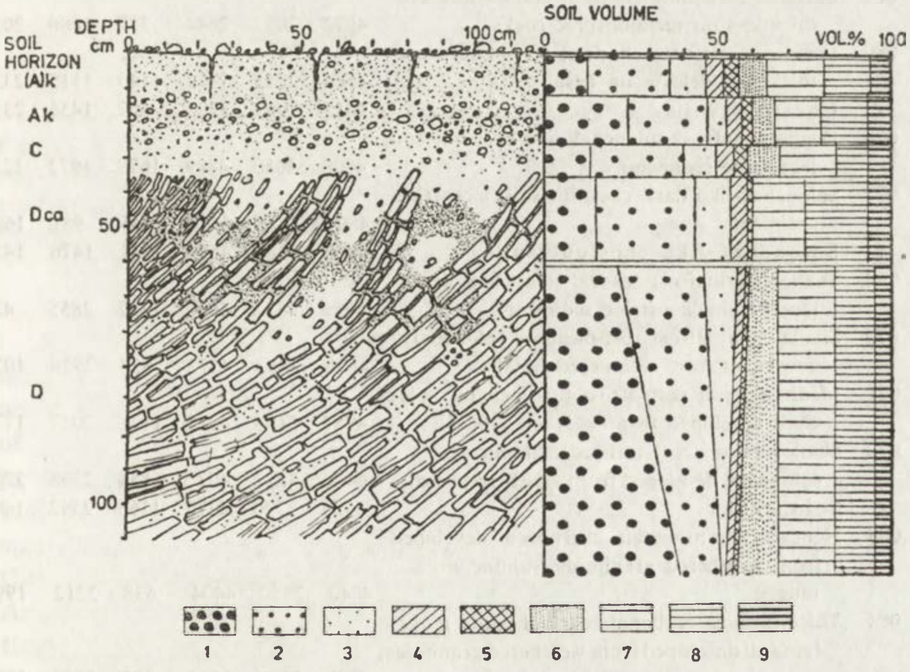

Fig. 25. Profile structure of chestnut soil farinose carbonateous (pit 081) developed on metamorphic rocks, as well as profile distribution of granulation and water-air conditions

Fractions: *1* — 1.0 mm; *2* — 1.0—0.1; *3* — 0.1—0.01; *4* — 0.01—0.002; *5* — 0.002, *6* — air capacity; *7* — capillary water capacity; *8* — field water capacity; *9* — wilting moisture capacity ski 1981). High alkalization of the non-carbonate part of the profile to pH_{KCl} of 7.8 to 8.5 (Table 7), as well as the occurrence of the crust formation layer and of the deflation covers points out, however, the recent processes typical of the desert steppes (Yunatov 1974; Lavrenko and Sumerina 1977). Both the prolonged soil droughts from late summer

Table 8. Water- and air capacity in soils of the Gurvan Turuu transect in the 100 cm thick layer

Profile	Type and kind of soil	Capacity in m^3/ha					
		TP	FWC	CWC	WM	WA	AC
085	Thick farinose-carbonate dark chestnut soil, deluvial covers on basalts	4809	2677	3878	567	2110	2132
074	Thick farinose-carbonate dark chestnut soil, deluvial covers on basalts	4548	1636	3068	364	1272	2912
075	Thick farinose-carbonate dark chestnut soil, deluvial covers on basalts	3672	2057	3596	443	1614	1462
073	Farinose-carbonate dark chestnut soil of medium thickness on basalts	5069	2016	2893	615	1401	3053
$\bar{x}$	Dark chestnut soils	4524	2069	3359	497	1599	2389
081	Farinose-carbonate chestnut soil of medium thickness on metamorphic rocks	4590	1848	3536	325	1573	2692
082	Farinose-carbonate chestnut soil of medium thickness on metamorphic rocks	4072	2037	2644	357	1680	2035
080	Farinose-carbonate chestnut soil of medium thickness, deluvia on basalts	4584	2255	3484	1140	1115	2329
$\bar{x}$	Chestnut soils	4415	2063	3225	607	1456	2352
076	Deep-permafrost solonchak-like chestnut soil, lacustrine sediments	4808	3650	4889	1678	1972	1258
077	Solonchak-like dark chestnut soil, lacustrine sediments	4809	3126	4430	2145	981	1683
$\bar{x}$	Solonchak-like chestnut soils	4808	3388	4659	1911	1476	1421
068	Shallow-permafrost takyric solonchak developed from lacustrine sediments	5039	4612	4693	1757	2855	427
070	Shallow-permafrost turf-meadow solonchak developed from weathered basalts	4870	3862	4572	934	2928	1028
071	Medium-depth permafrost turf-meadow solonchak developed from weathered basalts	4957	3185	4215	1128	2057	1772
072	Shallow-permafrost turf-sedge thufuric solonchak developed from weathered basalts	6426	3222	4022	854	2368	3204
$\bar{x}$	Solonchaks	5323	3720	4375	1168	2582	1603
088	Noncarbonte mountain chernozem developed from weathered granitoids, solifluction tongue	4840	2850	4404	638	2212	1990
084	Thick farinose-carbonate dark chestnut mountain soil developed from weathered granitoids, slope cover	4750	2790	3594	630	2160	1960
069	Very thick deluvial dark chestnut soils	4977	2146	4238	511	1635	2831
090	Very thick deluvial dark chestnut soils	4312	1418	2042	372	1046	2894
087	Very thick deluvial chestnut soil	3043	1399	2655	260	1139	1644
$\bar{x}$	Deluvial chestnut soils	4111	1654	2978	381	1273	2456

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to spring, and the high soil air capacity (53% of soil porosity) favour the thermogradient water-migration and condensation in soil on flat terrains (Kulik 1979). The above mentioned features as well as the relatively low wilting moisture capacity (11–14% of soil porosity, Fig. 25, Table 8, profiles 074, 070, 080, 081, 082, 085) determine the species composition and the coverage degree of the dry steppe vegetation.

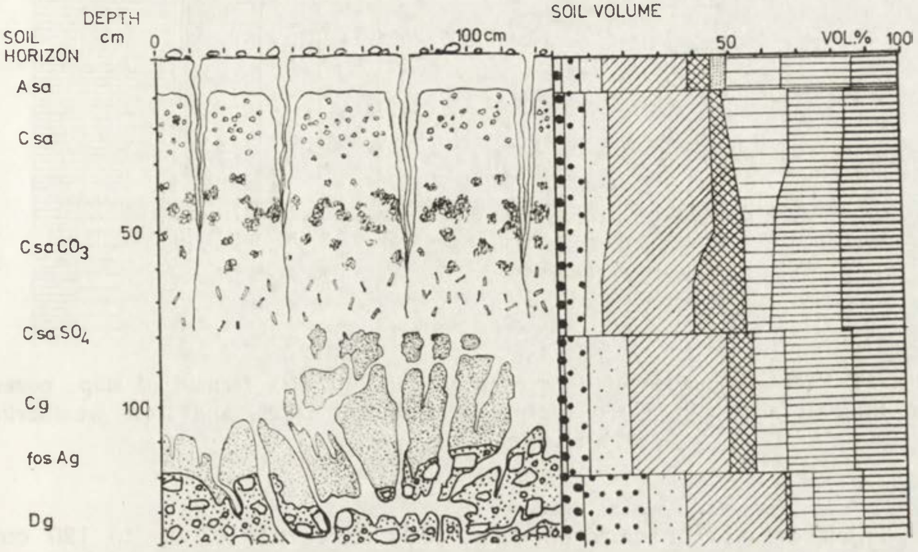

Fig. 26. Profile structure of solonchak chestnut soil (pit 076) formed of lacustrine sediments on fossile soil (fos Ag) wasted by frost processes. In the upper part, the younger cover of a depth of about 80 cm, with the system of two fissure-generations of the drying polygons. In the older material: successively horizons of salinization — sa, carbonate $CsaCO_3$ and gypsum $CsaSO_4$ precipitation
For explanation see Fig. 25

In the case of high content of floatable parts as well as of very fine sand fractions there are formed solonchak or solonetz chestnut soils with saline horizons (Fig. 26), of high wilting moisture capacity (20–41% of soil porosity) and low air capacity (24–35% of soil porosity, Table 8, profiles 076, 077). A relatively high humus content of 2.5 to 3.7%, neutral and alkaline reaction with pH of 6.8 to 7.2 and the possibility of sporadic inundation by precipitation waters make these soils resemble the solonchak and solonetz meadow-chestnut soils (Nogina *et al.* 1977; Andronikov and Shershukova 1978). According to the author's observations appreciable differences occur in the vegetation on these soils.

The possibility of the occurrence in the dry steppe of islets of dark chestnut soils is confirmed by the presence of dark chestnut farinose-carbonate soil on the northern slope of Bayan Ovo (Fig. 27), the soil containing about 5% of humus in the horizon A of a pH of 6.4 (Table 7).

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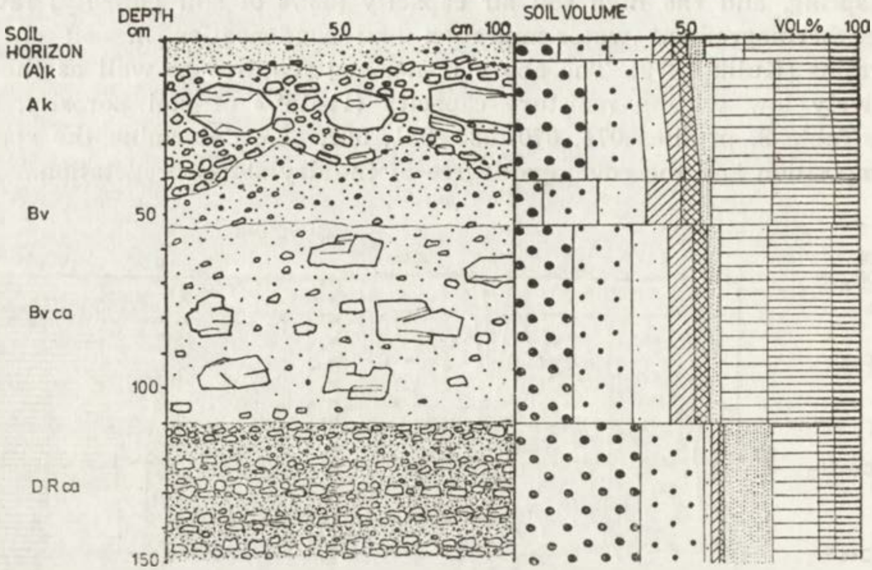

Fig. 27. Profile structure of dark chestnut soil (pit 084), formed of slope covers of different age with a red horizon carbonateous DRca, and frost weathering horizon carbonateous Bvca

For explanation see Fig. 25

Thick deluvia of dark chestnut soils (thickness of up to 190 cm, 3–5.4% of humus, pH of 5.1 to 9, Table 7, profiles 069, 087, 090) accumulated in the depressions on fossil dark chestnut farinose-carbonate soils can be regarded as indicators of transformation that took place in the cover of the Mongolia's zonal soils. These soils possess the most advantageous water properties with the lowest wilting moisture capacity amounting, on the average, to 9.3% of total porosity, and the highest air capacity — on the average of 60% porosity (Table 8) thus giving rise to an exuberant steppe vegetation. In the case of the occurrence of shallow soil-ground water, the above soils become saline.

To the interesting relicts of the more humid cold climate belong the islets of the mountainous non-carbonate chernozem in both solifluction niches and tongues on the northern slopes of Bayan Ovo; they are also found in similar position in other areas of the dry steppe zone (Andronikov and Shershukova 1978). The chernozem islets protruding a long way to the south are rich in humus to about 7%, with water-physical properties similar to the mountain dark chestnut soil (Table 8, profile 088).

A separate group of cryohydromorphic intra-zonal soils constitutes the associations of tacyric turf-meadow, turf-sedge and semi-desert solonchaks formed in depressions with shallow permafrost layer, of a temperature of −0.1 to −0.4°C and a water content of 45 to 75%. The cha-

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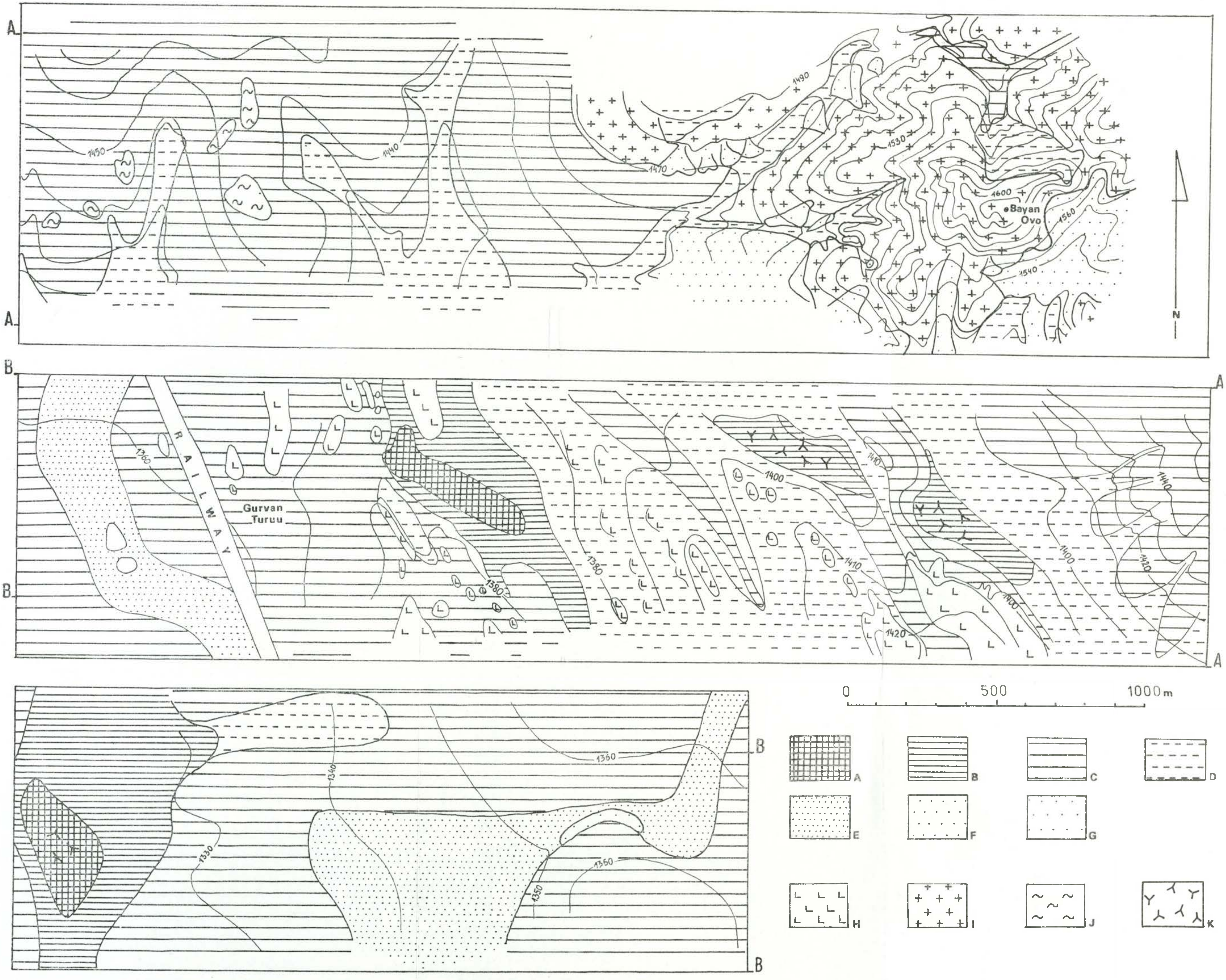

Fig. 17. Permeability of surface deposits within the transect

Infiltration capacity of the ground: *A* — 0, B — 0–1 mm/min, *C* — 1–2 mm/min, *D* — 2–3 mm/min, *E* — 3–4 mm/min, *F* — 4–5 mm/min, *G* — $>$ 5 mm/min; *H* — outcrops of basalts; *I* — outcrops of granites; *J* — outcrops of metamorphic rocks; *K* — polygons of cryogenic and thermal fissures

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racteristic of these soils, highly damp throughout the vegetational period, are the existing processes of congelicontraction and congeliturbation including the formation of thufur fields and periodical pingo as well as the thixotropic layer with illuvial-humic horizon above the permafrost (Kowalkowski *et al.* 1980c). A high carbonate content in the surface horizons amounting from 5 up to over 20% (Table 7) with constant moisture close to the full capillary water capacity, and under prevailing anaerobic conditions, points out a high concentration of CO_2 in these soils, that is readily bonded to $CaCO_3$. As a result of the continuous frost action the solonchaks in question have a high total porosity (Fig. 28, Table 8, profiles 068, 070, 071, 072). At a relatively high wilting moisture capacity (22% of soil porosity), available water capacity of the above solonchaks is high and amounts to 48% total porosity. Characteristic is, however, the high horizontal variability that is characterized by the humus content varying from 1.5 to 10% (Table 7). The salinity of the soils under consideration (pH of 8.1–9.6) and the wet permafrost result in high dispersion of the mineral materials, and, in vegetationless places, high eolian and water erodibility.

