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Depositional Environment of the St. Mary River Formation in Western Montana

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Undergraduate Thesis

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Abstract

In May 2013, the Two Medicine Dinosaur Center (TMDC) began excavation on a dinosaur bonebed in the St. Mary River Formation on Carey Butte, Montana. Since excavation started, four additional bonebeds have been discovered in the surrounding area. They display different depositional environments; two are in sandstone and the other three are in siltstone. The purpose of this study is to provide a depositional setting for the area that links all five sites together comprehensively by examining the sedimentology of the area. A stratigraphic analysis of the St. Mary River Formation of Carey Butte revealed four distinct facies associations. Facies Association 1 is made up of large sandstone lenses, which are interpreted as a large river channel. Facies Association 2 is made up of small sandstone lenses, which are interpreted as splay channels. Facies Association 3 is a series of thin sandstone and siltstone sheets, which are interpreted as crevasse splays. Facies Association 4 is a series of shale and siltstones, which are interpreted as overbank fines or floodplains. They are rich in organic material, both plant and vertebrate, and are heavily bioturbated. Together, these facies associations suggest that the depositional environment in this area was an anastomosing river system. This interpretation will provide a lithologic context for further paleontological work done on Carey Butte.

I. Introduction

In May 2013, the Two Medicine Dinosaur Center (TMDC) began excavation on a dinosaur bonebed in the St. Mary River Formation near Augusta, Montana. Since excavation started, four additional bonebeds have been discovered in the surrounding area. They display different depositional environments, two of the five bonebeds are in sandstone, while the other three are in siltstone. The purpose of my research is to provide a depositional setting for the area that links all five sites together comprehensively by examining the sedimentology of the area. As of right now, the data being collected from the dig sites is strictly paleontological. Combining the sedimentology from this study and paleontological data will provide the necessary geological context needed to do further research on fossil specimens that are collected near Augusta.

II. The literature so far

The area where TMDC's excavations are taking place has been identified as part of the St. Mary River Formation (Berg, 2008). The St. Mary River Formation (SMRF), also known as the Edmonton Formation in central-northern Alberta (Hamblin, 1998), is uppermost Campanian to upper Maastrichtian in age, roughly 83.6 to 66.0 million years old (Nadon, 1994), although the exact ages vary geographically. The SMRF conformably overlies the Horsethief Sandstone Formation in western Montana, the Fox Hills Sandstone Formation in eastern Montana and North Dakota (Hamblin, 1998) and the Blood Reserve Sandstone Formation in Canada (Smith, 1994). These sandstone formations overlie the Bearpaw Shale, a marine shale deposited during the encroachment of the Bearpaw Sea (a transgression of the larger Interior Cretaceous Seaway) (Smith, 1994; Fox 1978). To the east it grades into the Hell Creek Formation in Montana

(Hunter, 2010; Fox, 1978) and the Frenchman Formation in southern Canada. It is important to note that while correlations exist across the US-Canadian border, they are not well defined.

The SMRF has been interpreted by G.C. Nadon (1994) as a "deposit of anastomosed rivers that flowed northeastward over a broad, low-gradient plain." He came to this conclusion when he found large sandstone lenses (fluvial channels), small sandstone lenses (splay channels), sandstone/siltstone sheets (crevasse splays), and overbank fines (floodplain, marsh) throughout 531 meters of detailed, measured sections from southwestern Alberta. In Montana, that interpretation still holds, although the thickness is only 300-400 meters (as opposed to the 230-900+ m in Alberta (Nadon, 1994)) (Hunter, 2010). This interpretation is the consensus among St. Mary River Formation researchers.

Few fossils have been found in the SMRF. Nadon (1994) reported gastropod shell fragments as well as root casts in his sections, and others have found vertical burrows, oyster bars, and partial tree trunks (especially associated with coal seams) (Hamblin, 1998).

The most extensively researched SMRF outcrop in Montana for fossils is Shell Hill, a locality on the south bank of the Two Medicine River, south of Browning in Glacier County (Hunter, 2010). This locality is named for the abundance of hadrosaurid egg shell fragments found. J. P. Hunter (2010) reported dinosaur teeth and nests from the area as well. This site also yields mammal remains. In other Montana outcrops of the SMRF, researchers have noted dinosaur bone fragments, plant material, turtles, and freshwater mollusks (Weishampel, 1987). During the summer of 1986, 14 localities, 35 km north of Browning, in the upper 12 km of Little Rocky Coulee were prospected by David B. Weishampel and his crew. One area was Barnum Brown's original dig site where he collected a protoceratopsian in 1916. Weishampel and the rest of the crew found that the site was still producing bone fragments, including the remains of champosaur, turtle, crocodile, eggshell, and what may have been a new protoceratopsid. In the upper portion of Little Rocky Coulee, the crew collected ornithomimid remains, a baenid turtle, at least three types of eggshell, embryonic hadrosaurid material, and possible dromaeosaurid material (Weishampel, 1987).

Despite these discoveries only one dinosaur has ever been described from the St. Mary River Formation in Montana, the protoceratopsid *Montanaceratops cerorhynchus*, collected from Glacier County in 1916 by Barnum Brown (Sloan, 1974; Weishampel, 1987; Hunter, 2010).

Only a few outcrops in southwestern Alberta produce vertebrate material, most notable of which is Scabby Butte. Paleontologists have been collecting mammal teeth at Scabby Butte since 1957, as well as ceratopsian skull fragments. They have noted also noted brackish-water mollusks and other unidentifiable bone fragments (Sloan, 1974).

III. Methodology

III.i. Stratigraphic sections

Stratigraphic sections were measured using a Jacob staff, a metric tape measure, and a Brunton compass. Areas of Sections CB.2 and CB.3 were covered by debris, so in order to provide a continuous section a method called "Jaking over" was used. This technique requires using a Brunton compass against the Jacob staff to find the equivalent elevation – taking into account the dip of the bed – in a more accessible area. In the case of Sections CB.2 and CB.3, distinctive beds were used to Jake over, in addition to the Brunton and staff approach.

<u>III.ii. Petrographic samples</u>

Rock hand samples were collected from well-cemented sediments, almost all of which were sandstone. Most were collected with the intention of cutting them down to thin sections. Rock characteristics were observed using a 10x magnification hand lens. Grain size was determined using the Udden-Wentworth scale and roundness was determined using Powers' grain images (Boggs, 2012). Sandstone classification was determined using Folk's Sandstone Composition Classification diagram published in 1970. See Appendix A for hand sample descriptions.

<u>III.iii. Paleontologic specimens</u>

Bones and other fossils were initially identified by TMDC staff (Trexler, 2013). Most of the bones in the field area are black and/or varying shades of blue. Root casts, the second most common fossils, are compact, well-cemented, dark grey cylinders. All fossils found, with the exception of dinosaur bones which were not collected, were collected according to TMDC procedure. This involved marking the location and stratigraphic position of the specimens on a map. Specimens were cleaned with a toothbrush and tap water and the adhesive PaleoBond was used to fix damaged specimens. Butvar (polyvinyl butyral resin) was used to seal and consolidate specimens. A camera was used to capture multiple images of each specimen at different depths of focus. The images were then stacked and edited using Photoshop to create a single, in-focus image as close to real color as possible. See Appendix B for specimen descriptions.

III.iv. Thin sections

Thin sections were created from 2x3x1 cm blocks cut from their respective hand sample. Only four blocks could be cut due to the nature of the samples. Most were too poorly-cemented to withstand the sawing process. The intact blocks were sent to National Petrographic Service, Inc., where they were ground down to 30 micrometers thick. Only sample CB.3.4 has an upwards-direction indicator (a notch at the top of the section). Point counts of the four thin sections were conducted using a Leica DM EP polarizing microscope. A minimum of 500 framework grains was reached for each slide. Framework grains included variations of quartz, feldspar, and lithics. Sandstone classification was determined using Folk's Sandstone Composition Classification diagram published in 1970. See Appendix C for point count data.

IV. Results

IV.i Stratigraphic sections

Stratigraphic data was collected from three vertical sections measured across the exposed badlands (Figure 1). See Figures 3-5 for the final measured sections. Section CB.1, located above the initial excavation site, contains no horizontal offset, but dips approximately 5° along a 154°E trend line. Section CB.2 and CB.3 are composite sections because talus and Pleistocene sediments prevented continuous sections from being measured. Section CB.2 dips approximately 5° to the west. An exact trend line could not be measured due to the poor conditions of the beds. There are at least two distinct beds that can be correlated across Sections CB.2 and CB.3. One is a teal mudstone (marked with a teal star on Figures 4, 5, 6) and the other is a turquoise siltstone (marked with a turquoise star on Figures 4, 5, 7).

IV.i.1. Description of Section CB.1

The base of this section is buried, so 0.0 m marks the beginning of the exposed rock. 0.0 to 0.93 m is a fining up sequence from medium-grain sand to silt. 0.93 to 2.11 m is a red siltstone with approximately 30% interbedded blue siltstone and very fine sandstone. There is a sharp, conformable bottom contact. Root casts are found throughout the unit, along with small ripples and a horizontal burrow found in one of the blue siltstone interbeds 1.5 m up section (Fig. 8). This unit is capped by a caliche paleosol. 2.11 to 6.65 m is a blue-grey, mica-rich, medium sandstone. In some areas, the sandstone has eroded down through the paleosol, especially around large dinosaur bones. The lower half of the sandstone unit is trough cross-bedded while the upper half is massive. At the base of the unit is a dinosaur bonebed. Bones that have been pulled from here have been identified as hadrosaurid remains by TMDC staff. Next to the bones there is also a small series of very magnetite-rich laminae (Fig. 9). 6.65 to 6.74 m there is a brown siltsone with planar bedding and a sharp basal contact. 6.74 to 7.24 m there is a medium-grain sandstone with mud rip-up clasts 2mm in diameter. The basal contact is erosional. 7.24 to 8.14 m is a fining up sequence, going from a very coarse sandstone to a coarse sandstone. The basal contact is marked by the appearance of occasional granules mixed in with the sandstone in the lower part of the bed. Trough cross-bedding is found throughout the bed, but becomes more apparent near the top. 8.14 to 8.34 m is a poorly-sorted, coarse sandstone with a muddy matrix. It also marks the brief reappearance of granules. It is gradational with the sandstones above and below it. 8.34 to 9.49 m is another fining up sequence, this time from a coarse sandstone to a medium-grain sandstone. Small mud rip-up clasts can be found throughout the unit along with trough cross-bedding in the upper 30 cm. 9.49 to 10.09 m is a matrix-supported conglomerate with a medium-grain sand matrix that has a sharp basal contact. The clasts are made up mostly by large mudclasts (0.5-2 cm in diameter) and dinosaur bone fragments (up to 15 cm long) (Fig. 11). Roughly 40% of the conglomerate is interbedded coarse sandstone with cross-bedding (Fig. 12). 10.09 to 10.18 m is a small fining up sequence from medium-grain sandstone to silt. The base is erosional, and this is emphasized by the presence of lingoid ripples at the contact. Above the ripples in the finer-grained sediment is convolute bedding and soft sediment deformation (Fig. 13). 10.18 to 11.03 m is a fining up sequence from medium-grain sandstone to silt. This unit also has an erosional base, also due to basal ripples. The ripples only occur in the bottom 10 cm. Above this there is trough cross-bedding. 11.03 to 12.06 m there is a medium-grain sandstone with 20-30 cm scale trough cross-bedding. The basal contact is gradational. 12.06 to 12.36 m is a coarsening up sequence from a sandy silt to a medium-grain sandstone. It has a sharp basal contact but is heavily weathered. There is evidence of cross-bedding but the weathering prevents any positive identification of the type. 12.36 to 13.08 m is a medium-grain sandstone with interbedded silt. This unit is gradational at both the top and bottom contacts. 13.08 to 13.31 m is a medium-grain sandstone with planar bedding. 13.31 to 13.46 m is silt with planar bedding and a sharp basal contact. 13.46 to 13.74 m is a medium-grain sandstone with planar bedding and a sharp basal contact. This bed also marks the top of the outcrop.

