Cretaceous Research (1993) **14**, 127–144

Palaeontology, sedimentology and palaeoecology of the Iren Dabasu Formation (Upper Cretaceous), Inner Mongolia, People's Republic of China

P. J. Currie and D. A. Eberth

Royal Tyrrell Museum of Palaeontology, Drumheller, Alberta T0J 0Y0, Canada

Received 22 January 1991 and accepted 27 April 1992

Since the discovery of dinosaurs in the Iren Dabasu Formation at Iren Nor in 1922, several expeditions have collected fossils from the low-relief exposures in this relatively small area. Articulated dinosaur skeletons, bonebeds comprising dinosaurs and vertebrate microfossils, nests of dinosaur eggs, invertebrate shell beds and trace fossils have been found. Nevertheless, most of the Iren Dabasu collections have not been prepared or described and the geology of this site has remained unstudied. Thus, the fossil assemblages and depositional environments have remained poorly known and somewhat enigmatic.

The Sino-Canadian expeditions of 1988 and 1990 rekindled an interest in this formation and new results from these and previous expeditions are presented here. The fossil assemblage is close to that of the Bayn Shire Formation of Mongolia, but the generally accepted Cenomanian designation may be too old. The Iren Dabasu Formation comprises the remains of a low-sinuosity braided fluvial system that flowed toward the north-west and was deposited in a semiarid climate. Channels were broad (up to 1 km wide) and relatively shallow (less than 4 m deep). The floodplain was the site of frequent and energetic overbank flooding and early stages of soil formation. Although ephemeral floodbasin lakes and playas—resulting from overbank flooding—existed from time to time, there is no sedimentological or palaeontological evidence for laterally extensive and long term lacustrine environments as suggested by previous workers.

Key Words: China; Inner Mongolia; Late Cretaceous; Iren Dabasu Formation; Bayn Shire Formation; palaeontology; sedimentology.

1. Introduction

On April 25, 1922, a party from the American Museum of Natural History set up their camp at a telegraph station at the west end of a playa lake known as Iren Nor ("Shining Lake"; Obruchev, 1900–1901, referred to the lake as Iren Dabassun Nor). The locality was named Iren Dabasu ("Shining Salt") by the Mongolians and has since been called Erlian by the Chinese. The site is south-east of the border crossing between Inner Mongolia (People's Republic of China) and Outer Mongolia (Mongolia) and north-east of the city of Erenhot (Figures 1, 2). Within hours, fossils were discovered close to camp and Iren Dabasu became the first locality in central Asia to produce dinosaur bones. This was considered significant enough to write a paper immediately (Granger & Berkey, 1922, which was published before staff even left the field), and the term Iren Dabasu Formation was proposed for the Cretaceous beds.

Only a short time (April 25 to May 7) was spent at Iren Dabasu in 1922, but other field parties of the Third Central Asiatic Expedition (Andrews, 1932; expedition field notes in American Museum of Natural History) returned in 1923 (April 22 to approximately May 25) and 1928 (July 14 to 16). The most significant finds were made in 1923, and a number of partial skeletons were collected, along with hundreds of individual dinosaur bones excavated from bonebeds. Dinosaur egg shell was discovered at Iren Dabasu in 1923 by Granger and Morris, and four eggs were

0195-6671/93/020127 + 18 $08.00/0

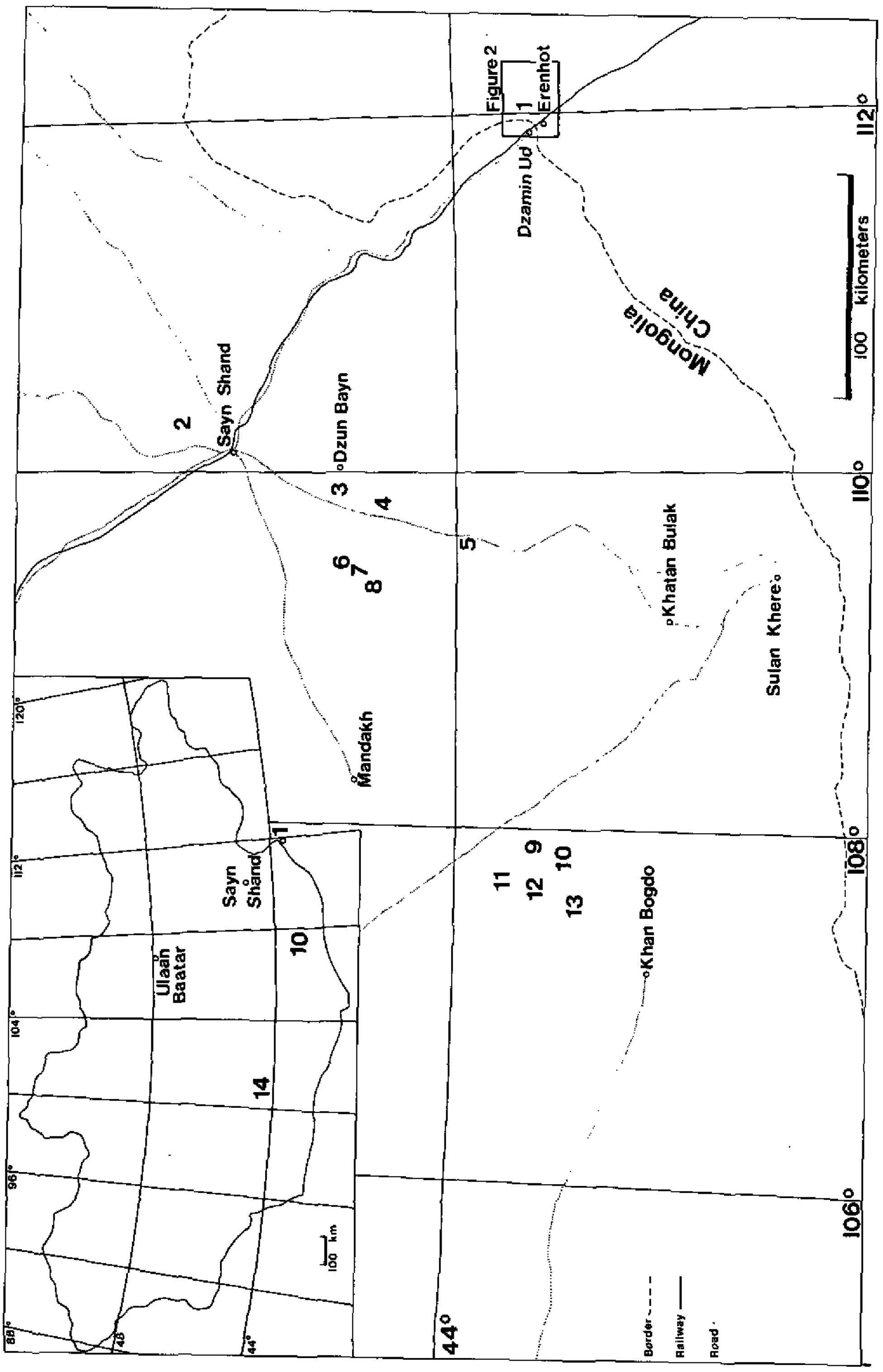

Figure 1. Bayn Shire and Iren Dabasu localities in Mongolia (entire country shown in inset) and the People's Republic of China. (Data from Marinov, 1971; Shuvalo Chikvadze, 1979; Tsibin & Kurzanov, 1979; Martinson, 1982). 1, Iren Dabasu; 2, Tel Ulan Ula; 3, Khongil Tsav; 4, Bayn Shire; 5, Ushiyn Khuduk; 6, Khara Kh Ula; 7, Shine Usu Khuduk; 8, Tsagan Teg; 9, Amtgay; 10, Bayshin Tsav; 11, Khongil Obo; 12, Deng Usu; 13, Urilibe Usu; 14, Shiregin Gashun.

collected from one or two nests in 1928. These were the first clearly identified dinosaur eggs ever found. The more significant discovery of intact dinosaur eggs from Shabarakh Usu did not occur until later in the 1923 expedition.

