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## New Stratigraphic Subdivision, Depositional Environment, and Age Estimate for the Upper Cretaceous Djadokhta Formation, Southern Ulan Nur Basin, Mongolia

Demberelyin Dashzeveg

*Geological Institute of the Mongolian Academy of Sciences*, sbayar68@yahoo.com

Lowell Dingus

*American Museum of Natural History*, ldingus@earthlink.net

David B. Loope

*University of Nebraska, Lincoln*, dloope1@unl.edu

Carl C. Swisher III

*Rutgers University*

Togtokh Dulam

*Mongolian Geological Survey*

*See next page for additional authors*

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**Authors**

Demberelyin Dashzeveg, Lowell Dingus, David B. Loope, Carl C. Swisher III, Togtokh Dulam, and Mark R. Sweeney

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## New Stratigraphic Subdivision, Depositional Environment, and Age Estimate for the Upper Cretaceous Djadokhta Formation, Southern Ulan Nur Basin, Mongolia

DEMBERELYIN DASHZEVEG,<sup>1</sup> LOWELL DINGUS,<sup>2</sup> DAVID B. LOOPE,<sup>3</sup>  
CARL C. SWISHER III,<sup>4</sup> TOGTOKH DULAM,<sup>5</sup> AND MARK R. SWEENEY<sup>6</sup>

### ABSTRACT

Studies of key and newly discovered sections of the Upper Cretaceous Djadokhta Formation along the southern margin of the Ulan Nur Basin allow a new subdivision based on lithology. The formation and its members were mapped at both Bayn Dzak, an area that includes the Flaming Cliffs, and Tugrugyin Shireh, an area about 50 km to the northwest of Bayn Dzak. Stratigraphic sections at both localities were remeasured. The considerably enlarged formation comprises a lower Bayn Dzak Member, dominated by moderate reddish orange sands with subordinate mudstone units, and an upper Tugrugyin Member, composed of pale orange to light gray sands. Investigations of key sections at Tsonzh and Alag Teer demonstrate the presence of transitional mudstone lenses between these members within the Djadokhta Formation. Two distinct, sandy, sedimentologic facies are recognized in both members. Cross-bedded intervals, occasionally exhibiting wind-ripple cross lamination, document the presence

<sup>1</sup> The Geological Institute of the Mongolian Academy of Sciences, Peace Street 63, Ulaanbaatar-51, Mongolia (sbayar68@yahoo.com).

<sup>2</sup> Division of Paleontology, American Museum of Natural History (ldingus@earthlink.net).

<sup>3</sup> Department of Geosciences, University of Nebraska, Lincoln, Nebraska 68588-0340 (dloope1@unlnotes.unl.edu).

<sup>4</sup> Department of Geology, Rutgers University, 610 Taylor Road, Piscataway, New Jersey 08854 (cswish@rci.rutgers.edu).

<sup>5</sup> Mineral Resources Authority of Mongolia, Mongolian Geological Survey, "Gurvan Talst" Company Ltd., Ulaanbaatar, Mongolia.

<sup>6</sup> Desert Research Institute, University of Nevada, 2215 Raggio Parkway, Reno, NV 89512 (mark.sweeney@dri.edu).

of a Cretaceous dunefield in the Ulan Nur Basin. Structureless intervals are interpreted to represent wet sandy fluvial deposits and debris flows that moved down the dune faces. In the Bayn Dzak Member, lenses of brownish mudstone are interpreted to represent interdune deposition in shallow ponds by fluvial action. Fluvial action is also represented in the Bayn Dzak Member by beds of caliche, which contain conglomerate at the base but fine upward into limestone.

The vertebrate fauna from the Djadokhta Formation is summarized. Although the Bayn Dzak fauna lived somewhat earlier than that from Tugrugyin Shireh based on the superposition of the members, it is not clear how much earlier. The fauna from the Djadokhta Formation has previously been assigned ages from Cenomanian to earliest Maastrichtian. New magnetostratigraphic data document a sequence of normal and reversed magnetozones through the Bayn Dzak Member up into the basal Tugrugyin Member. The presence of reversed magnetozones establishes that the sediments containing the faunas were probably deposited after C34n. The quick stratigraphic succession of normal and reversed magnetozones suggests, but does not clearly establish, that the sediments may have been deposited during the rapid sequence of polarity changes in the late part of the Campanian between about 75 to 71 Ma.

## INTRODUCTION

In 1922–1923 and 1925 the Central Asiatic Expedition (CAE) of the American Museum of Natural History worked in the Ulan Nur (= Ulaan Nuur of Benton, 2000) Basin (Berkey and Morris, 1927; Andrews, 1932; Morris, 1936). Bayn Dzak (= Bayan Zag of Benton, 2000) was the main locality to be studied by the CAE under the name of Shabarakh Usu (= Flaming Cliffs). There, Americans found dinosaur eggs and nests, Cretaceous mammals, complete skeletons of *Protoceratops*, and three forms of theropod dinosaurs, including *Velociraptor*, *Saurornithoides*, and *Oviraptor* (Osborn, 1924). Berkey and Morris first referred the recognized Djadokhta Formation to the Lower Cretaceous and then to the lower part of the Upper Cretaceous. Gradziński et al. (1977) provided the lists of fossils known at that time from the Djadokhta, younger Barun Goyot (= Barungoyot of Benton, 2000), and Nemegt Formations, and estimated the age of the Djadokhta Formation as ?upper Santonian and/or ?lower Campanian.

In 1946 the Bayn Dzak locality was reinvestigated by the Mongolian Paleontological Expedition (MPE) of the Academy of Sciences of the USSR, which was headed by Efremov (1949, 1954). The investigations yielded less significant results, including a complete postcranial skeleton of the armored dinosaur *Pinacosaurus grangeri* Gilmore (= *Syrmosaurus viminicaudus*) (Maleev 1952, 1954). Additional results regarding this spec-

imen were discussed by Maryńska (1971), in a paper not associated with the MPE.

In 1963–1971 the Polish–Mongolian Paleontological Expedition (PMPE) searched for Cretaceous mammals and dinosaurs at Bayn Dzak. The main result was the discovery of abundant fossils of multituberculates, eutherian and deltatheroidan mammals in the locality's concretionary sandstones (Kielan-Jaworowska, 1969, 1970; Kielan-Jaworowska and Dovchin, 1969; Kielan-Jaworowska and Barsbold, 1972), as well as numerous lizards (see Alifanov, 2000, for review), and a peculiar long-necked crocodile (Osmólska, 1972).

In 1971 a spectacular specimen termed the "fighting dinosaurs" was found by PMPE at Tugrugyin Shireh (= Tögrögiin Shiree of Benton, 2000). These articulated and associated skeletons of *Velociraptor* and *Protoceratops* are discussed by Kielan-Jaworowska and Barsbold (1972) and Osmólska (1993). Another interesting finding of the PMPE at Tugrugyin Shireh was skeletons of *Protoceratops andrewsi* preserved in a vertical position (Jerzykiewicz et al., 1993).

In 1969–1970 the joint Soviet–Mongolian Paleontological Expedition (SMPE) found skeletons of *Protoceratops andrewsi* and other fossils at Tugrugyin Shireh about 50 km northwest of Bayn Dzak. Other results of both the SMPE and its successor, the Russian–Mongolian Expeditions are reviewed by Kurochkin and Barsbold (2000).

From 1992 to the present, the Japan–Mongolia Joint Paleontological Expedition

(JMJPE) has conducted extensive field seasons throughout the Gobi Desert. A recent account of their activities at both Bayn Dzak and Tugrugyin Shireh is presented by Ishii et al. (2000, 2004).

In 1991 the Mongolian Academy of Science–American Museum of Natural History Expedition (MAE) began field investigations based on the Agreement on Scientific Cooperation between those two institutions. In 1991–1992, 1994–1996, and 1998 the MAE visited Bayn Dzak and Tugrugyin Shireh. Significant remains of multituberculates and placental mammals were collected. Many specimens in these collections are now being studied. The MAE investigated all previously studied reference sections and described some new key sections from the Djadokhta Formation, allowing a stratigraphic reassessment of this formation throughout the region. Major lithostratigraphic units and sedimentary facies were mapped, and samples for paleomagnetic analysis were collected from different sites and stratigraphic levels. It is noteworthy that despite extensive descriptions of fossil faunas, no regional stratigraphic scheme for correlating the sections and faunas of these Upper Cretaceous deposits in the Djadokhta Formation has been previously proposed. Investigations of the MAE resulted in a refined subdivision of these deposits in the Ulan Nur Basin that allow the stratigraphic relationship between the deposits at Bayn Dzak and Tugrugyin Shireh to be clarified.

#### SUBDIVISION OF THE UPPER CRETACEOUS DJADOKHTA FORMATION ALONG THE SOUTHERN BORDER OF THE ULAN NUR BASIN, MONGOLIA

The Djadokhta Formation is represented by moderate reddish orange and pale orange to light gray, medium- to fine-grained sands and sandstones containing subordinate layers of calcareous concretions and orangish brown silty clay. Total exposed thickness of the formation in the Ulan Nur Basin, a post-Oligocene tectonic depression (Gradziński et al., 1977) is at least 80 m. Highly fossiliferous, the formation can be divided into two members and correlated to analogous depos-

its in adjacent regions. The Djadokhta Formation was initially considered to consist only of reddish orange sandstones at Bayn Dzak. This understanding of its stratigraphic extent and lithologic composition held until recently. Discussions of earlier geologic studies in the region include Gradziński et al. (1969, 1977); Kielan-Jaworowska and Dovichin (1969); Gradziński (1970); Gradziński and Jerzykiewicz (1972); Kielan-Jaworowska and Barsbold (1972); Gradziński and Jerzykiewicz (1974); Osmólska (1980); Jerzykiewicz and Russell (1991); Jerzykiewicz et al. (1993); Kielan-Jaworowska et al. (2003); Benton et al. (2000) and chapters therein, including Benton (2000), Kurochkin and Barsbold (2000), Shuvalov (2000), and Jerzykiewicz (2000). Based on new stratigraphic and paleontologic data, however, the Upper Cretaceous Djadokhta Formation of the Ulan Nur Basin can now be subdivided into a lower Bayn Dzak Member and an upper Turgrugyin Member.

#### THE BAYN DZAK MEMBER

The Bayn Dzak Member forms a range of moderate reddish orange sandstones and moderate reddish brown mudstones, which occur only along the southern edge of the basin. The most complete and fossiliferous exposures of the member are exposed at Bayn Dzak, including the famous outcrops of the Flaming Cliffs (fig. 1; Berkey and Morris, 1927; Andrews, 1932; Gradziński et al., 1969, 1977; Lefeld, 1971; Novacek et al., 1994). The type section was recorded at the Flaming Cliffs (Gradziński et al., 1969: fig. 30). This section consists of strongly dissected scarps composed predominantly of moderate reddish orange sandstone. The central scarps form a large remnant named the Flaming Cliffs by the CAE, in which the combined strata rise more than 30 m above the floor of the local basin. The Bayn Dzak Member as exposed in the Flaming Cliffs section contains the following lithologic units (see fig. 2):

1. Well-sorted, unbedded, medium-grained sand of moderate reddish orange color (Ks). This unit varies between 2 m and 14 m in thickness along the main escarpment and contains the greatest number of dinosaur fos-



Fig. 1. View looking west at the eastern face of the main escarpment of the Flaming Cliffs. The person in the left-center foreground is walking just above the prominent Kcal Unit 4 in the Flaming Cliffs section (fig. 2), which overlies the prominent cliff-forming sands of Unit 3.

sils. Skeletons and skeletal fragments of *Protoceratops andrewsi*, *Pinacosaurus grangeri*, *Velociraptor mongoliensis*, *Oviraptor philoceratops*, and *Saurornithoides mongoliensis* were collected from this unit. Our investigation was unable to distinguish two, lithologically distinct, structureless sandstone units bearing calcareous nodules at the base of the Flaming Cliffs section. Thus, Unit 1 of this study combines Beds 1 and 2 of Gradziński et al. (1969).