IV.i.2. Description of Section CB.2

The base of this section is buried, so 0.0 m marks the beginning of the exposed rock. 0.0 to 2.22 m is a fining up sequence from a medium-grain sandstone to a clay. The sandstone is trough cross-bedded. 2.22 to 2.49 m is a small fining up sequence from a fine-grain sandstone to a clay. This unit has a sharp basal contact, with vertical burrows and mudcracks at the top (Fig.

14). 2.49 to 2.69 m is a blue-grey sandy silt with a sharp basal contact. 2.69 to 2.79 m is a red sandy silt with a sharp basal contact. 2.79 to 3.13 m is a medium-grain sandstone with a sharp basal contact. There is cross-bedding present, but it is heavily weathered and the type could not be identified. 3.13 to 4.29 m is a very fine-grain sandstone with a sharp basal contact. It is mostly massive, with trough cross-bedding appearing in the upper 20 cm of the unit. 4.29 to 4.65 m is a red siltstone that has a sharp basal contact, but grades into a blue siltstone above. 4.65 to 5.63 m is a siltstone that slowly grades from blue at the base to red at the top. 5.63 to 5.83 m is a blue siltstone with a sharp basal contact that grades into the unit above it. 5.83 to 6.08 m is a blue siltstone with interbedded fine-grain sandstone. The sandstone beds thicken and coarsen laterally to the north, getting up to a 1.0 m thick coarse sandstone (Fig. 15). 6.08 to 6.18 m is a blue siltstone that is gradational with the unit below. The top of this unit is capped by a caliche paleosol (Fig. 16). 6.18 to 6.49 m is a blue-grey siltstone that conformably overlays the paleosol below. 6.49 to 6.59 m is a carbonate concretion layer. It has sharp basal and upper contacts and is gastropod rich. This unit tapers off to the south before disappearing. 6.59 to 6.81 m is a black, organic-rich siltstone. There were also a variety of fossils found in this bed, including large and small clams, a tyrannosaur tooth, and small vertebrate material. 6.81 to 6.91 m is a red siltstone with a sharp basal contact. 6.81 to 8.13 m is a fining up sequence from a very fine-grain sandstone to a blue silt. This unit has a sharp basal contact. 8.13 to 8.40 m is a teal (dark green-blue) mudstone (Fig. 6). It has a sharp basal contact and is stained maroon on the surface from weathering. 8.40 to 9.20 m is a fine-grain sandstone with an erosional basal contact. The sandstone is trough cross-bedded. 9.20 to 9.56 m there is a red siltstone with a sharp basal contact. 9.56 to 9.82 m is a blue siltstone interbedded with fine-grain sandstone. This unit has a sharp basal contact. The sandstone interbeds display planar bedding. This grades into a fine-grain sandstone with interbedded blue siltstone from 9.82 to 10.23 m. This unit also displays planar bedding in the sandstone. 10.23 to 10.41 m is a red siltstone with a sharp basal contact. 10.41 to 10.71 m is a fine-grain sandstone with a muddy cement and a sharp basal contact. Faint trough cross-beds can be seen. These laminae are 0.5 cm in thickness. 10.71 to 10.81 m is a massive fine-grain sandstone with a muddy cement and a sharp basal contact. It grades into another fine-grain sandstone with almost no cement from 10.81 to 10.96 m. 10.96 to 11.04 m, the fine-grain sandstone regains a muddy cement. 11.04 to 11.28 m is a red siltstone with a sharp basal contact. It is capped by a caliche paleosol (Fig. 17). 11.28 to 11.78 m is a massive, fine-grain sandstone with a sharp basal contact. 11.78 to 12.19 m is a red-brown siltstone with a sharp basal contact. 12.19 to 12.65 m is a turquoise siltstone with a sharp basal contact. 12.65 to 12.72 m is a red siltstone with a sharp basal contact. 12.72 to 12.92 m is a blue siltstone with a sharp basal contact. 12.92 to 13.12 m is a red siltstone with a sharp basal contact. 13.12 to 13.31 m is a fine-grain sandstone with a sharp basal contact and severely weathered cross-bedding. 13.31 to 13.42 m is a red siltstone with a sharp basal contact. 13.42 to 13.84 m is a fine-grain sandstone with a sharp basal contact. It has trough cross-bedding with 1 cm-thick laminae. 13.84 to 14.13 m is a red siltstone with a sharp basal contact and a caliche paleosol cap. 14.13 to 14.45 m is a blue siltstone with a sharp basal contact. 14.45 to 14.64 m is a red siltstone with a sharp basal contact. 14.64 to beyond 15.40 m is a blue siltstone with a sharp basal contact. Above 15.40 m the section is covered by debris.

IV.i.3. Description of Section CB.3

The base of this section is buried, so 0.0 m marks the beginning of the exposed rock. 0.0 to 0.40 m is a massive, fine-grain sandstone. 0.40 to 0.91 m is a very fine, light brown-grey sandstone with a sharp basal contact. 0.91 to 1.21 m is a very fine, blue sandstone with a sharp basal contact. 1.21 to 1.36 m is a very fine, tan sandstone with a sharp basal contact. 1.36 to 1.61 m is a red mudstone (Fig. 18). It has a sharp basal contact and contains root traces. 1.61 to 2.10 m is a fining up sequence from a very fine sandstone to a blue silt. This unit has a sharp basal contact. 2.10 to 3.31 m is another fining up sequence from a medium-grain sandstone to a fine-grain sandstone. This unit has a sharp basal contact and contains shallow-angle trough cross-bedding. 3.31 to 3.36 m is a red siltstone with a sharp basal contact. 3.36 to 3.44 m is a fine-grain sandstone with a sharp basal contact. 3.44 to 3.63 m is a red siltstone with a sharp basal contact. The top of the unit is capped by a caliche paleosol. 3.63 to 3.68 m is a blue siltstone with a sharp basal contact. 3.68 to 3.96 m is a red siltstone with a sharp basal contact. 3.96 to 4.52 m is a fining up sequence from a silty very fine-grain sand to a silt. It has a sharp basal contact. 4.52 to 5.42 m is another fining up sequence from a medium-grain sandstone to a fine-grain sandstone. It has a sharp basal contact and contains trough-crossbedding. 5.42 to 5.76 m is a blue siltstone with a sharp basal contact. It has a caliche paleosol cap and contains root traces towards the top of the unit. 5.76 to 6.24 m is a blue-grey siltstone with a sharp basal contact. The upper 5 cm consists of discontinuous, gastropod-rich carbonate concretions. 6.24 to 6.66 m is a black siltstone with a sharp basal contact. This correlates to the black siltstone unit in Section CB.2. No vertebrate material was found, only snails and large clams. 6.66 to 6.76 m is a red siltstone with a sharp basal contact. 6.76 to 7.68 m is a blue-grey siltstone with a sharp basal contact. 7.68 to 8.08 m is a teal (dark blue-green) mudstone with a sharp basal contact. This correlates to the teal mudstone in Section CB.2. 8.08 to 9.09 m is a magnetite-rich medium-grain sandstone. It has an erosional basal contact. There is heavily convoluted bedding throughout the unit (Fig. 19-22). 9.09 to 10.02 m is a fine-grain sandstone with roughly 20% made up of silty interbeds. The unit is gradational with the one below it. It has planar bedding throughout the sandstone. 10.02 to 10.45 m is a tan siltstone with a sharp basal contact. 10.45 to 10.67 m is a blue siltstone with a sharp basal contact. 10.67 to 11.68 m is a coarsening up sequence from a red siltstone to a medium-grain sandstone with a sharp basal contact. 11.68 to 11.89 m is a red siltstone with a sharp basal contact. 11.89 to 12.27 m is a turquoise siltstone with a sharp basal contact. This unit correlates to the turquoise unit in Section CB.2. 12.27 to 12.44 m is a red siltstone with a sharp basal contact. 12.44 to 12.57 m is a blue siltstone with a sharp basal contact. 12.57 to 12.74 m is a red siltstone with a sharp basal contact. 12.74 to 12.79 m is a blue siltstone with a sharp basal contact. 12.79 to 12.89 m is a red siltstone with a sharp basal contact. 12.89 to 13.30 m is a fine-grain sandstone with a sharp basal contact. It has severely weathered cross-bedding. 13.30 to 13.88 m is a siltstone that grades from blue-grey at the bottom to red at the top of the unit. The unit has a sharp basal contact. 13.88 to 13.97 m is a fine-grain sandstone caliche nodule unit with a sharp basal contact. This unit contains root traces. 13.97 to 14.16 m is a reddish-brown siltstone with a sharp basal contact. 14.16 to 14.29 m is a blue siltstone with a sharp basal contact. 14.29 to 14.44 m is a red siltstone with a sharp basal contact. 14.44 to 15.16 m is a siltstone with a sharp basal contact. It grades from blue at the base to brown in the upper 30 cm. 15.16 to 15.34 is a blue siltstone with a sharp basal contact. 15.34 to 15.46 m is a brown siltstone with a gradational basal contact. 15.46 to 15.70 m is a blue siltstone with a gradational basal contact. 15.70 to 16.00 m is a brown siltstone with a sharp basal contact. This unit is rich in swelling clays, evidenced by the crumbling and delicate structure of the outer 5 cm of weathered sediment. 16.00 to 16.21 m is a blue siltstone with a sharp basal contact. 16.21 to 16.49 m is a reddish-brown siltstone with a sharp basal contact. 16.49 to 16.77 m is a fine-grain sandstone caliche nodule unit with a sharp basal contact. 16.77 to 16.95 m is a dark grey siltstone with a sharp basal contact. 16.95 to 17.40 m is a blue siltstone with a sharp basal contact. 17.40 to 17.52 m is a blue mudstone with a sharp basal contact. 17.52 to 18.00 m is a blue siltstone with a sharp basal contact. 18.00 to 18.61 m is a fining up sequence from a fine-grain sandstone to a blue mudstone. This unit has a sharp basal contact. 18.61 to 19.34 m is another fining up sequence from a medium-fine-grain sandstone to a very fine-grain sandstone. It has a sharp basal contact. The upper 15 cm of this unit is also made up of caliche nodules. It is also important to note that large (fist-sized) dinosaur bone fragments were present from this unit upwards, but a source was never found. 19.34 to 19.96 m is a blue siltstone with a sharp basal contact. 19.96 to 20.16 m is a red siltstone with a sharp basal contact. 20.16 to 20.35 m is a blue siltstone with a sharp basal contact. 20.35 to 20.83 m is a red mudstone with a sharp basal contact. 20.83 to 21.41 m is a fining up sequence from a fine-grain sandstone to a blue mudstone. This sequence has a sharp basal contact. 12.41 to 21.57 m is another fining up sequence from a blue siltstone to a blue mudstone. This sequence has a sharp basal contact. 21.57 to 21.68 m is a light grey siltstone with a sharp basal contact. 21.68 to 22.72 m is a third fining up sequence from a medium-grain sandstone to a blue mudstone. The base of this unit has a sharp contact and also a vertical burrow (Fig. 23). 22.72 to 23.02 m is a red mudstone with a sharp basal contact. 23.02 to 23.28 m is a very fine-grain sandstone with a sharp basal contact. 23.28 to 24.25 m is a fining up sequence from a medium-grain sandstone to a blue siltstone. This unit has a sharp basal contact. 65 cm up this unit there is a 2 cm thick bed of medium sandstone. 24.25 to 24.65 m is a red siltstone with a sharp basal contact. 24.65 to 24.80 m is a blue siltstone with a sharp basal contact. 24.80 to 25.19 m is a red silty mudstone with a sharp basal contact. 25.19 to 25.84 m is a fining up sequence from a fine-grain sandstone to a blue siltstone. This unit has a sharp basal contact and a caliche nodule cap with root traces. 25.84 to 26.16 m is a red siltstone with a sharp basal contact. 26.16

to 26.26 m is a blue-green siltstone with a sharp basal contact. 26.26 to beyond 26.31 m is a brown siltstone with a sharp basal contact. Above 26.31 m the section is covered by debris.

