

THE BARUUNGOYOT-NEMEGT TRANSITION (UPPER CRETACEOUS) AT THE NEMEGT TYPE AREA, NEMEGT BASIN, SOUTH CENTRAL MONGOLIA

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Abstract: The Baruungoyot and Nemegt formations interfinger through a minimum of 23 meters of stratigraphic section at Nemegt. This interfingering stratigraphic interval comprises the lower one-half of the Nemegt Formation's stratigraphic exposure in the area. This interfingering formational contact, as well as an upsection increase in conglomeratic sediments in the Nemegt Formation are evidence for progradation of the Nemegt clastics. We infer that during Nemegt "time," uplift in the paleo-Altan Nemegt source area increased both sediment supply and the depositional gradient, which, in turn, decreased accommodation. Decreased accommodation resulted in a preservational bias for channel-fill and sheet flood deposits. During progradation, a multi-kilometer-wide Nemegt meanderbelt episodically shifted its position to the southeast, and occasionally back-stepped to the northwest, thus leaving a succession of interfingering Baruungoyot and Nemegt tongues in the stratigraphic record. The meanderbelt hosted medium-size channels (~6 m deep and 75 m wide) that flowed to the southwest. Southeast of the meanderbelt, seasonally wet-dry distal-basin environments of the Baruungoyot Formation continued to exist during the time represented by the interfingering interval. The interfingering interval is the most vertebrate-fossil rich part of the stratigraphic section in this area (Nemegt meanderbelt tongues in particular). Rich fossil occurrences in this interfingering interval indicate that many of the Nemegt and Baruungoyot vertebrates from this interval co-existed.

Key words: Nemegt Formation, Baruungoyot Formation, Nemegt Basin, Mongolia, Gobi Desert, dinosaurs

INTRODUCTION

On the basin scale, the age and nature of the boundary between the Upper Cretaceous Baruungoyot Formation ("Barun Goyot" in much of the western literature) and overlying Nemegt Formation is poorly understood (Gradzinski *et al.*, 1977; Jerzykiewicz and Russell, 1991). Conventional practice is to regard both units as chronostratigraphically distinct, with the Nemegt Formation and its fauna regarded as younger than the Baruungoyot Formation and its fauna (e.g., Jerzykiewicz and Russell, 1991; Osmólska, 1997a, b; Jerzykiewicz, 2001; Shuvalov, 2001). In biostratigraphic terms, this inferred temporal dichotomy is supported by the distinctiveness of the faunas from the two units (there is some minor faunal overlap, including: *Avimimus portentosus*, "*Ingenia*," and *Tarchia*; Gradzinski *et al.*, 1977; Osmólska, 1997a, b).

During a one week visit to the Nemegt "locality" on a Nomadic Expeditions dinosaur tour of south central Mongolia in 2006, we had an opportunity to reassess the stratigraphic relationships of the two units. Our results indicate that there is a significant stratigraphic interval, at least 23 meters thick, in which the two units interfinger. This "interfingering interval" is uniquely rich in vertebrate fossils com-

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pared to other intervals of the Baruungoyot and Nemegt formations that occur below it and above it, respectively.

Here we describe the stratigraphy and architecture of this interfingering interval, infer its origins, and raise questions about its possible biostratigraphic significance. In this manuscript we follow the spellings of Benton (2001) for Mongolian locations and stratigraphic units, except in those cases where we quote original literature.

LOCATION, SETTING, METHODS

The type area, geological setting, sedimentology, and biostratigraphic importance of the Baruungoyot and Nemegt formations have been described by Gradzinski and colleagues in a succession of papers presenting the results of the Polish-Mongolian Palaeontological Expeditions (e.g., Gradzinski *et al.*, 1968; Gradzinski, 1970; Gradzinski *et al.*, 1977; Jerzykiewicz, 2001). Exposures of the Baruungoyot and Nemegt Formations are exposed patchily around the margins of the Nemegt Basin (Fig. 1), a narrow, east-west elongate subdivision of the larger “Gobi Basin” that formed and filled episodically due to graben and half-graben faulting/extension during the Mesozoic and Tertiary (Jerzykiewicz and Russell, 1991; Jerzykiewicz, 2001). Because of the general absence of discrete marker beds, microfossil biostratigraphy, and datable volcanics in the Cretaceous of southern Mongolia (cf. Osmólska, 1997b; Eberth *et al.*, 2009), it remains difficult to determine the precise age of these stratigraphic units and their fossils, and to correlate exposures between localities.

We employed standard methods for mapping, section and transect measurement, and sedimentary geology data-gathering. Previous stratigraphic/sedimentologic studies across northern China (Hendricks *et*