2. Well-cemented, reddish brown sandstones sometimes exhibiting large-scale crossbeds (Kcon), 5–7 m thick (fig. 3). Field investigations of the MAE in 1994–1995 documented that concretions in these deposits contain abundant remains of mammals, lizards, and other vertebrates. In 1964 the PMPE found a multituberculate cranium in situ (Gradziński et al., 1969, 1977). The remains of Cretaceous mammals and other small vertebrates are often derived from these sandstones at the base of the Flaming Cliffs scarp. Thus, Unit 2 of this study, which contains mammalian remains, is located above the dinosaur-bearing Unit 1 at

the base of the Flaming Cliffs sequence, and Unit 2 of this study is equivalent to Bed 3 of Gradziński et al. (1969).

3. Unbedded, moderate reddish orange sands with irregular sandstone concretions and calcareous nodules (Ks). This unit comprises about 12 m of structureless, cliff-forming, generally poorly consolidated sandstone (fig. 4). It is equivalent to Unit 4 of Gradziński et al. (1969).

4. Grayish white conglomerates with small rounded calcareous nodules and pebbles of crystalline rock at the base (fig. 5), fining upward into calcareous caliche at the top of the unit (Kcal). Unit 4 of this study equals Bed 5 of Gradziński et al., 1969).

5. Unconsolidated moderate reddish orange sands with small sandy irregular concretions (= Bed 6 of Gradziński et al., 1969). This unit was mapped as part of the Kcal complex on the Facies Map (map 2, pp. 12–13).

6. Light gray calcareous caliche conglomerate with caliche pebbles at base (fig. 5) (= Bed 7 of Gradziński et al., 1969). This unit

FLAMING CLIFFS

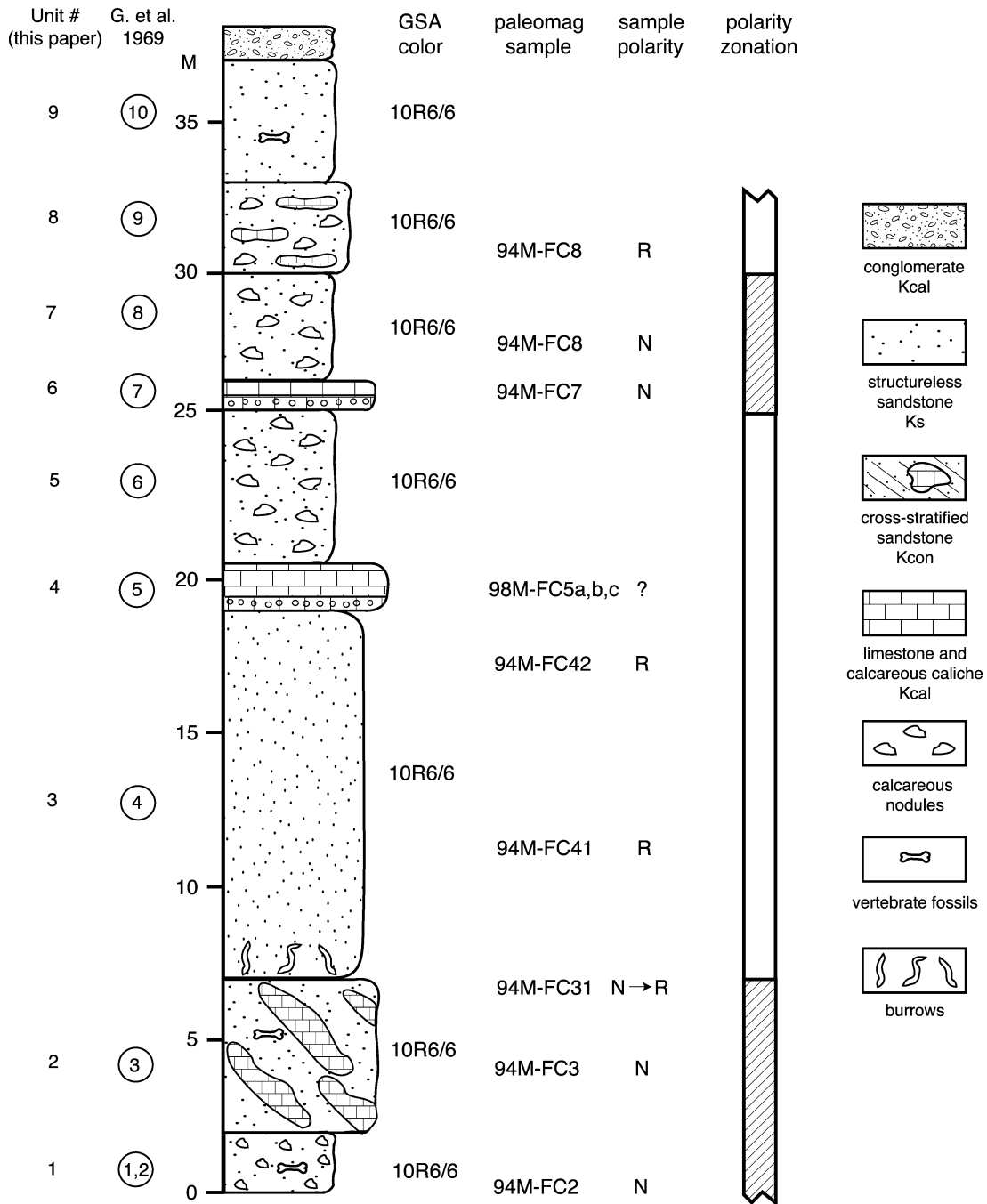


Fig. 2. Stratigraphic section at the Flaming Cliffs proper. Unit designations for this paper are at the far left. Unit designations for Gradziński et al. (1969) are to the immediate right. Colors are based on the GSA color chart. The position of the paleomagnetic samples is to the right of the section. The polarity of the samples is to the right of the sample number. The polarity zonation is at the far right.



Fig. 3. Resistant, reddish brown, concretionary sandstone of Unit 2 (Kcon) exposed to the east and near the base of the main escarpment of the Flaming Cliffs.

is mapped as part of the Kcal complex on map 2, pp. 12–13.

7. Moderate reddish orange, structureless sandstone with occasional irregular, rounded concretions (= Bed 8 of Gradziński et al., 1969). Thickness is 4 m. This unit is mapped as part of the Kcal complex on map 2, pp. 12–13.

8. Moderate reddish orange sands with rounded sandstone concretions (= Bed 9 of Gradziński et al., 1969). This unit is mapped as part of the Kcal complex on map 2, pp. 12–13.

9. Moderate reddish orange cemented sands and sandstone (= Bed 10 of Gradziński et al., 1969). In 1994 the MAE collected a skull of the lizard *Carusia intermedia* also known from the Cretaceous deposits of Khermin Tsav and Ukhua Tolgod from this unit, as well as *Chelonia* remains from this locality. This unit is mapped as part of the Kcal complex on map 2, pp. 12–13.

The upper part of the Bayn Dzak Member at the Flaming Cliffs has been eroded. Quaternary pediment sits atop the described section. The PMPE studied and described the

uppermost bed of the moderate reddish brown sequence of the Bayn Dzak Member located to the northwest of the Flaming Cliffs (Lefeld, 1971). See the subsequent description of Khren Tsav for details.

#### GEOLOGIC MAP OF MAJOR LITHOSTRATIGRAPHIC UNITS AT BAYN DZAK

Exposures of the Upper Cretaceous Djadokhta Formation are intermixed with those of Quaternary sediments across the northern two-thirds of the mapped region on map 1. The Djadokhta Formation represents the oldest rocks exposed in the mapped area. The Flaming Cliffs exposures of the Djadokhta Formation stand out in the northern quarter of the map as a southeast to northwest trending arc. To the south of the southeastern end of the Flaming Cliffs exposures, the Djadokhta Formation crops out at lower elevations near the bottom of the major drainage called Khatato Gol.

Overlying the Djadokhta Formation are sediments of the Paleocene Hashaat suite.





Fig. 4. Structureless, cliff-forming sandstone (Unit 3) exposed near the east end of the main escarpment of the Flaming Cliffs. Unit 4 can be seen on top of Unit 3.

These exposures rim those of the Djadokhta Formation in the central region of the mapped area on either side of the Khatato Gol.

Overlying the Hashaat suite are Eocene sediments. These are primarily exposed in the southernmost part of the mapped area, rimming the exposures of the Hashaat suite.

The youngest rocks in the mapped area consist of Quaternary alluvium, colluvium, and eolian sands. These are distributed throughout the mapped area.

#### FACIES MAP OF BAYN DZAK MEMBER AT BAYN DZAK WITH ENVIRONMENTAL INTERPRETATIONS

The Bayn Dzak Member at Bayn Dzak is composed of four different lithologic facies, shown on map 2, pp. 12–13. Very similar facies were recognized by Jerzykiewicz et al. (1993) and Eberth (1993) in exposures of the Djadokhta Formation at Bayan Mandahu in

northern China. Topographic and distance references are based on the topographic map for the Bayn Dzak area constructed by L. B. Roberts, F. B. Butler, and H. O. Robinson in 1925, which was printed in Gradziński et al. (1969: fig. 29). The four lithologic facies include the following:

1. Structureless sands, usually poorly consolidated and commonly containing irregular calcareous nodules, dominate Units 1 and 3 of this study. In situ dinosaur nests and skeletal remains are common in Unit 1. Calcareous nodules occurring as float on this unit occasionally contain fossils of mammals and lizards. Trace fossils, often mud filled, are common in unit 3. The fossils are identified as *Ophiomorpha* by Loope and Dingus (1999). These structureless sands are interpreted to represent fluvial deposits and are mapped as Ks. Other units of structureless sand are similar to the structureless sands described from Ukhaa Tolgod by Loope et al.



Fig. 5. View looking east at the western face of the main escarpment of the Flaming Cliffs, showing the two beds of light gray conglomerate (Units 4 and 6) near the top of the exposures.

(1998). There, the structureless units contain pebbles and cobbles floating in the sandy matrix that were much too large and heavy to be carried by the wind. This and the field relations of the structureless sand bodies, which were shingled in between cross-bedded sand bodies typical of eolian dunes, provided evidence that the structureless sands were deposited as sandslides at the base of the dunes (Dingus et al., in review). This interpretation differs from that of Eberth (1993), who interpreted structureless sandstone sheets at Bayan Mandahu to represent vertically aggrading, eolian sands that accumulated during very high energy wind storms, possibly in zibars.

Structureless sands that comprise Units 5, 7, 8, and 9 of the present study are more difficult to interpret environmentally. They are interbedded with caliche pebble conglomerates (see facies 3 below) that clearly represent a fluvial environment. At least one of the structureless sandstone units (#9) contains fossils of lizards and turtles. These

structureless sandstone units probably also represent fluvial deposits.

2. Concretionary sheets of sandstone forming large-scale crossbeds dominate Unit 2 of this study. These sheets consistently dip with an azimuth to the northeast at  $20^{\circ}$ – $30^{\circ}$ . Rare chunks of these concretionary layers contain in situ fossils of mammals. More commonly, nodules occurring as float on these outcrops contain fossils of mammals and lizards. Outcrops where these concretionary sheets dip with an azimuth to the northeast are interpreted to represent eolian crossbeds of Cretaceous dune deposits. These units are mapped as Kcon. Similar concretionary calcite underlying now buried dune lee slopes has recently been described from Quaternary eolian deposits in western China by Yang et al. (2003). Rhizoliths (calcite-replaced plant roots) are common within this facies. A similar facies, lacking rhizoliths, is present at Ukhaa Tolgod (E-2 facies of Dingus et al., in review).

3. Relatively thin beds of white calcareous

caliche containing basal pebbles of caliche and subordinate clasts of crystalline rock dominate Units 4 and 6 of this study. These units are unfossiliferous. They are interpreted to represent fining upward beds deposited by fluvial action. They are mapped as Kcal, and one can be traced across the Flaming Cliffs exposures for more than 1 km.

4. Beds of siltstone and mudstone, mapped as Km on map 2, occur as lenses interbedded with the structureless sands of facies Ks. These units are not laterally continuous for more than 100 m, and they are not fossiliferous. They are interpreted to represent fine-grained interdune units deposited in shallow ponds and depressions by fluvial action.

