RYSZARD GRADZIŃSKI & TOMASZ JERZYKIEWICZ

SEDIMENTATION OF THE BARUN GOYOT FORMATION

(Plates XXXIV-XLII)

Contents

Contents

Abstract. — The Barun Goyot Formation (previously termed Lower Nemegt Beds) is composed of clastic continental sediments of red-beds type; it is probably of Campanian age. The thickness of the formation exceeds 110 m. It is overlain by the Nemegt Formation (previously termed Upper Nemegt Beds), probably of Maastrichtian age; the passage between the two formations is gradual. A formal redefinition of the two lithostratigraphic divisions is presented in the paper. Five principal sediment types are distinguished in the Barun Goyot Formation, displaying sedimentary features indicative of various conditions of sedimentation. The lower part of the exposed profile of the Barun Goyot Formation is characterized by mega cross-stratified units, interpreted as dune deposits; they are intertonguing with water-deposited sediments laid in interdune areas. Channel deposits, attributed to intermittent streams are subordinate; massive sandstones, probably of various origin are predominating. The upper part of the profile of the formation is characterized by the predominance of flat-bedded sandstone units which were probably deposited in an intermittently flooded takyr-like area. The formation contains a rich and diversified fauna. Relatively numerous mammals and lizards occur in the whole profile, while remains of dinosaurs (bones and eggs), tortoises and crocodiles are present mainly in the lower part of the profile.

INTRODUCTION

The Upper Cretaceous deposits of the Nemegt Basin were discovered by the Mongolian Expedition of the USSR Academy of Sciences in 1946. The excavation works were carried out by Soviet expeditions in 1948 and 1949, and subsequently by the Polish-Mongolian Palaeontological Expeditions in 1964, 1965, 1970 and 1971. These works concentrated on the deposits of the Nemegt Formation (Upper Nemegt Beds) which contain numerous dinosaur bones. The underlying deposits of the Barun Goyot Formation (Lower Nemegt Beds) were regarded during the earlier expeditions as a barren series. Therefore, the geological investigations, and especially the sedimentological studies (GRADZIŃSKI, 1970) were devoted to the Nemegt Formation, while the Barun Goyot Formation received less attention.

However, a rich and diversified fauna containing, among others, numerous mammals was found in the deposits of the Barun Goyot Formation during the 1970 and 1971 expeditions (see KIELAN-JAWOROWSKA & BARSBOLD, 1972). The program of palaeontological excavation works carried out on the exposures of this formation made possible geological studies, which were more detailed than those in 1964 and 1965. A larger number of exposures were investigated, and the authors obtained numerous new data, providing for sedimentological interpretation of the deposits of the Barun Goyot Formation.

The authors participated in the Polish-Mongolian Palaeontological Expeditions as geologists responsible for the preparation of plans and profiles of exposures at which fauna was excavated; in addition they carried out geological investigations devoted mainly to sedimentological problems. The first author participated in the 1964, 1965 and 1970 expeditions, and the second author in the 1971 expedition. Rocks and soft-sediment samples collected by the authors during the expeditions were given successive numbers with the indication of the year: 1/64e 2/64..., 1/65, 2/65... etc. The numbers of some samples are given in the text and tables of the, present report, as well as in the paper by GRADZIŃSKI (1970). This collection is housed in the Department of Geology of the Jagellonian University, Cracow.

ACKNOWLEDGMENTS

The authors are greatly indebted to Prof. Z. KIELAN-JAWOROWSKA, Director of the Palaeozoological Institute, Polish Academy of Sciences, for the possibility of participation in the Polish-Mongolian Palaeontological Expeditions and also for the disscusion of some problems. All participants of the Polish-Mongolian Palaeontological Expeditions offered assistance during different phases of the field work, and special thanks are due to Dr. T. MARYAŃSKA and Dr. J. LEFELD. The authors also wish to thank Dr. E. TURNAU and Prof. S. DŻUŁYŃSKI (both of Institute of Geological Sciences, Polish Academy of Sciences) and Dr. R. UNRUG (Department of Geology, Jagellonian University, Cracow) for constructive criticism of the original manuscript.

GEOLOGICAL SETTING

The deposits of the Barun Goyot Formation are exposed in the Nemegt Basin, situated in the Gobi region of the Mongolian People's Republic. This basin, elongated in the East-West direction, forms a graben which is bordered on the northern and southern side by horst massifs. The graben is filled with flat-lying sedimentary rocks of Late Cretaceous and Paleogene age, belonging to a continental sedimentary series, deposited in Late Mesozoic and Tertiary time in the present-day Gobi and in adjoining areas of Central Asia. The faults bordering the Nemegt Basin are certainly younger than the sedimentary rocks filling the basin. The geological and morphological conditions existing in the Nemegt Basin do not permit a more exact determination of the age of faulting. However, the uniform tectonic character of the entire Gobi-Altai and Mongolian Altai supports the assumption that the principal faulting occurred after the Oligocene, or even after the Pliocene, as in other parts of these mountain chains, where faulting of this age has been proved (VASILEV *et al.*, 1959; NEKHOROSHEV, 1966).

The Upper Cretaceous deposits are exposed in the northern and central part of the Nemegt Basin. They consist here of two formations: the younger, called the Nemegt Formation (formerly Upper Nemegt beds) and the older — the Barun Goyot Formation (formerly Lower Nemegt Beds). The observations of GRADZIŃSKI (1970) prove that the Nemegt Formation is overlying concordantly the Barun Goyot Formation, and that there exists a gradual passage between them. The deposits of the Nemegt Formation are dipping to SWS at a very small angle (about 1 $\frac{1}{2}$°). Consequently, the exposures of the Nemegt Formation are situated in the western part of the Basin, i.e. in the western part the Nemegt locality and west of it, while the deposits of the Barun Goyot Formation are exposed in the eastern part of the Nemegt locality, and east of it (Text-fig. 1; see also GRADZIŃSKI, 1970, Text-fig. 1).

The exposures of the Barun Goyot Formation studied by the authors are distributed on an area of about 100 square km, situated north of the axis of the Basin. This area comprises the eastern part of the Nemegt locality, the Khulsan locality and the area within a radius of 5—6 km around the latter. General informations on the geology and morphology of these localities and schematic maps are given in the earlier papers (GRADZIŃSKI *et al.*, 1969; GRADZIŃSKI & JERZYKIEWICZ, 1972).

The existence of exposures of Cretaceous rocks in this area depends similarly as in other parts of the Nemegt Basin, upon development of the younger pediment surface. Two main pediment surfaces of different age are developed in the Nemegt Basin. The younger one is related to the base of the recent drainage system, i.e. to the base of the main sayr (wadi) of the basin and its principal tributaries. It develops at the expense of the older surface, which extends 20—45 m above. Steep erosional escarpments are well developed in the places where the expansion of the younger pediment surface is intensive. Locally, these escarpments are strongly dissected, and consists of systems of deeply incised ravines and isolated hills. Single isolated hills are also present on the surface of the younger pediment, and often have an outstandingly diversified morphology. These young erosional forms provide excellent and often very large exposures. On the other hand, the intervening pediment surfaces and the escarpments not eroded recently are nearly completely devoid of exposures of older rocks. Consequently, the groups of exposures in the investigated area are isolated and an exact correlation of the profiles of the exposures of the Barun Goyot Formation is difficult.

In the north-eastern part of the Nemegt locality the deposits of the Barun Goyot Formation are exposed in the lower part of the ravine walls, and are overlain by the deposits of the Nemegt Formation. Because of the strong dissection of the surface of the older pediment by a system of deep ravines, the intersection line of the boundary of these two formations is complicated. This is characteristic of the Red Field area and the adjoining sayrs (Viper Sayr, Goat Sayr, the terminal part of the Northern Sayr), of the Red Walls area and the western border of the Saksaool Field. The maximum height of the exposed profile of the deposits of the Barun Goyot Formation in these areas ranges from a few metres up to 30 m. The walls of the Eastern Sayr and of the isolated hills, called the Red Monadnocks, situated in the northern part of the Saksaool Field are composed nearly entirely of the deposits of the Barun Goyot Formation.

Another group of large exposures of the Barun Goyot Formation is situated in the south-eastern part of the Nemegt locality, in the area of the Southern Monadnocks. Profiles up to 35 m high can be observed there.

The largest group of exposures hitherto discovered, is situated in the Khulsan locality east of the Nemegt locality. These exposures form a broad belt along the dissected escarpment, bordering the Main Sayr valley from the west. The exposures are up to 25 m high. Smaller exposures are dispersed in a radius of several kilometres around the Khulsan locality. Other exposures of the Barun Goyot Formation are probably present farther north and north-east. However, the authors have had no opportunity to carry out observations in these exposures, which are probably smaller than the exposures described in the present paper.

STRATIGRAPHY

PREVIOUS WORK

Until the year 1970, when a rich determinable fauna was found in the deposits of the Barun Goyot Formation, there had been no data permitting a direct determination of the age of this formation. Conclusions pertaining to this question could be based only on the following premises: 1. the relation to the overlying deposits containing rich dinosaur remains i.e. to the Nemegt Formation (Upper Nemegt Beds), and 2. lithological comparisons with other formations of known age occurring in Southern Mongolia. Such comparisons were hampered by lack of detailed lithological descriptions of these formations and detailed data on their regional distribution, as well as by the great variability of the continental deposits occurring in this area. The opinions of the Soviet authors on the Cretaceous deposits of the Nemegt Basin published before the year 1966, were discussed in detail in the earlier paper of the first author (GRADZIŃSKI, 1970) and therefore, will be discussed here briefly.

The first informations on the succession, lithology and age of the Cretaceous deposits of the Nemegt Basin are given by EFREMOV (1950, 1954, 1955). This author distinguished two series in these deposits but did not introduce clearly defined lithostratigraphic terms. The upper series was called by EFREMOV the "fossiliferous series" or "the subaqueous deltaic channels deposits", and the lower one the "barren series" or the "unfossiliferous lacustrine sandstones". The upper series was assigned by the quoted author to the middle part of the Upper Cretaceous. The lower series was regarded as corresponding in age to the sediments of the lower part of the Upper Cretaceous exposed at Bayn Dzak (i.e. the Djadokhta Formation established by BERKEY & MORRIS, 1927).

The question of age of the "barren series" in the Nemegt locality was not taken into consideration by Soviet palaeontologists (MALEYEV, 1952, 1954; ROZHDESTVENSKY, 1957, 1965; MARTINSON, 1953, 1966), who studied the fauna of the overlying series. In general monographic publications on the stratigraphy of the Mongolian People's Republic (MARINOV, 1957; VASILEV *et al.*, 1959), the Upper Cretaceous deposits in the Southern Gobi were divided into two formations (sing. "svita") established previously in the Eastern Gobi: the Sayn Shand Formation and the Bayn Shireh Formation. The informations included in these publications do not provide, however, a clear view of the succession and age of the deposits of the Nemegt Basin.

New data were provided by the Polish-Mongolian Palaeontological Expeditions which worked in the Nemegt Basin in the years 1964 and 1965. Observations then made by the first

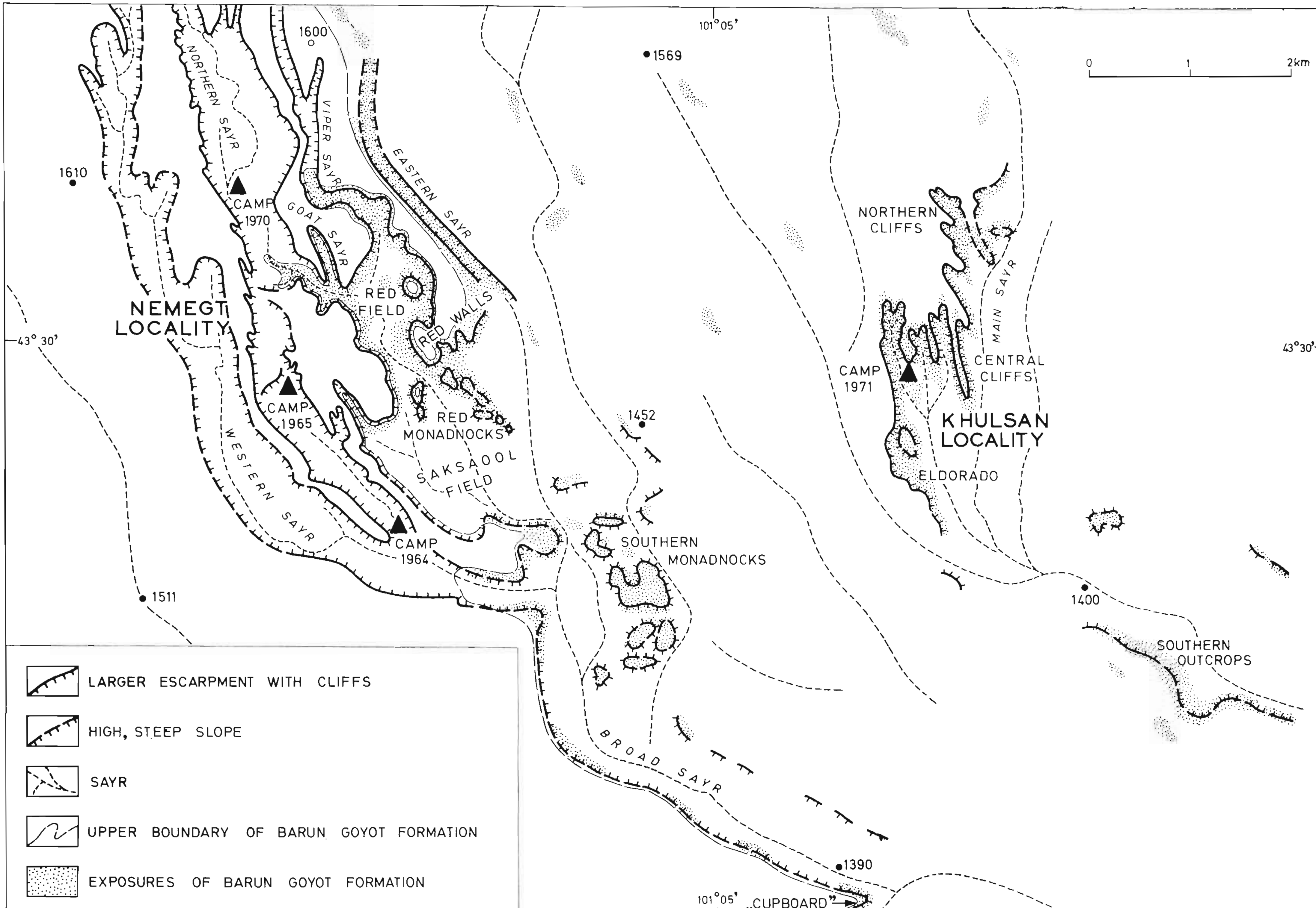


Fig. 1
Geological map of exposures of the Barun Goyot Formation in the Nemegt and Khulsan localities. Exposures of the Nemegt Formation in the locality not shown.

author permitted correcting the erroneous opinions of EFREMOV, (1950, 1954, 1955) on the great erosional disconformity between the two series (GRADZIŃSKI, 1970). A geological and geographical characteristics of the localities in which excavation works were carried out, was published in the first volume of the Results of these Expeditions (GRADZIŃSKI *et al.*, 1969). This description served the purpose of a detailed localization of the exposures and the excavation sites of the individual specimens. A lithostratigraphic division of the Late Cretaceous deposits of the Nemegt Basin was established in the same paper. In the whole basin these deposits were termed the Nemegt Beds, within which two divisions were established, namely the Lower Nemegt Beds and the Upper Nemegt Beds. This division corresponded, in principle, to the earlier series of EFREMOV (1960, 1954, 1955).

The new division was based upon detailed data of the lithology of the deposits, the area of occurrence, the character of the boundary of these divisions and the faunal zones present in the Upper Nemegt Beds. A detailed profile of the Nemegt locality established as a type profile for the two divisions of the Nemegt Beds was also published.

The English term "Beds" was used in the quoted paper according to the rules used in most European literature. The lack of geographical names in the neighbourghood of the Nemegt locality prompted the authors to use the terms "Upper" and "Lower". The established divisions merited a formation status (see GRADZIŃSKI, 1970, p. 154), according to the requirements of the American Code (1961). After submitting for publication the paper by GRADZIŃSKI *et al.* (1969), there appeared the Report of the Stratigraphical Code Sub-Committee of the Geological Society of London (1967), which recommends the usage of lithostratigraphic terms according to the American Code. The first of the present authors stated then, that because of specific field conditions (no possibility of determination of the lower boundary of the Lower Nemegt Beds) and general use of the established divisional names in palaeontological publications, a change of these names should be made only after more detailed studies of the sediments of the two divisions in the Nemegt Basin.

In the meanwhile, there appeared a short preliminary paper by MARTINSON *et al.* (1969) on the stratigraphic division of the Upper Cretaceous deposits of Mongolia. These authors introduced the term "Barungoyotskaya svita" for the Lower Nemegt Beds and the term "Nemegetiyskaya svita" for the Upper Nemegt Beds. These terms may be translated as "Barun Goyot Formation" and "Nemegt Formation". Although the terms introduced by the quoted authors agreed with the rules of the Soviet Code (1965), they did not fulfill the requirements of this code. The authors did not give the reasons for the change of existing names, did not explain the origin of the names, did not give precise localization of the type profiles and the geographical extension of the formations, and they did not provide a detailed characteristics of the deposits. Moreover, the boundary of the two formations is situated at a bed of conglomerate 2 metres thick, which cannot be found in the field. It should be stressed that the present authors have not seen a conglomerate bed, thicker than 0.5 metre in the Upper Cretaceous rocks of the Nemegt Basin.

REDEFINITION OF THE LITHOSTRATIGRAPHIC DIVISIONS

As stated above, the division of the Upper Cretaceous deposits was not formal, and therefore the present authors present a redefinition of the lithostratigraphical divisions.

The present authors adopt the names: Barun Goyot Formation and Nemegt Formation for the two divisions of the Upper Cretaceous rocks in the Nemegt Basin. The retaining of the names introduced by MARTINSON *et al.* (1969) is justified, because: 1) the both divisions used hitherto possess features qualifying them for the formation status, and 2) the Russian term "svita" corresponds, in general to the English term "formation". The present authors also take into consideration the fact that the names introduced by MARTINSON *et al.* (1969) are likely to be used by the Soviet and Mongolian authors. It is also important that the paleontological papers published hitherto on the basis of materials collected during the Polish-Mongolian Palaeontological Expeditions, concerned nearly exclusively specimens from the upper lithostratigraphic division, the name of which contained the word "Nemegt".

BARUN GOYOT FORMATION

Lower division of the Late Cretaceous rocks exposed in the graben of the Nemegt Basin. *Name:* derived from an ancient settlement, situated on the pediment south of the Nemegt Massif, (coordinates: 101°10′ longitude E and 43°36′ latitude N). The distorted name of this settlement is given on the Soviet maps as Barun Goyoteen Heed. *Dominant lithology:* red and red-brown sandstones poorly cemented, fine- and medium-grained as a rule. Locally subordinate beds of sandy siltstones or rare intercalations of sandy claystones of a more intense red-brown colour. Massive sandstones not stratified, or with large-scale cross stratigrafication, or channel and cut-and-fill structures. Intraformational conglomerates occurr occasionally and never form beds of larger continuity. *Area of occurrence:* exposures in the Nemegt Basin are situated east of the Nemegt locality and in the eastern part of this locality. *Lower boundary:* unknown. *Upper boundary:* defined in the exposures of the Nemegt locality. Gradual sedimentary passage to sediments of the Nemegt Formation. The boundary established arbitrally at the base of the first bed of rocks, typical for the Nemegt Formation (i.e. light-coloured, usually yellowish sands, often with accompanying intraformational conglomerates, containing relatively numerous dinosaur bones). *Thickness*; determined only by the spatial interpolation of the position of individual profiles, is of not less than 110 metres. *Fossils*: numerous lizards, relatively numerous mammals, and bones of crocodilians, dinosaurs (pachylocephalosaurids, ankylosaurids, *Protoceratops* sp., *Velociraptor* sp.), bird, tortoises, relatively numerous and diversified dinosaur eggs, diplopod myriapods. Characteristic mammals: *Chulsanbaatar vulgaris* KIELAN-JAWOROWSKA, *Nemegtbaatar gobiensis* KIELAN-JAWOROWSKA, *Djadochtatherium catopsaloides* KIELAN-JAWOROWSKA, *Zalambdalestes* sp., *Deltatheridium* sp. *Age*: probably Campanian (KIELAN-JAWOROWSKA & BARSBOLD, 1972; KIELAN-JAWOROWSKA, 1973), younger than the age of Djadokhta Formation. *Type sections*: exposures at the Khulsan locality (situation: see GRADZIŃSKI & JERZYKIEWICZ, 1972). *Equivalent names*: "barren series" or "red lacustrine sandstones" of EFREMOV (1950, 1954, 1955); Lower Nemegt Beds of GRADZIŃSKI *et al.* (1969), Barungoyotskaya svita of MARTINSON *et al.* (1969).

