The Paleontology, Geology and Taphonomy of the Tooth Draw Deposit; Hell Creek Formation (Maastrictian), Butte County, South Dakota.

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ABSTRACT

The "Tooth Draw Deposit" is an extensive, high diversity, multitaxic, dinosaur-rich, bone bed in the latest Cretaceous, Hell Creek Formation. The mapped portions of the deposit show a complex channel lag formed by a combination of both abiotic and biotic processes, at least 40 meters wide and well over 180 meters long. It is composed of interbedded sandstones and conglomerates representing fluvial, riverine deposition, a portion of which shows evidence of hyper-concentrated or debris flow rates. This lag has been sampled in different locations including the main "Tooth Draw Quarry (TD)", "Tooth Draw West (TDW)", "Tooth Draw South (TDS)" and "Becca's Tooth Draw (BTD)". To date, several thousand vertebrate specimens have been recovered over the last 15 years of work. These elements include both dinosaur and non-dinosaur remains, showing a diverse fauna of at least 21 dinosaur and over 48 vertebrate genera. Taphonomic markers indicate that there are at least two distinct communities represented by the deposit. One that represents a more localized fauna, caught up in the initial formation of the lag and another that represents reworked, hydraulically emplaced elements, likely accumulating from further upstream (parautochthonous). Many of the reworked elements show pre-depositional breaks, spiral fractures, bite marks, insect borings, and evidence of sub-aerial exposure. Tyrannosaurid teeth make up over 30% of the logged specimens, over 700 teeth, with more added each year. Dromaeosaurid teeth are also fairly common with over 180 specimens to date. Given the high numbers of shed theropod teeth, and the broken and bite marked bones, the most parsimonious conclusion is that portions of the Tooth Draw assemblage represent the remains of multiple seasons of feeding activity a short distance upstream along the ancient river system.

INTRODUCTION

THE HELL CREEK FORMATION

The Hell Creek Formation is one of the most vertebrate-rich rock units in the Western United States. It stretches across the states of Montana, North Dakota and South Dakota with equivalent units in Wyoming (Lance Formation), Colorado (Denver and Laramie Formations) and into Canada (Frenchman Formation). On average, it is approximately 100 meters thick (Murphy et. al., 2002; DePalma, 2010; Horner et. al., 2011; Fastovski and Bercovici, 2015) and where exposed, forms drab or "somber" colored badlands (Brown, 1907). Fossils are plentiful and can be found throughout most strata of the Hell Creek Formation (Stein, 2019).

Each year field crews from dozens of public and private entities explore the Hell Creek Formation looking for answers to some of paleontology's greatest mysteries (Stein, 2019). Due to its stratigraphic position, it is uniquely placed to answer key questions regarding evolution, diversity, climate change and, of course, the K-Pg extinction. As a result, understanding the health and composition of the Hell Creek ecosystem, prior to this monumental event, is of great importance. One of the best ways to determine the health of this ecosystem, and in fact, any ancient ecosystem, is by studying and sampling bone beds.

Bone beds are defined via Behrensmeyer (1991) and Rogers and Kidwell (2007) as "a relative concentration of vertebrate hard parts preserved in a localized area or stratigraphically limited sedimentary unit (e.g. a bed, horizon or stratum) and derived from more than one individual" (Behrensmeyer, 1991; Rogers and Kidwell, 2007; Eberth, et. al., 2007). They can be catastrophically emplaced in a sudden event or represent aggregations that are deposited over long stretches of time. They can preserve animals that are both autochthonous (animals preserved actually lived in the area where they are preserved) or allochthonous (animals preserved lived in an area far away from where they are preserved) or even parautochthonous (a mixture of the two or where elements have traveled only a short distance from where they originated) (Bates and Jackson, 1984; Samanthi, 2020). Bonebeds can be "biogenic" in origin, including "intrinsic biogenic concentrations" (as a result of behavior or activity of the animals actually preserved in the deposit) or "extrinsic biogenic concentrations" (as a result of other animals due to feeding or collecting behaviors) (Rogers and Kidwell, 2007). They can be "physical" in origin, including "hydraulic concentrations" (concentrations due to the actions of surface water flows, wind, water, etc.), "sedimentologic concentrations" (as a result of reworking, rapid burial in ash, debris flow or landslide, attritional, ie. a lack of sediment, or some other sudden sediment forced event), or even combinations thereof (Rogers and Kidwell, 2007). Bone beds can preserve complete articulated skeletons from multiple individuals and species, disarticulated remains from dozens of individuals and taxa or multiple combinations of articulated, associated and disarticulated remains. Deposits can be monotaxic or monodominant, where one taxa dominates, or multitaxic, where multiple taxa can be found in various concentrations (Behrensmeyer 1991, 2007; Eberth et. al., 2007).

Bone beds have been used to indicate various behaviors such as gregariousness or herding (e.g. Colbert, 1947; Madsen, 1976, Ostrom, 1986; Coombs, 1990; Ryan et. al., 2001; etc.), pack hunting (e.g. Maxwell and Ostrom, 1985), nesting (e.g. Horner, 1984), and others. They have helped to determine the species richness, diversity, mode and pace of evolution or extinction and other paleontologic inquiries. Taphonomic analysis of bone beds have been done in multiple rock formations yielding important data on ancient ecosystems and their faunal components (e.g. Dodson et. al., 1980; Fiorillo, 1996, 1998; White Fastovsky and Sheehan, 1998; Ryan et. al., 2001; Britt et. al., 2007; Eberth and Currie, 2010; Manning and Edgerton, 2014; Foster et. al., 2018; etc.).

Bone bed deposits in the Hell Creek Formation are not uncommon and are frequently discovered during exploration runs. Aggregations of dinosaur remains have been reported by multiple authors including: McKenna (1962), McKenna et. al., (1994), Triebold (1997), Pearson et. al. (2002), Bartlett (2004), Depalma (2010), Clemmons and Hartman (2014), Ullman et. al. (2017), Stein (2019) and others. The majority of well described sites are monodominant bone beds (Bjork, 1985; Christians, 1992; Weeks, 2016; Ullman et. al., 2017), consisting predominantly of one taxa. In the Hell Creek, the majority of these sites are dominated by the hadrosaurid, *Edmontosaurus* (Stein, 2019). Until recently, it was thought that monodominant ceratopsian bone beds were not present in the Hell Creek, leading some authors to conclude that the most common dinosaur, *Triceratops* (Scannella and Fowler, 2014; Stein, 2019), was not gregarious, but solitary (e.g. Dodson, 1996, Dodson et. al., 2004; from Mathews et. al., 2009). Over the last several years, this has been proven not to be the case (Mathews et. al., 2009; Scannella and Fowler, 2014; Bastiaans et. al., 2016).

Multitaxic bone beds, on the other hand, yield elements and teeth from many different taxa and often show a more broad picture of the ecosystem (Bartlett, 2004; Eberth, 2007). While some multitaxic bone beds in the Hell Creek have been studied and reported on in the literature (Triebold, 1997; Bartlett, 2004; DePalma, 2010), most are under-sampled and under explored (Stein, 2019). This is typical of most formations where monodominant bone beds appear to receive most of the academic attention (Eberth et. al., 2007). Unfortunately, bone beds are often very difficult to work, requiring “a long-term commitment of manpower and resources” (Eberth et. al., 2007, p. 267). This is especially true with multitaxic bone beds which can require years of collection to understand. This work requires a multi-disciplinary approach and the talents of multiple individuals.

This current study is a preliminary analysis and introduction to the geology, paleontology and taphonomic history of a high diversity, multi-taxic bone bed we call the “Tooth Draw Deposit (TDD)”, with a special emphasis on the original “Tooth Draw Quarry (TD)”. It should be considered an introductory primer on the fossils and geology of this bed, with additional, more detailed papers to follow as time permits. The Tooth Draw Deposit is rich in both plant and animal remains with a large and diverse fauna. It's geology indicates a complex depositional setting. It's taphonomy tells us the story of a unique ecosystem with a strange and wonderful cast of characters. It's analysis and long-term study will add yet another important chapter to the history of ancient life in the Late Cretaceous, before the dinosaurs breathed their final breaths.