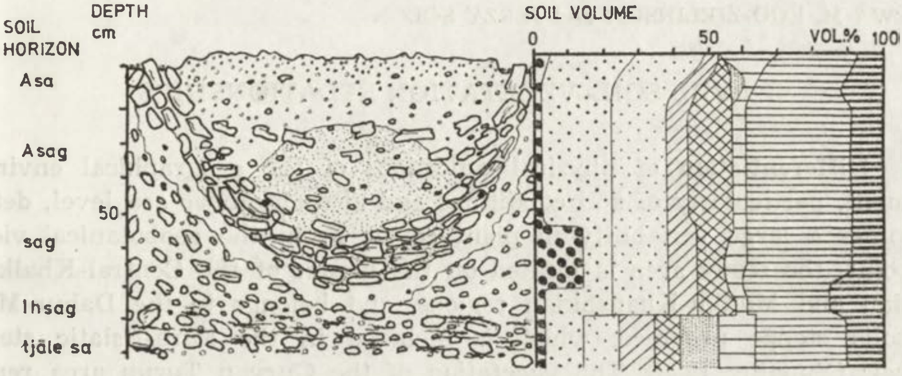

Fig. 28. Profile structure of turf-meadow solonchak (pit 070) formed of weathered basalts with cryogenic structures and illuvial-humus horizon (Ihsag), as well as profile distribution of granulation and of water-air conditions. The Asag, sag and Ihsag horizons are thixotropic. Permafrost from the depth of 80 cm

For explanation see Fig. 25

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VIII. SOIL–VEGETATION RELATIONSHIPS

Differentiation of physical conditions of the geographical environment, particularly of soil conditions and altitude above sea level, determines a large variability in plant cover. From the geobotanical viewpoint, the study area is located on the border of the Central-Khalkhasian and Munku-Khanshkian regions, and belongs to the Dahur-Mongolia steppe province, which is included in the Euro-Asiatic steppe belt (Yunatov 1950). The vegetation of the Gurvan Turuu area represents the southern variant of the dry steppes (Yunatov 1952; Yunatov and Dasniam 1979). It follows from the cartographic data and the authors' observations that the boundary between the northern and southern variants of the dry steppes is about 20–30 km north of Gurvan Turuu, near Maint Ula. The ratio of precipitation to moisture deficiency in the atmosphere, ranging from 0.10 to 0.15, classifies this area as insufficiently humid, i.e. semiarid. Annual precipitation of 180–250 mm meets plant requirements for water in 22–33%, and consequently only 40–60% of this area is covered with vegetation. The connection of this area with the southern subzone is proved by the frequent occurrence of the shrub *Caragana microphylla* (Pall.) Lam., which does not occur in the northern subzone of dry steppes.

This paper is an attempt to find relationships between the mosaic of soils and their plant cover on the Gurvan Turuu transect. The methods of soil examination are described in chapter VII. Plant cover was analysed, individual plants were collected and vegetation of some parts of the transect was mapped.

According to the soil types, three main types of plant communities can be distinguished on the transect. These are dry steppes on chestnut soil (forms with *C. microphylla* and without *C. microphylla)*, halophytes growing on solonchak soils and shrub-meadow-steppes vegetation on stony chestnut soils of the Bayan Ovo massif (Fig. 29).

The communities of dry steppes cover the largest area of the transect, and they generally determine the character of the landscape (Fig.

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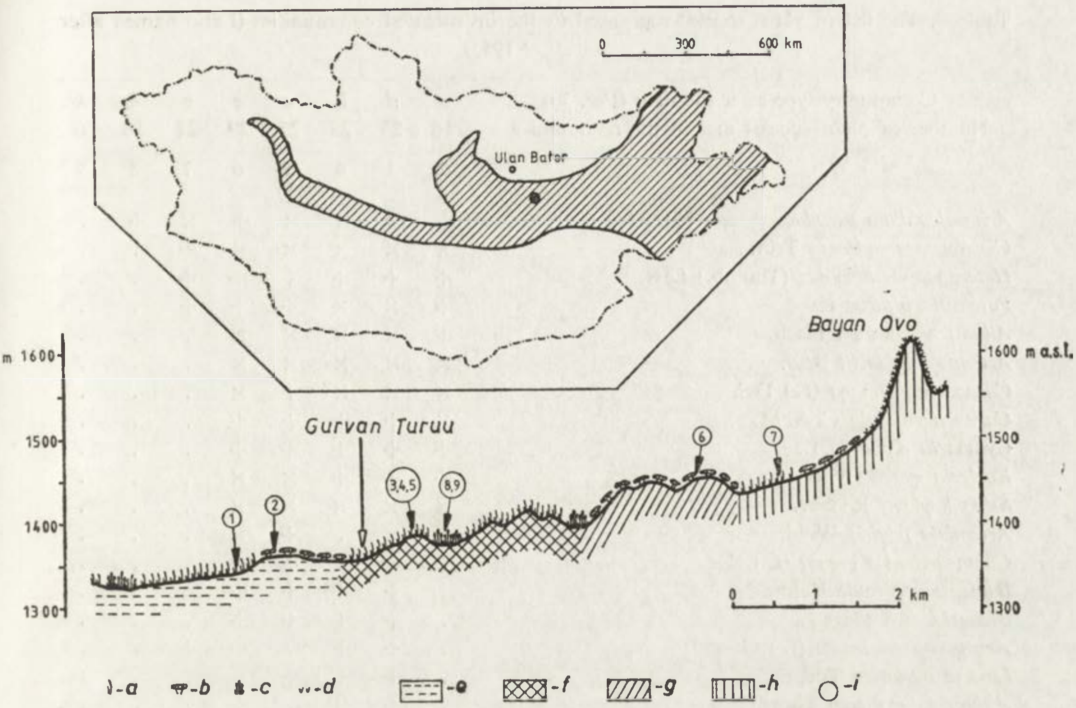

Fig. 29. A general pattern of the diversity of plant communities on the Gurvan Turuu transect in relation to geological substratum of relief. Upper part of the graph represents the location of the study area within the range of the southern subzone of dry steppes in Mongolia

a — dry steppes, form without *Caragana microphylla*; *b* — dry steppes, form with *Caragana microphylla*; *c* — halophilous vegetation; *d* — vegetation of the Bayan Ovo massif; *e* — deluvial substratum; *f* — basalt substratum; *g* — metamorphic substratum; *h* — granitoid substratum; *i* — study sites

29, forms *a* and *b*). They are dominated by *Aneurolepidium pseudoagropyrum* (= *Leymus chinensis*), *Cleistogenes sqarrosa*, *Allium bidentatum*, *Artemisia adamsii*, *Caragana pygmaea*, and *Stipa krylovii*. In different variants of dry steppe communities, some other species can also occur in rather large proportions. A distinct form of steppes is represented by the communities with a low shrub, *Caragana microphylla*, forming dense clumps. Due to the presence of this shrub they have a specific physiognomy and many other traits.

On the basis of physiognomic differences and floral composition of plant communities, three types of steppes without *C. microphylla* were distinguished (Table 9, types *a*, *b* and *c*) and two types with this shrub (Table 9, types *d* and *e*). In the western, lowest part of the transect, on deluvial materials in a tectonic depression, there are steppes without *C. microphylla*, characterized by floral scarcity (Table 9, type *a*), particularly by the absence of the species from the northern subzone of dry

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Table 9. The list of plant species registered in the investigated communities (Latin names after Grubov 1955)

Community type after the map (Fig. 30)	*a*	*d*	*b*	*c*	*e*	*g*	*h*	*k*
Number of plant species met in the community	16	23	28	25	29	21	18	6
1	2	3	4	5	6	7	8	9
Aneurolepidium pseudogropyrum Nevski	+	×	×	×	+	×	+	.
Cleistogenes sqarrosa Trin.	×	×	×	×	×	+	.	.
Heteropappus hispidus (Thumb.) Less.	+	+	+	+	+	+	.	.
Potentilla bifurca L.	+	×	×	+	+	+	.	.
Allium bidentatum Fisch.	+	×	×	×	×	.	.	.
Artemisia adamsii Bess.	×	×	×	×	×	.	.	.
Caragana pygmaea (L.) DC.	×	×	×	+	×	.	.	.
Carex duriuscula C. A. M.	×	+	+	+	+	.	.	.
Cymbaria dahurica L.	+	+	+	+	+	.	.	.
Koeleria gracilis Pers.	+	+	+	×	×	.	.	.
Stipa krylovii Roshev.	×	×	×	×	×	.	.	.
Artemisia frigida Willd.	+	×	.	+	×	.	.	.
Chamaerrhodos erecta (L.) Bge.	+	+	.	+	+	.	.	.
Bupleurum bicaule Helm.	.	+	+	+	+	.	.	.
Stellaria dichotoma L.	.	+	+	+	+	.	.	.
Agropyron cristatum (L.) Gaertn.	.	+	+	.	+	+	.	.
Linaria buriatica Turcz.	.	+	+	+	.	.	.	.
Allium polyrrhizum Turcz.	.	+	×	.	+	.	.	.
Asparagus dahuricus Fisch.	.	.	+	+	+	.	.	.
Artemisia scoparia W. et K.	+	.	+	.	.	+	.	.
Convolvulus ammani Desr.	+	.	+	.	.	.	.	.
Oxytropis oxyphylla (Pall.) DC.	+	.	.	.	.	+	.	.
Allium mongolicum Rgl.	.	+	+	.	.	.	.	.
Pedicularis flava Pall.	.	+	+	.	.	.	.	.
Scorzonera austriaca Willd.	.	+	+	.	.	.	.	.
Caragana microphylla (Pall.) Lam.	.	×	.	.	×	.	.	.
Saussurea salicifolia DC.	.	+	.	.	+	.	.	.
Oxytropis pumilla Fisch.	.	.	+	+	.	.	.	.
Haplophyllum dauricum (L.) G. Don.	.	.	+	.	+	.	.	.
Thermopsis lanceolata R. Br.	.	.	+	.	.	.	+	.
Dontostemon micranthus C. A. M.	.	.	.	+	+	.	.	.
Festuca dahurica Krecz. et Bobr.	.	.	.	+	+	.	.	.
Chenopodium acuminatum Willd.	.	.	.	+	.	+	.	.
Salsola collina Pall.	.	.	.	.	+	×	+	.
Hordeum brevisubulatum (Trin.) Link	.	.	.	.	.	+	+	.
Iris biglumis Vahl.	.	.	.	.	.	+	×	.
Carex enervis C. A. M.	.	.	.	.	.	+	×	.
Puccinlla tenuiflora (Griseb.) Scribn.	.	.	.	.	.	+	+	+
Saussurea salsa (Pall.) Spreng.	.	.	.	.	.	+	+	.
Polygonum sibiricum Laxm.	.	.	.	.	.	×	+	.
Taraxacum collinum (Turcz.) DC.	.	.	.	.	.	+	×	.
Chenopodium album L.	.	.	.	.	.	+	.	×
Saussurea papposa Turcz.	.	.	.	.	.	.	+	×
Arctogeron gramineum (L.) DC.	.	.	+	.	.	.	.	.
Astragalus mongolicus Bge.	.	.	+	.	.	.	.	.

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Table 9 (cont.)

1	2	3	4	5	6	7	8	9
Salsola monoptera Bge.	.	.	+	.	.	.	.	.
Artemisia dracunculus L.	.	.	.	+	.	.	.	.
Potentilla conferta Bge.	.	.	.	+	.	.	.	.
Potentilla sericea L.	.	.	.	+	.	.	.	.
Arenaria capillaris Poir.	.	.	.	.	+	.	.	.
Astragalus melilotoides Pall.	.	.	.	.	+	.	.	.
Oxytropis microphylla DC.	.	.	.	.	+	.	.	.
Ptilotrichum canescens C. A. M.	.	.	.	.	+	.	.	.
Sibbaldianthe adpressa (Bge.) Juz.	.	.	.	.	+	.	.	.
Artemisia siversiana Willd.	.	.	.	.	.	+	.	.
Lasiagrostis splendens (Trin.) Kunth.	.	.	.	.	.	×	.	.
Salsola pestifer A. Nelson	.	.	.	.	.	+	.	.
Astragalus adsurgens Pall.	.	.	.	.	.	+	.	.
Artemisia anethifolia Web.	.	.	.	.	.	.	+	.
Carex sabulosa Turcz.	.	.	.	.	.	.	+	.
Glaux maritima L.	.	.	.	.	.	.	+	.
Halerpestes ruthenica (Jacq.) Ovcz.	.	.	.	.	.	.	×	.
Halerpestes salsuginosa (Pall.) Greene.	.	.	.	.	.	.	×	.
Potentilla anserina L.	.	.	.	.	.	.	×	.
Oxytropis glabra (Lam.) DC.	.	.	.	.	.	.	+	.
Atriplex sibirica L.	.	.	.	.	.	.	.	+
Puccinella roshevitsiana (Schischk.) Krecz.	.	.	.	.	.	.	.	+
Suaeda corniculata (C. A. M.) Bge.	.	.	.	.	.	.	.	+

+ presence of the species; × dominant species

steppes. At the border of the depression, within the zone of basalts, the dry steppes have a distinct physiognomy due to the occurrence of the shrub *Caragana pygmaea*, which can grow to about 1 m high and does not form dense clumps. Their flora is rich and characterized by such species as *Pedicularis flava*, *Arctogeron gramineum*, and others (Table 9, type *b*).

Steppes without *C. microphylla* also occur on deep chestnut deluvial soils on weathered granitoids and metamorphic rocks, which occur on the transect. This form of steppe is characterized by a uniform structure and a small proportion of *C. pygmaea*, and also, in contrast to the other forms, by the occurrence of *Festuca dahurica* (Table 9, type *c*).

Caragana steppes (with *C. microphylla*) occur on the transect in two situations: on denuded stony-gravel hills within the range of basalts on metamorphic materials and in lower parts of the granitic Bayan Ovo massif. These forms of steppes differ from each other in the structure of *C. microphylla* clumps and also due to the fact that in the higher, eastern part of the transect there are such species as *Festuca dahurica*, *Asparagus dahuricus*, and others (Table 9, type e).

In general, in the steppe communities on the transect, the proportion of the species having the centre of their occurrence in the northern subzone of dry steppes, or in the forest-steppe zone, increases when one moves from lower to higher elevations. They include, for example *Asparagus dahuricus*, *Festuca dahurica*, *Linaria buriatica*, and *Stellaria dichotoma*.

Another group consists of the communities of halophytes (Fig. 29, type *c*). They cover moist and salty depressions, usually with permafrost in subsoil, and they represent a typical component of the landscape of dry steppes, though they occupy relatively small areas. The floral distinctness of halophilous communities is very high (Table 9, types *g*, *h* and *k*). A few types of these communities can be distinguished. The most common, showing a specific physiognomy, is the community of tall grass *Lasiagrostis splendens*, which reaches 1.5–2.0 m under favourable conditions, usually growing on marginal parts of solonchak soils (Table 9, type *g*; Photo 14).

The next community with characteristic species composition and distinct physiognomy is represented by wet pastures on permanently wet sites with permafrost close to the soil surface. This community consists of *Carex enervis*, *Iris biglumis*, *Potentilla anserina*, *Taraxacum collinum*, *Halerpestes ruthenica*, and *Halerpestes salsuginosa* (Table 9, type *h*). Although occurring infrequently, it seems to be characteristic of central-Asiatic steppes and deserts. Similar communities were described in northern Mongolia (Petrov 1963).

A special form of the halophilous vegetation has developed on permafrost takyric solonchak soils within the lake depression, which is seasonally filled with water. Plant communities there are diversified according to the concentration of salt, rate of the eolian and water erosion, water relations, and other factors. The greatest part of the bottom of this lake is occupied by a loose and very poor community dominated by *Chenopodium album*, and in marginal parts by *Saussurea papposa*. In addition, communities associated with vauclusian springs occur in the lake depression.

Halophilous vegetation also covers flat depression on chestnut and solonchak soils, which are occasionally flooded with rain water. Plant communities covering these sites of the transect are dominated by the sedge *Carex sp.* They were not studied in detail.

The third community type, after the communities of dry steppes and halophytes, is the vegetation of the upper slopes of the Bayan Ovo massif (Fig. 29, type *d*). The floral composition of the diversified plant communities of this area was not studied in detail. On the basis of their physiognomy, however, a few basic types can be distinguished:

— dry steppes on lower parts of the slopes, and also on rocky and stony southern slopes,

— short grass communities on sites particularly exposed to wind action,

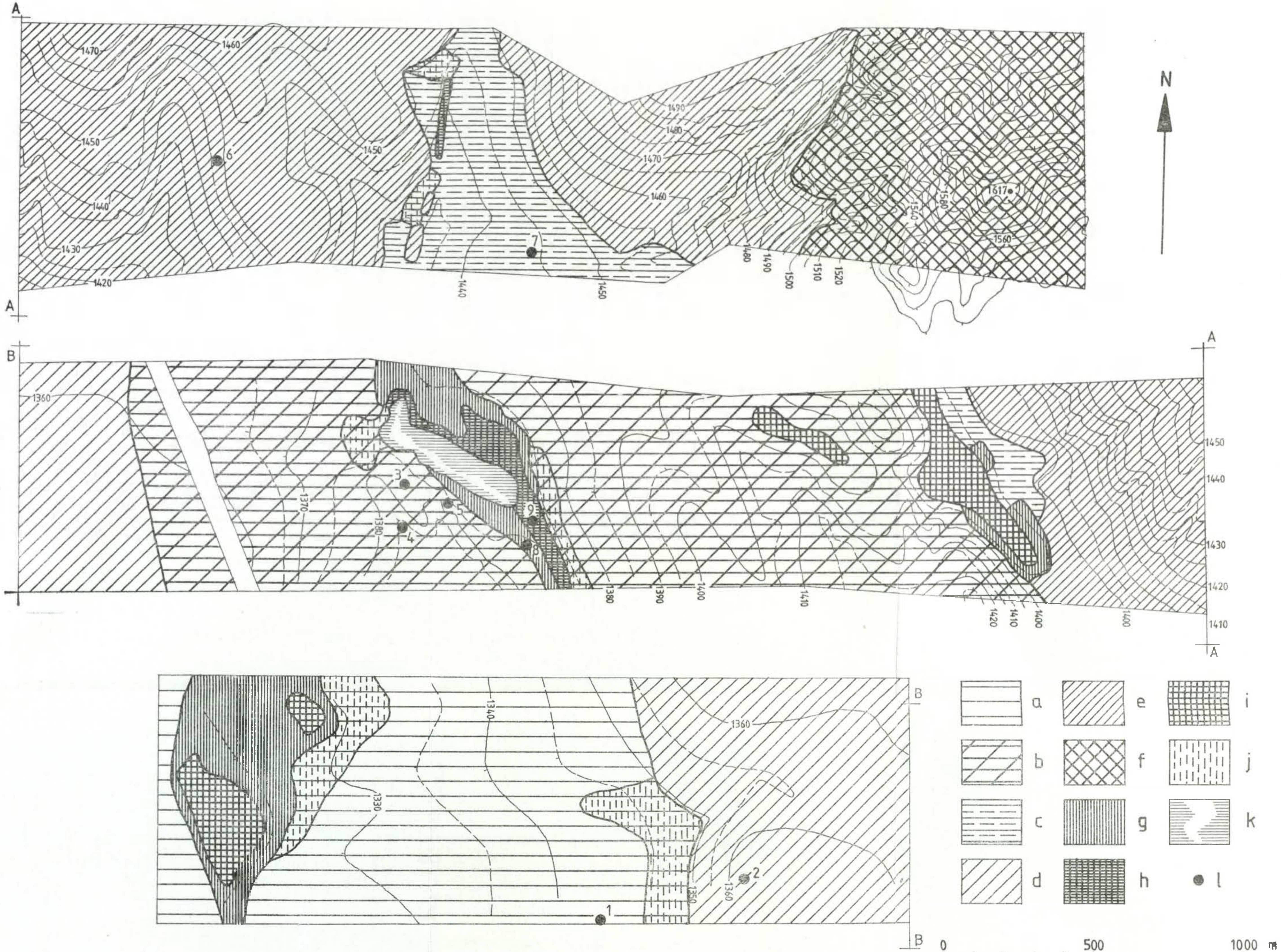

Fig. 30. Map of vegetation on the Gurvan Turuu transect

a — poor dry steppe (without *Caragana microphylla*) on deluvial substratum; *b* — dry steppe (without *Caragana microphylla*) on basalt substratum; *c* — dry steppe (without *Caragana microphylla*) on metamorphic and granitoid substratum; *d* — dry steppe with *Caragana microphylla* on deluvial substratum; *e* — dry steppe with *Caragana microphylla* on metamorphic and granitoid substratum; *f* — complex of plant communities of the Bayan Ovo massif; *g* — community of the grass *Lasiagrostis splendens*; *h* — *Carex enervis–Iris biglumis* community; *i* — community of halophytes with not described floral composition; *j* — loose bunches of *Lasiagrostis splendens* in steppe communities of *a*, *b*, *c* types; *k* — ephemeral halophilous vegetation of the basin of the temporary lake; *l* — study sites, numbered according to the order of their establishment