IV.ii. Thin sections

All thin sections, with the exception of CB.3.4, had less than 5% pore space. All sections showed a high percentage of lithics, about half of which were igneous. Monocrystalline (plutonic) quartz was also more prevalent that polycrystalline (metamorphic) quartz. Almost no potassium feldspars were present, nearly all feldspars counted were plagioclase. The grains themselves were sub-angular, with the exception of the monocrystalline quartz, which was almost always rounded. Using Folk's Sandstone Composition Classification (1970) and point count data, it was determined that all four sandstones used for thin section were igneous litharenites (Fig. 24).

V. Discussion

V.i. Depositional environment

The depositional environment of the St. Mary River Formation on Carey Butte, MT is an anastomosing river system. According to Nadon (1994), who conducted a stratigraphic analysis of an anastomosing river system in the SMRF in southwestern Alberta, there are four facies associated with anastomosing river systems. Facies Association 1 is made up of large sandstone lenses, which are interpreted as the main river channel. In Fig. 25, Facies 1 is highlighted in blue. Facies Association 2 is made up of small sandstone lenses, which are interpreted as splay channels. These are highlighted with yellow in Fig. 25. Facies Association 3 is a series of thin sandstone and siltstone sheets, which are interpreted as crevasse splays. These are highlighted with green in Fig. 25. Facies Association 4 is a series of shale and siltstones, which are interpreted as overbank fines or floodplains. They are rich in organic material, both plant and vertebrate, and are heavily bioturbated. In the Carey Butte sections, root traces and vertebrate fossils were found in siltstones matching Facies Association 4 descriptions. These are highlighted with red in Fig. 25.

V.ii. Provenance

Analysis of the four thin sections suggests that there are several sources for the grains deposited in the river channels on Carey Butte. By far the most prominent of these sources is volcanic, based on the high percentages of igneous lithic fragments (17-27%) in all the sampled sandstones. The igneous grains are also sub-angular, indicating that the source is nearby. Coincidently, there happens to be a volcanic neck, called Haystack Butte, located roughly 10 km southwest of Carey Butte. Further analysis will be needed to determine if Haystack Butte is a possible source of sediment for the SMRF on Carey Butte.

Another source of sediment is indicated by rounded monocrystalline quartz grains. These are the only rounded grains in the sandstone, suggesting they came from much further away than any other grains present.

Other sources include a limestone-dolomitic source and a metamorphic source.

VI. Conclusion

A stratigraphic analysis of the St. Mary River Formation of Carey Butte suggests that the depositional environment in this area was an anastomosing river system. This interpretation will provide a lithologic context for further paleontological work done on Carey Butte. This research also revealed that the large bonebeds being excavated near Section CB.1 are located at the bottom of different river channels, and that siltstone units like the black unit located 6.7 m up Section CB.2 have the potential for microsite excavations. Further work is still needed to provide a source for the sediment deposited in the rivers located on Carey Butte.

VII. Figures

Figure 1: Map of field area west of Augusta, MT. Measured section transects are in red.

Figure 2: Key for measured sections, Fig. 3-5.

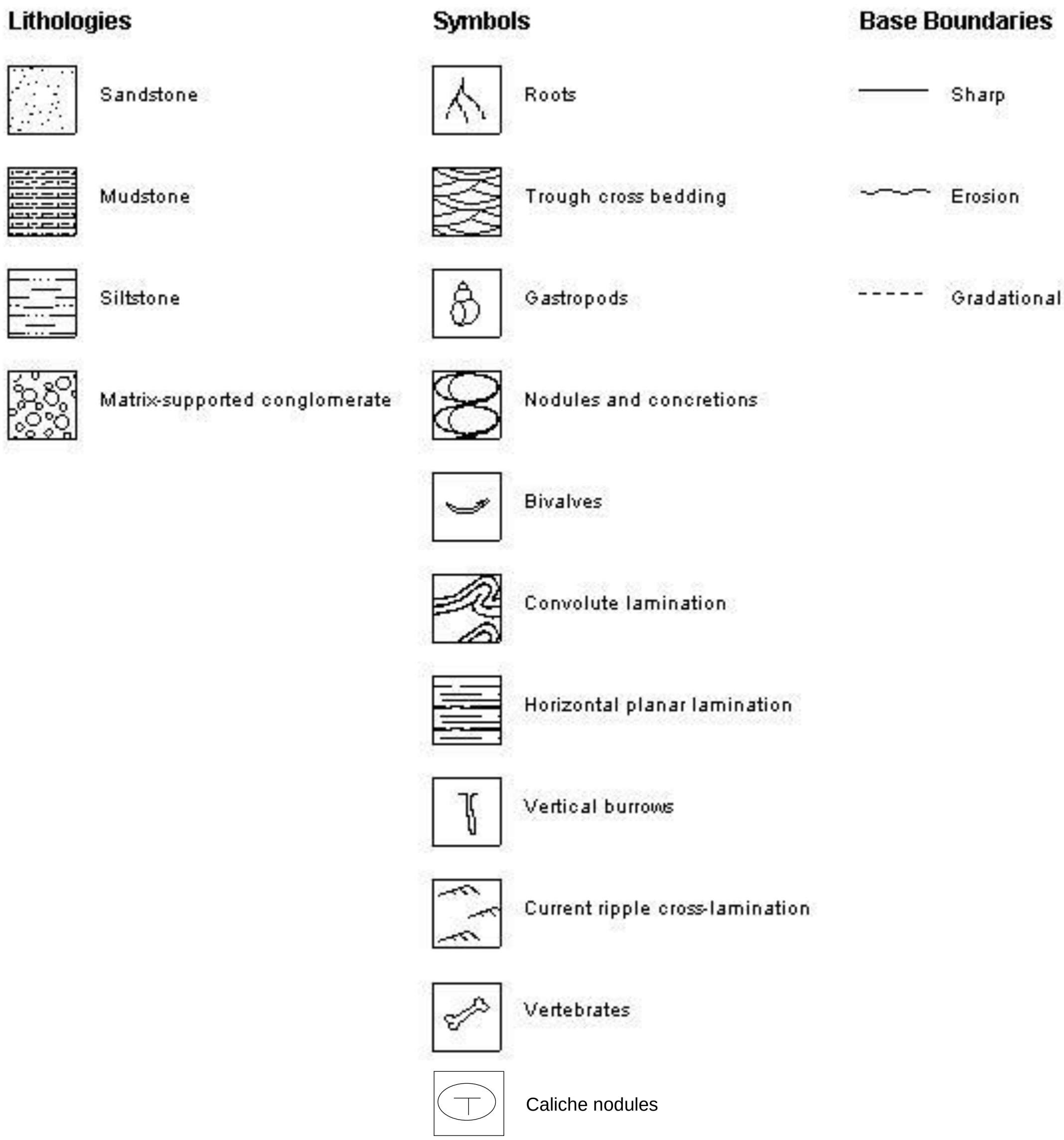


Figure 3: Measured stratigraphic section CB.1. See Fig. 2 for symbol key.