NEMEGT FORMATION

Upper division of the Late Cretaceous deposits exposed in the graben of the Nemegt Basin. *Name:* derived from a group of exposures situated in the central part of the pediment extending south of the Nemegt Massif, and called Nemegt locality in the Soviet (EFREMOV, 1950, 1954, 1955) and Polish literature (among others: GRADZIŃSKI *et al.*, 1969; GRADZIŃSKI 1970; GRADZIŃSKI & JERZYKIEWICZ, 1972; KIELAN-JAWOROWSKA & DOVCHIN, 1969). The central part of this locality has geographical coordinates; 101°03′ longitude E, and 43°29′3″

latitude N. *Dominant lithology:* light-coloured, yellowish, grey-brown, rarely red sands, only locally somewhat stronger cemented. Numerous but volumetrically subordinate intercalations of sandy claystones (often red-coloured), siltstones, and intraformational conglomerates; characteristic finding-upwards cyclothems; large-scale trough cross-stratification common in sands; numerous erosional channels, great vertical and lateral variability. Detailed descriptions published in GRADZIŃSKI (1970) and GRADZIŃSKI *et al.* (1969). *Area of occurrence:* exposures in the Nemegt Basin, situated west of the Nemegt locality and in the western part of this locality. *Lower boundary:* sedimentary passage into deposits of the Barun Goyot Formation, boundary established arbitrally (see p. 116). *Upper boundary:* in the region of the localities: Ulan Bulak, Naran Bulak and Tsagan Khushu erosional surface overlain by Paleogene deposits (Upper Paleocene or Lower Eocene age) without directly visible angular unconformity. The latter deposits begin with a conglomerate, pinkish-coloured, 2—5 m thick (GRADZIŃSKI *et al.*, 1969). Thickness of the whole unit, determined by the spatial interpolation of the position of individual profiles, amounts to about 400 m (GRADZIŃSKI, 1970, pp. 156—157): Profile exposed at the Nemegt locality — about 45 m, at the Altan Ula II locality — about 130 m. *Fossils:* relatively numerous dinosaur bones (carnosaurians, ornithomimids, sauropods, hadrosaurids, ankylosaurids), accompanied by tortoises, crocodiles, fishes, pelecypods, phyllopods, ostracods, gastropods, oogonia of Charophyta, calcified tree trunks. Zone of *Tarbosaurus bataar* (MALEYEV), *Saurolophus angustirostris* ROZHDESTVENSKY and *Dyoplosaurus giganteus* MALEYEV. *Age:* Maastrichtian (KIELAN-JAWOROWSKA & BARSBOLD, 1972). *Type sections:* Nemegt locality area (Red Field, Northern Sayr, Central Sayr), locality Altan Ula II, locality Altan Ula IV, locality Tsagan Khushu, northern parts of localities: Naran Bulak and Ulan Bulak (for situation of these localities see GRADZIŃSKI *et al.*, 1969; GRADZIŃSKI & JERZYKIEWICZ, 1972). *Equivalent names:* "fossiliferous series" or "subaqueous deltaic-channel deposits" of EFREMOV (1950, 1954,1955), Upper Nemegt Beds of GRADZIŃSKI *et al.* (1969), Nemegetiyskaya svita of MARTINSON *et al.*(1969).

RELATION BETWEEN THE OBSERVED PROFILES

Because of the isolation of the individual groups of exposures and the lack of key beds in the Barun Goyot Formation it is not possible to correlate exactly the profiles studied by the authors. Therefore, the method of spatial extrapolation was used to determine the relative position of the profiles in the succession (for details of this method see GRADZIŃSKI, 1970, pp. 155—156). On the basis of the measurements taken in the Nemegt locality, it was assumed that, in the studied region the dip of the beds amounts to 30 (± 2) m per 1 km to SSW, and the strike azimuth is 105°. The top of the Barun Goyot Formation in the south-western part of the Red Walls at the Nemegt locality was taken as a reference level, and the relative positions of selected profiles are shown in Text-fig. 2. The uppermost part of the Barun Goyot Formation is exposed around the Red Walls and in the neighbouring ravines, and also in the Red Monadnocks. The same part of the succession and the immediately underlying beds are exposed in the profile of the Southern Monadnocks. The profiles of the Khulsan locality have a much lower position. Single exposures distributed over the pediment between the Nemegt and Khulsan localities have an intermediate position. The oldest deposits of the Barun Goyot Formation, known to the authors, are exposed in small outcrops situated about 4 km east of Eldorado in the Khulsan locality. The known thickness of the Barun Goyot Formation amounts to 110 m. It should be stressed that the presented data are preliminary, and future, more detailed studies may change the assumptions on which the interpolation was based.

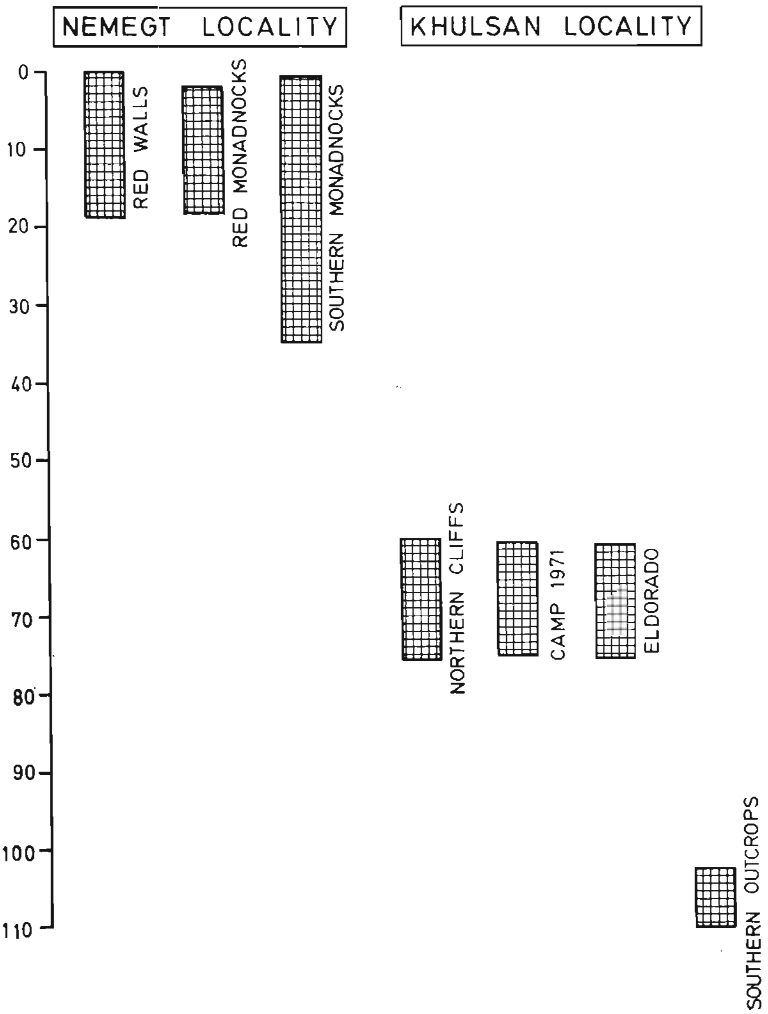


Fig. 2
Situation of profiles of exposures of the Barun Goyot Formation determines by spatial extrapolation; the top of the Barun Goyot Formation in the western part of the Red Walls used as reference level.

PETROGRAPHIC DESCRIPTION

The Barun Goyot Formation consists entirely of clastic sedimentary rocks. Sand-grade sediments predominate. They consist of poorly cemented, easily disaggregating sandstones, which may be crushed by hand. Silt-grade and clay-grade sediments are subordinate, while gravel-grade sediments, represented by intraformational gravels occur occasionally. Exotic gravels are rare; usually exotic pebbles are dispersed in the sandy sediments.

Nearly all sediments are red-coloured. By visual comparison with the Rock-Color Chart (GODWARD, 1963), the hue values of these rocks are estimated as 5 R, 8 R, and 5 YR, usually light-coloured (lightness values 7—5, occasionally 4); the chroma (saturation) values lie within the range of 1—6. Therefore, the described formation is regarded as typical red beds. The content of Fe_2O_3 usually amounts to 4—6 per cent, and the Fe^{3+}/Fe^{2+} ratio ranges in most cases from 10 to 20.

CLAY AND SILT-GRADE SEDIMENTS

Claystones are very rarely present in the Barun Goyot Formation and they always contain a large admixture of grains in the silt- and/or sand-grade. These rocks are moderately reddish-brown (10 R 4/5, 10 R 4/6). In thin sections the clay minerals appear as agglomerations of a brown-coloured substance, usually consisting of finely crystalline aggregates. These aggregates are often embedded in a groundmass, rich in silt-grade and sand-grade grains. Agglomerations of iron hydroxides are frequent. Sometimes the rocks contain psilomelane, forming small aggregates (1—5 mm), black-coloured, irregular in shape and dispersed. Rare, small crystals of gypsum are occasionally observed. Diffractograms of claystones indicate the presence of montmorillonite, illite and kaolinite, accompanied by haematite. The content of calcium carbonate ranges from 4.04 to 5.75 per cent (5 analyses). Small calcium carbonate concretions are very rare.

Siltstones usually contain admixtures of fine- and very fine-grained sand and of clay minerals. The rocks are usually light-brown in colour (5 YR 5/4). The calcium carbonate content ranges from 6.2 to 10.6 per cent (4 analyses). The rocks are, as a rule, non-laminated and usually non-fissile.

SAND-GRADE SEDIMENTS

Fine-grained and very fine-grained sandstones predominate in the sediments of the Barun Goyot Formation. Medium-grained sandstones are volumetrically subordinate, and coarser varieties are occasionally present. Loose sands are very rare, but poorly consolidated sandstones are relatively frequent. The rocks are usually light-brown in colour (5 YR 5/4), more rarely yellowish-orange (10 YR 6/4).

Among the detrital framework (without detrital matrix, 8 analyses) quartz forms 69—82 per cent, feldspars 18—28 per cent, other mineral constitutents 1—4 per cent. The quartz/feldspar ratio ranges from 2.42 to 4.40. Monocrystalline quartz grains prevail over polycrystalline ones. Wavy extinction is uncommon. Frequent inclusions consist of trails of liquid/gas bubbles, while mineral inclusions are rare. Feldspars are represented mainly by microcline and orthoclase, but plagioclases (mostly albite and oligoclase) are fairly common. The feldspars are usually fresh, but grains weathered to a varying degree are also present. Both weathered and non-weathered grains occur together, and are often observed in the same thin section. The sandstones sometimes contain small amounts of micas (chiefly muscovite). Epidote predominates among the heavy minerals (see Gradziński, 1970, Table 4).

The coarser varieties of sandstones also contain grains of source rocks. These grains represent the same rocks as the exotic pebbles (see p. 00). Occasionally, single fragments of rocks of intraformational derivation are also present. The matrix consists of aggregates of clay minerals, sometimes with a small admixture of silt-size grains. The content of calcite cement varies in a relatively wide range (4.5—15.6 per cent, 10 analyses), and is clearly correlated with the degree of the rock lithification. The grains of the detrital framework occasionally display the presence of a brown-coloured coating of clay minerals or trivalent iron compounds.

The degree of the rock cementation is usually small. Microscopic observations and results of chemical analyses indicate that calcium carbonate is the principal cementing material. However, distinct layers of strongly cemented sandstones are absent in the sediments of the Barun Goyot Formation, The degree of cementation shows no relation to the neighbourhood

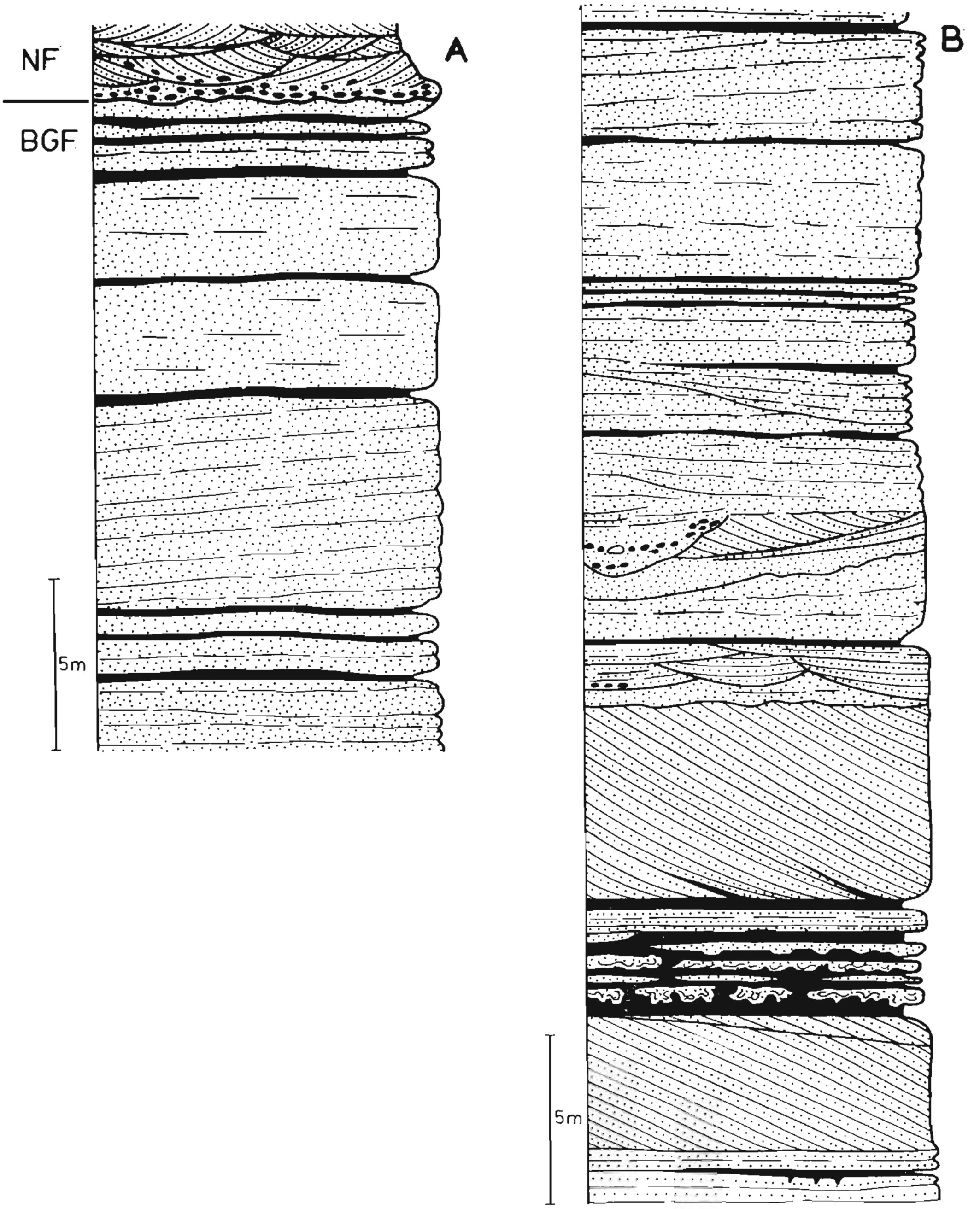
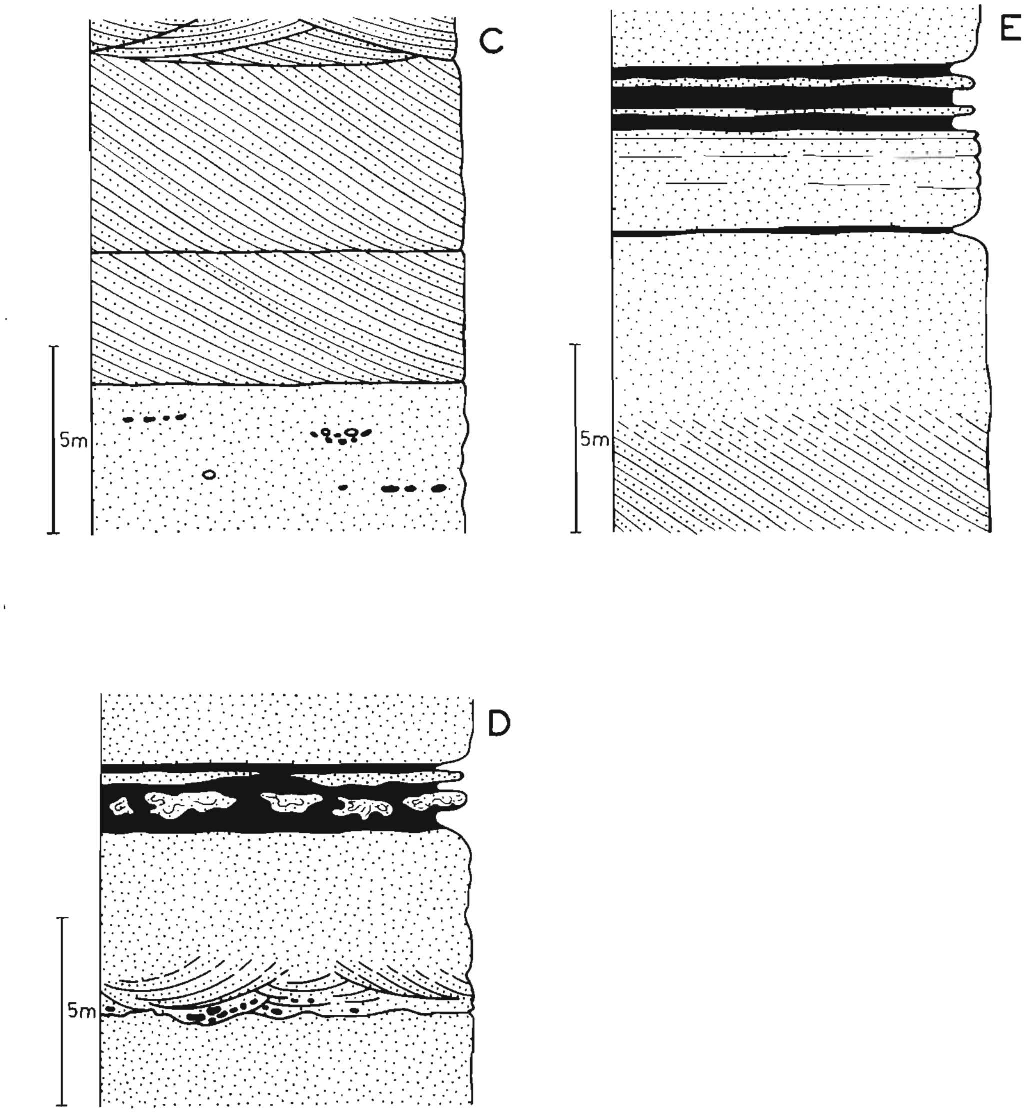
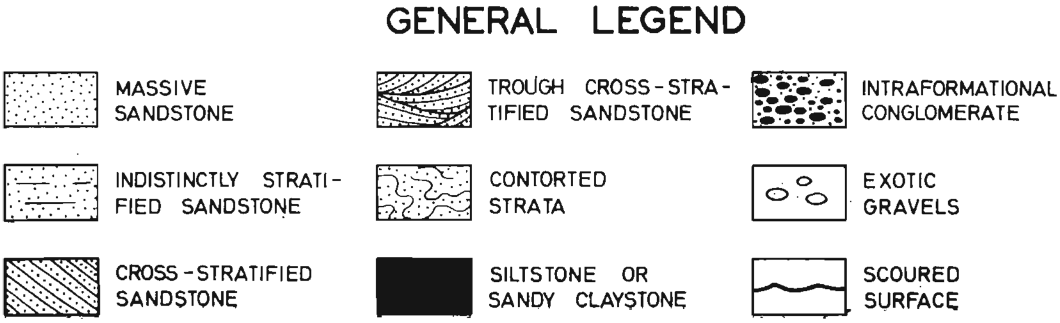


Fig. 3
Profiles of the Barun Goyot Formation: *A*-western part of the Red Walls, Nemegt locality (*BGF*-Barun Goyot Formation, *NF*-Nemegt Formation); *B*-eastern part of the Southern Monadnocks, Nemegt Locality; *C*-escarpment west of Camp 1971, Khulsan locality; *D*, *E*-Central Cliffs, Khulsan locality.


C
5m
E
5m
D
5m


GENERAL LEGEND
MASSIVE SANDSTONE
TROUGH CROSS-STRATIFIED SANDSTONE
INTRAFORMATIONAL CONGLOMERATE
INDISTINCTLY STRATIFIED SANDSTONE
CONTORTED STRATA
EXOTIC GRAVELS
CROSS-STRATIFIED SANDSTONE
SILTSTONE OR SANDY CLAYSTONE
SCOURED SURFACE

of claystone and siltstone beds or to the grain-size of the sandstones. Rare large, spheroidal concretions (1—4 m long) occur in sandstones of the Eastern Sayr in the Nemegt locality. The content of calcium carbonate in these concretions amounts to c. 35 per cent. This value corresponds fairly closely to the porosity of freshly deposited sediments of their grade (TRASK, 1931; HAMILTON & MENARD, 1956). In thin sections, numerous detrital grains of the same size range as in the enveloping rock are visible, dispersed in crystalline cement. Similar, but smaller

Table 1

Statistical parametres of granulometric composition of representative sandstone samples

	Sediment type	Sample No.	Md	M_z	σ_I	Sk_I	β_φ	K_G
1	Mega cross-stratified unit	84/70	2.00	2.03	0.62	+0.11	0.73	1.11
2	Mega cross-stratified unit	252/65	2.17	2.23	0.59	+0.18	0.74	1.03
3	Mega cross-stratified unit	21/65B	2.90	2.93	0.63	+0.10	0.22	1.13
4	Diversely stratified sandstone	253/65	2.47	2.58	1.02	—0.008	0.70	0.97
5	Diversely stratified sandstone	5/71	2.58	2.58	0.96	—0.003	0.72	1.21
6	Massive sandstone	86/70	2.63	2.67	0.75	+0.11	0.68	1.00
7	Massive sandstone	6/71	3.53	3.53	0.77	—0.012	0.72	0.91
8	Alternating claystones and sandstones	93/70	2.44	2.50	0.81	+0.14	0.60	0.91
9	Alternating claystones and sandstones	233/65	2.93	2.98	1.03	+0.27	1.71	1.77
10	Flat bedded sandstone unit	4/71	2.36	2.33	0.88	+0.09	0.67	1.31
11	Flat bedded sandstone unit	112/70	3.14	3.13	0.69	—0.016	0.68	1.02

cementational concretions are present locally in the Southern Monadnocks and in the Khulsan locality.