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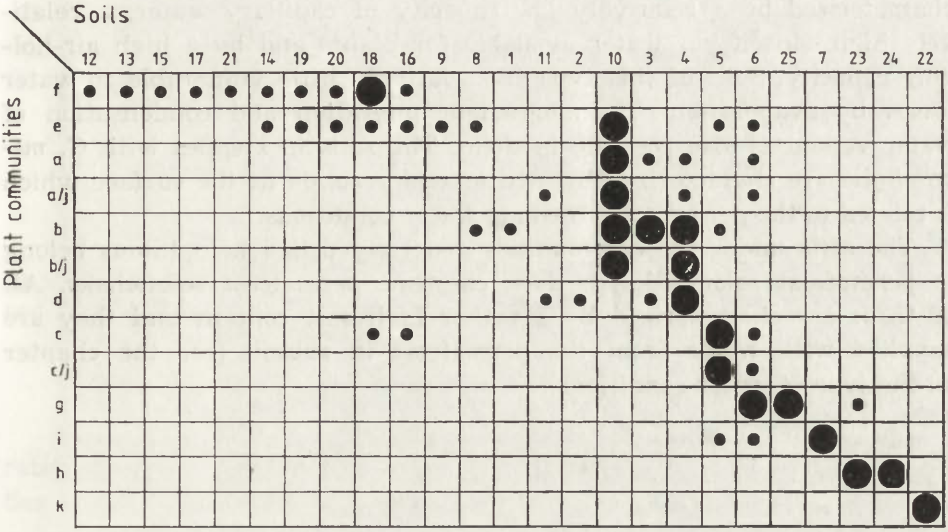

Fig. 31. Relationships between soil types and plant communities. Large circles denote a frequent correlation, and small circles denote a less common or occasional relation. Based on the comparison of the maps of plant communities (Fig. 30) and soils (Fig. 23). Plant communities (*a–k*) denoted as in Fig. 30. Soil types (*1–25*) denoted as on the soil map (Fig. 23)

— loose shrubs with *Amygdalus pedunculata* on stony southern slopes in upper parts of the massif,

— floristically rich steppes and meadow-steppes on northern slopes,

— tall perennial forbs in small depressions within the massif.

The basic features differentiating plant communities of the transect on different altitudes are shown in Figure 29 and, in more detail, on the map (Fig. 30). Comparing these figures, the relationships between the vegetation and soil types can be analysed, it should be remembered, however, that plant communities were studied in less detail than soils.

The relationships between plant communities and soils are shown in Figure 31. Because water is the most important factor for halophytes, their communities are much associated with specific soil types than the communities of dry steppes. Dry steppes occupy chestnut and dark chestnut soils, but no correlation was found between the humus content or soil depth and the basic differentiation of steppe communities. More important factors of differentiation are relative altitude, parent rock, mechanical composition of weathered material and sediments, as well as water relations. An additional reason is needed to explain why the steppe communities are represented by the form with *Caragana microphylla* and without this species. The steppes with deeply rooted *C. microphylla* generally occur on stony and gravelly chestnut soils characterized by a relatively low capacity of capillary water, a relatively high capacity of water available for plants and by a high air-holding capacity. Soils of this type are relatively little vulnerable to water losses by evaporation. Thermogradient migration and condensation of water vapour is also possible in them. The soils in steppes with *C. microphylla* are characterized by a little acid reaction at the surface which is related to the periodically flushing water conditions.

The soils under the communities generally called halophilous belong to permafrost solonchaks or dark chestnut permafrost solonchaks. All of them are characterized by a rather high salt content and they are supplied with water from the permafrost in subsoil (see the chapter on the type of water conditions).

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IX. SEASONAL DYNAMICS OF ABOVE-GROUND PHYTOMASS

An attempt was made to determine seasonal dynamics and growth rates of the above-ground plant biomass in a series of steppe communities on the transect.

METHODS

In early June, 1979 nine study sites were established on the transect (see map of plant communities, Fig. 30), and the above-ground phytomass was measured. Of the sites selected, seven represented dry steppes in different forms and two (sites 8 and 9) halophilous communities. The sites representing steppe communities were frequently sampled in order to get information on phytomass dynamics, while sites 8 and 9 were sampled only once, for comparative purpose.

Two of the sites covered with dry steppe (sites 1 and 2) were located in the zone of deluvial material in the western part of the transect. Site 1 represented a poor steppe occupying the bottom of a wide valley. Site 2 represented a steppe with *Caragana microphylla* and covered a gravelly hill. Only its parts beyond the *Caragana* clumps were sampled. Sites 3-5 represented steppe communities on basalt substratum. Site 3 was excluded from grazing by farm animals three years earlier, while all the other sites were grazed.

Site 6 was located on metamorphic materials and it represented a steppe with *Caragana microphylla*. Site 7 was located on an alluvial cone on lower slopes of the valley in the zone of granitoid substratum, and it represented a steppe without *Caragana microphylla*.

Sites 8 and 9, representing halophilous vegetation, were located near a lake in the central part of the transect. Site 8 was covered with the grass community *Lasiagrostis splendens*, and site 9 supported a pasture community with *Carex enervis*, *Iris biglumis*, *Potentilla anserina*, and other species.

The sampling procedure included collecting plant material lying on the ground ("lying" phytomass) and clipping live and dead standing plant parts ("standing" phytomass) from five squares of 1 m × 1 m^2 distributed at random on each site within a radius of about 10 m. This plant material was dried at 105°C, separated from soil particles and stones, and then weighed on a semi-analytical balance. This basic schema of sampling was slightly modified for some sites. On sites 3, 4 and 5, *Caragana pygmaea* was not sampled because large specimens of this species were unevenly scattered over the area and this could increase the sampling error. The biomass of *C. pygmaea* was measured on one occasion. All plants of this species were collected from 2 m × 10 m rectangles. There were six such rectangles on site 3, ten on site 4 and eight on site 5. The material collected was weighed and the results were calculated per m^2.

On site 6, representing the steppe with *Caragana microphylla*, samples were taken separately from the areas covered and not covered with this shrub, because the structure of this community was not uniform. There were five sampling areas of 0.25 m^2 on each of these two microcoenosis types (the term after Bannikova and Dylis 1978). In samples taken from the areas covered by shrubs, the standing biomass was divided into the *C. microphylla* steams and other plant species. The results for the areas between and under shrubs were calculated separately. A transect of 100 m × 5 m^2 was established and all the shrubs in it were measured. They occupied 20% of this area. Therefore, to calculate the phytomass of the whole site 6, a coefficient of 0.20 was used for the areas under shrubs and 0.8 for the areas between shrubs.

On sites 1–5 the first series of samples was taken on June 4–6, which can be considered the beginning of the growing season. On sites 6 and 7, standing biomass at the beginning of the growing season was estimated on June 17 separating the young, current-year standing crop from the older phytomass.

To estimate the rate of biomass regrowth, the above-ground phytomass was sampled on site 3 (enclosed area) again at the end of the growing season after a series of regular samplings. Also sites 8 and 9 were sampled again at the end of August, after sampling in the second half of July.

All results are given as mean values of five samples (or more for the phytomass of *Caragana pygmaea*) with a 0.90 confidence interval estimate.

RESULTS

SEASONAL VARIABILITY IN ABOVE-GROUND PHYTOMASS

The standing and lying phytomass are shown in Table 10 and Figure 32. It can be stated that the lying phytomass does not distinctly change over the year. On some sites no changes occurred at all, on other

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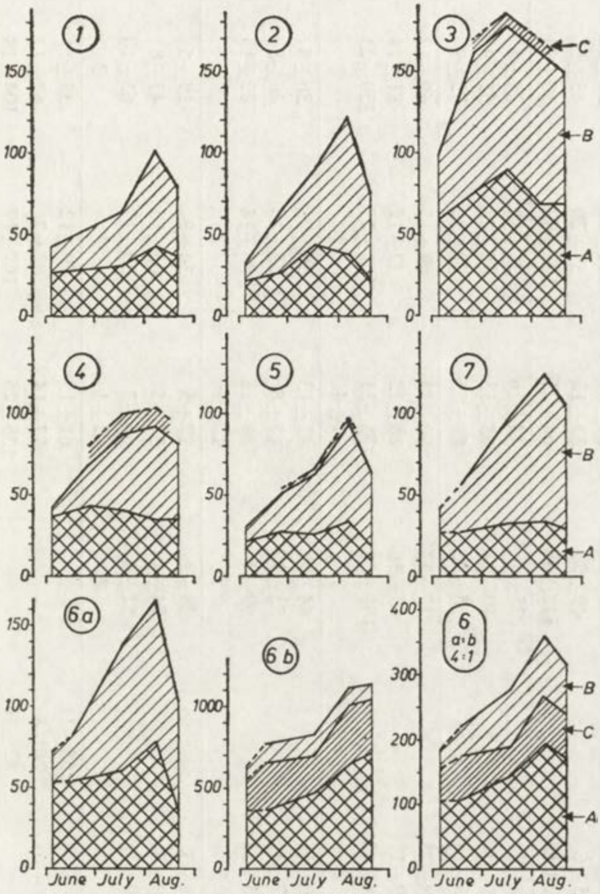

Fig. 32. Seasonal changes in the above-ground phytomass (in g/m^2) on different study sites of steppe communities (for explanations see map of plant communities, Fig. 30)

A — lying phytomass (litter); *B* — standing phytomass; *C* — proportion of *Caragana* stems in the standing crop (*Caragana pygmaea* on sites 3, 4 and 5, *Caragana microphylla* on site 6)

sites they are conspicuous but within the sampling error. Only on three sites out of seven were the changes in the amount of litter from month to month statistically significant.

In the communities of dry steppes without shrubs, the maximum litter biomass occurred in mid-summer, if at all. This increase was caused by the falling of plant parts from the preceding year, which were standing early in the season. From mid-summer a decrease in litter biomass was observed on some sites as a consequence of the decomposition and blowing away of plant remains.

A different pattern of changes in litter biomass was observed under *C. microphylla* shrubs in the *Caragana* steppe (site 6). The amount of litter increased there throughout the growing season, and this increase

Table 10. Seasonal dynamics of above-ground phytomass in plant communities of the Gurvan Turuu region (mean values for five samples and 0.90 confidence interval estimates are given in g/^{2}m)

Site	Phytomass fraction	Dates of sampling					
		4–6 June	17 June	26–28 June	17–20 July	6–10 August	20–22 August
1	litter	27±11		66±38	31±10	44±15	37±16
	standing	15±6		49±24	33±12	59±20	43±16
	total above-ground	42±15		115±48	64±21	103±32	80±30
2	litter	22±9		25±4	44±16	38±14	24±4
	standing	11±5		40±14	45±13	85±28	51±9
	total above-ground	33±14		65±15	89±25	123±35	75±9
3	litter	59±25		77±32	90±23	69±15	69±17
	standing of herbage	39±17		83±36	88±12	92±12	81±14
	above-ground without *Caragana*	98±42		161±56	178±31	161±25	150±23
	Caragana pygmaea	?		?	7±4	?	?
4	litter	36±16		44±9	41±13	36±7	36±8
	standing of herbage	7±4		35±9	48±8	57±10	46±8
	above-ground without *Caragana*	43±14		69±4	88±18	93±14	82±15
	Caragana pygmaea	?		?	12±4	?	?
5	litter	21±3		28±2	27±5	34±9	19±5
	standing of herbage	9±3		24±4	37±5	63±13	43±8
	above-ground without *Caragana*	30±5		52±4	64±7	97±17	63±10
	Caragana pygmaea	?		?	2±1	?	?
6 a	litter		55±11		61±19	79±12	38±11
	standing	(16±6)	26±8		77±14	87±7	67±17
	total above-ground		82±16		138±26	167±17	104±18
b	litter		369±70		479±210	660±197	722±197
	standing of herbage	(70±44)	111±44		138±50	109±31	103±44
	Caragana microphylla	(191±74)	297±99		224±101	359±194	323±119
	total standing		408±135		363±129	468±221	427±126
	total above-ground		776±196		842±322	1128±407	1148±161

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a:b = 4:1	litter		118	144	195±49	174
	standing		102	134	163±50	139
	total above-ground		221	278	359±95	313
7	litter		29±7	33±17	34±4	30±13
	standing	(12±2)	28±3	66±5	91±6	76±18
	total above-ground		57±3	99±24	125±6	106±30
8	litter			239±6		
	standing			529±92		
	total above-ground			768±91		
9	litter			zero		
	standing			156±65		

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was statistically significant. This was due to both a relatively high production of short-lived above-ground biomass by *C. microphylla* (flowers and leaves) and to the accumulation of dead organic matter carried under the shrubs by the wind. Thus, dead organic matter was retained under the shrubs, which was of great importance to soil processes (Kowalkowski 1980). As a result of this retention, a specific microrelief characteristic of deserts and semi-deserts is formed, which is called "bugor" in Mongolia (Yunatov 1950). In the Gurvan Turuu region "bugor" forms are veakly developed as compared with semi-desert areas, but they are clearly seen.

In contrast to litter, standing phytomass largely varied over the growing season, reaching a peak biomass early in August. The state close to the maximum lasted shortly. A different situation, however, was observed in the areas supporting *Caragana* shrubs, where the first period of growth, related to the foliation and flowering of *C. microphylla* at the turn of May and June was followed by a period of small variability in the standing phytomass. The above-ground parts of *C. microphylla* make up 70–80% of the total above-ground standing crop of this microcoenosis.

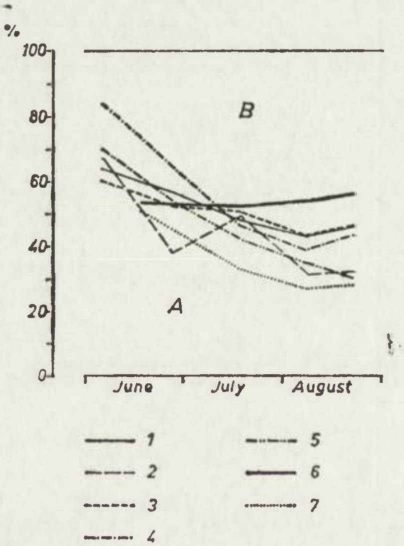

Fig. 33. The proportion of lying phytomass (*A*) to standing phytomass (*B*) in dry steppes over the growing season

1-7 study sites denoted as on the map of plant communities (Fig. 30)

The total above-ground phytomass (standing and lying) varies markedly over the season, mostly as a result of the growth of standing phytomass. The proportion of standing phytomass in the total above-ground phytomass varied on most of the sites from 30–40% early in the season to 55–75% in the period of peak above-ground phytomass

(Fig. 33). Only on the *Caragana* steppe (site 6) and to a lesser extent on the ungrazed steppe (site 3), was the proportion of standing to lying phytomass more stable over the season.

In general, in most communities of dry steppes the period of high phytomass is very short. The only exception is the microcoenosis of *C. microphylla* shrubs within the *Caragana* steppe.

REGROWTH RATE OF ABOVE-GROUND PHYTOMASS

The rate of above-ground phytomass regrowth after harvest was examined on site 3, representing an ungrazed steppe, and in part on sites 8 and 9, representing plant communities on salty soils. The results are presented in Table 11a, 11b and 12. Tables 11a and 11b show that rate of regrowth of above-ground plant parts in the steppe varies over

Table 11a. Plant biomas and growth rate for periods from first to second harvest on site 3

Date of first harvest Date of second harvest	5 June 18 Aug.	26 June 18 Aug.	17 July 18 Aug.	6 Aug. 18 Aug.	20 Aug. —
a. Regrowth time [days]	74	53	32	12	—
b. Standing phytomass at harvest 1st [g/m²]	39±17	83±36	88±12	92±12	81±14
c. Total above-ground phyto-mass at harvest 1st [g/m²]	98±42	161±56	178±31	161±25	150±23
d. Total phytomass at harvest 2nd [g/m²]	49±8	43±12	21±5	4±2	—
e. Total standing phytomass of two harvests [g/m²]	88±12	126±24	109±8	96±7	81±14
f. Total above-ground phytomass of two harvests [g/m²]	147±25	204±34	199±18	165±13	150±23
g. Mean daily growth rate (*d/a*)	0.66	0.80	0.66	0.37	—

Table 11b. Growth rate for different time periods on site 3 [g m^{-2} day^{-1}]

Period	Growth rate of above-ground standing phytomass *d/a*	above-ground standing phytomass *b/a*	total phytomass *c/a*
5 June–26 June	0.28	2.09	3.00
26 June–17 July	1.05	0.23	0.87
17 July–6 August	0.85	0.20	0.85
6 August–20 August	0.33	−0.78	−0.78
5 June–17 July	0.66	1.17	1.90
17 July–20 August	0.66	−0.20	−0.82
5 June–6 August	0.73	0.85	1.02
5 June–20 August	0.66	0.55	0.68

for symbols a, b, c, d, see Table 11a

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the season. At the beginning of the season (by the second half of June) and also at the end of the season (in August) it is low. A rapid regrowth of phytomass on mown areas occurs only in July.