The dinosaurs and turtles of Iren Dabasu were described by Gilmore (1933). No other primary paper has appeared on this fossil assemblage, although ornithomimid (Russell, 1972; Smith & Galton, 1990), tyrannosaurid (Mader & Bradley, 1989) and hadrosaur (Brett-Surman, 1979; Weishampel & Horner, 1986) specimens have been restudied.

In June 1959, the first Sino-Soviet expedition visited Iren Dabasu (Rozhdestvenski, 1977). With more than sixty people, supported by two "Stalin 100" bulldozers, a tremendous number of specimens were recovered in a 6-week period. Part of the material was shipped to the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Beijing, and some to Moscow (Paleontological Institute). Unfortunately, the political situation forced the premature termination of the expeditions the following year. Subsequently, deterioration of relationships between China and the Soviet Union made it impossible for the researchers to work together, and the split collection was put aside in both institutions. More than thirty crates of fossils in China remained unopened until 1990.

There were joint expeditions to Iren Dabasu supported by the Beijing Natural History Museum and the Inner Mongolian Museum (Hohhot) in 1972, 1973 and 1974; these expeditions worked mostly south of the ruins of the telegraph station. In 1976 and 1977, work focused on a single bonebed (Figure 2, site C), dominated by

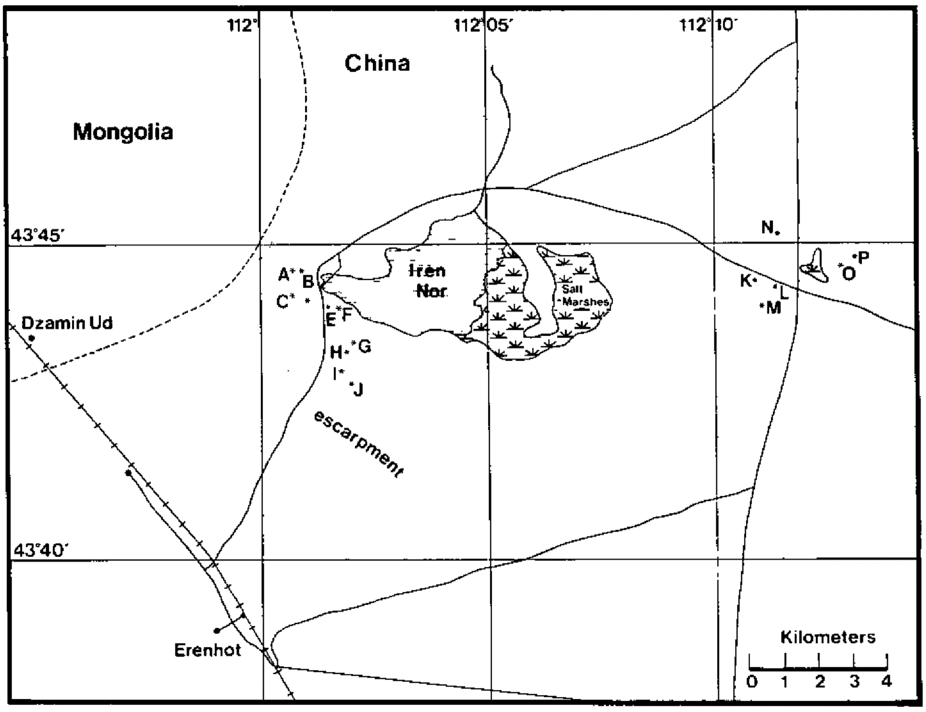

Figure 2. Collection sites in the Iren Dabasu Formation north-east of Erenhot, China. Map based on Berkey & Morris (1927), but with corrected information from an unpublished map surveyed by W. P. T. Hill in 1928 (American Musuem of Natural History archives), field observations by the authors, and Operational Navigation Chart ONC F8. Sites A to P are identified in Table 3.

hadrosaurs, west of the telegraph station. Some of the specimens (including ornithomimid and hadrosaur skeletons) were prepared for display in Hohhot, but most of the material has not been prepared yet and no scientific papers have come from this work.

Today, the closest city (13 km by road) to the Iren Dabasu site is Erenhot (also known as Erlian and Erlianhot), which is on the major rail line connecting China, Mongolia and the former Soviet Union. Staff of the Erenhot Dinosaur Museum have been collecting dinosaurs sporadically for many years, but since plans were developed for an expanded facility in 1988, collecting activities have been increased. The expanded museum includes casts of the ornithomimid and hadrosaur skeletons on display in Hohhot.

After a preliminary survey in 1987, Sino-Canadian expeditions worked the Iren Dabasu Formation north-east of Erenhot in 1988 and 1990. Nests of eggs and a partial skeleton of *Alectrosaurus* were among the prized specimens. Two hadrosaur bonebeds were opened up and systematically worked. However, one of the richest sources of fossils turned out to be the sediment piled up by the bulldozers of the Sino-Soviet expedition. After 30 years of exposure, wind and water erosion had left bone concentrated on the surface of each pile at the bonebeds (Figure 2, sites K, L, P). Collection and identification of this material has greatly expanded the faunal list of the Iren Dabasu Formation. Sedimentological studies were conducted during both years and are the first such studies of this formation.

2. Stratigraphy

The Iren Dabasu Formation (Irendabasu, Grabau, 1928) was named by Granger & Berkey in 1922, and formally defined by Berkey & Morris in 1927. The formation is intermittently exposed over an area of less than 20 km^2, among grass-covered, low-relief ridges and breaks on the southern side of the Iren Nor basin. South-west of Iren Nor, the thickness of the exposed portion of the formation, calculated from a composite section (Figure 3), is 18 m. East of Iren Nor, the cumulative thickness may be as great as 30 m (Berkey & Morris, 1927, p. 203; not measured by us). Limited exposures of the formation also crop out south-east of Erenhot (Berkey & Morris, 1927), but were not studied by us.

Berkey & Morris (1927) claimed that the formation lies unconformably on basement granites and slates that crop out extensively along the northern side of the Iren Nor basin. They implied that the exposed thickness of the formation approximates its total thickness. However, our reconnaissance failed to reveal any evidence of a flat-lying contact between the slates and Iren Dabasu clastics. We suggest that the abrupt lateral change (over a few metres) from highly foliated slates to Iren Dabasu clastics (with no intervening horizon of breccia or rip-up clasts) is more parsimoniously interpreted as evidence of an east–west trending fault or system of faults. In our interpretation, the slates and granites occur on the up-thrown side of a normal fault and the total subsurface thickness of the Iren Dabasu Formation is unknown. This interpretation is further supported by the facts that (1) the thickness of the Iren Dabasu Formation exposures (between the slates and overlying Eocene deposits) varies dramatically in the field area, and (2) 8 km to the north-east, foliated slates pass laterally into Eocene clastics. A history of normal faulting can easily account for such abrupt lateral changes in thicknesses and formational relationships and may ultimately provide an explanation as to how the

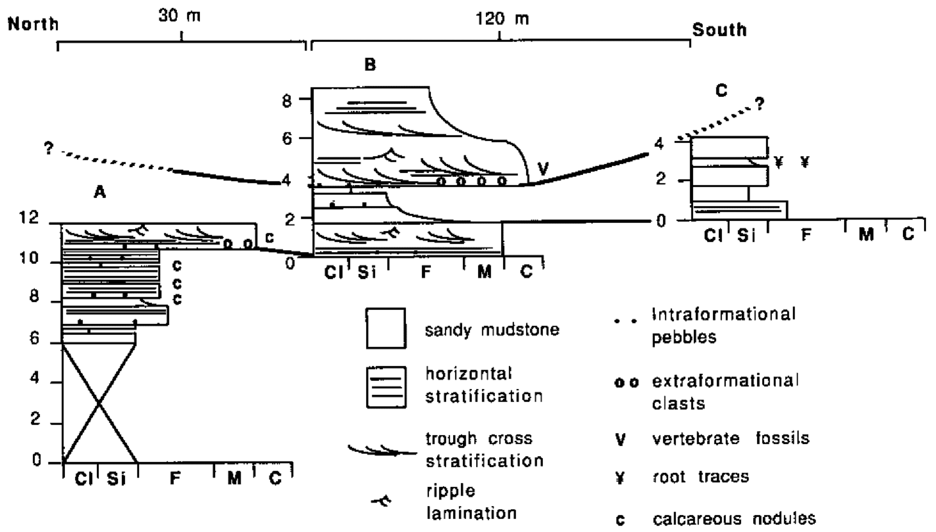

Figure 3. Three stratigraphic sections (A–C) measured near vertebrate locality 'F' (Figure 2). Note the apparent lenticularity of the 5-m-thick palaeochannel sandstone body in section B. Solid lines indicate lithostratigraphic correlation and measured extent of body; dashed lines indicate inferred correlation and extent. Vertical scale in meters. Lateral relationships not to scale.

modern Iren Nor lake basin originally formed, (the original interpretation, that the slate/Iren Dabasu contact is flat-lying, implies a complex and convoluted history of localized deposition and erosion). Parsimony notwithstanding, our reinterpretation must be tested with subsurface data before it is completely embraced.

