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CROCODYLIAN COPROLITES FROM THE EOCENE OF THE ZAYSAN BASIN, KAZAKSTAN

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Abstract—The Zaysan Basin of northeastern Kazakstan-northwestern China includes nonmarine coprolite-bearing strata of late Eocene age. Here, approximately 50 coprolites were collected from a single horizon stratigraphically low in the late Eocene (Ergilian land-mammal "age") Aksyir svita. Two morphologies are present within the coprolite sample: (1) relatively large coprolites (diameter and length generally > 20 mm) with rounded ends and cylindrical cross sections and (2) relatively small coprolites (length ~16-23 mm, maximum diameter 9-16 mm) that are rounded in shape. The larger coprolites are assigned to the ichnotaxon *Eucoprus*, whereas the smaller coprolites are assigned to *Alococopros triassicus*. The presence of the coprolites in lacustrine shoreline facies, co-occurrence of crocodylian body fossils in the coprolite-bearing strata and the similarity in shape and texture to modern crocodylian feces and lack of bony inclusions suggests a crocodylian producer for the Aksyir svita sample. The variation in their morphology, here assigned to two ichnotaxa, underscores the lack of a single, distinctive crocodylian coprolite morphology.

INTRODUCTION

The Zaysan Basin of northeastern Kazakstan-northwestern China (Fig. 1) is a collisional successor basin that formed during the Late Cretaceous (Graham et al., 1993; Allen et al., 1995). During the Late Cretaceous, a lake basin developed in the Zaysan Basin and has been there till the present (Lucas et al., 2000, 2009). Lake Zaysan is now one of the largest freshwater lakes of Central Asia.

Around the periphery of Lake Zaysan, particularly in the river drainages that enter it from the south and southeast, badlands have developed in the ancient basin fill, and this has also taken place in parts of the topographically less rugged terrain just north of the lake. These badlands mostly expose Eocene, Oligocene and Miocene sedimentary rocks that yield one of Asia's most significant records of early to middle Tertiary fossil mammals (e.g., Russell and Zhai, 1987; Lucas et al., 2009). Here, we document vertebrate coprolites from a locality in Eocene lake-margin strata in the Zaysan Basin. In this article, NMMNH refers to the New Mexico Museum of Natural History, Albuquerque, New Mexico.

LOCALITY AND STRATIGRAPHY

The coprolites reported here are from a locality along the Aksyir River south of Lake Zaysan, located at UTM zone 45, 385382E, 5255060N (datum: WGS 84). This locality is in the northern limb of Aksyir anticline 1 (cf. Russell and Zhai, 1987, p. 230) in the lower part of the Aksyir svita (Fig. 2). It is locality K38 of our field records (= NMMNH locality 3596). Also referred to as "Tagvy" (Russell and Zhai, 1987, p. 230), it was collected by one of us (SGL) on 18 June 1993.

Two lithostratigraphic (actually lithochronologic) schemes are generally applied to the Upper Cretaceous-Pleistocene strata of the Zaysan Basin. These schemes, of Lavrov and Yerofeyev (1958) and of Borisov (1963, 1983, 1984), employ the Soviet stratigraphic term svita as the basic unit of lithostratigraphic subdivision. These svitas are recognized not only by their lithologic characteristics; they also represent (at least in theory) isochronously-bounded time stratigraphic units defined by their fossil content.

Furthermore, the base of each svita is supposed to correspond to the initiation of a separate cycle of deposition. Each svita thus has lithologic, biochronologic and genetic (sedimentologic) significance, so that the svita has no precise equivalent in Western stratigraphic theory and terminology. We have begun to publish a strict lithostratigraphic scheme of the Upper Cretaceous-Cenozoic strata in the Zaysan Basin

FIGURE 1. Map of Kazakstan showing location of Zaysan basin.