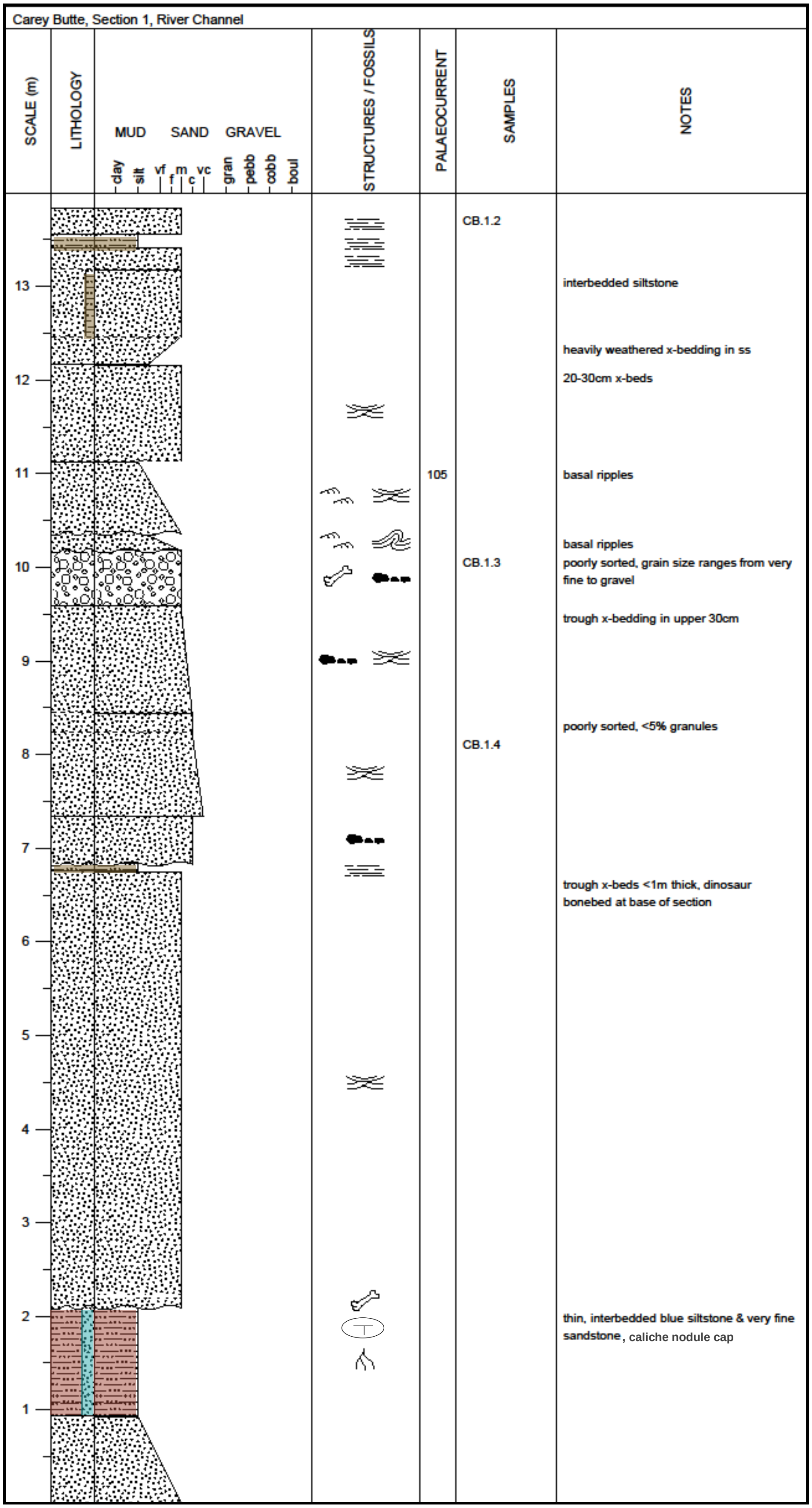
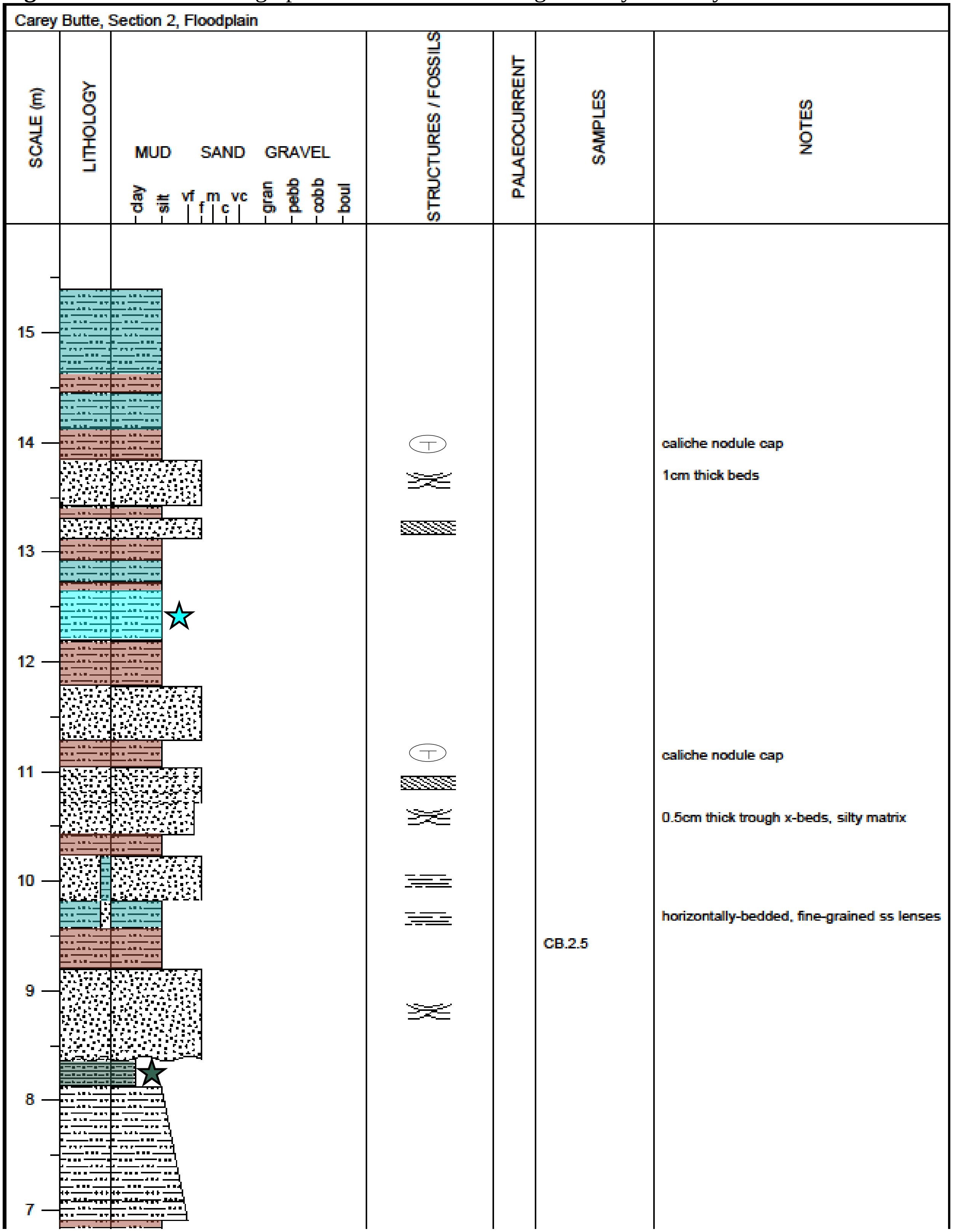


Figure 4: Measured stratigraphic section CB.2. See Fig. 2 for symbol key.



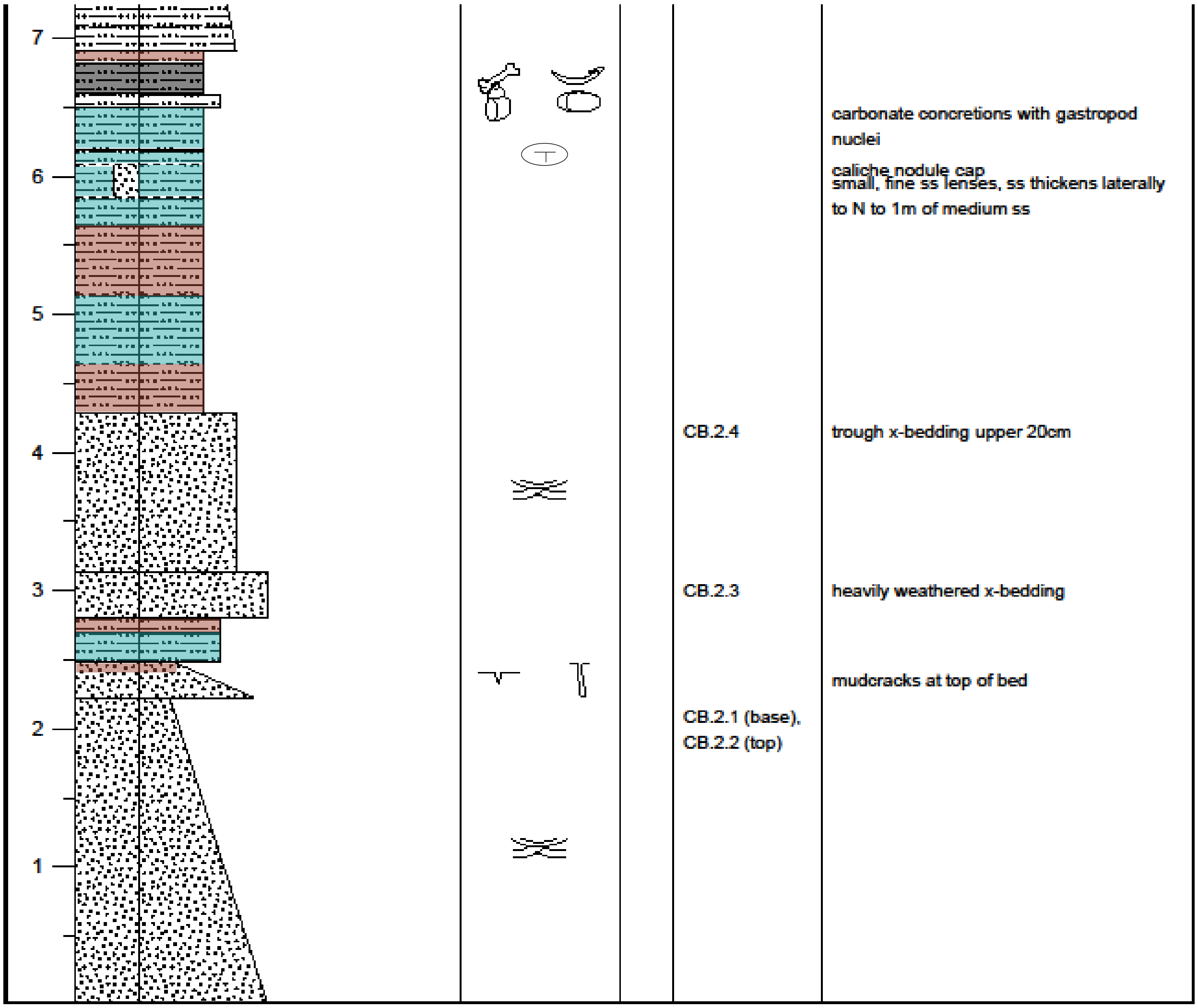
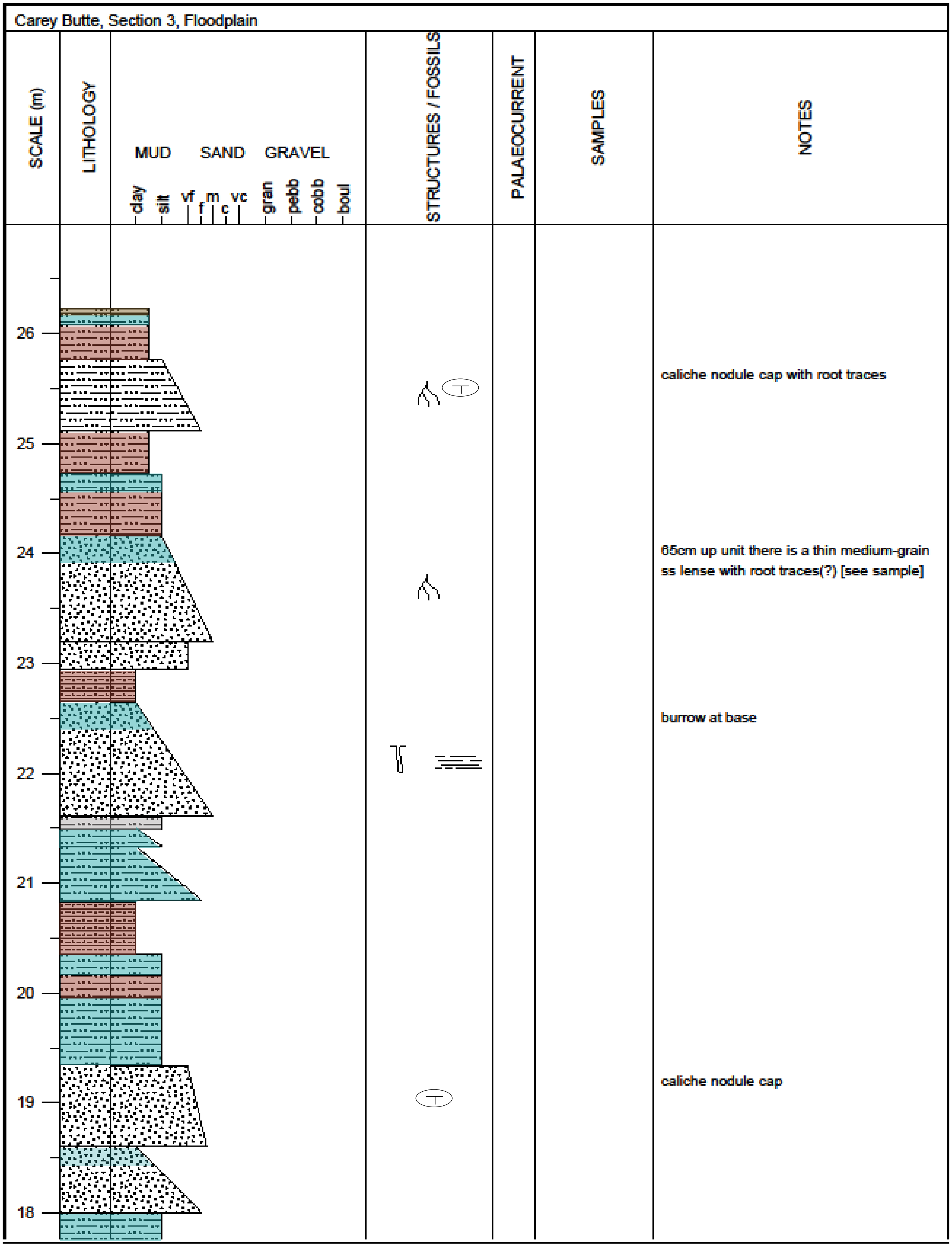
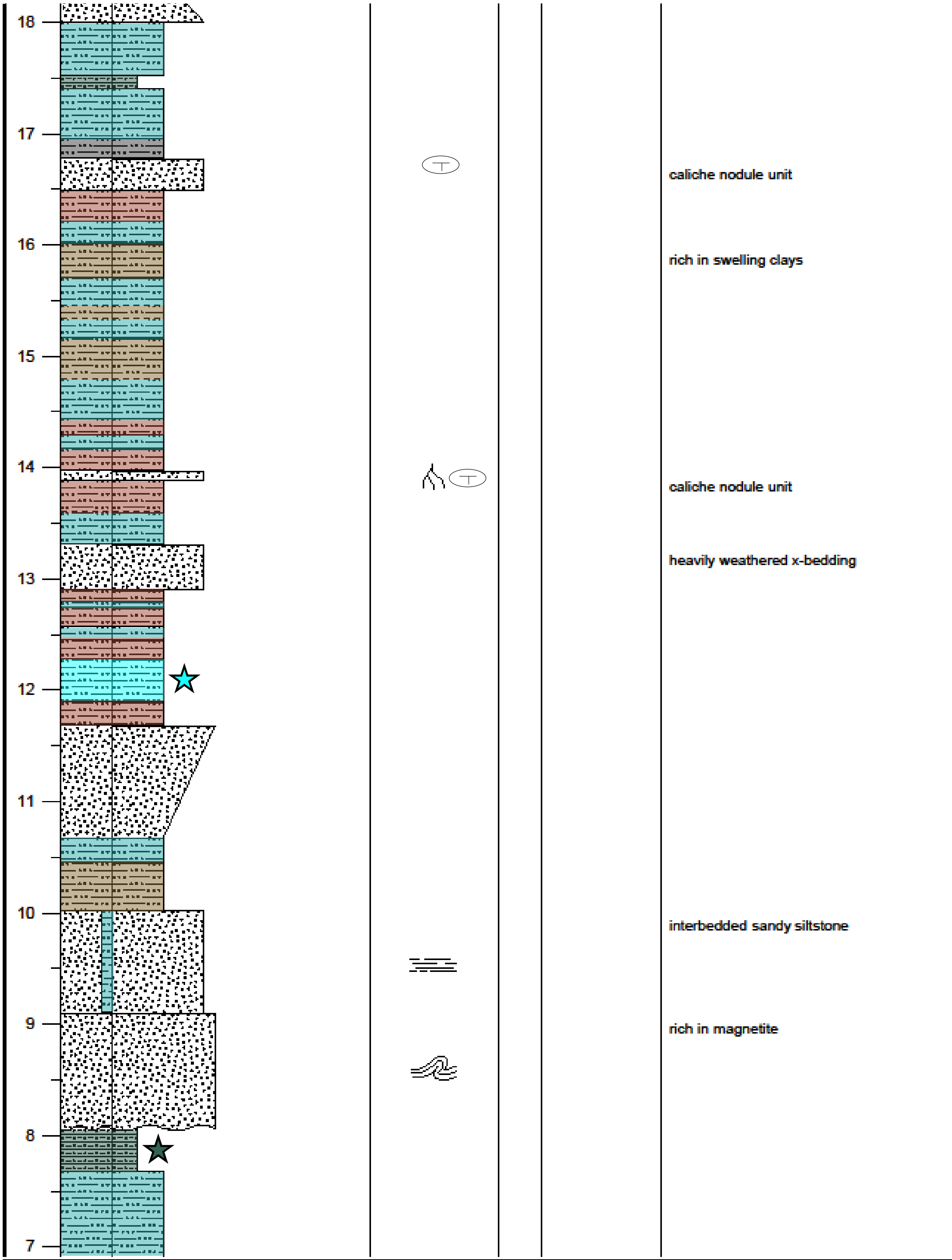