As noted above, the Iren Dabasu Formation is overlain unconformably by clastics of Eocene age. Granger & Berkey (1922) included the Eocene beds in the Iren Dabasu and originally assigned the entire unit to the Lower Cretaceous. Berkey & Morris (1927) recognized the unconformable relationship between the Eocene and Cretaceous beds, restricted the formation to those beds beneath the unconformity, and with the support of Matthew (in Berkey & Morris, 1927), maintained the Lower Cretaceous designation. Grabau (1928) placed the formation higher than the Djadokhta, and Morris (1936) put it in the Campanian. In contrast, most palaeontologists working on dinosaurs (Weishampel & Horner, 1986; Smith & Galton, 1990) have accepted the assignment of these beds to the Cenomanian as being reasonable given the rather primitive nature of the animals.

Our preliminary vertebrate fossil assemblage data (Table 1), as well as those of Jerzykiewicz & Russell (1991), suggest that the Iren Dabasu Formation is biostratigraphically equivalent to the upper portions of the Bayn Shire Formation of Mongolia, which crops out less than 200 km to the north-west (Figure 1). The Bayn Shire Formation is up to 300 m thick, comprises alternating, varicolored fossiliferous claystones and sandstones, and is overlain conformably by sediments of the Djadokhta Formation ("Dzhibkhalantskaya Zone" of Sochava, 1975, and Barun Goyot Formation of Martinson, 1982). The Bayn Shire Formation in eastern Mongolia is thought to range in age from Turonian to Campanian (Jerzykiewicz & Russell, 1991). A more detailed discussion of the age of the Iren Dabasu Formation with respect to the Bayn Shire Formation is presented below following the description of vertebrate taxa.

Table 1. Comparison of the faunas of the Iren Dabasu (People's Republic of China) and Bayn Shire (Mongolia). Only taxa known from the Bayn Shire of the southeastern Gobi are included. Shiregin Gashun is often included as a western extension of the Bayn Shire. However, there is little overlap

Taxa	Iren Dabasu	Amtgal	Bayn Shire	Bayshin Tsav	Deng Usu	Dersnil Khuduk	Khara Khutul	Khongil Obo
Taenidium	*Taenidium* sp.							
Anchorichnus	*Anchonchnus* sp.							
?Gyrolithes	*?Gyrolithes* sp.							
Cypridea				*C. cavernosa*				
Talicypridea				*T. longiuscula*				
Talicypridea				*T. biformata*				
Mongolianella				*M. cuspidigera*				
Cyclocypris				*C. transitoria*				
Cypria				*C. elata*				
Eucypris				*E. khandae*				
Eucypris				*E. bajshintsavica*				
Timiriasevia		*T. martinsoni*						*T. martinsoni*
Timiriasevia				*T. polymorpha*				
Sphaerograpta				*Sphaerograpta* sp.				
Gobiota		*G. multicostata*					*G. multicostata*	
Gobiota							*G. kharachutulica*	
Gobiota		*G. cf. elliptica*					*G. elliptica*	
Plicatotrigonioides							*P. khamarinensis*	
Pseudohyria	*P. gobiensis*	*Pseudohyria* sp.		*P. anda*			*P. cardiiformis*	*P. cf. tuberculata*
Pseudohyria							*P. corbiculoides*	*P. hongdica*
Pseudohyria								*P. cardiiformis*
Pseudohyria							*P. radiata*	*P. transaltaica*
Sainshandia							*S. unegetensis*	*Sainshandia* sp.
Sainshandia				*S. robusta*		*S. robusta*	*S. bainshirensis*	
Parreysia							*P. gobiensis*	
Psorula								
Psorula								
Cuneopsis								
Lanceolaria								
Pleurobema								
Unioasia								
Protelliptio								
Myledaphus	*Myledaphus* sp.							
Hybodus	*Hybodus* sp.			*H. asiaticus*				
Lepisosteus	*Lepisosteus* sp.							
Amia	*Amia* sp.							
Teleost	vertebrae							
Adocus	*Adocus* sp.	*A. amtgai*				*Adocus* sp.		
Basilemys	*Basilemys* sp.	*Basilemys* sp.	*B. orientalis*	*B. orientalis*	*Basilemys* sp.		*Basilemys* sp	
Charitonyx							*C. tajanikolaevae*	
Hoplochelys							*Hoplochelys* sp.	
Lindholmemys	*Lindholmemys* sp.							
Mongolemys				*M. elegans*				
Kizylkumemys		*K. shuwalovi*					*Kizylkumemys* sp.	
Trionyx	*Trionyx* sp.			*Trionyx* sp.		*Trionyx* sp.	*Trionyx* sp.	*Trionyx* sp.
Lacertilia	vertebrae							
Plesiosauria	vertebrae							
Pterosauria	humerus							
Shamosuchus	*Shamosuchus* sp.	*S. ulgicus*		*S. ulgicus*			*S. major*	
Dromaeosauridae	isolated bones							
Velociraptor	teeth, claws			*Velociraptor* sp.				
Sauromithoides	metatarsals							
Archaeornithomimus	*A. asiaticus*			*Archaeornithomimus*				
Garudimimus	?			*G. brevipes*				
Avimimus	isolated bones							
Alectrosaurus	*A. olseni*			*Alectrosaurus* sp.				
Sauropoda	isolated bones			X				
Erlicosaurus	*Erlicosaurus* sp.			*E. andrewsi*				
Segnosaurus	*Segnosaurus* sp.	*S. ghalbiensis*					*S. ghalbiensis*	
Enigmosaurus	?						*E. mongoliensis*	
Hypsilophodontid	isolated bones							
Bactrosaurus	*B. johnsoni*			?				
Hadrosaurinae								
Gilmoreosaurus	*G. mongoliensis*							
Amtosaurus		*A. magnus*						
Maleevus								
Talarurus	*Talarurus* sp.		*T. plicatospineus*					
Microceratops								
Paraspheroolithus	*P. irenensis*							

3. Sedimentary Geology

The Iren Dabasu clastics comprise fine-grained to pebbly arkoses, lithic arenites and sublitharenites (*sensu* Folk, 1980), and a variety of sandy silt- and claystones with localized occurrences of carbonate nodules and rare occurrences of tabular carbonate beds. Localized extraformational and well-rounded bone pebbles are common in association with arenites. Arenites are moderately sorted and comprise subangular to subrounded grains. Mineralogically, arenites are sparite-cemented and are domi-

between the faunas of the two areas, indicating that the Shiregin Gashun sites were temporally and/or environmentally distinct. The western extension of the Bayn Shire has therefore been listed in a separate column at the end. (See Figure 1 for localities).

