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GEOLOGY OF THE DJADOKHTA FORMATION AT BAYN DZAK (MONGOLIA)

(Plates XIX-XXI)

Abstract. — On the basis of a study of sedimentary features the depositional environment of the Djadokhta Formation may be defined as perilacustrine. The Djadokhta Formation of Coniacian or Santonian age (KIELAN-JAWOROWSKA, 1968/69) crops out in the northern part of the Mongolian Gobi Desert north of the Gurvan Saikhan Mts. It consists of alternating sandy and calcareous beds. The character of the sandy horizons points to an aeolian origin. The upper sandy, and calcareous beds are lacustrine in origin. At least part of the arenaceous material of the Djadokhta Formation was probably deposited in form of coastal dunes situated near lakes. The analysis of heavy minerals has revealed that the sandy material of the Djadokhta Formation at Bayn Dzak and vicinity does not come from the denudation of the Oshih Formation as was supposed by BERKEY and MORRIS (1927). Remarks are made concerning some taphonomic problems relating to the vertebrate skeletons and nests of reptilian eggs. Complete or almost complete skeletons and complete skulls of reptiles are common, whereas isolated bones are extremely rare in the Djadokhta Formation. Isolated teeth of *Protoceratops andrewsi*, *Pinacosaurus grangeri*, and undetermined small theropods are frequently found in the sandy beds. Smaller fossils, such as mammal and lizard skulls and also crocodile remains are preserved predominantly in sandy concretions. All the vertebrate remains found so far in the Djadokhta Formation show no trace of post mortem transportation.

INTRODUCTION

The Upper Cretaceous Djadokhta Formation[1] of Bayn Dzak (formerly named Shabarakh Usu) was explored by the Polish-Mongolian Palaeontological Expeditions (of which the present author was a member) during the field seasons of 1964—65 (KIELAN-JAWOROWSKA & DOVCHIN, 1968/69). Additional geological research was carried out by the author in the years 1967 and 1968. The accounts of previous investigations of the Bayn Dzak area are presented in earlier papers (GRADZIŃSKI *et al.*, 1968/69, LEFELD, 1965).

The geological observations carried out by the present author at Bayn Dzak and in the surrounding area are concerned primarily with geological documentation, i.e. the geological sections, their correlation and the sedimentology of the Upper Cretaceous deposits. The results of these researches, presented here, have led to a reconstruction of the depositional environment of the Djadokhta Formation. The geology of the sedimentary basin in which the Djadokhta Formation is situated is poorly known, therefore, the geological information actually presented cannot be compared with that of the adjacent areas. All the analytical data in this paper refer to the most representative section of the Djadokhta Formation; the „Flaming Cliffs" at

[1] The term Djadokhta Formation was introduced by the members of the Central Asiatic Expedition of the American Museum of Natural History during the early 1920s for the Upper Cretaceous sediments at Shabarakh Usu (present name Bayn Dzak). It has been widely used in paleontological literature. According to Dr. BARSBOLD's information the term „Djadokhta" is a result of incorrect spelling of a Mongolian name.

Bayn Dzak. The section is given in the paper by GRADZIŃSKI *et al.* (1968/69). The analysed samples bear the same numbers as the individual beds of the section. The collection of samples from the Bayn Dzak area and neighboring sites is housed in the Palaeozoological Institute of the Polish Academy of Sciences in Warsaw.

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GEOLOGICAL SETTING

The Bayn Dzak area is situated in the northern part of the Mongolian Gobi Desert in a vast sedimentary basin, whose boundaries are vague in many places. The southern boundary of this basin coincides with the northern border line of the Gurvan Saikhan mountain ranges (Text-fig. 1). In the north the basin reaches almost as far as Arvaykher, the center of the South-Khangay aymak. Its eastern and western boundaries are less easily defined. Many larger and smaller post-Mesozoic horsts of Paleozoic rocks occur in various places throughout the basin. To the north, in the immediate vicinity of Bayn Dzak, there is a zone of basaltic rocks. A prominent peak in these basalts, the Khurul Obo, is illustrated by BERKEY & MORRIS (1927). In the opinion of these authors, the Khurul Obo basalts may underlie the Djadokhta Formation, and can possibly be correlated with the Oshih basalts. This relationship has not been investigated. Little detailed work has been done in the neighbouring mountain ranges of the Gurvan Saikhan and the Arts Bogdo; only the paper by LEBEDEVA (1934) gives some information about the Gurvan Saikhan range. The petrography of the above mentioned massifs is practically uknown. The area in question is, however, shown on the general geological map of the Mongolian People's Republic (OBRUCHEV, 1957). Some data concerning the geological development of the sedimentary basin lying north of the Gurvan Saikhan mountains were presented by BERKEY & MORRIS (1927). From the geological research done so far it is known that this basin is filled with Cretaceous, Paleocene, such as the Khashaat (Gashato) Formation, and younger continental deposits and basalts. The Djadokhta Formation is known to crop out only at Bayn Dzak, Khashaat (Gashato), Bor Hunto (north of the Bulgan somon), and Tugruk; all these sites are north of the Gurvan Saikhan ranges. At Khashaat, the Upper Cretaceous sediments are disconformably covered by the Khashaat Formation of Paleocene age (GRANGER & SIMPSON, 1923, MATTHEW & GRANGER, 1925, MATTHEW, GRANGER & SIMPSON, 1929, NOVOZHILOV, 1954).

The age of the Djadokhta Formation has recently been a matter of controversy (LEFELD, 1965). KIELAN-JAWOROWSKA (1968/69, 1970) estimated the age of this formation as Coniacian or Santonian on the basis of the differentiation of the mammalian fauna found at Bayn Dzak. The age estimation as ?Cenomanian by MCKENNA (1969), seems to be erroneous

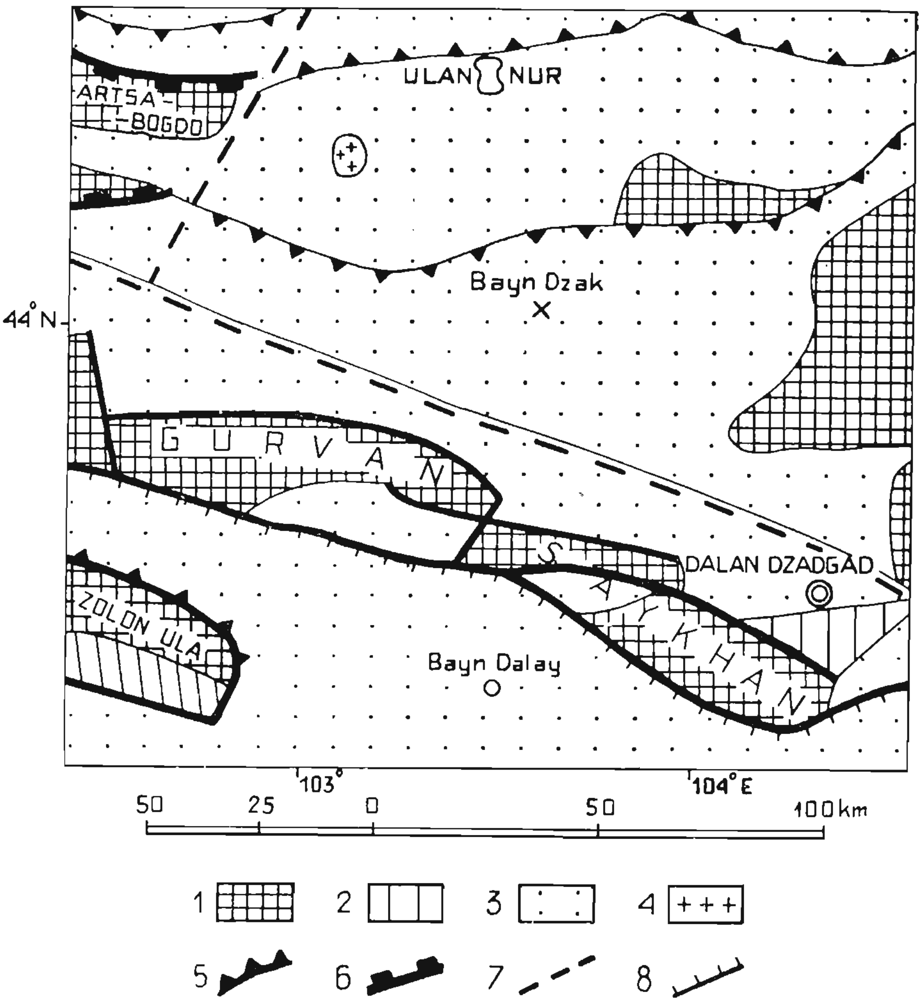

Fig. 1

Tectonic sketch-map of the vicinity of Bayn Dzak (after IVANOV, 1957 — in: VASILYEV *et al.*, 1959). *1* — Hercynnian structures (Middle Paleozoic), *2* — Upper Paleozoic, *3* — Cretaceous and Tertiary, *4* — Mesozoic granitoids, *5* — dislocations in basins, *6* — deep fractures, *7* — deep fractures buried under Mesozoic rocks, *8* — Meso-Cenozoic dislocations.

According to LEBEDEVA (1932) clastic sediments containing vertebrate bones similar to those found in the Bayn Dzak area occur in the intramontane depressions south of the Gurvan Saikhan Mts. In the Gurvan Saikhan, this author (1934) also found the so called Bayn Buluk beds that might, tentatively, correspond to the Djadokhta Formation. Some isolated teeth of *Protoceratops andrewsi* and *Oviraptor* (?) were reported from Ulan Tsonch (BOHLIN, 1953).

The latter locality is situated to the north-northwest of the Hoang-Ho river and the Ordos massif in Inner Mongolia. These beds were interpreted by BOHLIN *(l. c.)* as lacustrine or deltaic sediments. It is also worthy of note that, even in that distant site, the sediments containing *Protoceratops* remains are underlain by basalts.

The beds of the Djadokhta Formation at Bayn Dzak lie almost horizontally, dipping at an angle of 1°—1.5° toward south-east, and at an angle of about 30' toward north-west. Only slight elevation is noted at the Flaming Cliffs. Some vertical cracks filled with reddish-brown clay occur elsewhere in the Djadokhta Formation, usually bearing in the NNE direction. In MORRIS'S opinion (MS, 1923) they were related to the warping of the region. Neither the bottom of this formation nor its contact with the neighboring Khurul Obo basalts are known.

The escarpment at Bayn Dzak, along which the Upper Cretaceous sediments crop out, comprises a morphological boundary between the desert steppe zone, over the escarpment, and the desert basin floor, below the cliffs (see Plate VI in GRADZIŃSKI *et al.*, 1968/69). The desert steppe over the Bayn Dzak escarpment is an almost flat structural surface covered with a thin veneer of gravel. The escarpment itself shows a young morphological stage of development with steep, picturesque cliffs (such as the Flaming Cliffs) with numerous ravines and sayrs i.e. dry stream channels. Toward the north, west and east of the Flaming Cliffs the morphology of the escarpment is less diversified, although some monadnocks occur (such as „The Ruins"). There are some steep walled ravines at Khashaat.

Principal sections and their correlation

The type section of the Djadokhta Formation at Bayn Dzak is that of the Flaming Cliffs (GRADZIŃSKI *et al.*, 1968/69). Practically no lateral change is observed in the lithology of this formation along the Bayn Dzak escarpment. For comparative reasons a section exposed near

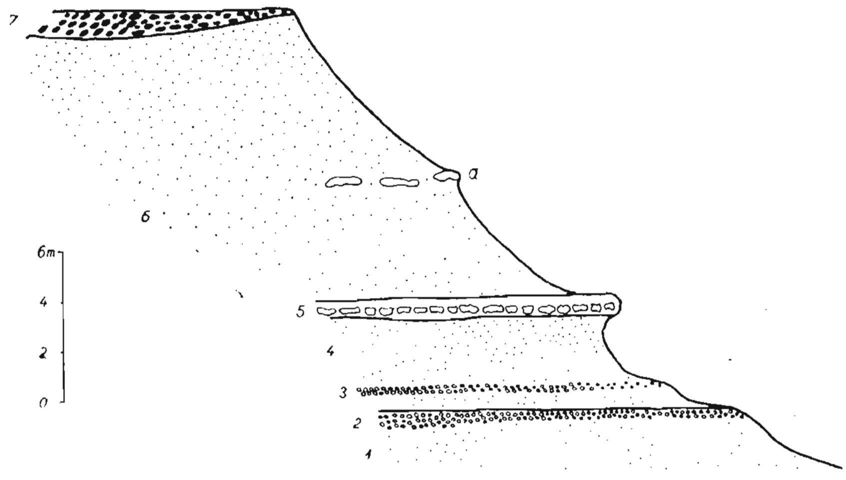

Fig. 2

Section of the Djadokhta Formation near the Caravan Trail at Bayn Dzak. Explanations — see text.

the Caravan Trail at Bayn Dzak (see Text-fig. 29 in GRADZIŃSKI *et al.*, 1968/69) is presented here (Text-fig. 2 and Plate XXI—1). It exhibits very well developed and exposed calcareous beds. The section is as follows (from bottom to top):

1) reddish-orange to brick-orange (10 R 6.5/7) [2] arkosic, poorly diagenised, friable sands.