(Lucas et al., 2000, 2009, 2012). Pending completion of this work, we refer the coprolite-bearing horizon to the lower part of the Aksyir svita of Borisov's stratigraphy (Fig. 2; Appendix).

The coprolite-bearing horizon at NMMNH locality 3596 is a 2-3 cm thick bed of sandy shale and ripple-laminated fine sandstone with numerous disorganized coprolites, almost all of which were broken prior to fossilization. The coprolites show no preferred orientation, and all appear to have had their surfaces abraded/polished (Fig. 3). The bed is ~40 m above the base of the Aksyir svita and can be traced on strike for tens of meters (Fig. 2). We interpret the coprolite bed as an allochthonous lag deposit of an old shoreline or beach of paleo-Lake Zaysan (also see Martinson and Kyansep-Romashkina, 1980). Thus, we consider this deposit to be a physical accumulation of coprolites, which is an accretionary latrinite (sensu Hunt and Lucas, 2012a).

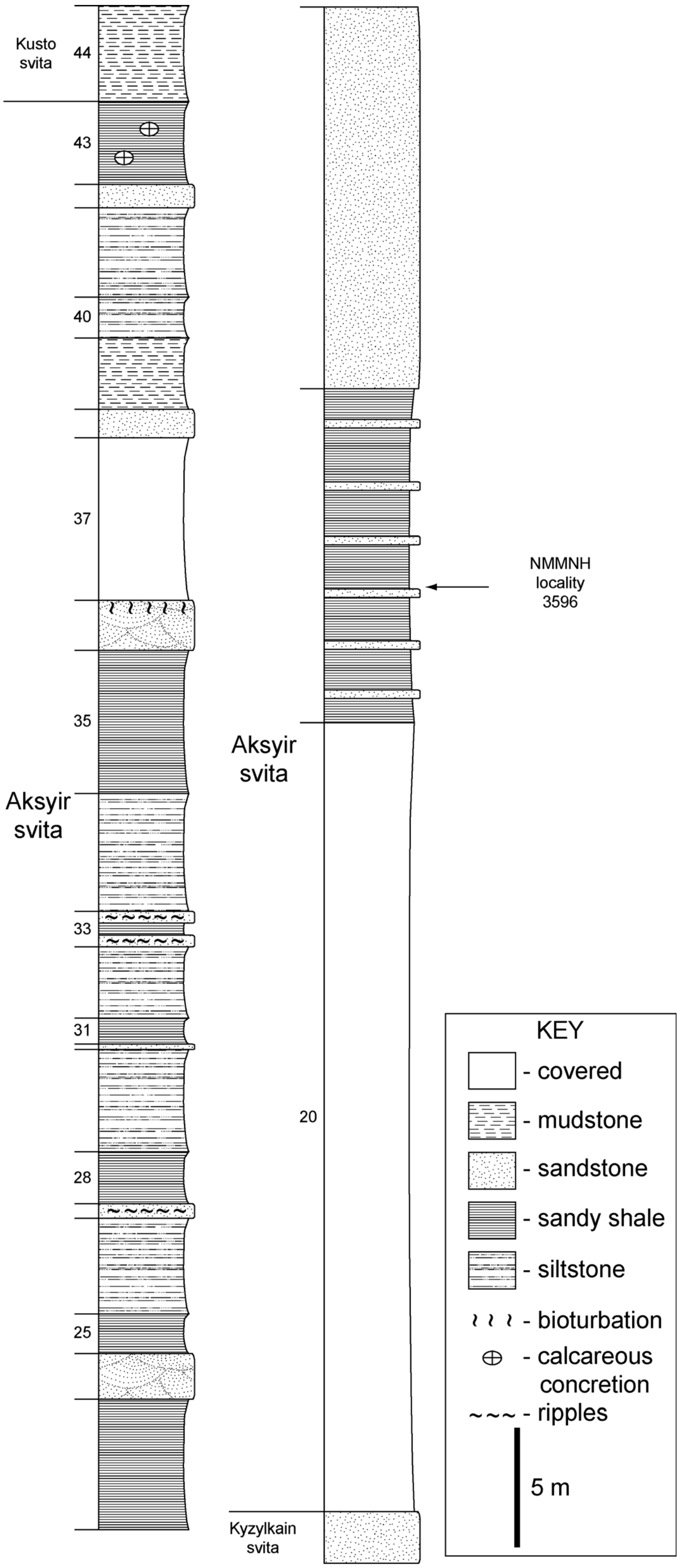

FIGURE 2. Measured section of Aksyir svita on northern limb of Aksyir anticline 1 in the Zaysan basin, Kazakstan showing stratigraphic location of coprolite locality. See Appendix for description of numbered lithologic units.

PALEONTOLOGY

The Upper Cretaceous-Cenozoic deposits of the Zaysan Basin have received intensive study, especially because of their rich fossil record. Borisov (1963), Martinson and Kyansep-Romashkina (1980), Gabuniya et al. (1983), Ilinskaya et al. (1983), Gabuniya (1984a, b), Russell and Zhai (1987) and Lucas et al. (2000, 2009) reviewed much of this record. Lacustrine and/or lacustrine margin deposits in the Zaysan basin produce extensive fossil assemblages of megaflora, charophytes, ostracods, unionid bivalves, nonmarine gastropods, freshwater fishes, turtles and mammals. Crocodylian fossils are restricted to the middle-late Eocene part of the section, and there is a sparse fossil bird record. The fossil mammals are particularly important because they provide the most precise age control of the Tertiary part of the section (Russell and Zhai, 1987; Emry et al., 1998; Lucas et al., 2009).