Khongil Tsav	Sheeneh Usu Khuduk	Tel Ulan Ula	Tsagan Teg	Ulan teg	Unegtu Ula	Urlibe Usu	Ushyin Khuduk	Shiregin Gashun
								C. cavemosa
						G. multicostata		
							G. cf. kharachutulica	
				P. gobiensis		P. cf. khamarinensis		
P. unegetensis	P. unigetensis		P. tuberculata		P. turistschewi	P. pusilla		P. cardiiformis
P. hongilica	P. anda		P. hongilica			P. cf. turistschewi		
P. marginodentata			P. marginodentata					
P. janshini			P. radiata					
S. unegetensis	S. sculpturata		S. sculpturata	S. sculpturata	S. sculpturata	Sainshandia sp.		
	S. robusta		S. robusta		S. robusta			
	P. acuta		P. acuta					
	P. mica		P. mica					
			C. gracilis					
			L. angustata					
			P. gloria					
			U. multa					
			P. notabilis					
							Adocus sp.	
							Basilemys sp.	Basilemys sp.
?							L. martinsoni	L. martinsoni
								Mongolemys sp.
						K. shuwalovi		
						Trionyx sp.	Trionyx sp.	Trionyx sp.
S. major								S. gradiifrons
								Isolated bones
								M. disparoserratus
		egg/embryo						M. gobiensis

nated by monocrystalline quartz with quartz overgrowths (<50% of the framework) and alkali feldspars (sanidine/orthoclase; <25% of the framework). Plagioclase (<10% of the framework) is commonly present in highly altered form and is, thus, difficult to identify. A variety of polycrystalline quartz grains is present (<12% of the framework) and rock fragments (metamorphic, chert and other sedimentary varieties) are locally abundant.

Silt- and claystone beds possess a variety of features that indicate early stages of palaeosol development including gleying, root traces and clay-lined peds

(Retallack, 1990). Associated carbonate nodules comprise massive micritic glaebules with sparite-filled fractures and 'floating', sparite-encircled clastic grains, all typical of caliches (Allen, 1986; Retallack, 1990). One occurrence of a tabular dolomite bed was noted by Jerzykiewicz in 1988 and occurs in the highest portion of the stratigraphic section east of Iren Nor. Hand samples and thin sections show a clotted fabric comprising almost pure micrite and microspar. Clastic grains are extremely rare. Although not conclusive, the tabular geometry and absence of clastics suggest a lacustrine or playa origin. Unfortunately, poor exposure precludes a better understanding of this deposit.

Analyses of facies and palaeocurrent data reveal that the exposed portion of the formation was deposited in a coarse-grained, low sinuosity, fluvial system that flowed north-westward. The system comprises coarse and fine members representing channel and interchannel deposits, respectively. Coarse-grained members of channel origin are erosionally-based and laterally extensive perpendicular to palaeoflow direction (up to 1 km). They are typically less than 4 m thick and are composed of fining- and thinning-upward sets of large-scale trough cross-bedding, horizontal-planar and ripple lamination (all sets are less than 50 cm thick). Large-scale troughs are typically 1–3 m wide and are commonly exposed in plan view. Disarticulated to partially associated vertebrate fossils and bone pebble lags are locally abundant at or near the base of coarse members in association with very coarse to granulitic trough cross-beds.

Palaeocurrent measurements (170) taken from trough crossbeds and ripple lamination over the entire field area indicate a strongly unidirectional flow to the north-west with ancillary flow to the north-east and south-west (Figure 4). Morris (1923, unpublished fieldnotes) suggested that flow was to the east in the lowermost exposures where pelecypods were found in a small outcrop of cross-bedded sandstones. We have observed, however, that throughout the field area palaeocurrent azimuth directions are tightly grouped over distances of tens of metres. Thus, it is most likely that Morris' data were collected from a local ancillary system of flow, oblique to the regional trend.

Modern low sinuosity fluvial systems can be classified as straight, braided, anastomosed, or as some combination of these (e.g., Miall, 1978; Smith, 1983; Walker & Cant, 1984). The shallow and broad nature of the Iren Dabasu

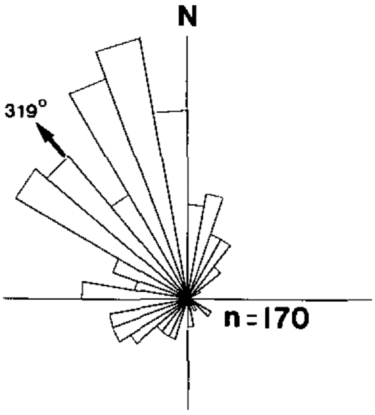

Figure 4. Palaeocurrent rosette constructed from 170 palaeocurrent azimuth readings taken from large-scale trough cross-beds ($n = 164$), ripple lamination ($n = 4$) and parting lineation ($n = 2$). Vector mean indicated by arrow and calculated using method of Curray (1956).

palaeochannels and the strongly localized variation in palaeocurrent directions are most compatible with a braided fluvial interpretation.

Fine-grained members comprise two types: (1) tabular bodies (<2 m thick) of thinly bedded (less than 10 cm), heterolithic sand-, silt- and claystone and (2) a variety of massive sandy siltstone and claystone deposits (up to 2 m thick) with caliche nodules, vertebrate eggshell and whole *in situ* eggs (in nests) and other features indicative of incipient palaeosol development (see above). The tabular bodies are dominated by planar beds of ripple lamination and horizontal stratification with thin intervening sets of silt- and claystone, and pass laterally into trough cross-bedded sandstones. We interpret these deposits as thin, sheet splays emanating from shallow, broad primary fluvial channels. Similar deposits are common features of modern and ancient fluvial systems (e.g., McKee *et al.*, 1967; Tunbridge, 1981; Collinson, 1986). Massive silt- and claystone beds are interpreted as suspension deposits that accumulated in a variety of floodplain settings. Incipient palaeosol development, caliches and dinosaur nests attest to depositional hiatuses.

The architecture of the coarse and fine members is difficult to establish in this region because of low relief. However, our three measured sections and a lateral facies profile (Figure 3) show that coarse channel members typically fine upwards into sheet splay or massive floodplain deposits.

On the basis of the foregoing, we interpret the Iren Dabasu fluvial system as a north westerly flowing, low-sinuosity, braided fluvial system punctuated by broad (<1 km wide), shallow (<4 m deep) channels. Flow rates were highly variable and flow periodically spilled out onto the floodplain burying dinosaur nesting sites and interrupting or terminating palaeosol and caliche development. A semi-arid climate is indicated by the presence of caliche nodules (Goudie, 1983; Retallack, 1990) and the possible occurrence of a playa limestone. In such a climatic setting flow rate variation may have occurred seasonally.

The Bayn Shire Formation of Mongolia is similar to the Iren Dabasu in comprising a sequence of interbedded conglomerates, arenites and, silt- and claystones. Large-scale cross-bedding is present in some sandstone beds. In contrast to the Iren Dabasu Formation, the conglomerates of the Bayn Shire are, for the most part, intraformational (Jerzykiewicz & Russell, 1991), comprising reworked caliche nodules. The higher concentration of extraformational clasts in the Iren Dabasu Formation indicates that the Erenhot locality is closer to source than the Bayn Shire localities. This interpretation is compatible with our palaeocurrent data, which imply that the Iren Dabasu fluvial system was in a more proximal palaeogeographic position relative to the Bayn Shire fluvial system.

4. Palaeontology

4.1. *Invertebrates*
Pelecypods were collected by the Central Asiatic Expedition from two 'small patches' of shells occurring very low in section in pebbly, very coarse-grained sandstone beds separated by a meter of sandy siltstone. The pelecypods were described by F. Stearns MacNeill (in Morris, 1936) as a monospecific assemblage of the freshwater unionid *Pseudohyria gobiensis*. *Pseudohyria gobiensis* is not known from the Bayn Shire of the south-eastern Gobi of Mongolia, although other species of *Pseudohyria* have been identified (Table 1; Martinson & Kolesnikov, 1974; Martinson 1982). No pelecypods were encountered during the Sino-Canadian expeditions of 1988 and 1990 indicating that pelecypods are rare. Trace fossils

(RTMP 89.132.8–89.132.15) recovered by the Sino-Canadian expedition in 1988 include *Taenidium*, *Anchorichnus*, ?*Gyrolithes*, several unidentified taxa, and rhizoliths (P. A. Johnston, pers. comm., 1991).

4.2. *Vertebrates*
Dasyatid (Hypolophidae) ray teeth and vertebrae, and hybodontid shark teeth and spines were collected from the Iren Dabasu in 1987, 1988 and 1990. These specimens are closest to *Myledaphus tritus* (Nessov & Udovichenko, 1986) and *Hybodus kansaiensis* (Nessov & Khisarova, 1988), respectively. Glikmana (in Shuvalov & Trusova, 1979) referred shark teeth from the Bayn Shire Formation of Baishi Tsav to *Hybodus asiaticus* n. sp. To the best of our knowledge, this species has never been properly diagnosed, nor have any of the teeth been illustrated. Gar scales, and amiid and teleost bones were recovered from channel deposits at Iren Dabasu. Fish have been reported from the Bayn Shire (Efremov, 1949) but have not been identified or described.