[2] All colour designations according to the G. S. A. Rock Color Chart.

2) a bed full of orange-pinkish (10 R 6/5) calcareous concretions. They vary in size from 0.5 to 2.5 cm and are very sandy.

3) another bed of similar concretions. The concretions in both these horizons weather white.

4) reddish-orange to brick-orange (10 R 6.5/7) arkosic, poorly diagenised sends, very similar to those of horizon 1. This bed corresponds to horizon 6 of the Flaming Cliffs.

5) white, sandy marls. This rock looks like a sandy bed partly cemented by calcium carbonate. There are portions of brick-orange arenaceous rock that are barely cemented with carbonates, whereas other parts of the same rock are firmly cemented (Text-fig. 3). The thickness of this bed is 0.6—0.8 m. This horizon corresponds to bed No. 7 of the Flaming Cliffs.

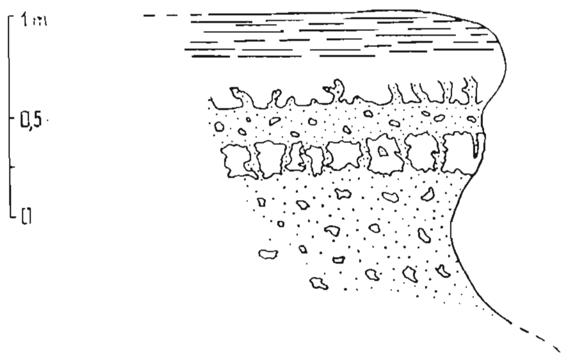

Fig. 3

A detail of the calcareous horizon 5 of the section in Fig. 2. *dotted* — sands, *dashed* — calcareous bed, horizontally fractured, *white* — calcareous, slightly arenaceous sediment.

6) reddish-orange to brick-orange (10 R 6.5/7) arkosic sands. A distinct level of sandy concretions occurs within the bed *(a)*. Numerous sandy concretions can be traced in some places in the upper part of these sands. A turtle skeleton (carapace) was found in this bed, near the Caravan Trail.

This section differs from that of the Flaming Cliffs in the greater thickness of the sandy bed separating the calcareous horizons (2, 3 and 5).

Section at Khashaat

The Upper Cretaceous sediments of the Djadokhta Formation dip under the Paleocene Khashaat (Gashato) Formation toward the south-southeast. The section of the Djadokhta Formation at Khashaat is less than 0.5 km from the nearest outcrop of the Khashaat Formation. The section from bottom to top is as follows (Text-fig.4) (Plate XIX, Fig. 1):

1) reddish-orange to brick-orange (10 R 6.5/7) arkosic poorly diagenised, friable sands with locally distributed sandy concretions. This bed corresponds to horizon 4 of the Flaming Cliffs;

2) brick-orange calcerous sandstones. This bed disappears in some places, and forms an intercalation in horizon 1;

3) two beds of calcareous conglomerates interbedded with sands like those of horizon 1. The higher bed is the more calcareous as a result of intense cementation of the rands with carbonates. These beds correspond to horizon 5 of the Flamming Cliffs;

4) calcareous marls, somewhat conglomeratic at the bottom. They weather white. This is the counterpart of horizon 7 of the type section of Bayn Dzak;

5) brick-orange to reddish-orange arkosic poorly cemented sands identical with those of horizon 1;

6) brick-orange sandstones, bound with calcareous cement. Numerous larger and smaller holes filled with sand occur everywhere in these sandstones. This bed corresponds to horizon 6 of the type section at Flaming Cliffs.

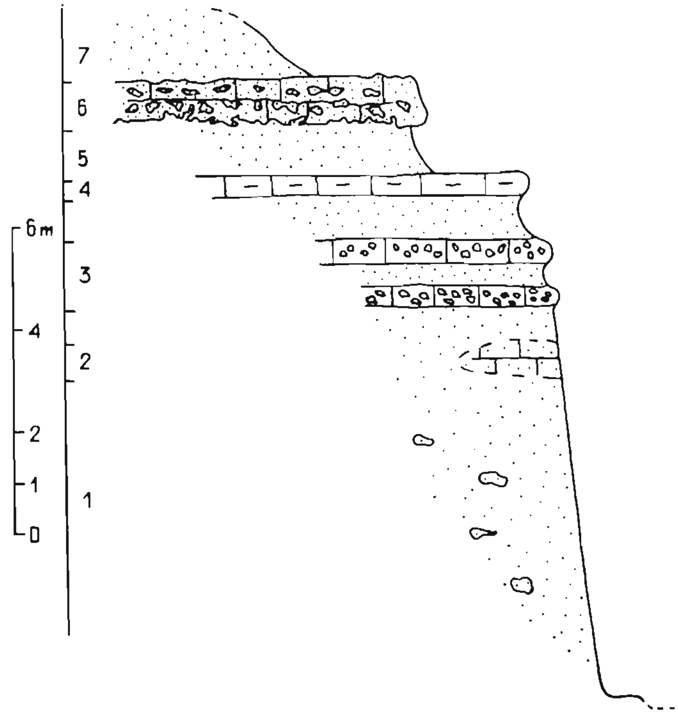

Fig. 4
Section of the top beds of the Djadokhta Formation exposed in the eastern cliff-wall of the Khashaat sayr at Khashaat. Explanations — see text.

A nest of large elongated reptile eggs (about 18 cm in length) with corrugated shells were found in horizon 5. The Paleocene Khashaat Formation rests on various layers of the Djadokhta Formation but most frequently on horizon 6 of the above section.

Section of a Butte, situated west of "The Ruins"

At a distance of 650 meters west from a monadnock called the "Ruins" there is a butte that shows the presence of a clay bed. As the clay beds are absent in the Djadokhta Formation of Bayn Dzak this section is of interest. The sequence is as follows (Text-fig. 5):

1) reddish-orange to brick-range (10 R 6.5/7) arkosic sands rich in sandy and calcareous, the latter small, concretions. The calcareous concretions form a thin layer at top of this bed *(a)*;

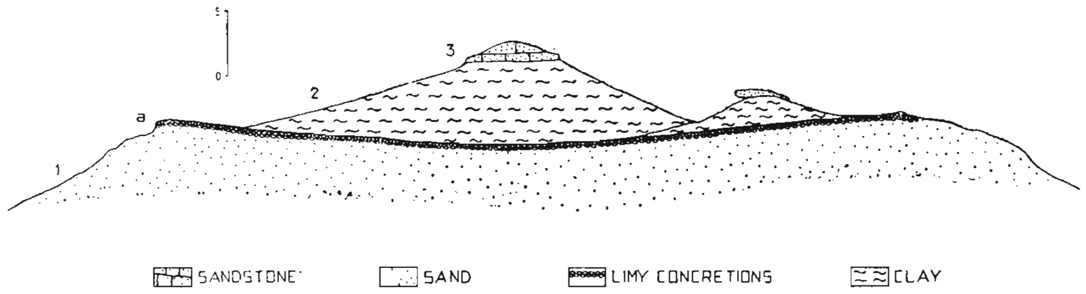

Fig. 5
Section of a butte, situated west of „The Ruins" at Bayn Dzak. Sketch after a photograph. Explanations — see text. Scale in metres.

2) moderate reddish-brown (10 R 4.5/6) silty clays, slightly carbonaceous, without obvious stratification;

3) orange-brick horizontally bedded sandstones. Isolated, small bone pieces (probably of *Protoceratops*) occur elsewhere in the bed.

Sections at Bor Hunto

About 17 km west of Bayn Dzak, and 20 km north of the Bulgan somon an escarpment called Bor Hunto (MORRIS, MS, 1923) faces north along a broad, shallow valley with an approximately east-west direction. A prominent, but rather small, basaltic mesa occurs several

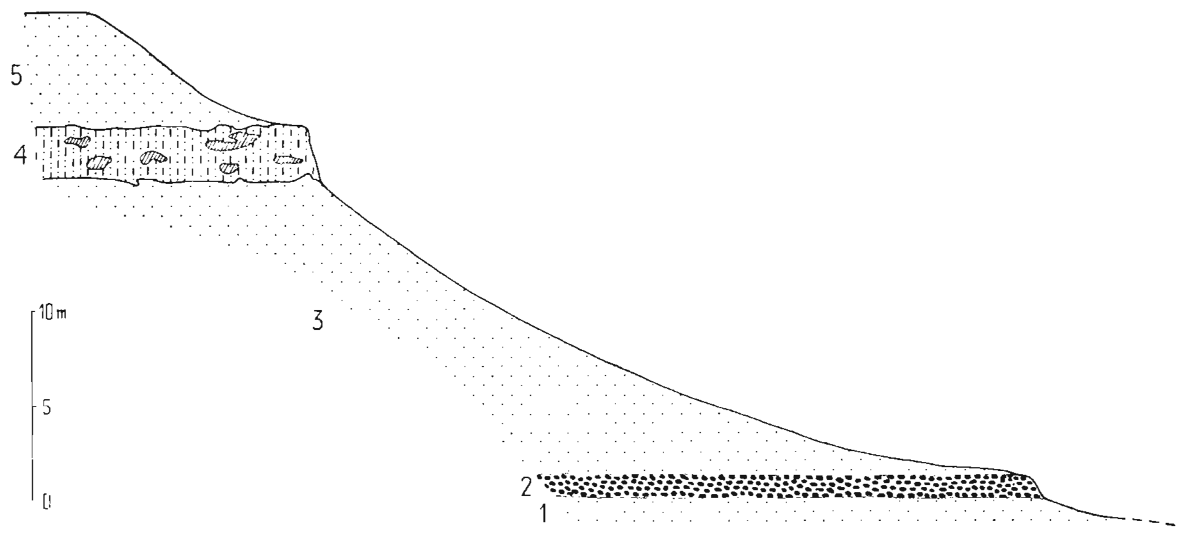

Fig. 6
Section of the Djadokhta Formation at the eastern termination of the Bor Hunto Valley. Explanations — see text.

kilometers north of the Bor Hunto escarpment. Bor Hunto offers much worse exposures than those at Bayn Dzak. A section of a cliff in the eastern part of the Bor Hunto escarpment is as follows (Text-fig. 6):

1) reddish-orange to brick-orange (10 R 6.5/7) poorly diagenised sands;

2) calcareous conglomerates showing numerous small calcareous nodules;

3) reddish-orange to brick-orange arkosic sands exactly as those of horizon 1. They correspond probably to horizon 4 of the Flaming Cliffs of Bayn Dzak;

4) reddish-orange sandstones, which are cavernous to a considerable extent. The caverns are filled with the typical Djadokhta sand. Bottom contact with the horizon 3 is indistinct;

5) reddish-orange to brick-orange arkosic sands.