Mammals from the Aksyir svita are of late Eocene age (Ergilian land-mammal "age"). These mammals are present stratigraphically low in the Aksyir svita at Chakelmes and Kiin Kerish Mountains and at some locations southeast of Lake Zaysan (Lucas et al., 1996; Emry et al., 1997, 1998; Bayshashov and Lucas, 2001; Lucas, 2006). The coprolites documented here are from the interval of the Aksyir svita that contains Ergilian mammal fossils.

COPROLITES

The NMMNH collection includes 30 catalogued individual coprolites and ~25 more coprolites catalogued as a single lot from NMMNH locality 3596. We illustrate representative coprolites and polished cross sections of coprolites from this sample (Fig. 3). We divide these coprolites into two morphological groups (Groups A and B). The first group, Group A, are relatively large (diameter and length generally > 20 mm) with rounded ends and cylindrical cross sections (Fig. 3, Table 1). These coprolites are mostly straight, but some have slight flexure of their long axes. All have smooth or slightly pitted, untextured outer surfaces. Polished cross sections and broken ends reveal no inclusions of bones, teeth or scales.

The second morphology of coprolites, Group B, are relatively small (length ~16-23 mm, maximum diameter 9-16 mm) and are rounded in shape (Fig. 3, Table 1). One of these specimens preserves faint striations (Fig. 3A-D). Like the larger coprolites, surface textures are smooth or slightly pitted, and internally there are no osseous inclusions.

The smaller coprolites from the Aksyir svita probably all had some striations, but have been abraded smooth. We tentatively assign them to *Alococopros triassicus* (Hunt et al., 2007) because of their striations and their small size. They differ from the holotype and referred specimens (Hunt et al., 2007, figs. 3A-B) in the faintness of the longitudinal striations. This is the recognized first occurrence of this ichnospecies in the Cenozoic. The larger coprolites can be coprolites can be identified as *Eucoprus* ichnosp. (Hunt and Lucas, 2012b).