The grain-size distribution of sand-grade sediments was analysed chiefly by sieving (19 samples); besides, the hydrometric method (5 samples) and the microscopic analysis (point couter, 7 thin sections) were used. Sandstones from all principal sediment types (see p. 129) were studied. Selected results of sieve analysis are given in Table 1 and in Text-figs. 4 and 5. The sandstones are, as a rule, fine-grained, moderately sorted and slightly positively sekewed.

Sphericity and roundness were determined in the 0.5—0.375 mm grade, by visual comparison with the standard table published by KRUMBEIN & SLOSS (1963, fig. 4—10, p. 111). The determinations were carried out for 12 samples, of 100 grains each, The mean values of

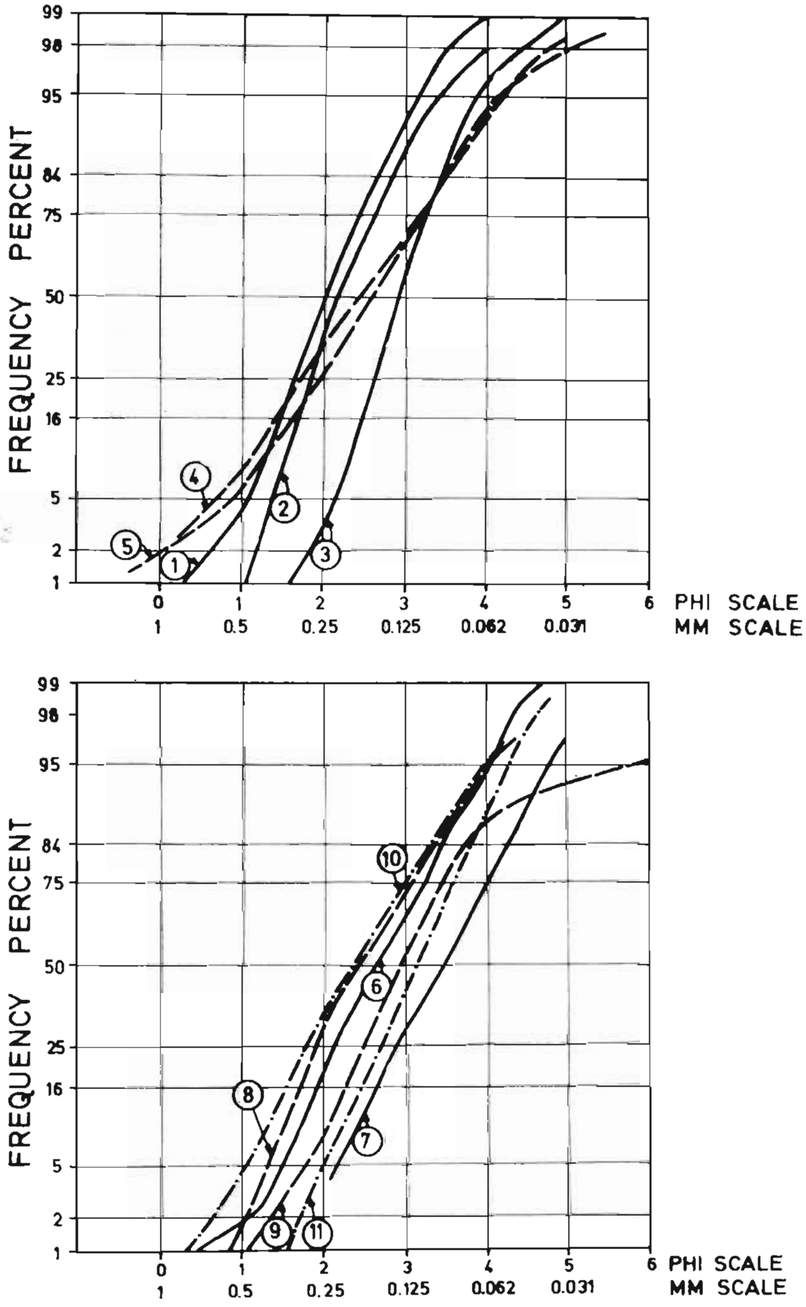


Fig. 4
Grain-size distribution of sandstones. Numbers in circles refer to samples, the parameters of which are shown in Table 1.

roundness for individual samples range from 0.44 to 0.58. Subrounded and rounded grains predominate in the samples, and are accompanied by subangular and well rounded grains. The mean values of sphericity range from 0.66 to 0.72.

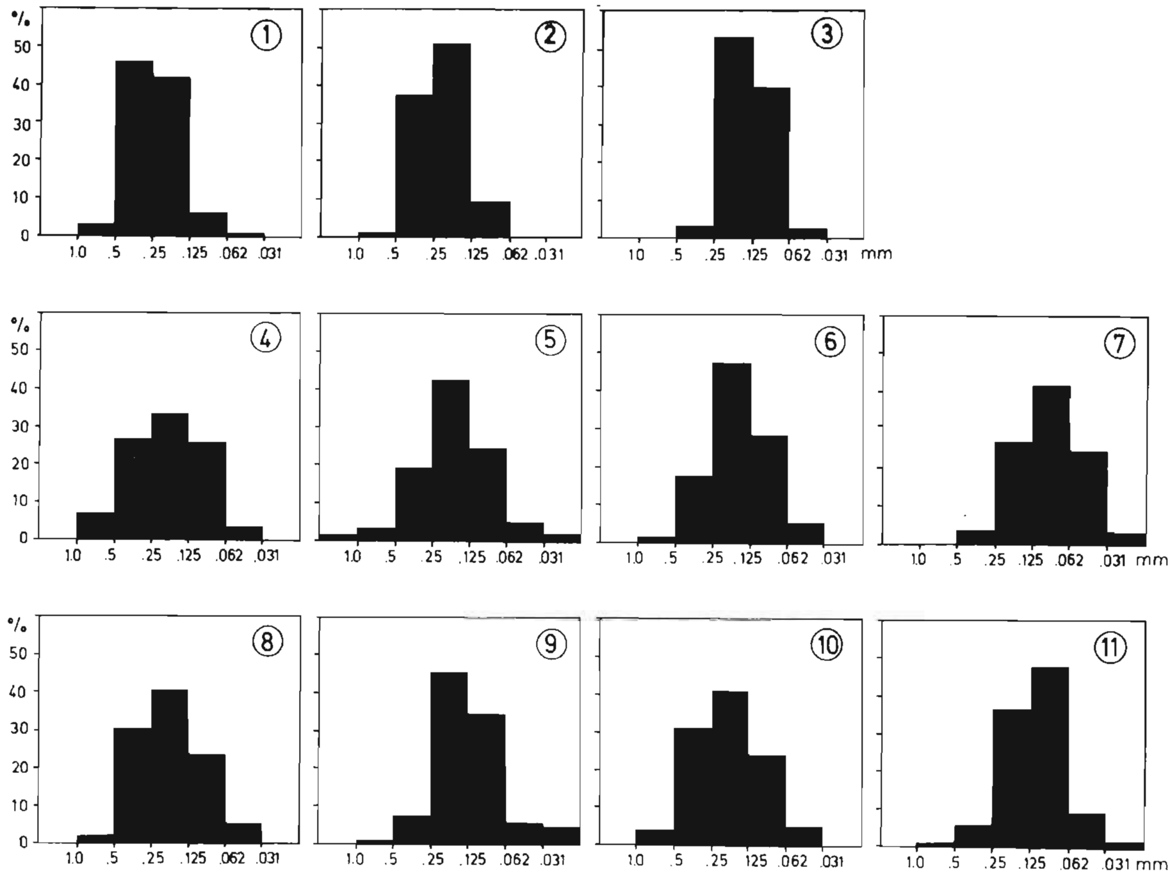


Fig. 5
Histograms showing grain-size distribution in sandstones. Numbers in circles refer to samples with parameters shown in Table 1, and cumulative curves shown in Text-fig. 4.

INTRAFORMATIONAL GRAVELS

Rock fragments of local origin occasionally occur in the sandstones. They comprise fragments of sandy claystone and siltstone and, less frequently, fragments of sandstones and cementational calcareous concretions. The fragments are usually pebble-sized, less frequently cobble-sized, and quite exceptionally boulder-sized (Pl. XL, Figs 1,2). The degree of rounding variable. Single pebbles, usually discoidal in shape, are dispersed in some sandstone beds. Occasionally, thin curled claystone flakes are present in the sandstones. Their occurrence is certainly related with suncracking.

EXOTIC GRAVELS

Exotic gravels are rare and, as a rule, single pebbles occur dispersed in the sandy sediments. Small pockets, filled with exotic pebbles embedded in an abundant sandy groundmass, are exceptionally found. The diameter of the exotic pebbles usually ranges from 3 to 8 cm, reaching a maximum value of 13 cm. The authors assembled a collection of 164 exotic pebbles exceeding 3 cm in diameter, and several samples containing smaller pebbles. The majority of exotic pebbles have been collected in the Eldorado exposures in the Khulsan locality; the others have been collected in the Southern Monadnocks in the Nemegt locality and in exposures situated about 4 km NW of Khulsan.

The exotic material represents principally pyroclastic rocks (strongly silicified lava agglomerates, tuff breccias and tuffs), arkoses, porphyries and porphyrites, granites and associated vein rocks. Gneisses, orthophyres, jaspers, quartzites and other strongly silicified rocks (probably cherts) are present in smaller amounts. The majority of pebbles display a strong epidotization. More detailed petrographic descriptions are given by GRADZIŃSKI (1970). The pebbles are subangular, subrounded or rounded regardless of their size.

PRINCIPAL SEDIMENT TYPES

The following sediment types, differing both in lithology and in associations of sedimentary structures, are distinguished in the Barun Goyot Formation: 1) flat-bedded sandstone units, 2) mega cross-stratified units, 3) massive, "structureless sandstones", 4) diversely stratified sandstones, 5) alternating claystones and sandstones. In some exposures the boundaries between these sediments are clear-cut, while in others they are poorly visible. However, in the opinion of the present authors the differences between the principal sediment types are significant and indicate different conditions of accumulation. Therefore, the distinguished sediment types are described below. Explanations of the terminology in use are given in the Appendix (p. 143).

FLAT-BEDDED SANDSTONES UNITS

This type of sediments is represented by units at least a few metres thick, consisting chiefly of sandstones and containing subordinate intercalations of siltstones and sandy claystones. The boundaries of beds are indistinct and generally related to gradual changes in lithology. Most beds are horizontal and display great lateral persistence. Sometimes, individual beds can be traced for at least 100 m, and frequently over much larger distances, limited only by the size of exposures. However, the wedging out of individual beds is fairly common. Units of inclined beds sometimes occur between the horizontally bedded units. The former are usually 2—5 m thick, and the angle of dip of the inclined beds is small, ranging from 2° to 5°.; the lateral persistence of these units is relatively large. It can be often seen that the inclined beds gradually flatten and pass into horizontal beds.

The sandstone beds are usually of medium scale, more rarely thin or thick, occasionally very thick. The beds of siltstones and sandy claystones are usually thin, rarely thicker. The sandstones are usually of fine- and very fine-grade. Most sediments of the described units seem to be structureless and internal structures, when present, are poorly visible. Crude horizontal lamination is relatively frequent. Cross-stratification, present occasionally, is represented by large-scale trough-type, probably tabular-planar type, and small-scale cross-stratification resembling flaser structure.

Erosional channels are rare. Their usual width range is 6—40 m, and the depth range 1—4 m. The channel index (defined as width/depth ratio, BLUCK & KELLING, 1962) has values within a range of 6—10. The bottom of the channels is usually regular. In the marginal parts of the channels their bottom becomes flat and gradually passes into horizontal bedding surfaces. Composite channels, constisting of two superposed channels are sometimes observed. The sediments filling the channels are usually identical to those in which the channel is incised

Fig. 6
Flat bedded sandstone units. Silty sandstones shown by dense stippling. For other symbols see Text-fig. 3, p. 121. Red Field, Nemegt Locality.

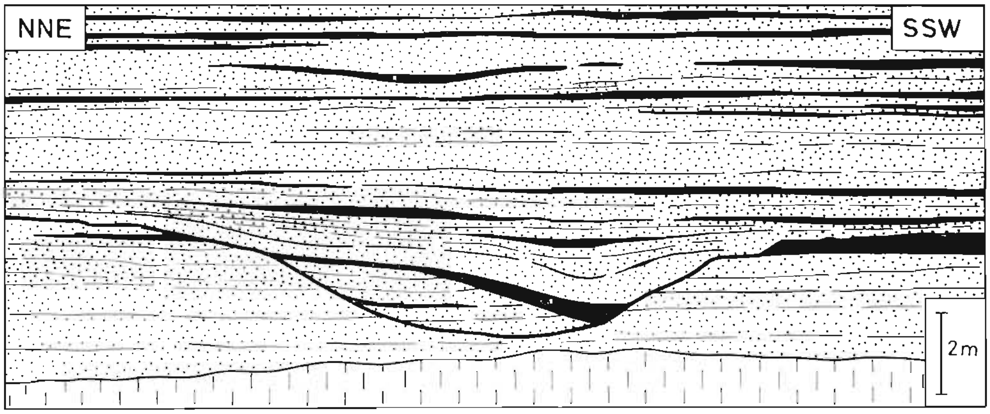


Fig. 7
Composite channel in flat-bedded sandstone units. Red Monadnocks, Nemegt locality. For explanations see Text-fig. 3, p. 121.

Within the channel the beds generally lie concordantly on its bottom and wedge out at the sides of the channel. Upwards, these sediments pass continuously into the overlying horizontal beds. No intraformational gravels or conglomerates have been observed on the bottoms of the channels. The erosional channels are most frequent in the uppermost part of the Barun Goyot Formation.

Deformational structures are relatively rare. They are best developed within the sediments filling some of the erosional channels. Such structures are present either in single sandstone beds overlying a sandy claystone bed, or in several alternating beds of claystone and sandstone. Various phases of the process of deformation can be observed, ranging from a slight bending of the sediment, up to a strong folding and disruption of the beds. The character of deformations suggests that their origin is due to instability related to reversed density gradients; these deformations represent various phases of sinking of the sandy sediment (see ANKETELL *et al.*, 1970). Tubular structures are locally present especially in the intercalations of siltstones and sandy claystones. They have 15—25 mm in diameter and are up to 20 cm long, more or less vertical, straight or slightly twisted. Similar horizontal tubes have been observed in a few cases. The tubes are filled with sandy material, distinctly coarser than the enclosing rock (Text-fig. 8).

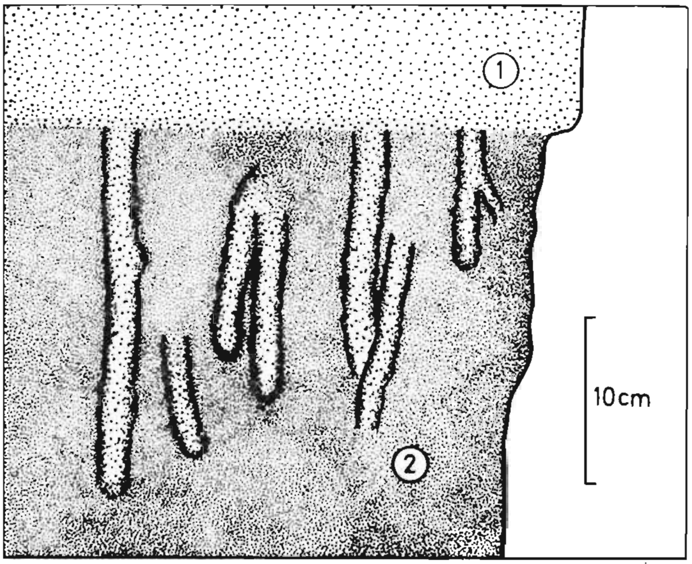


Fig. 8
Tubular structures in flat-bedded sandstone unit. *1*-fine-grained sandstone; *2*-silty clayey sandstone. Red Walls, Nemegt locality.

The surface of tubes displays small, irregularly distributed swellings. The described tubes are most probably traces of roots, but some of them may be burrows.

It should be stressed, that neither beds of intraformational conglomerate nor pockets filled with fragments of local rocks have been found the flat-bedded units. The local presence of dispersed small exotic pebbles (diameter 10—15 mm) accompanied by pebbles of sandy claystones of similar size, has been observed only in a few instances, in structureless sandstone.

Flat-bedded units have a tendency to form vertical walls, often more than 10 m high. This type of sediments is most frequently observed in the upper part of the profile of the Barun Goyot Formation (near the Red Field and in the neighbouring sayrs, in the northern part of the Saksaool Field, in the upper part of walls of the Eastern Sayr), where they predominate over other types of sediments. On the other hand, in the lower part of the profile (lower part of walls of the Southern Monadnocks and Eastern Sayr, exposures in the Khulsan locality), the flat-bedded units are rare.

MEGA CROSS-STRATIFIED UNITS

Very thick cross-stratified units form the second principal type of sediments. They were termed mega units because of their great thickness, and in order to distinguish them from other large-scale cross-stratified units. The thickness of these units ranges from 3 to 10 m, and usually exceeds 5 m. The thickest observed unit (at the Khulsan locality, near Camp 1971) exceeds 10 m in thickness, as well as the size of the exposure. Because of the nature of the exposures, often only the lower or the upper part of these units is visible (Pl. XXXVI, Fig. 2, Pl. XXXVII Fig. 1, Pl. XXXVIII, Figs. 1, 2). The lateral continuity of units amounts, at least, to several tens of metres; it is often limited by the boundaries of the exposures. In the Khulsan locality one of the units was traced (along the strike of the cross-strata) for 300 m. The described units often pass laterally or upwards into "structureless" sandstones. Some of the units intertongue with sets of horizontal beds of alternating sandy claystones and sandstones (see p. 136).

The bounding surfaces of the described units have been observed in some exposures. The contact surface of the two neighbouring units (e.g. in the Khulsan locality, near Camp, 1971; Pl. XXXVI, Fig. 2; Text-fig. 3*C*) is smooth and horizontal; it can be traced along several

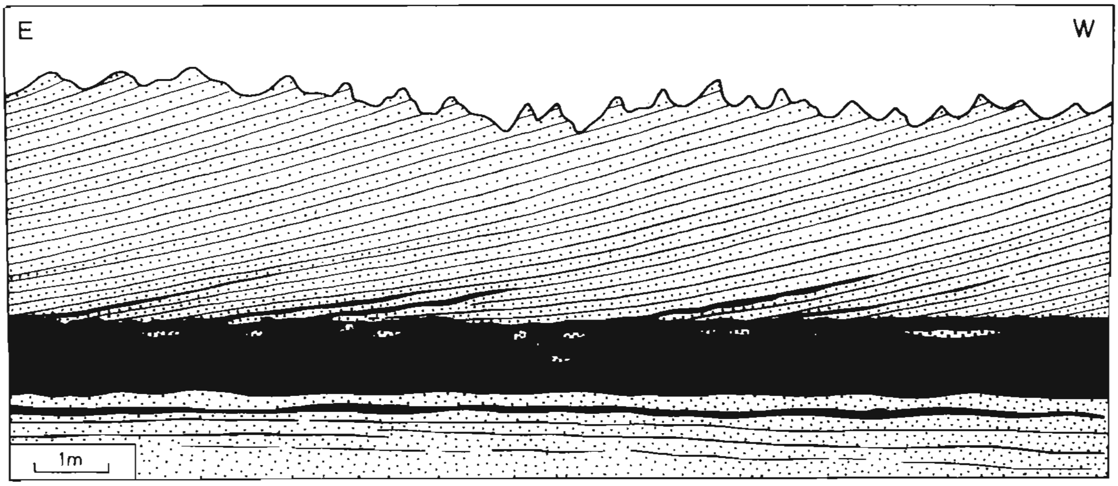


Fig. 9
Alternating sandy claystones and sandstones and a mega cross-stratified unit. The top of the exposure formed by a miniature bad-land surface. Eastern part of the Southern Monadnocks, Nemegt Locality.

tens of metres. The cross-strata of the lower unit form a large angle with this surface (about 25°), and are most probably truncated. The cross-strata of the upper unit are either tangential, or angular, forming various angles with the contact surface. Contacts of the mega cross-stratified units and beds of sandy claystone are well exposed in the Southern Monadnocks of the Nemegt locality (Text-fig. 9). Above the beds of sandy claystones the cross-strata are tangential to the bounding surface (Pl. XXXVIII, Fig. 1). The cross-strata of the unit underlying the claystone are diagonal to the upper bounding surface, forming an angle of 25—28° (Pl. XXXVIII, Fig. 2). Both the lower and the upper bounding surfaces are extensive, smooth and horizontal. The majority of the described units has tabular-planar cross-stratification.

Most mega cross-stratified units appear as individual, very thick sets. It can be often seen that, in reality, such units are composed of a number of smaller intrasets showing small differences in dip, separated by inclined additional bounding sufaces; such sets are generally tabular-planar, more rarely wedge-shaped, and exceptionally trough-shaped (Text-fig. 10). The thickness of the cross-strata ranges from 1 mm to several centimetres. The individual cros-strata are marked by grain-size gradation. The continuity of the individual cross-strata is generally large, especially in the central part of the units. Many cross-strata can be followed along the dip for a few metres.