These facies can be mapped across the Bayn Dzak region, as was done using air photos taken in August of 1996. The facies are exposed on and to the north of a 7-km-long scarp that separates a plateau capped by Quaternary pediment to the south and a basin filled with Quaternary colluvium, alluvium, and eolian dune deposits to the north. The eastern leg of the scarp trends nearly east to west, beginning just west of the Khatato Gol and extending to the main exposures of the Flaming Cliffs. The western leg of the scarp trends more northwest and extends past the Ruino to the Volcano.

Most of the eastern leg of the scarp is formed by Ks. Isolated outcrops of Kcon protrude out of the Quaternary colluvium that forms the floor of the basin to the north of the scarp. Many of these outcrops are formed by concretionary sheets representing Unit 2. Fourteen attitudes were measured on these sheets. The azimuths of dip directions on these sheets interpreted as large-scale eolian crossbeds range from N 25°E to N 85°E. Near the top of the scarp, a prominent bed of Kcal can be traced along the western quarter of the eastern leg. It sits immediately on top of Unit 3, which represents the structureless sands that comprise most of the exposures that form the Flaming Cliffs proper.

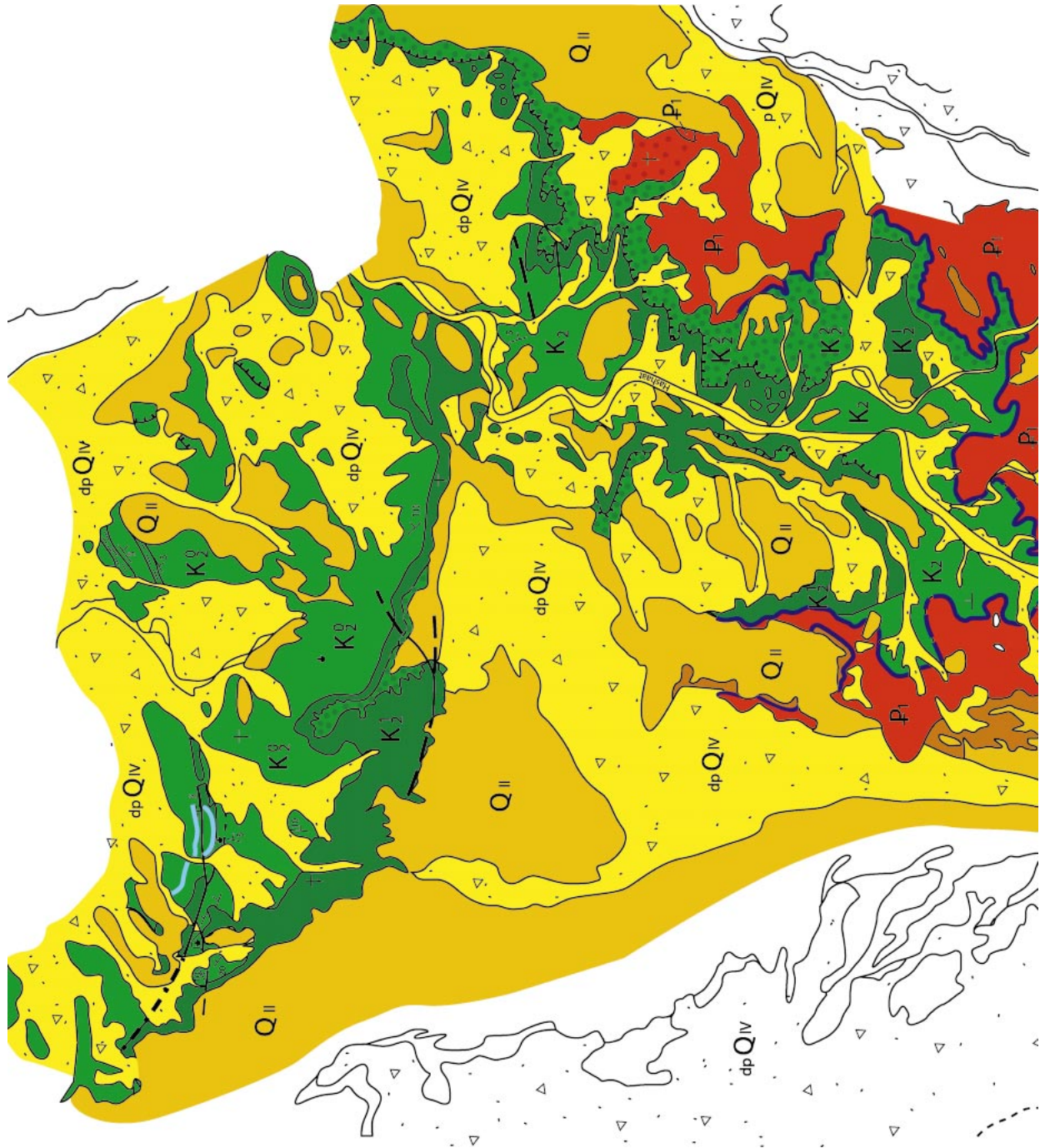
The Flaming Cliffs themselves, capped by Qp, jut northwest out from the plateau into the basin to the north. A small northeast-southwest trending fault cuts across the southern end of the Flaming Cliffs. Offset is between 1 m and 2 m, with the northwest block containing the Cliffs being down-

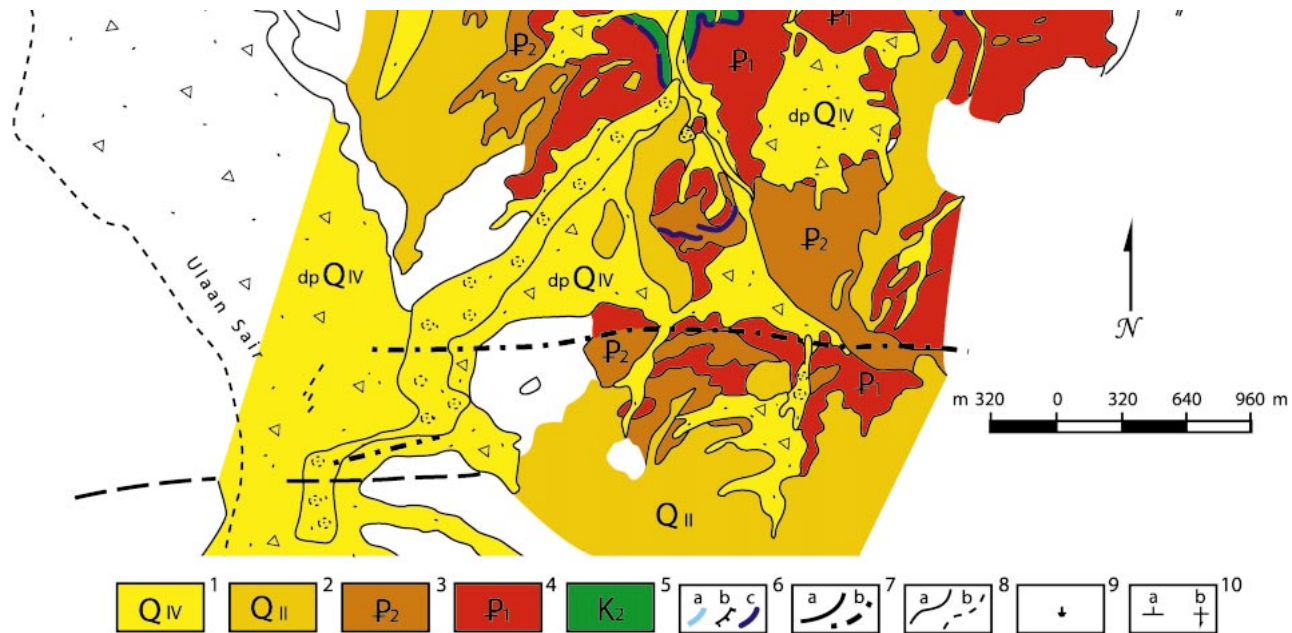
dropped in relation to the southeast block that forms the main plateau capped by Qp. Another small fault trending nearly east to west cuts across the northern end of the Cliffs. A remnant of the Cliffs exposures sits to the north of this fault. The base of the remnant is formed by Kcon of Unit 2, but the higher parts of the remnant are capped by Ks of Unit 3. The remnant appears to represent a block of the Flaming Cliffs exposure that has dropped 3–5 m along the fault in relation to the main units that form the extant Cliffs. The prominent Unit 4 of Kcal can be traced completely around the top of the main Cliffs exposures immediately on top of the prominent cliff-forming Ks of Unit 3. The Kcal of Unit 4 is extremely well cemented and resistant. It clearly protects the poorly consolidated sands of Unit 3 from more accelerated erosion and allowed the distinctive geomorphologic relief of the Flaming Cliffs to develop.

At the base of the northwest corner of the Flaming Cliffs lies a distinctive set of concretionary sandstone sheets composing Kcon of Unit 2. Ten attitudes recorded on these sheets reveal dip directions with azimuths ranging from S 6°E to N 10°E, with most attitudes between N 25°E and N 50°E. Again, these sheets are thought to represent large-scale eolian crossbeds.

A prominent northwest-southeast trending drainage lies immediately west of the main exposures of the Flaming Cliffs (fig. 5). In the exposures along the southwest side of the drainage, the prominent Kcal of Unit 4 can be traced for about 600 m to the northwest where it pinches out. In the southernmost exposures of the scarp along the southwest side of the drainage, isolated outcrops of Kcon appear to be shingled in between outcrops of Ks. Rhizoliths oriented parallel to the crossbedding are prominently preserved on the tops of the sheets (Loope and Dingus, 1999). This sequence represents one of the clearest examples of the field relations between the eolian crossbedded sheets of Kcon and the structureless sandslides of Ks exposed in the Bayn Dzak region. Six attitudes were recorded on the concretionary sheets in this area. The azimuths of dip directions range from N 20°E to N 35°E.