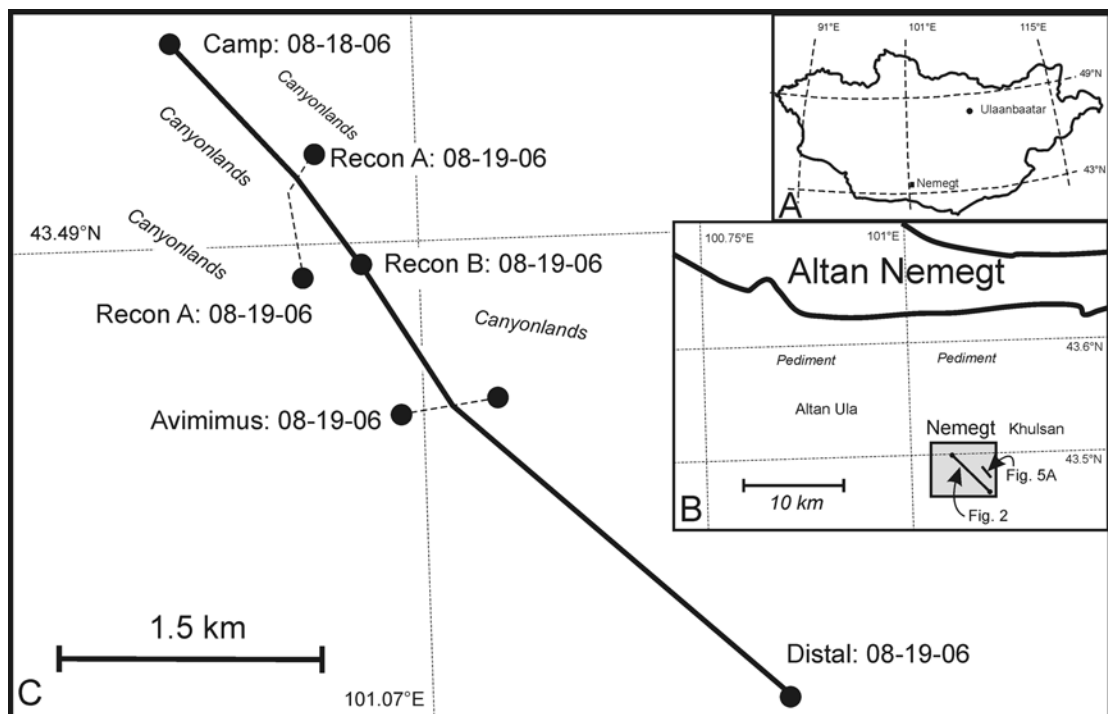


Fig. 1. Locality maps. A, Location of the Nemegt locality in south central Mongolia. B, Location of the Nemegt cross-section shown in Figure 2 and relative to the modern day Altan Nemegt uplift front; C, Locations of the five measured sections used in this study (see Appendix 1 for details). Dashed lines in ‘C’ indicate section extents.

al., 1992; Eberth *et al.* 2001) have shown that a sequence stratigraphic approach (e.g., Miall, 1991; Catuneanu, 2003) can be used to correlate between localities, and infer the temporal significance of surfaces and formational boundaries. Thus, our focus was on identifying and interpreting lithologic and sedimentologic changes, and changes in stratigraphic architecture.

We studied the transition between the Baruungoyot and Nemegt formations at “Nemegt,” a small area of canyonlands 10-15 kilometers south of an east-west trending Tertiary uplift referred to as “Altan Nemegt” (Fig. 1; Gradzinski, 1970; Gradzinski and Jerzykiewicz, 1974a; Gradzinski *et al.*, 1977). Here, Upper Cretaceous strata dip structurally $\sim 3^\circ$ to the southwest. Even though outcrops of the Nemegt and Baruungoyot formations can be traced patchily southward in the small canyon system that dissects the pediment of the Altan Nemegt, the amount and direction of structural dip in the bedrock is similar to the modern pediment gradient, resulting in bedrock exposures with limited stratigraphic thicknesses, even where multiple sections are correlated across kilometers.

We focused mostly on the interfingering interval between the two formations (“passage series” of Gradzinski, 1970). There was insufficient time to restudy the thick packages of Baruungoyot redbeds below the interfingering interval at Khulsan (east of Nemegt), or the outcrops of the Nemegt Formation above the interfingering interval at Altan Ula (west of Nemegt). These are described in detail by Gradzinski (1970) and Gradzinski and Jerzykiewicz (1974a, b). Although DAE, as a member of the Korean-Mongolian International Dinosaur Project expedition in 2007, collected data from the Baruungoyot-Nemegt transition at Kheermen Tsav (100 km west of Nemegt), those data will be presented elsewhere.

MEASURED SECTIONS

We measured six sections at Nemegt. However, only five include the interfingering interval between the Baruungoyot and Nemegt formations (Appendix 1) and are used here. When correlated, the five sections comprise a cross-section that is 5.2 kilometers long (Figs. 1, 2A) and a composite section that is 54 m thick (Fig. 2B).

Data from the measured sections confirm many of the sedimentological details that were described and interpreted by Gradzinski and his colleagues (see references listed above). In particular, the Baruungoyot Formation comprises a stacked succession of tabular redbeds consisting of fine grained sediments deposited in alluvial (channel, floodplain, and floodbasin), lacustrine, and eolian environments (Fig. 3). Invertebrate feeding traces are common throughout the Baruungoyot sediments (Fig. 3D and E), and dinosaur tracks andurbation are locally abundant, especially in overbank mudstones and channel abandonment mudstones that are overlain by sand and silty channel fill deposits.

In contrast, the Nemegt Formation comprises a stacked succession of light grey to tan colored alluvial channel, splay, and sheetflood deposits. The alluvial channel deposits are overwhelmingly dominated by stacked successions of large-scale inclined beds (Fig. 4A), which are interpreted by Gradzinski *et al.* (1977) and us as lateral accretion deposits in meandering rivers. Large-scale inclined surfaces bound sets of trough cross-beds and current ripples (Fig. 4B), which we interpret as the preserved remains of subaqueous dunes and ripples that migrated along submerged point bar surfaces and channel thalwegs. In situ caliches are present (Fig. 4C) but not abundant, whereas reworked caliches (Fig. 4D) are ubiquitous, occurring commonly as CaCO_3 -cemented lag deposits at the base of upward-fining paleochannel successions (see sections in Appendix 1). As in the Baruungoyot Formation, simple tubular invertebrate feeding traces are common throughout deposits of fine grained sandstone and siltstone.

Dinosaur tracks in mudstone are particularly well preserved due to infilling by CaCO_3 -cemented sandstones (Fig. 4F; Currie *et al.*, 2003). The uppermost one-third of the Nemegt exposures in the field area reveals an increase in reworked-caliche conglomerates. At the very top of our southern-most measured sections (“Avimimus” and “Distal,” see Appendix 1), CaCO_3 -cemented sandy sheets containing well-round-