Fig. 10
Intertonguing of a mega cross-stratified unit with alternating sandy claystones and sandstones. Arrows show occurrences of mudcracks. Northern Cliffs, Khulsan locality.

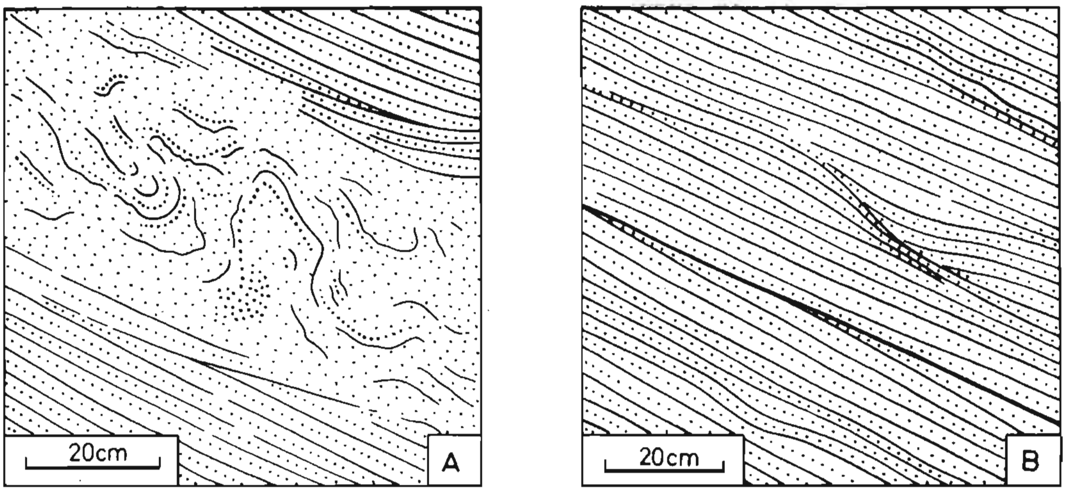


Fig. 11
Intertonguing of a mega cross-stratified unit with alternating sandy claystones and sandstones. Arrows show occurrences of mudcracks. Northern part of Northern Cliffs, Khulsan locality.

In the middle part of the units, the cross-strata are arranged regularly, and have a dip of a constant, relatively large angle, usually 25—30°, with the maximum value of 36°. The direction of the dip is usually constant, and its variation is less than 20° for measurements taken 50 m and even 100 m apart from each other. Sometimes, a discordant arrangement of sets of cross-strata can be observed; the sets are separated by flat additional surfaces, inclined in the same direction as the cross-strata. These additional surfaces usually truncate the cross-strata that dip at a higher angle (Text-fig. 11 *B*).

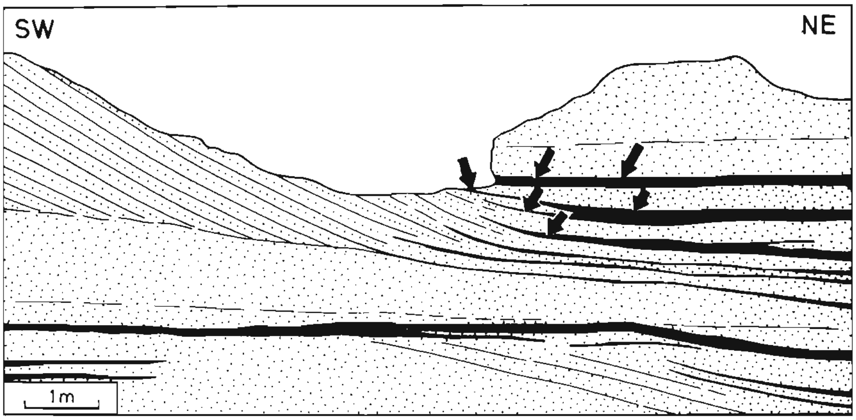


Fig. 12

Fragment of the upper part of a mega cross-stratified unit. Drawing after photograph. Vicinity of Camp 1971, Khulsan locality.

In the lower part of the units the arrangement of cross-strata is often less regular, and individual cross-strata often wedge out. The observed additional surfaces are parallel to the underlying cross-strata, while the overlying cross-strata are often diagonally superposed

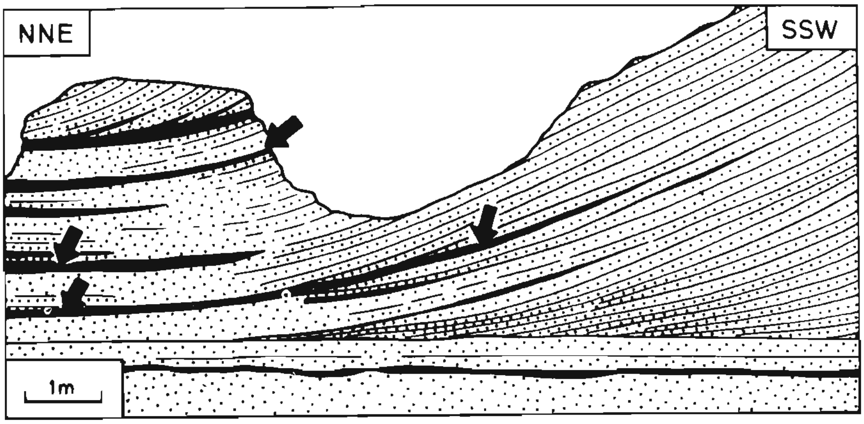


Fig. 13

Examples of structures in the middle part of mega cross-stratified units. *A*-overturned folds and overtrust; *B*-additional bounding surfaces and warps (the middle warp asymmetrically filled). Eldorado, Khulsan locality.

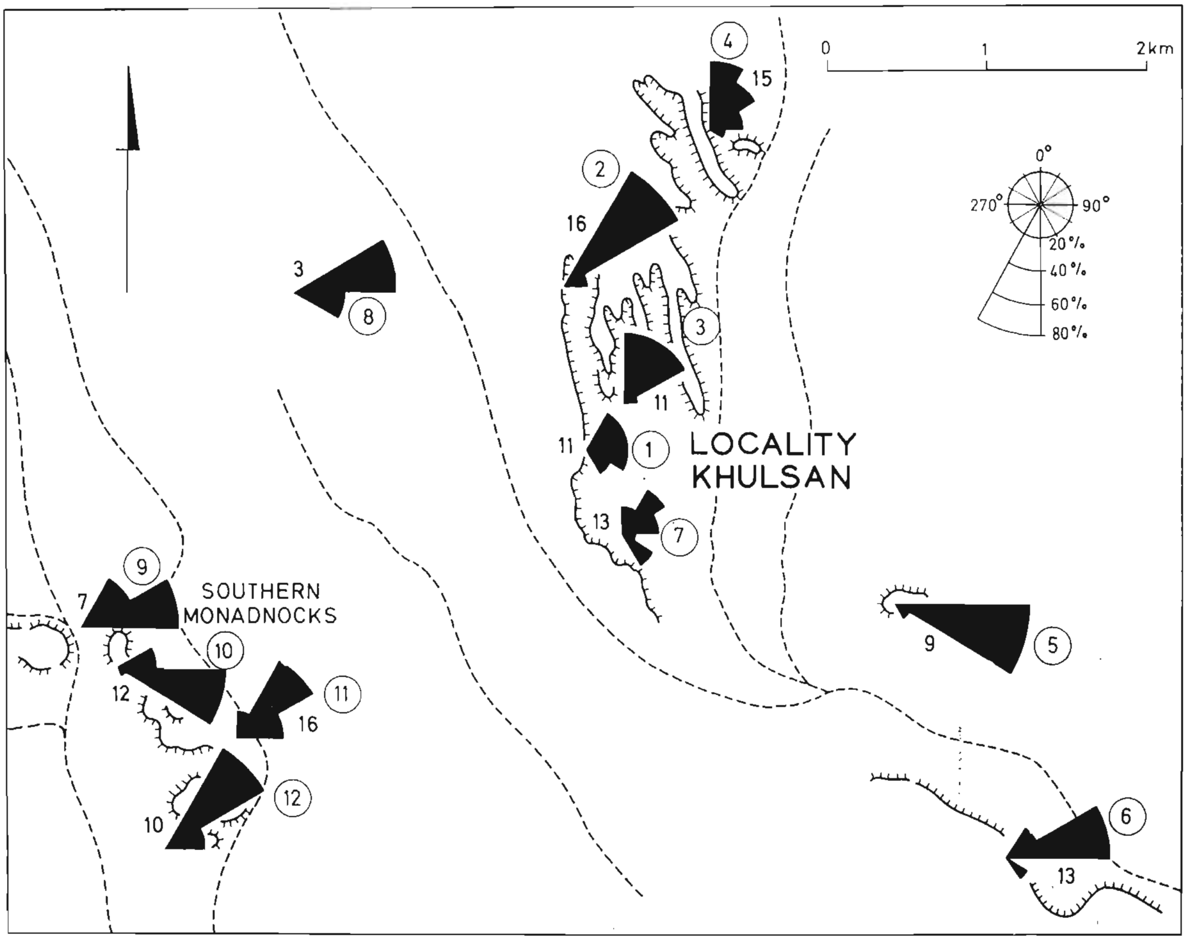


Fig. 14

Rose diagrams of dip directions of cross-strata in mega cross-stratified units. Numbers in circles refer to station number, the numbers without circles indicate numbers of measurements within stations.

on these surfaces. The angle of dip of the cross-strata is smaller, as a rule, than in the middle part of the units. Also in the upper part of some units the cross-strata are less regularly arranged. Additional bounding surfaces, present here, separate intrasets of wedge, tabular or trough shape. The angles of dip of the cross-strata are sometimes smaller than in the middle part of the units, and the direction of dip is more variable. However, the directions of dip of the cross--strata in the intrasets generally do not differ in more than 45° from the direction of the regularly arranged cross-strata within an individual unit.

Deformational structures are rare. When deformed, the cross-strata are contorted and occasionally disrupted. Sometimes, in the deformed zones the primary structures are partly or completely obliterated. The deformations affect only some cross-strata, lying among the undisturbed cross-strata (Text-fig. 11*A*). It indicates that the deformations were epizodic during the deposition of the whole mega cross-stratified unit.

The mega cross-stratified units are usually composed of fine- or medium-grade sand, moderately sorted. The amount of frosted quartz grains ranges from 21 to 45 per cent in the

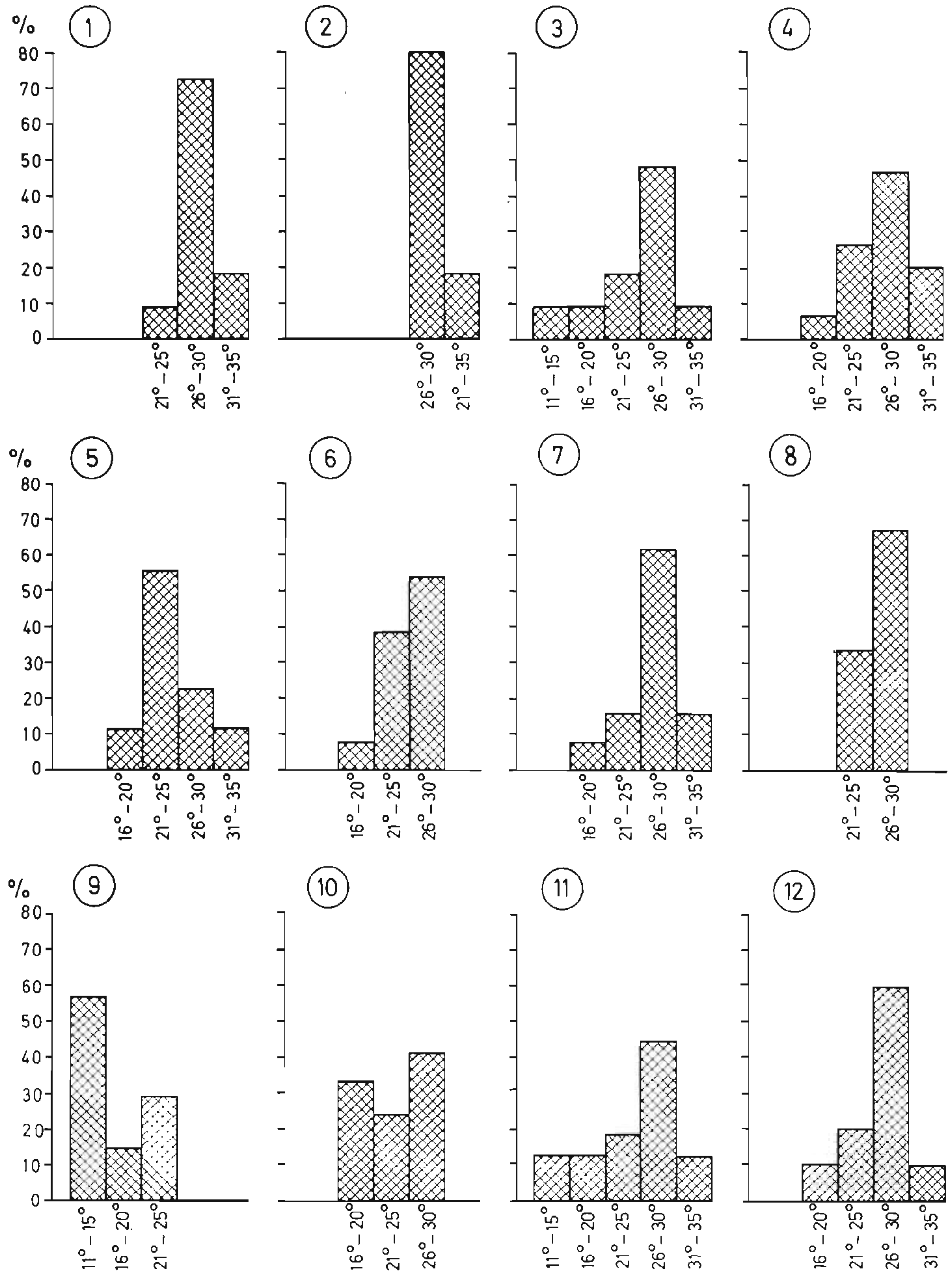


Fig. 15
Histograms of maximum angle of cross-strata dip in mega cross-stratified units. Numbers of stations in circles (compare Text-fig. 14, p. 131).

studied samples. While this paper was in press, the authors obtained the electron microphotographs of the quartz grains from the mega-units: these reveal the presence of the meandering ridges, graded ares and numeraus pitted surfaces, the textures considered to be characteristic for grains of aeolian environment. Laminae, composed of grains exceeding 1 mm in diameter, are exceptionally found. No exotic and intraformational pebbles have been found in the cross-strata of the described units.

Special attention should be paid to the interfingering of cross-strata sets with beds of sandy claystones, observed in some units. The best examples are adduced by exposures in the northern part of Southern Monadnocks at the Nemegt locality, and in the Northern Cliffs

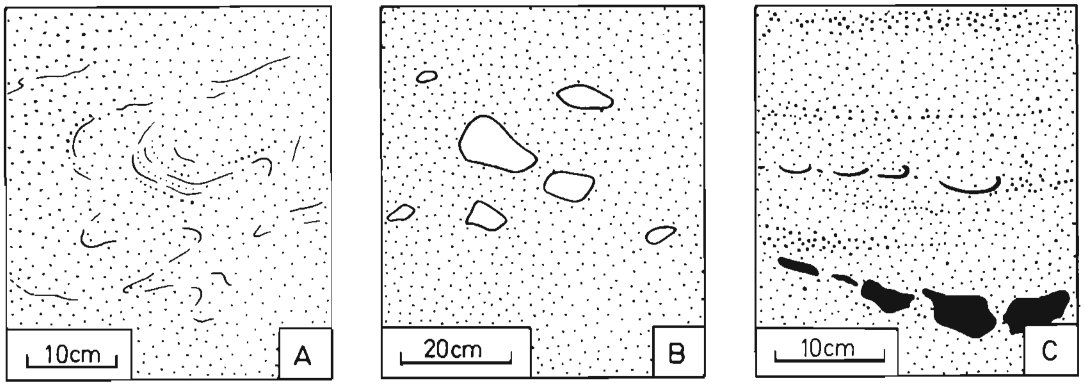


Fig. 16

Fragments of beds of massive sandstones. *A*-traces of deformational structures, Southern Outcrops, Khulsan locality; *B*-dispersed exotic gravels, Eldorado, Khulsan locality; *C*-intraformational gravels, sections of curled clay flakes and bands of coarser grains, Eldorado, Khulsan locality.

at the Khulsan locality. Sometimes, it is visible only in the lower part of the mega cross-stratified unit (Text-figs. 9, 12). Between the sets of cross-strata, reaching tangentially the lower boundary of the unit, there occur concordant intercalations of sandy claystone. Down-dip, these intercalations flatten and merge with the horizontal bed of sandy claystone underlying the whole unit. In other cases, the whole mega cross-stratified unit passes laterally into a set of horizontal alternating beds of sandstone and sandy claystone (Text-fig. 13). Casts of mudcracking polygons were observed in several cases on the bases of cross-strata sets, underlain by sandy claystone intercalations (Pl. XXXVII, Fig. 2). Such structures are probably fairly common, but they cannot be easily observed because of the poor cementation of the sediments and the presence of vertical walls in the exposures.

Table 2

Vector resultant and consistency ratio of dip directions of cross-strata in mega cross-stratified units

Station No	Number of Measure-ments	Consistency ratio	Direction of vector resultant	Station No.	Number of Measure-ments	Consistency ratio	Direction of vector resultant
1	11	0.86	84°	7	13	0.80	73°
2	16	0.95	51°	8	3	0.93	83°
3	11	0.95	40°	9	7	0.97	66°
4	15	0.89	47°	10	12	0.96	100°
5	9	0.98	112°	11	16	0.92	52°
6	13	0.90	73°	12	10	0.87	56°

The authors carried out 136 measurements of directions of the cross-strata dip in the mega cross-stratified units (Text-fig. 14). The measurements were taken only in such parts of the exposures where three-dimensional observations were possible. The mean directions for stations were obtained by graphical vector summation (see REICHE, 1938). The consistency ratio (i.e. the ratio of the length of the vector resultant to the sun of length of the individual vectors) was used to evaluate the variance of the current directions. Within stations this variance is small, as the values of the consistency ratio range from 80 to 98 (Table 2).

MASSIVE, "STRUCTURELESS" SANDSTONES

The massive sandstones are apparently devoid of internal structures. Their bed thickness ranges from 1 m to a few metres. The bounding surfaces of beds are often indistinct and difficult to determine. Sometimes, these sandstones pass laterally into another type of sediment with distinct internal structures; quite often, the mega cross-stratified units pass upwards into structureless sandstones (Text-fig. 3-*E*).

The sandstones are, as a rule, fine-grained and moderately sorted. Intraformational gravels are present in some beds. The pebbles are randomly dispersed; sometimes, they form bands and, rarely, they fill small erosional pockets. Occasionally, single large blocks or pebbles of sandy claystones or of stratified sandstones are embedded in structureless sandy material (Text-fig. 16*C*). The observed maximum diameter of such blocks amounts to 30 cm. Single, large pebbles of exotic rocks are very rare (Text-fig. 16*B*). Horizons of isolated claystone flakes, bent upwards, were observed in some beds (Text-fig. 16*C*). They are interpreted as curled clay flakes, connected with mudcracking.

The described rocks are devoid of visible structures, but it cannot be excluded that special methods (e.g. X-ray radiography) might prove the presence of structures obscured by homogeneity of grain-size. However, such investigations have not carried out. Indistinct traces of intercal structures are visible in some beds. They consist of horizontal lamination and deformational structures of overturned folds (Text-fig. 16*A*). Individual beds of massive sandstones display a varying degree of sorting of the material. Some beds are composed of moderately well sorted sand and they contain a very small percentage of silt-grade grains. Others are poorly sorted and often contain a large admixture of grains smaller than sand-grade.

Massive, "structureless" sandstones occur chiefly in the exposed lower part of the Barun Goyot Formation, where they predominate. In the upper part of the profile they are less frequent and subordinate in relation to flat-bedded sandstone units, which predominate in that part of the profile.

DIVERSELY STRATIFIED SANDSTONES

The term "diversely stratified sandstones" is used here to denote sandy sediments, in which there occurs an assemblage of various sedimentary structures, consisting of cross-stratification, horizontal lamination and crude wavy lamination, which are often accompanied by intercalations of structureless sediment; the sandstones belonging to the described type are characterized by the presence of numerous scoured surfaces and erosional pockets, and of pebbles of locally derived rocks, sometimes with an admixture of small exotic pebbles (Text-fig. 17). The sandstones are, as a rule, fine-grained and moderately or poorly sorted.