Just northwest of these exposures a small

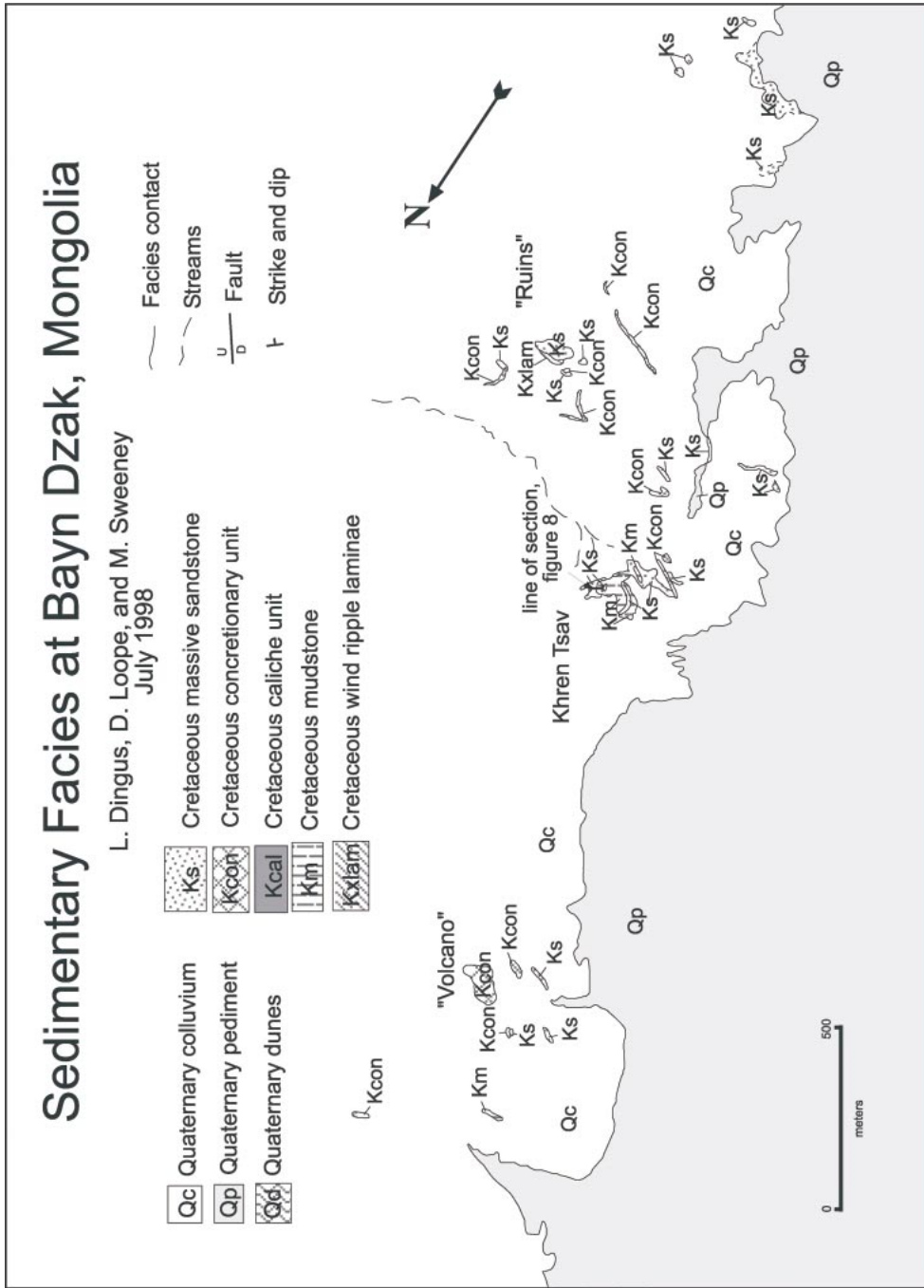




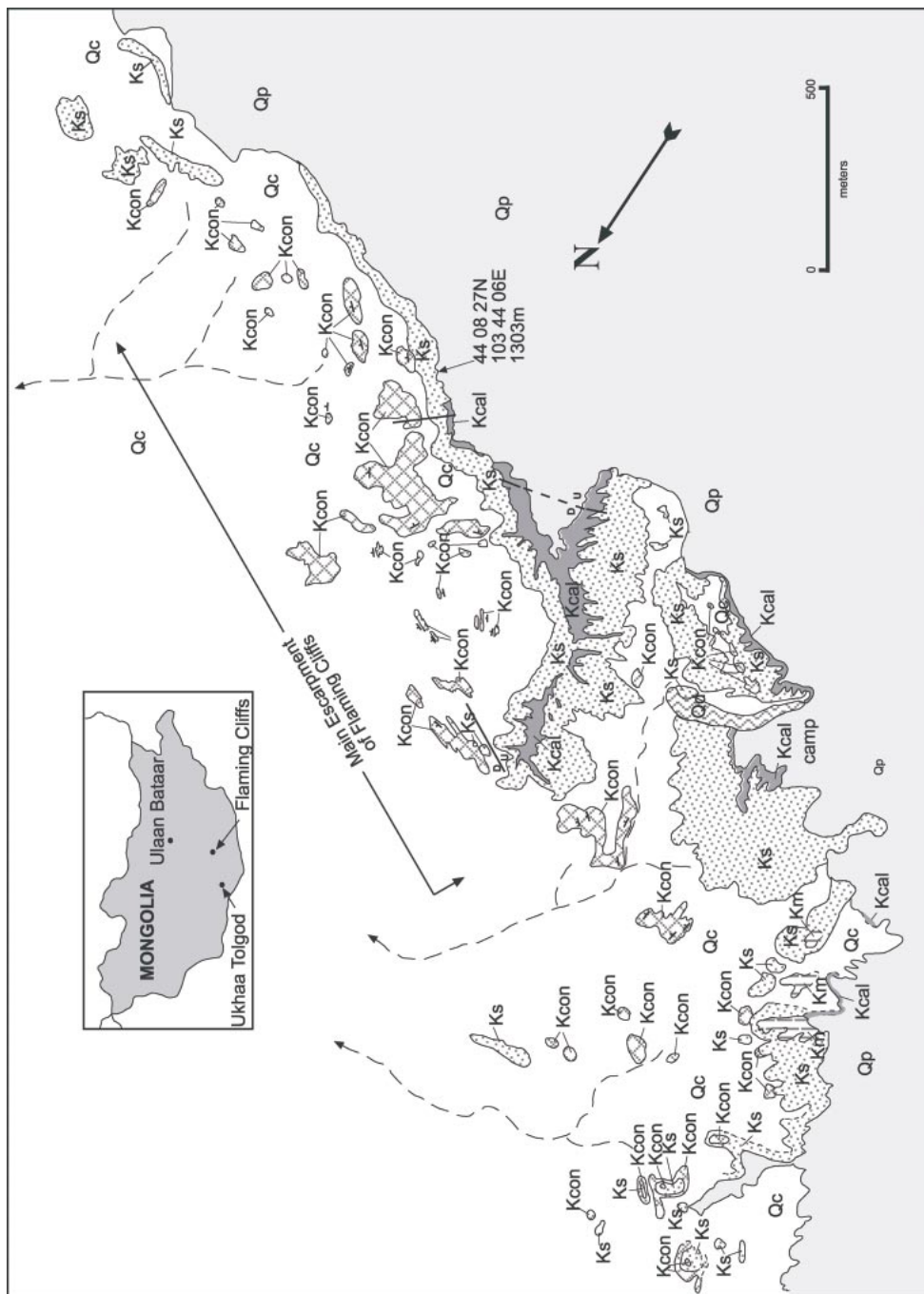
Map 1. Geologic map of major lithologic units at Bayn Dzak. Compiled by T. Dulam in July 1998.

1. Holocene eolian sands vQiv; deluvid sands dpQiv; lake clay and sand lQiv; proluvial sand and debris pQiv.
2. Pleistocene deluvial-prodeluvial sands and debris, partly with limy matrix.
3. Eocene; small grained shingles composed of less rounded and less sorted sands, and thin layers of white limy marl (1–2 cm).
4. Paleocene; Hashaat Suite: coarse-grained sands of brownish yellow, red, and greenish colors with thin layers of shingled red and reddish brown clay, and greenish gray aleurite, marl.
5. Upper Cretaceous; Bayn Dzak Member: K0/2 lightly colored sandstone, sand, K1/2 reddish, weakly lithified, small-medium-grained sand. In the lower part of the section, horizontally oriented sandstone nodules are common. K2/2 non-lithified red sands, rich with mud craters, footprints, and fewer sandstone nodules.
6. Reference horizons. a: white horizon with hard calcareous sandstone nodules. b: white conglomerates and layers of marl with reworked marl nodules. c: brecciated marl with lithic fragments.
7. Faults: a: known; b: inferred.
8. Geologic boundaries: a: clear; b: unclear.
9. Points of observation of fossil bone.
10. Orientation of bedrock: a: inclined; b: horizontal.

The entire undivided map may be printed from the AMNH library catalog at <http://library.amnh.org/pubs>.



Map 2. Facies map of Bayn Dzak Member at Bayn Dzak. The map has been divided into two halves. The left half (this page) represents the northwest portion of the study area, which extends from the Volcano to the Ruins.



Map 2. Continued. The right half (this page) represents the southeast portion, which includes the Main Escarpment of the Flaming Cliffs. The line of section for fig. 2 is plotted just northwest of 44 08 27 N, 103 44 06 E. The entire undivided map may be printed from the AMNH library catalog at <http://library.amnh.org/pubs>. The map was compiled by L. Dingus, D. Loope, and M. Sweeney in July 1998.



Fig. 6. View looking east from the western rim of the basin at Bayn Dzak at exposures of the Ruins.

northeast–southwest trending drainage is flanked on the northwest by a large modern sand dune (Qd). Our camp usually occupies the point on the Qp-capped plateau just northwest of this dune.

From our camp, the scarp trends more northwest toward the Ruins and the Volcano. About 750 m northwest of camp, three distinctive mudstone units are exposed in the lower portion of the scarp. They crop out as laterally discontinuous lenses and represent small interdune deposits interbedded with structureless sands of Unit 3 that lie above the concretionary sheets of Unit 2.

Two kilometers northwest of the Flaming Cliffs lies the prominent scarp remnant named the Ruins by the PMPE (fig. 6), which provided skeletons of the long-necked crocodile, *Gobiosuchus kielanae* (Osmólska, 1972). An exposure of wind-rippled, cross-laminated sand occurs on the northern side of the remnant. Concretionary sheets of sandstone, presumably representing Unit 2, lie at the base of the remnant. The Ruins are

capped by structureless sands (Ks) containing occasional dinosaur skeletons and abundant trace fossils. Presumably these sands represent Unit 3.

About 700 m northwest of the Ruins lie the exposures of Khren Tsav (fig. 7). The section exposed here (fig. 8) is quite significant. The basal 10 m are composed of moderate reddish orange, structureless sandstone (Ks), probably representing Unit 3 exposed at the Flaming cliffs. Vertebrate fossils, including a skull and skeletal fragments of *Zalambdalestes*, were collected in situ. Trace fossils of *Ophiomorpha* are also abundant. In the main hill at the site, the structureless sands, probably representing fluvial deposits, are immediately overlain by 5 m of orangish brown mudstone (Km), representing fluvial pond deposition. The sequence is capped by 2–3 m of moderate reddish orange structureless sand. However, just west of the main hill, at the stratigraphic level of the mudstone, concretionary sheets of sandstone (Kcon) crop out. Four attitudes representing





Fig. 7. View looking west at the exposures of Khren Tsav showing the prominent unit of brown mudstone interpreted to represent interdune deposition by fluvial processes in ephemeral lakes or ponds.

dip directions on these sheets range from azimuths of N 18°E to N 30°E. The contact between these units is either eroded or not exposed. However, three environmental facies appear to be represented in close lateral proximity: eolian dune deposits represented by the crossbedded concretionary sheets, fluvial sands represented by the structureless and fossiliferous sandstone, and interdune fluvial pond deposits represented by the mudstone.

Almost 2 km further northwest of the Ruins lies the locality named the Volcano by the PMPE. Most of the conical remnant of the scarp is covered by colluvium; however, a few outcrops are exposed. A couple of patches of structureless concretionary sandstone lie at the base. Nodules in these massive concretions contain fossils of lizards, crocodiles, dinosaurs, and mammals. Above near the peak, a small patch of concretionary sandstone is overlain by a small outcrop of structureless sandstone containing abundant rhizoliths—among the best examples in the Bayn Dzak area. It is unclear how these outcrops correlate with exposures to the southeast because of extensive intervening covered areas.

#### STRATIGRAPHIC POSITION OF MAMMALIAN FOSSILS IN THE BAYN DZAK MEMBER

In 1924 and 1925 the CAE discovered Cretaceous fossils of mammals and small dinosaurs at the Flaming Cliffs. However, neither the geographic position of the mammalian locality nor the stratigraphic position of the fossiliferous units in the Flaming Cliffs section were precisely reported (Efremov, 1954). The fossils were merely reported to have been found in small concretions. The mammalian fossils described from the formation are the following.

During fieldwork by the MPE, Novojilov (1954) studied the stratigraphic position of mammalian fossils from Bayn Dzak. He suggested that the Cretaceous mammalian fauna was derived from a concretionary bed in the formation below the Paleocene fossiliferous exposures to the southeast discovered by the CAE called Hashaat.