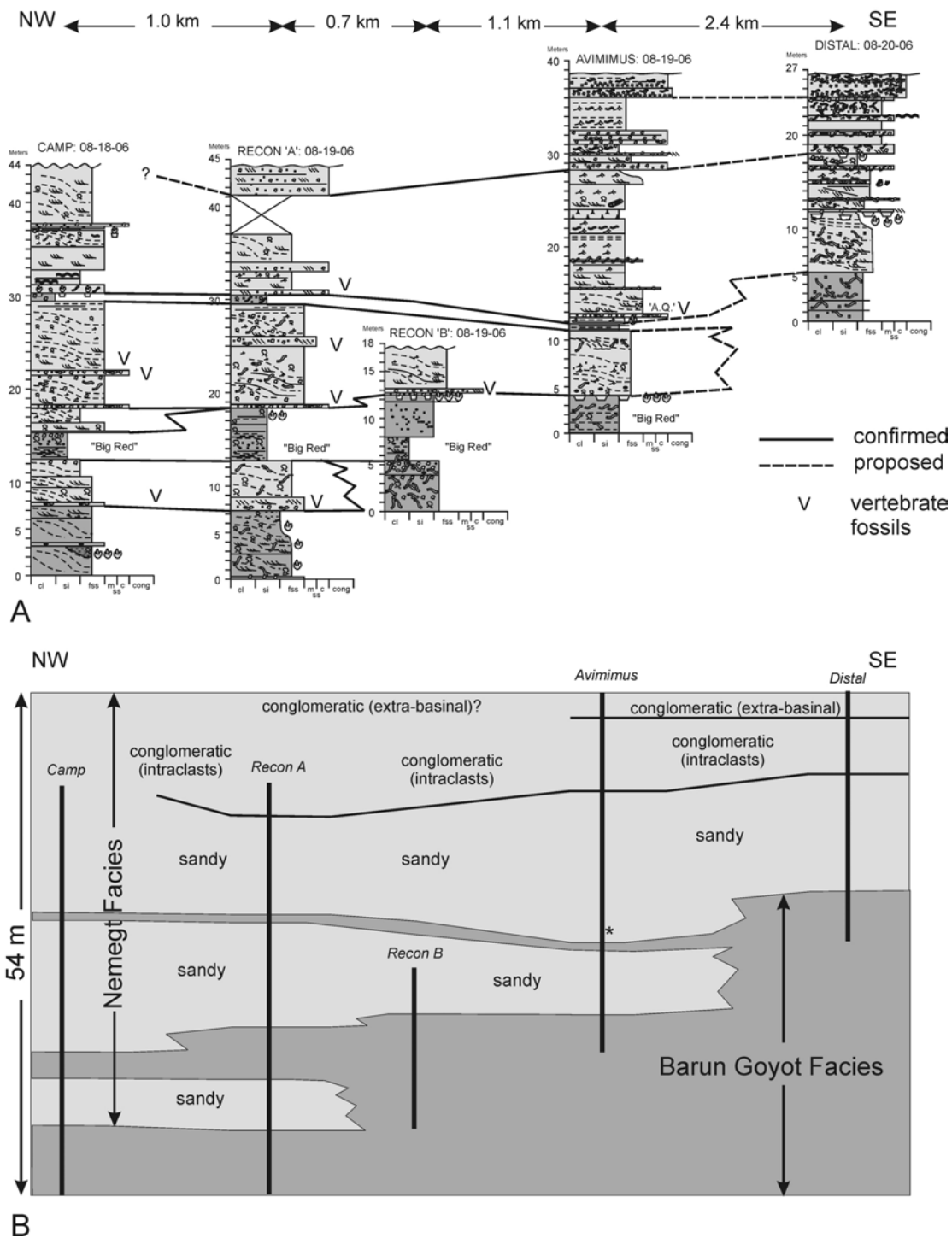


Fig. 2. A, Correlation of 5 measured sections at Nemegt. Each section is shown in detail (with symbol key) in Appendix 1. B, Simplified correlation diagram showing (1) the overall progradational nature of the Nemegt Formation clastics relative to the Barun Goyot Formation, and (2) the coarsening upward nature of the Nemegt in this part of the section.