The described sediments usually fill erosional channels. These channels are of a different width, ranging from a few tens of centimetres to several metres (Pl. XXXVI, Fig. 1, Pl. XXXIX,

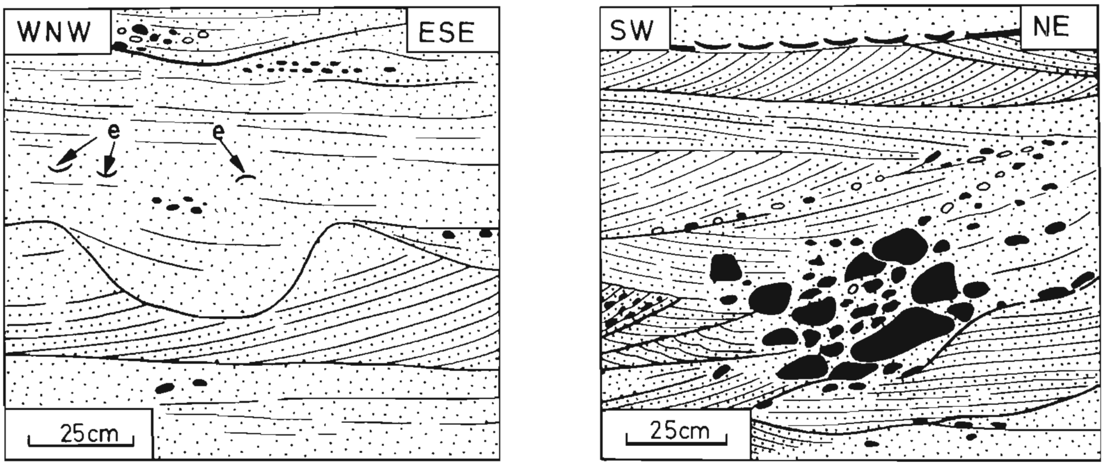


Fig. 17
Examples of sedimentary structures in diversely stratified sandstones (vertical profiles); at the top of the right drawing sections of cracked and curled clay flakes are visible; *e* — fragments of dinosaur eggs. Eldorado, Khulsan locality.

Figs. 1, 2). The channels have distinct, erosional lower surfaces and are incised either in massive, structureless sandstones (Pl. XXXIX, Fig. 1, Pl. XL, Fig. 1), in flat-bedded sandstones (Pl. XXXIX, Fig. 2), or in mega-cross-stratified units (Pl. XL, Fig. 2). Lateral interfingering of the diversely stratified sandstones with mega-cross-stratified unit was also observed. Sometimes, diversely stratified sandstones occur within the horizons of massive, structureless sandstones, but the contact of these two sediment types is poorly visible.

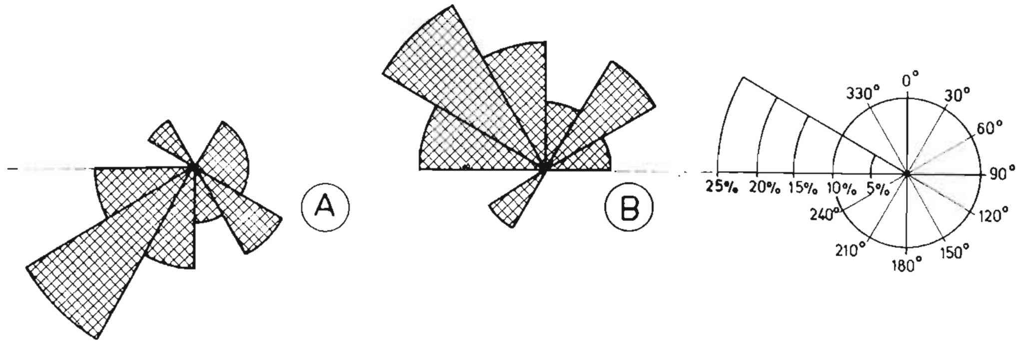


Fig. 18
Diversely stratified sandstones (channel deposits); the arrow points to the place where a fossil mammal was found. Eldorado, Khulsan locality.

The stratification of the sediments filling the erosional channels is very diversified. The boundaries of beds are often indistinct, or have the character of erosional surfaces. Most beds wedge out at a short distance. However, some tabular and wedge-shaped beds can be traced for several metres. Trough cross-stratification often predominates in the sediments filling the erosional channels. The sets of cross-strata range in thickness from a few centimetres to 20—30 cm and, as a rule, wedge out at a distance of less than 1 m. The lower bounding surfaces of these sets are either trough-shaped or irregular, and rarely planar. As a rule, the cross-strata are tangential to the lower bounding surface. The angle of the cross-strata dip is usually small and its maximum value reaches 25°. The directions of dips are variable (Text-fig. 18).

Structureless and indistinctly stratified sandstones accompany the cross-stratified sets (Pl. XXXIX, Fig. 1; Text-figs. 17, 18). Sometimes, horizontal and crude wavy lamination is present. All sediments of the described type contain small pebbles of local origin (represented by siltstones, sandy claystones and calcareous concretions), and single larger pebbles and small cobbles of exotic rocks. Intercalations of poorly laminated or structureless siltstones and/or sandy claystones are occasionally present in the sandy sediments.

The described type of sediments occurs nearly exclusively in the lower part of the observed profile of the Barun Goyot Formation, i.e. in the Khulsan locality, in the lower part of walls of the Southern Monadnocks and in the terminal part of the Eastern Sayr. It is only exceptionally present in the upper part of the profile.

ALTERNATING CLAYSTONES AND SANDSTONES

Alternating beds of sandy claystones and sandstones usually form complexes 2—4 m thick. Claystones predominate in some complexes (Pl. XXXVIII, Figs. 1, 2), while in others sandstones form the major constituent (Pl. XXXVII, Fig. 1). The sediments belonging to the described type are often quite similar to the flat-bedded sandstones. However, they usually differ from the latter in having more distinct internal structures in the sandstone beds, frequent lateral interfingering with sediments of mega cross-stratified units, and smaller lateral continuity of individual beds.

Horizontal and crude wavy lamination is common in the sandstones beds; indistinct cross-stratification is rare; some parts of the beds appear structureless. Large-scale deformational structures are rarely present. They are best visible in exposures on the north-eastern side of the Southern Monadnocks. The character of these deformations indicates that they are genetically related to instability in density stratification (cf. ANKETELL *et al.*, 1970; CEGŁA & DŻUŁYŃSKI, 1970). Various phases of sinking of sandy sediment into clayey sediment are visibile in these exposures (Pls. XLI, XLII; see also GRADZIŃSKI, 1970, Text-fig. 25-D, p. 200). The early phases of sinking are usually present at the base of thick sandstone beds, overlying thin beds of sandy claystone. The sand/clay interfaces are slightly undulated. Thin and medium-scale beds of sandstone separated by claystone are usually more strongly deformed; they maintain continuity, but the bounding surfaces are strongly deformed; more frequently the sandstone beds are disrupted and form isolated load casts within the claystone beds. Sandstones overlying thick beds of claystone are most intensely deformed. The sinking sandstone often forms typical drop structures. Isolated sandy blocks are the final product of these deformations. It should be stressed that in many exposures there are no strongly developed deformational structures.

Frequently, the horizontal alternating beds of sandstones and claystones interfinger laterally with mega cross-stratified units. The details have been given above (p. 130).

The complexes of alternating claystones and sandstones were observed in the Southern Monadnocks and in the Khulsan locality.

SEDIMENTOLOGICAL INTERPRETATION

Among the five distinguished principal types of sediments, the mega cross-stratified units display the most numerous assemblage of features which can be used to determine the conditions of their deposition. In the opinion of the present authors, the mega cross-stratified

units are aeolian deposits. It is indicated by the assemblage of the following features:
1) large thickness of the individual units,
2) relatively large maximum angle of the cross-strata dip,
3) series of additional bounding surfaces within units, dipping with moderately high angles and truncating cross-strata inclined at higher angle,
4) large lateral continuity of units,
5) relatively constant direction of the cross-strata dip over the whole investigated area,
6) tabular-planar shape of the majority of individual sets within the units,
7) presence of local deformational structures,
8) moderate sorting (good or fair, according to the scale of PAYNE, 1942), predominance of grains of fine or medium sand grade,
9) presence of frosted and pitted sand grains.

The features of cross-stratification (1, 2, 3, 6), displayed by the described type of sediments, correspond closely to the features tabulated by McKEE (1966, p. 59) for recent dune sediments in the White Sands. Having compared the features listed above with the description of aeolian sediments given by Bigarella (1972), the present authors conclude that the assemblage of features is typical for dune sands. The relatively low roundness of the sand grains does not provide evidence against the aeolian origin of the mega cross-stratified units. Although some dune sands constist of well rounded quartz grains, in many others most grains are subrounded to subangular, both in recent sediments (see NORRIS & NORRIS, 1961, p. 612; GLENNIE, 1970, figs. 134, 135), and in ancient ones (e.g. Navajo Sandstone Formation, HARSHBARGER *et al.*, 195, p. 22; Rock Point and Luckachuai Members of the Wingate Sandstone Formation, op. cit., pp. 10 and 11; Chuska Sandstone, WRIGHT, 1956; POOLE, 1962, p. 147). It should be stressed that, according to BIGARELLA (1970, p. 12): "textural characteristics are not conslusive". On the strength of the data on the process of rounding of the sand grains (see KUENEN, 1960), it is supposed that the relatively low rounding of grains, observed in the described sediments, is the result of a short period of aeolian abrasion (see also WRIGHT, 1956, p. 972). The same explanation is probably offered to the relatively small number of frosted quartz grains. According to KUENEN & PERDOCK (1962), frosting is caused by microchemical attack of the quartz surface associated, perhaps, with desert dews.

The tabular-planar shape is a characteristic feature of most mega-cross-stratified units. Extensive smooth horizontal surface, forming the top of units and sharply truncating the underlying cross-strata observed in several exposures, merit special consideration. Such surfaces are known from ancient aeolian sediments (e.g. Navajo, Wingate and Coconino sandstones of the Colorado Plateau). According to STOKES (1968), the process of formation of such surfaces is related to water-table control of deflation. The rise of the water-table in the area covered by dune sand makes the wind action remove only the dry sand above the water-table. The deflation reaches only the top of the zone of saturation; in this way a flat horizontal surface is exposed. The dimensions of such a surface may range from a few square metres to tracts of many square kilometres. Such a surface may be subsequently covered by dune sands. It also seems probable that sediments of another origin may be deposited over such a surface.

According to STOKES (1968, p. 510), the described process of formation of smooth horizontal surfaces, which truncate dune sands, is to be expected in interior basins with abundant sand, strong wind action, and a water-table which rises with sedimentation and occasionally reaches the surface.

The very rare occurrence of sets of trough cross-stratification in the described type of sediments is also characteristic of dune sands, both recent and ancient (McKEE & TIBBITS, 1964; McKEE, 1966; BIGARELLA *et al.*, 1969; GLENNIE, 1970; ALMEIDA, 1953; BIGARELLA & SALAMUNI, 1961; BIGARELLA, 1972; see also HARSHBARGER *et al.*, 1957; STOCKES, 1961).

The assumption of aeolian origin of the described type of sediments also explains the lack of observations of ripple marks. Ripple marks are infrequently preserved in ancient aeolian sandstones (BIGARELLA, 1972, p. 27). If preserved, their crests and troughs are subparallell to the dip direction of the cross-strata surfaces (McKEE, 1945, p. 316; POOLE, 1962, p. 148) and, therefore, not readily observable. Aeolian ripple marks are often composed of homogeneous material and devoid of internal structures, as indicated by observations of SHARP (1963, p. 612) and McKEE (1945, p. 329). Therefore, they are best visible on exposed surfaces of cross-strata; because of the poor cementation of the sediments of the Barun Goyot Formation, the authors have had no possibility to observe such surfaces.

The alternation of more and less resistent cross-strata, observed in some units, can be compared with a similar, but more regular structure present in aeolian sandstones of the Colorado Plateau, especially in the Navajo Sandstone. The regular alternation of thin and thick components is called by STOCKES (1964) aeolian varving, and is attributed to alternating periods of strong effective and low effective wind action.

The relatively large lateral continuity of individual mega cross-stratified units and the small variation of dip directions of cross-strata, observed over a large area, suggest that the described units are deposits of transverse dunes. The structures present in the described sediments are closely related to structures of recent dunes of this type (McKEE, 1966). The lower and middle parts of ancient dunes are most probably preserved in the deposits of the Barun Goyot Formation. These dunes were formed by unidirectional westerly winds.

Deformational structures observed locally in the mega cross-stratified units are regarded as normal features of dune deposits. Deformational structures in aeolian sediments were noted, among others, by McKEE (1945, 1966), McKEE *et al.* (1971), BIGARELLA *et al.* (1969), PEACOCK (1966) and GLENNIE (1970). In the opinion of the present authors, processes of deformation of the sediments of the mega cross-stratified units could probably cause complete obliteration of primary structures in large portions of these sediments and thus produce a part of the structureless sandstones. It refers especially to these structureless sandstones which show similar textural features as the mega cross-stratified sandstones, and contact laterally or overlie the latter without a distinct boundary. Examples of similar structureless sandstones (or containing only traces of internal structures) are given by PEACOCK (1966) from the Permo-Triassic sandstones of Morayshire. The quoted author expressed the opinion that small deformations related to saturation of the sand with water, or with other causes, could involve the obliteration of any structures in the dry, uncompacted sand. This opinion is based, among others, on the observation of BAGNOLD (1960, pp. 240—241), that on the lee sides of dunes the sand may behave like dry quicksand.

Intertonguing of sediments of the mega cross-stratified units with alternating sandstones and claystones has been observed in some exposures. This indicates that the latter type of sediment was deposited synchronously with the dune sands. The features of the alternating claystones suggest that these sediments were deposited in intermittent lakes, existing in interdune areas and covering the peripheral slopes of dunes. Examples of similar lakes of this type are given by GLENNIE (1970 p. 58). Similar sediments are known from the Santana Sandstone of Triassic age which underlied the Botucatú Sandstone; ALMEIDA (1953, p. 13) interprets them as sediments deposited by muddy waters flooding parts of dune fields, and compares them with sediments of recent "bahrs", known from Central Asia and the Chad region.

The character of most lower bounding surfaces of the sets of alternating beds of claystone (which are flat, horizontal and often truncate the underlying mega cross-stratified units) allows a suggestion that they were formed by the water-table control of deflation in interdune areas (see p. 137). It is possible that not all sediments of that type, especially the sandstones with horizontal or gently undulating lamination, were deposited in water. The material of these beds could accumulate by adhesion of wind-blown sand over a moist surface or, possibly, it represents sheet-sands. According to GLENNIE (1970, p. 108), horizontally bedded sheet-like sands occur in recent deserts over wide areas without the presence of interbedded beds of fluviatile origin. BAGNOLD (1960, pp. 149—158, Pl. 19) explains the origin of wind-deposited sheet sand and presents examples of their stratification.

The presence of rare gypsum crystals and the lack of halite crystals in the described sediments do not provide evidence against the presented interpretation of the alternating claystones, and sandstones. Some recent desert lakes are devoid of larger concentrations of salt (GLENNIE, 1970, p. 58). The present authors observed an intermittent interdune lake in the Nemegt Basin, south of the locality Altan Ula IV, with sandy clay sediments, entirely devoid of salt. POWERS *et al.* (1960, p. 100) mention the existence of sebkha-like areas in the Arabian Peninsula, which are devoid of salt deposits; their local name is Qīcān.

The diversely stratified sandstones display features indicating deposition caused by running waters. Their fluvial origin is evidenced by: 1) numerous cross-stratified sets of trough-shape, 2) numerous erosional pockets and scoured surfaces, 3) large local variaton of dip directions of cross-strata, 4) variable, often poor or moderate sorting of grains, 5) presence of frequent intraformational gravels and, occasionally, of exotic gravels. The assemblage of sedimentary structures indicate deposition both in the lower and in the upper flow regime, the latter being indicated by frequent crude horizontal lamination. The relatively small thickness of units, their small lateral continuity observed in exposures and lateral contacts with other types of sediments indicate that the diversely stratified sandstones were deposited by streams with frequently changing channels. Sometimes, these streams eroded dunes, while in other cases their beds were filled by dune sands. From time to time these streams flooded interdune areas.

Large sandstone blocks of undoubtedly local origin, occasionally present in the channel deposits, deserve special consideration. These blocks indicate that, probably locally, the cementation of a part of sediments of the Barun Goyot Formation was very rapid. Recent analogues may be found in the well known rapid cementation of some wadi deposits by calcium carbonate (GLENNIE, 1970, p. 34).

The sediments termed in this paper "massive, structureless sandstones" are, probably, of a different origin. A part of them may represent dune sands which were subjects for deformations, obliterating entirely the primary structures (see p. 133). It seems probable that the formation of dry quicksand contributed to the obliteration of internal structures (compare BAGNOLD, 1960, pp. 240—241). Such an origin of the structureless sandstones is suggested by indistinct traces of folding or fracture, which are occasionally visible in thick beds of structureless sandstones overlying, without a distinct boundary, some mega cross-stratified units.

Many structureless sandstones, however, display indistinct traces of horizontal stratification; such rocks consist of moderately to poorly sorted grains, and contain locally pebbles and blocks of intrabasinal rocks. Such sandstones contain the relatively greatest number of large dispersed pebbles of exotic rocks. The admixture of silt-grade grains and clay is large. All these data suggest that the discussed sediments were deposited by sediment-laden water, which has density and viscosity similar to mudflows.

Finally, the flat-bedded sandstone units are regarded by the present authors as deposited in flat areas, intermittently flooded by muddy waters, saturated with sediment. Deposition was similar there to that in recent intermittent lakes, occupying the central parts of interior basins with developed takyrs (playas). This interpretation is suggested by the following observations: 1) predominantly horizontal bedding, 2) great lateral continuity of beds, 3) predominantly small thickness of beds, 4) relative large admixture of silt- and clay-grade material, 5) small number of organic remains. The presence of rare and generally shallow erosional channels is related to local erosion of water, flowing towards the lower parts of the playa. Such channels may be compared with recent playa grooves, described by REEVES (1968, p. 100—101). The inclined beds with very low angle of dip, observed occasionally, are probably the result of deposition of consecutive layers of sediment on slightly inclined shores of wide channels of this type.

OCCURRENCE OF ORGANIC REMAINS

The fauna of the Barun Goyot Formation is rich and varied in comparison with other Cretaceous formations of Mongolia. Several specimens of dinosaurs, very numerous dinosaur eggs, a few crocodiles, several tortoises, a pterosaur, about 80 specimens of lizards, about 50 specimens of mammals, and specimens of diplopod myriapods and isolated sauropod teeth were found within a few weeks in the Khulsan and Nemegt localities (see KIELAN-JAWOROWSKA & BARSBOLD, 1972; GRADZIŃSKI & JERZYKIEWICZ, 1972).

Most of the fauna listed above was found in the Khulsan locality. Unfortunately, informations on the type of rocks in which the fossils were found are not complete. This is caused

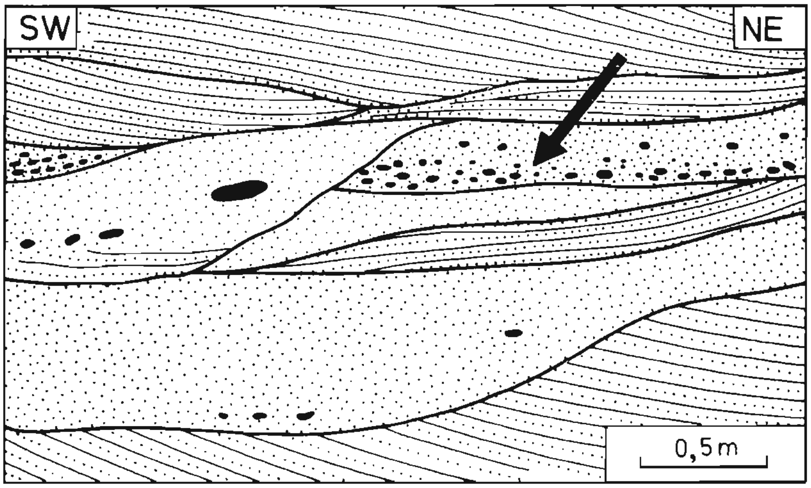


Fig. 19
Rose-diagrams of directions of cross-strata dip in diversely stratified sandstones. *A*-Eldorado, Khulsan Locality; *B*-Southern Monadnocks, Nemegt Locality.

by the course of excavation works (rapid excavation of small-size specimens) and, moreover, many specimens, especially of lizards and mammals were found in small loose rock fragments. However, it can be generally stated that most probably all specimens, both found loosely and in situ, occurred in sandstones.

Rare specimens of lizards and mammals found in the rock in situ always occurred in diversely stratified sandstones, in sediments containing small intraformational pebbles (Text-

-fig. 19). Several other specimens representing these groups were found loosely at the foot of walls in which diversely stratified sandstones or massive sandstones are exposed. Several specimens of tortoises, the bird (and probably several specimens of lizards) were found in massive sandstones. These sandstones displayed traces of indistinct horizontal stratification, dispersed intraformational pebbles and single exotic pebbles, and often contained fragments of dinosaur eggs. It can be concluded, therefore, that these fossils were buried by water-deposited sediments.

All the dinosaurs found excepted one specimen occurred in massive sandstones, apparently devoid of internal structures. The skeleton of the ankylosaurid dinosaur (No. 11, in Text-fig. 4 in GRADZIŃSKI & JERZYKIEWICZ, 1972) was found in massive sandstones which passed laterally, not far away, into typical deposits of the mega cross-stratified unit. One specimen, which was not excavated because of a very poor state of preservation, occurred within the megacross-stratified unit; this specimen, found in the year 1970, probably represented *Protoceratops* sp. The specimens of dinosaurs were usually represented by skulls and parts of skeletons with a small degree of disarticulation of bones. Only one specimen (ankylosaurid dinosaur) displayed a nearly complete articulation. It can not be excluded, however, that most of the specimens had probably a greater "completeness" at the time of final burial than the excavated skeletal material; in many cases the incomplete state of the skeletal material results from recent erosion and weathering. It is worth noting that single or incomplete bones of dinosaurs were extremely rarely foun in the sediments of the Barun Goyot Formation.