7
6
5
4
3
2
1
carbonate concretions with gastropod nuclei
caliche nodule cap
small, fine ss lenses, ss thickens laterally to N to 1m of medium ss
CB.2.4
trough x-bedding upper 20cm
CB.2.3
heavily weathered x-bedding
mudcracks at top of bed
CB.2.1 (base),
CB.2.2 (top)

Figure 5: Measured stratigraphic section CB.3. See Fig. 2 for symbol key.




18
17
16
15
14
13
12
11
10
9
8
7
caliche nodule unit
rich in swelling clays
caliche nodule unit
heavily weathered x-bedding
interbedded sandy siltstone
rich in magnetite

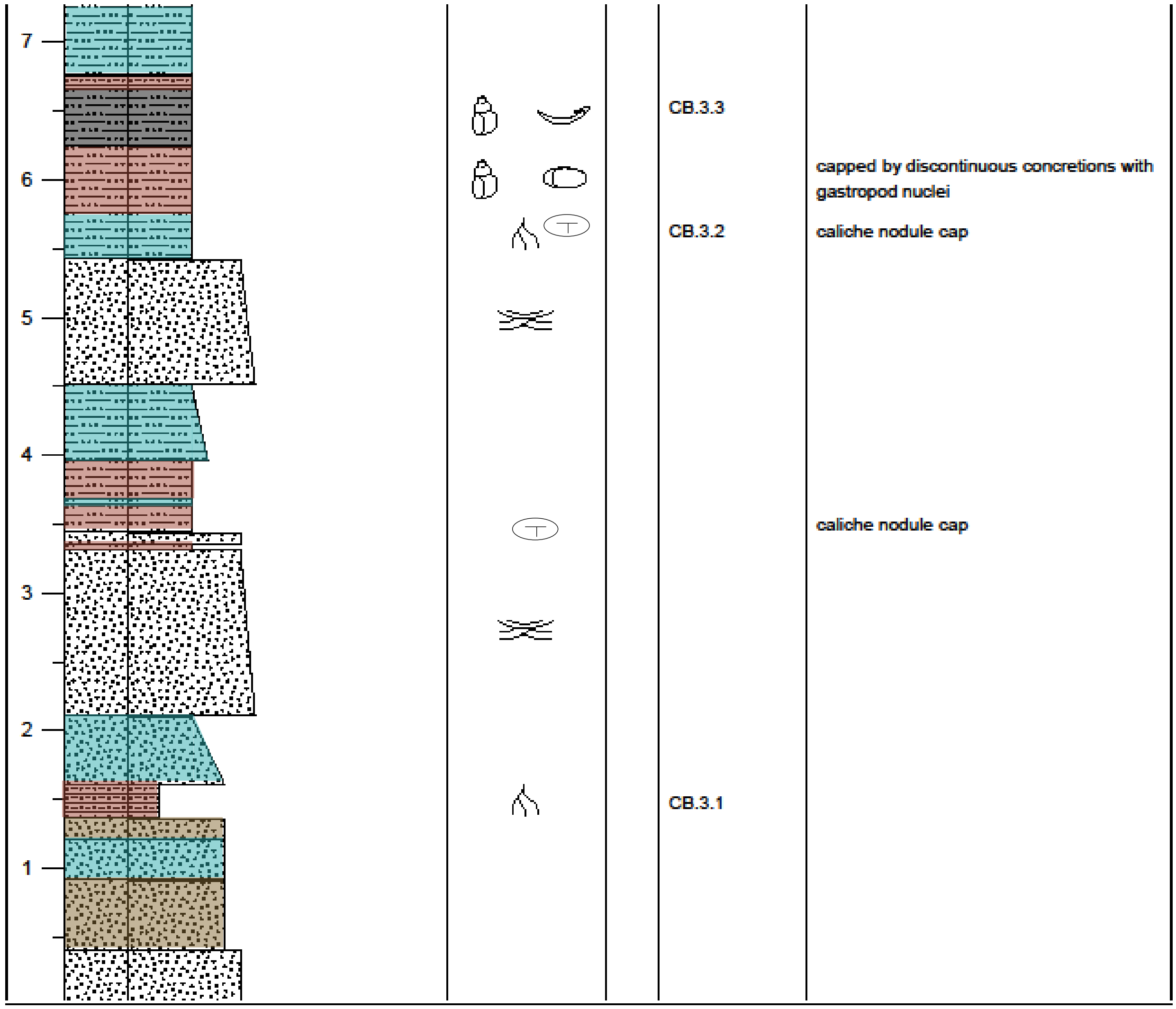

7
6
5
4
3
2
1
CB.3.3
capped by discontinuous concretions with gastropod nuclei
CB.3.2
caliche nodule cap
caliche nodule cap
CB.3.1

Figure 6: Teal marker bed used to correlate Sections CB.2 and CB.3. Bed marked with a teal star.

Figure 7: Turquoise marker bed used to correlate Sections CB.2 and CB.3. Bed marked with a turquoise star.