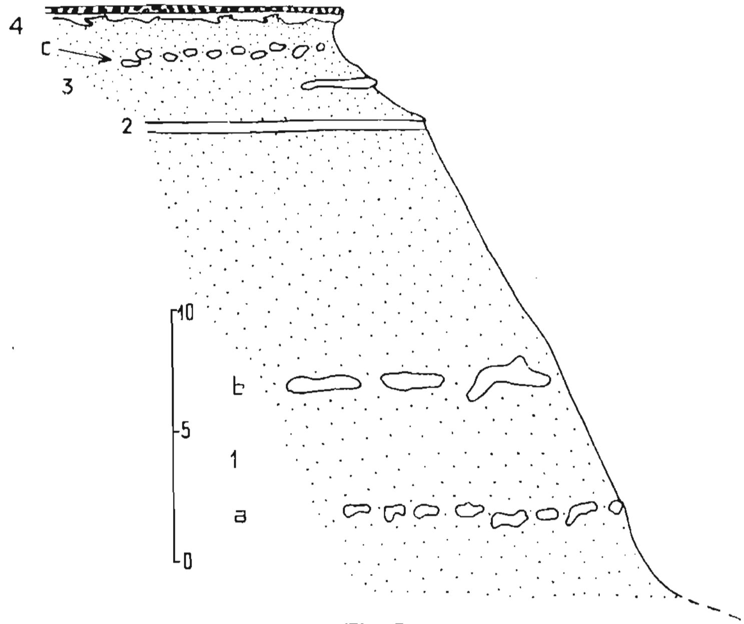

Fig. 7

Section of the Djadokhta Formation at the western part of the Bor Hunto Valley. Explanations — see text. Scale in metres.

No complete skeletons were found at Bor Hunto although some isolated reptile remains occur in some places on the desert floor which stretches north of the escarpment. The Bor Hunto valley is a tributary of a larger one which is perpendicular to the former and leads northward. A prominent cliff occurs on the western wall of this valley; the section there is as follows (Text-fig. 7):

1) reddish-orange to brick-orange (10 R 6.5/7) arkosic, friable poorly diagenised sands that contain a) a level of isolated sandy concretions, and b) level of larger interconnected sandy concretions. This bed corresponds to horizon 4 of the type section at Bayn Dzak;

2) brick-orange (colour as above) concretionary sandstones;

3) reddish-orange to brick-range (10 R 6.5/7) arkosic sands, very similar to horizon 1. They contain a level (c) of isolated, calcareous concretions. It is a probable counterpart of horizon 6 of Bayn Dzak;

4) white sandy marls, which correspond to horizon 7 of the type section at the Flaming Cliffs. This marly bed is covered by recent gravels (conglomerates) probably of Pleistocene age.

No vertebrate remains were found near this site. The higher horizons of the Djadokhta Formation crop out further west at Tugruk (NIKOLOFF & HUENE, 1966).

The correlation of the above sections was based on the calcareous horizons which as they were led down in a subaqueous environment, show good continuity from site to site. As it can be seen from the Text-fig. 8, some arenaceous beds show small changes in thickness.

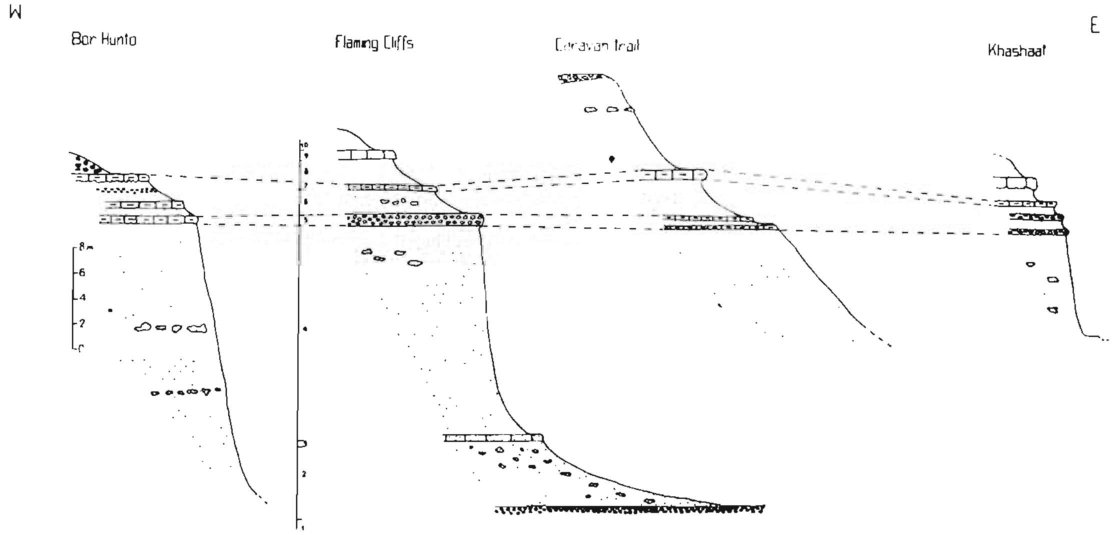

Fig. 8
Correlation of the Djadokhta Formation, based on the sections at Bor Hunto, Bayn Dzak and Khashaat. Numbers refer to the beds of the type section of the Flaming Cliffs at Bayn Dzak.

LITHOLOGY

The Djadokhta Formation at Bayn Dzak and in the vicinity represents a sequence of alternating arenaceous and calcareous sediments. The arenaceous beds of the formation outnumber, and are usually thicker, than the calcareous ones. The latter occur predominantly in the upper part of the Djadokhta sequence (see preceding pages) and as a rule are much better lithified than the former. The Djadokhta sands are friable and are easily crushed by hand. The arenaceous beds contain numerous sandy concretions that are incomparably harder than the surrounding sands. The term „Djadokhta sands" is used here for the poorly diagenised arenaceous beds of the formation. These sandy layers are of red-bed type.

ARENACEOUS SEDIMENTS

The sandy beds of the Djadokhta Formation at Bayn Dzak and in the vicinity appear massive and structureless (Berkey & Morris, 1927, p. 157—158). The rocks are weakly cemented with calcium carbonates and iron oxides. The per cent weight content of CO_2 in the arenaceous beds ranges from 9.7 % to 46.9 % (see Table 1). The Djadokhta sands show only small quantities of iron compounds, which range from 0.08 weight per cent in the sandy concretions to 0.50 % in the sands. The sandy fraction consists predominantly of quartz and, to a lesser degree, of feldspars which constitute only about 1/12th of the quantity of quartz grains in the coarsest grade. In silty and finer grades the quantity of feldspars seems to be slightly greater; these are usually fresh in the coarser grades but more weathered in the finer fractions. As shown in the diffractograms, such clay minerals as illite and montmorillonite are present in all the sandy samples examined (see Table 2), and only traces of kaolinite exist in the samples from horizons 2, 4 and 6 (i.e. bottom beds).

Typical loess-like vertical jointing can be observed elsewhere on the steep cliff walls at Bayn Dzak.

Table 1

Content of CO_2 in samples (in weight per cent)

Analysis No.	Horizon	Weight per cent of CO_2	Remarks
1	2	9·7	sandstone concretions
2	2	32·3	conglomeratic concretions
3	2	46·9	calcite concretions
4	4	12·6	cementation of a nest of reptile eggs
5	7	26·4	
6	7	27·8	
7	7	26·5	
8	7	2·3	
9	9	33·6	sandstone concretions

Table 2

Results of X-ray analyses

No	Minerals	Bayn Dzak horizons						Szabarakh Usu *	Bor Hunto	Tugruk	Oshih		
		2	4	6	8	9	10				1	2	3
1	feldspars	++	++	++	++	++	++	++	++	++	++	+	++
2	quartz	++	++	++	++	++	++	++	++	++	++	+	++
3	calcite	—	tr	—	+	(+)+	+	—	—	—	+(+)	+	++
4	illite	+	+	+	+	+	+	+	+	+	+	++	+
5	montmorillonite	+	+	+	+	+	+	+	+	+	+	+	+
6	chlorite and or kaolinite	tr	tr	tr	—	—	—	+	—	+	tr	tr	+
7	analcite	—	—	—	—	—	—	+	—	—	—	+	+

Explanations: ++ main component — not stated
+ subordinate component tr — trace

* The name Shabarakh Usu refers here to the well, situated in the north-western part of the Bayn Dzak area

Analysis of heavy minerals

Twelve samples taken from the various beds in the profile of the Djadokhta Formation at Bayn Dzak, and also samples from Bor Hunto, Tugruk and Oshih were analysed. The heavy minerals were separated in bromoform. The results of the analyses are presented in Table 3.

All the samples from Bayn Dzak, Bor Hunto and Tugruk (i.e. from the Djadokhta Formation) show a large content of epidote. This is predominantly pistacite, which is rich in iron. Epidotes poor in iron and exhibiting a low birefringence are less common. High quantities of epidote were also noted by Gradziński (1970) in the Nemegt Beds (Maastrichtian) of the Trans-Altay Gobi Desert. In Western Mongolia, Nowakowski (1969) noted large quantities of epidote in the Baykalian saussurized gabbros, basalts and ryodacites of the Khasagtu mountains. It seems probable, therefore, that the basement rocks of the whole Western and Central Mongolia are rich in epidote as is reflected by the large quantities of this mineral in clastic deposits. The opaque minerals include magnetite and rusty iron oxides, mostly consisting of the products of an alteration of an iron rich epidote. Strikingly small quantities of epidote, as compared to the Bayn Dzak samples, occur in the Oshih Formation (see Table 3). This clearly contradicts the hypothesis of BERKEY and MORRIS (1927) who derivated the Djadokhta clastic material from the denudation of the Oshih Formation. The quantities of opaque minerals in the Oshih samples are much higher than those of the Djadokhta Formation. The relatively large quantities of rounded zircon grains, the presence of rutile and tourmaline, and large quantities of iron oxides suggest that the Djadokhta clastic sediments may have derived from a source area in which reworked clastic deposits were subject to erosion. Metamorphic and igneous rocks were probably less important sources, although garnet is present in all the samples examined. The degree of roundness of heavy minerals also suggests that reworked deposits were the source material for the Djadokhta Formation. The epidotes, staurolites and andalusites are rounded, the zircons are subrounded and the garnets are fractured.

Table 3

Composition of heavy minerals in percentages by volume

No.	Minerals	Bayn Dzak horizons						Shabarakh Usu * clay	Bor Hunto sandstone	Tugruk sandstone	Oshih		
		2	4	6	8	9	10				sandstone	siltstone	sandstone
1	Anatase	2·1	—	1·2	0·6	0·8	—	—	0·8	—	—	—	—
2	Andalusite	—	2·3	—	—	—	—	—	—	2·1	—	—	—
3	Apatite	—	—	—	—	—	—	trace	—	—	5·4	—	0·8
4	Biotite	—	—	—	—	—	—	—	—	—	—	3·9	—
5	Brookite	—	0·9	—	—	—	—	—	—	—	—	—	—
6	Chlorite	—	—	—	—	—	—	—	—	—	2·0	—	—
7	Zircon	9·2	3·9	19·2	8·1	6·8	6·3	21·4	12·9	9·5	16·7	1·2	0·9
8	Kyanite	—	1·0	—	—	trace	—	—	—	0·9	—	—	—
9	Epidote	43·4	46·1	21·1	31·9	17·3	51·3	30·3	37·9	33·0	2·4	5·2	0·4
10	Garnet	4·5	2·8	3·7	3·0	2·4	4·8	5·2	1·8	8·1	22·3	0·4	1·1
11	Hornblende	—	—	1·3	—	—	—	—	—	—	—	7·0	—
12	Rutile	0·8	0·4	0·9	0·8	1·1	1·1	1·4	—	0·6	2·3	—	—
13	Spinel	—	—	—	0·7	—	—	—	—	—	—	—	—
14	Staurolite	—	1·7	1·7	0·6	0·4	2·3	—	—	2·2	—	—	—
15	Sillimanite	—	—	1·8	—	—	—	—	—	—	—	—	—
16	Tourmaline	1·1	2·1	2·1	—	trace	—	0·5	0·8	0·6	4·1	—	—
17	Opaque minerals	38·9	38·8	47·0	54·3	71·2	34·2	41·2	45·8	43·0	44·8	82·3	96·8

* The name „Shabarakh Usu" refers here to the cliff situated near the Shabarakh Usu well at Bayn Dzak.

Granulometric composition

The Djadokhta sands seem to be apparently uniform in grain size (BERKEY & MORRIS, 1927, p. 157—158). Generally speaking these rocks may be defined as fine and very fine sands, or very coarse silts, according to Wentworth's scale (see KRUMBEIN & SLOSS, 1963, p. 96). Sieve analysis has been used to examine the granulometric composition of the Djadokhta arenaceous sediments. Four sand samples were taken from horizons 2, 4, 6 and 10. They were crushed and mechanically sieved. The first analysis revealed the existence of abundant aggregates composed of small sand grains fused together with calcium carbonate. In order to disintegrate these aggregates, the same samples were then treated with hydrochloric acid, dried and resieved.