Considering various possibilities of two harvests over the season, it has been found that the greatest harvest can be obtained if the first mowing is at the end of June and the second one around mid-August. Thus it seems that the efficiency of pasturage could be increased if some steppe areas were grazed twice a year, namely by the beginning of June and then at the end of summer.

The regrowth rate of the above-ground phytomass in the communities covering wet, salty soils is about twice that in the steppe community in the same period (Table 12).

DIVERSITY OF PLANT COMMUNITIES WITH RESPECT TO ABOVE-GROUND PHYTOMASS

Maximum standing biomass can be considered a characteristic of plant communities. Its variability is shown in Figure 34. It clearly indicates that the classification of plant communities based on their physiognomy is supported by the differences in the amount of above-ground phytomass.

The richest above-ground phytomass, both standing and lying, was in the community of the grass *Lasiagrostis splendens*. The proportion of lying phytomass was relatively small while the standing phytomass even at the end of summer, included many dead parts, probably last-year leaves and stems of *L. splendens*.

A high above-ground phytomass is also characteristic of the *Caragana* steppe. The proportion of litter was high in this habitat. This community and the preceding can be considered a storage area of organic matter in the landscape.

The community of pasture with *Iris biglumis* on site 9, must function in quite a different way because the lying phytomass was almost completely lacking there in mid-summer, and nearly the whole above-ground phytomass consisted of the current-year green plant parts. Therefore, it may be suggested that this ecosystem has a high production and a high turnover rate (see also the chapters XII and XIII).

It follows from the comparison of the above-ground phytomass in the ungrazed habitat (site 3) and in the grazed habitats (sites 4 and 5), that grazing lowers the maximum above-ground phytomass by about 30–40% in dry steppes of this type.

The above-ground phytomass of grazed dry steppes without shrubs is little differentiated, as compared with other types of communities. It is worth noticing that they occur on different substratum, thus the type of substratum is of no great importance to the amount of above-ground phytomass.

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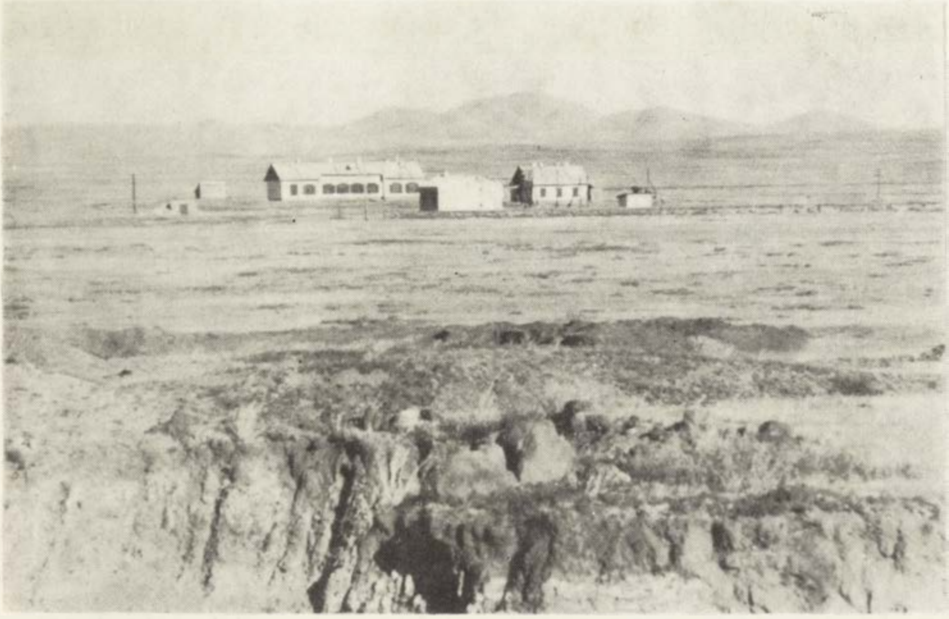

Photo B. Nowaczyk

Photo 1. Mongolian-Polish Research Station in Gurvan Turuu. The hilly part of the Middle Khalkhasian Plain in the background

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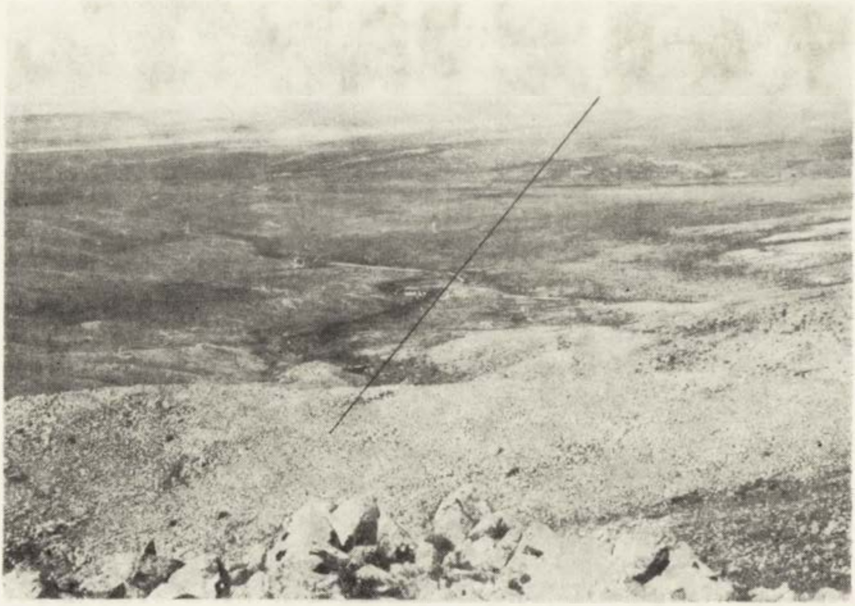

Photo K. Kossobudzki

Photo 2A. Eastern part of the transect showed from the Bayan Ovo Massif to the Gurvan Turuu Station

Photo K. Kossobudzki

Photo 2B. Western part of the transect showed from the west end of the transect to the Gurvan Turuu Station

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Photo B. Nowaczyk

Photo 3. Middle Khalkhasian Plain. Flat-floored tectonic valley on the background of undulated Eastern Plateau

Photo A. Kotarba

Photo 4. Dry valley (sair) with debris transported by episodic waters

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Photo B. Nowaczyk

Photo 5. Fault-blocks topography flanking Eastern Upland

Photo A. Kotarba

Photo 6. Strongly weathered boulder of Quaternary fluvial origin in the Graben Valley floor

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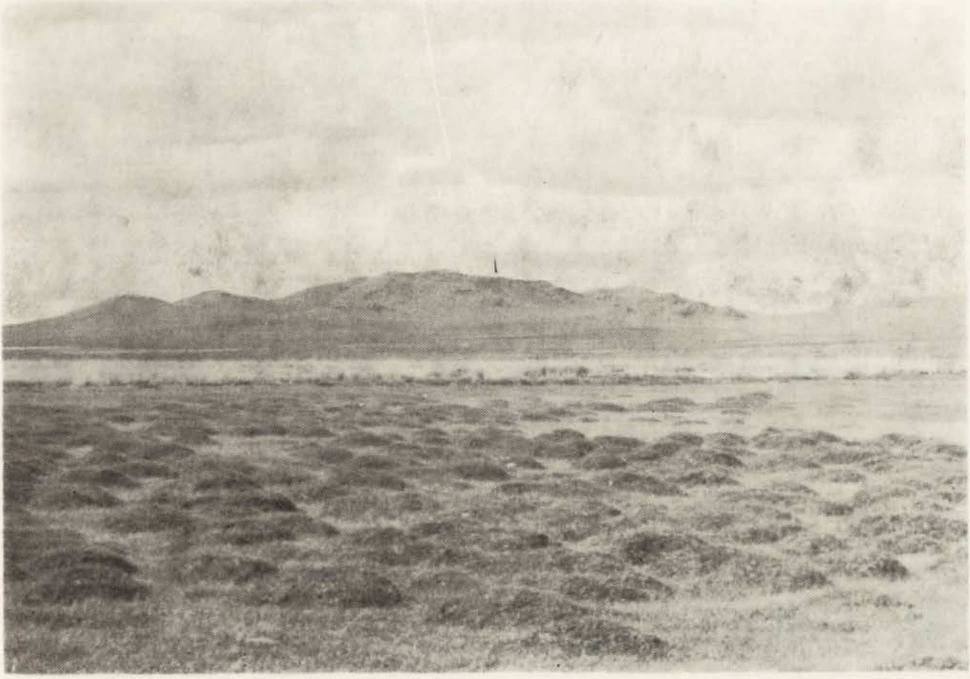

Photo B. Nowaczyk

Photo 7. Bayan Ovo hill of erosional-denudational origin. In the front small hills called "bugors" are visible

Photo B. Nowaczyk

Photo 8. Surface of planation with the Gurvan Cochio tors-residuals associated with metasomatic altered granite

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Photo B. Nowaczyik

Photo 9. Monoclinal ridges of tectonic-denudational origin occurring east of Gurvan Turuu

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Photo A. Kowalkowski

Photo 10. Strongly denudated hills in the area of Bayan Ovo. Southern slopes are short and stony. The bottoms of valleys are filled by deluvial soils

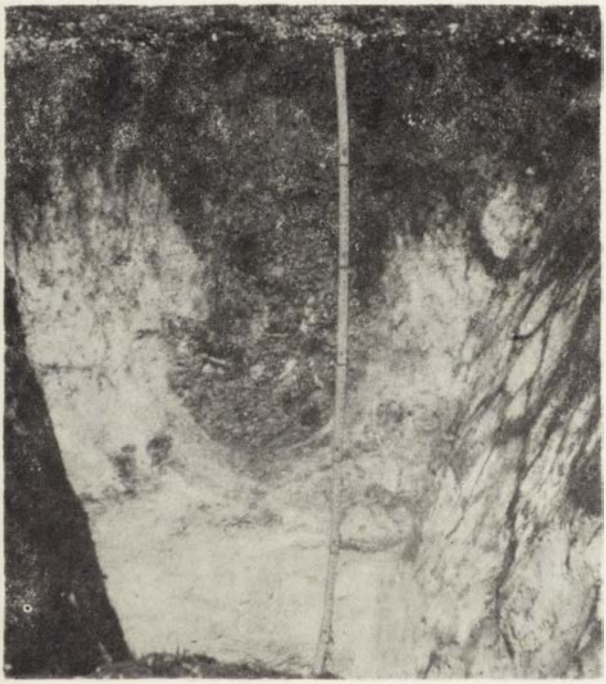

Photo A. Kowalkowski

Photo 11. Frost fissures in the carbonate horizon filled by material from cover layer

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Photo A. Kowalkowski

Photo 12. Deflation cover on the surface of dark chestnut soil

Photo A. Kowalkowski

Photo 13. Deflation cover formed on the surface of tacyric solonchak from the material in-blown

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Photo K. Kossobudzki

Photo 14. The clump of high grass *Lasiagrostis splendens*

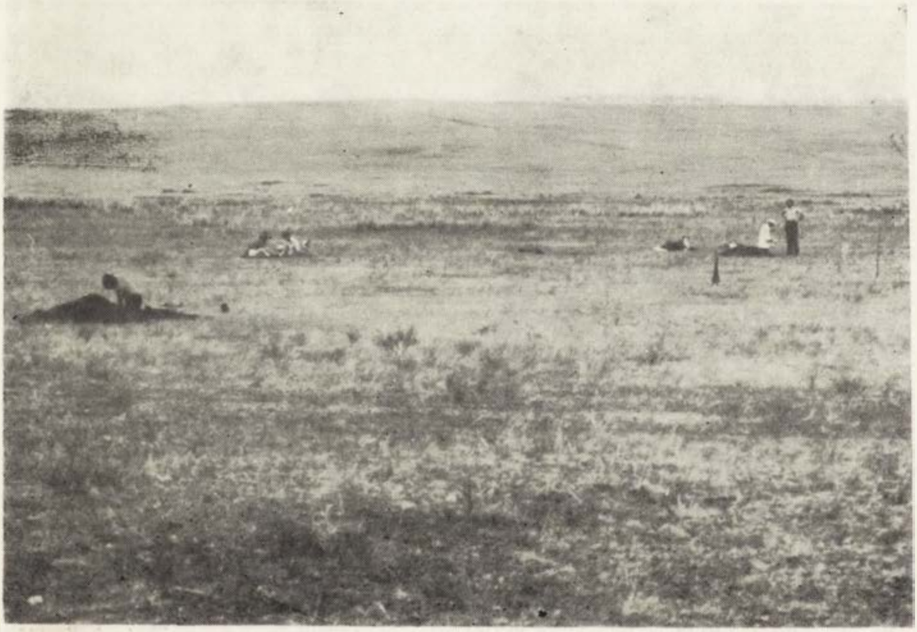

Photo K. Kossobudzki

Photo 15. Root sampling on the stand 1

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Photo A. Bremeyer

Photo 16. Cows grazing in the eastern part of transect. The shadows of clouds are visible

Photo A. Bremeyer

Photo 17. The sheep farm in the vicinity of Gurvan Turuu. Feaces of the animals drying on the roofs serve as fuel

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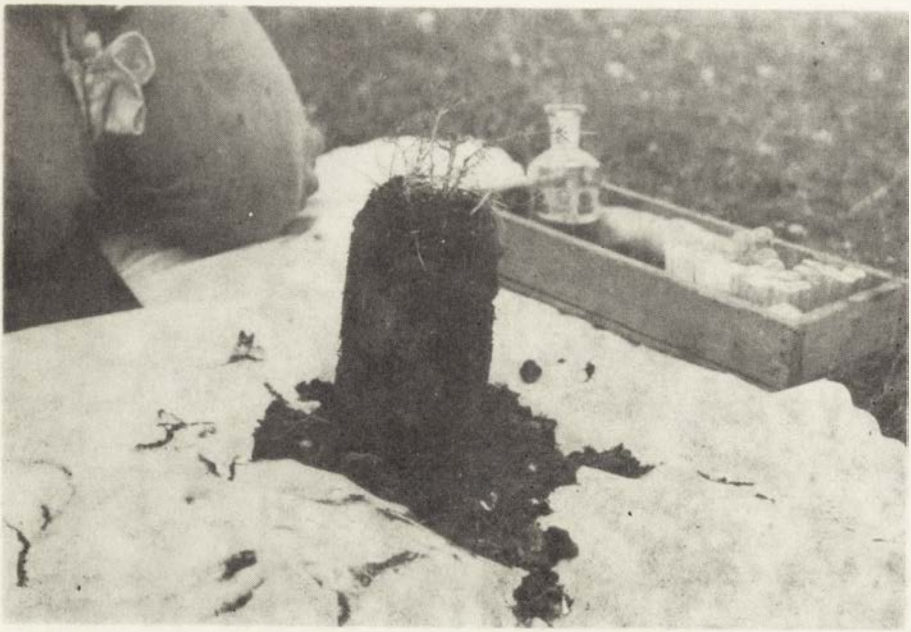

Photo K. Kossobudzki

Photo 18. The core of soil taken for the extraction of macrofauna

Photo K. Kossobudzki

Photo 19. Small ant nest in the central, basalt part of the transect

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Photo A. Bremeyer

Photo 20. Litter samples exposed for decomposition on site 3

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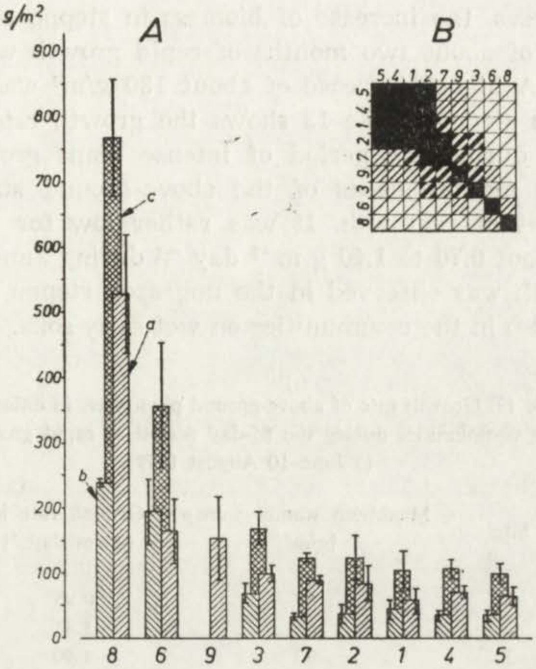

Fig. 34. Diversity of plant communities on the basis of the maximum standing above-ground biomass. Study sites denoted as on the map of plant communities (Fig. 30)

A — measured maximum standing crop of above-ground phytomass (*a* — standing phytomass, *b* — lying phytomass, *c* — total above-ground phytomass) with the confidence interval estimate of the mean; *B* — similarity in the above-ground phytomass of the study sites. Study sites are compared on the basis of the distinguished fractions of the above-ground phytomass (*a*, *b*, *c*), which are considered as separate features, and it is assumed that there are differences between them when the confidence estimates of the means do not overlap. The difference between the study sites may concern one, two, or three features, or there may be no difference at all. The increasing similarity is denoted by the signs with an increasing proportion of black

Table 12. Regrowth rate of above-ground phytomass in plant communities on saline soils

Indices	Site 8	Site 9
Regrowth time	21 July–18 Aug.	20 July–18 Aug.
Standing phytomass at first harvest [g/m²]	529±92	156±65
Regrowth biomass [g/m²]	42±33	44±16
Regrowth rate [g/m²/day]	1.50	1.52

PRIMARY PRODUCTION OF PLANT COMMUNITIES UNDER STUDY IN A PERIOD FROM JUNE TO AUGUST

On the basis of measurements of the above-ground phytomass at successive intervals, it is possible to calculate its increase from the beginning of growth in June to the maximum standing crop in July–Au-

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gust. In most cases, the increase of biomass in steppe communities during the period of about two months of rapid growth was 50–90 g dry weight per m². A higher increase of about 180 g/m² was recorded only on the *Caragana* steppe. Table 13 shows the growth rate of the above-ground biomass during the period of intense plant growth, calculated either from the measurements of the above-ground standing crop or from the amount of regrowth. It was rather low for grazed steppes, ranging from about 0.70 to 1.40 g m^{-2} day $^{-1}$ during June–July. A higher rate of growth was observed in the ungrazed steppe, in the *Caragana* steppe, and also in the communities on wet salty soils.