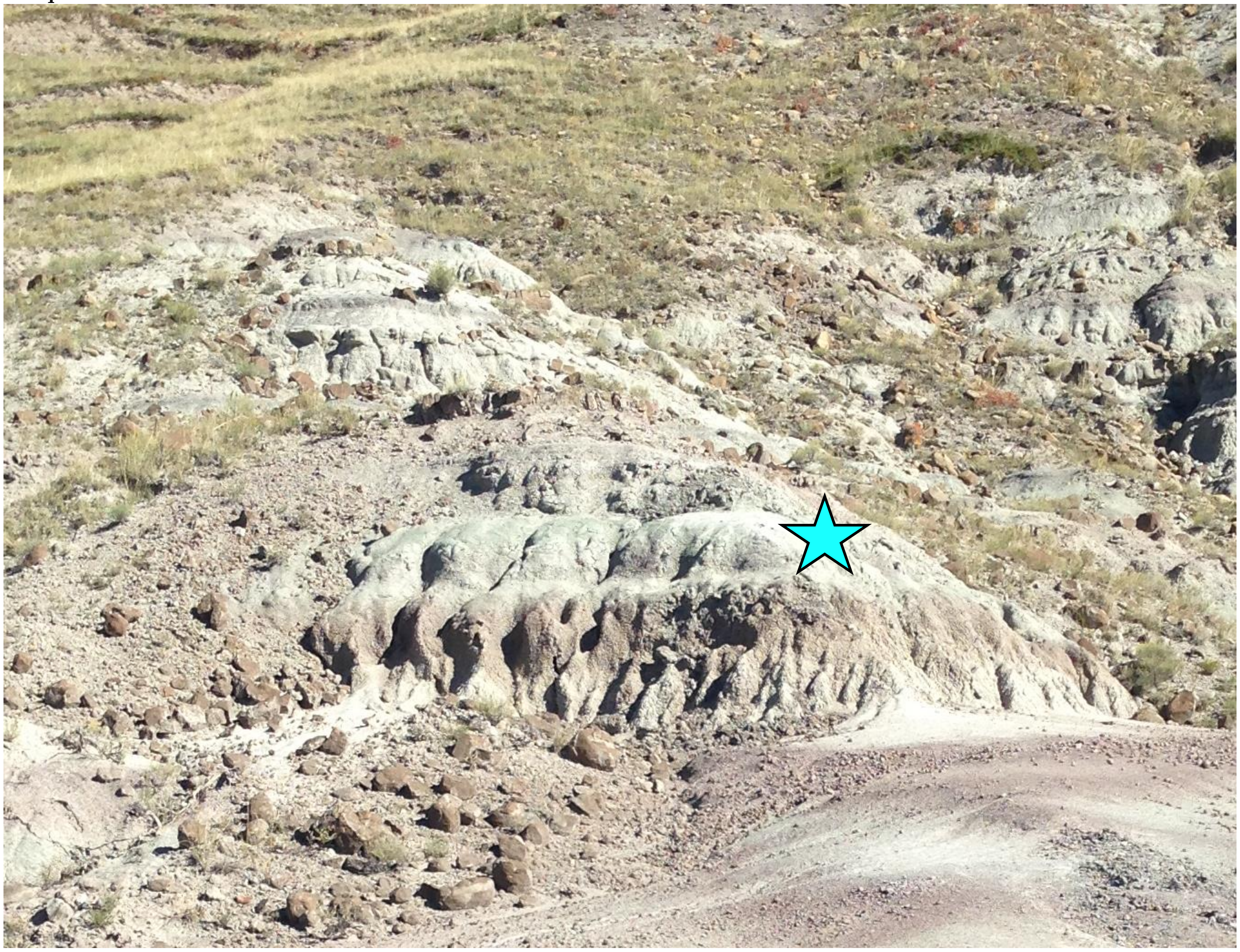


Figure 8: Small ripples and a horizontal burrow 1.5 m up section. Ripple crests marked by yellow dotted lines, burrow indicated by a solid yellow arrow.

Figure 9: Magnetite-rich cross-bed from 2.0 m up Section CB.1, directly adjacent to the dinosaur bonebed.

Figure 10: Stacked river channels from 6.8 m up Section CB.1. The dotted line represents the bottom of a second channel.

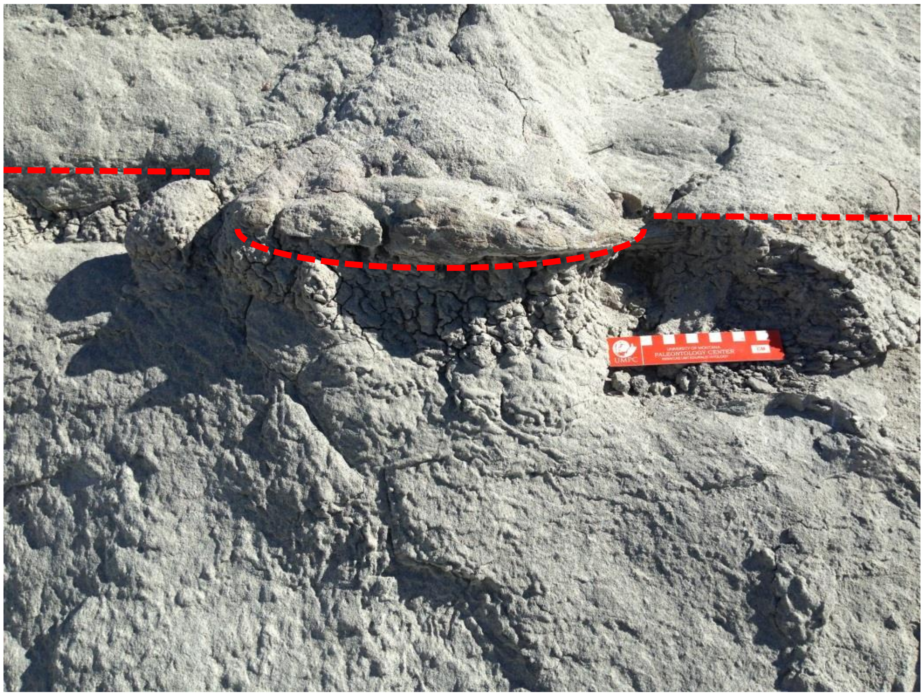


Figure 11: Dinosaur bone fragment 9.75 m up Section CB.1 in the conglomerate unit.

Figure 12: 10.0 m up Section CB.1 A conglomerate unit with trough cross-bedding and mud clasts. Dotted lines indicate bedding, the star indicates a concentration of mudclasts.

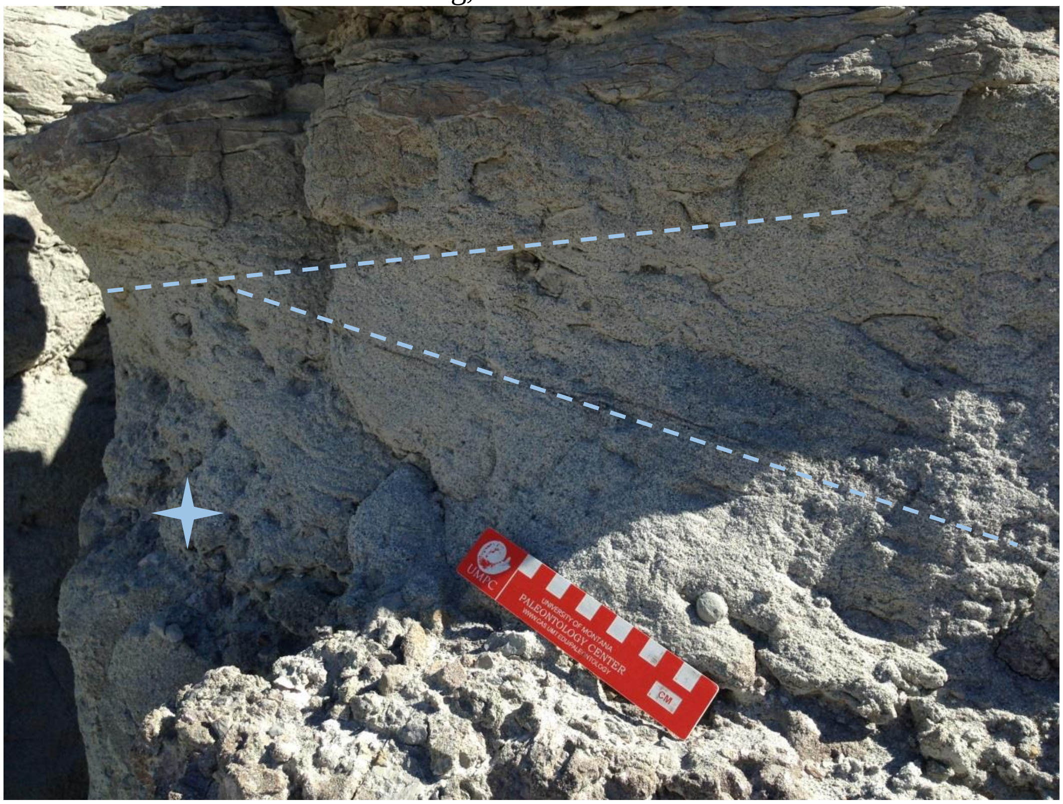


Figure 13: 10.25 m up Section CB.1. The red bracket indicates lingoid ripples. The yellow bracket indicates convolute bedding. The orange dotted line traces a laminae plane.

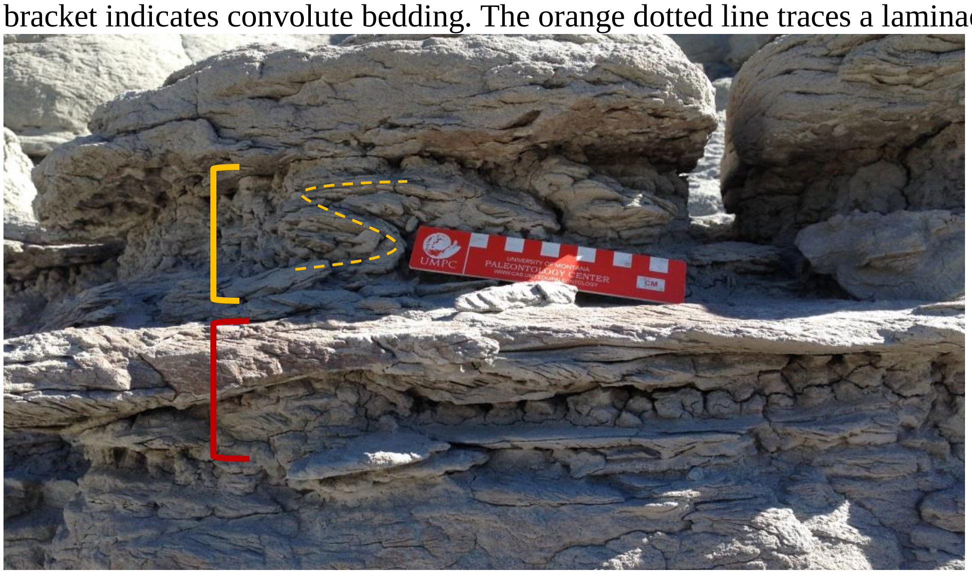


Figure 14: 2.5 m up Section CB.2. Mudcracks in a blue clay in-filled with a red clay.

Figure 15: 6.0 m up Section CB.2. Sandstone interbedded in a siltstone thicken and coarsen laterally to the north.

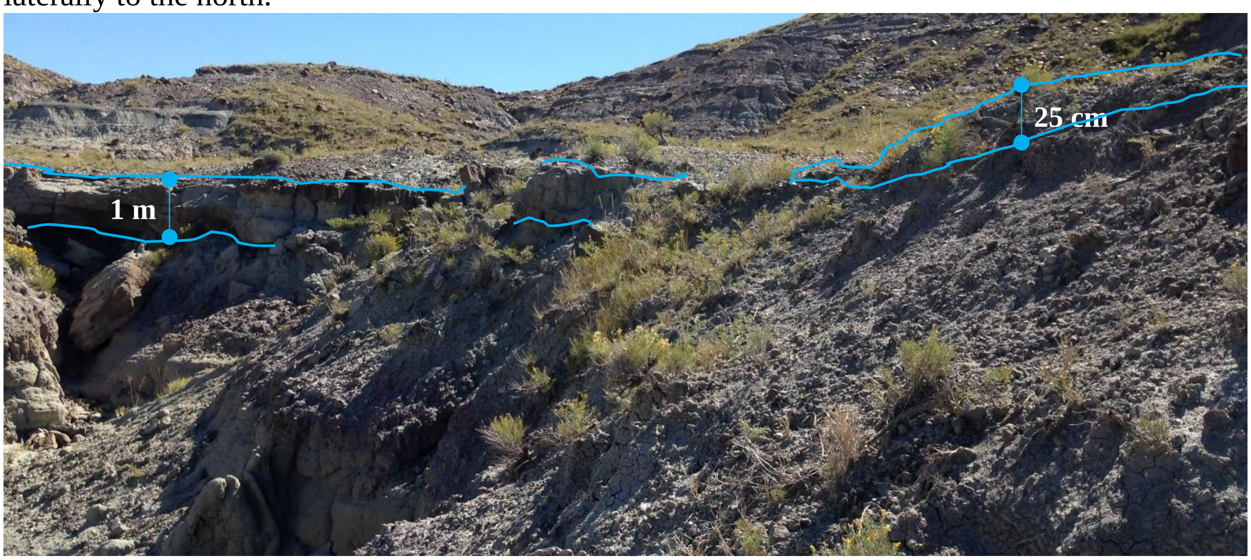


Figure 16: 6.18 m up Section CB.2. Caliche paleosol cap on a blue siltstone.