The second analysis showed practically no aggregates. The results of the sieve analyses are presented in Text-fig. 9. The samples sieved after treatment with hydrochloric acid are indicated by a notation's (e.g. 4'). The results of both sieve analyses are presented because it was difficult to decide whether these aggregates were blown into the environment, or were formed in situ during the diagenetic processes. The moment measures and the statistical analysis of the results of the sieving were calculated by J. STOCHLAK of the Geological Department of Warsaw University. The data is presented in Tables 4 and 5. The values of the Inclusive Graphic Standard Deviation (σ) show that the sorting of the Djadokhta sands is moderate (values 0.66

Table 4

Moment measures of four Djadokhta sand samples

Sample No.	5φ	10φ	16φ	25φ	50φ	75φ	84φ	90φ	95 φ
2	1·47	1·64	1·77	1·92	2·40	3·00	3·30	3·55	3·84
2′	1·48	1·64	1·78	1·93	2·50	3·07	3·32	3·49	3·64
4	1·41	1·56	1·68	1·89	2·54	3·12	3·37	3·57	3·84
4′	1·64	1·84	1·96	2·28	2·65	3·13	3·33	3·46	3·88
6	1·94	2·14	2·34	2·55	3·21	3·83	4·13	4·40	4·74
6′	1·94	2·14	2·36	2·60	3·26	3·91	4·22	4·48	4·82
10	1·28	1·65	1·83	2·02	2·51	2·98	3·26	3·46	3·74
10′	1·87	1·99	2·17	2·37	2·80	3·28	3·50	3·78	4·06

Table 5

Results of statistic analysis of the Djadokhta sands granulometry (in phi scale)

	Numbers of samples								Author(s) of formula
	2	2′	4	4′	6	6′	10	10′	
Md	2·40	2·50	2·54	2·65	3·21	3·26	2·51	2·80	INMAN, 1952
M	2·53	2·55	2·52	2·64	3·23	3·29	2·54	2·83	INMAN, 1952
So	0·54	0·57	0·61	0·42	0·64	0·65	0·48	0·45	TRASK, 1932
σ	0·76	0·77	0·84	0·68	0·89	0·93	0·71	0·66	KRUMBEIN *et al.*
Sk	0·12	0·0	—0·07	0·11	—0·04	—0·01	—0·02	0·05	TRASK, 1932
α	0·17	0·06	—0·01	—0·07	0·27	0·03	0·07	0·05	INMAN, 1952
α_2	0·33	0·07	0·10	0·01	0·01	0·12	0·00	0·24	INMAN, 1952
β	0·54	0·40	0·43	0·63	0·56	0·54	1·07	0·64	INMAN, 1952
σ_I	0·74	0·71	0·79	0·78	0·87	0·90	0·72	0·66	FOLK & WARD, 1957
Sk_I	0·20	0·31	—0·47	0·04	0·06	0·05	0·02	0·10	FOLK & WARD, 1957
K_G	0·89	0·77	0·81	0·95	0·89	0·90	1·05	0·98	FOLK & WARD, 1957

in sample 10′ to 0.90 in sample 6′). The size distribution curves are either unimodal (sample 2'), or unimodal with a distinct „tail" of finest clay fractions (samples 4′, 6′ and 10′).

The sample 6′ can be regarded as bimodal due to the large „tail" of the finest fraction. As a rule the curves are positively skewed (Sk_I values 0.31 and 0.20) and nearly symmetrical (Sk_I values 0.04, 0.05 and 0.102). The positive skewness of the sample 2′ may support the aeolian

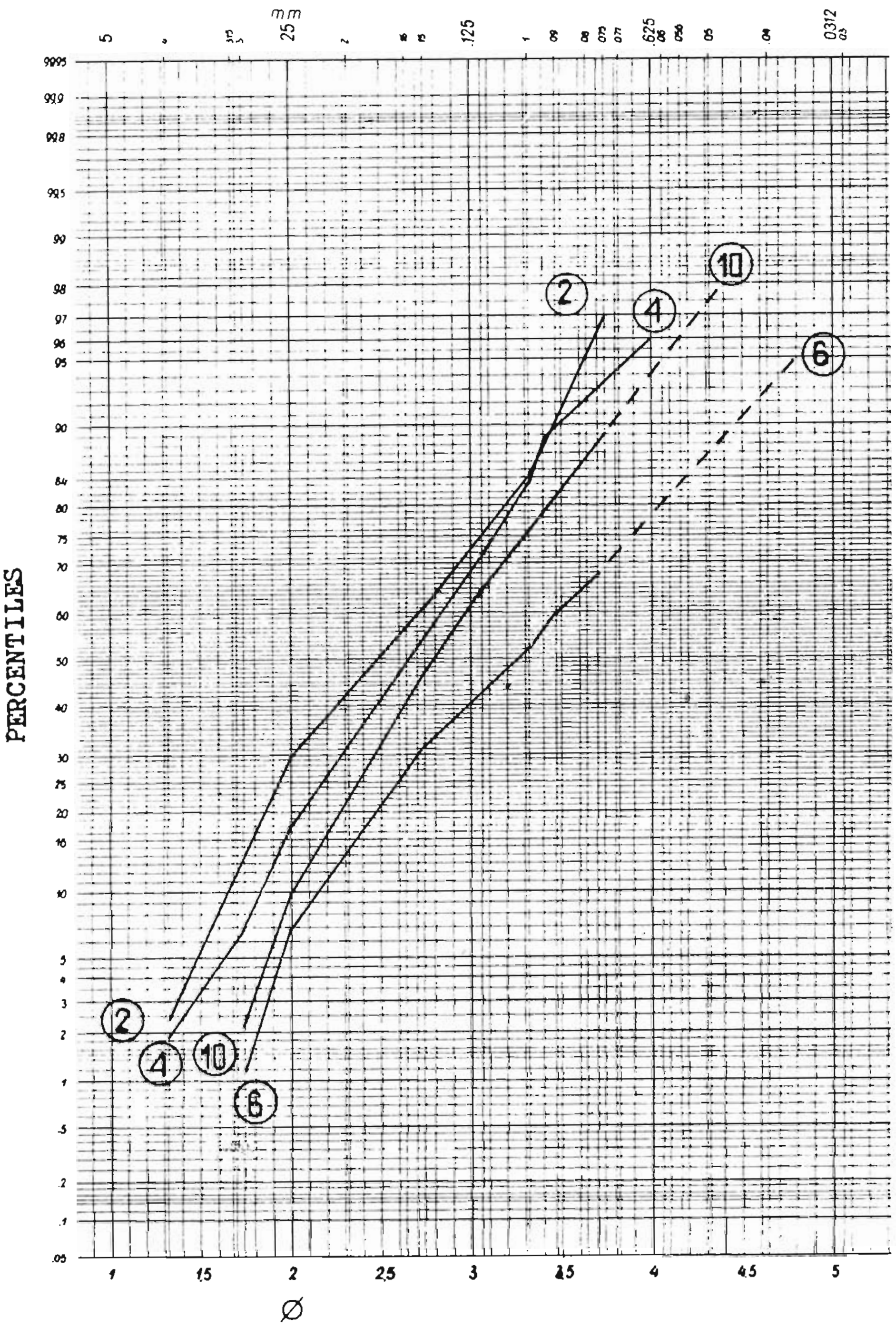

Fig. 9

Cumulative curves of the Djadokhta arenaceous sediments. Numbers of the curves refer to the horizons of the type section at Bayn Dzak.

hypothesis of the origin of the Djadokhta sands. The majority of the curves are platykurtic, except the curves of the samples 4′ and 10′, which are mesokurtic (see K_G values — Table 5).

Roundness and sphericity of grains

The roundness and sphericity of the sand grains has been determined for the grades 0.4—0.8 mm and 0.4 mm, by visual comparison with the standard table (KRUMBEIN & SLOSS, 1963, Fig. 4—10, p. 111). Three sand samples were analysed, namely those from horizons 2, 4 and 10. The parameters for 100 grains in each of the two grades mentioned above have been separately determined. The histograms of roundness are presented in Text-fig. 10, and

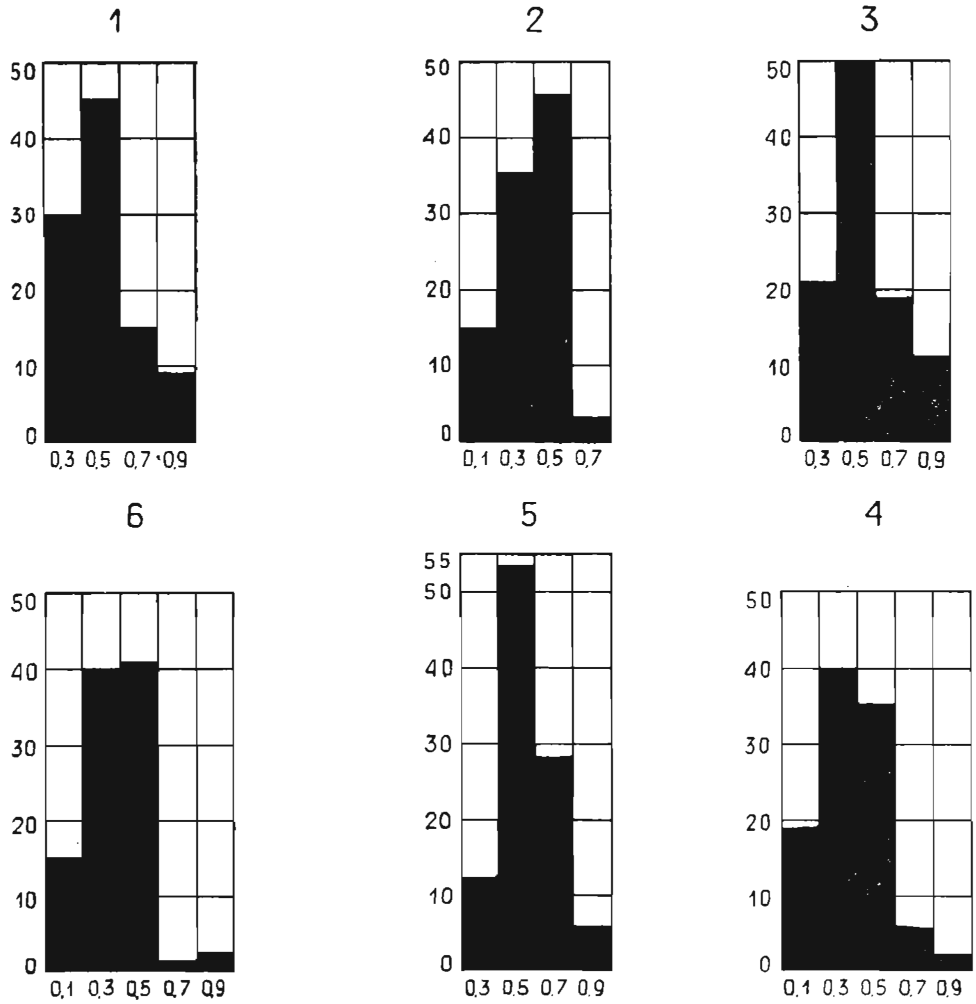

Fig. 10

Histograms of roundness of the Djadokhta sands. *1* — sample 2, grade 0.4—0.8 mm, *2* — sample 2, grade < 0.4 mm, *3* — sample 4, grade 0.4—0.8 mm, *4* — sample 4, grade < 0.4 mm, *5* — sample 10, grade 0.4—0.8 mm, *6* — sample *10*, grade < 0.4 mm.

those of sphericity — in Text-fig. 11. Moderate roundness values are characteristic for the grades 0.8—0.4 mm, whereas those of the grade smaller than 0.4 mm are slightly lower (0.35 and 0.33 — see Table 6). Large quantities of broken grains, which must have been rounded or subrounded originally, were observed (Plate XX, Fig. 3). Such a situation is typical in many loess deposits (SMALLEY & VITA-FINZI, 1968).