LOCAL AND REGIONAL GEOLOGY

The Tooth Draw Deposit is located on a private ranch in the northeastern corner of Butte County, South Dakota, approximately 23 miles northeast of the town of Newell (Figure 1). Outcrops can be found in a moderately sized patch of badlands, at the base of a geographically prominent set of buttes called “Deer's Ears Buttes”. These buttes have a vertical relief of over 100 meters and are thus a prominent geographical feature that can be seen for many miles. The Deer's Ears Buttes are within the Moreau River drainage, just a couple miles south of the Moreau River along the southern margin of the Williston Basin. Beds in this area are generally flat lying with a slight 1-2 degree dip to the northeast (Lange, 1963; Talbot, 1985) with some exceptions (Malinzak, 2018).

The Deer's Ears Buttes themselves, are an erosional feature and a product of differential weathering. It, and its nearby sisters of Castle Rock and Haystack Butte, are essentially held up by a cap of highly cemented, coarse-grained, lithic arenite sandstone and conglomerate of the Eocene age, Dazzling White Sands (DWS) unit of the lower Chadron Formation (Talbot, 1985). This informal unit was originally named by Lilligraven in 1970, during his description of the geology of the Slim Buttes. The Slim Buttes themselves can be found approximately 25 miles to the north of Deer's Ears Buttes and the Tooth Draw Deposit.

The caprock of DWS at Deer's Ears is only 6-7 meters thick, but is resistant enough, at present, to keep the softer, underlying rocks from completely eroding away. Large boulders, many over eight meters in diameter, can be found as talus, down the slopes of the buttes and in the catch basins and badlands below them. The bulk of the Quaternary Colluvium (QC) in this area is also composed of weathered remains of this unit and that of the Hell Creek. Vertebrate fossils, including reported Titanothere remains (personal communication Leonard Licking, 2006), turtle shell and bone fragments have been found within the caprock and in some of the boulders downslope from it.

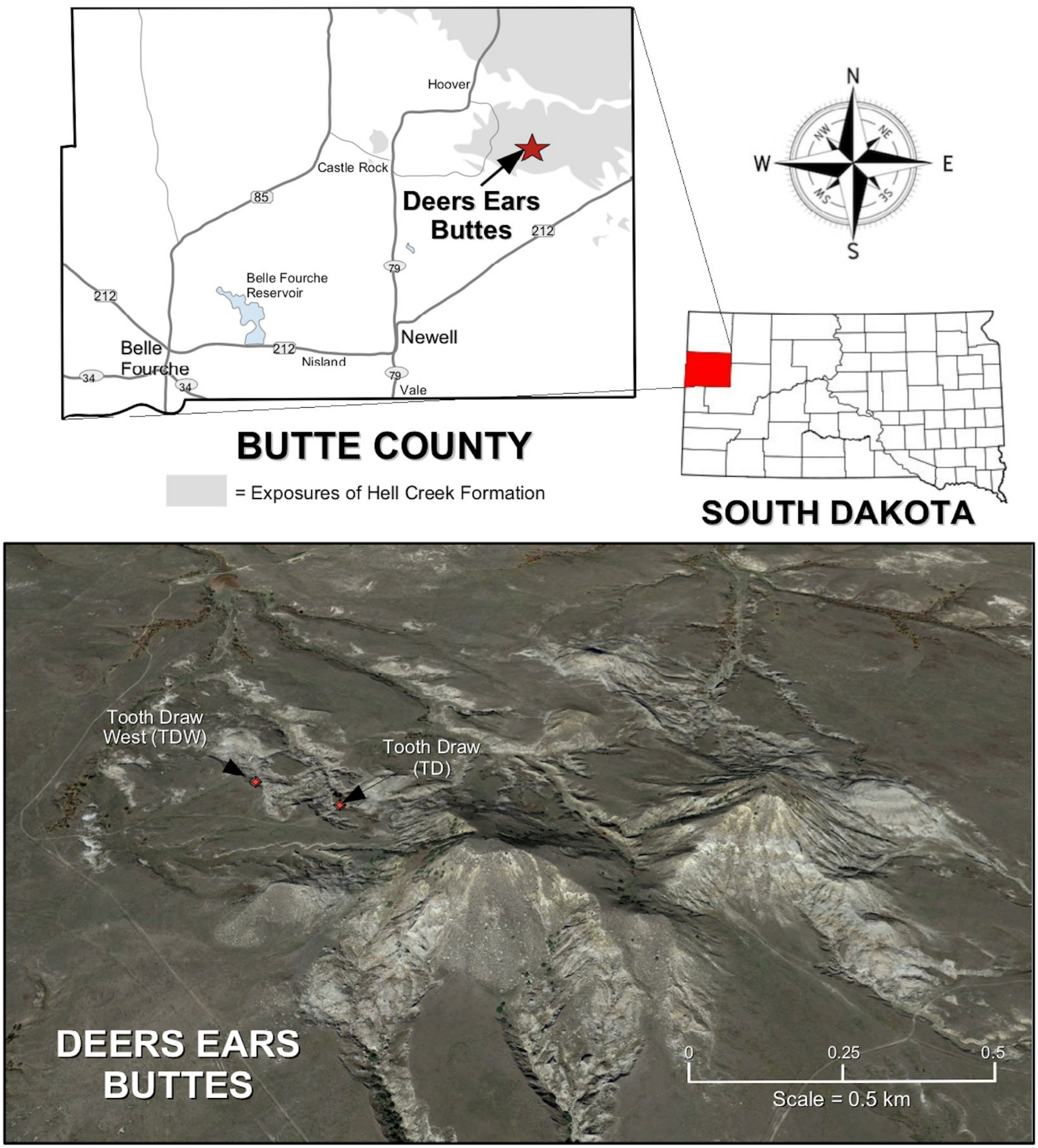


Figure 1- Site Location Map. The Deers Ears Buttes are a prominent geomorphic feature in northwestern Butte County, South Dakota. The buttes have been known for years, originally mapped from a distance as early as 1874, but very little geologic or paleontologic work was done there until the 1980's. The buttes consist of two main peaks, Deers Ears East and Deers Ears West, as well as several secondary peaks and associated badlands. To date over 25 different dinosaur bearing fossil localities have been identified, along with one partial collection of nodosaur scutes and several recovered skeletons of *Edmontosaurus* and *Triceratops*.

Unconformably, below the DWS in the Deer's Ears Buttes area is a 25-30 meter section of the Paleocene, Ludlow Member of the Fort Union Formation (Talbot, 1985). The Ludlow in this area consists of pastel colored, yellow, gray, tan, and pink clayshale, claystones, mudstones, siltstones and occasional sandstones. The finer grained lithologies dominate, and are well cemented, often breaking along lamina or with conchoidal fracture. Much of this formation is covered by heavy amounts of talus and sparse vegetation of grasses, sage and low scrub trees. Extensive, laterally-traceable lignite beds, reported in other Ludlow outcrops (Testin, 2013), are notably absent from the Ludlow on the Deer's Ears. There is no basal lignite, and most beds of shale and siltstone, with a few exceptions, do not contain any observable plant material or vertebrate fossils.

Underlying the Ludlow is the Latest Cretaceous, 66-67 million year old, (Maastrichtian), 90-100 meter thick, Hell Creek Formation. As with most described Hell Creek sections, the Hell Creek on the Deer's Ears, consists of somber-colored, light gray to yellow sandstones, siltstones, claystones and darker-colored, interbedded, bentonite-rich mudstones and carbonaceous shales. Orange to red-brown colored, lenses of clay-pebble to ironstone-pebble conglomerate are also found, indicating riverine channel deposition. Siderite concretions, paleosols and concreted channel fill deposits are often present. All of these were deposited along a broad, coastal flood plain, just inland from the Western Interior Seaway.