Figure 17: 11.28 m up Section CB.2. A caliche paleosol cap (base in orange) over a red siltstone (base in red), which in turn overlies a fine-grain sandstone.

Figure 18: 1.6 m up Section CB.3. A red star marks the red mudstone bed.

Figure 19: 8.75 m up Section CB.3. Convolute bedding in a medium-grain sandstone.

Figure 20: 8.75 m up Section CB.3. Convolute bedding in a medium-grain sandstone.

Figure 21: 8.75 m up Section CB.3. Convolute bedding in a medium-grain sandstone.

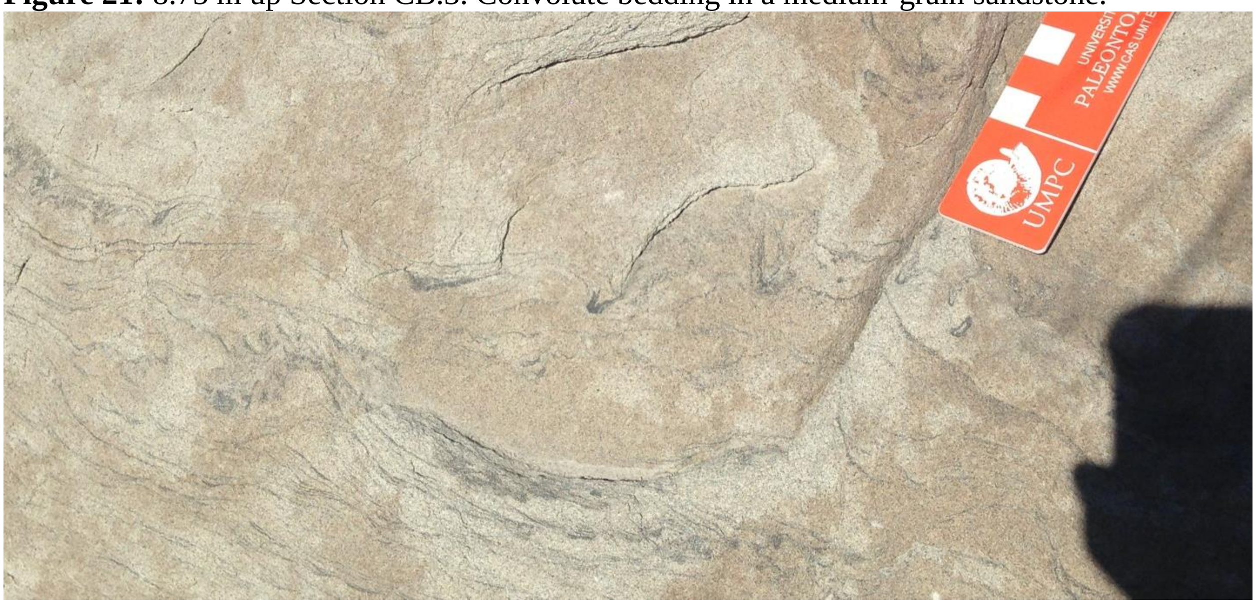


Figure 22: 8.75 m up Section CB.3. Convolute bedding in a medium-grain sandstone.

Figure 23: 21.68 m up Section CB.3. The yellow arrow indicates a vertical burrow in a medium sandstone at the base of a fining upwards sequence.

Figure 24: Ternary diagram showing the sandstone composition and classification of the four thin section samples using Folk's Sandstone Composition Classification diagram (1970).

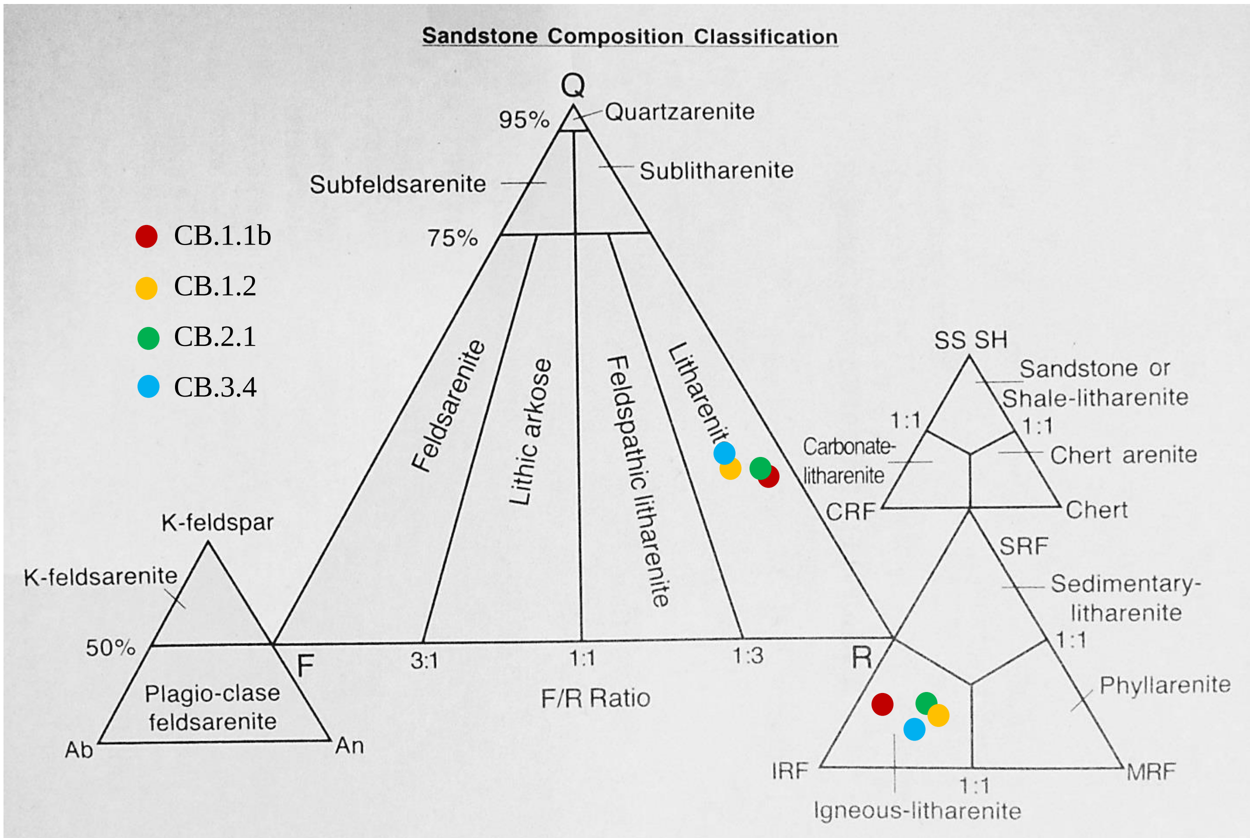
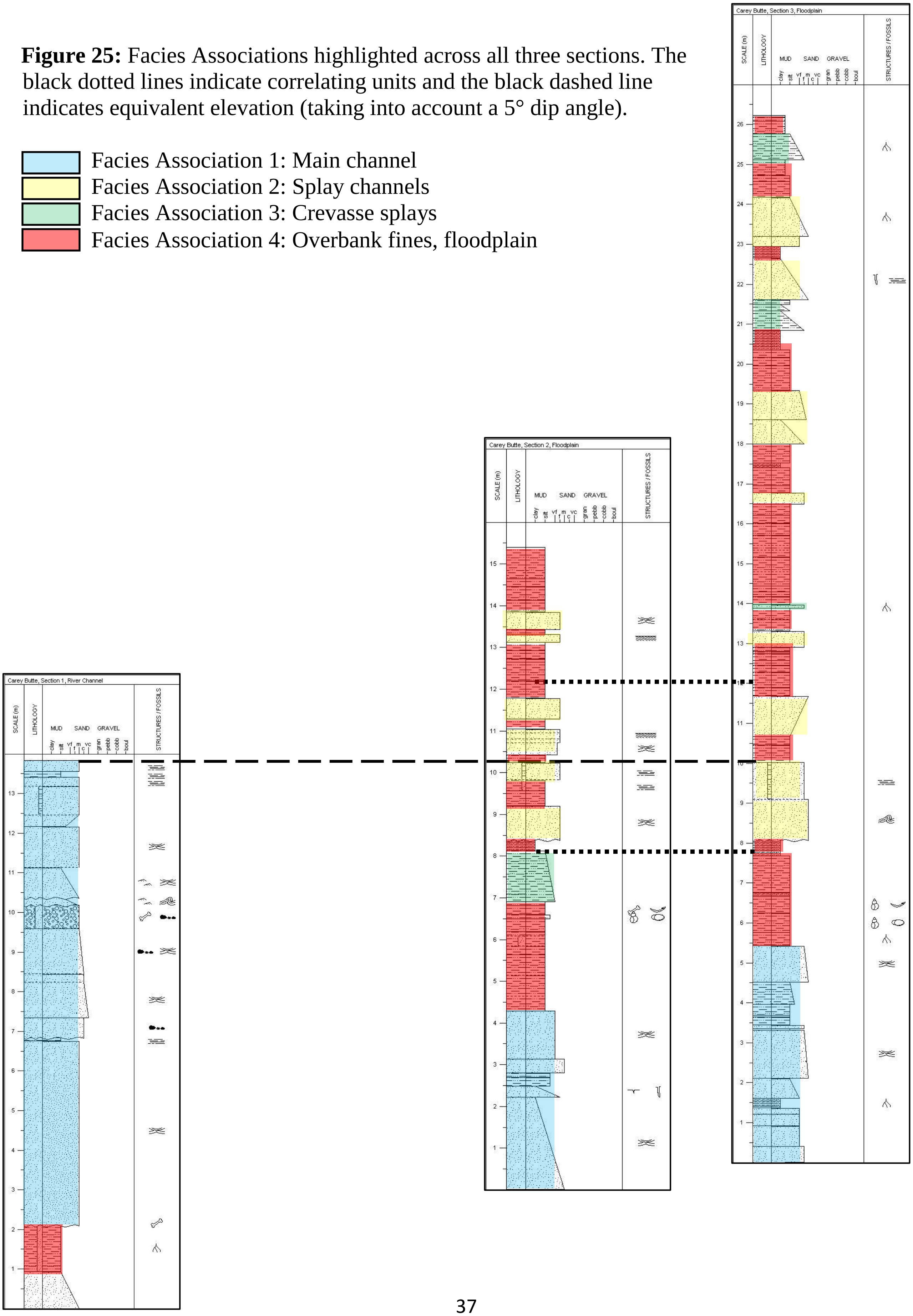


Figure 25: Facies Associations highlighted across all three sections. The black dotted lines indicate correlating units and the black dashed line indicates equivalent elevation (taking into account a 5° dip angle).