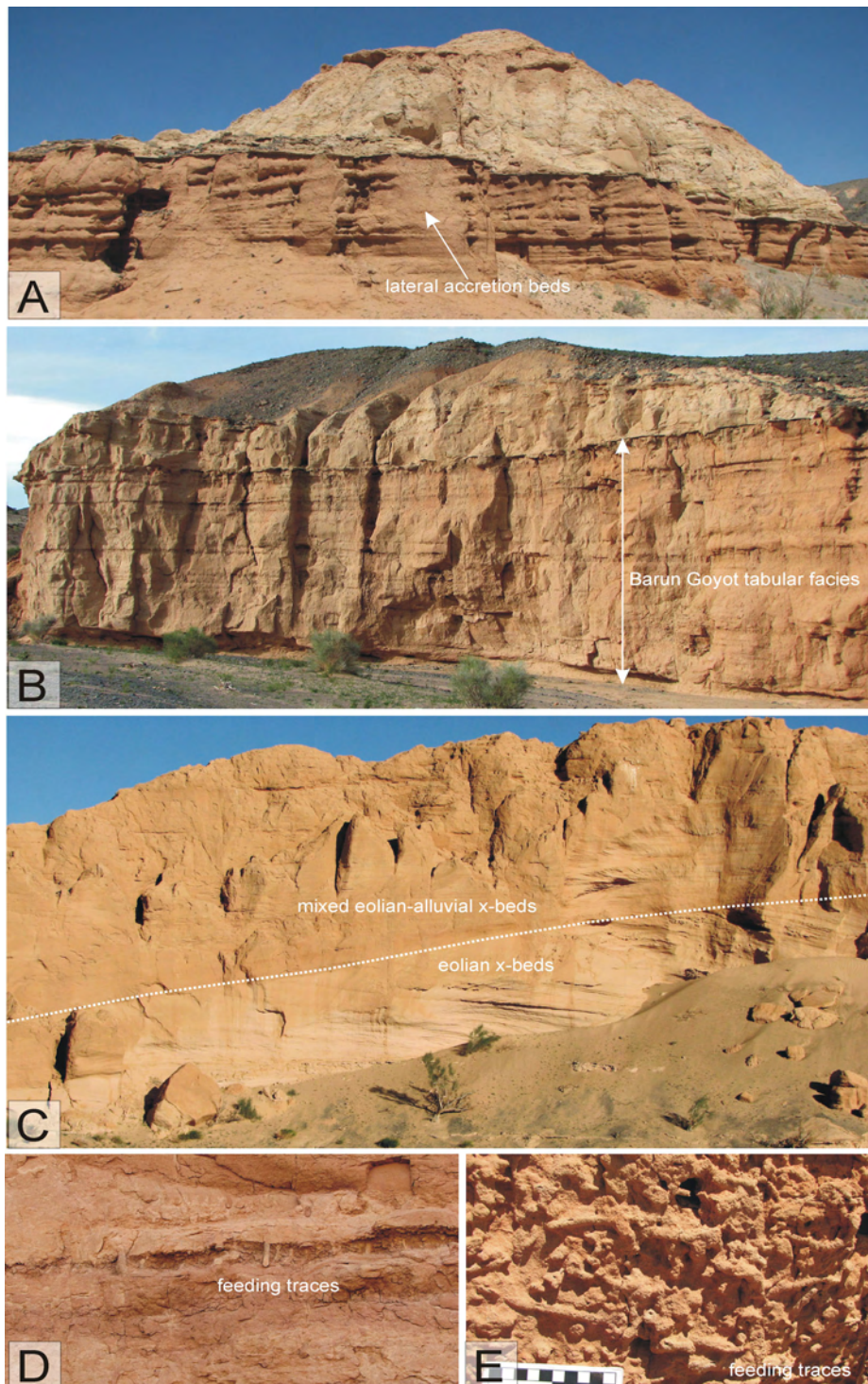


Fig. 3. Photographs showing the most typical facies in the Baruungoyot Formation. A, Lateral accretion beds in a 4 meter thick meandering stream deposit. Localized contact with the Nemegt Formation overlies the inclined beds; B, Typical horizontally bedded mudstones and fine sandstones. Horizontally bedded interval is ~ 6 meters thick; C, High relief inclined surface separating giant eolian cross beds (below) from alluvial cross bedded strata above; D and E, Typical examples of simple tubular burrow fills interpreted by us as nonmarine invertebrate feeding traces.

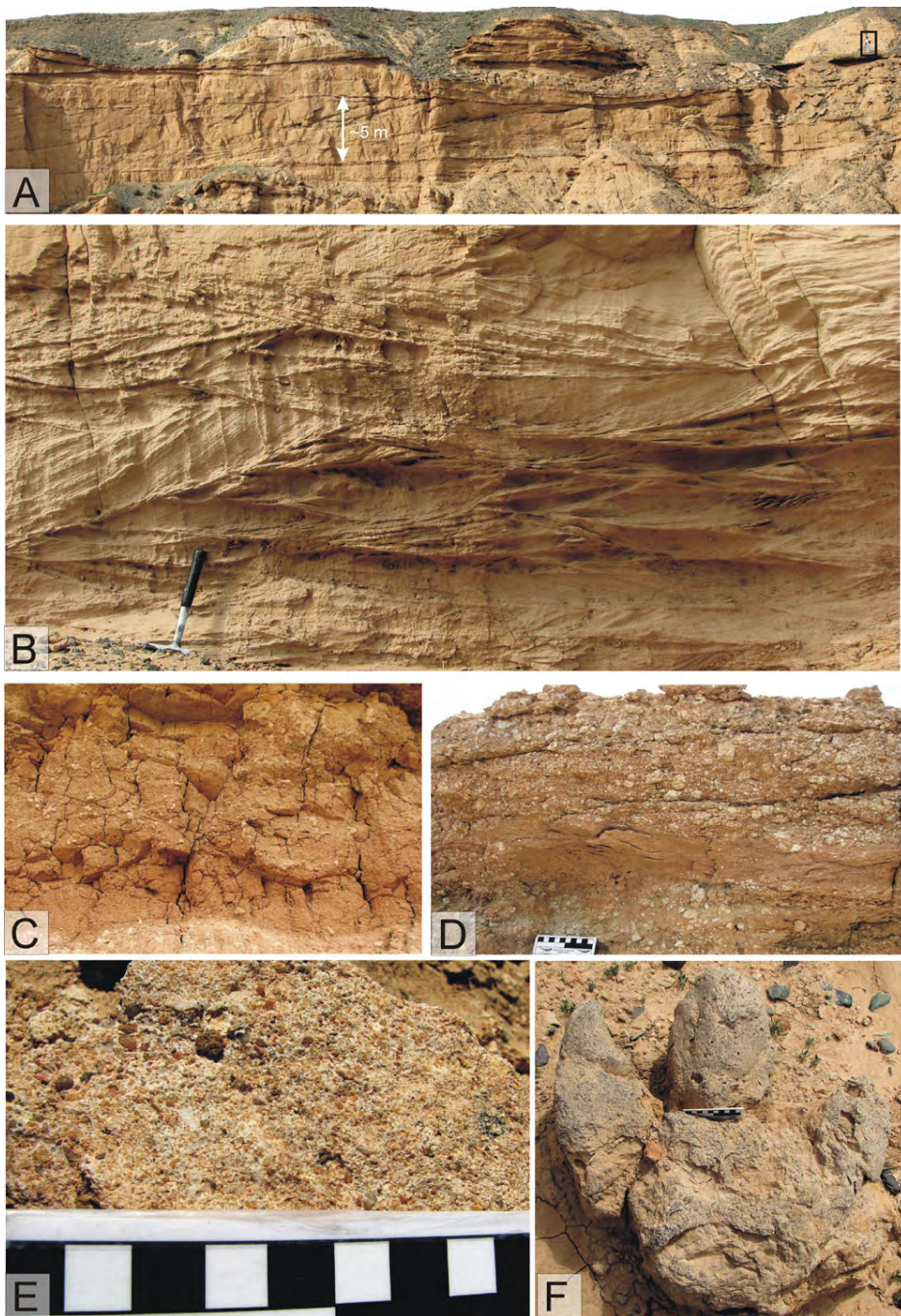


Fig. 4. Photographs showing the typical facies in the Nemegt Formation. A, Sandy lateral accretion beds in a 5 meter thick meandering stream deposit. Person for scale in the upper right. This paleochannel succession was used to calculate the reconstructed dimensions of one of the larger meandering channels in the Nemegt Formation. Calculations from Schumm and Khan, (1971) Bankful depth is estimated at 6 m (precompacted vertical relief), whereas bankful width is calculated at 75 m ($1.5 \times$ lateral accretion surface width [50 m]); B, Meter-thick deposit of trough cross-bedded sandstone; C, In-situ caliche glaebules and concretions; D, Reworked caliche clasts in a normal-reverse graded sandstone deposit; E, Granule-stone at the top of the “Avimimus” measured section (see Appendix 1); F, well-cemented track-fill of a hadrosaur dinosaur; originally located at the base of a cliff-forming sandstone at meter 30 in the “Camp” section (see Appendix 1).

ed to sub-angular metamorphic granules and pebbles are ubiquitous. Unlike the Baruungoyot Formation, where mudstones comprise more than three-quarters of any section (see Gradzinski *et al.*, 1977), the Nemegt Formation sections that we examined are heavily dominated (>80%) by channel fill sandstones and sandy-to-pebbly sheet-flood deposits of probable distal alluvial fan origin (Appendix 1).