The complete dinosaur eggs were found, as a rule, in massive sandstones, sometimes in the immediate neighbourhood of mega cross-stratified units, and often also in sandstone beds alternating with sandy claystones. The diplopod myriapods were found in the same types of rocks.

The following fossils were found in the Nemegt locality (in the Red and Southern Monadnocks): 17 specimens of mammals, several lizards, rare fragments of dinosaur eggs, few sauropod teeth, and a few skeletons of tortoises. The latter were found in the lower part of the profile, exposed in the Southern Monadnocks (see Text-fig. 3*B*); the authors do not have information on the type of sandstone in which these fossils occurred. The other specimens were found in loose, small rock fragments.

Typical dune deposits are generally poor in organic remains in comparison with the accompanying deposits of other origin. The former contain only some dinosaur skeletons and a minor part of dinosaur eggs. Most of the fauna occurrs in water-deposited sediments. The reasons for this distribution of fossils are probably complex. Presumably, ecological differences between nearly completely bare dunes and the interdune depressions which had, at least, a partial vegetation cover were of primary importance; the depressions were also the place where water occurred in form of intermittent streams, lakes and, possibly, also springs. Differences in deposition rate of dune sediments and sediments of rainstorm waters were probably also important. Rainstorm floods in semiarid climate can deposit sediments a few metres thick during a very short time (see McKEE *et al.*, 1967). Therefore, the probability of burial of animal remains is greater in beds of intermittent streams and in their peripheries than in dune areas.

DEPOSITIONAL ENVIRONMENT OF THE BARUN GOYOT FORMATION

The presented data are leading to the following general conclusions on the depositional environment of the Barun Goyot Formation. The deposits of this formation were laid in a relatively flat and probably extensive area, with boundaries probably extending beyond the recent

Nemegt Basin. This area had the character of a subsiding continental basin. The detrital material transported into the basin consisted nearly exclusively of sand grade, and was derived from the same source as the material of the overlying Nemegt Formation (GRADZIŃSKI, 1970). The source area did not lie in the immediate neighbourhood but at a distance of a hundred or more kilometres away. The position of the source area is unknown, and it can be only indirectly inferred that it was situated in the north-east.

The occurrence of a very small number of single but relatively large exotic pebbles is related, in the opinion of the present authors, to periodic existence of upper flow-regime conditions during fluvial transport and deposition of the clastic material. FAHNESTOCK & HAUSHILD (1962) maintain, on the basis of flume studies, that transport of such pebbles in a mass of finer-grained sediments may take place only in upper fow-regime conditions. With the decelaration of current such pebbles are deposited, and sink slowly in the underlying sandy sediment.

The lower part of the studied profile of the Barun Goyot Formation was most probably deposited under conditions of hot and semiarid climate. The water-table probably lay at a small depth below the surface, and the rainfall was not very small, so that vegetation was possible along the beds of intermittent streams and probably also in other low areas. Interdune lakes fed by ground water were probably also formed owing to the small depth of the water-table. Other intermittent lakes were supplied by periodic streams and flooded interdune areas and parts of streambeds, blocked by migrating dunes. Climatic conditions, lack of continuous vegetation cover and strong winds made the formation of dunes possible. These dunes were mostly of transversal-type and migrated eastward from the west, driven by unidirectional winds. The aeolian abrasion of sand was not long, as it is indicated by a generally low rounding and slight frosting of grains. The lack of ventifacts and other traces of sand blast on the surface of exotic pebbles, and the absence of desert varnish are connected, in the opinion of the present authors, with an insignificant number and great dispersion of exotic pebbles. Therefore, there was no condition to form, a deflation pavement, and to develop the discussed features of pebbles.

During the deposition of the upper part of the profile of the Barun Goyot Formation, no dunes were formed in the investigated area which was flat, and probably resembled the central parts of some recent interior basins. This flat area was intermittently flooded, and the deposition in the periodic lakes can be probably compared with deposition taking place in recent playa lakes. However, the area differed principally from a typical playa in lacking chemical precipitation. At the end of the Barun Goyot age a drainage system spread over the area and, in consequence, the overlying Nemegt Formation has a typical fluvial character. This change was however gradual. It was first heralded by the appearance of an increasing number of erosional channels among the flat-bedded sandstone units in the upper part of the Barun Goyot Formation. The deposition of the first complex of beds displaying the features of typical fluvial channel deposits (the base of this complex forms the arbitrary top boundary of the Barun Goyot Formation) was not synchronous in the whole area and did not change immediately and radically the morphology of the region and the conditions of sedimentation. Therefore, in the lower part of the Nemegt Formation (i.e. in the Passage Series of GRADZIŃSKI *et al.*, 1969) there occur alternating fluvial sediments and deposits entirely similar to flat-bedded sandstone units, typical for the upper part of the Barun Goyot Formation. The incipient local extent of the fluvial channel facies may explain the imperceptible lateral passage between deposits of the two formations observed in the Nemegt locality in the Viper Sayr and in the neighbourhood of the Red Fields.

CONCLUSIONS

1) The Barun Goyot Formation consists exclusively of clastic continental deposits of red-beds type. Sand-grade sediments are dominant as arkoses; siltstones and sandy claystones occur as subordinate lithological components. Intraformational gravels form locally small occurrences, and exotic pebbles are rare. All clastic material was probably derived from the same source as the material of the overlying Nemegt Formation.

2) The sediments of the Barun Goyot Formation were deposited in various conditions. The lower part of the known profile of this formation consists of intertonguing and/or alternating dune deposits, deposits of intermittent lakes existing in interdune areas and channel deposits. These sediment types accompany predominating massive sandstones. A part of the latter seems to represent aeolian sandstones, in which internal structures were obliterated by penecontemporaneous deformations; another part was probably deposited by sediment-laden waters, similar tu mudflows. The upper part of the profile is characterized by the predominance of sediments with relatively large lateral persistence of individual beds; these sediments were probably deposited over a flat area similar to recent takyrs or playas, intermittently flooded by sediment-laden water.

3) The gradual passage to deposits of the Nemegt Formation was the result of a gradual spreading of a drainage system over the area.

4) The sediments of the Barun Goyot Formation were probably deposited in semi-arid climatic conditions, but with significant rainfall, so that gypsum and halite were not precipitated.

5) Relatively numerous specimens of mammals and lizards occur in the whole known profile the Barun Goyot Formation. Remains of dinosaurs, tortoises and crocodiles are restricted mainly to the lower part of the profile. The mega cross-stratified units and the alternating claystones and sandstones are poorest in fauna.

6) The origin of the massive sandstones and of the gradual passage between the Barun Goyot Formation and the Nemegt Formation require further studies.

Polish Academy of Sciences
Institute of Geological Sciences
Geological Laboratory
31-002 Kraków, ul. Senacka 3
August 1972

Polish Academy of Sciences
Institute of Geological Sciences
Geological Laboratory
of Old Structures
50-205 Wrocław, ul. Cybulskiego 30
August 1972

APPENDIX

Terminology

BEDDING

The term "bed" is used in this paper for determining a stratification unit. This term corresponds to a "stratum" according to the definition given by Payne (1942, p. 1742), and is somewhat wider in application than the term "bed" in the sense of McKee & Weir (1953); some beds described here corresponds to "sets" and "cosets" of these authors. The thickness classification of beds is based on the scale of Ingram (1954): 1—3 cm — very thin; 3—10 cm — thin; 10—30 cm — medium, 30—100 cm — thick, above 100 cm — very thick.

For the sake of simplicity, the adjecive "horizontal" is used for beds, which are generally parallel to the principal surface of accumulation of the formation; in fact, such beds dip at an angle of 1-2.

INCLINED STRATIFICATION

The used classification and terminology is based on the same principles as in the paper of Gradziński (1970, pp. 184—185). The term "inclined stratification" is used to define stratification of primary origin, inclined to the principal surface of accumulation of the formation. This term is used in its general and purely descriptive sense (see also POTTER & PETTIJOHN, 1963, p. 69). The term "cross-stratification" is used to denote a particular type of inclined stratification. It is limited to structures confined to a single sedimentation unit (in the sense of JOPLING, 1964). A set of cross-strata forms "the smallest and most basic group unit" (MCKEE & WEIR, 1953, p. 383). Thus, a continuous series of cross-strata is inclined to the lower bounding surface of this set. However, this surface may display various attitudes with respect to the princicipal surface of accumulation of the formation. The term "coset" is used here in the sense of ALLEN (1963, p. 98), to denote an assemblage of vertically adjoining sets, which are essentially similar in type of cross-stratification. The descriptions and classifications of cross-stratified structures are chiefly based on the geometric features of the latter. The terminology used here is based on that of MCKEE & WEIR (1953). The modifications concern the criteria and descriptive terms listed below:

1) Magnitude of set (see ALLEN, 1963): small-scale ($<$ 5 cm), large-scale ($>$ 5 cm),

2) Grouping of sets (see ALLEN, 1963): solitary, grouped.

3) Shape of lower bounding surface of set (simplified after ALLEN, 1963): planar, trough, irregular,

4) Relation of cross-strata to the lower bounding surface of set (after ALLEN, 1963, with the "concordant" type omitted): angular (diagonal), tangential,

5) Relation between the lower bounding surface and the stratification of the underlying set (simplified after CROOK, 1956): parallel, non-parallel.

SORTING

The scale for sorting is used after FOLK & WARD (1957): σ_I below 0.35 — very well sorted; σ_I 0.35-0.50 — well sorted; σ_I 0.50-1.00 — moderatelly sorted; σ_I 1.00-200 — poorly sroted; σ_I 2.00-4.00 — very poorly sorted; σ_I above 4.00 — extremely poorly sorted.

REFERENCES

ALLEN, J. R. L. 1963. The clasification of cross-stratified units, with notes on their origin. — *Sedimentology*, **2**, 93-114 Amsterdam.

ALMEIDA, F. F. M. 1953. Botucatú, a Triassic desert of South America. — C.-R. XIX Congr. Géolog. Intern., 19e Sess., 9-24, Alger.

AMERICAN Commission on Stratigraphic Nomenclature. 1961. Code of stratigraphic nomenclature. — *Bull. Amer. Assoc. Petrol. Geol.*, **45**, 645-665, Tulsa.

ANKETELL, J. M., CEGŁA, J. & DŻUŁYŃSKI, S. 1970. On the deformational structures in systems with reversed density gradients. — *Roczn. Pol. Tow. Geol.*, **40**, 3-30, Kraków.

BAGNOLD, R. A. 1960. The physics of blown sand and desert dunes. (2-nd repr.), p. 265, London.

BARSBOLD, R. 1974. Saurornithoididae, new family of small theropod dinosaurs from Central Asia and North America. Results Polish-Mongol. Palaeont. Exped., V. — *Paleont. Pol.*, **30**, 5-22, Warszawa.

BERKEY, CH. & MORRIS, F. K. 1927. Geology of Mongolia. Natural History of Central Asia, 2. — *Amer. Mus. Nat. Hist.*, 1-475, New York.

BIGARELLA, J. J. 1972. Aeolian environments: their characteristics, recognition, and importance. *In:* RIGBY J. H. & HAMBLIN WM. K. (eds.), Recognition of ancient sedimentary environments. — *Soc. Econ. Paleont. Miner., Spec. Publ.*, **16**, 12-62, Tulsa.

—, BECKER, R. D. & DUARTE, G. M. 1969. Coastal dune structures from Paraná (Brazil). — *Marine Geol.*, **7**, 5-55, Amsterdam.

—, & SALAMUNI, R. 1961. Early Mesozoic wind patterns as suggested by dune bedding in the Botucatú Sandstone of Brazil and Uruguay. — *Bull. Geol. Soc. Amer.*, **72**, 1089-1106, New York.

BLUCK, B. J. & KELLING, G. 1963. Channels from the Upper Carboniferous coal measures of South Wales. — *Sedimentology*, **2**, 29-53, Amsterdam.

CEGŁA, J. & DŻUŁYŃSKI, S. 1970. Układy niestatecznie warstwowane i ich występowanie w środowisku peryglacyjnym. — *Acta Univ. Wratislav.*, **124**, 17-42, Wroclaw.

CROOK, K. A. W. 1965. The classification of cross-stratified units on a paper by J. R. L. Allen. — *Sedimentology*, **5**, 249-252, Amsterdam.

EFREMOV, I. A. — see ЕФРЕМОВ, И. А.

ELŻANOWSKI, A. 1974. Preliminary note on the Palaeognathous bird from the Upper Cretaceous of Mongolia. Results..., V. — *Palaeont. Pol.*, **30**. 103-109 Warszawa.

FAHNESTOCK, R. K. & HAUSHILD, W. L. 1962 Flume studies of the transport of pebbles and cobbles on a sand bed. — *Bull. Geol. Soc. Amer*,, **73**, 1431-1436, New York.

FOLK, R. L. & WARD, W. C. 1957. Brazos River bar: a study in the significance of grain size parameters. — *J. Sediment. Petrol.*, **27**, 3-26, Tulsa.

GLENNIE, K. W. 1970. Desert sedimentary environments. — *Developments in Sedimentology*, **14**, 1-222, Amsterdam.

GODWARD, E. N. (Chairman). 1951. Rock-coclor chart (2nd ed.). Rock Color Chart Committee. Geol. Soc. Amer., New York.

GRADZIŃSKI, R. 1970. Sedimentation of dinosaur-bearing Upper Cretaceous deposits of the Nemegt Basin, Gobi Desert, Results..., II. — *Palaeont. Pol.*, **21**, 147-229, Warszawa.

—, & JERZYKIEWICZ, T. 1973. Additional geographical and data from the Polish-Mongolian geological Palaeontological Expeditions. Results..., IV. *Ibidem*, **27**, 17-30.

—, KAŹMIERCZAK, J. & LEFELD, J. 1969. Geographical and geological data from the Polish-Mongolian Palaeontological Expeditions. Results..., I. — *Ibidem*, **19**, 33-82.

HAMILTON, E. L. & MENARD, H. W. 1956. Density and porosity of sediments of San Diego, California. — *Bull. Amer. Assoc. Petrol. Geol.*, **40**, 754-761, Tulsa.

HARSHBARGER, J. W., REPENNING, C. A. & IRVING, J. H. 1957. Stratigraphy of the Uppermost Triasic and Jurassic rock of the Navajo Country. — U. S. *Geol. Surv. Prof. Paper*, **291**, 1-74, Washington.

JOPLING, A. V. 1964. Interpreting the concept of the sedimentation unit. — *J. Sediment. Petrol.*, **34**, 156-172, Tulsa.

KIELAN-JAWOROWSKA, Z. 1974. Multituberculate succession in the Late Cretaceous of the Gobi Desert (Mongolia). Results..., V. *Palaeont. Pol.*, **30**, 23-44. Warszawa.

—, & BARSBOLD, R. 1972. Narrative of the Polish-Mongol. Palaeont. Exped. Results..., IV. *Ibidem*, **27**, 5-13.

KIELAN-JAWOROWSKA, Z. & DOVCHIN, N. 1969. Narrative of the Polish-Mongolian Palaeontological Expeditions 1963-1965. Results..., I, *Ibidem*, **19**, 7-30.

KRUMBEIN, W. C. & SLOSS, L. L. 1963. Stratigraphy and sedimentation. 2nd ed., 1-660, San Francisco.

KUENEN, PH. H. 1960. Experimental abrasion: 4, Aeolian action. — *J. Geol.*, **68**, 427-449, Chicago.

—, & PERDOK, W. G. 1962. Experimental abrasion: 5. Frosting and defrosting of quartz grains. *Ibidem*, **70**, 648-658.

MALEYEV, E. A. — see МАЛЕЕВ, Е. А.

MARINOV, N. A. — see МАРИНОВ, Н. А.

MARTINSON, G. G. — see МАРТИНСОН, Г. Г.

—, SOCHAWA, A, V., RARSBOLD, R. — see МАРТИНСОН Г. Г., СОЧАВА, А. В., БАРСБОЛД, Р.

MARYAŃSKA, T. & OSMÓLSKA, H. 1974. Pachycephalosauria, a new suborder of ornithischian dinosaurs. Results..., V. — *Palaeont. Pol.*, **30**, 45-102, Warszawa.

MCKEE, E. D. 1945. Small-scale structures in the Coconine Sandstone of northern Arizona: *J. Geol.*, **53**, 313-325, Chicago.

— 1966. Structures of dunes at White Sands National Monument, New Mexico (and comparision with structures of dunes from other selected areas). — *Sedimentology*, **7**, 1-70, Amsterdam.

—, CROSBY, E. J. & BERRYHILL, H. L. 1967. Flood deposits, Bijou Creek, June 1965. — *J. Sediment. Petrol.*, **37**, 829-851, Tulsa.

—, & TIBBITTS, G. C. 1964. Primary structures of a seif dune and associated deposits in Libya. — *Ibidem*, **34**, 5-17.

—, & WEIR, G. W. 1953. Terminology for stratification and cross-stratification in sedimentary rocks. — *Bull. Geol. Soc. Amer.*, **64**, 381-390, New York.

—, DOUGLAS, J. R. & RITTENHOUSE, S. 1971. Deformation of lee-side laminae in aeolian dunes. — *Bull. Geol. Soc. Amer.*, **82**, 359-378, New York.

MŁYNARSKI, M. 1972. Zangelia testudinimorpha n. gen., n. sp., a primitive land tortoise from the Upper Cretaceous of Mongolia. Results..., IV. — *Palaeont. Pol.*, **27**, 85-92, Warszawa.

NEKHOROSHEV, V. P. — see НЕХОРОШЕВ, В, П.

NORRIS, R. M. & NORRIS, K. S. 1961. Algodones dunes of southeastern California. — *Bull. Geol. Soc. Amer.*, **72**, 605-620, New York.

PAYNE, T. G. 1942. Stratigraphical analysis and environmental reconstruction. — *Bull. Amer. Assoc. Petrol. Geol.*, **26**, 1697-1770, Tulsa.

PEACOCK, J. O. 1966. Contorted beds in the Permo-Triassic aeolian sandstones of Morayshire. — *Bull. Geol. Surv. Gr. Brit.*, **24**, 157-162, London.

POOLE, F. G. 1962. Wind directions in Late Paleozoic to Middle Mesozoic time on the Colorado Plateau. — *U. S. Geol. Surv. Prof. Paper*, **450-D**, 147-151, Washington.

POWERS, R. W., RAMIREZ, L. F., REDMOND, C. D. & ELBERG, E. L., Jr. 1966. Geology of the Arabian Peninsula. Sedimentary geology of Saudi Arabia. — *U. S. Geol. Surv. Prof. Paper*. **560-D**, 1-147, Washington.

REEVES, C. C., Jr. 1968. Introduction to Paleolimnology. — *Developments in Sedimentology*, **11**, 1-228, Amsterdam.

REPORT of the Stratigraphical Code Sub-Commitee. 1967. *Proc. Geol. Soc. Lond.*, **1938**, 75-87. London.
ROZHDESTVENSKY, A. K. — see Рождественский, А. К.
SHARP, R. P. 1963. Wind ripples. — *J. Geol.*, **71**, 617-636, Chicago.
STOKES, WM. L. 1961. Fluvial and aeolian sandstone bodies in Colorado Plateau. *In:* L. A. PETERSON & S. C. OSMOND (eds), Geometry of sandstone bodies. *Amer. Assoc. Petrol. Geol.*, 151-178, Tulsa.
—, 1964. Aeolian varving in the Colorado Plateau. — *J. Sediment. Petrol.*, **34**, 429-432, Tulsa.
—, 1968. Multiple parallel truncation bedding planes — a feature of wind-deposited sandstone formations. — *Ibidem*, **38**, 510-515.
SOVIET stratigraphic classification, terminology and nomenclature — see Межведоственный Стратиграфический Комитет СССР.
TRASK, P. D. 1931. Compaction of sediments. — *Bull. Amer. Assoc. Petrol. Geol.*, **15**, 271-276, Tulsa.
WRIGHT, H. E., Jr. 1956. Origin of the Chuska Sandstone, Arizona—New Mexico: a structural and petrographic study of a Tertiary aeolian sediments. — *Bull. Geol. Soc. Amer.*, **67**, 413-434, New York.
VASILEV, V. G., VOLKHONIN, V. S., IVANOV, A. KH., MATROSOV, N. A. *et al.* — see Василев, В. Г., Волхонин, В. С., Иванов, А. Х., Матросов, Н. А. и др.
Ефремов, И. А. 1950. Тафономия и геологическая летопись. Кн. I. — *Тр. Палеонт. Инст. АН СССР*, **24**, Москва—Ленинград.
—, 1954. Палеонтологические исследования в Монгольской Народной Республике. Предворительные результаты экспедиции 1964, 1948 и 1949 гг. — *Тр. Монг. Ком. АН СССР*, **59**, 3-32, Москва.
—, 1955. Захоронение динозавров в Нэмэгэту (Южная Гоби, МНР). *Вопр. Геол. Азии*, **2**, 789-809, Москва.
Малеев, Е. А. 1952. Некоторые замечания о геологическом возрасте и стратиграфическом распределении панцырных динозавров Монголии. — *Докл. АН СССР*, **4**, 893, Москва.
—, 1954. Панцырные динозавры верхнего мела Монголии (семейство Syrmosauridae). — *Тр. Палеонт. Инст. АН СССР*, **48**, 142-170, Москва.
Маринов, Н. А. 1957. Стратиграфия Монгольской Народной Республики. АН СССР, 1-266, Москва.
Мартинсон, Г. Г. 1953. Новые унеониды из верхнемеловых отложений Монголии. — *Докл. АН СССР*, **89**, 1, 167-178, Москва.
—, 1966. О сопоставлении мезозойских и континентальных отложений Монголии с другими районами Азии. — Мат. Геол. Монг. Нар. Респ., 61-64, Москва.
—, Сочава, Г. Г., Барсболд. Р. 1968. О стратиграфическол расчленении верхнемеловых отложений Монголии Докл. АН СССР, 189, 1081-1084, Москва
Межведостvenный Стратиграфический Комитет СССР. 1965. Стратитграфическая класификация, терминология и номенклатура. НЕДРА, 1-70, Ленинград.
Нехорошев, В. П. 1966. Тектоника Алтая — *ВСЕГЕИ, Н. сер.*, **139**, 1-28, Москва.
Рождественский, А. К. 1957. Краткие итоги изучения ископаемых Монголии по материалам Монгольской палеонтологической экспедиции АН СССР в 1946-1948 гг. — Vertebr. Palasiat., **1**, 3, 169-183, Peking.
—, 1965. Возрастная изменчивость и некоторые вопросы систематики динозавров Азии. — *Палеонт. Журнал*, **3**, 95-109, Москва.