Turtles are common and diverse within the Iren Dabasu Formation (Table 1). Trionychid shell fragments (Gilmore, 1931; Yeh, 1965) are common in the bonebeds. Other trionychoidean (in the sense of Meylan & Gaffney, 1989) turtles identified in the Iren Dabasu include an adocid (*Adocus*), a nanhsiungchelyid (*Basilemys*) and a lindholmemyid (*Lindholmemys*) (D. Brinkman, pers. comm., 1990), all of which have been reported from the Bayn Shire (Table 1).

Plesiosaur vertebrae were collected by the Sino-Soviet expedition and indicate the presence of a large form (an anterior caudal centrum in the collections of the IVPP has a transverse diameter of more than 5 cm). The Cretaceous coastline was not close to this site, and the presence of such a large plesiosaur probably indicates a large enough river channel to permit this typically marine animal to penetrate so deeply inland.

Only one lizard bone has been identified (IVPP 200788-116), so it would appear that these animals were not common in the Iren Dabasu palaeoenvironment.

A partial skull (IVPP 180788-101) and numerous disarticulated elements of a shamosuchid crocodile were collected in 1988. The material has not been studied in detail, so it is not possible to determine to which species of *Shamosuchus* it belongs, although two species are known from the Bayn Shire (Efimov, 1983) in adjacent parts of Mongolia (Table 1).

Isolated pterosaur bones were recovered from the Iren Dabasu in 1959 and 1987. A humerus in the Sino-Soviet collections in Beijing suggests that the pterosaur was quite large (Dong Z. M., pers. comm., 1990).

Isolated dromaeosaurid teeth and bones are common in the Iren Dabasu, and were originally reported by Gilmore (1933). Most of these can be attributed to *Velociraptor*, although some of the teeth suggest that there was a second, larger species of an indeterminate dromaeosaurine dromaeosaurid.

Troodontid bones are rare, but include distinctive third metatarsals (AMNH 21751, 21772, IVPP 230090-16), in which the distal articulation extends onto the posterior surface of the bone in a broad tongue (Wilson & Currie, 1985). A femur (PIN 2549-100, Kurzanov 1987) collected by the Sino-Soviet expedition is probably from a troodontid. These bones are provisionally referred to *Saurornithoides*, which is the largest genus of Asian troodontid presently known.

Avimimid bones are common in the Iren Dabasu and can be found in the collections of the American Museum of Natural History (New York), the Paleontological Institute (Moscow), and the Institute of Vertebrate Paleontology and

Paleoanthropology (Beijing). Direct comparison between isolated *Avimimus* bones from the Iren Dabasu and the type specimen of *Avimimus portentosus* in Moscow failed to reveal any differences. The Iren Dabasu avimimid material is presently under review (Currie, Zhao and Kurzanov, in preparation).

Gilmore (1933) referred ornithomimid material from the Iren Dabasu to a new species, *Ornithomimus asiaticus*. This was redesignated by Russell (1972) to a new genus, *Archaeornithomimus*, which was characterized as an ornithomimid with a primitive metacarpus and an apparently short metatarsus. The species was reviewed recently by Smith & Galton (1990), who provided illustrations and measurements of bones that had not been referred to in the earlier papers. Unfortunately, no cranial material was collected by the American Museum. The present whereabouts of a partial skull found by the Sino-Soviet expedition is currently unknown. Most of the Iren Dabasu specimens are individual bones of disarticulated skeletons. Given the variability evident in the collections, there is a high probability that more than one ornithomimid species was present at Iren Dabasu.

In 1981, Barsbold described a new genus and species of ornithomimid from the Bayn Shire Formation at Bayshin Tsav. *Garudimimus brevipes* is known from good cranial and reasonable postcranial material, which Barsbold believes is different enough from previous known ornithomimids to merit the establishment of a new family. In contrast with the more advanced forms, he noted that the ilia are shorter than the pubis, the first pedal digit has not been lost, and the third metatarsal is not as compressed proximally. However, the *Garudimimus* metatarsus is somewhat crushed, the third metatarsal is recessed from the extensor surface of the metatarsus, and the second and fourth metatarsals approach each other (even though they do not actually touch in the holotype). This indicates that the second and fourth metatarsals probably did contact proximally on the extensor surface in the living animal.

Smith & Galton (1990) noted the presence of a concave facet on Metatarsal II, which indicates that the first digit may be present in *Archaeornithomimus*. The relative proportions of the metatarsal elements are also similar to those of *Garudimimus* (Table 2). Metatarsal comparison, therefore, shows the two genera to be close in evolutionary development, and there is a distinct possibility that at least some of the *Archaeornithomimus* specimens are actually *Garudimimus*.

Barsbold (1983) and Barsbold & Osmólska (1990) noted that the dorsal and sacral vertebrae of *Garudimimus* lack pleurocoels in the centra, which is not the case in other ornithomimids. There are six sacral vertebrae in the holotype, compared with an estimated five in *Archaeornithomimus* (AMNH 6576). The low number in the Iren Dabasu specimen may be attributable to its immaturity, although the presence of pleurocoels shows that this specimen cannot be referred to *Garudimimus*.

Barsbold (1983) states that both ornithomimids and garudimimids are found in

Table 2. Comparison of measurements of pedal elements of *Archaeornithomimus* (after Smith & Galton, 1990) and *Garudimimus* (taken from photograph of specimen).

Genus	mt II	mt III	mt IV	II-1
Archaeornithomimus	257 (0.90)	286 (1.00)	259 (0.91)	70.8 (0.25)
Garudimimus	207 (0.93)	223 (1.00)	203 (0.91)	63.0 (0.28)

Phalanx II-1 was misidentified as IV-1 by both Gilmore (1933) and Smith & Galton. The length of each element is in millimetres, and the figure in brackets represents its fractional length of mt III.

the Bayn Shire, and superficial examination of the Iren Dabasu ornithomimid material suggests that more than one genus may be present. It is therefore also conceivable that both *Archaeornithomimus* and *Garudimimus* are found in both the Iren Dabasu and Bayn Shire.

Alectrosaurus olseni was originally described by Gilmore (1933) on the basis of specimens from Iren Dabasu, and was subsequently reviewed by Mader & Bradley (1989). Better cranial material was described by Perle (1977), who has been studying more recently discovered postcranial specimens (Perle, pers. comm. 1989). Although *Alectrosaurus* is clearly a tyrannosaurid (Mader & Bradley, 1986), it is more primitive than other species of this family. The absence of denticles on the premaxillary teeth (Perle, pers. comm. 1989; IVPP 180788-104) suggests that it should be included in the Aublysodontinae.

Segnosaurids were reported from the Iren Dabasu by Mader & Bradley (1989), and isolated elements were commonly recovered by the Sino-Canadian expeditions in 1988 and 1990. A well-preserved dentary with teeth is in the collections of the Erenhot Dinosaur Museum. The isolated elements are indistinguishable from *Erlicosaurus andrewsi* and *Segnosaurus ghalbiensis* bones in the collections of the Paleontological Institute (at the Central State Museum) in Ulaan Baatar. There are a few elements from the Iren Dabasu that may also be referable to the more poorly known segnosaur *Enigmosaurus*.

Sauropod femora and a tibia now on display at the Erenhot Dinosaur Museum were collected from Sites C and O (Figure 2). A single *Euhelopus*-like spatulate tooth in the same museum suggests that the sauropod was a camarasaurid. Isolated sauropod bones have also been found at Bayshin Tsav.

The Iren Dabasu hadrosaurs are relatively well known (Gilmore, 1933; Brett-Surman, 1979, 1980; Weishampel & Horner, 1986), although only a small portion of the available material has been studied. Future study of the immense collections in Hohhot, Erenhot and Beijing of *Bactrosaurus johnsoni* and *Gilmoreosaurus mongoliensis* has the potential to reveal complete anatomical information for these primitive hadrosaurine and lambeosaurine hadrosaurs, including information on growth and variation. Only *Gilmoreosaurus* has come from Site O (AMNH Quarry 149, see Table 3), but both species have been collected from Site K (Figure 2).