The sphericity values for the grades 0.8—0.4 mm are also moderate (see Table 7). Slightly lower values are noted for the grade smaller than 0.4 mm. The presence of a few well rounded large grains was observed in all the samples examined. In all the samples the smaller grains

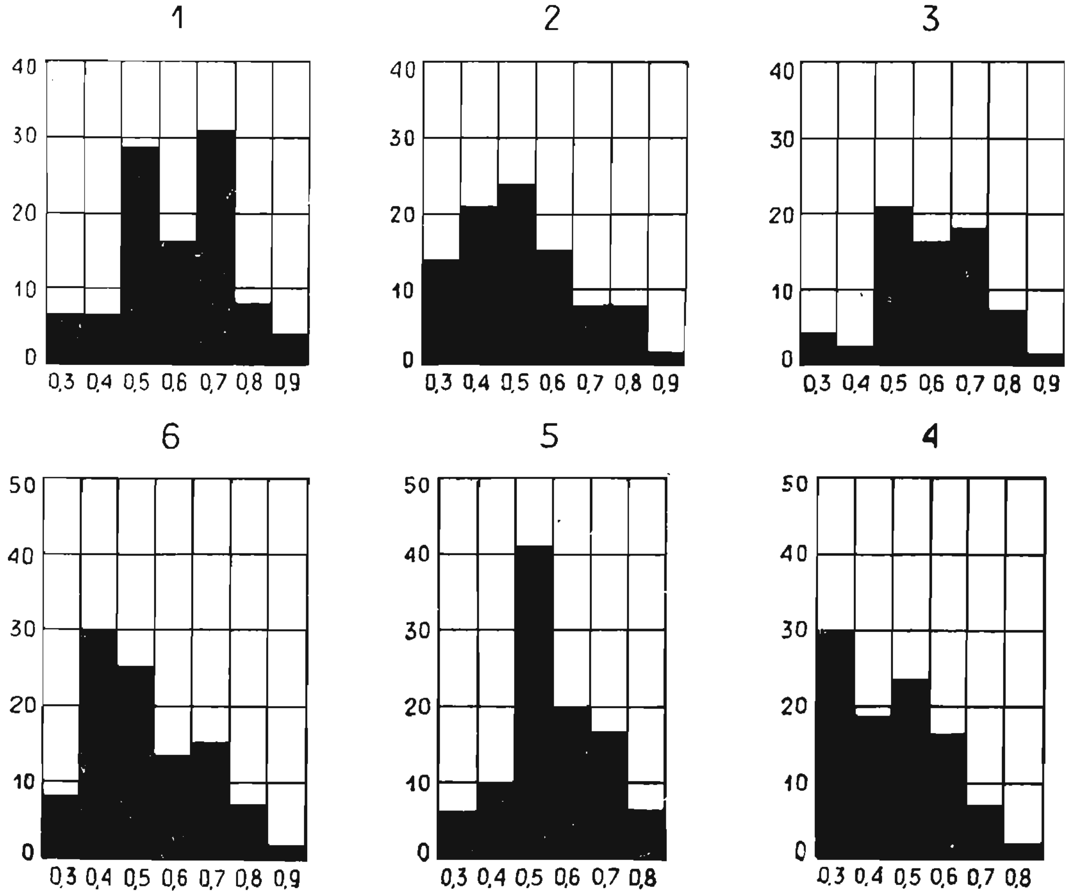

Fig. 11

Histograms of sphericity of the Djadokhta sands. *1* — sample 2, grade 0.4—0.8 mm, *2* — sample 2, grade < 0.4 mm, *3* — sample 4, grade 0.4—0.8 mm, *4* — sample 4, grade < 0.4 mm, *5* — sample 10, grade 0.4—0.8 mm, *6* — sample 10, grade < 0.4 mm.

were usually less rounded than the larger ones. CAILLEUX & DEVYATKIN (1969) investigated the surface morphology of the quartz grains from the Djadokhta Formation of Bayn Dzak. Their conclusion was that a part of these grains were shaped by aeolian action and by lake waves.

Table 6

Roundness of sand grains

Sample from horizon No.	Grade	
	0·8 mm—0·4 mm	< 0·4 mm
2	0·48	0·35
4	0·40	0·33
10	0·51	0·35

Table 7

Sphericity of sand grains

Sample from horizon No.	Grade	
	0·8 mm — 0·4mm	< 0·4 mm
2	0·59	0·52
4	0·61	0·44
10	0·55	0·53

Exotic pebbles

A few exotic pebbles were found in the Djadokhta Formation. They come from the following horizons: top and base of horizon 4, and horizons 5 and 7. The exotic pebbles from horizon 4 are, as a rule subangular and 5—6 cm to 3—4 cm in diameter, the latter being the most common. Some smaller ones are about 1.5—0.5 cm in diameter. These are usually sharp-edged fragments of igneous rocks: granites, tonalites and eruptive rocks. The composition of exotic pebbles found in the Djadokhta Formation is shown in Table 8. The most commonly occurring exotics are small pebbles of Paleozoic limestones. Most pebbles from horizon 4 are fresh rocks although some are of igneous rocks and limestones. Those from horizons 5 and 7 are more weathered. This is well illustrated by igneous rocks and graywackes, and greenstones. The latter are sharp-edged and suggest that fresh material was being eroded not very far from the deposition area. Small pebbles, with the exception of the limestones, from horizons 5 and 7 show rather poor rounding. Large pebbles in horizon 4 are usually subangular, smooth and relatively well rounded. Many pebbles from horizons 5 and 7 are covered with black varnish, which does not seem to be of primary origin.

The differing petrographic content of the three pebble groups suggests that some differences in morphology existed in the source areas during the deposition of the Djadokhta Formation. The composition of these exotic pebbles may suggest that this material came from various sources. Some of it may have derived from the denudation of Jurassic or older conglomerates. This applies mainly to the well rounded pebbles of radiolarite, quartzite and quartz (Plate XXI, Fig. 4). Nothing precise, however, can be deduced about the derivation of these exotic pebbles until the petrography of the Gurvan Saikhan and Arts Bogdo mountain ranges is investigated in detail.

Table 8

Composition of exotic pebbles

Rock type	Colour	Number of pebbles in horizons		
		4	5	7 *
tonalites	white (N 9)	2		
granites		2		
other igneous rocks		2		1
vein quartz	white (N 9)			1
greywackes	olive-gray (5 Y 4/3)	2		1
quartzites	reddish-brown (10 R 5/6)	3		1
radiolarites	dusky-red (5 R 3·5/4)	2		
,,	darkreddish-brown (10 R 3/4)			4
other siliceous rocks	blackish-red (5 R 2·5/3)	2		2
greenstones	dusky yellow-green (5 GY 4/2)		1	7
silty limestones	moderate brown (5 YR 3/3)		4	2
,, ,,	light-brown (5 YR 6/5)		2	
limestones	dark yellowish-brown (10 Yr 5/2)		3	
,,	brownish-black (5 YR 3/1)		2	
,,	white-pinkish (5 YR 9/1)	1		
limonites	moderate-brown (5 YR 3/3)		2	
total number of pebbles analysed		14	14	19

* In addition some small (about 1 cm) fragments of eruptive rocks full of plagioclases have been found in horizon 7.

The majority of this material comes from reworked sediments, as was already noted by MORRIS (MS, 1923, Book VII, p. 108) who wrote: „these are pebbles in the (*n* plus *1*) generation, derived from another sediment".

Bedding

The arenaceous beds of the Djadokhta Formation show few traces of stratification. Bedding exists in a few places only, and in such cases it is cross-stratified in type. In the northwestern part of the Bayn Dzak escarpment there is a monadnock called „The Ruins" (see GRADZIŃSKI *et al.*, 1968/69), Plate 6, Fig. 2). On its northwestern wall a distinct cross-stratification is discernible (Text-fig. 12). These sets of cross strata probably dip to leeward and may

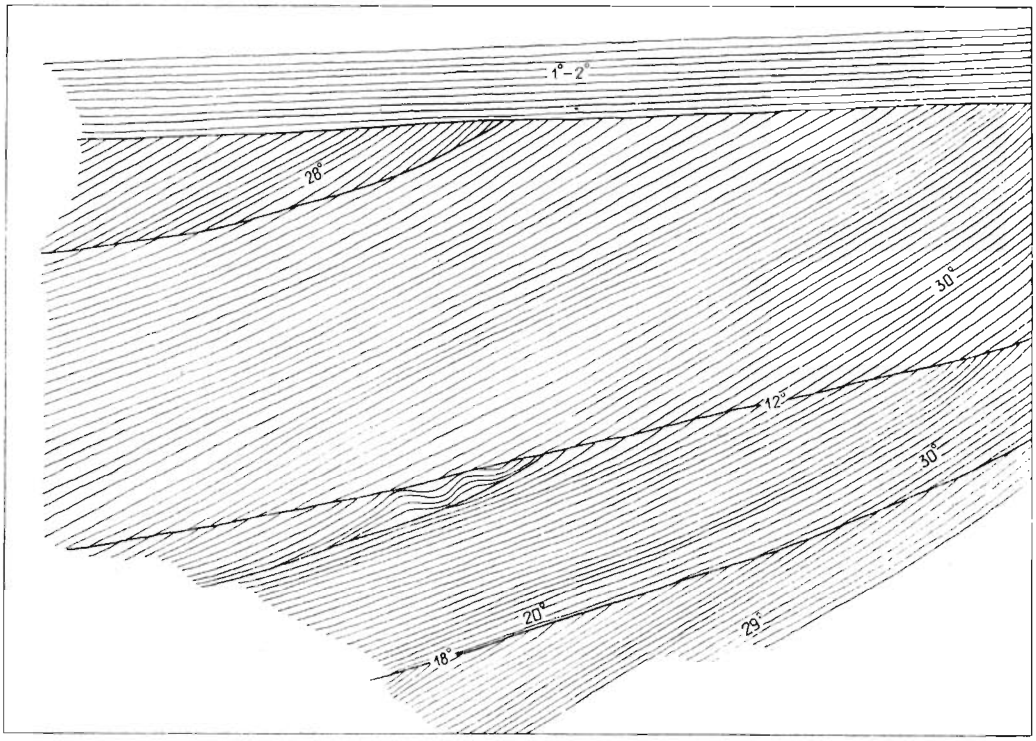

Fig. 12
Aeolian type cross-stratification at „The Ruins". Azimuth of the wall 53°.

represent leeward side of an ancient coastal dune. Their strike and dip direction is 114° 25° N. They are such as those shown in Plate III-D of McKEE (1966). Some irregular or contorted layers between the sets of undisturbed strata occur in the lower part of the section resembling those in McKEE's *(l. c.)* photograph on Plate IV-*B*. According to this author such contorted layers probably result from irregular slumping or avalanching. The section of the cross strata at „The Ruins" seems to be almost parallel to the dip direction and that at Text-fig. 12 shows a well situated at an angle of 82° in relation to the former one. Some cemented large scale cross strata occur at the butte situated approximately half way between „The Ruins" and the Flaming Cliffs. This butte was ilustrated by BERKEY and MORRIS (1927, p. 356, Fig. 152). The bedding at this butte was hardened by a secondary cementation with calcium carbonate probably due to the percolation of ground waters through the Djadokhta Formation in later times. The strike and dip of these cross strata are 126°/31° N, 139°/36° N and 140°/28° N. The stratification occurring at „The Ruins" is most probably of aeolian type.

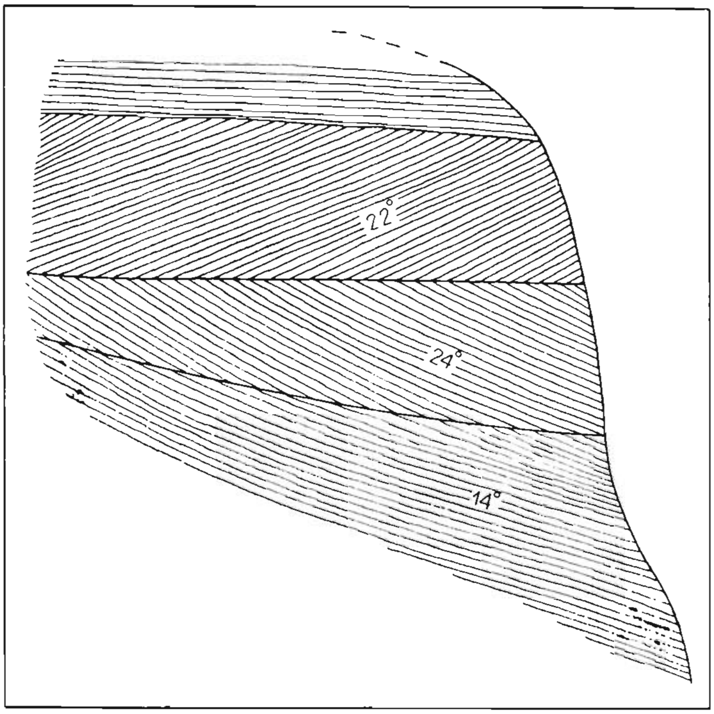

Fig. 13
Aeolian type cross-stratification at „The Ruins". A wall situated at an angle of 82° to that of the Text-fig. 12.