R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XXXIV

Fig. 1. Khulsan locality, part of Northern Cliffs. Main Sayr in centre, behind it Southern Outcrops .
Fig. 2. Khulsan locality, view northward from above Camp 1971. Mega cross-stratified unit visible at left

Photo: T. Jerzykiewicz

1

2

Palaeontologia Polonica, No. 30, 1974

R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XXXV

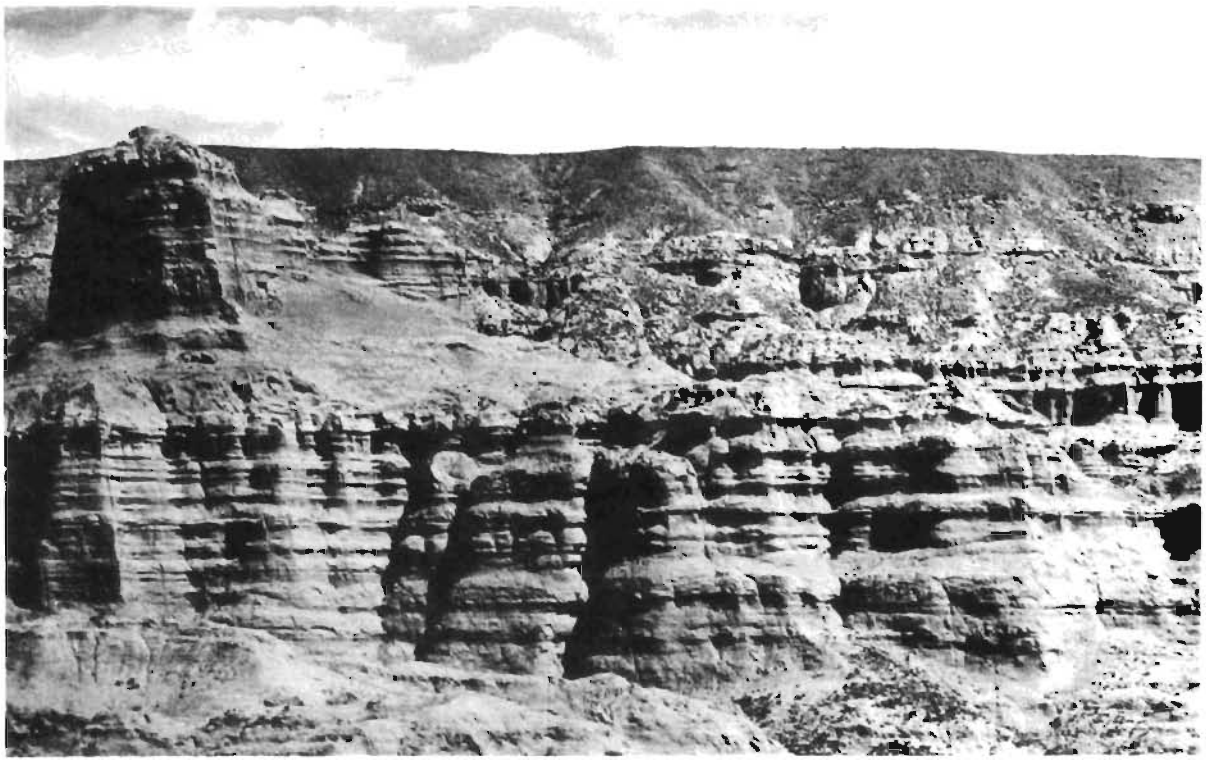
Fig. 1. Flat bedded sandstone units of Barun Goyot Formation exposed in vertical walls of the Red Field. Sediments of Nemegt Formation exposed above, on slopes. Height of walls 25-30 m. Nemegt locality.

Photo: W. Skarżyński

Fig. 2. Flat bedded sandstone units. Height of wall in lower part of exposure is 7 m. Nemegt locality northern part of Red Field.

Photo: W. Maczek

1



2

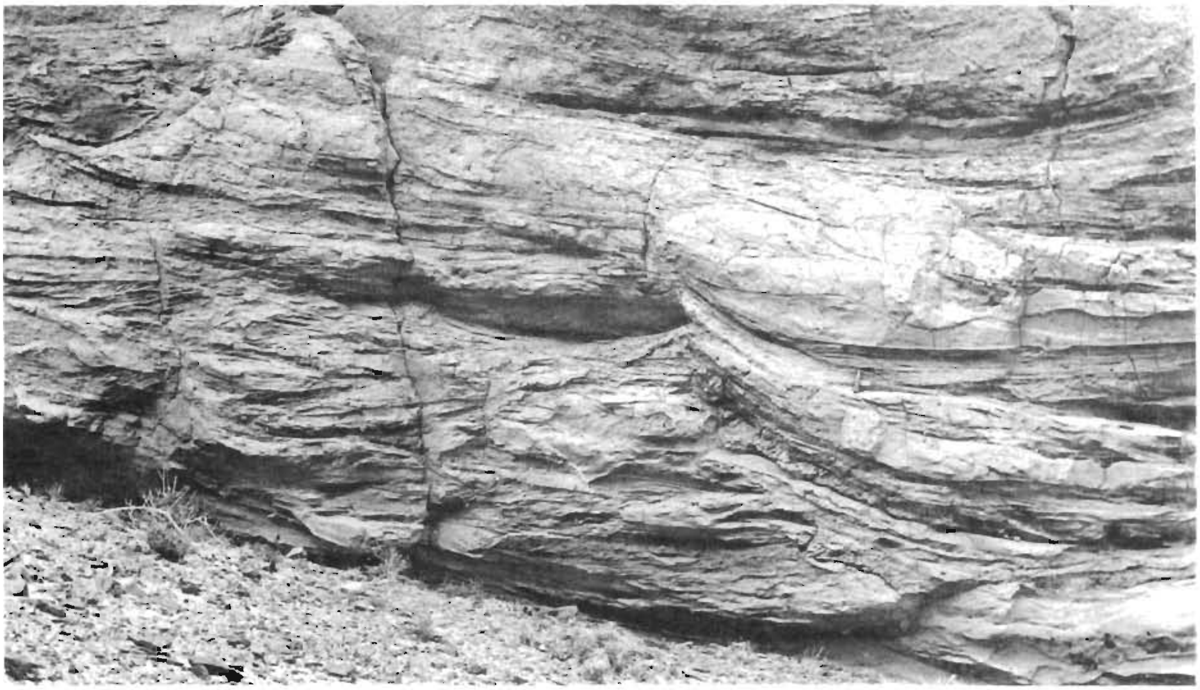
R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XXXVI

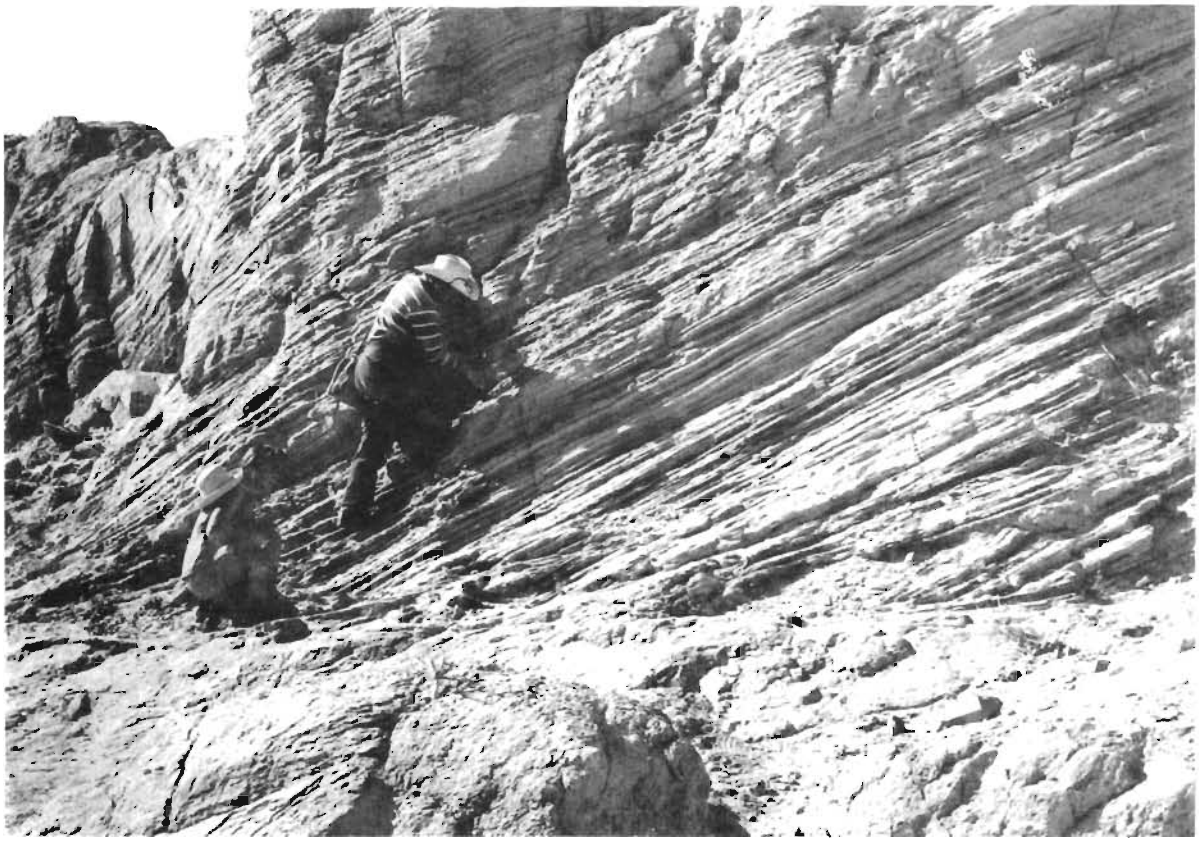
Fig. 1. Diversely stratified sandstone; large-scale trough cross-stratification visible. Height of exposure 3.2 m. Khulsan locality, near Camp 1971.

Fig. 2. Lower part of mega cross-stratified unit. Khulsan locality, near Camp 1971

Photo: T. Jerzykiewicz



1



2

R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

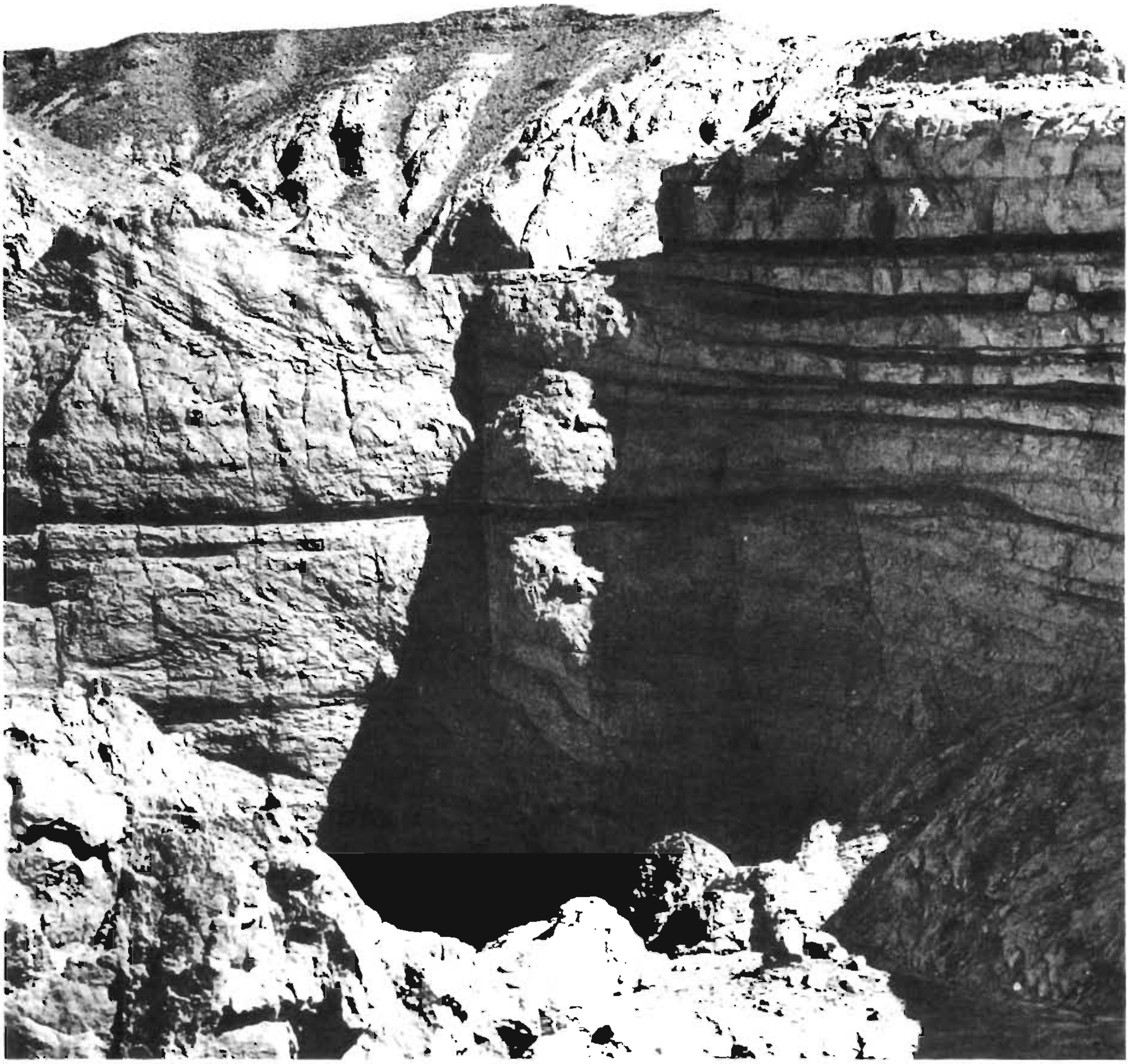
PLATE XXXVII

Fig. 1. Intertonguing of a mega cross-stratified unit with alternating sandy claystones and sandstones. Height of exposure 7 m. Khulsan locality, Northern Cliffs

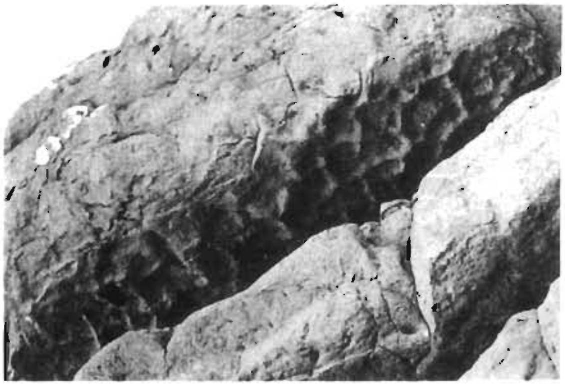
Fig. 2. Base of one of sandstone beds visible in Fig. 1, with casts of dessication cracks. Compare Text-fig. 12, p. 130

Fig. 3. Fragment of spherical dinosaur egg with thick shell Massive sandstone, Khulsan locality, between Camp 1971 and Eldorado

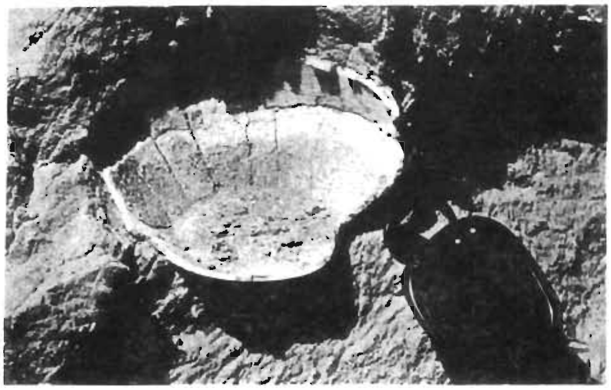
Photo: T. Jerzykiewicz



1



2



3

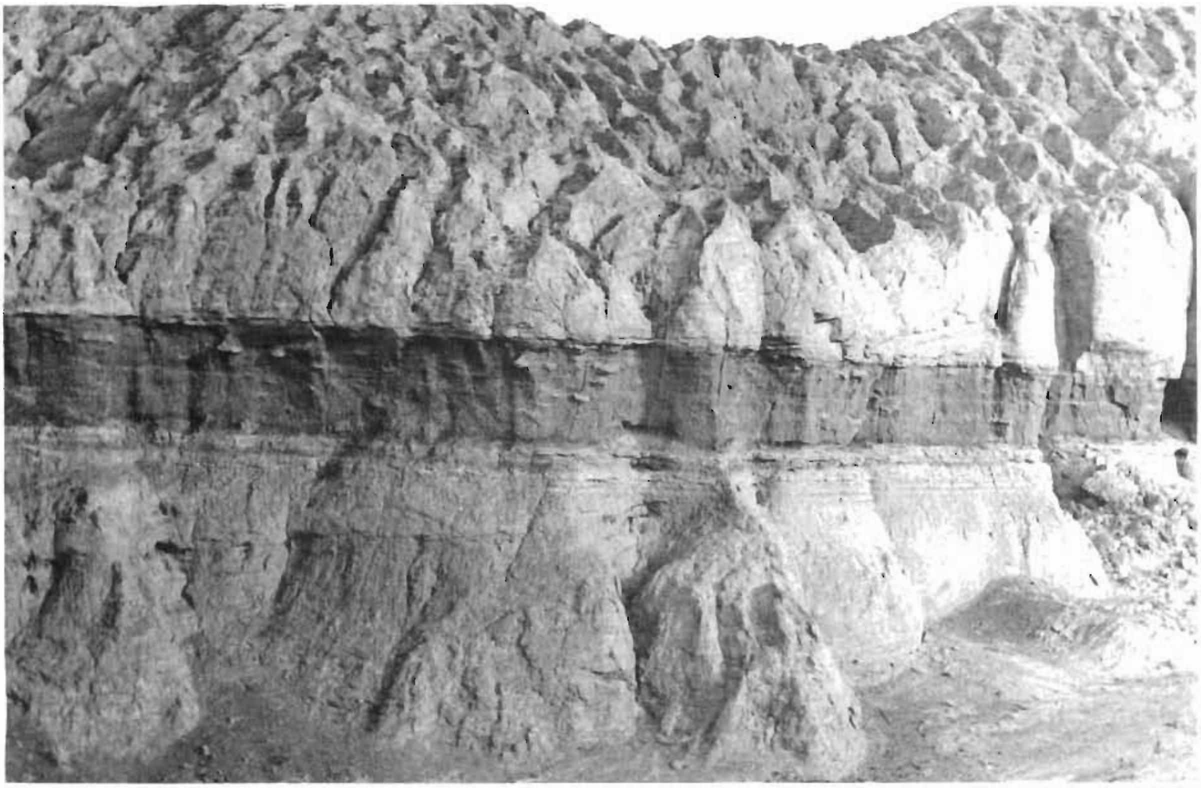
R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XXXVIII

Fig. 1. Alternating sandy claystones and sandstones between two mega cross-stratified units. Height of exposure 8 m Nemegt locality, Southern Monadnocks

Fig. 2. Mega cross-stratified unit and overlying alternating sandy claystones and sandstones. Height of exposure 6 m. Nemegt locality, Southern Monadnocks