THE NW-SE TRANSECT

We correlated numerous surfaces and stratigraphic sub-units within the five measured sections (Figs. 2 and 5A) by walking them out or following them visually at distance in the field. Mapping of the interfingering interval of the Baruungoyot and Nemegt formations was relatively easy because of obvious differences in the color, lithologies, and weathering of these two units (Fig. 5).

The resulting cross-section (Fig. 2) reveals that the Nemegt Formation became interfingering with the Baruungoyot Formation as it prograded to the southeast across a distance of no less than 5.2 kilometers. The interfingering interval comprises two distinct tongues of the Nemegt Formation, which comprise the lower one-half of the formation's exposure in the field area (Fig. 2B). The lower tongue extends southeastward for at least 1.3 km, whereas the upper tongue extends southeastward for almost 4 km before abrupt truncation (Fig. 5A).

Both tongues comprise meandering channel deposits with paleocurrent and architectural data that indicate flow was toward the southwest, approximately 90° to the direction of tongue truncation (Appendix 1; Fig. 4A; Gradzinski, 1970, fig. 26), and broadly subparallel to the inferred front of the source area (Cretaceous-age Altan Nemegt).

By far, the vast majority of Nemegt Formation vertebrate fossils occur in the lower one-half of the Nemegt Formation exposures in this area, and within or just above the zone of interfingering (see vertebrate fossil distributions in Appendix 1 and Fig. 2).

The upper one-half of the Nemegt Formation comprises a continuous sheet of sediment, approximately 27 m thick (Fig. 2). However, as noted above, this portion of the Nemegt yields evidence of an upsection transition from sandy meandering channel deposits to an uppermost stratigraphic interval dominated by sheetflood deposits, which comprise intraformational caliches and extraformational metamorphic granules and pebbles (Fig. 2B).

DISCUSSION

The data presented above indicate that the stratigraphic transition between the Baruungoyot and Nemegt formations in the Nemegt Canyon region involved significant changes through time in sediment supply and depositional gradient. These changes clearly influenced the depositional settings of the Nemegt Basin, but did not do so instantaneously. Both formations interfinger through a stratigraphic interval that is at least 23 meters thick, and thus represents a time when Baruungoyot and Nemegt environments and vertebrate faunas coexisted.

This interfingering interval was noted by Gradzinski (1970), but was apparently regarded as a minor aspect of the formational transition (see Gradzinski 1970, fig. 3; Gradzinski *et al.*, 1977, fig. 12). However, there are three aspects of this transition that underscore its importance: (1) the exposed interval of interfingering represents one-half of the full exposure of the Nemegt formation in this area; (2) the interfingering interval hosts, by far, most of the vertebrate fossils (and quarry sites) that we observed (at least in the Nemegt Formation); and (3) limited outcrop prevent a fuller understanding of whether or not this interfingering is also expressed (a) upsection and out into the basin, and/or (b) down section and toward source.

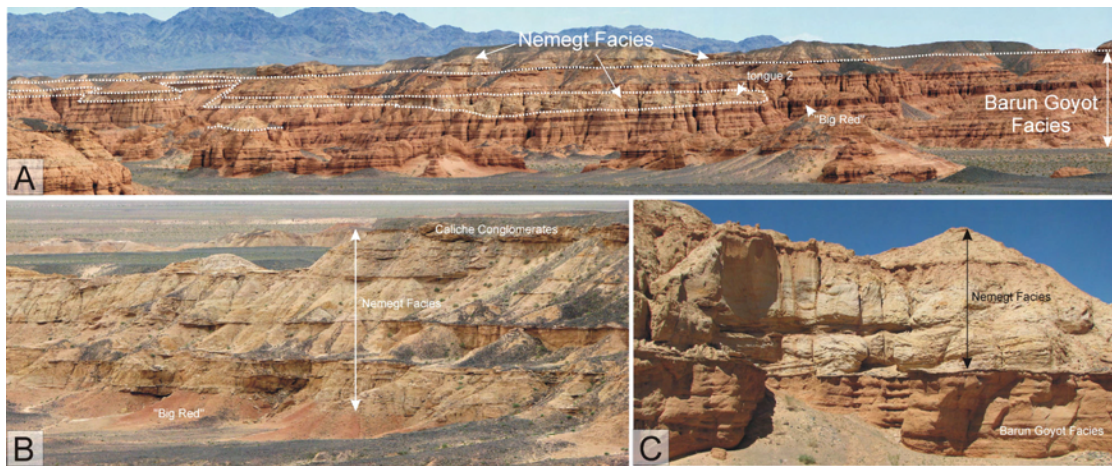


Fig. 5. Photographs showing the interfingered contact between the Baruungoyot and Nemegt formations at Nemegt. A, Clearly labeled contact. Photograph is looking east-northeast, and location of outcrop is indicated as “Fig. 5A” in Figure 1B. Note the Nemegt sandstone tongue (above “Big Red”) with (1) thick, right-dipping inclined surfaces (lateral accretion surfaces), (2) a localized lenticular cross-sectional shape, and (3) a blunt termination. All of these features indicate this sandstone body was deposited by a meandering channel that was migrating to the right (southeast) and was eventually abandoned. The small width of the channel [indicated by the width of any inclined surface] relative to the extent of the tongue suggests that this channel was part of a larger meanderbelt. Paleoflow direction is out of the picture toward the southwest. The Altan Nemegt is in the background. B, Part of the Recon A measured section. Note the presence of “Big Red,” a prominent redbed tongue of the Baruungoyot in this area. See Appendix 1 “Recon A” for details. C, Sharp contact of the Nemegt Formation on the Baruungoyot Formation close to the “Camp” section (see Appendix 1).

We interpret the interfingering interval as an important reflection of how the Nemegt depositional system evolved through time. The section and cross-section data presented here suggest that along the south flanks of the Altan Nemegt, proximal alluvial fan deposits (hypothesized to exist in the subsurface north of Nemegt) merged down-dip (southeastward) into a prominent meanderbelt of sandy meandering channels that flowed to the southwest, subparallel to the uplift front (cf. Legarreta and Uliana, 1998, fig. 7). Our outcrop data indicate that the largest channels in the meanderbelt were ~6 meters deep and ~75 meters wide (calculations follow Schumm and Khan [1971] as applied to the inclined bedded strata shown in Fig. 4A). Gradually, sediment supply rates and depositional gradient increased, causing the meander belt to prograde episodically to the southeast. During overall progradation, however, tectonic adjustments likely resulted in some occasional backstepping of the meanderbelt -- thus creating the interfingering tongues of the Baruungoyot and Nemegt formations.