Table 13. Growth rate of above-ground phytomass in different plant communities during the 85-day period of rapid growth (5 June–10 August 1979)

Site	Maximum standing crop [g/m²]	Growth rate in [$g^{-2}m$ day^{-1}]
1	59	0.95
2	85	1.41
3	92	1.90
		0.73[a]
4	67	0.78
5	65	1.05
6	87[b]	1.48[b]
	163[c]	2.75[c]
7	91	1.31
8	529[d]	1.50[a]
9	156[d]	1.52[a]

a Calculated from measured regrowth biomass.
b Patches without *Caragana microphylla*.
c The whole site, including the area occupied by *Caragana*
d Measured on one occasion; it is not known if this is a maximum.

Unpublished data of Cogzolma show that at the end of September the steppe vegetation in the Gurvan Turuu region enters the state of winter rest, and the above-ground standing crop shows a level similar to that at the end of May. It can be calculated from this that the rate of decrease in the above-ground phytomass from its maximum to its state at the end of the season is about 1.0–1.5 g m^{-2} day^{-1} for ungrazed steppes without *Caragana* shrubs. Assuming that the reduction in plant biomass (caused by small natural consumers) during June–August is similar to that in August–September, the net primary production of these ecosystems can be calculated adding the probable losses in phytomass to the measured increase in phytomass in the same period. The production calculated in this way was about 170–200 g/m²

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during about 70 days, that is about 2.5–3.0 g m^{-2} day^{-1} for the ungrazed sites.

In the grazed sites the increase in biomass was by about 15–30% lower than in the enclosed sites. This was due to the fact that farm animals used about 0.5 g m^{-2} day $^{-1}$ of above-ground phytomass, thus over the growing season (120 days) they removed about 60 g/m^2, or about one-third of the annual net primary production of above-ground parts.

DISCUSSION

According to the data available, the above-ground phytomass in the zone of dry steppes of Central Asia ranges from about 39 to about 102 g d.wt./m^2 (Gordeeva 1977; Gordeeva *et al.* 1977; Mirostnitsenko 1967, 1975; Poluskin and Gorskova 1979; Sukhovierko 1978). The present results are consistent with the literature data. This does not imply that they are exactly the same, because of the great importance of such factors as the amount of precipitation in a given region (Mirostnitsenko 1975) or in a given year (Sukhovierko 1978), as well as grazing. Therefore, the consistence of the results means that taking into account the specific character of plant communities, geographical location, and the utilization of the area, the results obtained are a good supplement to the already existing data from the Mongolian steppes.

The estimated primary production of dry steppes common in the Gurvan Turuu region (170–200 g/m^2 over about 70 days of growing season) is comparable with the literature data for corresponding climatic-vegetational zones. For dry steppes of the USSR this is 120–300 g/m^2, and for short-grass prairies in North America 70–350 g/m^2 (Iwaki 1979).

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X. STRATIFICATION OF PLANT BIOMASS

INTRODUCTION

It follows from many studies carried out in dry steppes, that the major part of plant biomass in ecosystems is in the soil. The above- and below-ground plant biomass were simultaneously studied in Mongolia (Bannikova 1978; Bannikova and Dylis 1978; Davarzamts 1974; Gordeeva 1977; Mirostnitsenko 1967), and they show that, like in other steppe regions, proportions between the above- and below-ground biomass vary as one moves from relatively humid to dry regions (Walter 1968, 1976). On the basis of the available ecological data (Numata 1979), it is assumed that the ratio of the above- to below-ground plant biomass or the so-called top/roots ratio can be used as a good index of the zonal diversity of steppe plant communities. Therefore, on the basis of the data on the above- and below-ground biomass standing crop, it is possible to calculate the top/roots ratio in particular regions, and to compare these results in order to determine zonal variability in this index. Following the division of Mongolia into zones and subzones proposed by Yunatov (1950, 1952), it can be stated that the top/roots ratio ranges from 1:9 to 1:25 in the northern subzone of the zone of dry steppes, it is about 1:40 in the southern subzone, and it varies from 1:50 to 1:120 in the zone of semideserts. Although the results are rather largely scattered for particular regions, which can be due to differences in sampling methods and to other factors discussed below, the north-southern variability in the top/roots ratio is very distinct.

The objective of the present study is to determine the stratification of plant biomass in different ecosystems, and to estimate the top/roots ratio for plant communities in the Gurvan Turuu region.

STUDY AREA AND METHODS

Below- and above-ground plant biomass was sampled at six points of the transect (Photo 15). They are denoted by numbers as shown on Figure 30. The following communities were under study: a poor steppe

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without *Caragana microphylla*, located in the valley at the western end of the transect (site 1); a steppe without *C. microphylla*, on gravelly hills (site 2); a dry steppe on basalt substratum (site 5); a steppe with *C. microphylla*, on metamorphic substratum (site 6); a steppe without *C. microphylla*, at the foot of the Bayan Ovo massif (site 7); and a wet pasture with *Carex enervis* and *Iris biglumis*, in the central part of the transect (site 9).

Below-ground plant biomass was measured in mid-July. Samples were taken from the layers 0–5, 5–20, 20–40, and 40–60 cm deep. On each site two samples were taken from each layer. The surface area of each sample was 15 × 30 cm and the depth was equal to the thickness of the layer. These samples were washed on soil sieves to isolate live and dead plant parts. Then the material was dried at 105°C and weighed. The results were calculated per m^2.

In Table 14 the results obtained for the below-ground plant biomass are compared with maximum above-ground standing crop biomass obtained when its seasonal dynamics was examined. Mean values for all sites were calculated and variability coefficients were determined for particular fractions of plant biomass.

RESULTS

Stratification of the below-ground biomass is shown in Figure 34. In the studied ecosystems, below-ground biomass ranged from 2000 to about 5000 g/m^2, the highest values being reached in the steppe with *Caragana microphylla*. The major part of plant material was in the top 5 cm deep layer. From 30 to 45% of the total plant biomass of the community was found there. It mostly consisted of stems and roots. This is most pronounced in the community with *Carex enervis* and *Iris biglumis* forming a dense sod (Fig. 35). The amount of plant biomass drops at a higher or lower rate with increasing soil depth. This decrease is most drastic on sites 1 and 7, that is, in the communities on dry, dark chestnut soils of a high thickness. On these sites, the fraction of roots from the 40–60 cm deep layer accounts for 10–14% of the roots from the 5–60 cm layer, while on the stony and gravelly sites, and also on the moist solonchak, this fraction accounted for 18.7–22% of the roots in the whole profile (5–60 cm).

It is also worth noticing that the variability in plant biomass between sites, characterized by the coefficient of variability, decreased with increasing depth to 20–40 cm, and then increased again at a depth of 40–60 cm. It may be stated, therefore, that the layer 20–40 cm deep is characterized by the lowest variability in plant biomass. In the higher layers the variability related to differences in plant communities is more pronounced, while in the deeper layers the differences in subsoil are more important.

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Table 14. Phytomass stratification in the study sites

Indices	Site 1	2	5	7	6	9	$\bar{x}$	V_x [%]
Total community phytomass [g/m²]	2450.5	3090.3	2239.0	3595.3	5206.0	4711.7	3548.8	75.7
Including:								
standing phytomass [g/m²]	58.6	84.9	62.7	91.3	163.6	155.9	102.8	99.8
	(2.4)	(2.7)	(2.8)	(2.5)	(3.1)	(3.3)	(2.9)	
litter phytomass [g/m²]	44.2	38.4	33.9	34.0	195.4	0	57.6	268.8
	(1.8)	(1.2)	(1.5)	(0.9)	(3.7)	(0.0)	(1.6)	
total above-ground phytomass [g/m²]	102.8	123.3	96.6	125.3	359.0	155.9	160.5	138.6
below-ground phytomass 0–5 cm [g/m²]	942.2	1244.9	672.9	1255.6	1769.4	2141.4	1337.7	89.9
	(37.7)	(40.3)	(30.0)	(34.9)	(34.0)	(45.4)	(37.7)	
below-ground phytomass 5–20 cm [g/m²]	688.0	550.4	617.1	1130.9	1323.3	960.0	878.3	78.9
	(28.1)	(17.8)	(27.6)	(31.4)	(25.4)	(20.4)	(24.7)	
below-ground phytomass 20–40 cm [g/m²]	565.4	834.2	528.9	744.0	1178.2	845.6	787.7	66.5
	(23.1)	(27.0)	(23.6)	(20.7)	(22.6)	(17.9)	(22.2)	
below-ground phytomass 40–60 cm [g/m²]	145.1	337.1	323.6	309.6	576.2	608.5	383.4	102.9
	(5.9)	(10.9)	(14.4)	(8.6)	(11.1)	(12.9)	(10.8)	
total below-ground phytomass [g/m²]	2347.7	2967.0	2142.4	3470.0	4847.0	4555.8	3388.3	74.1
top/roots ratio	1:40.1	1:34.9	1:34.2	1:38.0	1:29.6	1:29.2	1:33.9	12.9
	0.0249	0.0286	0.0293	0.0263	0.0337	0.0342	0.0295	

$\bar{x}$ — arithmetic mean for six sites, V_x — variability coefficient $S_{\bar{x}}$ 100%. Note: Per cent values in brackets.

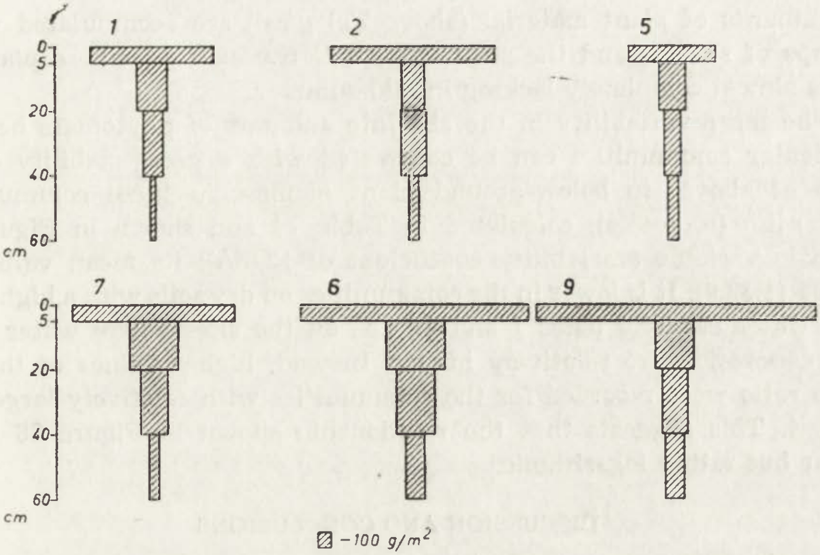

Fig. 35. Stratification of underground phytomass on investigated sites

Sites designation as in Fig. 30

Above-ground plant biomass accounted for a small proportion of the total plant biomass (3–7%) and was more variable (variability coefficient 138.6%) than the below-ground biomass. It ranged from about 100 to 360 g/m², including about 60 to 160 g/m² of maximum standing biomass, the variability coefficient between sites being about 100%.

Lying phytomass shows a large variability from site to site (variability coefficient of 268.8%). This is mostly due to a specific character of two communities, the steppe with *Caragana microphylla*, where lar-

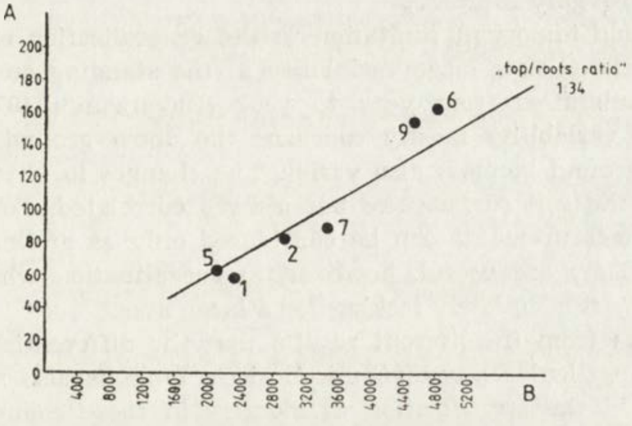

Fig. 36. The relation between above-ground standing crop (*A*) and underground phytomass (*B*) on investigated sites in g·m⁻²

Sites designation as in Fig. 30

ge amounts of plant material (above 700 g/m^2) are accumulated within clumps of shrubs, and the pasture with *Carex enervis*, where plant litter is almost completely lacking in mid-summer.

The large variability in the absolute amounts of phytomass between particular communities can be contrasted with a great stability of the ratio of above- to below-ground plant biomass in these communities. This ratio (top/roots), calculated in Table 14 and shown in Figure 36, is little variable (variability coefficient of 12.9%); its mean value was 0.0295 (1:33.9). It is lower in the communities on dry soils with a high capillary water capacity (sites 1 and 4), i.e., on the sites where water losses by evaporation are relatively higher. Instead, higher values of the top/roots ratio were recorded for the communities with relatively large phytomass. This suggests that the relationship shown in Figure 36 is not linear but rather logarithmic.

DISCUSSION AND CONCLUSIONS

Before the proper discussion, two problems should be noted. First, all the study sites were grazed by farm animals. Grazing is followed by a decrease in the amount of the above-ground biomass and often a parallel increase in the below-ground biomass. As a result, the ratio of the above- to below-ground phytomass markedly declines. On the basis of the data obtained by Zlotin *et al.* (1979), the top/roots ratio can be calculated for ungrazed communities (1:4.2), moderately grazed (1:7.2) and heavily grazed (1:13.7). This indicates that when the proportions of above- to below-ground phytomass are compared for different regions, the intensity of grazing should be considered. It can be accepted that in Mongolia, grazing is a commonplace factor, therefore the effect of grazing can be partially neglected when data from different regions are roughly compared.

The second important limitation to the generalization of the present results is related to a large variability in the standing crop biomass of steppe communities from year to year (Davarzamts 1974; Gordeeva 1978). This variability mostly concerns the above-ground biomass but the below-ground biomass also varies. The changes in phytomass above and below the soil surface are not always correlated. For this reason point-time measurements can be considered only as preliminary approximations. They are useful, however, in the situation when long-term data are almost completely lacking for a large area.

It follows from the present results that the differentiation of vegetation into particular physiognomic-floristic types is also manifested in differences in the stratification of biomass in these communities. Differences in the phytomass stratification between particular communities are an effect of diversified site conditions and heterogeneity of vegetation forms adapted to these conditions.

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The high stability found in the present study for the ratio of the above- to below-ground plant biomass of the communities covering a large part of the local vegetation diversity confirms that the top/roots ratio is a useful index for the study of zonal diversity of vegetation. The ratio of about 1:34 obtained in this study for the northern part of the southern subzone of dry steppes in Mongolia is a good supplement to the already known data discussed at the beginning of this paper.

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XI. PRELIMINARY CHARACTERISTICS OF THE FAUNA

INTRODUCTION

The aim of the study carried out in the summer of 1979 was to determine the composition and abundance of invertebrates on the transect Gurvan Turuu. This was a short-term study, and thus of a preliminary character, but because many different methods were used it provided rather comprehensive data. Two years earlier free-living mammals were studied in this area. They were identified to species, their numbers were estimated, and for some of them food consumption and metabolic rate were determined (Zieliński 1981; Weiner and Górecki 1982). In sum, we have information on most of the wild animals living in steppes of the Gurvan Turuu region, and we can make attempts to estimate their role in steppe ecosystems.

There are cattle, horses and camels grazing there free over the year (Photo 16, 17). To get a relative estimate of the time they spent on the study sites, the amount of dung dropped by them was estimated.

Permanent sampling sites represent western, central and eastern parts of the transect. They are numbered as on the map of plant communities in Figure 30. Detailed characteristics of soils and plant cover are given in chapters VI–X.

An additional site, the so-called Station, was located in the central part of the transect, and was used to sample for the purpose of this section only. It supports an *Artemisia* steppe spotted with scarce *Caragana* shrubs. The site Station was used to observe the daily cycle of invertebrate fauna because it was close to the meteorological station which worked on a daily cycle. These data will be published later, together with corresponding topoclimatic data.

METHODS

To get a comprehensible picture of the invertebrate fauna on the transect, several methods of sampling were used.

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To estimate the density of soil fauna, soil cores of 100 cm² × 15 cm in volume were taken with a metallic device driven into the hard, stony soil by a heavy hammer. These cores were put on a white piece of plastic material spread on the sampling site, and the animals were separated by hand. From each site 10 samples were taken on one date.

To estimate the activity of invertebrate fauna on the soil surface, Barber pitfall traps were used. These were plastic cups put into soil so that the rims were at the level of the soil surface. They were filled with ethylene glycol (a poisonous, preserving alcohol) to one-fourth of their volume. These traps were used on four sites in series of 10 on each, and checked every several days for a period of about two months.

On one date all the sites were visually examined, and the following materials were recorded (Photo 18): the density of active ant nests on an area of 500 m² (5 m × 100 m²), density of the fauna moving on the soil surface, within a 15 min period; and the density of droppings of cattle and horses, considered as an index of the time spent by these animals in the study sites. On one date, the invertebrate fauna was also caught by means of a sweep-net on two sites of group III, that is, at the eastern end of the transect on site 6, with a rather high density of *Caragana* shrubs, and on site 7, without this shrub. A series of 10 samples comprising 25 sweeps each was taken from each of these sites.