DISCUSSION

The fundamental problem when interpreting vertebrate coprolites has always been identifying the producer (Hunt and Lucas, 2010). The coprolites described here are a case in point. Their abundance in a stratum we interpret as lake margin deposits suggests an amphibious or aquatic producer. Size, shape and the lack of obvious osseous inclusions well match those of extant crocodylian feces (see the descriptions and illustrations of extant crocodylian feces in Milàn and Hedegaard, 2010; Milàn, 2012), and bones/teeth of crocodylians are known from the lower Aksyir svita. The Aksyir svita coprolites also resemble what appear to be *bona fide* fossil crocodylian coprolites (Sawyer, 1981; Souto, 2010; Milàn, 2010).

However, as Hunt and Lucas (2010) cogently argued, there is no particular morphology that diagnoses a coprolite as crocodylian. Thus, in the case of the Aksyir svita coprolites attribution to a crocodylian is based on: (1) inferred aquatic/amphibious producer base on abundance in

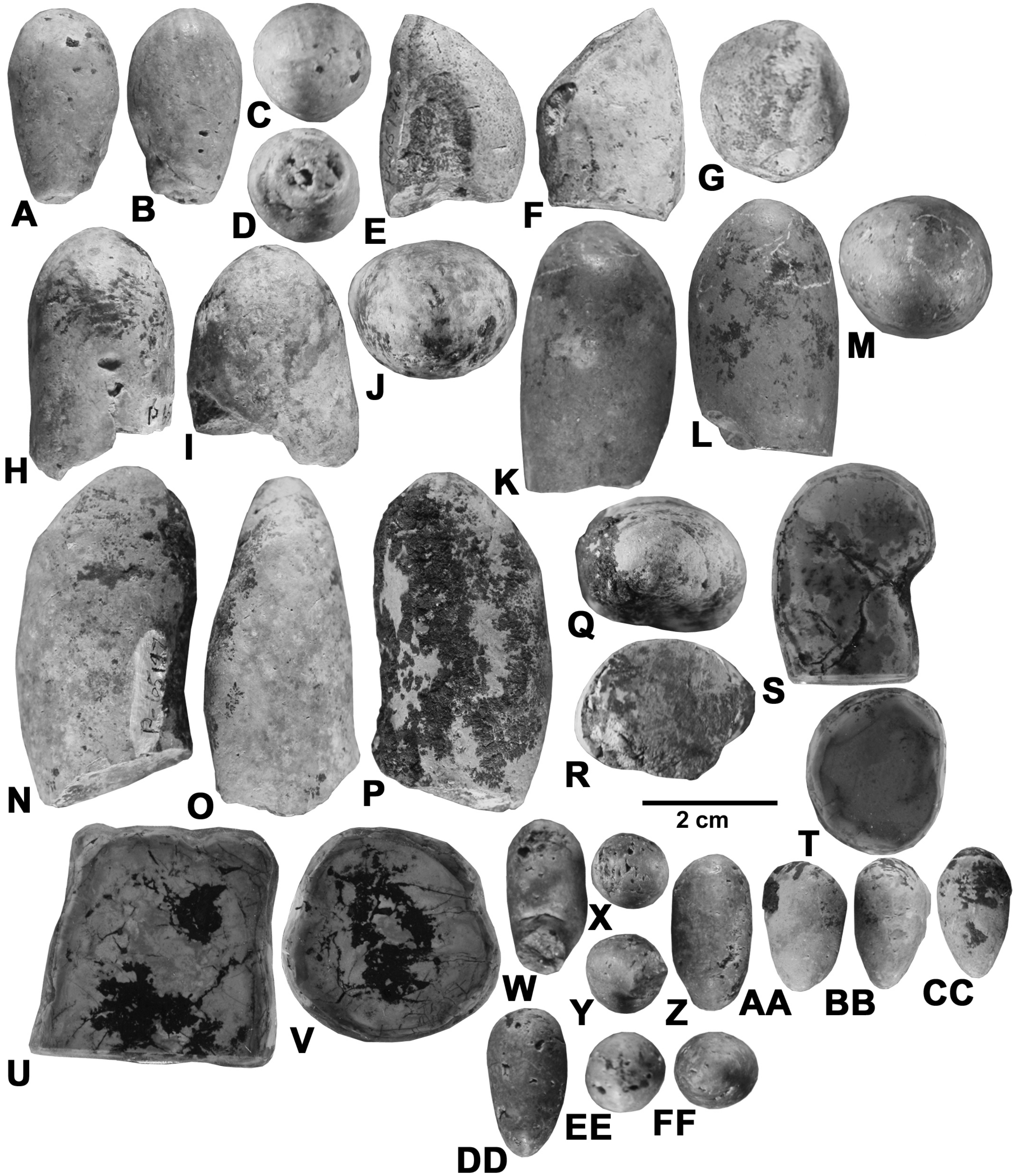

FIGURE 3. Crocodylian coprolites from the lower part of the late Eocene Aksyir svita in the Zaysan basin of Kazakstan. **A-R**, **W-FF**, Coprolites in external view and **S-V**, coprolites in cross sectional view. **A-R**, **U-V**, Group A coprolites and **W-FF**, Group B coprolites. **A-D**, NMMNH P-65161. **E-G**, NMMNH P-65146. **H-J**, NMMNH P-65151. **K-M**, NMMNH