Fossils of plants and animals are quite common throughout the Hell Creek Formation in the Deer's Ears Buttes area. In fact, over 25 different dinosaur-bearing fossil localities can be found within the two square mile area of the Deer's Ears Buttes (Stein, in preparation). These include the remains of isolated skeletons, including multiple partial skeletons of *Triceratops* and *Edmontosaurus*, abundant microsites, and both monodominant (*Edmontosaurus*) and multitaxic bone beds. The Hell Creek Formation is exposed along the lower 2/3 of the buttes and forms incised badlands along its base and the drainages that flow outward from it. The Tooth Draw Deposit is located within a large patch of these badlands, on the northwest edge of the Deer's Ears Buttes Area, in a narrow southwest trending rill that drains into a larger northwest trending ravine.

Conformably underlying the Hell Creek in the area, is the Late Cretaceous, 67-70 million year old, Fox Hills Sandstone. This formation is approximately 60 meters thick (more or less) in the area and forms a series of low ridges and gullies on the south side of the Deer's Ears Buttes (Lange, 1963; Talbot, 1985). It consists of light gray to buff colored, fine-grained sandstones that were deposited in a marginal marine environment along the western coast of the Western Interior Seaway. These sandstones are generally unconsolidated and weather rapidly. Occasional beds of well cemented and/or concreted, cross-bedded, brownish sandstones, that are more resistant to erosion, are, however, present and can be found in sparse outcrops. Due to its highly eroded nature, good exposures of Fox Hills Sandstone, in the Deer's Ears area, are few and far. Unfortunately, the best outcrops, including those with a clear Hell Creek/Fox Hills contact are located on private ranches to the south of the Buttes, that are currently off limits to exploration.

A HISTORY OF EXCAVATION

The “Deer's Ears” were first mapped (from a distance), in the mid to late 1800's (Ludlow, 1874) and were briefly explored for vertebrate specimens by the famous field paleontologist, John Bell Hatcher in 1891 (Marsh, 1831-1891 in Yale archives; Gilmore 1913;1915; Stein, 2014). During the summer of 1891, Hatcher was passing though the area and paused just long enough to collect a *Thescelosaurus* scapula, that was later used to assist in the description of the type specimen of *Thescelosaurus neglectus*, Gilmore, 1913;1915. This scapula is curated in the National Museum of Natural History as USNM V7760-1 and is the earliest known vertebrate specimen from the Deer's Ears Butte area. Despite the discovery, Hatcher did not return to the buttes and while some geologic mapping and oil exploration was done in the area during the 1920's and 1960's, no known paleontological investigations took place there until the mid 1970's. It was not until 1985 before a detailed stratigraphic section of the buttes themselves was made by Talbot (Talbot, 1985).

The original site of the Tooth Draw Quarry (TD) was discovered by the ranch owner's first wife, Mary Ann Licking, some time around 1980. Mary Ann and the Licking family initially surface collected the site recovering multiple tyrannosaur teeth, ornithischian bones and microfossils. The Lickings invited Dr. Phil Bjork, then curator of the South Dakota School of Mines and Technology Geology Museum, to inspect the site and showed him their discoveries. The SDSMT crews, under Dr. Bjork had been prospecting the ranch since 1975, but according to family members, “did not do much excavation”. At Tooth Draw, the SDSMT crew reportedly surface collected a nice T. rex tooth and excavated an unknown leg bone from the site, but, according to Leonard Licking (2018), “did not express much interest in working the deposit”. They made sporadic trips to the ranch from 1980-1988, but reportedly never returned to the Tooth Draw Quarry. Unfortunately, after multiple disagreements with the land owners, the SDSMT crews were no longer welcome on the ranch after 1988.

Sometime around 1992, Pete and Neal Larson of the Black Hills Institute were invited to prospect on the ranch and were shown the original workings at the Tooth Draw Quarry (personal communication Neal Larson 2020 and Leonard Licking 2018). They collected a large ornithischian illium approximately 7-8 meters above the main Tooth Draw Quarry, but reportedly did not do any excavation in the quarry itself. They came back the following year, but shortly after arriving on the ranch, the “Sue T. rex controversy” erupted and the BHI crews were never able to return to the ranch.

Figure 2- The Tooth Draw Quarry Then and Now. When originally discovered the deposit was coming out of a narrow gully, down low in the badlands on the northwest corner of Deers Ears Buttes. Now, the quarry has since expanded with the removal of large swaths of overburden on both sides of the main draw.

In the spring of 1996, Mary Ann Licking passed away. Her son Mike, daughter Becca, and husband Leonard surface collected the site from time to time, but no serious excavation took place for the next ten years. Several commercial fossil hunters explored the ranch at this time, but according to Leonard, they did not dig in or claimed to not dig in the Tooth Draw Quarry. Based upon scattered reports from social media, however, some of these groups likely surface collected the site without notifying the land owner.

In May of 2006, the author was given access to the ranch to explore for fossils. One of the first specimens discovered on the property included a partial *Triceratops horridus* skeleton located two miles east of the main TD quarry. While excavating this new specimen, Leonard and the Licking family reported the old TD quarry to me and brought me to the site. Initial inspection of the Tooth Draw Quarry showed a 1-2 meter thick, channel lag deposit eroding out of a narrow gully with approximately 5-8 meters of overburden. Abundant dinosaur bones, teeth and microfossils were immediately discovered both as float and in-situ. A casual survey indicated that the deposit was quite extensive, cropping out over 30 meters to the south, 10 meters to the north and across the main draw approximately 20 meters to the west. Unfortunately, excavation of the *Triceratops* skeleton, the large degree of overburden and other priorities prevented much serious work at the Tooth Draw Quarry early on. Occasional surface collecting and minor excavation occurred, but this was mostly salvage work along the weathered wall.

Serious excavation began in earnest during the spring of 2009 (Figure 2). Material was excavated and prepared to determine the bone density and faunal composition. The deposit was further traced and mapped to another section over 180 meters away to the northwest. This site was designated "Tooth Draw West". Another section along the west ravine was examined and designated "Tooth Draw Site "B" aka "Becca's Tooth Draw". Due to the large volume of material eroding out of the quarry walls, the nature of that material and the constraints of working such a large deposit, it was determined to be a perfect location for tourist activities. It was at this point that the original Tooth Draw Quarry became our main tour guest site and we began to develop it into an educational attraction. Since this time, over 3,000 tour guests from all over the world have visited the site, helping to document and recover thousands of vertebrate specimens.

Institutional Abbreviations

National Museum of Natural History (NMNH), the University of Kansas (KU), the North Carolina Museum of Nature and Science (NCSM), The McKinney Geology Teaching Museum (MGTM), The Royal Tyrrell Museum (RTMP), The Fukui Dinosaur Museum (FDM), PaleoAdventures Research Collection (PARC), and the Katholieke Universiteit Leuven (KUL).

MATERIALS and METHODS

FIELD COLLECTION

Field collection by the author and PaleoAdventures field crews continues to the present day. Since this is a private locality, all specimens recovered here were placed into three distinct categories: "common", "commercial" or "scientifically significant". Unidentifiable, weathered or pre-depositonally broken fragments of bone (usually under 5 cm) ("bone pebbles" as described by Eberth, 2007), along with ubiquitous Hell Creek fossils such as worn ceratopsian and hadrosaurian teeth were considered "common" and were frequently given away to tour guests or volunteers. Commercially viable *Tyrannosaurid* teeth, average quality, partial to complete *Edmontosaurus* or *Triceratops* bones, not thought to be connected to a skeleton, were considered "commercial", and were often sold to help fund the excavations. All scientifically significant bones, including those from rare genera, pathological bones, or important microfossils were, however, retained in what is known as the PaleoAdventures Research Collection (PARC). This collection is digitally curated and available to all researchers, via the online database found here: http://www.virtualdinosaurmuseum.com. All of these specimens are available for personal inspection, with notice and a legitimate research proposal. Small collections of TD specimens have also been sold or donated to other, more permanent institutions, including the National Museum of Natural History (NMNH), the University of Kansas (KU), the North Carolina Museum of Nature and Science (NCSM), The McKinney Geology Teaching Museum (MGTM), The Royal Tyrrell Museum (RTMP), The Fukui Dinosaur Museum (FDM), and the Katholieke Universiteit Leuven (KUL).