Hadrosaurs are not well known from the Bayn Shire, although an undescribed lambeosaurine (Maryańska & Osmólska, 1981) is present at Bayshin Tsav.

A few isolated bones collected by the Sino-Canadian effort are from a primitive ornithischian, and have been tentatively identified as hypsilophodont.

Gilmore (1933) identified an ankylosaur ilium and caudal vertebra in the collections from the Iren Dabasu in the American Museum of Natural History. An ankylosaurid skull collected by the Sino-Soviet expedition is housed in the collections of the IVPP, but has not been studied yet. Two species are known from the Bayn Shire of south-eastern Mongolia (Tumanova, 1987), of which *Talarurus plicatospineus* seems to be closest to the Iren Dabasu specimen in Beijing.

No evidence of protoceratopsians has been recovered in the Iren Dabasu. In Bayn Shire beds of western Mongolia, the protoceratopsian *Microceratops* has been identified at Shiregin Gashun (Maryańska & Osmólska, 1975). *Microceratops* is otherwise known only from the Alashan Desert and one other locality in the western part of Inner Mongolia (Bohlin, 1953).

Dinosaur eggs (*Paraspheroolithes irenensis*, see Zhang, 1979) collected in 1922 (Van Straelen, 1925), 1928 and 1988 are almost round with diameters between 9 and 10 cm. The AMNH eggs were discovered in "red sandy clay, the highest

Table 3. Iren Dabasu localities.

Figure 2	AMNH #	CCDP #	Description
A	138		
B	136		
C		7	
D		11	
E		2	
F	131		
G		9	
H		8	

I		10
J		
K	?141	1
L		
M		4
N	142	6
O	?148	3
P		5

Alectrosaurus, *Segnosaurus*
Alectrosaurus, *Segnosaurus*
Bonebed
Microvertebrate site
Microvertebrate site, dinosaur nests
?
Alectrosaurus
Sauropod eggs
Turtle skull

Bonebed

Bonebed

Bonebed

Dinosaur nests

?

Bonebed

Bonebed

The Sino-Soviet expedition of 1959 worked at sites K, L and P. Site C was worked by the Beijing Natural History Museum and the Inner Mongolia Museum in 1976 and 1977).

fossil-bearing unit yet found in the Iren Dabasu" (Berkey & Morris, 1927) in what was suspected to be two distinct nests. The shell was described by Van Straelen (1925) as thick (1.2 mm) and he felt that histologically it was closest to the sauropod *Hypselosaurus priscus* from France. The site (Figure 2, M) was rediscovered in 1988 and five nests were identified with up to 23 eggs in each. The eggs are smooth shelled. Hadrosaur eggs from Alberta are larger and have a pebbly texture (personal observation), so it is not unreasonable to assume the eggs from the Iren Dabasu were laid by a theropod. Based on the smaller size of possible velociraptorine eggs recovered from Bayan Manduhu (China) and the larger size of an allosaurid egg from Utah (Hirsch *et al.*, 1989), it is conceivable that the eggs were laid by a theropod of roughly the size of the Iren Dabasu ornithomimids. Although *Alectrosaurus* is not significantly larger than the largest ornithomimid, it is a much rarer animal, and therefore is less likely to be the animal that laid the half dozen or so nests of eggs.

Two large, round thick-shelled (2 mm) eggs (IVPP 240788-113) collected in 1988 at Site H have been tentatively identified as those of a sauropod, because of their similarity to sauropod eggs from France and India (Mohabey, 1987). The smooth-shelled eggs were broken, so the diameter could not be estimated. In the same area, fragments of a small, thin-shelled egg (IVPP 240788-101) were discovered. A fourth type of egg (IVPP 250790-1, 250790-2, 250790-3) was discovered in 1990 just east of Site E (Figure 2). These smooth-shelled, round eggs have thick shells (2 mm) relative to their small size (egg diameter is 7.5 cm). Five nests (each about 35 cm across) were discovered at the same level in a relatively small area with up to 11 eggs per nest.

Of the four types of eggs identified in the Iren Dabasu, none approach the elongate "protoceratopsian" egg type identified from the Djadokhta and other Upper Cretaceous formations of China and Mongolia. Sochava (1972) identified a possible protoceratopsian embryo associated with egg shell from the Bayn Shire at Tel Ulan Ula. However, only a poorly formed metatarsus is present and this is insufficient to identify the specimen as much better than an ornithischian.

Despite a strong focus on collecting microvertebrates by the Sino-Canadian expeditions, not a single mammal tooth or bone has been found to date.

5. Age of the Iren Dabasu Formation

The palaeontological data presented above have important implications for the assessment of the age of the Iren Dabasu Formation at Iren Nor. In the Bayn Shire Formation, the turtle *Kizylkumemys shuwalovi* is replaced by *Lindholmemys martinsoni* in younger parts of the section, a replacement that in Kazakhstan occurs in late Turonian time (Nessov, 1984). Shuvalov & Chkhikvadze (1979) pointed out that the faunas (characterized by *Gobiolla multicostata, Gobiolla elliptica, Kyzylkumemys shuwalovi* and possibly *Charitonyx tajanikolaevae*) at sites in the lower part of the Bayn Shire (Amtgai, Khara Khutul) suggest the beds are Cenomanian to Turonian, whereas the uppermost beds (characterized by *Sainshandia robusta, Basilemys orientalis* and *Lindholmemys martinsoni*) are Coniacian-Santonian. The occurrence of *Lindholmemys* in the Iren Dabasu Formation at Iren Nor and its stratigraphic occurrence in only the upper levels of the Bayn Shire in Mongolia suggest that the Iren Dabasu Formation is equivalent to the uppermost levels of the Bayn Shire.

The presence of *Saurornithoides* and the highly specialized *Avimimus* in the Iren Dabasu Formation is puzzling in light of their apparent absence in the Bayn Shire. These genera (as well as *Velociraptor*) are characteristic of Djadokhta (Campanian) and younger sediments in Mongolia and their presence may indicate that the Iren Dabasu was deposited later in time than the majority of Bayn Shire sites in Mongolia. The fauna from Bayshin Tsav, 300 km west of Erenhot, is the closest to that of the Iren Dabasu (Table 1), and may be equivalent in time and environmental conditions. Thus, we conclude that the Iren Dabasu Formation at Iren Nor is younger than Cenomanian and is best considered early Senonian in age. Preliminary data suggest that it may ultimately prove to be as young as Campanian.

6. Discussion of depositional environments and palaeoecology

6.1. *Depositional environments*

On the basis of sedimentological evidence presented above, we interpret the Iren Dabasu Formation as the remains of a fluvial system deposited in a semi-arid climate and comprising broad and shallow braided channels, and subaerially exposed floodplains that were the sites of palaeosol and caliche formation and short-lived pond/lacustrine or playa environments. This interpretation differs significantly from that of Berkey & Morris (1927, pp. 376, 377) and Morris (1936, pp. 1513, 1514) who described the depositional environments of the Iren Dabasu Formation as lakes and floodplains. These previous interpretations were based largely on palaeontological data and almost no sedimentological data. Our sedimentological data notwithstanding, we believe that the available palaeontological evidence is also more consistent with the fluvial interpretation proposed here.

The trace fossil assemblage is diagnostic of neither a lacustrine nor a fluvial setting and can only be interpreted as evidence of a freshwater (nonmarine) depositional environment (P. A. Johnston, pers. comm., 1991). The presence of *Pseudohyria* is also equivocal. Kolesnikov (1977) studied the microstructure, chemical and physical characteristics of the shells of *Pseudohyria* from the Bayn Shire Formation and concluded that these forms were living in the shallows of large, alkali lakes in a hot, arid climate. However, *Pseudohyria* is an extinct clam of the family Unionidae whose

modern members inhabit freshwater rivers and lakes. There is no conchological basis for interpreting *Pseudohyria gobiensis* as strictly fluvial or lacustrine. Morris (1936) believed that the presence of only one species of pelecypod in the Iren Dabasu Formation was indicative of a stressful environment compatible with a semi-arid lacustrine basin interpretation. Although we agree that the basin was semi-arid, such an interpretation does not prove the existence of lakes. Thus, although the Bayn Shire *Pseudohyria* may well have inhabited shallow lakes, there is no primary evidence that such was the case in the Iren Dabasu Formation.