Photo: T. Jerzykiewicz



1

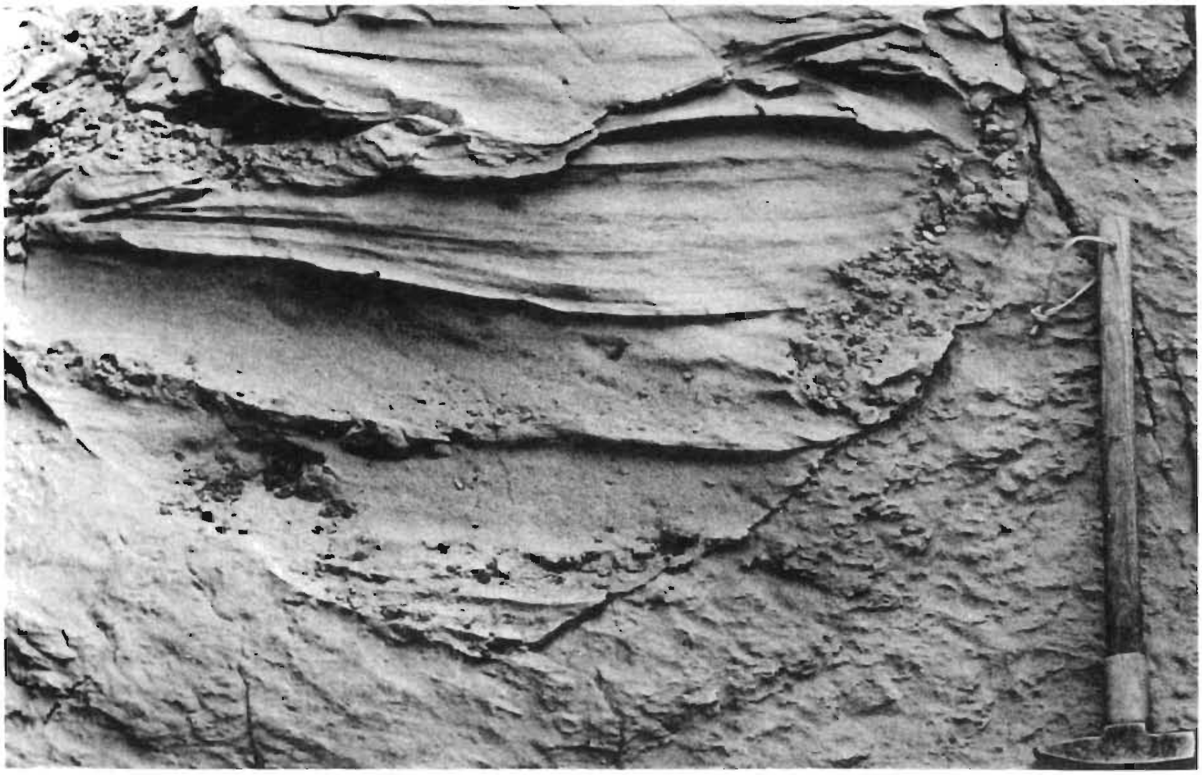
Palaeontologia Polonica, No. 30, 1974

R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XXXIX

Fig. 1. Erosional channel incised in massive sandstone. Khulsan locality, near Camp 1971
Fig. 2. Sediments filling erosional channel. Khulsan locality, near Camp 1971

Photo: T. Jerzykiewicz



1

2

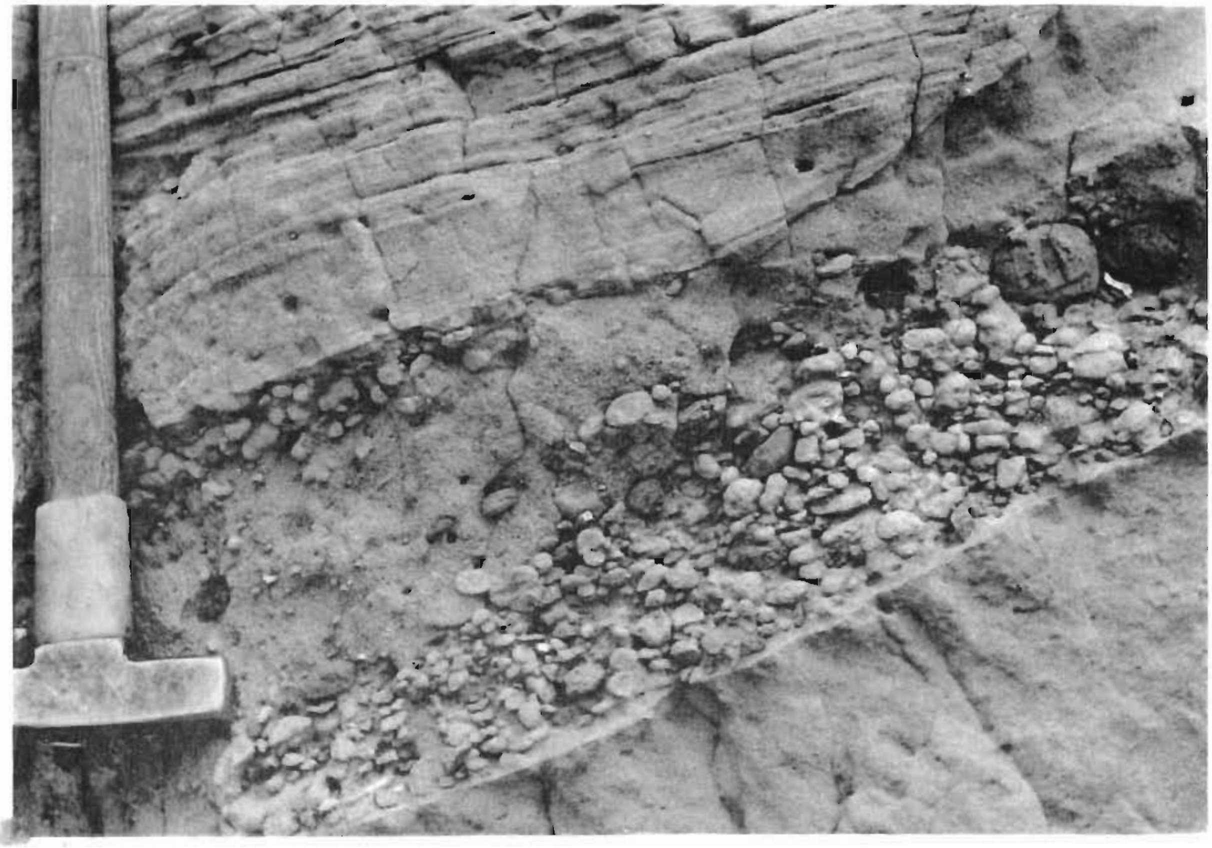
R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XL

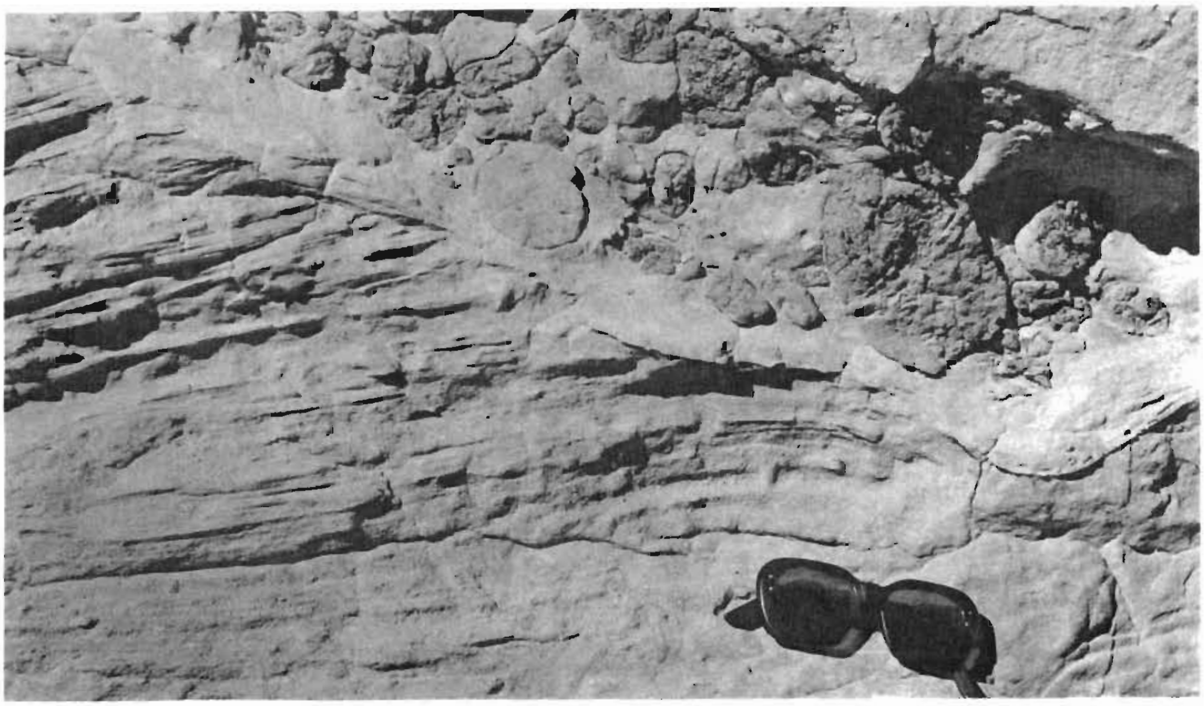
Fig. 1. Basal part of erosional channel incised in massive structureless sandstone. Intraformational conglomerate composed of pebbles of sandstones and sandy claystones. Khulsan locality, near Camp 1971

Fig. 2. Basal part of erosional channel incised in mega cross-stratified unit. Pebbles of sandy claystones and siltstones are present in channel-fill. Khulsan locality, near Camp 1971

Photo: T. Jerzykiewicz



1



2

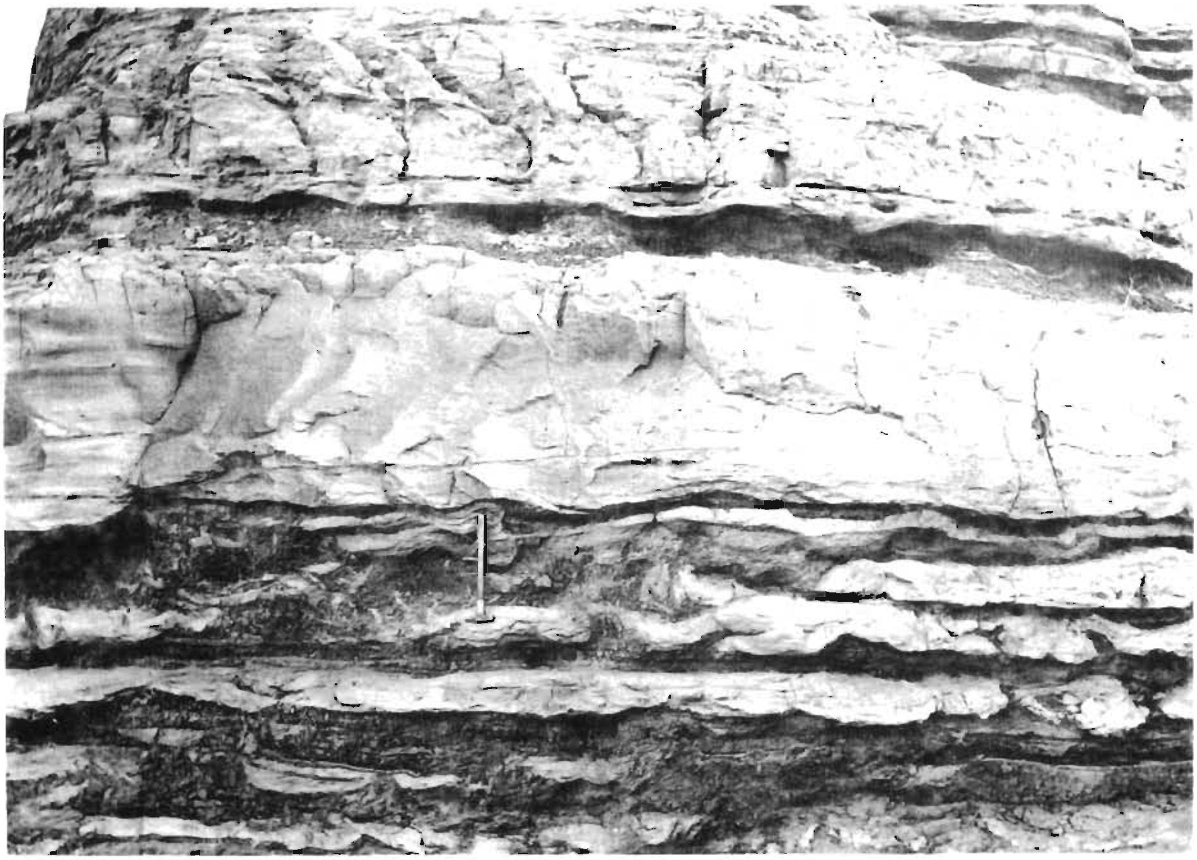
Palaeontologia Polonica, No. 30, 1974

R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

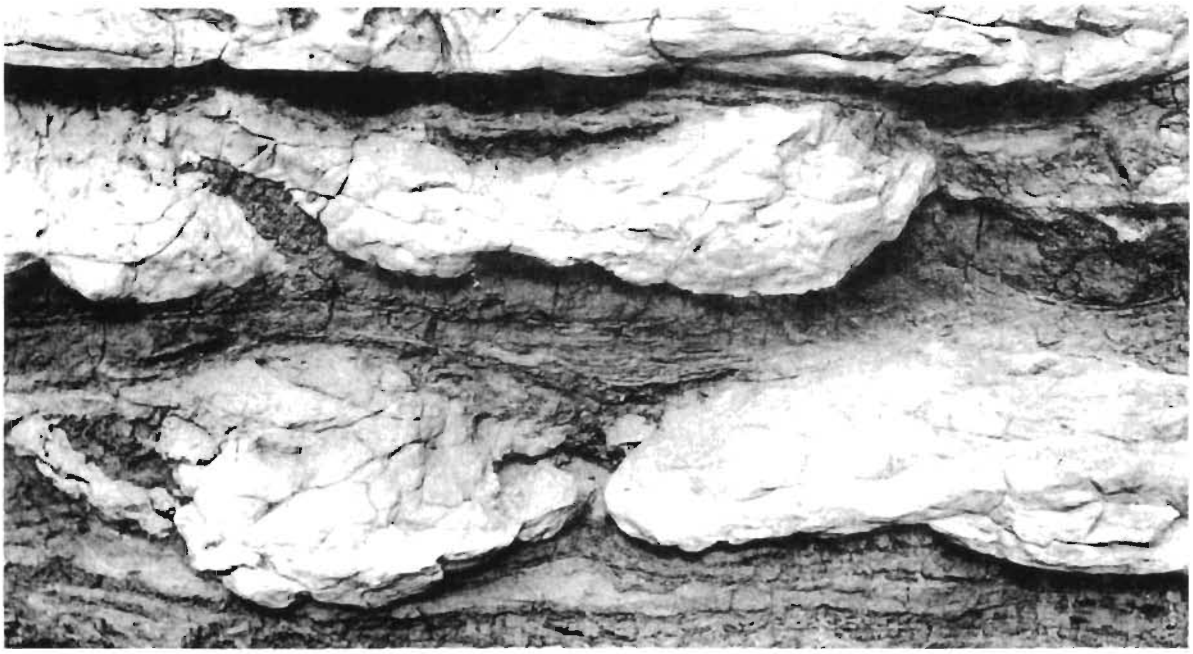
PLATE XLI

Fig. 1. Alternating sandy claystones and sandstones. Note lamination in sandstones and various phases of deformation caused by unstable density stratification. Nemegt locality, Southern Monadnocks.
Fig. 2. A fragment of Fig. 1 (lower right); disrupted sandstone bed forming load casts in sandy claystone.

Photo: T. Jerzykiewicz



1



2

Palaeontologia Polonica, No. 30, 1974

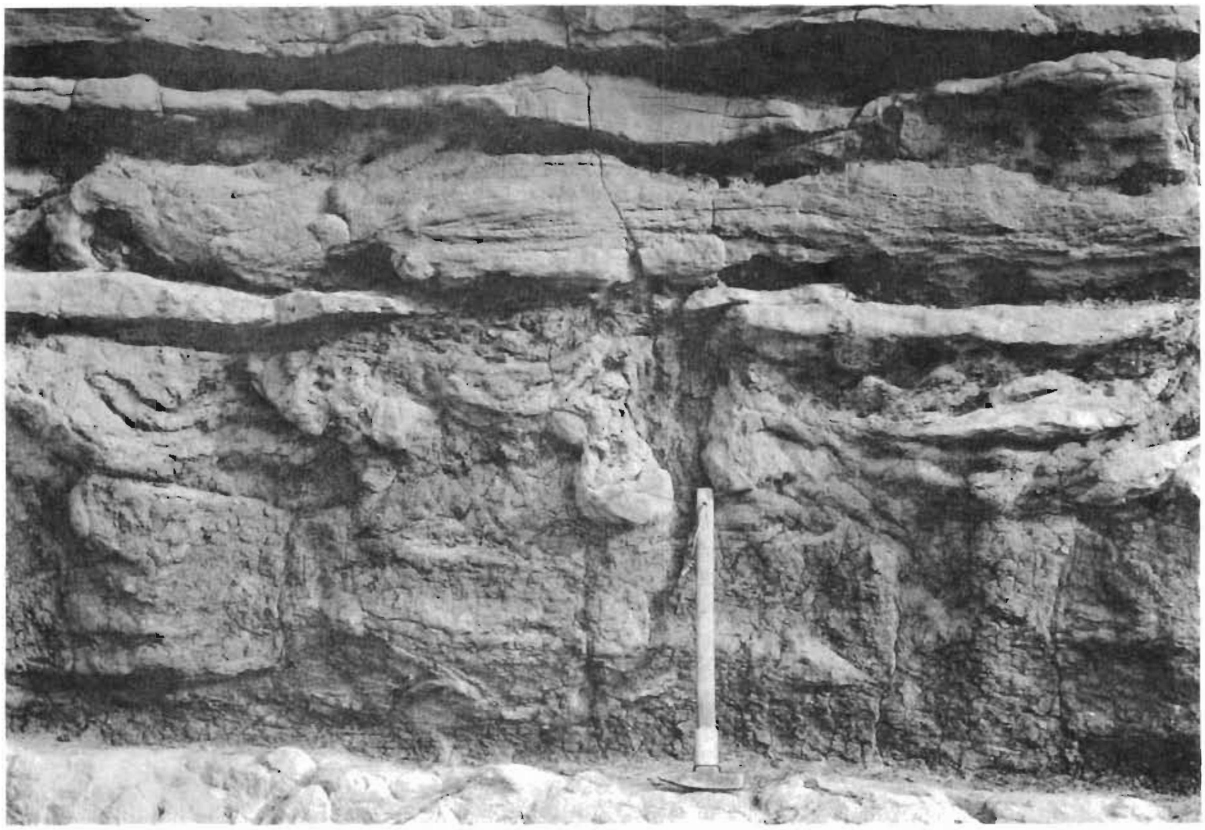
R. GRADZIŃSKI & T. JERZYKIEWICZ: SEDIMENTATION OF BARUN GOYOT FORMATION

PLATE XLII

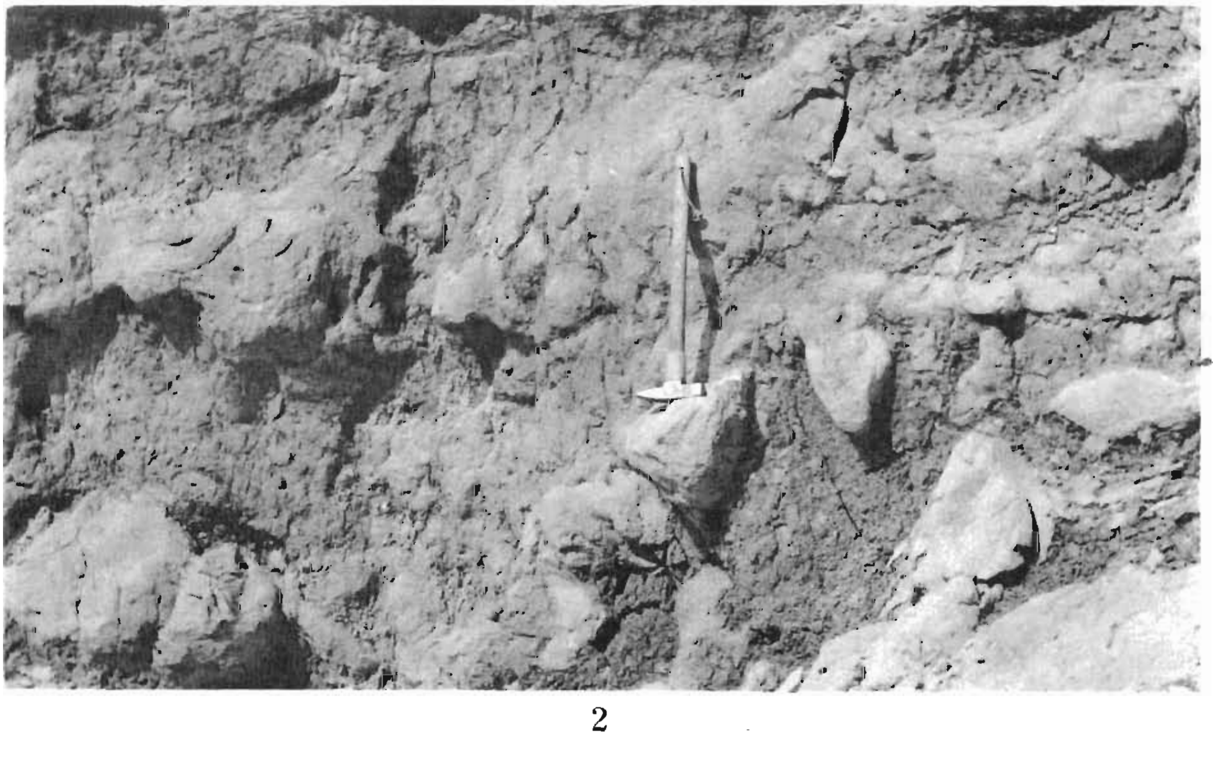
Fig. 1. Load casts in alternating sandy claystones and sandstones. Nemegt locality, Southern Monadnocks.

Fig. 2. Alternating sandy claystones and sandstones; and advanced phase of deformation related to unstable density stratification. Khulsan locality, near Camp 1971

Photo: T. Jerzykiewicz



1



2