All significant vertebrate specimens (commercial or scientifically significant), greater than 5 cm in length, unusual microfossils, and theropod teeth, were often photographed in situ, measured, mapped to position and orientation, and recorded in a yearly log book. A permanent baseline was first surveyed in 2006 using a combination of transit compass, tape measure and GPS. Mapping of significant fossils was achieved using the radial-arc method. This data was then recorded in the log book and later digitized using Open Office Draw. Additional field notes, sketches of the geology, and sketches of the elements were often made in a separate field journal.

Specimens were collected in plaster jackets, placed in aluminum foil envelopes or plastic baggies for transport to the lab. Significant specimens were given field numbers based on the quarry name, year of collection and sequential number in order of discovery. In order to collect as much of the material as possible, most of the debris pulled from the quarry wall was dry screened daily, using simple ¼ and/or ⅛ inch mesh bucket screens. Periodically, a portion of the discarded material was also collected and wet screened, with ⅛ inch mesh wire screens. Additional microfossils were recovered by this method, but much of this material has not been identified or entered into the database at present. For the purposes of this paper, only major specimens logged in the log book, will be used in this study.

STRATIGRAPHIC AND GEOLOGIC METHODS

A complete geologic survey and stratigraphic section along various tracts through the Deer's Ears Buttes area was conducted during the summer of 2016. Additional work has been conducted since then, to further clarify each of the strata, identify the relative position of the Tooth Draw Deposit within the Hell Creek and to correlate it to other Hell Creek sections. These were compared to previous sections done by Talbot in 1985 and to other sections across the Hell Creek Formation. Much of this work is preliminary, however, and additional testing is required for greater precision. Since the Deer's Ears Buttes have a vertical relief of well over 100 meters in this area, several reasonably complete sections were possible (Figure 3). Strata were measured using a Jacob's staff, laser level, GPS and compass. Each strata was described and samples were collected for petrographic analysis and future testing. The bulk of this information is being compiled for a separate paper, to be published at a later date (Stein, in preparation).

Detailed geologic cross sections of the bone bed were also measured (every other year), along key areas of the quarry wall. This was achieved by carving a vertical section down through the deposit and measuring the thickness of each horizon, using a Jacobs staff or tape measure. Changes in the lithofacies were observed by standard hand specimen petrographic analysis. Observations included color, grain size, angularity, mineralogy, and sedimentary structures (Compton, 1985). This data was recorded in the yearly log book and field journals and was later digitized using Open Office Draw. All lithologic descriptions follow Raymond, 1984 and the classification of clastic sedimentary rocks by Dott, 1964 (sandstones) and Folk, 1974 (shales, mudstones and siltstones).

LABORATORY METHODS

Specimens were prepared using standard hand preparation (dental picks, pin vices, hobby knives, brushes) and mechanical preparation techniques (rotary grinders, air scribes, and light air abrasion on Comco MB-1000, using sodium bicarbonate “composite formula”) (Stein, 2009). Due to gypsum mineralization in many of the elements, chemical preparation methods were not used.

Paleobond cyanoacrylate superglues of various strengths were employed to bond fragile bones together. Paleobond glues consisted of mostly Penetrant Stabilizer, though 4417 and 4418 were also experimented with in the field and PB-40, PB100x and PB750 were certainly employed for large breaks on dense cortical layers requiring strength. After removal of the matrix, the surfaces of most of the elements were coated with a thin layer of polyvinyl acetate (PVA) to preserve and protect the delicate remains. Most specimens were then curated in the PaleoAdventures Research Collection without any further restoration. Specimens that were deemed important enough for molding and casting were, however, restored using Paleobond “Paleosculpt” epoxy resin when necessary. This restoration was principally “crack fills” to add strength and stability, but on occasion larger areas of missing bone were restored. This restoration was done in a different color to provide a clear differentiation between original fossil bone and the restoration. Any areas with suspected bite marks or borings were left as pristine as possible.

Specimens were then measured, photographed, compared to available literature, identified and then curated in our online database. Specimens were identified down to the most detailed level of taxonomy possible. Other researchers, familiar with Hell Creek Formation remains, were often consulted during identification, to ensure a second opinion on questionable specimens.

TAPHONOMIC METHODS

Taphonomic bone bed analysis were conducted using the standard techniques outlined by Rogers et. al. (2007) and Eberth et. al. (2007). For most analysis, data was transferred from yearly log books, field and laboratory log sheets, field journals and direct observations of the collection. For bone modifications a representative subset of 514 elements from the PARC collections were directly observed under magnification to estimate breakage patterns, weathering, abrasion, bite marks and bioerosion. Bone breakage fracture patterns are based from Gruwald (2016) classification, which is modified from Shipman (1981). Weathering stages were taken from Behrensmeyer (1978), Shipman, 1981 and Eberth et. al. (2007). Ontogenetic stage estimates were conducted based on a relative comparison of size of isolated elements to size of elements from more complete skeletons and descriptions of skeletons elsewhere.

RESULTS

STRATIGRAPHY

A total of seven stratigraphic sections with complete sedimentary logs were made during the summer of 2016. Three of which, cut through or near the Tooth Draw Deposit. The most complete sections include those taken at Tooth Draw itself (Figure 4) and another along the northern flank of Deer's Ears West (DEW). This latter section is the most complete, crossing the K-Pg boundary and through both the Fort Union and Chadron Formations. This section measures some 84 meters in height.

From these sections it was determined that the Tooth Draw Quarry (TD) is approximately, 58 meters below the suspected K-Pg boundary. This places it somewhere in the lower middle of the Hell Creek Formation, equivalent to the lower "Marmath Member" of Frye, (1969) or at the base of the informally named "JenRex Sandstone", "East Ried Coulee Unit", as per the lectostratatype section by Hartman et. al (2014). The JenRex Sandstone, at 11.9 meters (Hartman, 2014), roughly correlates in lithology, structure and distance below the K-Pg boundary with the cross bedded sandstone units of TD-6 through TD-10 horizons, just above the original Tooth Draw Quarry. According to Hartman, the base of the JenRex Sandstone often is a scoured, "basal lag of mollusks and and rip-up mud clasts" (Hartman, 2014 p.109). While there have been no mollusks found at or in the Tooth Draw deposit, the downcutting basal lag with "rip ups", described by Hartman et. al., appears similar. Barnum Brown, while describing the Hell Creek Formation in 1907, also noted a laterally extensive basal conglomerate at this approximate level. He wrote, "Beds of river-sorted gravel occur in these two strata. They invariably contain waterworn fragments of bones and shells... gravel is cemented into a conglomerate capping a low ridge. The bed is 100 yards long and stained a dark rusty color..." (Brown, 1907). While the TD deposit seems to match the position and lithology of the basal JenRex Sandstone it is unlikely equivalent, given the long geographical distance between it and Tooth Draw. Due to the variability of the Hell Creek terrestrial ecosystem and it's "rapid lateral facies changes" (Testin, 2013, p. 9-10), member designations away from the original sections described by Brown, Frye and Hartman are likely only loosely associated, and direct chronostratigraphic correlation may not be applicable (Murphy et. al., 1995; Harman and Kirkland, 2002; Testin, 2013; Hartman, 2014).

The exact nature of the K-Pg contact on the Deer's Ears is also unclear at this time, warranting further investigation. This boundary, and the section leading up to it, is unlike any other described K-Pg boundaries in the literature. There is no basal lignite or "z coal" present. The contact appears to be unconformable and there is a possibility that significant sections of the upper Hell Creek or the Lower Ludlow were eroded away during the Paleocene (Talbot, 1985). There is some indication that the sediments leading up to the boundary are marginal marine and may be related to a heretofore undescribed tongue of the Cannonball Seaway.