Geological investigations at Bayn Dzak were pursued in greater detail by the PMPE (Gradziński et al., 1969, 1977; Lefeld, 1965, 1971). The PMPE confirmed the occurrences of Cretaceous deposits of the Djadokhta Formation. Fossils were reported from three lo-

TABLE 1  
The Bayn Dzak Fauna

---

|   |
|---|
| <b>Reptilia</b>   |
| Chelonia indet. Gilmore, 1931                                 |
| Squamata  |
| Iguania   |
| <i>Isodontosaurus gracilis</i> Gilmore, 1943                  |
| <i>Mimeosaurus crassus</i> Gilmore, 1943                      |
| <i>Priscagama gobiensis</i> Borsuk-Bialynicka and Moody, 1984 |
| Scincomopha   |
| Teiidae   |
| <i>Macrocephalosaurus ferrugenous</i> Gilmore, 1943           |
| <i>Adamisaurus magnidentatus</i> Sulimski, 1972               |
| Incertae sedis  |
| <i>Conicodontosaurus djadochtaensis</i> Gilmore, 1943         |
| <i>Globaura venusta</i> Borsuk-Bialynicka, 1988               |
| <i>Slavoia darevskyi</i> Sulimski, 1984                       |
| Anguimorpha   |
| <i>Telmasaurus grangeri</i> Gilmore, 1943                     |
| <i>Carusia intermedia</i> Borsuk-Bialynicka, 1985             |
| <i>Bainguis parvus</i> Borsuk-Bialynicka, 1984                |
| <i>Estesia mongoliensis</i> Norell et al., 1992               |
| Gekkota   |
| Gekkonidae  |
| <i>Gobekko cretacicus</i> Borsuk-Bialynicka, 1990             |
| Archosauria   |
| Crocodyliformes   |
| Giobiosuchidae  |
| <i>Gobiosuchus kielanae</i> Osmolska, 1972                    |
| Paralligatoridae  |
| <i>Shamosuchus djadochtaensis</i> Mook, 1924                  |
| Dinosauria  |
| Saurischia  |
| Theropoda   |
| Dromaeosauridae   |
| <i>Velociraptor mongoliensis</i> Osborn, 1924                 |
| Troodontidae  |
| <i>Saurornithoides mongoliensis</i> Osborn, 1924              |
| Oviraptoridae   |
| <i>Oviraptor mongoliensis</i> Osborn, 1924                    |
| Avialae   |
| Mononykinae indet.  |

---

TABLE 1  
(Continued)

---

|  |
|--|
| Ornithischia   |
| Ankylosauria   |
| Ankylosauridae   |
| <i>Pinacosaurus grangeri</i> Gilmore, 1933                         |
| Neoceratopsia  |
| Protoceratopsidae  |
| <i>Protoceratops andrewsi</i> Granger and Gregory, 1923            |
| <i>Bainoceratops efremovi</i> Terschenko and Alifanov, 2003        |
| <b>Mammalia</b>  |
| Multituberculata   |
| Djadochtatherioidea  |
| Sloanbaataridae  |
| <i>Sloanbaatar mariabilis</i> Kielan-Jaworowska, 1970              |
| Djadochtatheriidae   |
| <i>Djadochtatherium matthewi</i> , Simpson, 1925                   |
| <i>Kryptobaatar dashzevegi</i> Kielan-Jaworowska, 1970             |
| <i>Catopsbaatar catopsaloides</i> Kielan-Jaworowska, 1974          |
| Incertae sedis   |
| <i>Kamptobaatar kuczynskii</i> Kielan-Jaworowska, 1970             |
| <i>Bulganbaatar memegbaataroides</i> Kielan-Jaworowska, 1974       |
| Eutheria incertae sedis  |
| Asioryctitheria  |
| Asioryctidae   |
| <i>Kennalestes gobiensis</i> Kielan-Jaworowska, 1969               |
| Zalambdalestidae   |
| <i>Zalambdalestes lechei</i> Gregory and Simpson, 1926             |
| Metatheria   |
| Deltatheroidea   |
| Deltatheriidae   |
| <i>Deltatheroides cretacicus</i> Gregory and Simpson, 1926         |
| <i>Deltatheridium praetribuberculate</i> Gregory and Simpson, 1926 |
| Theria incertae sedis  |
| <i>Hyotherium dobsoni</i> Gregory and Simpson, 1926                |

---

calities: (1) the Main Mammal Field, along the eastern margin at the base of the Flaming Cliffs; (2) the Ruins, about 2400 m to the northwest of the Flaming Cliffs; and (3) the Volcano, about 2 km to the north of the Ruins, where the lower Kcon nodules produced remains of mammals and other vertebrates. According to Polish accounts (Kielan-Jaworowska, 1969, 1970; Gradziński et al., 1977) these three localities yielded numerous skulls and jaws of mammals as well as abundant fossil remains of lizards, crocodiles, and other vertebrates. Several mammal specimens have been found in situ in all three above mentioned localities. So, restriction of the mammalian fossils to the Upper Cretaceous Djadokhta Formation was definitely established.

In 1991–1992, 1994–1996, and 1998 the Bayn Dzak locality was reinvestigated by the MAE, which made collections of the Cretaceous remains from the three PMPE localities (above), as well as from two new localities in the Bayn Dzak region. (1) A cranium and associated skeletal fragments of *Zalambdalestes* were collected from the basal, moderate reddish orange sands of the Khren Tsav section. (2) The cranium and jaws of placental mammals were found in the moderate reddish orange sandstones of Unit 5 along the scarp near the Flaming Cliffs. In 1971, a multituberculate cranium was also collected there by Dashzeveg.

#### BIOCHRONOLOGIC INTERPRETATIONS FOR THE BAYN DZAK FAUNA

The known vertebrate fauna from the Bayn Dzak Member is listed in table 1. Relatively recent studies discussing the lizard faunas from this area include Sulimski (1975), Borsuk-Bialynicka (1984, 1991a, 1991b), Gao and Norell (2000), and Alifanov (2000). Relatively recent references for the area's archosaurian fauna include Maryńska (1971, 1977), Osmólska (1972, 1976), Maryńska and Osmólska (1975), Norell et al. (1994), Chiappe et al. (1998), and Benton et al. (2000). Relatively recent papers concerning the mammalian fauna for the area include Kielan-Jaworowska (1970, 1975, 1984), Kielan-Jaworowska and Hurum (1997, 2001),

Kielan-Jaworowska et al. (2000), Novacek et al. (1997), Rougier et al. (1977, 1996, 1998), Smith et al. (2001), and Wible and Rougier (2000). Recent studies focusing on dinosaur and other fossil eggs from the area include Mikhailov (1994, 1995, 1996), Mikhailov et al. (1994), Sabath (1991), and Norell et al. (1994).

There are no radioisotopic dates from beds in the sequence that produce the Bayn Dzak fauna. According to different authors, its age has been reported to range from Cenomanian to Early Maastrichtian. Berkey and Morris (1927) placed it in the early Late Cretaceous. Polish authors variously assigned it to a range between the Coniacian and the Santonian (Gradziński et al., 1969; Kielan-Jaworowska, 1969, 1970, 1974; Kielan-Jaworowska and Dovchin, 1969; Lefeld, 1965, 1971). McKenna (1969) suggested a Cenomanian age. Rozhdestvensky, in his study of Mongolian dinosaurs (1971), inferred the probable age of the fauna to be late Santonian or possibly early Campanian. Fox (1978) suggested a Campanian age based on comparisons between Mongolian, American, and Canadian dinosaurs from the Late Cretaceous. Lillegraven and McKenna (1986) considered the Bayn Dzak fauna to be of Campanian-Early Maastrichtian age. Jerzykiewicz et al. (1993) and Eberth (1993) assign a Campanian age to the Djadokhta faunas from both Bayan Mandahu and Bayn Dzak. Most recently, Averianov (1997) tentatively agreed with Gradziński et al. (1977) that the fauna from the Djadokhta Formation is early Campanian in age, based on comparisons of mammalian and marine taxa from the Darbasa Formation of Kazakhstan. So, although most recent workers have assigned a Campanian age to the fauna from the Djadokhta, there has historically been little consensus among biochronologic age estimates and no evidence independent of faunal comparisons.

#### MAGNETOSTRATIGRAPHY OF THE BAYN DZAK MEMBER

Magnetostratigraphic samples were collected for analysis from both the Flaming Cliffs and Khren Tsav sections (figs. 2, 8). A more detailed account of all the magneto-

stratigraphic data for localities discussed in this paper is being prepared for a separate publication. The results are as follows.

At the Flaming Cliffs, Units 1 and 2 at the base of the section described here occur in a zone of normal polarity. Above, Unit 3, which comprises the principal cliff-forming sandstone, is reversed. The polarities of Units 4 and 5 are presently undetermined. Units 6 and 7 are of normal polarity, and the top of the section represented by Unit 8 is reversed.

At Khren Tsav (fig. 8) two samples in the lower structureless sandstone are reversed, suggesting but not establishing a correlation to Unit 3 of the Flaming Cliffs section. One sample in the overlying mudstone is also reversed (M. C. McKenna, personal commun.). One sample from the uppermost sandstone unit is also questionably reversed.

#### MAGNETOSTRATIGRAPHIC IMPLICATIONS FOR THE AGE OF THE BAYN DZAK FAUNA

The presence of reversed magnetozones in both the Flaming Cliffs and Khren Tsav sections means that most of these units must be younger than Chron 34n—the upper boundary of which represents the boundary between the Santonian and the Campanian at about 83.5 Ma (Gradstein et al., 1995). The quick stratigraphic succession of normal and reversed magnetozones in the Flaming Cliffs section suggests that the sediments were deposited during the rapid sequence of polarity changes in the late part of the Campanian incorporating the end of Chron 33 and Chron 32 between about 75 and 71 Ma (Gradstein et al., 1995). However, this tentative correlation to the Geomagnetic Polarity Timescale cannot yet be certainly established.

#### TRANSITIONAL DEPOSITS BETWEEN THE BAYN DZAK AND TUGRUGYIN MEMBERS

Investigations by international paleontologic expeditions, which were conducted during the past 40 years, have greatly enhanced our knowledge of Cretaceous vertebrates from the Bayn Dzak and Tugrugyin Shireh localities. It was discovered that, although color differences characterize the

Bayn Dzak and Tugrugyin Members, these two localities produce many of the same dinosaur and mammal taxa, including *Protoceratops andrewsi*, *Saurornithoides mongoliensis*, *Oviraptor philoceratops*, *Kryptobaatar dashzevegi*, and *Zalambdalestes leichei*. The principal difficulty in establishing the geochronological succession between the Bayn Dzak and Tugrugyin deposits was the lack of sections containing transitional beds that document their superpositional relationships. In 1993–1996, the MAE investigated two such key sections.

*The Tsonzh section.* Dashzeveg discovered this section in 1984, about 10 km to the southeast of the Flaming Cliffs. The low scarps at Tsonzh face north and pass upward into an inclined plateau that extends to the south (fig. 9A). Both the Bayn Dzak and Tugrugyin Members are exposed at Tsonzh, along with interbedded transitional lenses of mudstone (fig. 10). The lower Bayn Dzak Member is represented by well-sorted, moderate reddish orange sands. A tooth of *Protoceratops andrewsi* was found by Dashzeveg near the middle of this unit. Transitional beds are represented by lenses of compact brown mudstone, which rests in some places on the eroded underlying Bayn Dzak Member. The overlying Tugrugyin Member is represented primarily by yellowish gray to very light gray sands and sandstones (fig. 9). The transitional clay lenses are wedged into the sands of the Tugrugyin Member in some places. In 1993, the MAE collected scattered remains of a large theropod in the Tugrugyin Member. A paleomagnetic sample taken from the transitional reddish brown clay is reversed in polarity (M. C. McKenna, personal commun.)

*The Alag Teer section.* Dashzeveg discovered the Alag Teer (= Alag Teeg of Benton, 2000) section in 1964 (fig. 11). It lies 3.5 km from the main eastern scarp of Tugrugyin Shireh. The succession of beds is recorded in figure 12, and includes moderate reddish brown sandy siltstone at the base, overlain by interbedded moderate reddish orange sandstone and very pale orange sandstone. Above these lies yellowish gray sandy siltstone and interbedded moderated reddish orange sandstone and very pale orange sand-