The Iren Dabasu vertebrate assemblage is similar in basic composition to nonmarine vertebrate assemblages known from the Late Cretaceous coastal plains of North America (e.g., Dodson, 1983; Eberth, 1987) and is essentially terrestrial. Notable non-terrestrial vertebrates include hybodont sharks, rays and plesiosaurs, forms that are also present in the Late Cretaceous coastal plain of North America and are regarded as having periodically inhabited estuarine to coastal fluvial environments, not lakes. Their presence in the Iren Dabasu Formation clearly indicates that the basin was externally drained with a brackish and/or salt water connection. However, our palaeogeographic data are currently insufficient to indicate correctly the location of this connection.

6.2. *Palaeoecology*

Vertebrate-fossil lags at or near the base of coarse-grained channel deposits suggest that avulsive emplacement of these palaeochannels was accompanied by reworking, sorting and concentration of skeletal material and perhaps by mass mortality of vertebrates caught during the flooding events. Fossiliferous localities are laterally extensive over tens to hundreds of metres. The taxonomic composition at each locality is variable (Gilmore, 1933), suggesting that the fossil assemblages reflect, in some measure, in-life heterogeneous faunal distributions across the floodplain.

The association of nests of fossil eggs (representing at least four species of dinosaurs) with incipient palaeosols and caliche nodules indicates that portions of the floodplain were subaerially exposed for relatively long periods of time and were a favoured breeding habitat for some vertebrates. In his study of the egg shells, Van Straelen (1925) noted the striking differences in microstructure between the eggs of the Djadokhta and Iren Dabasu formations. He believed that those of the Djadokhta were adapted for incubation under arid conditions, and thus implied that those of the Iren Dabasu were not.

A rough tally of Sino-Soviet field identifications shows that ankylosaurs (27 bones) and sauropods (7 bones) were relatively uncommon in the Iren Dabasu, 'theropods' (including large theropods, small theropods and segnosaurs, but not ornithomimids) were more common (400 specimens), ornithomimids were numerous (more than a thousand bones) and hadrosaurs were dominant (almost 1500 specimens). These trends were reflected by the Sino-Canadian collections of 1988 and 1990. The apparent high numbers of carnivorous dinosaurs can be attributed mostly to ornithomimids and segnosaurids. The former are generally considered to be omnivorous. Segnosaurs may have been herbivores (Barsbold, 1983), but the possibility that they were also piscivorous should not be ruled out.

Acknowledgments

We would like to thank Dong Zhiming (Institute of Vertebrate Paleontology and Paleoanthropology, Beijing), Eugene Gaffney (American Museum of Natural

History, New York), Sergai Kurzanov (Paleontological Institute, Moscow), Li Rong (Inner Mongolian Museum, Hohhot) and Zhang Quanzhong (Erenhot Dinosaur Museum, Erenhot) for access to specimens (and in some cases field notes) from the Iren Dabasu in their care. We are also grateful to library staff at the American Museum of Natural History for assistance in relocating field notes and photographs in the archives. Additional information on the Sino-Soviet expeditions was provided by Drs Zhou Minchen and Zheng Jiajian (IVPP, Beijing). Dr Tom Jerzykiewicz (Institute of Petroleum and Sedimentary Geology, Calgary) and our colleagues (Dr Donald Brinkman, Dr Paul Johnston and Mr Kevin Aulenback) at the Royal Tyrell Museum all worked at Erenhot with us, and freely provided information in their specialities. Will Downs (Northern Arizona University) translated a number of the Chinese papers that were used in this study. The manuscript was reviewed by Dale Russell (Canadian Museum of Nature) and Tom Jerzykiewicz. All figures were done by the authors, but the assistance and advice of Donna Sloan are gratefully acknowledged. And finally, the Sino-Canadian expeditions and subsequent research would not have been possible without the financial assistance of the Donner Foundation (Toronto) and the Ex Terra Foundation (Edmonton).

References

Allen, J. R. L., 1986. Pedogenic calcretes in the Old Red Sandstone facies (Late Silurian–Early Carboniferous) of the Anglo-Welsh area, Southern Britain. In *Paleosols* (ed. V. P. Wright), pp. 58–86 (Princeton University Press, Princeton, New Jersey).

Andrews, R. C. 1932. *The new conquest of Central Asia, natural history of Central Asia, volume 1*, i + 678 pp. (American Museum of Natural History, New York).

Barsbold, R. 1981. Toothless carnivorous dinosaurs of Mongolia. *Joint Soviet-Mongolian Paleontological Expedition Transactions* **15**, 28–39. [In Russian].

Barsbold, R. 1983. Carnivorous dinosaurs from the Cretaceous of Mongolia. *Joint Soviet-Mongolian Paleontological Expedition, Transactions* **19**, 5–120. [In Russian].

Barsbold, R. & Osmólska, H. 1990. Ornithomimosauria. In *The Dinosauria* (eds Weishampel, D. B., Dodson, P. & Osmólska, H.), pp. 225–244 (University of California Press, Berkeley).

Berkey, C. P. & Morris, F. K. 1927. *Geology of Mongolia, natural history of Central Asia, volume II*, xxxi + 475 pp. (American Musuem of Natural History, New York).

Bohlin, B. 1953. Fossil vertebrates from Mongolia and Kansu. *Reports from the Scientific Expedition to North-West Provinces, Under the Leadership of Dr. Sven Hedin, Sino-Swedish Expedition Publication* **37**, 1–113.

Brett-Surman, M. 1979. Phylogeny and palaeobiogeography of hadrosaurian dinosaurs. *Nature* **277**, 560–562.

Brett-Surman, M. 1980. The Iren Dabasu fauna from Mongolia. *Mesozoic Vertebrate Life* **1**, 19–22.

Chkhikvadze, V. M. 1987. Sur la classification et les caractères de certaines tortues fossiles d'Asie, rares et peu etudiées. *Studia Palaeocheloniologica* **2**, 55–86.

Collinson, J. D. 1986. Alluvial Sediments. In *Sedimentary environments and facies* (ed. Reading, H. G.), pp. 20–62 (Blackwell Scientific Publications, Oxford).

Curray, J. R. 1956. The analysis of two dimensional orientation data. *Journal of Geology* **64**, 117–131.

Dodson, P. 1983. A faunal review of the Judith River (Oldman) Formation, Dinosaur Provincial Park, Alberta. *The Mosasaur* (Delaware Valley Paleontological Society) **1**, 89–118.

Eberth, D. A. (ed.) 1987. Palaeoecology of the Upper Cretaceous Judith River Formation at Dinosaur Provincial Park, Alberta, Canada. Mesozoic Terrestrial Ecosystems Fieldtrip Guidebook. *Occasional Paper of the Tyrrell Museum of Palaeontology* **1**, 33 pp.

Efimov, M. B. 1983. Revision of the fossil crocodiles of Mongolia. *Soviet-Mongolian Paleontological*

Expedition, *Transactions* **24**, 76–95. [In Russian].
Efremov, I. A. 1949. Preliminary results of the work of the first Mongolian Paleontological Expedition of the Academy of Sciences, U.S.S.R., 1946. *Akademia Nauk S.S.S.R.*, *Trudy Mongolskaya Komissiia* **38**, 5–28. [In Russian].
Folk, R. L. 1980. *Petrology of sedimentary rocks.* 182 pp. (Hemphill Publishing Company, Austin).
Gilmore, C. W. 1931. Fossil Turtles of Mongolia. *American Museum of Natural History, Bulletin* **59**, 213–257.
Gilmore, C. W. 1933. On the dinosaurian fauna of the Iren Dabasu Formation. *American Museum of Natural History*, *Bulletin* **67**, 23–78.