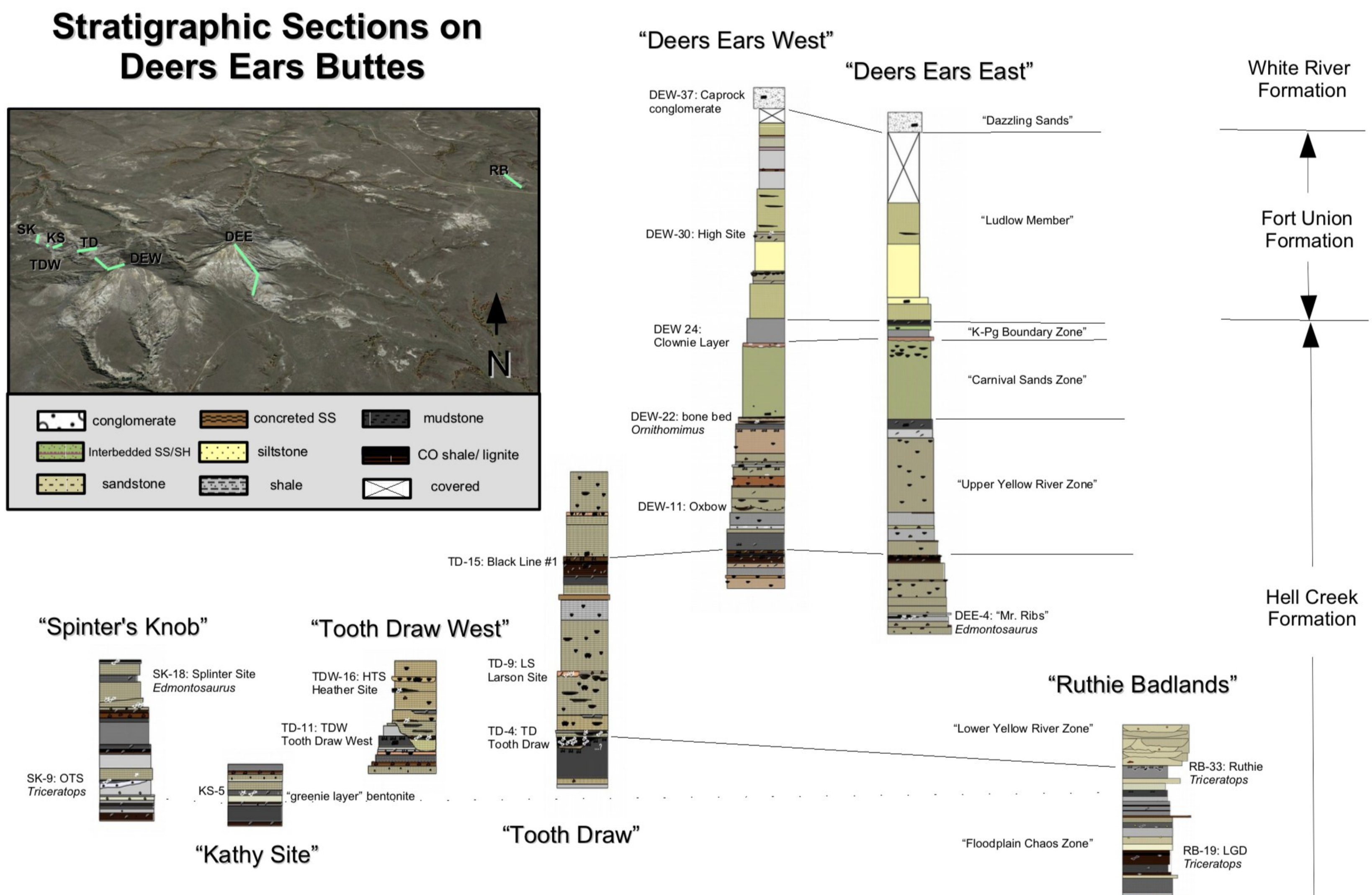


Figure 3- Stratigraphic Sections. A total of seven stratigraphic sections have been completed on the Deers Ears Buttes with more planned in the future. All measurements are taken from the top of the Hell Creek Formation and the K-Pg boundary as a reference point. The Tooth Draw Quarry is approximately 58 meters below the suspected boundary layer, placing it in the lower middle of the unit.

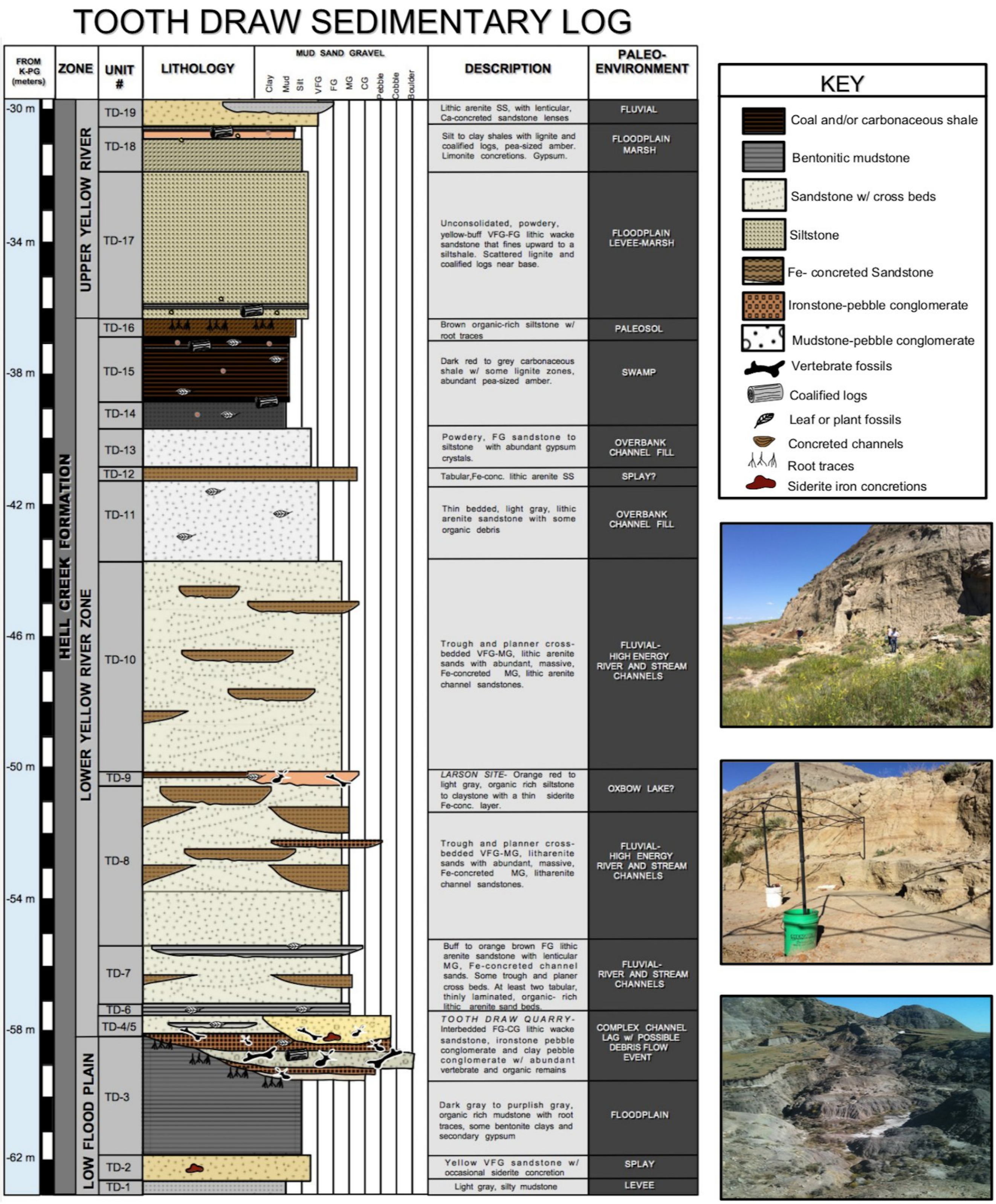


Figure 4- Sedimentary Log Tooth Draw Quarry. The Tooth Draw Quarry is approximately 58 meters below the suspected KT boundary at the base of what we call the Lower Yellow River Zone. This zone is generally a fining upward sequence, beginning with a basal lag (TDD) scouring into the lower floodplain mudstones, eventually going into a channel fill section and finally a return to floodplain and swamp deposits. There are several locations above and below that contain bone beds and microsites.