### Khren Tsav

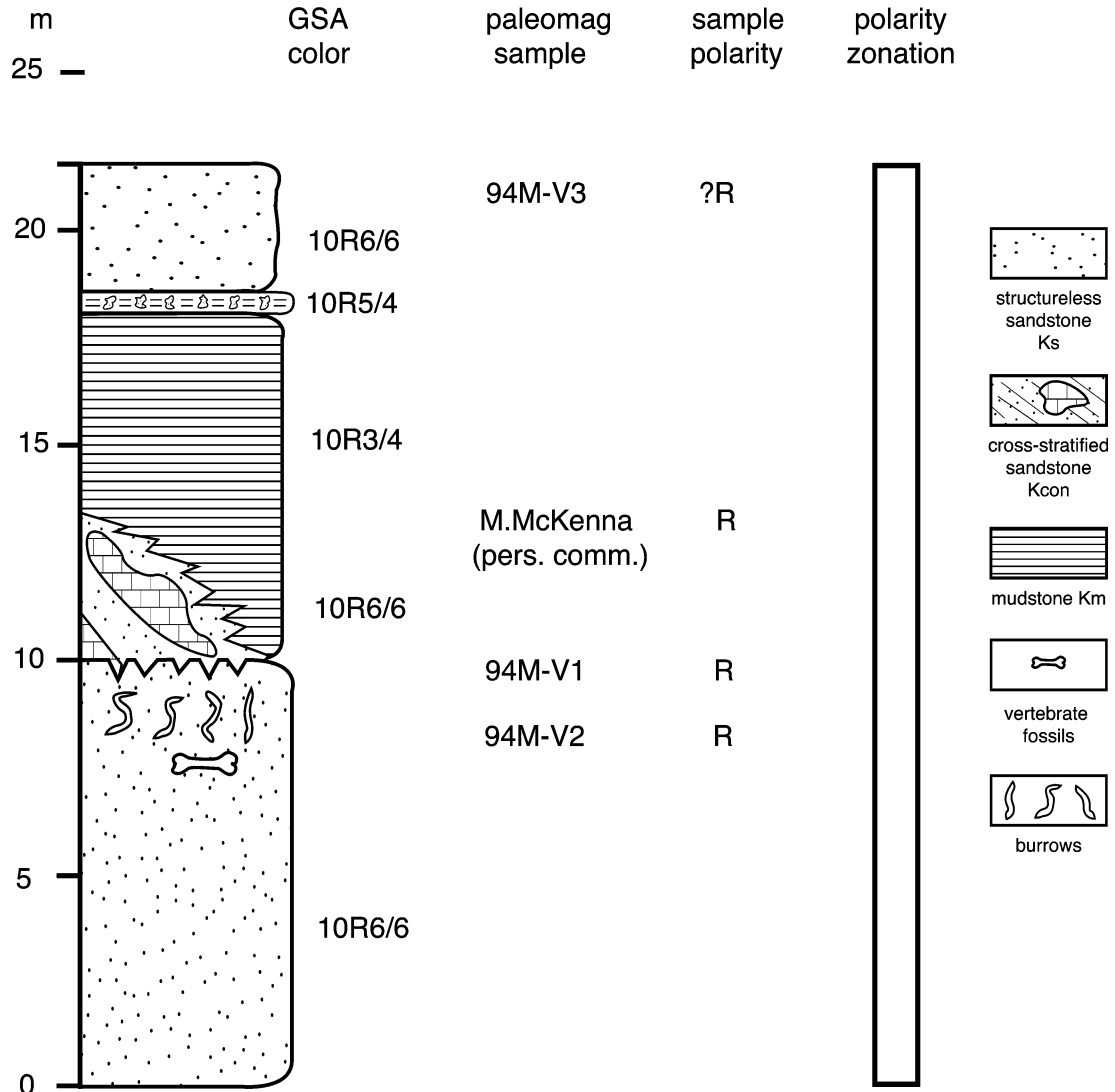


Fig. 8. Stratigraphic section at Khren Tsav. Paleomagnetic samples are listed to the right of the section. The lithologic key is on the right. The polarity of samples is listed to the right of the sample numbers.

stone. Very pale orange sandstone caps the section.

Like Tsonzh, this section is noteworthy for demonstrating the superpositional relationship between moderate reddish orange sandstones and moderate reddish brown mud-

stone typical of the Bayn Dzak Member in the lower portion of the section and very pale orange sandstones typical of the Tugrugyin Member in the higher portion. The interplay between units typical of Bayn Dzak and Tugrugyin lithology, as well as the fact that typ-

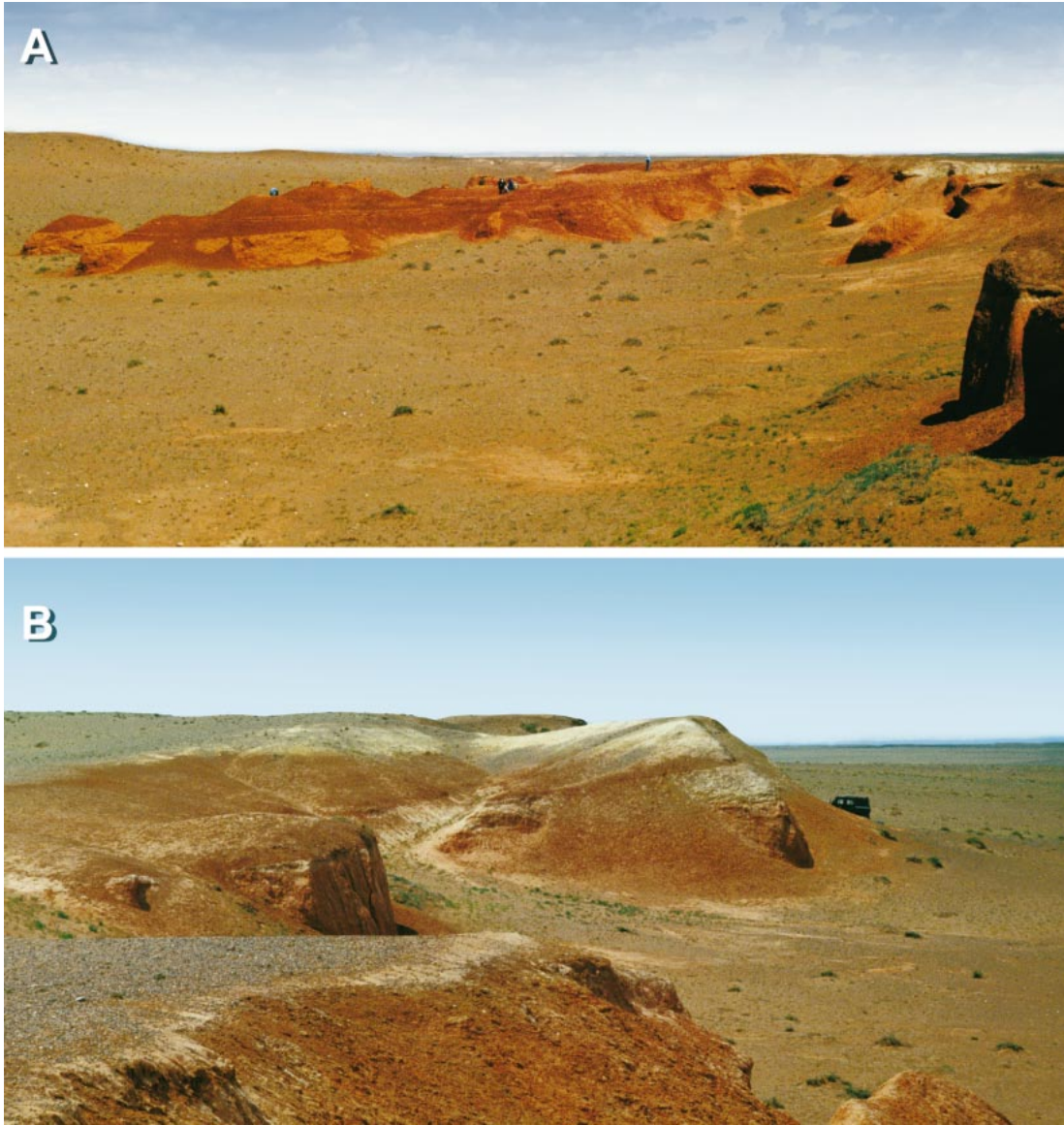


Fig. 9. **A.** Overview looking east at the eastern exposures of Tsonzh showing brown mudstone, similar to that exposed near the top of the section at Khren Tsav, wedged between underlying, structureless, reddish orange sandstone of the Bayn Dzak Member and overlying pale orange to light gray sandstone of the Tugrugyin Member. **B.** View looking west at the western exposures at Tsonzh showing reddish orange sandstone of the Bayn Dzak Member underlying pale orange to light gray sandstone of the Tugrugyin Member.

ical Bayn Dzak units underlie the typical Tugrugyin units as at Tsonzh, suggest that this sequence documents a transition between the Bayn Dzak and Tugrugyin Members. Unit 5 at Aleg Teer represents the base of the typical Tugrugyin sands exposed in the main

scarp at Tugrugyin Shireh (see next section). So, the Alag Teer section is a direct lateral extension of the deposits at Tugrugyin Shireh; however, the stratigraphically lower transitional units exposed at Alag Teer are not exposed at Tugrugyin Shireh.

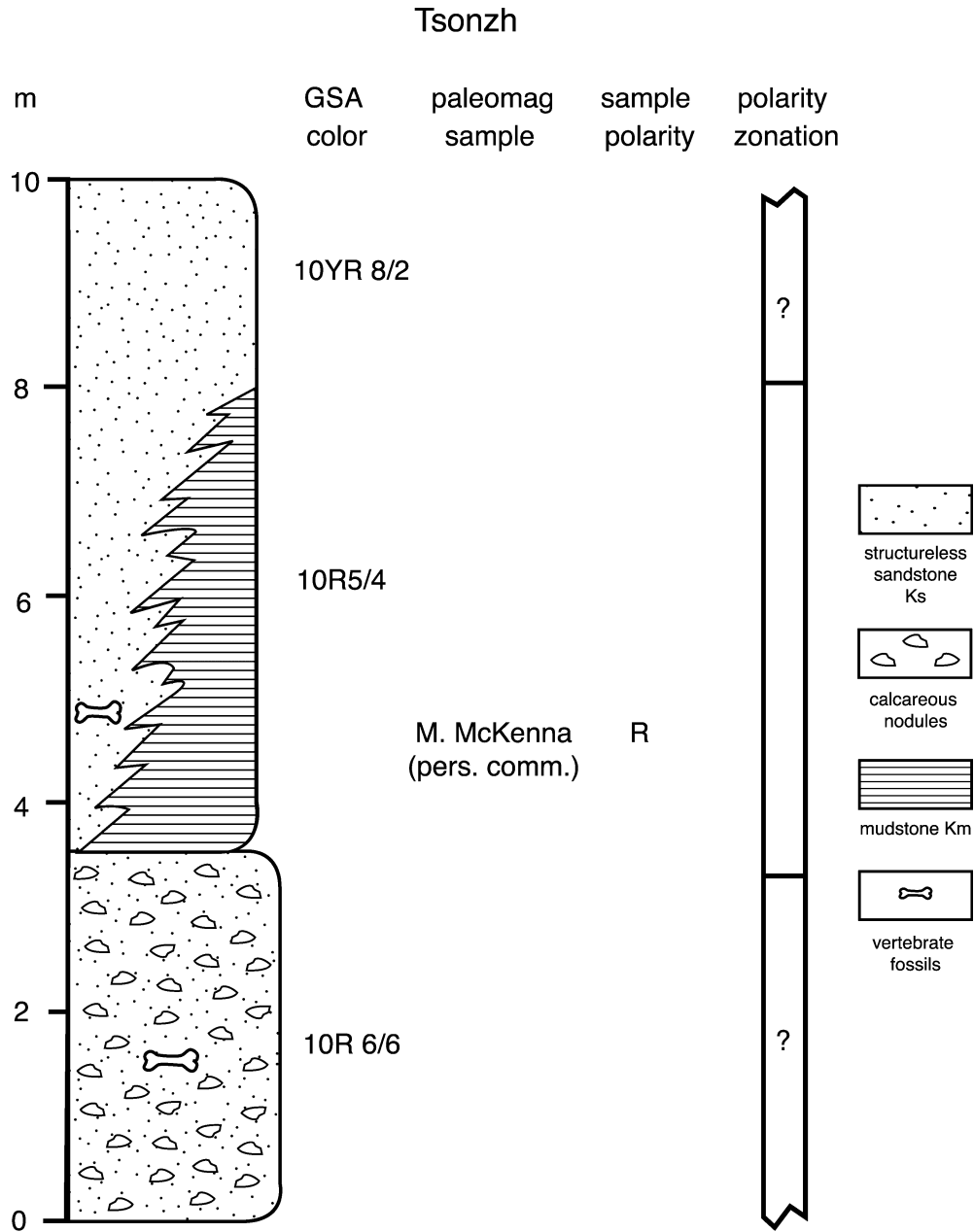


Fig. 10. Stratigraphic section at Tsonzh. The lithologic key is to the right of the magnetostratigraphic data.

Dinosaurs from Aleg Teer are restricted to Unit 2, which contains the alternation of Bayn Dzak and Tugrugyin sandstones. Fossils of hadrosaurs and *Pinacosaurus* were found in the Tugrugyin sands in the main exposure at Alag Teer (Fastovsky et al., 1997; Watabe and

Suzuki, 2000). Plant remains occur commonly in the reddish brown mudstones.