The overall upsection shift from Baruungoyot seasonal wetlands and eolian dune fields, to sandy meandering channels (lower and middle Nemegt exposures), and eventually, into sheet flood deposits dominated by reworked caliches and extrabasinal clasts (upper Nemegt exposures) suggests ongoing uplift in the source area, an increasing sediment supply and depositional gradient, and a commensurate decrease in accommodation. Climate changes, marked by seasonal to decadal long increases in both rainfall and aridity, are also likely to have influenced these changes (Gradzinski *et al.*, 1977). Decreased accommodation during Nemegt ‘time’ resulted in a preservational bias favoring channel-fill and sheet-flood deposits (cf. Cateneanu, 2003).

During the time represented by the lower one-half of the cross-section shown in Figure 2, distinctive Nemegt and Baruungoyot strata and vertebrates were being deposited at the same time, but in the meanderbelt and more distal floodbasin/eolian portions of the basin, respectively. On the time scale represented by the upper one-half of the cross-section in Figure 2, sediments sourced from the Cretaceous

Altan Nemegt poured in from the north, eventually swamping the field area with distal alluvial fan deposits, and shifting the position of the meander belt farther to the southeast. To what extent (temporally and geographically) the Nemegt meanderbelt continued to prograde to the southeast is unknown due to outcrop limitations.

CONCLUSIONS

We have documented that the Baruungoyot-Nemegt formational contact interfingers through a minimum of 23 meters of stratigraphic section at Nemegt. This interfingering interval represents one-half of the stratigraphic extent of the Nemegt Formation's exposure in this area. We regard this interfingering interval and the upsection increase in conglomeratic sediments as strong evidence for the southeastward progradation of Nemegt Formation clastics. These data suggest uplift in the northern source areas resulting in an increased sediment supply, an increase in depositional gradient, and a commensurate decrease in accommodation.

Progradation involved the episodic southeastward shifting of a kilometer wide meanderbelt that hosted channels flowing to the southwest. Farther southeast of the meanderbelt, seasonally wet and dry flood-basin environments of the Baruungoyot Formation remained in existence for an unknown amount of time.

Although the different depositional settings of the Baruungoyot and Nemegt formations makes it unlikely that there is much taphonomic equivalency in their fossil assemblages, the assemblages that occur through the 23 meter thick interfingering interval are best interpreted as coeval.

These data and interpretations now raise important new questions: (1) What was the full range of tectonic and climatic influences on the changes in depositional style and stratigraphic architecture that has been documented here? (2) What was the full range and distribution of coeval depositional environments across the Nemegt Basin during the transition? (3) How do these interpretations relate to the stratigraphic intervals exposed at Altan Ula and Kheermen Tsav? And (5) what are the implications of these data for biostratigraphic comparisons of Baruungoyot and Nemegt faunas?

ACKNOWLEDGEMENTS

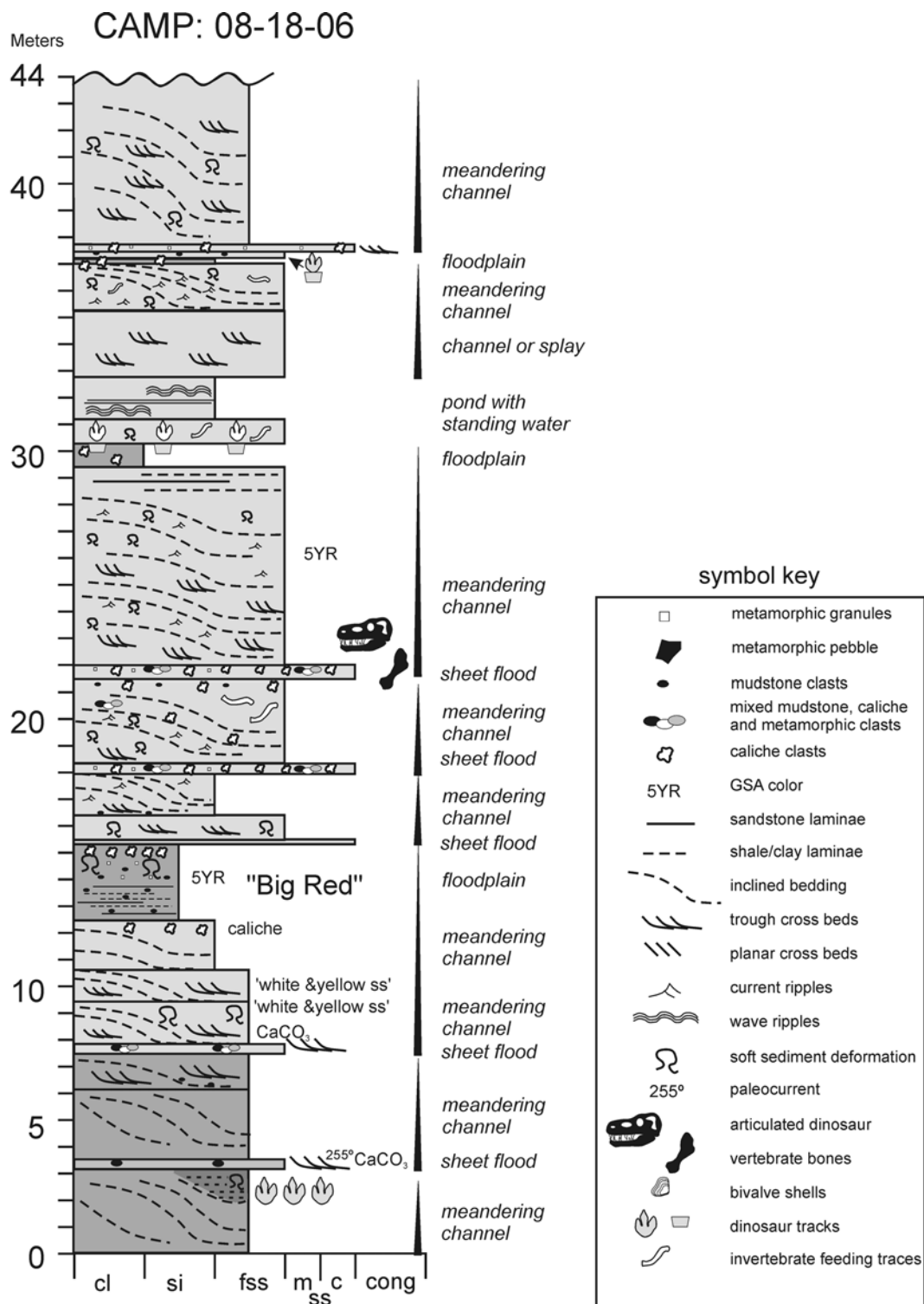
We thank Nomadic Expeditions and the Mongolian Academy of Sciences for the opportunity to visit Nemegt in 2006. We thank all members of the 2006 expedition for their tireless efforts and positive spirit. We also thank Yuong-Nam Lee and the organizers of the 2009 Goseong International Dinosaur Symposium for the invitation to participate in this symposium, and the opportunity to view Upper Cretaceous rocks at Kheermen Tsav in 2007.