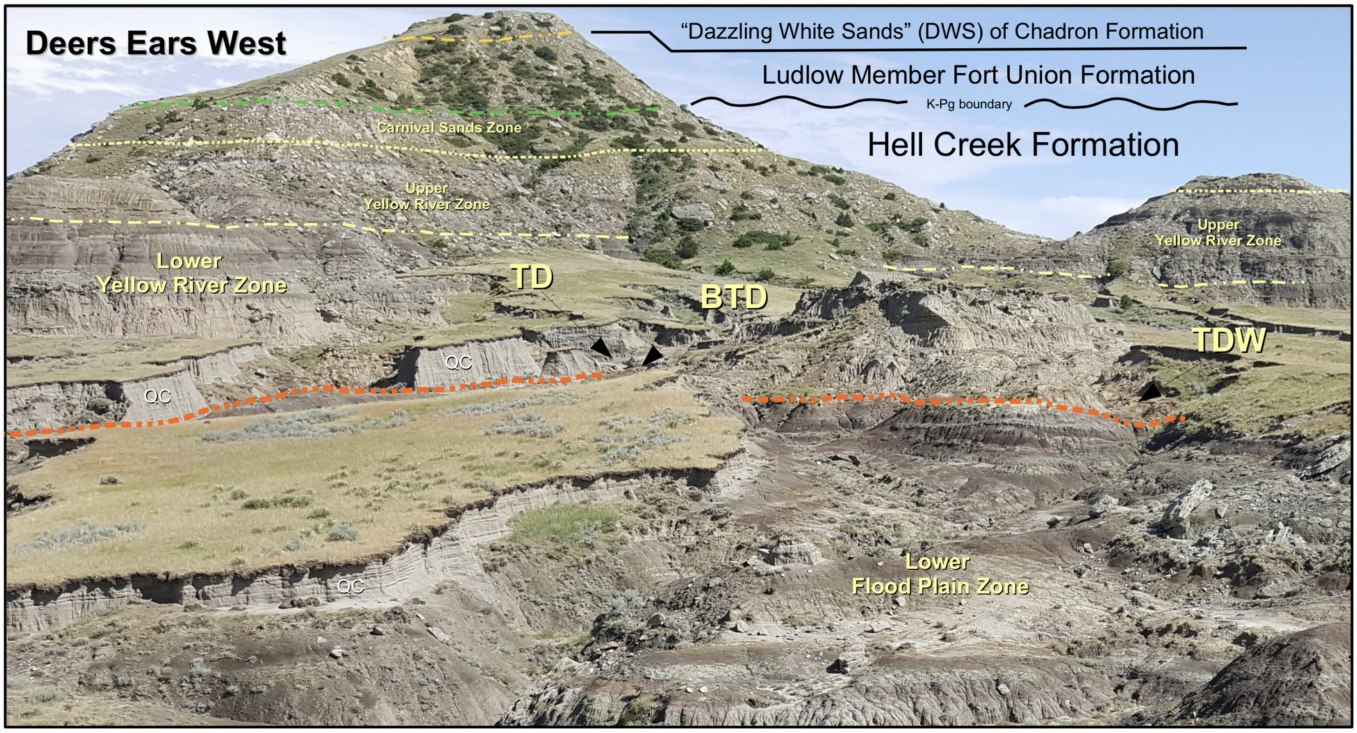


Figure 5- Informal Stratigraphic Zones. The stratigraphy of the Deers Ears Buttes is unlike the most well-known and described Hell Creek sections observed in Montana or North Dakota. Given its long distance away from the original beds described by Brown in 1908, the Lectostratotype section described by Hartman et. al., 2014 and the sections and members named by Frye, 1969, we have broken the unit into six informal zones that better fit our section: These zones are, from lowest to highest: 1)The Big Sandy Zone, 2) The Lower Floodplain Zone, 3) The Lower Yellow River Zone, 4) The Upper Yellow River Zone, 5) The Carnival Sands Zone, and 6) The K-Pg Boundary Zone. These zones are likely regional in character, but not valid beyond Butte County, Southern Harding County, Perkins County and Meade County. Given the variable nature of the Hell Creek Formation they should not be elevated to member status. This image is facing the buttes and looking south-southeast towards the Tooth Draw, BTD and Tooth Draw West Quarries. You can see that they are all on the approximate stratigraphic level. A number of bentonite beds can be found in this area, and it is hoped that we will be able to get a more accurate date of the beds with future testing.

As a result of such differences and given the large distance from the sections done by other authors, the Hell Creek portion of the Deer's Ears section was split into six informal, localized subdivisions or zones, based upon the interpreted paleoenvironment of deposition (Stein in preparation). They include a basal distributary sequence, a lower flood plain sequence, two, generally fining upward fluvial sequences, a fining upward marginal marine sequence, and a thin boundary sequence. These informal units are named as follows: 1) The Big Sandy Zone, 2) The Lower Flood Plain Zone 3) The Lower Yellow River Zone, 4) The Upper Yellow River Zone 5) The Carnival Sands Zone and 6) the K-Pg Boundary Zone. Each of these informal names are briefly described below (Figure 5).

The "Big Sandy Zone" is a basal section of light colored, unconsolidated and powdery sandstones representing low velocity distributary channels at or near the margin of the seaway. This zone is at least 12 meters in thickness. Though covered on the ranch, it likely conformably overlies the Fox Hills Formation (Talbot, 1985). The exact boundary between the two is indeterminate at this time as extensive ground cover obscures the contact and very little work has been done on it. To date, this zone is largely unfossiliferous, but occasional sandstone beds reveal leaf impressions and rare micro-sites. One prominent site we call the "Enigma Quarry" (ENS), at the top of this zone, however, is quite fossiliferous. And may in fact be a seasonal lake deposit. Abundant leaf impressions, microfossils, several complete turtle shells, young crocodile material, varanid lizard, *Triceratops* and dromaeosaurid elements have been recovered from here.

The "Lower Flood Plain Zone" predominantly consists of 18-20 meters of thin to medium bedded, multi-colored (light and dark gray, greenish-gray, pale purple and pale pink), bentonite-rich mudstones, siltstones and carbonaceous shales. Occasional volcanic ash layers, rich in bentonite, fine sands and silts and the occasional thin lignite are also present. While some beds are laterally traceable across outcrops, most change facies rapidly. Siderite iron concretions, are locally abundant and limonite or jarosite concretions are often found as secondary rinds forming around bits of lignite or coarser sand. It predominantly represents flood plain deposition with minor development of poorly drained paleosols and may be loosely equivalent to the Fort Rice Member of Frye, 1969 (Talbot, 1985). Partial skeletons, minor bone beds and isolated vertebrate remains, particularly ornithischian bone fragments, are commonly found within this zone.

The "Lower Yellow River Zone" consists of 22-23 meters of yellow to light gray, medium bedded, trough and planar cross-bedded, fine-grained sandstones of fluvial origin. The unit often begins with a scoured, basal lag of conglomerate that is quite extensive. In other areas of the ranch, the lag is less fossiliferous or bound by paleosol, often with associated or isolated *Triceratops* or *Edmontosaurus* remains. From this, the sandstone generally fines upward until softer unconsolidated sandstone and siltstones begin coming in. These are generally channel fill sandstones, showing cross bedding and cross laminations. It ends with another carbonaceous shale and floodplain mudstone with plant fossils, root traces, localized pea-sized amber and finally minor paleosol development. These upper beds are generally a dark grey color, full of organics and represent swampier conditions. These upper beds are traceable for a significant distance across the buttes.