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IX. Acknowledgements

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This paper represents my own work in accordance with University regulations.

Appendices

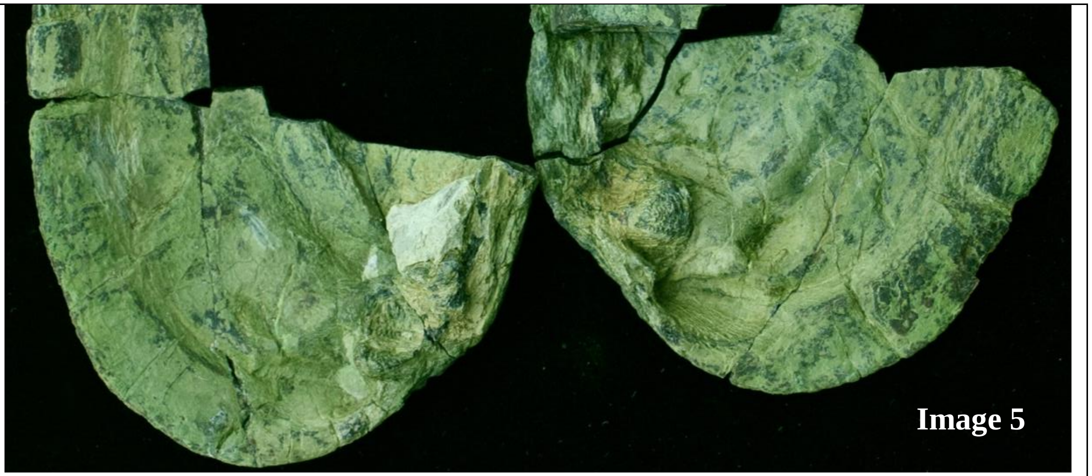
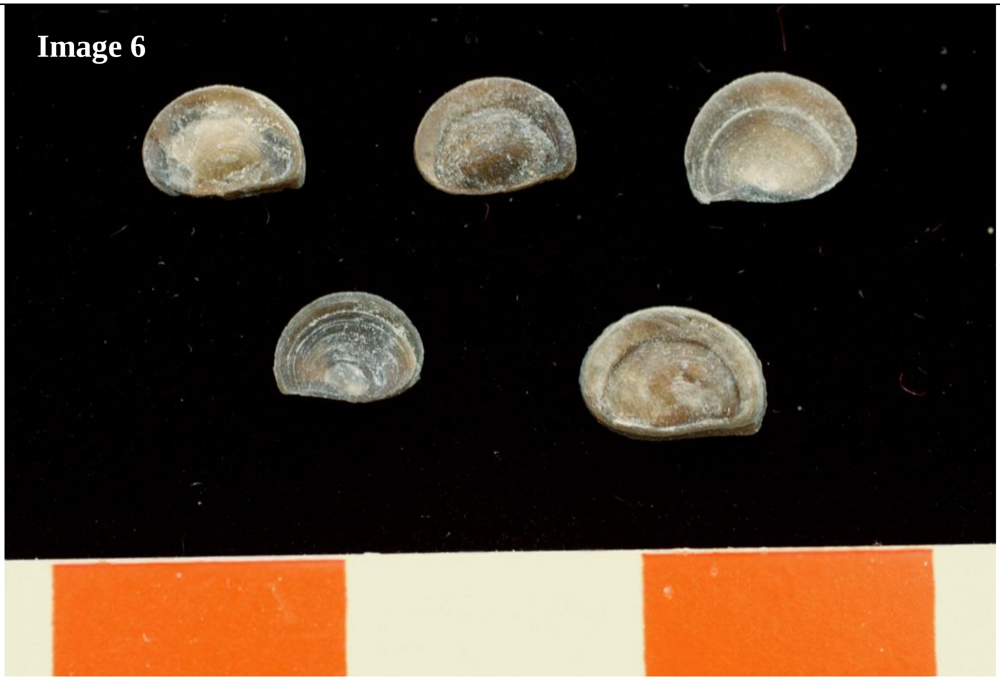
Appendix A. Rock hand sample descriptions

Sample No.	Location	Grain size	Roundness	Sorting	Color	Features	Composition	Notes	Rock name
CB.1.1a	2.11 m up CB.1	Medium	Subangular	Poor	Light blue-grey	Cross-bedding	50% lithics 35% quartz & feldspar 5% dolomite 5% magnetite 5% micas, chlorite/glauconite	Along certain bedding planes, grains tend to be coarser and the composition magnetite-rich	Lithrenite
CB.1.1b	2.11 m up CB.1	Medium	Subangular	Poor	Light blue-grey	Cross-bedding		Along certain bedding planes, composition tends to be magnetite-rich	Igneous litharenite
CB.1.2	13.5 m up CB.1	Medium	Subangular	Poor	Light blue-grey	Massive		Limestone fragments present	Igneous litharenite
CB.1.3	10.0 m up CB.1	Matrix: coarse Clasts: pebble	Matrix: Subangular Clasts: Rounded	Poor	Medium grey-teal	Matrix-supported	Matrix: 40% quartz & feldspar 35% lithics 15% chlorite/glauconite 10% magnetite Clasts: Mudrock	Bone-pebbles present but rare	Extraformational matrix-supported conglomerate
CB.2.1	0.2 m up CB.2	Medium	Subangular	Poor	Light blue-grey	Massive			Igneous litharenite
CB.2.2	2.5 m up CB.2	Very fine silt	NA	NA	Light teal	Mudcracks and vertical burrows	NA		Mudstone
CB.2.3	3.0 m up CB.2	Medium	Subangular	Poor	Light blue-grey	Massive	40% lithics 45% quartz & feldspar 10% chlorite/glauconite 5% magnetite		Litharenite
CB.2.4	4.0 m up CB.2	Fine	Subangular	Poor	Light blue-grey	Massive	40% lithics 45% quartz & feldspar 10% chlorite/glauconite 5% magnetite		Litharenite
CB.3.4	8.75 m up CB.3	Medium	Subangular	Poor	Light blue-grey	Soft-sediment deformation, trough cross-bedding		Very little cement, certain bedding planes are magnetite-rich	Igneous litharenite

*highlighted green used for thin section

Appendix B. Fossil specimen descriptions

Field Number	**Characteristics & Tentative ID**	**Photographs (scale bar square = 1cm)**
CB.2.22a	Clam Location: CB.2, 6.70 m 6.5x4x1 cm Bright yellow-green in color In Image 4 there are edge pieces that do not have contact points with the main shell. Image 5 is a close-up of the fold hinge seen in Image 3.	   

		
CB.2.22b	Clams Location: CB.2, 6.70 m 6x4x1 mm Light brown/tan in color, tends to be iridescent near hinge These specimens represent only a very small fraction of those on site. They are by far the most numerous fossil coming out of the black siltstone unit.	

CB.2.22c	Snail Location: CB.2, 6.55 m 2x1.5x0.5 cm Conispiral, asymmetrical, pale yellow-green shell with grey matrix inside the shell, shell twists clockwise from the apex to the body whorl. Abundant within the concretion unit, especially in Section CB.3.	

CB.2.23a	Tyrannosaur Tooth Location: CB.2, 6.70 m 2.5x1.5x1 cm Sky blue interior with a dark bluish-brown exterior.	 Image 8  Image 9	

CB.2.24a	Seed pods [(?)] Location: CB.2, 6.70 m 10x4x4 mm Black/dark brown in color with lighter staining (tan, grey).	

CB.2.24b	Snails Location: CB.2, 6.55 m 2x1.5x0.5 cm Conispiral, asymmetrical, pale dark green-grey shell with grey matrix inside the shell, shell twists clockwise from the apex to the body whorl. Abundant within the concretion unit, especially in Section CB.3.	
CB.2.24c	Clam Location: CB.2, 6.70 m Bright yellow-green in color	

CB.2.25	Vertebrate skull or vertebrae (?) Location: CB.2, 6.70 m Up to 1.5 cm across, but majority of fragments are < 1.0 cm Bone has sky blue exterior with dull crimson interior Some fragments, like the left-most piece in Image __ and the circled pieces in Image __, are pitted, but all other fragments are smooth.	 Image 13  Image 14

		Image 15

Appendix C. Thin section point count data
*Framework grains highlighted in green

CB.1.1b				
Mineral	**Quantity**	**Percent**	**Notes**	**Totals**
Polycrystalline Quartz	37	5.78	>1% zebra chert presence	Total: 640 Framework: 500
Monocrystalline Quartz	151	23.59		
Igneous Lithics	171	26.72		
Metamorphic Lithics	73	11.41		
Sedimentary Lithics	49	7.66		
Clay Cement	41	6.41		
Calcite Cement	2	0.31		
Calcite	10	1.56		
Dolomite	49	7.66		
Chlorite	0	0.00		
Chlorite Cement	1	0.16		
Biotite	6	0.94		
Muscovite	1	0.16		
Magnetite	13	2.03		
Pore Space	17	2.66		
Plagioclase	19	2.97		
K-spar	0	0.00		

CB.1.2				
Mineral	**Quantity**	**Percent**	**Notes**	**Totals**
Polycrystalline Quartz	68	10.29	Sedimentary lithics made up largely by limestone	Total: 661 Framework: 500
Monocrystalline Quartz	112	16.94		
Igneous Lithics	115	17.40		
Metamorphic Lithics	102	15.43		
Sedimentary Lithics	52	7.87		
Clay Cement	11	1.66		
Calcite Cement	7	1.06		
Calcite	12	1.82		
Dolomite	67	10.14		
Chlorite	3	0.45		
Chlorite Cement	22	3.33		
Biotite	7	1.06		
Muscovite	2	0.30		
Magnetite	16	2.42		
Pore Space	14	2.12		
Plagioclase	48	7.26		
K-spar	3	0.45		

CB.2.1				
Mineral	**Quantity**	**Percent (%)**	**Notes**	**Totals**
Polycrystalline Quartz	67	11.28	Most of the calcite is replacement, metamorphic lithics made up largely of quartz	Total: 594 Framework: 500
Monocrystalline Quartz	104	17.51		
Igneous Lithics	137	23.06		
Metamorphic Lithics	124	20.88		
Sedimentary Lithics	43	7.24		
Clay Cement	12	2.02		
Calcite Cement	8	1.35		
Calcite	12	2.02		
Dolomite	34	5.72		
Chlorite	0	0.00		
Chlorite Cement	0	0.00		
Biotite	5	0.84		
Muscovite	3	0.51		
Magnetite	11	1.85		
Pore Space	9	1.52		
Plagioclase	22	3.70		
K-spar	3	0.51		

CB.3.4				
Mineral	**Quantity**	**Percent**	**Notes**	**Totals**
Polycrystalline Quartz	49	6.72		Total: 729 Framework: 500
Monocrystalline Quartz	138	18.93		
Igneous Lithics	144	19.75		
Metamorphic Lithics	84	11.52		
Sedimentary Lithics	36	4.94		
Clay Cement	2	0.27		
Calcite Cement	34	4.66		
Calcite	51	7.00		
Dolomite	34	4.66		
Chlorite	0	0.00		
Chlorite Cement	0	0.00		
Biotite	6	0.82		
Muscovite	0	0.00		
Magnetite	28	3.84		
Pore Space	74	10.15		
Plagioclase	48	6.58		
K-spar	1	0.14		