RESULTS

EPIGEAN FAUNA ON THE SOIL SURFACE

A total of 5917 epigean invertebrates was caught in pitfall traps. The number of animals varied from 2.8 to 7.8 per trap per day. They consisted of: *Coleoptera* 25%, *Formicidae* 22%, *Araneida* 19%, *Diptera* 18%, *Hymenoptera* 6%, *Orthoptera* 5%, and *Homoptera*, *Heteroptera*, *Collembola* — 1% each. Also some *Myriapoda* and *Opiliones* were trapped.

Epigean fauna of the study sites was dominated by four main groups (Table 15) such as beetles (*Coleoptera*), ants (*Formicidae*), flies (*Diptera*) and spiders (*Araneida*). Their proportion ranged from 78 to 86% of the total fauna trapped. The two most abundant groups, i.e., ants and beetles, will be discussed in more detail.

Ants. The only survey of ten sites showed that the number of ant nests was the highest on three of them Table 16). These were sites 4, 5 and Station, which were all located on basalts. Over the whole of this area of gently rolling hills, covered with weathered basalt there frequently occur small ant nests, the round entrances to which are bordered with small crowns of soil carried out from deeper layers (Photo 19). The density of these nests ranged from 30 to 36 per m², thus it was very high and much higher than on the other sites. The lowest den-

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Table 15. Proportion of four main invertebrate groups in the total number of the epigean fauna (Barber's pitfall traps method) in per cent

Group	Station	Site		
		6 encl.	7	9
Coleoptera	20	23	39	19
Formicidae	30	26	9	23
Diptera	16	16	13	26
Araneida	12	16	18	18
Σ	78	81	79	86

sity of ant nests was found on sites 2 encl. and 2: that is, on very poor and dry parts of the steppe, covered with *Stipa* grass located in the western part of the transect (sites 1,2, 2 encl., group I).

Table 16. The number of active ant nests recorded in July 1979 (mean values per 100 m^2)

Site	Number of ant nests	Estimate error
1	4.2	±3.0
2	1.4	±0.7
2 encl.	0.8	±0.2
4	34,6	±14.1
5	36.4	±11.3
6	3.8	±2.6
7	3.6	±1.6
8	9.2	±3.8
9	3.8	±1.05
Station	30.8	±14.9

The four species of ants trapped on site Station, located on basalts, were also found on the other sites (Table 17). They were, however much more abundant on basalts, this being caused by a greater density of their nests and greater trap ability (Table 15).

The results of trapping can provide some information on the size of ant nests. Traps adjacent to a nest or put on ant trails catch a large percentage of the inhabitants of this nest. There were three such traps in the study plot and they caught respectively 118 and 119 individuals of *Formica sanguinea* and 100 individuals of *Formica picea* for a few days, and then no more ants were caught. It is probable that these were almost the whole populations inhabiting the small nests adjacent to these traps.

All the ant species of the genus *Formica* caught in the study area were feeding mostly on honeydew. The species of the genus *Myrmica* belongs to predators and the species of the genus *Proformica* represents

Table 17. Species composition of ants caught by pitfall traps on the transect during July–August 1979

Site	Species
Station	*Formica picea* Nyl.*
	Formica uralensis Ruzs.
	Formica brunneonitida Dl.
	Myrmica sp.
6. Steppe with *Caragana microphylla*	*Formica picea* Nyl.
	F. sanguinea Latr.*
	F. brunneonitida Dl.
	Proformica sp.
	Myrmica sp.
7. Steppe without *Caragana microphylla*	*Formica picea* Nyl.
	Polyergus rufescens nigerrimus Marik.
	Proformica sp.*
	Myrmica sp.
9. Solonchak at lake bottom	*Formica picea* Nyl.*
	F. uralensis Ruzs.
	F. pisarskii Dl.
	Myrmia sp.

* Dominant species.

pantophages, that is, ants with a very large food spectrum. *Polyergus rufescens nigerrimus* is a social parasite. Therefore, a large majority of the ants caught, reaching up to 72%, feed on honeydew, 18% represents omnivorous ants, and only 10% belong to predators.

Beetles. The beetles caught in pitfall traps were dominated by two families, *Carabidae* (mostly predators) and *Tenebrionidae* (phytophages). The next group a little less abundant included beetles of the family *Silphidae*. Other families accounted for less than 10% of the total. The proportions of particular families in the total of 1524 coleopteras caught were as follows: *Carabidae* 25%, *Tenebrionidae* 19%, *Silphidae* 16%, *Histeridae* 9%, *Curculionidae* 6%, *Phalacridae* 6%, *Staphylinidae* 5%, *Chrysomelidae* 5%, *Coccinelidae* 4%, *Cerambycidae* 3%, and *Dermestidae* 1%.

A few representatives (less than 1%) of other families were also caught, such as *Hydrophilidae*, *Scarabaeidae*, *Buprestidae*, *Cicindelidae*, *Anthicidae*, and *Meloidae*. Thus, beetles are a rich group, consisting of as many as 17 families. The beetles of the two most abundant families have been identified to genus. *Carabidae* were represented by the following proportions of various genera: *Harpalus* sp. 31%, *Pterostichus* sp. 25%, *Carabus* sp. 20%, *Corsyra* sp. 8%, *Taphoxemus* sp. 5%, and the genera *Bembidion* sp., *Agonum* sp. and *Dichirotrychus* sp. in very low proportions. The *Tenebrionidae* were represented by *Scytis* sp. 81%, *Anatolica* sp. 14% and *Blaps* sp. 5%. In addition, two genera

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of the families *Cerambycidae* and *Anisotomidae* were identified. These are *Eodorcadion* sp. and *Liodes* sp., which were abundant on only one site, namely on the wet solonchak. Thus these are genera characteristic of these specific conditions.

As far as feeding habits of the beetles caught are concerned, many of them are necro- and coprophagous invertebrates. If we include in this group *Silphidae*, *Histeridae* and *Scarabaeidae*, they accounted for 25% of the *Coleoptera* caught. *Carabidae*, the dominant family, together with *Staphylinidae* and *Coccinellidae*, accounting jointly for 34% of the *Coleoptera* caught, are generally classified as predators. *Curculionidae*, *Meloidae*, *Chrysomelidae* and *Tenebrionidae* composing 30% of the *Coleoptera*, can be considered as phytophages or detritophages. Feeding habits of some Asiatic genera are not known, thus they cannot be classified to trophic groups. Therefore the above trophic characteristic of the whole families is a rough approximation.

INVERTEBRATE FAUNA CAUGHT BY OTHER METHODS CATCH PER TIME UNIT AND BY SWEEP-NETTING

The results of catch per time unit on six sites are shown in Table 18. In addition to the always abundant beetles rather large numbers of spiders and orthopterans were also recorded by this method. The most abundant spider families included *Thomisidae* and *Lycosidae*. The beetles were largely dominated by the genus *Scythis* sp. (*Tenebrionidae*), the abundance of which was the highest of all the other invertebrates recorded.

Sweep-netting was used once on two sites of group III. One of them (site 6) was densely covered with the shrub *Caragana microphylla*, and

Table 18. Epigean fauna caught in 15-minute periods in July 1979

Group	Site 1	2	2 encl.	4	5	6	Σ	
Araneida								
Thomisidae	1		2	1		3	7	
Lycosidae	3		1	1		1	6	
Salticidae						1	1	16
Drassidae					1		1	
Others					1		1	
Coleoptera								
Scarabeidae						1	1	
Cerambycidae						2	2	
Scythis sp.	7	8	11	6	8	19	59	63
Mylabris sp.		1					1	
Orthoptera	3	1		3		7	14	
Formicidae	2		3			1	6	
Heteroptera						2	2	

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the other (site 7) was without this shrub. The results are shown in Table 19. It can be seen that phytophages were markedly more abundant on the plot covered with *Caragana*, and in particular the number of sucking phytophages like homopterans was substantially larger there.

Table 19. Invertebrates caught by the sweeping method in two sites, with and without *Caragana microphylla* shurbs (mean numbers per 25 sweeps)

Group	Steppe with *C. microphylla*	Steppe without *C. microphylla*
Homoptera	253.0	1.6
Orthoptera	2.5	2.4
Aphidae	9.0	0
Lepidoptera	0.3	0
Σ *phytophages*	264.8	4.0
Coleoptera	1.5	0.8
Diptera	2.0	0.6
Heteroptera	0.8	0
Araneida	1.0	0.2

MACROFAUNA OF THE TOP SOIL LAYER

On the basis of soil samples taken on one occasion, the composition and density of soil macrofauna were estimated. Ants were the most abundant group. They accounted for 67% of the total number of soil fauna. Beetles accounted for 30%. Their most abundant families included *Carabidae* (21% of the beetles), *Tenebrionidae* (17%) and *Anthicidae* (13%). Larvae accounted for almost a half (45%) of the whole beetle material. On the average, these two groups, beetles and ants, contributed to as much as 97% of the total number of macrofauna in the top soil layer. Therefore, the statement that the soil fauna of dry steppes of the region of Mongolia under study consists of ants and beetles is not exaggerated.

The density of macrofauna per m² is shown in Table 20. These data characterize the total density of macrofauna and the density of the two dominant groups, ants and beetles. It seems that the high densities for the whole macrofauna cannot be considered as comparable since very high numbers of ants on some sites raise total densities to a higher level than that which could be really expected. The methods applied in this study are not suitable for estimating ant numbers; it is probable that little ant nests were sampled as a whole. In this situation the main emphasis will be put on other components of the fauna, particularly on beetles. As already noted, almost a half of the beetles recorded were in the larval stage and they were not identified. Of the adults, *Carabidae* and *Tenebrionidae* were identified to genus. *Tenebrio-*

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Table 20. Density of total macrofauna (number per m^2) in soil cores 15 cm deep

Site	Density		
	total	ants	beetles
1	320	270	50
2 encl.	160	30	110
4	533	367	93
5	553	503	43
7	216	106	110
8	203	143	60
9	666	533	133

nidae were highly dominated by the genus *Scythis* sp., which accounted for 89% of the *Tenebrionidae* caught, 45% of the *Coleoptera*, and 69% of the two dominant families, *Tenebrionidae* and *Carabidae*. The *Carabidae* comprised such genera as *Pterostichus* sp., *Harpalus* sp., *Amara* sp., *Bembidion* sp., *Corsyra* sp., and *Microlestes* sp. Among other beetles there were rather abundant representatives of the genus *Mylabris* sp., of the family *Meloidae*, and also of the families *Anthicidae*, *Cerambycidae*, *Chrysomelidae*, and *Scarabaeidae*. The total density of beetles (Table 20) was high, and the highest one, recorded on the moist site 9, was due to a high number of larval coleopterans. In addition to beetles and ants, also sparse spiders, larval lepidopterans, flies and hymenopterans were recorded in the soil.

DISCUSSION

Although the sampling period was short, it can be concluded that the invertebrate fauna of the study plots was relatively diversified and abundant. The density of soil beetles was similar to that found by Ulykpan (1976, 1977, 1978), who studied dry and desert steppes of the same region of Mongolia; the densities of adult beetles ranged in his study from 44.6 to 88.6 individuals per m^2. The same similarity concerns the taxonomic composition of soil fauna: beetles were highly dominated by two families, *Carabidae* and *Tenebrionidae*. Also some genera are the same. The genus *Scythis* sp. dominating our material also occur in the materials collected by Ulykpan, as represented by one species, and classified to phytophagous pests. However, Mordkovitch and Afanasiev (1980) have found that in dry steppes of Kazakhstan, *Tenebrionidae* play an important part in litter transformation. During 40 days these beetles used up to 10 g of litter per m^2, which accounted for about 20% of the litter biomass. *Tenebrionidae* have a stimulating effect on cellulolytic microflora developing in their dung. The intensity of this action increases southwards, and as a result the cycling of nutrients in ecosystems is speeded up. Since other large detritophages are lacking there (only one earthworm was found in all samples), we are motivated to classify *Tenebrionidae* after Mordkovitch and Afanasiev (1980) as detritophages; they would be the main detritophages in these ecosystems.

The abundance of the fauna associated with plants was estimated only on two sites. Surprisingly high numbers of sucking phytophages on *Caragana* shrubs suggest that the grazing trophic chain must be well developed in dry steppes with *Caragana microphylla*. If it can be accepted that some ants on the transect feed on honeydew, then also on other sites, without *C. microphylla*, there are aphids producing honeydew. They were not revealed by the methods used in this study. Also the numbers of orthopterans, a group difficult to quantitatively assess, were below the expected level in pitfall traps, sweep net and in samples per unit time.

As far as the vertebrate fauna is concerned, we have some data on mammals. Cattle, horses, sheep, goats and camels permanently roaming the steppe spent most of their time in the depression and at the edge of the salt lake (basalt section of the transect), the evidence for this being provided by large amounts of dung on sites 8 and 9, many times larger than on the other sites (Table 21). Due to this the only moist sites along the transect were at the same time well fertilized. Consequently, the drying lake bottom always supports green grass and sedges, and the margin is covered by *Lasiagrostis splendens*, the tallest grass in this area.

Table 21. The number of droppings voided by domesticated animals on the study sites in July 1979 (mean values per 100 m^2)

Site	Number of droppings	Estimate error
1	7.6	± 1.6
2	3.6	± 0.9
4	7.8	± 2.9
5	7.6	± 4.4
6	7.2	± 1.5
7	7.0	± 3.5
8	24.0	± 5.2
9	37.6	±11.7
Station	9.0	± 3.0

The wild mammals of the Gurvan Turuu region were examined during earlier expeditions: Transmongolia 77 and Transmongolia 78. Small mammals were represented by nine species such as *Mustela nivalis* L., *Ochotona daurica* Pal., *Marmota bobac* M., *Allactaga sibirica* F., *Mus musculus* L., *Phodopus sungorus* Pal., *Meriones unguiculatus* Milne-Edwards, *Alticola argentatus*, and *Microtus brandti* Raddo. According to Weiner *et al.* (1982), *M. bobac* and *M. brandti* are the most important

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species in this steppe. *M. bobac* belongs to important game animals in Mongolia. The annual bag is about one million individuals, and this probably accounts for the gradual decline in the population of this species, which has its southern boundary in the region of Gurvan Turuu. The density on the study area was 9.7 individuals per hectare (970 per km²). The Brandt vole population, like populations of other species of this genus, was subject to high number fluctuations. In 1977 the population was low, reaching 21.8 individuals per hectare, while in 1978 there were 110 voles per ha (Zieliński 1981). Similarly, the vole colonies occupied 12% and 40% of the steppe in 1977 and 1978, respectively. Weiner *et al.* (1982) have estimated that the two dominant species, *M. brandti* and *M. bobac* annually remove 283 kg of dry plant material per hectare (this amount includes plants consumed and plants destroyed during foraging and burrowing), which means that rodents removed about 10% of the total above-ground plant biomass in the study area. At the same time easily available nutrients, in the form of dung voided by rodents, were permanently released into the ecosystem. The estimated amount of dung was 52 kg per hectare, including 2.2 kg N, 0.31 kg P, and 0.62 kg K.

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XII. THE RATE OF DECOMPOSITION OF PURE CELLULOSE AND PLANT LITTER

INTRODUCTION

This paper presents the results of the study, conducted in July and August 1979, on decomposition rate of dead plant material (litter) and pure cellulose in different types of steppe ecosystems located on the Gurvan Turuu transect.

The rate of decomposition is a measure of the biological activity of the soil, that is, the rate of biological processes occurring in soils of various ecosystems; it is a good index of the rate of matter cycling in ecosystems.

STUDY AREA AND METHODS

The study area surrounded the research station Gurvan Turuu. Climatic conditions, soils and plant cover are described in preceding chapters. The study sites denoted on the map of plant communities (Fig. 30) by numbers 1, 2, 4–9 are considered good representatives of all types of steppes occurring in this region, including shrubby and herbaceous steppes and those on soils with greater moisture and salt contents. Some additional study plots were located on enclosed areas of site 2 (called 2 encl.) and site 6 (called 6 encl.).

The objective of this study was to estimate the variability in the decomposition rate of dead organic matter and cellulose in different steppe ecosystems.

The rate of cellulose decomposition was measured at the soil surface and in soil horizon A_1, 0–10 cm deep. The rate of litter decomposition was measured at the soil surface (Photo 20).

On each of the study plots 10 litter samples and 10 cellulose samples were put on the soil surface, and also 10 cellulose samples were put in the 0–10 cm layer of soil.

The so-called litter-bag method was used to analyse the decomposition of litter. The bags were made of nylon mesh screen with a mesh size of 1.2 mm. About 4 g of dry autochthonous plant material was put into each bag.

To determine the decomposition rate of pure cellulose samples, filter papers 9 cm in diameter were used. They were put on the soil surface or perpendicularly placed in the 0–10 cm soil layer. They were wrapped in mesh screen of a mesh size of 1.2 mm as well. Before putting them in the field, these filter papers were boiled in 2% KOH, tared after being leached in distilled water, and then sterilized in an autoclave. After a two-month period of exposure in the field, the filter papers were boiled again in KOH to eliminate intermediate products of the decomposition of cellulose and microorganisms, and then they were dried at 105°C and weighed. To determine the weight of mineral impurities, the filters were combusted in an oven at 500°C, and finally the losses in weight during the period of exposure in the field were calculated.

The rate of litter and cellulose disappearance estimated from the losses in the weight of the material exposed in the field is expressed in mg $g^{-1}day^{-1}$.

RESULTS

Significant differences were found in the rate of cellulose and litter decomposition between the steppe ecosystems under study (Table 22 and 23) when such processes were analysed as (a) the rate of cellulose decomposition in soil *in situ*, and (b) the decomposition rate of dead plant material on the soil surface.

To test the statistical significance of the difference in the rate of cellulose decomposition in soil between the study plots, the variance was analysed and the *F*-ratio was calculated (Table 22).