The "Upper Yellow River Zone" is likely loosely equivalent to the lower portion of the "Huff Member", of Frye's, 1969 classification (Talbot, 1985). It consists of a second sequence of generally fining upward, sandstones and siltstones that are also approximately 22-23 meters in thickness. This zone is slightly more variable, however, with rapid lateral facies changes, thinner and less laterally consistent sandstone beds and more mudstone and siltstone. In some areas of the ranch it begins with a basal lag of clay pebble or ironstone pebble conglomerate, but in others it is merely a fine grained unconsolidated lithic arenite sandstone. On Deer's Ears West, it actually begins with a 4-5 meter thick, mudstone-siltstone sequence with root traces and fine beds before getting into a more traditional, sandy channel fill sequence.

Overlying the Upper Yellow River Zone, is a 12-13 meter section of alternating, greenish-gray sandstone and pale pink silt shale that we call the "Carnival Sands Zone". This section is well cemented and often forms cliffs devoid of vegetation. On the south side of Deer's Ears West, it sometimes shows large, cannonball-shaped, Fe-rich, sandy concretions, especially in its mid to upper reaches, but this is not always the case. Talbot, 1985 considered the Carnival Sands to be part of the Huff member and suggested that it was deltaic in origin. In the Deer's Ears Buttes area the lithologies, sequence and sedimentary structures suggest that it may very well be marginal marine in origin, possibly representing an estuary or tidal flat.

In the main Deer's Ears West section, the Carnival Sands Zone begins with a 1 meter thick, basal lag of well-sorted, light gray to orange, sandy, clay pebble conglomerate that is locally fossiliferous. It pinches in and out along the contact, but is laterally extensive and traceable. We call this the DEW-22 layer and it is another multitaxic bone bed, with both dinosaur and non-dinosaur remains. At a spot we call the DEW-22N Site, we have recovered the fragmentary, disarticulated, but associated remains of a small ornithomimid along with a mix of well preserved turtle, crocodile, fish and *Thescelosaurus* material. On the opposite side of the buttes, on the same stratigraphic horizon, we have a site we call DEW22S. Here we have recovered an unidentified, partial theropod pes phalanx and other mixed vertebrate remains.

Conformably overlying the basal DEW-22 layer begins the main series of interbedded sandstones and shales. The sandstones are a buff to a light greenish gray, fine-grained lithic arenite with a mix of well sorted, sub-angular to sub-rounded grains of quartz, feldspar, lithic fragments and mica, with very little clay or matrix and a non-calcareous cement. The shales are a pale pink color with a mix of clay and silt with no visible organics or carbonaceous material. The sandstones begin thick bedded, but get progressively thinner as you go upsection. The interbedded shales remain about 10-20 cm in thickness until the top where they grade into a very unusual variegated, dark gray, light gray, pale purple, pale pink, and yellow mud/clay section we call "the stripey" layer (Figure 6C). Stripey is about 2 meters in total thickness, but individual clay layers are usually less than 2 cm each. This unit shows signs of soft sediment deformation, and possible bioturbation. Large, 2 cm diameter, vertical root traces (personal communication Steve Hasiotis, 2017), that were originally thought as ophiomorpha burrows, are found frequently in this unit. Other than the unusual root traces it appears unfossiliferous, but further investigation is planned. Above this unusual layer the sequence ends with a short section of interbedded greenish gray sandstones and interbedded siltshale similar to those below.

Overlying the Carnival Sands zone is a short, 5-6 meter section, that we call the "K-Pg Boundary Zone". This consists of a lower 1-2 meters of medium gray to blue-gray, sometimes yellow brown to pale purple to pale pink, bentonitic claystone, that is laterally consistent and traceable across the buttes. It generally weathers light to medium grey and forms a pop-corny texture when dried out. It's upper surface is irregularly scoured by a very unusual bed consisting of a chaotic mix of yellow to pale pink, sandy, clay pebble conglomerate. Clasts are angular to sub-rounded and consist of a poorly sorted mix of pink, gray and yellow claystone, some clearly ripped up from the underlying beds. Interspersed within the bed are irregularly shaped, yellow iron concretions and locally abundant displaced rhizoconcretions (Figure 6A). This unique "turbated" or erosional layer is

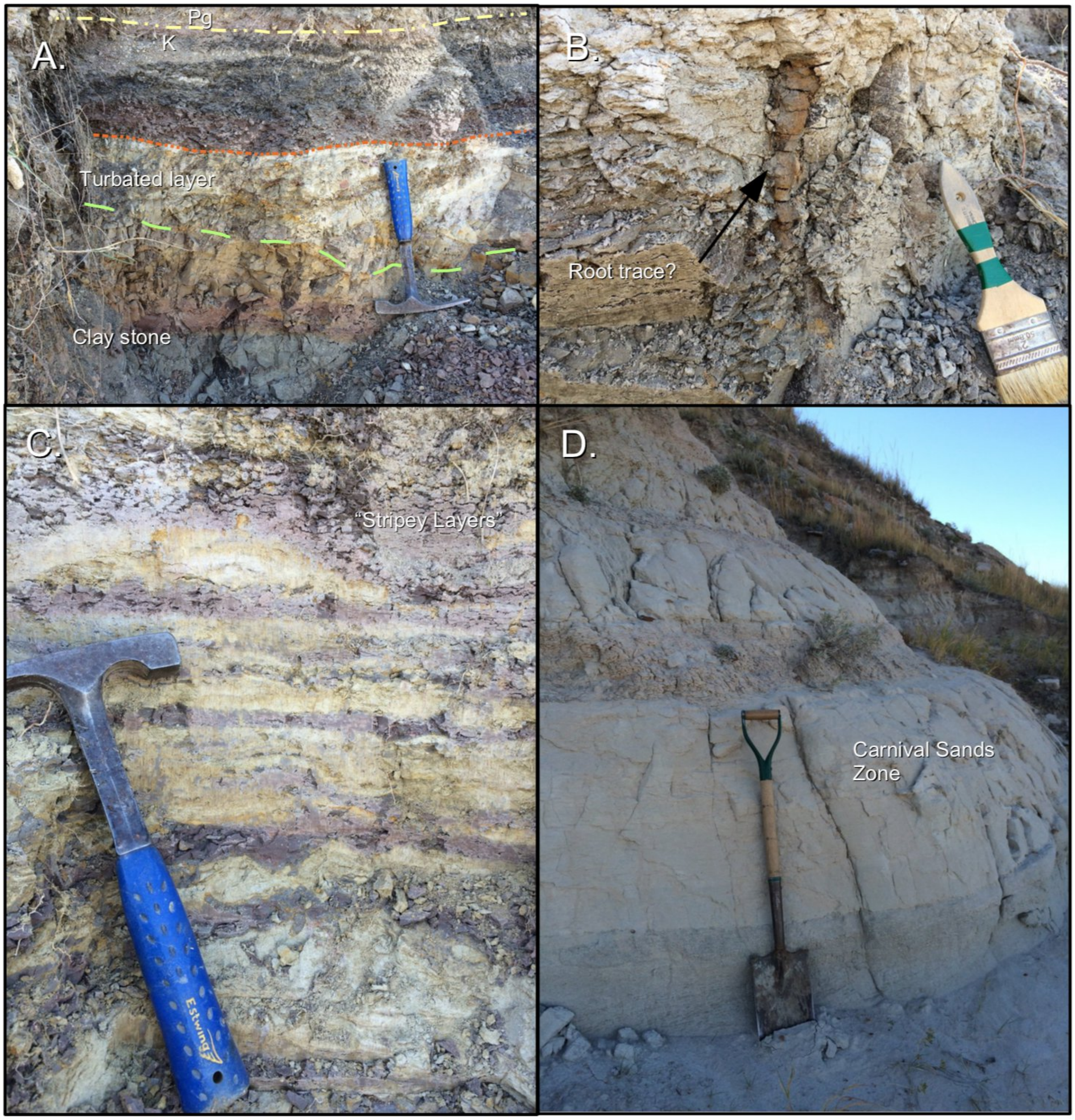


Figure 6- K-Pg Boundary Layers and Upper Hell Creek. The upper portions of the Hell Creek Formation exposed on the Deers Ears is markedly different than those seen in northwestern South Dakota, Southwestern North Dakota and Montana. Here we find an unusual fining upwards sequence of rocks that appear to represent marginal marine to tidal-flat facies, leading up to A) a highly turbated layer interpreted to be very near or on the K-Pg Boundary. B) Close up of some of the suspected burrows or root traces below the K-Pg Boundary zone. C) Unusual variegated clay layers showing bioturbation. D) Alternating fine sandstones and maroon silt-shales of the Carnival Sands Zone. Further work is necessary to determine the exact nature of this contact.