Four magnetostratigraphic samples were collected and analyzed (fig. 12). The fact that the sandy siltstones at the base of the Aleg Teer section are of normal polarity indicates



Fig. 11. View looking south at the exposures at Aleg Teer, just north of the exposures at Tugrugyin Shireh, showing reddish orange sandstone of the Bayn Dzak Member underlying pale orange to light gray sandstone of the Tugrugyin Member, identical to the superpositional relationships seen at Tsonzh.

that they formed at a different time than the transitional mudstones of reversed polarity at Khren Tsav and Tsonzh to the east.

#### THE TUGRUGYIN MEMBER

The key stratigraphic section is exposed at the Tugrugyin Shireh locality, 23 km to the northwest of the administrative center at Bulgan. The section was discovered by Dashzeveg in 1963. Two years later, Nikoloff and Dashzeveg revisited it (Nikoloff and Huene, 1966). The Tugrugyin Shireh locality is a scarp about 2.5 km long capped by a plateau of Quaternary pediment (fig. 13A,B). The exposures of the scarp are monotonous light gray sands and sandstones. The Tugrugyin Shireh scarp faces south, and the plateau is inclined to the north.

The locality was investigated by the PMPE and by the SMPE in 1969–1974 (Belyaeva et al., 1974). This locality produced the interlocked specimens of *Velociraptor* and *Protoceratops* referred to as the “fighting dinosaurs” (Kielan-Jaworowska and Barsbold, 1972; Osmólska, 1993). Most re-

cently, the locality was reviewed by Fastovsky et al. (1997) and results of the JMJPE are summarized in Watabe and Suzuki (2000). The lizard fauna, in particular, was reviewed by Gao and Norell (2000), and the anatomy of a dromaeosaurid skeleton was described by Norell and Makovicky (1997).

Fastovsky et al. (1997) document three stratigraphic sections across the scarp totaling 30 m. The sandstones of the Tugrugyin Member are described as thickly bedded, with large-scale, high-angle crossbeds distinctive of eolian dune slip faces. The crossbeds dip with an azimuth to the east-northeast, indicating predominantly westerly winds in the region during the Cretaceous. Three types of trace fossils are described and attributed to burrowing, probably by arthropods. Articulated skeletons of *Protoceratops* are common and often oriented parallel to the east-northeast dip direction of the crossbeds. Fastovsky et al. (1997) attribute their death to both sandstorms and less dramatic causes. The paleoenvironment is thought to represent a distal, basinward setting on a nearby braid-



Alag Teer

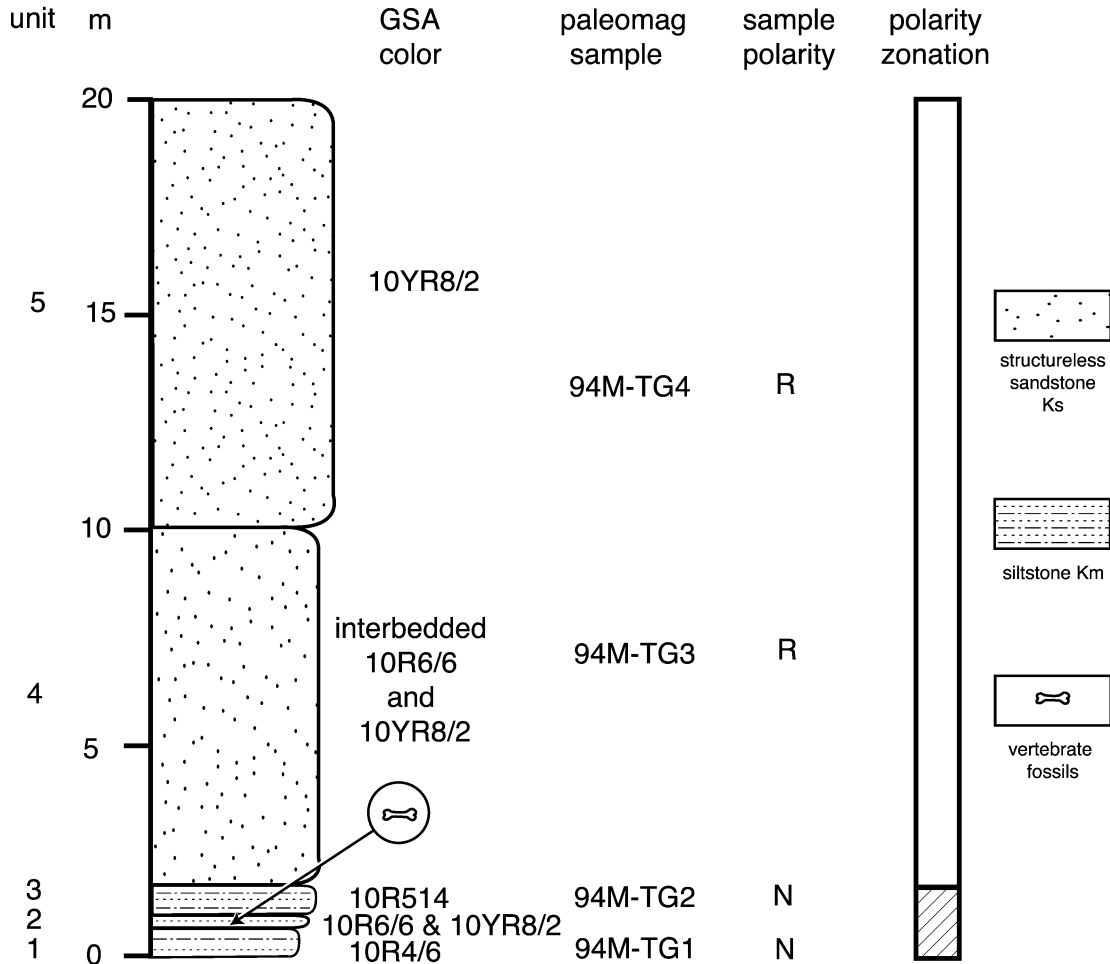


Fig. 12. Stratigraphic section at Alag Teer. The lithologic key is to the right. Unit numbers of this paper are listed to the far left of the section. Colors are based on the GSA color chart. The position of samples is listed to the immediate right of the colors. The polarity of samples is shown to the right of the sample numbers. Polarity zonation is at the far right.

plain-to-eolian suite of depositional environments. This paleoenvironmental interpretation is in accordance with that suggested for Djadokhta Formation exposures at Bayan Mandahu in northern China studied by Eberth (1993).

THE TUGRUGYIN SHIREH SECTION

Our section documents 52 m of light gray, crossbedded, and structureless sands and

sandstones belonging to the Tugrugyin Member at Tugrugyin Shireh (fig. 14). Crossbedded units are rich in trace fossils, as noted by Fastovsky et al. (1997). Crossbeds are defined by thin concretionary sheets composed of iron oxide-cemented carbonate. Crossbedded units are laterally traceable for less than several hundred meters. They are interbedded and laterally pass into massive units of structureless sands and sandstones.

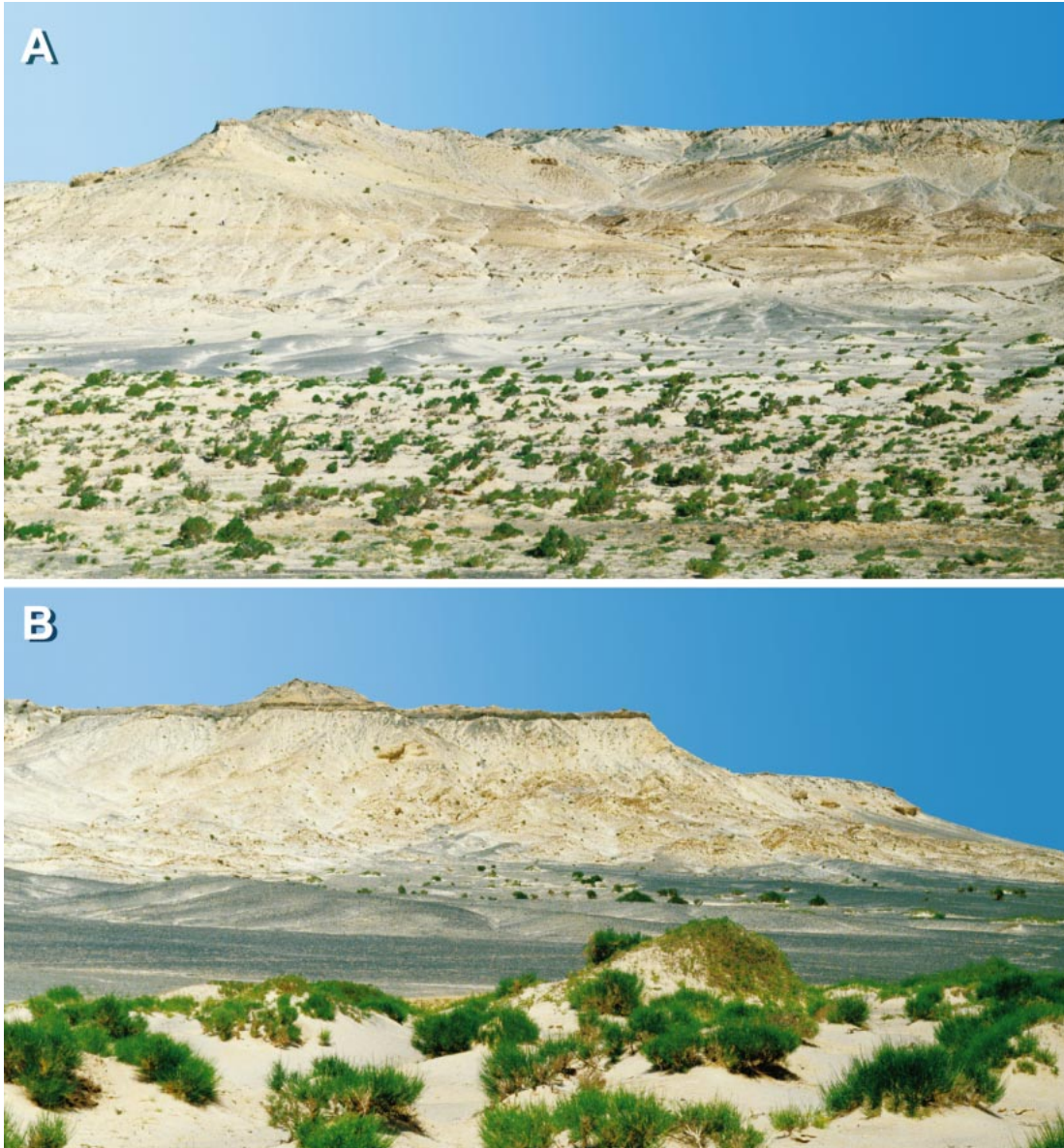


Fig. 13. **A.** View looking northwest at the western end of the main escarpment at Tugrugyin Shireh showing exposures of the Tugrugyin Member. **B.** View looking east at the eastern end of the main escarpment at Tugrugyin Shireh showing exposures of the Tugrugyin Member.