Table 22. The rate of pure cellulose decomposition in soil (0–10 cm) values in mg g^{-1} day^{-1}. Analysis of variance and significance F: V_{OB} — mean square for plots; V_e — mean square for error

Site	Sample										
	1	2	3	4	5	6	7	8	9	10	$\bar{x}_i$
2 encl.	8.9	11.8	9.8	10.4	7.4	6.6	9.3	6.2	5.6		8.4
2	11.8	9.7	9.8	11.2	14.0	12.3	6.5	5.5			10.1
1	10.0	6.8	7.8	6.7	8.7	8.4	9.6	9.9	7.4		8.4
4	11.4	7.8	9.6	8.7	12.5	10.3	5.7	7.3	10.2		9.3
5	12.4	13.9	15.1	15.4	10.5	11.0	6.4	7.4	12.9		11.7
6 encl.	7.0	10.2	10.1	10.6	8.0	10.7	9.3	4.7	12.3	11.2	9.4
6	12.2	15.4	13.8	12.4	12.5	15.1	12.2				13.4
7	10.4	10.0	6.8	9.8	11.8	16.0	12.7	13.2	15.4		11.8
8	14.8	11.0	10.2	9.2	7.6	14.9	16.7	14.5			12.4
9	3.7	5.1	6.7	8.1	7.7	10.7	5.4	6.8			6.8
$\bar{x}_j$	10.3	10.2	9.97	10.1	10.1	11.6	9.4	8.4	10.6		

⟨$V_{OB} = 35.0$; $V_e = 5.5$; $F_{OB} = 6.4$; $F_{0,05} = 2.1$⟩

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Table 23. The rate of litter decomposition on soil surface in steppe ecosystems

Site number	Amount of decomposed litter [mg/day]	Standard error
1	12.95	±3.8
2 encl.	9.51	±5.4
4	14.75	±5.4
6 encl.	21.86	±8.2
6	15.67	±1.5
8	15.50	±3.1
7	18.50	±5.3
5	16.54	±3.9
9	31.54	±6.2

To compare means between objects a new test of Duncan was used (Fig. 37). The significance level of 0.05 was used. On the basis of this analysis, the following groups of habitats can be distinguished according to an increasing rate of cellulose decomposition in their soil (Fig. 37):

— site 9 — 6.8 mg $g^{-1}day^{-1}$,
— sites 2 encl. and 1 — 8.4 mg $g^{-1}day^{-1}$,
— sites 4 and 6 encl. — 9.3 and 9.4 mg $g^{-1}day^{-1}$,
— sites 2, 5, 7, and 8 — 10.1, 11.7, 11.8 and 12.4 mg $g^{-1}day^{-1}$,
— site 6 — 13.4 mg $g^{-1}day^{-1}$.

Thus, the lowest decomposition rate of cellulose in soil was found at the bottom of the temporary salt lake in the basalt part of the transect (site 9) and the highest one in the soil of site 6 (representing the eastern part of the transect) which consisted of gentle slopes supporting a *Caragana* steppe.

The differences in the rate of litter decomposition (Table 23) were even more pronounced than the rate of cellulose decomposition. The liter samples exposed on the soil surface disappeared at a rate of 9 to 30

Table 24. The rate of organic matter decomposition and topoclimatic characteristic of different steppe types along the transect

Data	Groups of sites		
	I	II	III
Rate of cellulose decomposition in soil [mg g^{-1} day^{-1}]	9.0	10.5	11.5
Rate of litter decomposition [mg g^{-1} day^{-1}]	3.5	4.9	4.2
Number of days with a maximum temperature above 25°C	16	15	12
Minimum air temperature [°C]	9.3	9.8	9.5
Mean minimum relative air humidity	40	44	43
Mean relative air humidity	60	66	59

Note: Climatic data after Lenart (1979).
Mean values for sites: I (1, 2, 2 encl.) — western part; II (4, 5) — central part; III (6, 6 encl., 7) — eastern part.

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mg dry weight per day. The lowest rate of litter decomposition, like that of soil cellulose, was characteristic of poor, dry steppes in the western part of the transect. The highest rate of litter decomposition was noted on the bottom of the temporary salt lake covered with dense, evergreen sedges (site 9, Table 24). An attempt was made to compare the decomposition rate of litter and soil cellulose with topoclimatic characteristics of various parts of the transect (Table 24). For this purpose three groups of sites have been distinguished. Comparing the mean rate of cellulose decomposition in soils of the eastern, central and western parts of the transect, we can see that it is the highest for sites 6 and 7, located in the eastern part of the transect on granitoid weatherings (site group III). The sites in the central part of the transect (site group II) on weathered basalt, are characterized by lower cellulose decomposition rates. The group of sites representing a poor steppe on deluvial soil in the western part of the transect (group I) has the lowest rate of cellulose decomposition. The rate of litter decomposition (Table 24) followed the same pattern also for the sites of group I, where it was the lowest. The

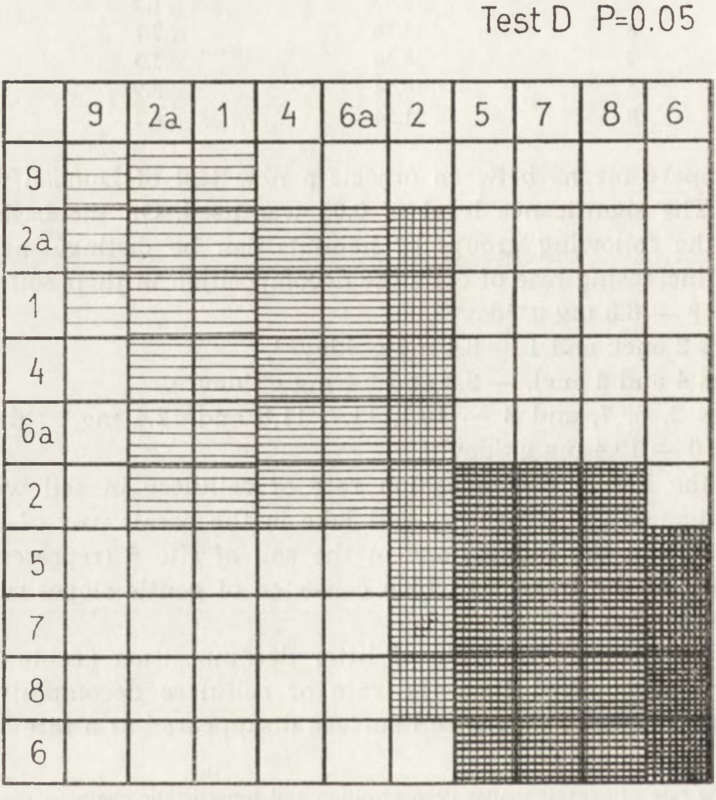

Fig. 37. The comparison and grouping of studied ecosystems according to the rate of pure cellulose decomposition

Sites designation as in Fig. 30

Table 25. The rate of organic matter and cellulose decomposition in steppe ecosystems [mg g^{-1} day^{-1}]

Site	Litter, soil surface 1	Cellulose, soil surface 2	Cellulose, soil 0–10 cm 3
2 encl.	2.6	1.2	8.4
6 encl.	3.3	1.3	9.4
1	3.5	1.4	8.4
4	4.0	1.4	9.3
6	4.2	1.4	13.4
8	4.5	1.3	12.4
7	5.0	1.0	11.8
5	5.9	1.3	11.7
9	8.5	1.7	6.8

$$\frac{\text{litter surface}}{\text{cellulose surface}} = 3.4$$

$$\frac{\text{cellulose soil}}{\text{cellulose surface}} = 7.9$$

rate of litter decomposition on sites II was similar to that on sites III.

All of the study sites and methods have been compared in Table 25. The results are expressed in mg g^{-1}day^{-1}. A great difference was found in the rate of cellulose decomposition between the soil surface and top soil layer to a depth of 10 cm. On the average, it was eight times higher in the soil than on the soil surface. The rate of cellulose decomposition on the soil surface was very slow, reaching less than one-third of the decomposition rate of plant litter exposed on the soil surface.

Site 6, which is dominated by *Lasiagrostis splendens*, is characterized by a high rate of cellulose decomposition in soil and a rather high rate of litter decomposition on the soil surface. The adjacent site 9 (lake bottom) has the lowest rate of cellulose decomposition in soil (6.8 mg g^{-1}day^{-1}), but the highest rate of cellulose and litter decomposition on soil surface (1.7–8.5 mg g^{-1}day^{-1}).

DISCUSSION

The decomposition rate of organic matter and cellulose found for steppe ecosystems near Gurvan Turuu can be compared to those obtained for other grasslands. Ulehlova (1976) gives the following figures for a *Seratulo-Festucetum-Commutatae* grasslands:

— cellulose decomposition rate (soil 0–10 cm) — 6.5 mg g^{-1}day^{-1};

— litter decomposition rate on soil surface — 3.35 mg g^{-1}day^{-1}.

Heal and Perkins (1978) found the following rates of litter decomposition on soil surface of the montane community *Agrostis-Festuce*: 6.5 mg g^{-1}day^{-1} in July, 3.3 mg g^{-1}day^{-1} in autumn, 4.7 mg g^{-1}day^{-1} from May to November.

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Since the climate of Mongolia is strongly continental, a greater decrease in the rate of decomposition could be expected in the ecosystems under study. The Gurvan Turuu transect is located in the centre of the Asiatic continent, and it is characterized by large annual variability in temperatures and by high daily amplitudes. In January mean minimum air temperatures drop to −26°C, and the absolute minimum is less than −45°C. The mean minimum in July, which is the warmest month, is about 10°C, and the absolute minimum is below zero. The mean maximum exceeds 20°C, and the absolute maximum can reach 36°C (Olecki 1977; chapter IV). It should also be remembered that thermal conditions in soils of this area can be locally complicated, as this area lies on the border of permafrost. Along the transect, permafrost occurs at a depth of 225 cm on site 1, and at 70 cm on site 9 (Wicik and Kossobudzki 1979).

The growing period (mean daily temperatures above 5°C) lasts about 141 days in this area (e.g. from May 5 to September 23, 1976); thus it covers merely 39% of the year (Olecki 1977). The period when the temperature of the soil surface is lower than 0°C lasts from mid-October to mid-April, thus the soil is frozen for half the year.

Characteristic of the climate of this area are also high amplitudes of daily temperatures, particularly in spring, when they exceed 40°C (Olecki 1977). Under such climatic conditions, the biological processes occurring in the soil are inhibited in winter (for about half the year), and in the warm part of the year they are limited to a certain depth. A reduction in the activity of living organisms can be partly replaced by drastically acting abiotic factors that are considered a cause of the so-called abiotic decomposition, that is, the decomposition at a reduced activity of microflora and invertebrate fauna. Certainly the processes of soil freezing and thawing are also important here (Goodall and Perry 1979). According to Heal and Perkins (1978) the leaching of nutrients from litter could have a marked effect on the rate of decomposition. These authors have found that in the first stages of decomposition about 20% of nutrients is leached. Vossbrinck (1976) reports that in a dry American prairie about 30% of plant material is decomposed by abiotic factors.

According to Zlotin (1974), abiotic decomposition in summer is an effect of photochemical oxidation of organic matter caused by solar energy; short-wave radiation with a wave length of less than 400 μm being most active. Zlotin (1974) has found that as much as 70% of the litter of steppe ecosystems near Kursk is decomposed by abiotic factors. High temperatures at the soil surface speed up abiotic decomposition. Some data indicate that photo-oxidation can also occur in the absence of water (Terenin 1967). This could be the case in central Mongolia under the conditions of drought and heavy insolation.

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Using the topoclimatic characteristics obtained by Lenart (1979) at the same time the ecological studies were conducted, it is possible to relate the rate of cellulose and litter decomposition with basic abiotic factors such as temperature and humidity.

The western part of the transect covered with a rather poor steppe is the warmest and driest part since it has the lowest mean minimum relative air humidity and the highest number of hot days with temperature over 25°C (Table 24). The decomposition rate of both litter and cellulose was the lowest there (sites group I).

The eastern most elevated part of the transect, with sites of group III (6, 6 encl. and 7), has different thermal and moisture conditions. It is a rather rich shrub steppe with *C. microphylla* and *C. pygmaea* protecting the soil of this area from excessive heat radiation. This is probably a reason why, as indicated by the climatic research of Lenart (1979), the minimum air temperatures are higher in this part of the transect than in the western part covered with sparse vegetation. It should be added that in steppes with large proportions of *Caragana* shrubs there is more organic matter accumulated on the soil surface (Kowalkowski 1977; chapter VIII), which has an effect on physico-chemical and biological processes occurring in soil. The sites of group III are characterized by a slightly higher rate of litter and cellulose decomposition.

Topoclimatic conditions were also favourable in the central part of the transect, located on basalts. The air humidity was higher and temperature fluctuations lower because of the nearby lake, which was surrounded by sites of group II and also by sites 8 and 9.

Site 9 is worth special attention. It lies on the bottom of a temporary salt lake, in the central part of the transect, and is characterized by the highest mean temperature of July (16.2°C) and the highest mean and minimum relative air humidity (66 and 40%, respectively). In this site, classified as a sod-meadow solonchak, the water content always exceeds that at which the withering of plants begins (Kowalkowski 1977). Frequently the water is stored in amounts exceeding biological demands, and the period of high soil moisture is prolonged by at least one and a half month. In addition to the accumulation of water in the lake depression, the air humidity was also higher than at other sites (permafrost area). Due to such thermal-water conditions, the decomposition of organic matter on soil surface was intense (the highest rate of litter and cellulose decomposition on soil surface along the transect). The rate of cellulose decomposition in the soil, however, was the lowest. This was probably an effect of an excessive water content in the soil, combined with oxygen deficiency. The biological activity of solonchak soils has to be reduced also by a high concentration of salt. Even 0.1% salt has a reducing effect on the activity of microorganisms (Napliekova 1974).

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XIII. THE PRODUCTION-DECOMPOSITION BUDGET OF ORGANIC MATTER

This study was carried out on 11 sites representing all basic types of dry steppes and also solonchaks occurring on the Gurvan Turuu transect. Geological, climatic, hydrological, edaphic, botanical and zoological characteristics of these sites are presented in preceding sections. In this section there is an attempt to develop an ecological synthesis on the basis of a part of the collected data. We will try to make a budget of basic ecological processes such as production and decomposition of organic matter in ecosystems.

The methods of sampling and material processing are described in detail in preceding sections.

RESULTS

SEASONAL CHANGES IN LIVE AND DEAD PLANT BIOMASS

To characterize seasonal changes in biomass, the materials from two enclosed, ungrazed sites, 2 encl. and 6 encl. were used. These sites were sampled for the longest time, that is, for 140 days of the growing season of 1978. The increase of dead and green biomass was calculated as a difference between two successive measurements. The results are presented in Table 26 and Figure 38. The changes of the two components of plant biomass, i.e., in dead and live phytomass, are different. The increase in live biomass ended in June on the two sites. Then the increase in live plant biomass was negative. This means that the losses per each square metre exceeded the growth, which certainly was continued. An opposite pattern was observed for dead plant material. In the first half of summer, when the live biomass increased, the amount of dead material per unit area dropped. On site 6 encl. the positive increase in the dead matter began during the same ten-day period in which the live biomass began to decrease. On site 2 encl. changes in the direction of

Table 26. Increases in plant biomass on two enclosed sites of the steppe of Gurvan Turuu in ten days periods, 1978 [$g \cdot m^{-2} \cdot d^{-1}$]

Site (encl.)	Indices	May		June			July			August			September		
		20	30	10	20	30	10	20	30	10	20	30	10	20	30
2	Green biomass		0.9	2.0	3.1	3.8*	2.0	1.2	−2.3	−3.3	0.4	−1.4	−0.5	−0.9	−5.2
	Dead biomass		−2.2	−0.6	−0.4	−1.4	−1.4	1.2	0.7	0.0	1.2	0.3	0.7	0.5	1.5
6	Green biomass		1.0	2.0	3.7*	3.0	0.8	−1.2	−1.3	−0.3	−3.3	0.3	−2.9	−1.9	−4.4
	Dead biomass		−1.9	0.5	−2.5	−0.9	−0.4	−2.0	0.3	3.9	2.0	−1.9	1.1	0.2	3.6

* Maximum values of production.

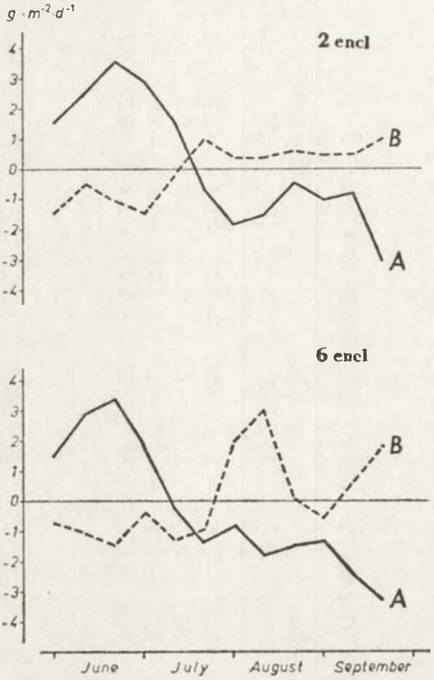

Fig. 38. Increases in green (*A*) and dead (*B*) plant biomass on enclosed sites

these two processes occurred during 20 days. These two opposite processes are almost perfectly separated in time, each of them covering half of the season. The dominance of growth and the dominance of the disappearance of plant biomass occurred in two separated halves of the season.

On the basis of samples taken at 10-day intervals on the ungrazed sites, the maximum production of green biomass can be estimated under these conditions. It was rather high and very similar on the two sites, reaching 3.7–3.8 g m^{-2} day^{-1}. Such a high production rate was maintained for ten days or less (samples were taken at 10-day intervals) and in 1978 it occured in June (Table 26).

For these two enclosed sites the sums of positive and negative increases of dead plant material were also calculated over the growing season of 1978:
site 2 encl.: Σ increases = 6.1 g·m^{-2}, Σ losses = 6.0 g·m^{-2},
site 6 encl.: Σ increases = 11.0 g·m^{-2}, Σ losses = 9.6 g·m^{-2}.
It follows from this that on ungrazed sites the annual increases in dead plant material only slightly exceed the losses. On the poorer site, 2 encl., these two processes were almost completely balanced. On site 6 encl. which is richer, with denser vegetation, small amounts of litter were stored.

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COMPARISON OF PRODUCTION AND DECOMPOSITION OF ORGANIC MATTER IN DIFFERENT TYPES OF STEPPES

For ten study sites the rates of production and decomposition of organic matter were calculated, and an attempt to calculate the budget of these processes was made (Table 27). It was assumed that the maximum above-ground standing crop is equal to the total above-ground plant production on each site. Therefore, knowing the length of the growing season in the two years, the mean rate of daily production could be calculated. For seven out of ten study sites it was less than 1 g per day per m^2, therefore it was very low. Two ecosystems, one of group III (form with *Caragana microphylla*), and the other dominated by the tall grass *Lasiagrostis splendens* (site 8), were characterized by very high increases in plant biomass; they were 3.01 and 5.76 g per day per m^2, respectively. Also on site 9, with *Carex enervis* on solonchak, the above-ground production was rather high, equal to 1.69 $g \cdot m^{-2} \cdot day^{-1}$.