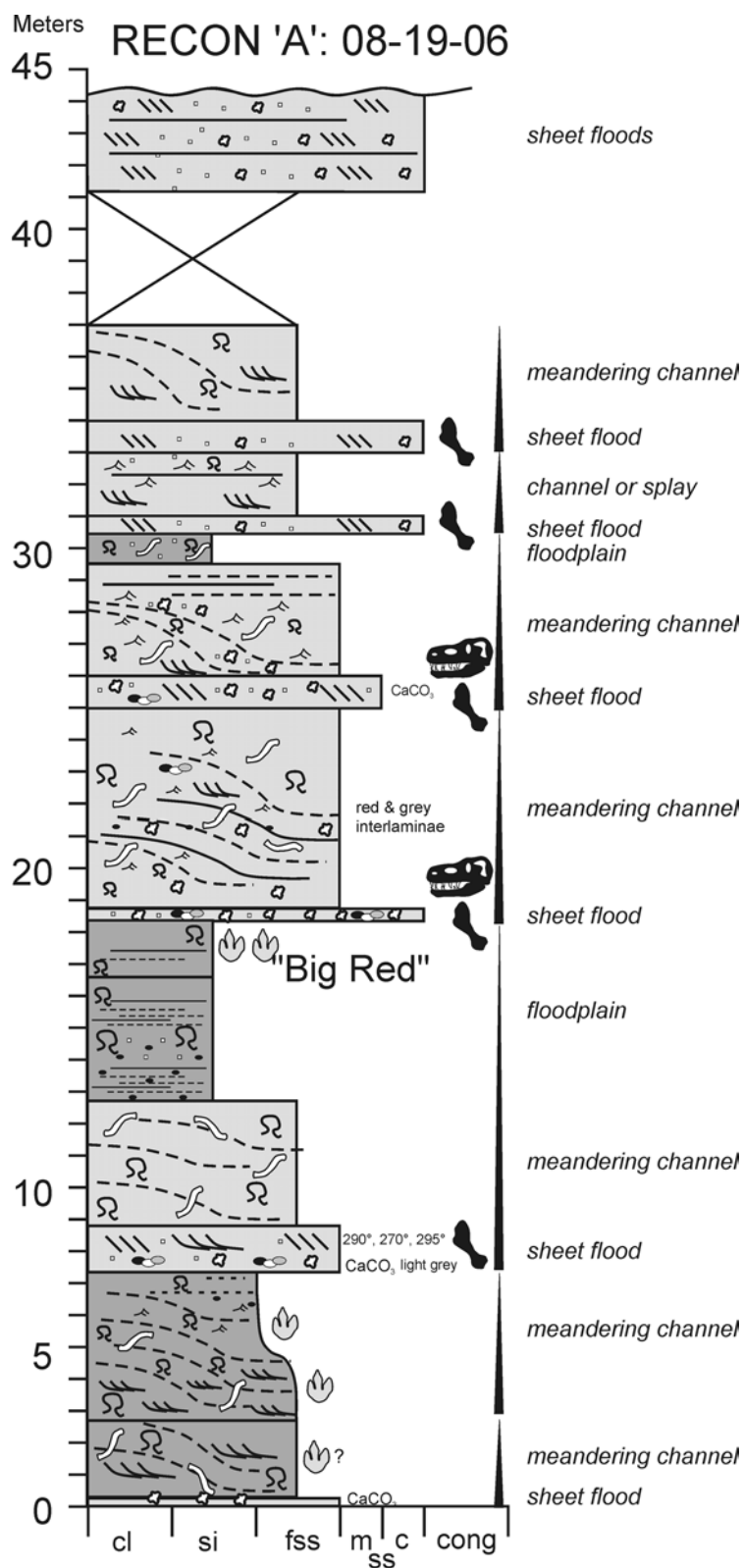
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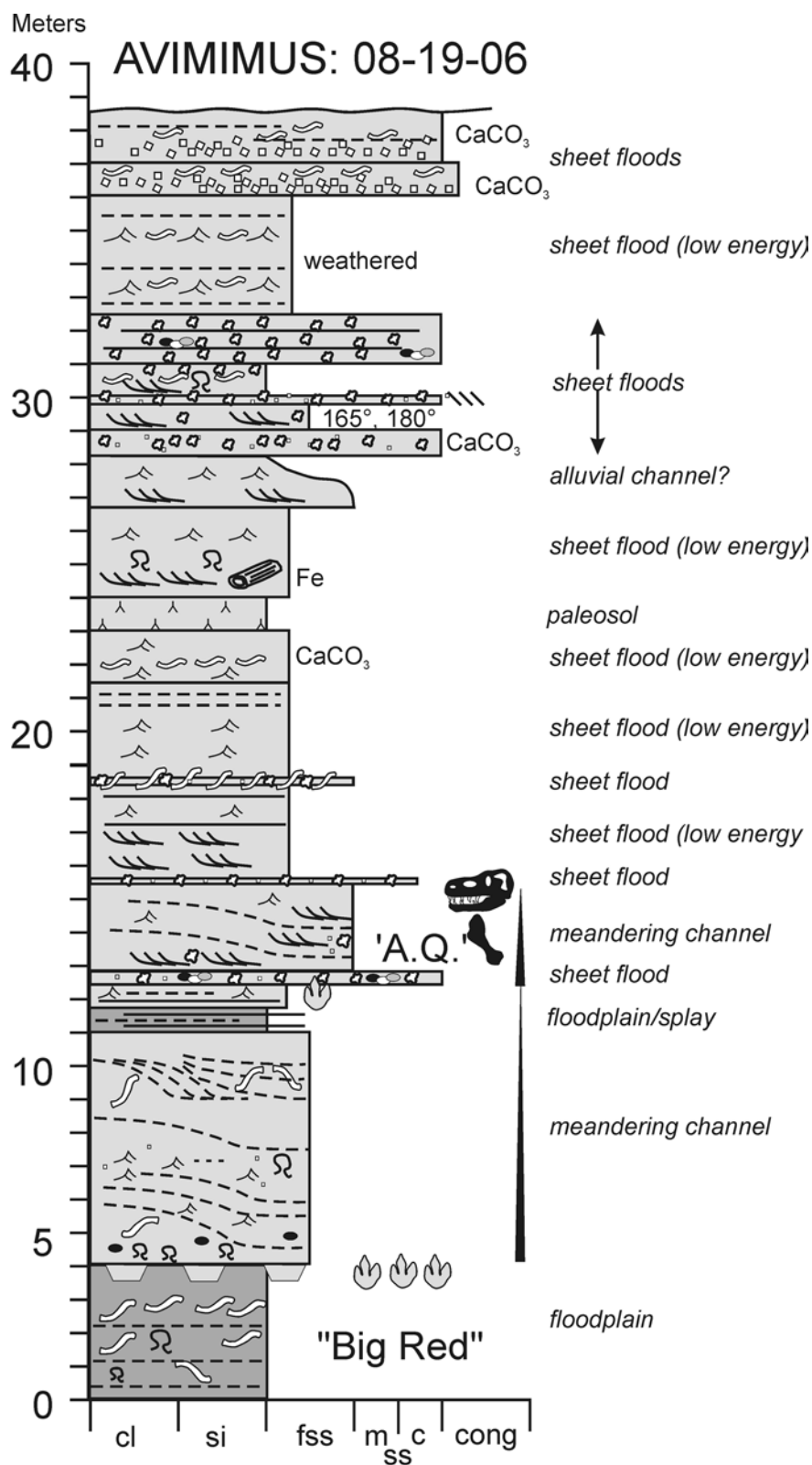
Five measured sections from the Nemegt area. Symbol key is included in the Camp Section. Paleoenvironmental interpretations are listed to the right, and are based on our interpretations and those published by Gradzinski (1970), Gradzinski and Jerzykiewicz (1974b), and Gradzinski *et al.* (1977). Abbreviations: cl, claystone; si, siltstone; fss, fine grained sandstone; mss, medium grained sandstone; css, coarse grained sandstone; cong, conglomerate; **A.Q.** in the *Avimimus* section, stratigraphic position of the *Avimimus* Quarry (Currie *et al.*, 2008). The location of the base of each section is as follows:

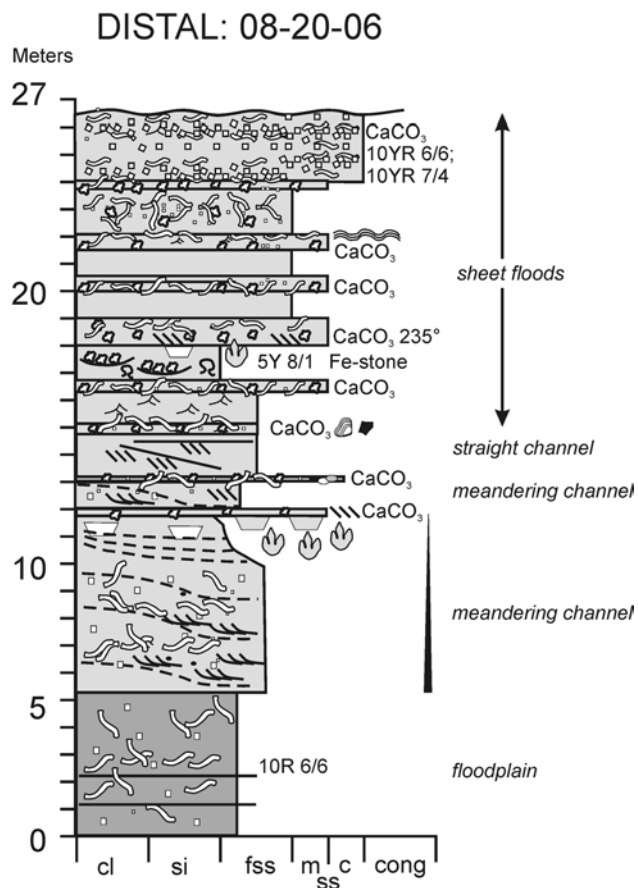
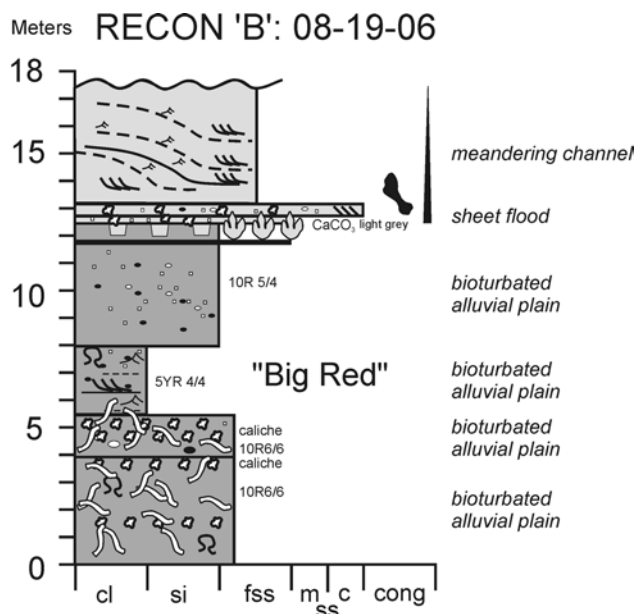
Camp	08-18-06:	43° 30.044'N; 101° 03.157'E
Recon A	08-19-06:	43° 29.678'N; 101° 03.746'E
Recon B	08-19-06:	43° 29.327'N; 101° 03.945'E

Avimimus 08-19-06: 43° 28.940'N; 101° 04.298'E
 Distal 08-20-06: 43° 27.943'N; 101° 05.755'E









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