Goudie, A. S. 1983. Calcrete. In *Chemical sediments and geomorphology* (eds Goudie, A. S. & Pye, K.), pp. 93–131 (Academic Press, London).
Grabau, A. W. 1928. *Stratigraphy of China, Part 2, Mesozoic,* 774 pp. (Geological Survey of China, Peking).
Granger, W. & Berkey, C. P. 1922. Discovery of Cretaceous and older Tertiary strata in Mongolia. *American Museum of Natural History Novitates* **42,** 7 pp.
Hirsch, K. F., Stadtman, K. L., Miller, W. E. & Madsen, J. H., Jr. 1989. Upper Jurassic dinosaur egg from Utah. *Science* **243,** 1711–1713.
Jerzykiewicz, T. & Russell, D. A. 1991. Late Mesozoic stratigraphy and vertebrates of the Gobi Basin, a review. *Cretaceous Research*, **12**, 345–377.
Kolesnikov, C. M. 1977. Taxonomic microstructural specificity of lamellibranch shells of the genus *Pseudohyria,* from Cretaceous deposits of the Gobi. *Soviet-Mongolian Paleontological Expedition, Transactions* **4,** 97–105. [In Russian].
Kurzanov, S. J. 1987. Avimimidae and the problem of the origin of birds. *Soviet-Mongolian Paleontological Expedition, Transactions* **31,** 1–92. [In Russian].
Mader, B. J. & Bradley, R. L. 1989. A redescription and revised diagnosis of the syntypes of the Mongolian tyrannosaur *Alectrosaurus olseni. Journal of Vertebrate Paleontology* **9,** 41–55.
Marinov, N. A. 1971. Geological map of the Mongolian People's Republic, 1:500,000. 4 sheets. Academy of Sciences of the Mongolian People's Republic, Ulaan Baatar.
Martinson, G. G. 1982. Upper Cretaceous molluscs of Mongolia (systematics, stratigraphy, taphonomy). *Soviet-Mongolian Paleontological Expedition, Transactions* **17,** 1–83. [In Russian].
Martinson, G. G., & Kolesnikov, C. M. 1974. Cretaceous limnetic mollusca from fossiliferous rock tables in Mongolia. *Soviet-Mongolian Paleontological Expedition, Transactions* **1,** 235–246. [In Russian].
Maryańska, T. & Osmólska, H. 1975. Protoceratopsidae (Dinosauria) of Asia. *Palaeontologia Polonica* **33,** 133–181.
Maryanska, T. & Osmólska, H. 1981. Cranial anatomy of *Saurolophus angustiostris* with comments on the Asian Hadrosauridae (Dinosauria). *Palaeontologia Polonica* **42,** 5–24.
McKee, E. D., Crosby, E. J. & Berryhill, H. L. 1967. Flood deposits. Bijou Creek, Colorado. June, 1965. *Journal of Sedimentary Petrology* **37,** 829–851.
Meylan, P. A. & Gaffney, E. S. 1989. The skeletal morphology of the Cretaceous cryptodiran turtle, *Adocus,* and the relationships of the Trionychoidea. *American Museum Novitates* **2941,** 60 pp.
Miall, A. D. 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In *Fluvial sedimentology* (ed., Miall, A. D.), pp. 597–604 (*Canadian Society of Petroleum Geologists, Memoir* **5**).
Mohabey, D. M. 1987. Juvenile sauropod dinosaur from Upper Cretaceous Lameta Formation of Panchmahals District, Gujarat, India. *Journal of the Geological Society of India* **30,** 210–216.
Morris, F. K. 1936. Central Asia in Cretaceous time. *Bulletin of the Geological Society of America* **47,** 1477–1534.
Nessov, L. A. 1984. Data on Late Mesozoic turtles from the USSR. *Studia Palaeocheloniologica* **1,** 215–223.
Nessov, L. A. & Udovichenko, N. I. 1986. New finds of Cretaceous and Paleogene vertebrate remains in Middle Asia. *Paleontological Questions* **9,** 129–136, 158–161. [In Russian].
Nessov, L. A. & Khisarova, G. D. 1988. New data on Late Cretaceous vertebrates from Shakh-Shakh and Baybolat (northeastern Pryaral'e). *Materials on the History of Fauna and Flora of Kazakhstan* **10,** 5–14. [In Russian].
Obruchev, V. A. 1900–1901. *Central Asia, northern China and Nan Shan. Report on the Explorations of* 1892–1894. 2 volumes (St. Petersburg). [In Russian].
Perle, A. 1977. On the first discovery of *Alectrosaurus* (Tyrannosauridae, Theropoda) from the Late Cretaceous of Mongolia. *Problems of Mongolian Geology* **3,** 104–113. [In Russian].
Retallack, G. J., 1990. *Soils of the past,* 520 pp. (Unwin Hyman, Boston).
Rozhdestvenski, A. K. 1977. The study of dinosaurs in Asia. *Journal of the Palaeontological Society of India* **20,** 102–119.
Russell, D. A. 1972. Ostrich dinosaurs from the Late Cretaceous of western Canada. *Canadian Journal of Earth Sciences* **9,** 375–402.
Shuvalov, V. F. & Chkhikvadze, V. M. 1979. On the stratigraphic and systematic position of some freshwater turtles from new Cretaceous localities in Mongolia. *Soviet-Mongolian Paleontological Expedition, Transactions* **8,** 58–76. [In Russian].
Shuvalov, V. F. & Trusova, E. K. 1979. Upper Cretaceous conchostracans of Mongolia. *Soviet-Mongolian Paleontological Expedition, Transactions* **8,** 83–93. [In Russian].
Smith D. G., 1983 Anastomosed fluvial deposits: modern examples from Western Canada. In *Modern and ancient fluvial systems* (eds Collinson, J. D. & Lewin, J.), pp. 155–168 (*International Association of Sedimentologists, Special Publication* **6**).
Smith, D. & Galton, P. 1990. Osteology of *Archaeornithomimus asiaticus* (Upper Cretaceous, Iren Dabasu Formation, People's Republic of China). *Journal of Vertebrate Paleontology* **10,** 255–265.
Sochava, A. V. 1972. The skeleton of an embryo in a dinosaur egg. *Paleontological Journal* **4,** 88–92. [In Russian].

Sochava, A. V. 1975. Stratigraphy and lithology of southern Mongolia. *Joint Soviet-Mongolian Scientific Research Geological Expedition, Transactions* **13,** 113–182. [In Russian].
Tsibin, J. I. & Kurzanov, S. M. 1979. New data on Upper Cretaceous vertebrate localities of the Baishin-Tsav region. *Soviet-Mongolian Paleontological Expedition, Transactions* **8,** 108–112. [In Russian].
Tumanova, T. A. 1987. The armored dinosaurs of Mongolia. *Soviet-Mongolian Paleontological Expedition, Transactions* **32,** 1–80. [In Russian].
Tunbridge, I. P. 1981. Sandy high-energy flood sedimentation—some criteria for recognition, with an example from the Devonian of S.W. England. *Sedimentary Geology* **28,** 79–96.
Van Straelen, V. 1925. The microstructure of the dinosaurian egg shells from the Cretaceous beds of Mongolia. *American Museum of Natural History, Novitates* **173,** 4 pp.
Walker, R. G. & Cant, D. J. 1984. Sandy fluvial systems. In *Facies models.* (ed. Walker, R. G.), 71–90 pp. (*Geoscience Canada Reprint Series* **1**).
Weishampel, D. B. & Horner, J. R. 1986. The hadrosaurid dinosaurs from the Iren Dabasu Formation (People's Republic of China, Late Cretaceous). *Journal of Vertebrate Paleontology* **6,** 38–45.
Wilson, M. C. & Currie, P. J. 1985. *Stenonychosaurus inequalis* (Saurischia: Theropoda) from the Judith River (Oldman) Formation of Alberta: new findings on metatarsal structure. *Canadian Journal of Earth Sciences* **22,** 1813–1817.
Yeh, H.-K. 1965. New materials of fossil turtles of Inner Mongolia. *Vertebrata PalAsiatica* **9,** 47–78.
Zhang, Z. K. 1979. Progress in the research of dinosaur eggs. In *Mesozoic and Cenozoic red beds of South*

China, Selected Papers from the "Cretaceous-Tertiary Workshop," Nanziong, Guangdong Province (eds Institute of Vertebrate Paleontology and Paleoanthropology & Nanjing Institute of Paleontology), pp. 330–340 (Science Press, Beijing). [In Chinese].