Litter biomass was estimated on each site (Matuszkiewicz *et al.* 1980b), and mean values were calculated for each site. Very large amounts of litter were characteristic of site 6 *Caragana* (steppe on granites with *Caragana microphylla*) and site 8 (tall grass *Lasiagrostis splendens*, on solonchak).

The rate of litter disappearance from nylon mesh bags was estimated for all the sites over a period of 60 days of the growing season of 1979 (Breymeyer and Grabińska 1980). On this basis, the daily and seasonal rate of litter disappearance was calculated. Generally, the sites of higher productivity were characterized by a higher litter biomass and a higher disappearance rate of litter. The only exception was site 9, with *Carex enervis*, where litter was so scarce that it was practically impossible to pick it up from short, very dense, brush-like vegetation. However, among green plants, small scarce yellow pieces were seen, thus it was assumed that on this site there were about 5 g of litter per m^2. As a result, though this site is characterized by a very high rate of litter and cellulose decomposition in nylon bags exposed on the soil surface (Breymeyer and Grabińska 1980), the calculated amount of litter decomposed over the year on this site was very small.

The budget of production and decomposition of above-ground organic matter is calculated as the daily production/daily decomposition ratio. This ratio ranged from 1.4 to 5.9 for different ecosystems, except for site 9 (Table 27, Fig. 39).

A similar ratio was calculated for the production and decomposition of below-ground plant material (Table 28). The number of study sites was smaller here, since below-ground plant biomass was estimated for only six ecosystems. It was assumed that this was a mean biomass and

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Table 27. Data for the calculation of above–ground production–decomposition budgets in 10 steppe ecosystems

Site	Maximum above-ground standing crop Pp in $g \cdot m^{-2} \cdot y^{-1}$	Daily above-ground[a] production $[g \cdot m^{-2} \cdot day^{-1}]$	Mean litter biomass $[g \cdot m^{-2}]$	Rate of litter decomposition in bags $[mg \cdot g^{-1} \cdot day^{-1}]$	Litter decomposed on sites per day $[g \cdot m^{-2} \cdot day^{-1}]$	Litter decomposed on sites per season $[g \cdot m^{-2} \cdot y^{-1}]$	Budget $\frac{\text{rate of production}}{\text{rate of decomposition}}$
2 encl.	126.0	0.90	59.1	2.57	0.152	21.3	5.92
1	58.6	0.64	41.2	3.50	0.144	13.3	4.44
4	57.5	0.63	38.4	3.99	0.153	14.1	4.12
5	62.7	0.68	26.1	5.91	0.154	14.2	4.42
6 encl.	104.0	0.74	79.4	3.33	0.264	36.9	2.80
6	87.5	0.95	58.3	4.19[b]	0.244	22.5	3.89
7	91.3	0.99	59.9	5.00	0.300	27.6	3.30
6 Car.[d]	276.8	3.01	497.5	4.19[b]	2.085	191.8	1.44
8	529.5	5.76	239.3	4.47	1.337	123.0	4.31
9	155.9	1.69	5.0[c]	8.52	0.042	3.9	40.24

Pp — plant production.

[a] – It was accepted that the growing season covered 140 days in 1978 and 92 days in 1979 (Lenart 1979).

[b] – Litter bags were put within the area under *Caragana* shrubs and in the grass between; this is a mean value from 10 samples.

[c] — This is an arbitrary value, scarcely visible amount of litter were not estimated by weight on this site.

[d] – All figures for *Caragana microphylla* microcoenosis (see chapter IX); woody parts extracted from Pp estimate.

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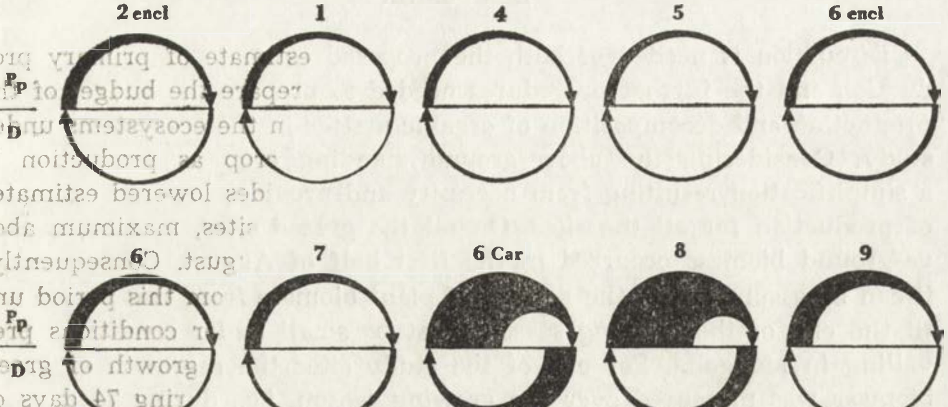

Fig. 39. Graphical presentation of the budgets of the production and decomposition of organic matter in some grassland ecosystems of the Gurvan Turuu transect

P_p— plant production of organic matter; D — decomposition of organic matter

Table 28. Data for the calculation of production-decomposition budgets of organic matter in upper soil layer

Site	Plant biomass in 0-5 cm layer [g·m^{-2}]	Production as 25% of mean biomass [g·m^{-2}·y^{-1}]	Decomposition of plant[a] matter in soil [g·m^{-2}·y^{-1}]	Budget rate of production / rate of decomposition
2	1244.9	311.2	276.7[b]	1.12
1	942.2	235.5	90.4	2.61
5	672.9	143.2	134.9	1.06
6	1769.4	442.3	209.3	2.11
7	1255.6	313.9	328.4	0.96
9	2141.4	535.4	15.2	35.20

Note: it has bean accepted that the measured root biomass is close to the mean biomass.

a — It was calculated assuming that the rate of litter decomposition in soil is higher than on the soil surface in the same relative proportion as the measured rate of pure cellulose decomposition.

b — It has bean assumed that the rate of litter decomposition on site 2 does not differ from that on site 2 encl. (litter bags on site 2 were destroyed by wind).

production was calculated as 25% of this biomass, according to the proportions found for Asiatic grasses by Iwaki (1979). The ratio production/decomposition for below-ground plant parts ranged between 1 and 2.6 except for site 9 where it was very high, as in the case of the above-ground production. This means that production does not overweight decomposition below the ground, in contrast to the situation above the ground.

DISCUSSION

Discussion is needed of both the proposed estimate of primary production and the further procedures needed to prepare the budget of the production and decomposition of organic matter in the ecosystems under study. Considering the above-ground standing crop as production is a simplification resulting from necessity and provides lowered estimates of production for all the sites. On all the grazed sites, maximum above-ground biomass occurred in the first half of August. Consequently, it can be assumed that the growth of plant biomass from this period until the end of the growing season must be small under conditions prevailing in Mongolia. For one of the study sites the regrowth of green biomass was measured over the growing season, i.e., during 74 days of the summer of 1979. It has been shown that the regrowth, which exceeded the June standing crop at the beginning of the season, markedly declined with time. The regrowth recorded in the last period of sampling, from 10 to 22 August, was only 4.5 $g \cdot m^{-2}$, this accounting for only 5% of the standing crop on August 10. Thus, the increase in biomass is very small after the maximum in August, and the error in the production estimate is likely to be small as well. It should be noted here that the temperatures in September in Gurvan Turuu can drop below 0°C and it may be snowing. More doubtful is the estimate of production on solonchaks (sites 8 and 9) where sampling was made on only one occasion. The results obtained for site 8, covered with the tall grass *Lasiagrostis splendens*, can be compared with data collected in 1973–1974 on a dry Mongolian steppe of the same phytogeographical region by Gordeeva *et al.* (1977). In their studies the site with *L. splendens* reached peak biomass on August 5 in 1973 and as late as on August 20 in 1974. The increase in green plant biomass during the period from the end of July to the peak was 14% of the total standing crop in 1973 and 23% in 1974. In our studies site 8 was sampled at the end of July, therefore plant production of this site can be underestimated by 14–23%. Another doubt about our materials from this site results from the fact that the green biomass of *L. splendens* was not separated from yellow. For the other sites it was rather reasonably assumed that if very short vegetation is heavily grazed, the small amount of yellow biomass in August is the current-year biomass, and therefore, it can be included to the current-year production. This is not the case of *L. splendens*. The woody stems of this tall grass are stiff, and it is very probable that persist from season to season if not grazed in winter. According to Gordeeva *et al.* (1977), in the second half of summer, the green biomass of *L. splendens* accounts for 40–80% of the total standing crop; these authors distinguished between the last-year and older dead (yellow) biomass, but the criteria are not clearly stated. Because we did not make this distin-

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ction in our study site, it is possible that production is overestimated. It seems, however, that our site was more intensely grazed and more productive (529 g m^{-2} versus 438 g m^{-2} in Gordeeva's study), and this suggests that it contained larger amounts of green biomass.

To calculate root production, it was assumed that they accounted for 25% of the mean below-ground biomass to a depth of 60 cm. This proportion is generally used in Japanese studies reviewed by Iwaki (1979). Because it was found for Asiatic species of grass, it is likely to be valid for Mongolian grass.

The budget calculated for two layers of the steppe vegetation (above- and below-ground plant biomass) also need some discussion. A question arises whether or not the excess of production over decomposition has to indicate that the studied ecosystems tend to accumulate organic matter. It should be remembered that the above-ground organic matter produced in summer is grazed throughout the year by cattle not provided with other food supplies. Is, therefore, the excess of production over decomposition in summer grazed during the cool part of the season? At the beginning of the growing season some amounts of dead vegetation were standing on the study sites. This, if production exceeds decomposition in summer and after winter the remains of last-year dead vegetation are noted, it may be suggested that some amount of the organic matter is accumulated in the study ecosystems. This accumulation probably occurs in soil depressions or in places covered with shrubs; from all exposed areas or slopes organic matter is removed by strong winds, particularly frequent in this part of Mongolia. Consequently, the excess of production is unevenly distributed in this area as an effect of heavy eolian erosion.

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XIV. FINAL REMARKS

Steppes are a very old plant formation of the Asiatic continent. Fossil pollen typical of steppe vegetation was found in Cretaceous and Tertiary deposits of the Lake Valley in Mongolia (Oszast 1970). In the Pliocene the steppes of central Mongolia already represented a permanent formation. Great climatic changes in the Quaternary period were followed by changes in the range of the steppe zone and even by changes in the species composition. In more humid periods the zone of steppes was shifted to the south, towards semi-deserts, and from the north the range of taiga increased. In drier periods the zone of steppes moved to the north, being replaced by semi-deserts in the south. The present central part of the 300 km wide steppe zone of central and eastern Mongolia was probably covered with steppes all the time, though the proportions of particular species could vary. The Quaternary changes in temperature and humidity are testified to by fossil floras recorded in this area (Golubieva 1976; Vipper *et al.* 1976), as well as by the relief of earth surface (Klimek 1980). On this basis the last change in climate which took place in the Holocene was detected. In the period between 5000 and 2000 B.C. the climate at the northern edge of the steppes was warmer and more humid (Klimek 1980). This palaeo-geographical viewpoint inclines us to suggest that the steppe formations were very stable over geological time.

The relief of the Gurvan Turuu region and the extremely continental climate also accounted for the stabilization of steppe landscapes in this region. Small amplitudes of relative altitude (100–200 m), relatively small inclination of slopes, and a thin cover of weathered material on steep slopes can potentially restrain the processes of soil washing off and linear erosion. Climatic conditions, in particular low precipitation and of short duration, combined with high evaporation, do not promote ample surface and linear run-off. Only heavy thunderstorms in summer can initiate such processes. Because they occur when the steppe vegetation reaches its maximum developement and, therefore, protects the soil from erosion, even the erosion initiated in upper parts of the slopes

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is inhibited in lower parts due to the presence of protective plant cover. For this reason, in years with typical weather conditions erosion by water is limited to small areas on stepper slopes surrounding tectonic depressions. Clear traces of linear erosion can be observed e.g. on the slopes of the Bayan Ovo massif and on the southern rim of the Eastern Upland.

Strong winds blowing in the winter-spring period represent a greater potential threat to the degradation of earth surface in the steppe plains, as compared with the erosion by water. But, due to nomadic traditions, the steppe utilized only as a pasture can effectively inhibit deflation. The only exception are the margins of temporary lakes, where an excessive concentration of animals drinking water gives rise to a complete destruction of plant cover. Lake deposits dry up during the dry season and they are blown out and transported over small distances. When it is raining, the slopes bordering these lakes are the places from which water starts to run off or from which the deposits blown out of the lakes are transported back to these lakes.

The long term stability of steppe communities in central Mongolia has been proved by palaeobotanical and palaeogeographical studies. Does it imply that these ecosystems are characterized by ecological stability as well? On the basis of the data available from Central Mongolia, we can consider two aspects of ecological stability. One is manifested in similar, stable proportions of distinct groups of organisms important to the functioning of the ecosystem. A classical example of ecosystems that are not stable in this sense can be tundra because of mass appearances of lemmings every several years. These rodents reach such large numbers that they completely destroy vegetation, and then they die, while the ecosystem is restored during a period of several years. Similar damage to vegetation is caused by locusts that cyclically appear and travel in swarms. Short-grass prairies of the Great Plains in the western states of the USA are invaded every several years by grasshoppers closely related to locusts (Bhatnager and Pfadt 1973; Blocker 1969). These prairies are similar to dry Mongolian steppes, and they receive very similar annual precipitation. But in the Gurvan Turuu region we did not record large densities of *Orthoptera*, and neither did the available literature data provide evidence for this. Instead, the studies on rodents (*Rodents in* ..., 1982) seem to suggest that these animals can have mass appearances in the Gurvan Turuu steppes. Zieliński (1981) has found that the population of field voles occurring in this region in one year was five times larger than in the preceding year. This was a rather sharp increase in numbers, indicating that the population of this rodent can escape from the controlling effect of regulatory mechanisms and, therefore, can destroy the habitat. Consequently, the ecosystems of Gurvan Turuu can be unstable in the first sense that we are considering.

The other aspect of ecosystems stability is an equilibrium between basic processes within the ecosystem, such as the production and decomposition of organic matter, which are responsible for ecosystem self-sustaining. Intense ecological studies on this subject were carried out during the expedition TRANSMONGOLIA '79 in ten steppe types in the Gurvan Turuu region. In some of these ecosystems (solonchaks, steppe with *Caragana microphylla*) the production of organic matter outweighed the decomposition. However, since no clear accumulation of dead organic matter on soil surface was observed, except for the areas under *C. microphylla* shrubs and stony cult mounds "ovo" where some litter accumulates, it is probably blown out and also consumed by animals during winter. A rapid increase in organic matter on solonchaks is also balanced by grazing which is more intense here since these areas have more moisture, and farm and wild animals concentrate in them. In the other, less productive ecosystems, the production of organic matter is almost completely balanced by its decomposition; grass stems lying on soil surface are very sparse, and the content of organic matter in upper soil layers is small.

Data on the long-term changes in ecological processes occurring in these steppe are very poor. To give an example, we can report the results of a 5-year study carried out in Mongolia by Sukhovierko (1978) in comparable dry steppes located 1400–1500 m above sea level on chestnut soils (a steppe with *Stipa krylovii, Poa attenuata, Agropyron* cristatum, and others). The maximum dry standing crop in q/ha varied as follows:

1971	1972	1973	1974	1975
20.1	20.6	13.8	22.2	10.0

This is a rather high variability but also met under milder climatic conditions than those of Mongolia.

Generally, the Mongolian steppes have the following structural characteristics:

As in other dry, climax grassland communities (North-American prairies, Russian steppes), the above-ground plant parts are largely developed. Root biomass exceeds many times the above-ground plant biomass. This should also be the case of production. It has been found that root production in dry American prairies is ten times as high as production of above-ground parts (Sims and Singh 1971). It seems, however, that root production in Mongolian steppes is limited by permafrost close to the soil surface on some sites and also by the fact that the whole soil profile is frozen for a long time in winter.

Wild mammals are predominated by "tarbagan" (*Marmota bobac*) and Brandt field voles. Both are herbivorous and burrowing species, and for this reason they play an important part in the speeding up of

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nutrient cycling in steppe ecosystems (Zimina and Zlotin 1980; *Rodents in* ..., 1982). In dry American steppes two similar groups of burrowing mammals, the prairie dogs and small rodents, are the most abundant and most important herbivores, but they are not represented by the same species (French 1979).

Epigean and soil invertebrates are dominated by omnivorous ants and phytophagous beetles. The beetles are particularly abundantly represented by the family *Tenebrionidae*, which is not very abundant in dry American prairies, where the family *Scarabaeidae* replace it (Breymeyer 1978, 1980).

Human interference, and in particular the latest efforts at modifying the traditional land utilization, can rapidly and effectively destroy the present, rather stable situation. In areas adjacent to large concentration of men, vast areas are under cultivation. The destruction of natural plant cover is followed by a catastrophic eolian erosion; in steppes of northern Mongolia the soil has been irreversibly destroyed as a result of prolonged utilization. Very similar situations are known from the history of the North-American continent in the period of great migrations from the East Coast to the West. The soil of dry prairies was subject to such a heavy eolian erosion after the removal of sward and after plowing that farms were buried under sand. According to Evenari *et al.* (1976) in the Mediterranean region a destroyed site of *Artemisia* needs ten years to recover, and the authors consider this as a very short time for plants of semi-desert habitats. The observation of abandoned crop-fields in Mongolia, which are not numerous so far, also shows that they recover very slowly, and even after many years of succession the vegetation does not reach the state of the original steppe community.

Another threat to the steppe ecosystems is brought about by the tracks of vehicles, the number of which is growing. As no permanent, hardened roads are established, heavy cars rapidly destroy the plant cover of vast areas. Such damaged routes are also eroded by water and wind. Since the soil on them is firm the chance for the regrowth of plant cover is small.

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ISBN 83-04-01411-4

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