Red pigmentation

The Djadokhta areanceous sediments are almost invariably reddish-orange (10 R 6.5/7) in colour. All the sedimentary features of these deposits allow their classification as red bedse So far there are few indications for the origin of the reddish tint seen in these sediments. Concentrations of iron-bearing minerals (limonite?) occur as coatings on the sand grains and fill the pits on the grain surfaces as well as inbetween the grains. The presence of reddish clastic fragments (brown-reddish clays) within the firmly cemented calcareous conglomerates of horizon 7 seem to suggest a primary origin at least for a part of the Djadokhta reddish clastics. Nevertheless, these clastic fragments may well have derived from other older formations. In the latter case the reddish tint of the Djadokhta sands may be secondary in origin, or diagenetic.

CALCAREOUS SEDIMENTS

In the upper part of the Djadokhta sequence at Bayn Dzak there are two, and in som. places, three, distinct calcareous layers showing clear stratification and continuity all over the whole area. These beds are in fact conglomerates, because they contain many calcareous pebbles identical both in composition and shape with the calcareous concretions in the underlying sandy bed (horizon 4). The latter result from calcium carbonate precipitation within the arenaceous sediments which took place under the lacustrine conditions of horizon 5. The same concretions were finally deposited in the overlying calcareous conglomerates as a result of the reworking of the underlying sandy bed. The microscopic examination of thin sections revealed that these calcareous concretions are full of detrital grains, predominantly quartz, coated with carbonates (Plate XX, Fig. 4). If the carbonate coatings of the quartz grains are primary, then they may be analogous to the similar coatings found on the grains in loesses. On the other hand, they might have been formed in the lacustrine environment in which case, they have nothing in common with loess-like clastics. Despite the overwhelming numbers of calcareous pebbles, there are also some of exotic rocks (see Table 8). The cement of these conglomerates is composed of calcium carbonates with a large admixture of detrital quartz grains, undoubtedly deriving from the reworking of the Djadokhta sands. Various stages of the cementation of the sands with carbonates may be observed. In some cases the rock is hard and looks like a limestone (most common in horizon 7), whereas in other cases, the cement is weak and scanty and the calcareous pebbles are inadequately bound. In some places horizon 7 shows a layer devoid of the calcareous pebbles and consisting of limy parts separated by sandy portions (Text-fig. 3). This bed shows the various stages of the cementation of Djadokhta sands with carbonates. Its bottom part is only partially cemented, whereas its upper portion is a lithified limestone. The cementation is primary and has taken place under lacustrine conditions of deposition. The abundance of carbonates (see Table 1) seems to suggest rather warm climatic conditions for these lakes; this coincides well with the presence of crocodiles. It is not out of the question that some leaching processes (secondary in relation to the original sediment) might have taken place in these calcareous beds, as is reflected by the incomplete cementation of the sand by carbonates. The abundance of sand and silt grains in the limestones of horizons 5 and 7 seem to suggest that the aeolian deposition did not stop during the sedimentation of these calcareous beds. As may be seen from the sections, shown here, another period of aeolian sedimentation followed the lacustrine regime of the Djadokhta Formation. These higher sandy layers of the formation have yielded only small quantities of fossils such as nests of eggs and few multituberculate skulls as well as a turtle carapace.

CONCRETIONS

The Djadokhta Formation abounds in concretions of various kinds. They vary in shape, mineral composition and form of occurrence. Some may be classified as primary in origin, whereas others are definitely secondary in this respect (diagenetic or epigenetic). The primary concretions occur in both the sandy and calcareous beds. Near the top of the sandy beds lenses of calcareous concretions imbedded in sandy material can be seen. These are more or less spherical or sometimes horizontally oval limy nodules 2—3 mm to 2—4 cm in diameter, and always contain abundant detrital quartz grains 0.03—0.4 mm in diameter. Feldspar grains, which is usually microkline, are also present but in smaller quantities. The quårtz grains show limy coatings, similar to those of loess (Plate XX, Fig. 4). As a rule, the detrital grains are sharp-edged. Calcareous concretions occur in the form of lense-like concentrations in sand in the upper part of horizon 4 (Plate XX, Fig. 1). They are most abundant, however, in the conglomerates of horizons 5 and 7. In the latter instance they may have been washed out of horizon 4 as they are found as pebbles in the conglomerates. Their concentration in the conglomerates may therefore be treated as somewhat secondary, and their origin is probably due to calcium carbonate precipitation from lake water in the Djadokhta sands, which are porous and highly permeable. The cementation of some of the vertebrate remains (e.g. crocodile bones and some nests of eggs) is of the same character. It was noticed by Morris (MS, 1923, Book VII) that the bones might to some extent have facilitated the formation of concretions. However, in a specific case, it is not always easy to determine whether these concretions are primary or secondary in origin.

Secondary concretions

Sandy concretions are the most common type of concretions in the Djadokhta Formation. These are nodular, knob-like, ball-like, pipe-like or spherical in shape and range from 2 cm up to several meters in size (Plate XIX, Fig. 3).

Some forms of these sandy concretions have been investigated by MORRIS (MS, 1923) who referred to them as „sheel-like" weathering for they form sheel-like tubes, chimneys etc., and protrude from the sandy walls at Bayn Dzak and Khashaat. This is explained by the fact that the concretions are more resistant to denudation than the Djadokhta sands. The distribution of these secondary concretions seems at first sight to be haphazard. They are abundant in some places whereas in the others they are extremely rare or absent. In fact, their orientation pattern and distribution appear to reflect the patterns of the movement of migrating ground waters through the Djadokhta Formation. Such phenomena are known from the Arikaree group of Nebraska (SCHULTZ, 1941) and from the Wasatch and Lance Formations in Wyoming, Nebraska and South Dakota (MESCHTER, 1958). According to MESCHTER, well formed calcareous concretions are generally found in relatively well-sorted, massive, fine- to coarse-grained sandstones. This is also true of the concretions in the Djadokhta Formation. The boundaries between the concretions and the uncemented sands are invariably sharp. In some cases, groups of such sandy concretions form horizontal levels which suggest that the calcium carbonate cementation took place along a ground water table. In other cases, the horizons of these concretions form sheet-like dipping sandstone planes which follow the directions of the cross-bedding. Some horizontal concretionary sandstone levels also occur, as for example in horizon 3 of the Flaming Cliffs section. A very peculiar form of the sandy concretions exists on the desert floor about 1400 meters to the north-west of the Flaming Cliffs. These forms look like „petrified plants or shrubs" (Plate XIX, Fig. 2), and their origin is due to the phenomena mentioned above but the surrounding sand has been blown away, and the concretions, as more resistant forms, remain on the desert floor. Some tube-like sandy concretions may represent secondarily cemented burrows, but this question is very difficult to decifer.

REMARKS ON THE CONDITIONS OF BURIAL AND PRESERVATION OF THE VERTEBRATE REMAINS

The Djadokhta Formation at Bayn Dzak has yielded a large number of skeletons, skulls and other skeletal fragments of reptiles, mammals and also reptilian eggs. The list of the groups of fauna so far found in this locality is presented in Table 9. It is remarkable that skeletons of *Protoceratops andrewsi* far outnumber all other specimens found, as was noted by MORRIS (MS, 1923). The state of preservation of skeletons, skulls and other remains is usually very good. The bones, except those found in sandy concretions (predominantly skulls of mammals, lizards and crocodiles), are not mineralized but some broken are filled with the Djadokhta sand. Skulls of mammals and lizards are preserved chiefly in sandy concretions, or less frequently, in sands. In some cases parts of these skulls are slightly damaged by chemical processes (leaching), most probably active during diagenesis. The majority of the reptile skeletons and skulls, and the mammal and lizard skulls were found in horizon 2. This was also the case for the findings of the Central Asiatic Expedition of the American Museum of Natural History (MORRIS, MS, 1923), and is probably due to the extensive exposure of this horizon in the desert surface, whereas other horizons of the Djadokhta Formation are exposed only in the steep cliff walls. Almost all the remains of crocodiles were found in the horizon 2 just above the calcareous concretionary level.

Table 9

List of groups of vertebrates found at Bayn Dzak

Group	Horizon	References
Ornithischia	2	GRANGER & GREGORY, 1923; GREGORY & MOOK, 1925; BROWN & SCHLAIKJER, 1940; MALEYEV, 1952*a*, *b* 1954; MARYAŃSKA, 1971.
Saurischia	2, 4, 5	OSBORN, 1924.
Crocodilia	2	MOOK, 1924.
Chelonia	8	
Sauria (Lacertilia)	2, 4	GILMORE, 1943.
Ophidia (Serpentes)	2	SULIMSKI (personal communication).
Multituberculata	2, 4, 8	SIMPSON, 1925, 1928*a*, *b*; GREGORY & SIMPSON, 1926; KIELAN-JAWOROWSKA, 1969, 1970, 1971.
Insectivora	2, (4?)	SIMPSON, 1928*a*, *b*; GREGORY & SIMPSON, 1926; KIELAN-JAWOROWSKA, 1968/69.
Reptile eggs	2, 4, 6, 8	VAN STRAELEN, 1925, 1928; SCHWARZ *et al.*, 1961; SOCHAVA, 1969.

The conditions of preservation and burial of vertebrate remains in the Djadokhta Formation are very interesting. In theis context the notes of MORRIS (MS, 1923) are worth mention. In the opinion of the members of the American Expedition (as related by MORRIS, *l. c.*) the majority of the skeletons found were lying in normal or side position. In some cases the necks were bent backwards, and the skulls were lying against the pelvic bones.

In complete or almost complete skeletons, the bones were all in natural articulation. Some skulls of *Protoceratops andrewsi* were found alone but some skeletons showed a „frog" position, with their hind limbs doubled under the body. The same can be said of one *Protoceratops* skeleton found by the Polish-Mongolian Palaeontological Expedition in 1964, and of a postcranial mammal skeleton found in 1969. MORRIS wrote (MS, 1923, p. 19) that the skeletons „were not deformed by pressure after burial". This was also observed in the majority of the reptile skeletons found by the Polish-Mongolian Expedition. This may prove that burial took place under subaerial conditions. A perfect skeleton of the *Pinacosaurus grangeri* (MARYAŃSKA, 1971) showed no deformation that might have resulted from pressure. It was found as lying in a normal position with its ribs distended and partly broken but not displaced. Practically all of the bones were in their natural positions. MORRIS wrote (MS., 1923, Book VII, p. 107) that „GRANGER called attention to the round distended ribs, the thorax is not flattened... This is taken as evidence that the carcass dried up on the surface, and was drifted full of sand and covered by sand — presumably windblown". MORRIS wrote of one *Protoceratops* skeleton (*l. c.*, Book VI, p. 106): „the skeleton shows very little dissociation of bones... the hindlimbs lie with their ends in the articular positions, doubled under the body. Clearly the creature lay upon a firm surface... and must have been buried promptly enough that there still was tissue holding the bones in their places where the skeleton was covered".

Among the crocodile remains found by the Polish-Mongolian Expedition at Bayn Dzak there are several skulls, one disarticulated skeleton and a skeleton encased in dermal armour. These fossils were found in sandy concretions only slightly above the calcareous bed which is evidently of lacustrine origin. It is highly probable that these crocodiles were connected with that particular bed.

As it can be seen from the above statements, the Djadokhta reptiles probably were buried quickly under conditions of rapid sand accumulation (MORRIS, MS, 1923, Book VII). In MORRIS's opinion „the creatures died on land", hence in subaerial conditions. The considerable number of skeletons and skulls of *Protoceratops andrewsi* in the Djadokhta Formation by comparison with numbers of other forms attracted the attention of American palaeontologists in early twenties (MORRIS, MS, 1923, Book VII, BERKEY & MORRIS, 1927). No traces of theropods were found, except „one tooth of carnivore" (MORRIS, *l. c.*). MORRIS's hypothesis explaining these facts was that, possibly, the herbivorous creatures starved for want of food or were killed by an epidemic. Isolated teeth of *Protoceratops andrewsi*, *Pinacosaurus grangeri* and undetermined small theropods are frequently found in the sandy beds. The teeth of theropods exactly the same as those found at Bayn Dzak, are known to occur in the Lower Nemegt Beds (GRADZIŃSKI, 1970).