P-65149. **N-R**, NMMNH P-65147. **S**, NMMNH P-65170. **T**, NMMNH P-65154. **U**, NMMNH P-65168. **V**, NMMNH P-65167. **W-Z**, NMMNH P-65154. **AA-CC**, NMMNH P-65148. **DD-FF**, NMMNH P-65158. **A-D**, **W-FF**, are assigned to *Alococopros triassicus*. **E-V**, are identified as *Eucoprus* ichnosp.

a lacustrine shoreline facies; (2) presence of crocodylian body fossils in the strata that yield the coprolites; and (3) the similarity in shape, texture and lack of bony inclusions to modern crocodylian feces and some coprolites very likely to have been produced by crocodylians. We point out the possibility, though, suggested to us by C. Diedrich (written commun., 2012) that some of the smaller coprolites documented here might have been produced by a fish (also see Wuttke, 1998).

The Aksyir svita coprolites thus can be confidently assigned to a crocodylian producer. The variation in their morphology, here assigned to two ichnotaxa, underscores the lack of a single, distinctive crocodylian coprolite morphology.

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APPENDIX - DESCRIPTION OF MEASURED STRATIGRAPHIC SECTION: AKSYIR RIVER ANTICLINE NORTH LIMB

Section begins at UTM 386343, 5257390N (datum: WGS 84), on south limb of anticline; strata dip 21° to S 20°W. Section top is at UTM 387066, 5259710N (datum: WGS 84). The Aksyir svita portion of the section is depicted in Figure 2.