No facies map of the small-scale units at Tugrugyin Shireh is yet available; however, some preliminary observations can be noted as a basis for further testing during upcoming field investigations. Two distinct sedimentologic facies appear to be represented by the crossbedded sands and the structureless

sands. We agree with Fastovsky et al. (1997) that the crossbedded sands represent sediment deposited by eolian processes on the lee faces of dunes. The massive structureless sands, however, exhibit no definitive sedimentary structures typical of eolian deposits. Instead, these could represent dune-derived

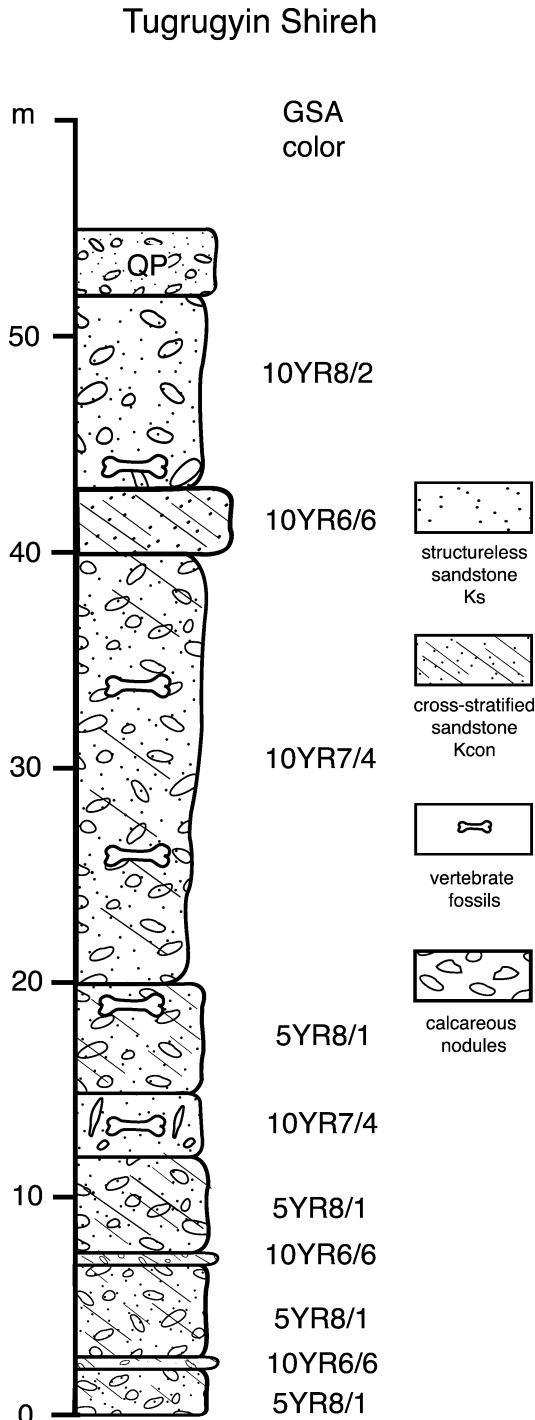


Fig. 14. Stratigraphic section at Tugrugyin Shireh. The lithologic key is to the right. The colors are based on the GSA color chart.

sandslides generated on the lee faces of eolian dunes.

The known vertebrate fauna collected at Tugrugyin Shireh is listed in table 2. At least most of the large vertebrate skeletons and smaller fossils contained in irregular iron carbonate nodules are found in the structureless sands and sandstones, as at Ukhaa Tolgod. Vertebrate fossils collected by the MAE include *Protoceratops andrewsi*, *Velociraptor mongoliensis*, *Shuvuuia deserti*, *Zalambdalestes leichei*, *Kryptobaatar dashzevegi* (Rougier et al., 1996), and abundant lizard fossils (Gao and Norell, 2000).

### GEOLOGIC MAP OF MAJOR LITHOSTRATIGRAPHIC UNITS AT TUGRUGYIN SHIREH

The oldest rocks in the mapped area consist of Late Cretaceous sands, primarily representing the Tugrugyin Member of the Djadokhta Formation with subordinate outcrops of the Bayn Dzak Member (map 3). They are exposed throughout the northern half of the mapped region in discontinuous patches, some of which contain outcrops of the moderate reddish orange sandstone of the Bayn Dzak Member at Aleg Teer. However in the southern half of the mapped area, sandstones of the Tugrugyin Member form a prominent arc beginning in the southwest corner that extends first to the east before turning north along the eastern edge of the map. The main escarpment of Tugrugyin Shireh forms the southernmost leg of this arc.

Overlying the Djadokhta Formation is a mixture of Quaternary alluvium, colluvium, and eolian sands. These are exposed throughout the mapped region.

### BIOCHRONOLOGIC INTERPRETATIONS FOR THE TUGRUGYIN SHIREH FAUNA

As noted in tables 1 and 2, numerous taxa are found in both the Bayn Dzak and Tugrugyin Shireh faunas. Based on the stratigraphic relationships presented here it is clear that the Tugrugyin Member overlies the Bayn Dzak Member, making it somewhat younger. However, it is not yet possible to estimate the precise temporal difference.

TABLE 2  
The Tugrugyin Shireh Fauna

---

**Reptilia**

Squamata

Iguania

*Isodontosaurus gracilis* Gilmore, 1943

*Flavigama dzerzhinski* Alifanov, 1989

*Mimeosaurus crassus* Gilmore, 1943

*Zapsosaurus sceliphros* Gao and Norell, 2000

*Temujinia ellisoni* Gao and Norell, 2000

Teiidae

*Adamisaurus magnidentatus* Sulimski, 1972

*Dzhadochtoosaurus giganteus* Alifanov, 1993

*Gurvansaurus potissimus* Alifanov, 1993

Varanidae

*Cherminotus longifrons* Borsuk-Bialynicka, 1984

Dinosauria

Saurischia

Theropoda

Dromaeosauridae

*Velociraptor mongoliensis* Osborn, 1924

Incertae sedis

*Archaeornithoides deniosauriscus* Elzanowski and Wellnofer, 1992

Avialae

*Shuvuuia deserti* Chiappe et al., 1998

Enantiornithes

*Euenantiornithes* indet. Suzuki, Watabe, and Tsogtbaatar, 1999

**Mammalia**

Multituberculata

Djadochtatherioidea

Djadochtatheriidae

*Kryptobaatar dashzevegi* Kielan-Jaworowska, 1970

*Djadochtatherium matthewi* Simpson, 1925

Eutheria incertae sedis

Asioryctitheria

Asioryctitheria

*Kennalestes gobiensis* Kielan-Jaworowska, 1969

Zalambdalestidae

*Zalambdalestes lechei* Gregory and Simpson, 1926

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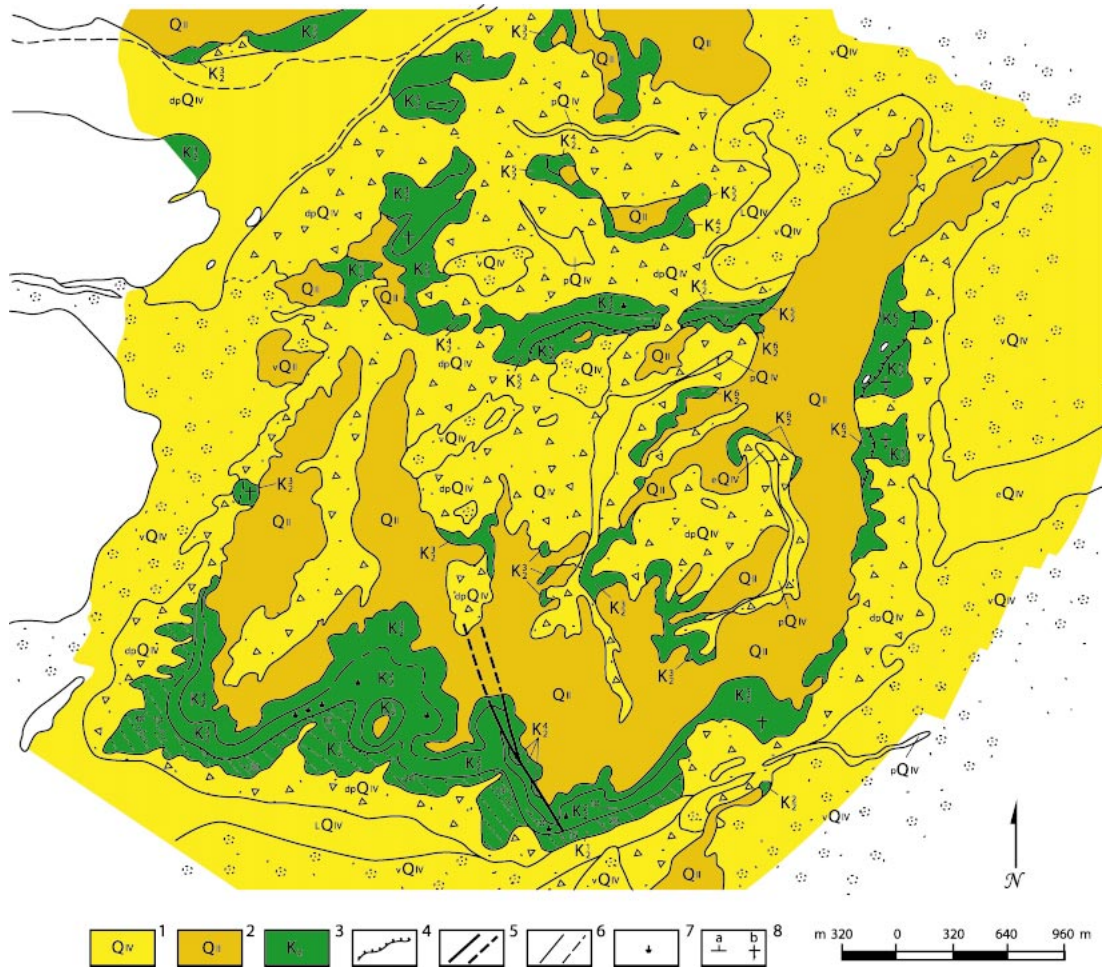
MAGNETOSTRATIGRAPHIC  
IMPLICATIONS FOR THE AGE OF THE  
TUGRUGYIN SHIREH FAUNA

As noted in a previous section on the sequence at Alag Teer, the basal, light gray sands of the Tugrugyin Member in Units 4 and 5 are reversed. This polarity corresponds to the uppermost beds of the Bayn Dzak Member at the Flaming Cliffs, the mudstone at Khren Tsav, and the mudstone at Tsonzh. If the zones of reversed polarity at these localities correlate, it means that these units must be younger than Chron 34n—the upper boundary of which represents the boundary between the Santonian and the Campanian at about 83.5 Ma (Gradstein et al., 1995). The quick stratigraphic succession of normal and reversed magnetozones in the Flaming Cliffs section suggests, but does not clearly establish, that the sediments were deposited during the rapid sequence of polarity changes in the late part of the Campanian incorporating the end of Chron 33 and Chron 32 between about 75 and 71 Ma (Gradstein et al., 1995).

CONCLUSIONS

Two new members can be broken out within the Djadokhta Formation based on exposures at Bayn Dzak, Tugrugyin Shireh, Tsonzh, and Alag Teer. The lower member, named the Bayn Dzak, is composed of moderate reddish orange, crossbedded, and structureless sandstones, with subordinate deposits of brown siltstone and mudstone. The crossbedded and structureless sandstones respectively represent eolian dunes and fluvial deposits or sandslides that occurred on the dune faces. The mudstone and siltstone represents an interdune facies deposited by fluvial action. The upper member is named the Tugrugyin Member and consists of very pale orange to light gray sands that also represent a crossbedded dune facies and a structureless sandslide facies. Transitional mudstone and siltstone units separate the two members at Tsonzh and Alag Teer.

Vertebrate fossils occur almost exclusively in the structureless sandstones of both members. Although the fauna from the Bayn Dzak Member is somewhat older than that from the Tugrugyin Member, based on the superpositional relationships, many of the



Map 3. Geologic map of major lithologic units at Tugrugyin Shireh. Compiled by T. Dulam in July 1998. **1.** Holocene: eolian sands, vQiv; deluvial sands, dpQiv; lake clay and sand, lQiv; proluvial sand and debris, pQiv. **2.** Pleistocene: deluvial-proluvial sand and debris, partly with limy matrix. **3.** Upper Cretaceous: Tugrugyin Member: K1/2 yellowish, weakly lithified, small-medium-grained sand. White sand slice. K2/2 unlithified, yellowish sands containing concretionary white sandstone nodules. K3/2 less concretionary white sand. K5/2 white sand. K6/2 white sand. Bayn Dzak Member: K4/2 red sand with light spots. **4.** Unlithified, white sand, rich with mud craters, footprints, and less sandstone nodules. **5.** Faults: a: known; b: inferred. **6.** Geologic boundaries: a: clear; b: unclear. **7.** Points of observation of fossil bone. **8.** Orientation of bedrock: a: inclined; b: horizontal.

same taxa have been collected from both members. It is not yet possible to estimate precisely the temporal difference separating the faunas from the two members.

New magnetostratigraphic samples throughout the Bayn Dzak Member and at the base of the Tugrugyin Member document the presence of a sequence of normal and reversed magnetozones. Previous biochronologic age estimates taken in conjunction

with this new magnetostratigraphic data suggest that the fossiliferous sediments of the Djadokhta Formation were most likely deposited during the quick succession of normal and reversed intervals in the late Campanian between 71 and 75 Ma.

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