Several trace fossils were found near the Flaming Cliffs in the sands and sandstones of horizons 2 and 3. One well preserved specimen (Plate XXI, Fig. 2) strongly resembles *Zoophycos* (HÄNTZSCHEL, 1960).

Preservation of nests of eggs

Nests of eggs and also several isolated specimens were found in horizons 2 and 3, at the top of horizon 4 and in horizon 7 at Bayn Dzak, and in horizons 7 and 9 at Khashaat. Many broken eggshell fragments also occur over the vast desert steppe surface at Bayn Dzak. They come from horizon 7 which forms the structural plane of the steppe. Eggs 7 cm in length, with smooth shell surfaces occur in horizons 2, 3 and 4. Another variety of smooth eggs, 12 cm in length, occurs in the same horizons. Moulds of very small eggs (probably crocodile (BROWN & SCHLAIKJER, 1940) or lizard or snake eggs) 2.7—3 cm in length, are known to occur in horizon 4. Large eggs, with corrugated shell surfaces, 15—18 cm in length, occur in horizons 7 and 9. Two eggs-bearing horizons occur at Bayn Dzak, according to Soviet paleontologists (NOVOZHILOV, 1954). The lower one coincides with horizons 2, 3 and 4, and the upper one with horizons 7 and 9.

The complete nests of reptile eggs reveal a perfect state of preservation. The vertical position of the eggs in a nest is shown in Text-fig. 14. MORRIS (MS, 1923, Book VII) observed that both ends of the eggs in nests are slightly telescoped, which is probably due to compaction of the sediments. It was observed in one case, that the sand filling a lower part of an egg was partly cemented by calcium carbonate up to a certain level. This probably resulted from water filling the cup- or glass-like end of the egg. The fossil water „level" so marked is slightly tilted, demonstrating the post-cementation warping of the Djadokhta Formation.

No agent other than the wind could have buried the nests of reptile eggs, in MORRIS's opinion (MS, 1923, Book VII, p. 111). In this context he wrote: „Wind-blown sand could cover delicate objects such as eggs rapidly and without disturbing their arrangement". It should be added here that neither stratification nor bedding was noted around the nests of eggs. In some cases the nests are slightly cemented with carbonates, predominantly near their bottom. In other cases they are preserved in almost uncemented Djadokhta sand.

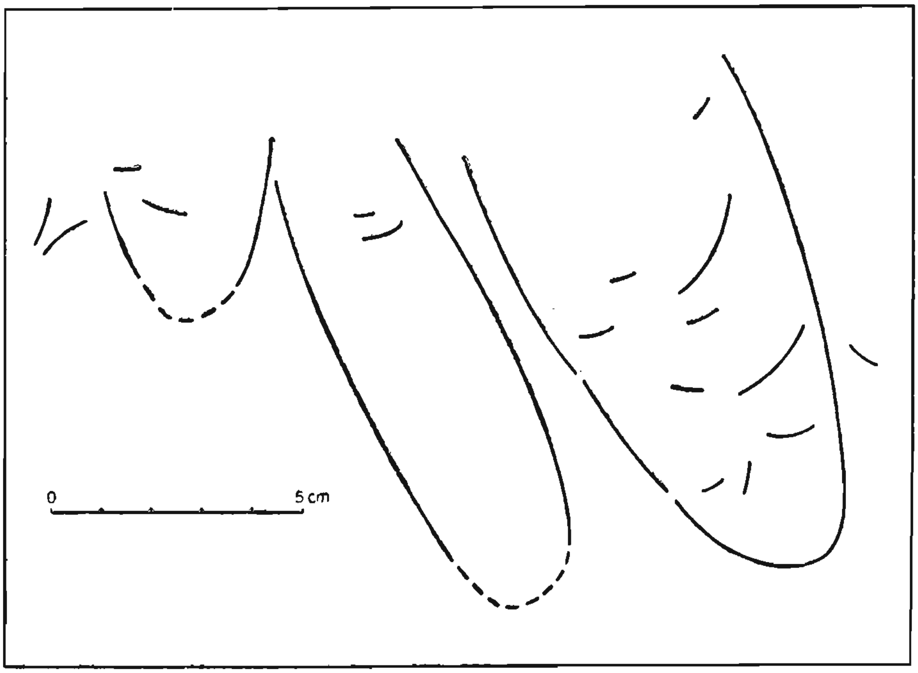

Fig. 14

A vertical section through a part of a nest of reptile eggs, showing the original position of eggs. Fragments of eggshells, derived from the upper parts of the eggs, are visible inside the preserved egg parts. Horizon 4 (top), near the Flaming Cliffs, at Bayn Dzak.

Processes leading to the enrichment in mammal and lizard skulls in some sites at Bayn Dzak

It is worthy of note that the localities in which larger numbers of mammal and lizard skulls are found, are characterized by a relatively young morphology. Most of the mammal and lizard skulls from Bayn Dzak were found in sandy concretions which are abundant on the desert floor in some places. Concentration of these concretions was the result of the rapid denudation of the nonresistant Djadokhta sand; the more resistant sandy concretions remain on the desert floor. In the primary Cretaceous sediments, the mammal and other small vertebrate remains were probably more or less evenly distributed. As a result of the epigenetic development of concretions, some of those remains have been incorporated within these concretions. During the denudation processes those fossils which were preserved in concretions were much more likely to survive than those in the sand. In sites of young morphology, the majority of the concretions washed out of the Djadokhta Formation have remained undamaged on the present desert surface. This accounts for the fact that so many mammal and lizard skulls have been encountered at Bayn Dzak in sandy concretions.

CONCLUSIONS

Reconstruction of the depositional environment

The depositional environment of the Djadokhta Formation may be defined as a perilacustrine one. The conglomeratic, calcareous beds represent a lacustrine deposition in which temperature conditions were favourable for carbonate sedimentation. Alternating with these calcareous beds, the arenaceous horizons show many features of a wind-blown aeolian deposit. Such an explanation for the origin of the sandy beds was postulated by BERKEY & MORRIS (1927). A few preserved places with aeolian cross-stratification seem to suggest that at least a part of the Djadokhta sands might originally have formed coastal perilacustrine dunes. In most places, however, these sands do not show any trace of stratification. Contrary to the opinion of BERKEY & MORRIS *(l. c.)* the Djadokhta sands contain large quantities of clay fractions, which might have been deposited from suspension. Traces of typical fluvial regime were found only in few places in the formation (Text-figs. 15, 16). Few tangential cosets preserved

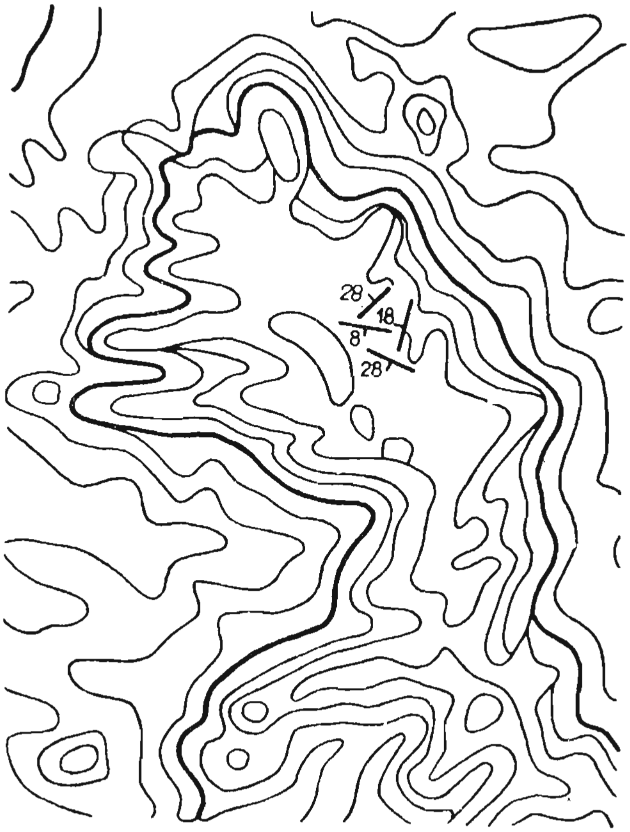

Fig. 15
Directions of cross-bedding in the calcareous bed 5 at the Flaming Cliffs.

in the calcareous conglomerates may indicate some local currents within the lake basins, or may represent inflows of water to the reservoirs. That the calcareous sedimentation was to a large degree concretionary in character is proved by the existence of a great number of small calcareous concretions within the lacustrine beds.

The arenaceous beds of the Djadokhta Formation are characterized by a high uniformity of material. In general, it may be classified as fine to very fine sand or coarse silt with large amount of clay grade. The general features of the Djadokhta sands were well known to BERKEY & MORRIS (1927). The author's investigations fully confirm the suggestions of these authors concerning their origin. The most important sedimentary features of these sands are: fine clastic material, abundance of feldspars, imperfect rounding of grains, large quantity of wind corroded sand grains (CAILLEUX & DEVYATKIN, 1969), carbonate coatings on grains (Plate XX, Fig. 4), presence of a clay fraction (illite, kaolinite, montmorillonite), general lack of stratification, massive, thick beds, typical loess-like jointing clearly observable on the steep walls, lack of cementation except due to iron oxides on grains. The stratification that can be seen at „The Ruins", is typically aeolian in type.

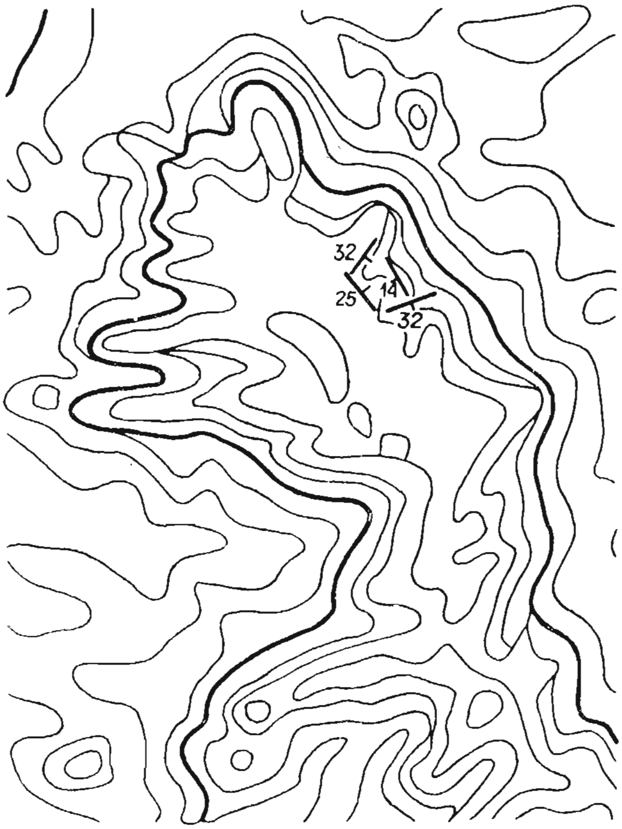

Fig. 16
Directions of cross-bedding in the calcareous bed 7 at the Flaming Cliffs.

The presence of mammal and lizard remains seems to prove subaerial conditions of deposition. The undistorted nests of reptile eggs demonstrate that no currents were in action during the sedimentation of the Djadokhta sands. Also the state of preservation of the skeletons of *Protoceratops* and *Pinacosaurus* shows that these remains were not transported post mortem. The presence of aquatic forms such as crocodiles and turtles favors a perilacustrine environment of deposition for the Djadokhta Formation as a whole. The Djadokhta Formation outcrops in only a few localities in the northern part of the Mongolian Gobi Desert, so difficulties exist in the extrapolation of these environmental conditions. Nothing is presently known of the derivation of the arenaceous material.

Palaeoclimatic indications

The climate of the Djadokhta times may be tentatively considered as a warm one, with possible intermittent semi-arid periods represented by the arenaceous beds. The warmth of the climate is demonstrated by the presence of crocodiles which, at present cannot survive in moderate climatic conditions with colder seasons. The calcareous sedimentation also seems to support this hypothesis. The alternation of sandy and calcareous beds may reflect climatic fluctuation of semiarid (sands), and more humid (calcareous beds) periods.