unit	lithology	thickness(m)
Sarybulak svita:		
67	Clayey sandstone; dusky yellow (5Y6/4) and grayish orange (10YR7/4); very fine-grained; limonitic grains; ripple laminated; crest of third hogback.	**4.1**
66	Sandy mudstone; pale olive (10Y6/2); many calcrete nodules; calcareous; some pink bands.	**8.8**
65	Sandstone; pinkish gray (5YR8/1); fine- to medium–grained; poorly sorted; subrounded; quartzarenite; conglomerate at top of unit consists mostly of granite clasts up to 3 cm in diameter; clasts are pink, gray and black; conglomerate is matrix supported; unit has complex multistoried troughs and ripple laminae; much bone at 45385648E, 5255435N (datum: WGS 84).	**4.4**
Zaysan svita:		
64	Silty mudstone and siltstone; mudstone is pale olive (10Y6/2); calcareous; siltstone is very pale orange (10YR8/2) with dark yellowish orange (10YR6/6) limonitic mottles; calcareous.	**19.4**
Akzhar svita:		
63	Sandy mudstone; moderate reddish brown (10R4/6); calcareous; forms a prominent red band; only locally exposed in gully cuts.	**4.0**
62	Covered; appears to be clay much like unit 28.	**6.7**
61	Sandstone and conglomerate; yellowish gray (5Y8/1) with brownish gray (5YR4/1) halos on rhizoliths; very fine- to very coarse-grained; angular; poorly sorted; very micaceous; clasts are quartzite and metamorphic lithics up to 3 cm in diameter; forms a low ridge in the strike valley; intensive rhizolith bioturbation.	**2.3**
Nura svita:		
60	Claystone; same colors and lithologies as units 54 and 55.	**3.4**
59	Gravelly sandstone interbedded with sandy siltstone; sandstone is yellowish gray (5Y8/1); medium- to very coarse-grained; subrounded; poorly sorted; quartzarenite; calcareous; clayey siltstone is light greenish gray (5GY8/1); calcareous; calcareous nodules like unit 54; top sandstone is heavily bioturbated and well indurated.	**2.5**
58	Silty mudstone; greenish gray (5GY6/1); some dark yellowish orange (10YR6/6) limonitic mottles; not calcareous; also bentonitic mudstone; olive gray (5Y4/1); not calcareous.	**1.2**
57	Mudstone with sandstone lenses; black (N1); sandstone is very light gray (N7) and light brownish gray (5YR6/1); medium grained; subrounded; well sorted; clayey quartzarenite; calcareous.	**1.7**
56	Sandy bentonitic mudstone; olive gray (5Y4/1); concretionary band at base with calcareous nodules that are grayish yellow (5Y8/4) with olive black speckles (5Y2/1); concretions are up to 7 cm in diameter; forms a rusty brown band.	**2.3**
Oshagande svita:		
55	Sandstone; pale greenish yellow (10Y8/2); very fine grained; well sorted; subrounded; quartzarenite; slightly micaceous; not calcareous; friable; some troughs.	**1.2**
54	Shale; same color and lithology as unit 52.	**0.8**
53	Silty shale; light greenish gray (5GY8/1) with limonitic splotches that are dark yellowish orange (10YR6/6) and same color as plant debris; abundant fossil leaves at UTM 45385627E, 5255311N (datum: WGS 84).	**0.7**
52	Shale; yellowish gray (5Y8/1) with dark yellowish orange (10RY6/6); limonitic bands; some layers sandy; not calcareous; contains fossil leaves.	**2.3**
51	Sandstone and siltstone; sandstone is grayish orange (10YR7/4) with some dark yellowish orange (10YR6/6); very fine grained with some medium grains; quartzarenite; limonitic; not calcareous; very pale orange (10YR8/2) with dark yellowish brown (10YR4/2) splotches; not calcareous; unit is thinly interbedded; laminar to ripple laminated; forms a tall cliff.	**14.0**
50	Silty mudstone; dark yellowish orange (10YR6/6); bentonitic; not calcareous.	**1.5**
49	Sandstone; same color and lithology as unit 47.	**4.5**
48	Mudstone; same colors as unit 8; limonitic plates are very dense (Mg/Fe rich), up to 1 cm thick and weather dark yellowish orange (10YR6/6) fresh, weathering to dark yellowish brown (10YR4/2); 2-3 cm limonitic crust at base; not calcareous.	**1.0**
47	Very micaceous sandstone; yellowish gray (5Y8/1) with light olive gray (5Y6/1) clayey lenses; trough crossbedded; some limonitic crusts; very-fine to medium grained; poorly sorted; subangular; quartzarenite; much muscovite; some limonite; not calcareous; forms a cliff at the base of the second cuesta.	**8.4**
Kusto svita:		
	Units 44-45-46 form a small hogback in the strike valley between the two cuestas.	
46	Bentonitic mudstone; same color and lithology as unit 44. 1 cm thick limonitic crust at base; much covered.	**9.4**
45	Siltstone; very pale orange (10YR8/2) with moderate reddish brown (10R4/6) mottles; not calcareous; limonitic.	**1.0**
44	Bentonitic mudstone; dark yellowish brown (10YR8/2) and light olive gray (5Y5/2); not calcareous.	**4.0**
Aksyir svita:		
43	Sandy shale; mottled gray and orange.	**3.5**
42	Sandstone; same color and lithology as unit 38.	**1.0**
41	Sandy siltstone; very pale orange (10YR8/2) with mottles of dark yellowish orange (10YR6/6); calcareous concretions up to 5 cm in diameter are yellowish gray (5Y8/1) with speckles of olive black (5Y2/1); calcareous.	**3.7**
40	Siltstone; mottled very pale orange (10YR8/2) and dark yellowish orange (10YR6/6); not calcareous.	**1.7**
39	Sandy claystone and clayey sandstone; mottled very pale orange (10YR8/2), dark yellowish orange (10YR6/6) and yellowish gray (5Y8/1); very limonitic; sand lithologies identical to unit 38.	**3.0**
38	Sandstone; very pale orange (10YR8/2); fine- to medium-grained; subangular; poorly sorted; quartzarenite.	**1.2**
37	Totally covered.	**6.8**