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Warszawa, April 1970

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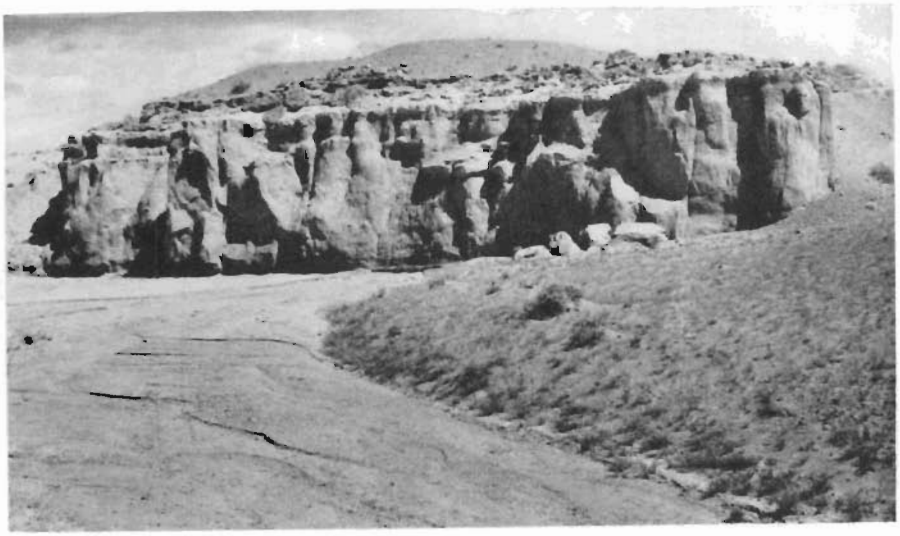
PLATES

J. LEFELD: GEOLOGY OF THE DJADOKHTA FORMATION

PLATE XIX

Photo: J. Lefeld



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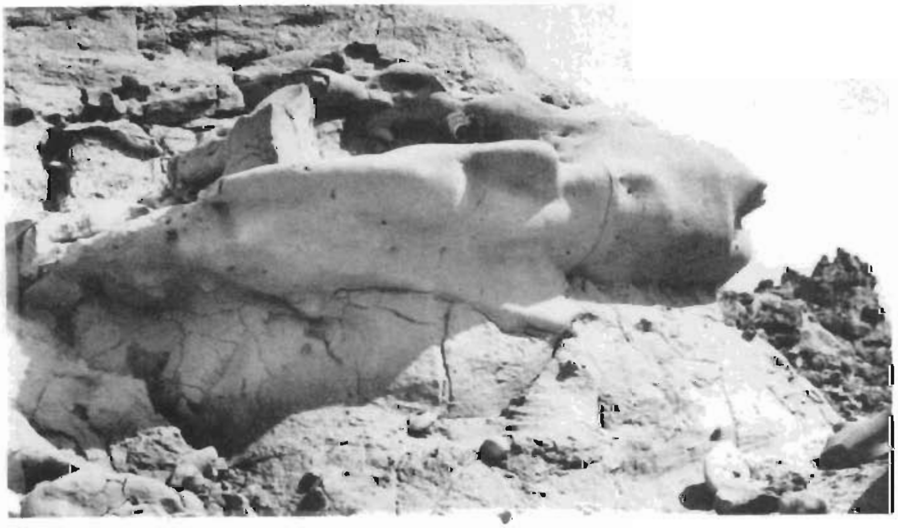

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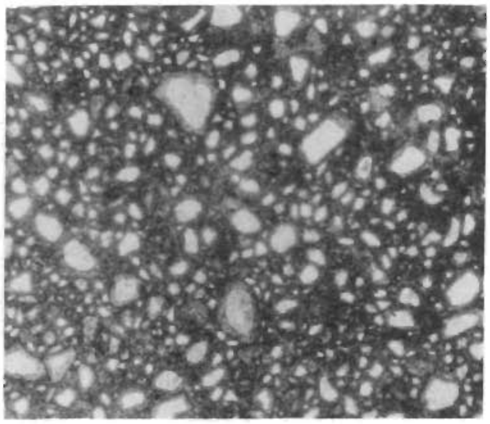
J. Lefeld: Geology of the Djadokhta Formation at Bayn Dzak

J. LEFELD: GEOLOGY OF THE DJADOKHTA FORMATION

PLATE XX

		Page
Fig. 1.	A point at the Flaming Cliffs at Bayn Dzak, showing the upper calcareous horizon. Lenticular concentrations of white, calcareous concretions within the sandy beds are visible at the bottom, and the marly bed — at the top of the photograph. The thickness shown is less than 1 m.	105
Fig. 2.	A section through a nest of reptile eggs exposed in the cliff wall, about 500 metres SSE of the Flaming Cliffs; 1/3 of natural size	122
Fig. 3.	This section of a calcerous concretion. Calcareous coatings over the quartz grains are clearly visible; ×17	119
Fig. 4.	Thin section of the Djadokhta sandstone. Broken quartz grains may be seen; ×17	109

Photo: J. Lefeld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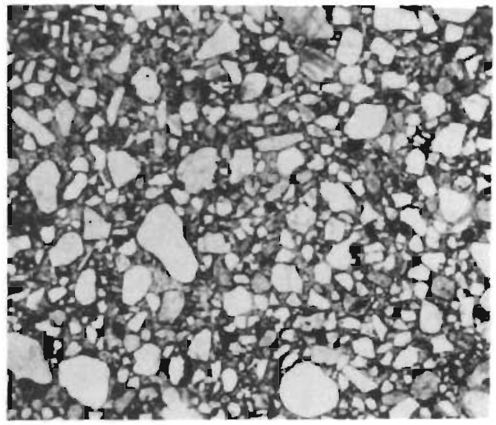
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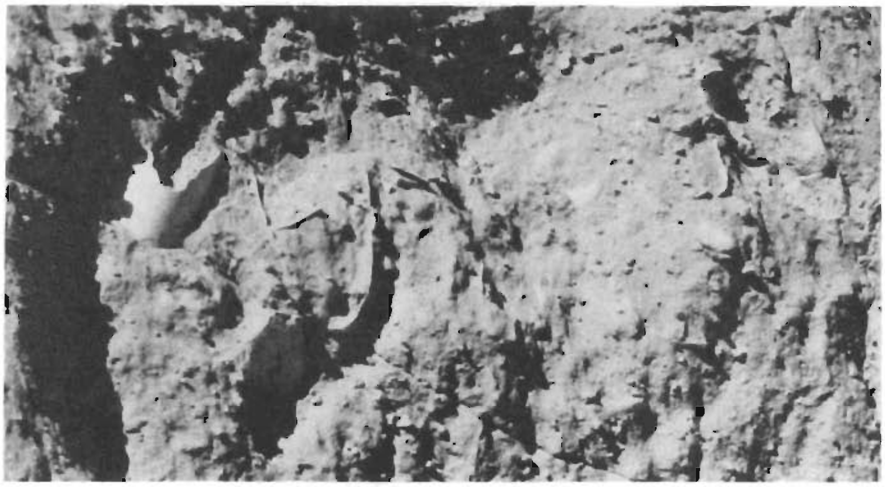
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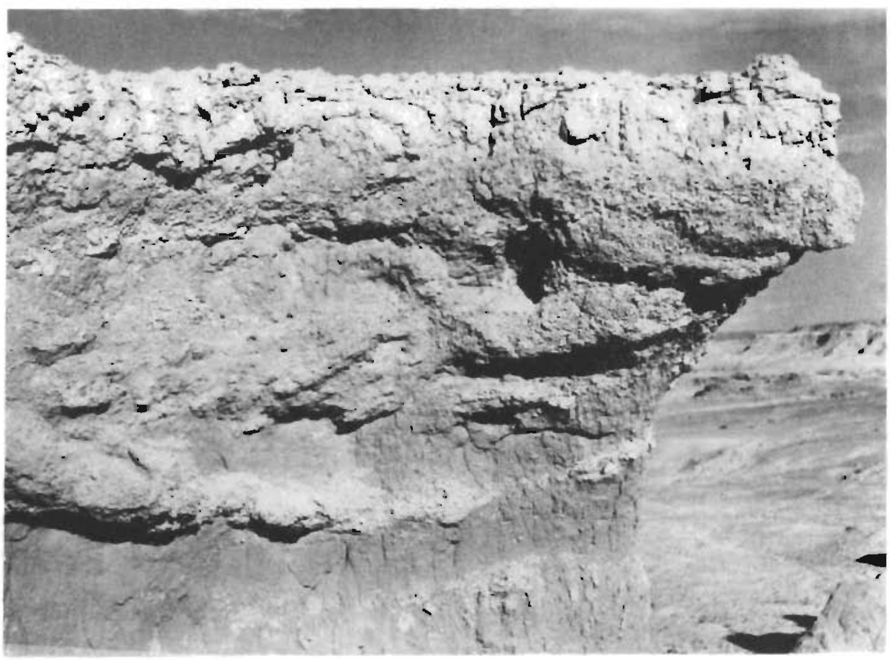
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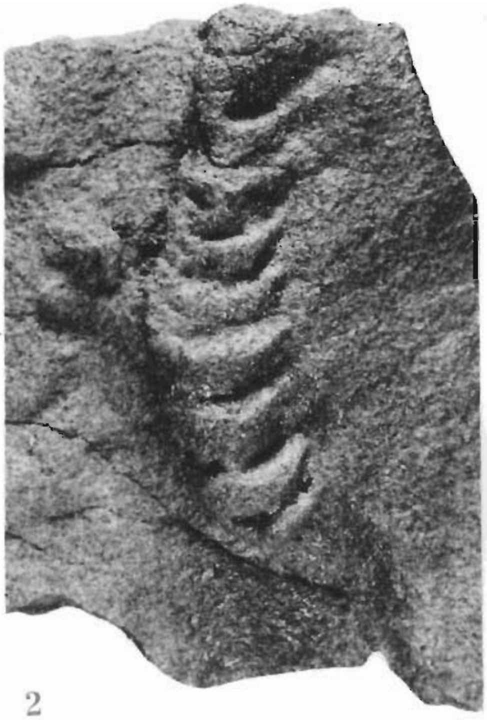
J. LEFELD: GEOLOGY OF THE DJADOKHTA FORMATION AT BAYN DZAK

J. LEFELD: GEOLOGY OF THE DJADOKHTA FORMATION

PLATE XXI



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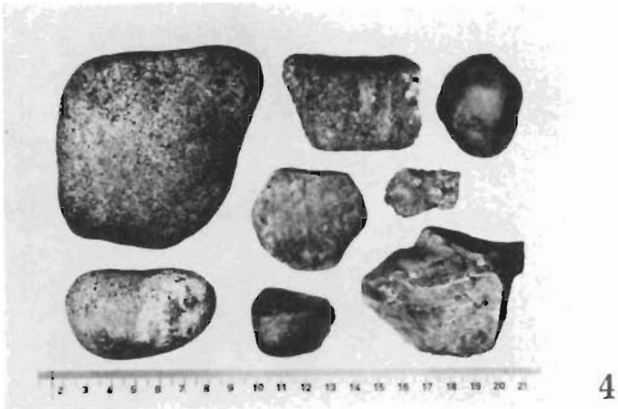

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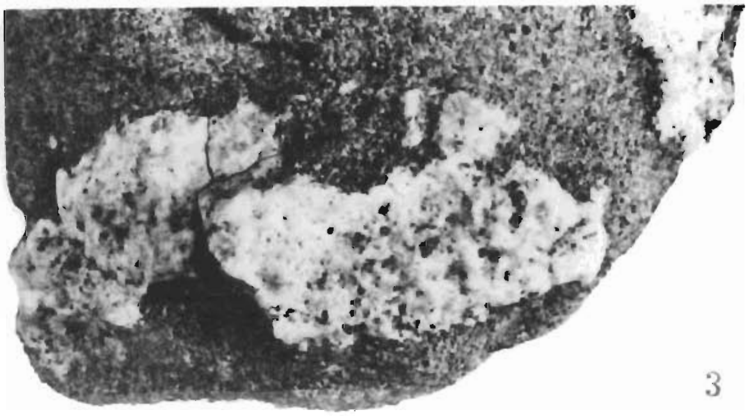

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