From this point upward strata dip 25° to N 25°E; this is at UTM 45385702 E, 5254583N (datum: WGS 84); top of unit 36 is a dip slope with much cover, so there are a few meters of inaccuracy between the two parts of the section.

36 Muddy sandstone and sandstone; grayish yellow (5Y8/4) with pale yellowish orange (10YR8/6); same lithology as unit 27; sandstone is light brownish gray (5YR6/1); calcareous; top of unit trough-crossbedded and bioturbated; some laminae; friable. **2.1**

35 Sandy shale; moderate yellowish brown (10YR5/4) to light brown (5YR6/4) with yellowish gray (5Y7/2) limonitic bands; calcareous. **6.0**

34 Sandy siltstone; dusky yellow (5Y6/4) to light olive brown (5Y5/6); not calcareous. **5.0**

33 Sandstone and intercalated shale; sandstone is grayish yellow (5Y8/4); calcareous; shale is sandy, moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4) with light olive gray (5Y6/1); thin ledges of sandstone have hummocky ripple laminations; not calcareous. **1.5**

32 Siltstone, same color and lithology as unit 29. **3.0**

31 Sandy shale, same color and lithology as unit 28. **1.1**

30 Sandstone, same color and lithology as unit 27. **0.1**

29 Muddy, sandy siltstone and silty- to fine-grained sandstone; yellowish gray (5Y7/2). **4.3**

28 Sandy shale and limonitic sandstone; light olive gray (5Y6/1) with dark yellowish orange (10YR6/6) flecks and pale red (5R6/2) mottles. **2.2**

27 Sandstone; bluish white (5B9/1) to light brownish gray (5YR6/1); bioturbated and ripple laminated; indurated; ledgy; calcareous. **0.6**

26 Siltstone; yellowish gray (5Y7/2); not calcareous. **4.0**

25 Sandy shale; dark yellowish orange (10YR6/6) with very pale orange (10YR8/2); kaolinitic; not calcareous; prominent red band. **1.7**

24 Sandstone; yellowish gray (5Y8/1) to brownish gray (5YR4/1); medium-grained; litharentie; limonite is brownish gray (5YR4/1); hummocky to trough crossbedded; calcareous. **1.9**

23 Sandy shale; light olive gray (5Y6/1) with moderate brown (5YR4/4) and bluish white (5B9/1); pale yellowish orange (10YR8/6) and dusky brown (5YR2/2) limonite sandstone lenses; laminar; locality K37. **5.5**

22 Sandy siltstone and silty sandstone; bluish white (5B9/1) to very light gray (N8); dark yellowish orange (10YR6/6); limonite; flaser bedding; laminar to ripple laminated; not calcareous; forms a cliff. **16.0**

21 Shale and sandy shale in 0.5-0.8 m interbeds with lenses of ripple-laminated sandstone; yellowish gray (5Y8/1) to pale olive (10Y6/2) weathered; fresh moderate olive brown (5Y4/4) and moderate brown (5YR4/4); not calcareous; coprolite locality K38 (NMMNH locality 3596) is 7 m above base. **14.0**

Above unit 20 dip is 25° to N 25°E.

20 Covered to base of Aksyir coprolite beds. There is a fault here in the covered interval, offset here to localities K38 and K39. **33.0**

Kyzylkain svita:

19 Micaceous sandstone; very pale orange (10YR8/2) with dark yellowish orange (10YR6/6); calcareous; medium-grained. **2.2**

Sargamys svita:

18 Sandy shale; moderate brown (5YR3/4) and pale red (5R6/2); not calcareous; forms a bright red band. **8.8**

17 Sandy shale; yellowish gray (5Y7/2); bentonitic; not calcareous. **13.0**

16 Sandstone; dark yellowish orange (10YR6/6) to light brown (5YR4/6); limonitic; micaceous; quartzarenite; coarse-grained; calcareous. **8.5**

15 Clayey sandstone; yellowish gray (5Y8/1); fine-grained; powdery; calcareous. **7.5**

14 Sandy shale; same color and lithology as unit 12. **8.0**

13 Slightly sandy shale; pale red (10R6/2) to moderate red (5R4/6) with mottles of light greenish gray (5GY8/1); gypsiferous; not calcareous. **6.0**

12 Sandy shale; yellowish gray (5Y8/1) with grayish orange (10YR7/4) to dark yellowish orange (10YR6/6) mottles; gypsiferous; not calcareous. **9.0**

11 Sandy shale; pale yellowish orange (10YR8/6) to moderate yellowish brown (10YR5/4) with dusky brown (5YR2/2) mottles; not calcareous. **6.0**

Above this unit offset approximately 200m to NW.

10 Shaly sandstone; same color and lithology as unit 8. **4.6**

9 Shaly sandstone; grayish orange (10YR7/4) with yellowish gray (5Y8/1) mottles; coarse-grained; not calcareous; Sargamys svita fossil vertebrates. **0.6**

8 Shaly sandstone; light brown (5YR5/6) with yellowish gray (5Y8/1) streaks; fine-grained; not calcareous. **3.5**

7 Sandstone; dark yellowish orange (10YR6/6) to grayish orange (10YR7/4) with flecks of yellowish gray (5Y8/1) and very pale orange (10YR8/2); limonitic quartzarenite; coarse-grained; not calcareous. **1.4**

Above this unit section offsets to north limb of anticline; dip is 66° to N15°E.

Obayla svita:

6 Sandy shale; dark yellowish orange (10YR6/6) and yellowish gray (5Y7/2); not calcareous. *Triplopus chikhivadzei* site is near top of unit at 47° 26.27N; 85° 25.11E. **7.0**

5 Sandy shale; moderate yellowish brown (10YR5/4); yellowish gray (5Y7/2) and dark gray (N3); not calcareous. **12.0**

4 Clayey sandstone and sandy claystone; moderate yellowish brown (10YR5/4) with yellowish gray (5Y7/2) mottles; coarse-grained; quartzarenite; not calcareous. **3.1**

3 Sandy shale; moderate yellowish brown (10YR5/4) with yellowish gray (5Y8/1) and dusky brown (5YR2/2) mottles. **7.2**

2 Sandstone; pale olive (10Y6/2) and dark yellowish orange (10YR6/6) mottles; fine-grained; micaceous; calcareous; forms a white "calichified" stripe. **1.1**

1 Sandy shale; moderate brown (5YR4/4) with yellowish gray (5Y8/1) and dark gray (N3) mottles; weathers to a "popcorn" surface texture; locality K8 is 8 m below top of unit; unit is at core of anticlinal axis. **15.0**