usually less than 30 cm in thickness and can be found on both the East and the West Deer's Ears Buttes. It weathers a yellow or pink and is quite striking when found. Shortly above this scoured and turbated layer, we return to fine sediment deposition with a 30 cm bed of dark gray to pale pink clay shale with interbedded, thin layers of a light colored claystone. On Deer's Ears East this is overlain by a very short section of additional light gray clay shales. On Deer's Ears West the upper gray clayshale can be another 2 meters in thickness. The nature of this zone is still under investigation, but this is the suspected boundary layer. Above this, we find the soft, pastel-colored, yellow silt shales and sandstones interpreted to be the Ludlow Member of the Fort Union Formation. This dramatic change in color from somber gray to pastel yellow, along with a definite change in slope, and an increase in vegetative ground cover all suggest that the boundary between Hell Creek and Ludlow lies here (Schulte, 1957; Murphy et. al., 2002; Testin, 2013).

Talbot's (1985) thesis and stratigraphic section attempted to correlate this upper zone with Frye's (1969) Pretty Butte Member. He further appeared to suggest that the turbated layer represented an erosional unconformity between the Upper Hell Creek and the lower Ludlow member of the Fort Union Formation. While this may be the case, the sequence, structures, chaotic rip-up clasts and stratigraphic position indicate that something more interesting may be going on here, including the possibility of a marginal marine, K-Pg boundary impact-related event. Additional testing is required to understand the precise nature of this contact and its significance.

BONE BED GEOLOGY

The Tooth Draw Deposit is generally 1.5-2.0 meters in thickness and can be broken down into several bone-bearing, litho-facies horizons, labeled A through E (Figure 7). These horizons have variable thickness and their full lateral extent is indeterminate at this time. Bone bearing horizons are covered by overburden to the east, thickest at the main TD quarry and tend to thin and become less complex towards the northwest. The bone bearing horizons of the deposit overlay a scoured contact with the underlying floodplain mudstone (F) though the specific lateral extent and architecture of the channel is inconclusive at this time due to the large degree of overburden. The distance from the main TD quarry to the TDW quarry is 180 meters so the bone bed continues for at least this distance and likely continues under the overburden in both directions, for some length. The deposit is at least 40 meters in width though its edges are also obscured at this time by overburden to the south and colluvial fill to the north. Assuming the width of the channel is relatively consistent and based on its given exposure, the entire deposit is likely over 7,000 m^2 or more. To date, only about 264 m^2 of this material has been thoroughly excavated (153 m^2 at TD + 96 m^2 at TDW + 15 m^2 at BTD). This means that we have been digging at an average rate of around 18-19 m^2/year (Figure 8).

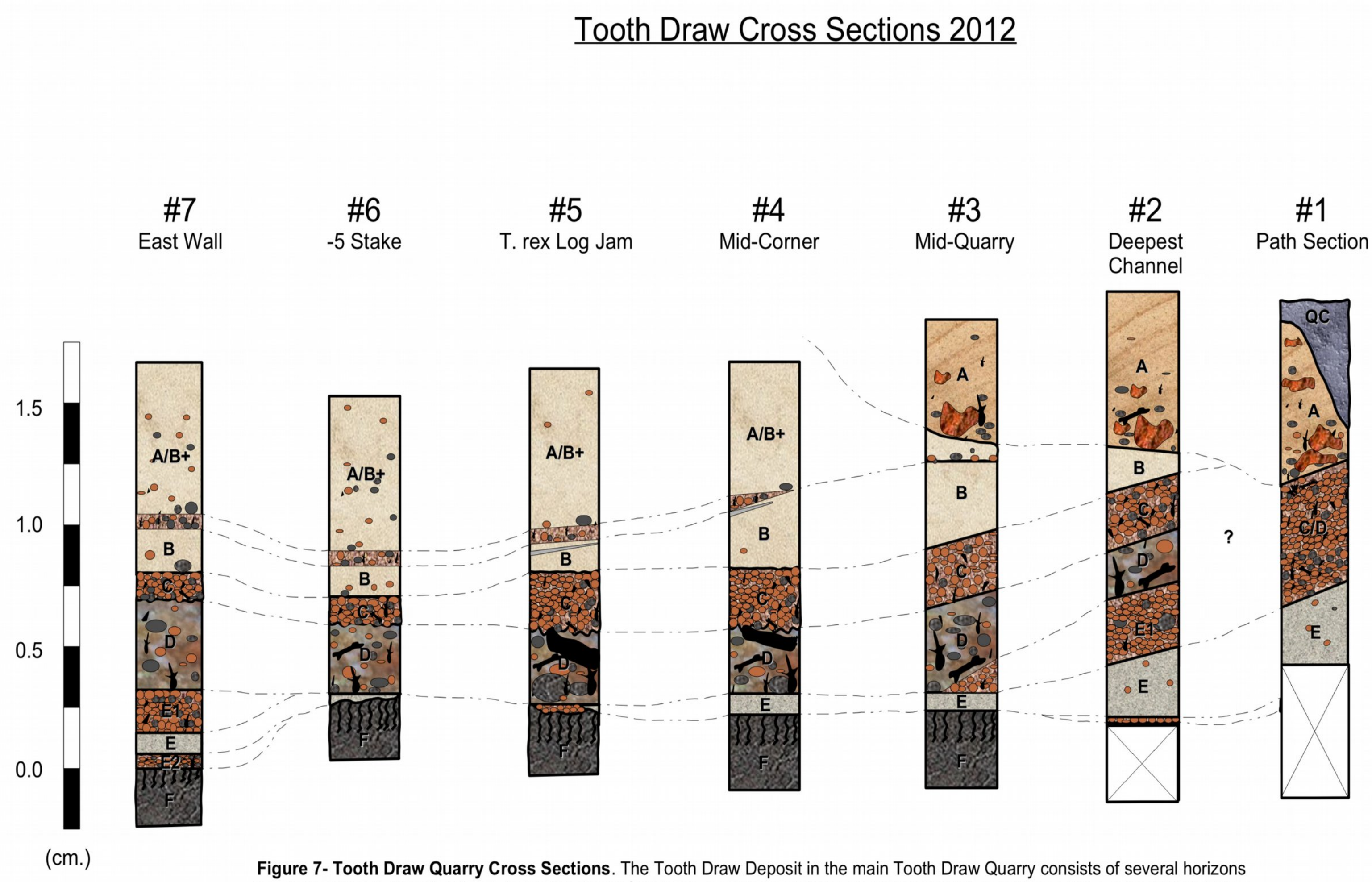


Figure 7- Tooth Draw Quarry Cross Sections. The Tooth Draw Deposit in the main Tooth Draw Quarry consists of several horizons we designated A thru F, with F, being the basal floodplain mudstone and the erosional boundary between the Lower Yellow River Zone and the Lower Floodplain Zone. Vertebrate specimens can be found in all of the layers, but tend to be concentrated in the A, C and D horizons. The A horizon is a typical channel lag deposit with waterworn and re-worked elements. The C horizon is a reworking and re-sorting of the lower D and E horizons. The D horizon, however, shows evidence for highly turbulent flow rates and likely represents a debris flow or hyper-concentrated flow event.

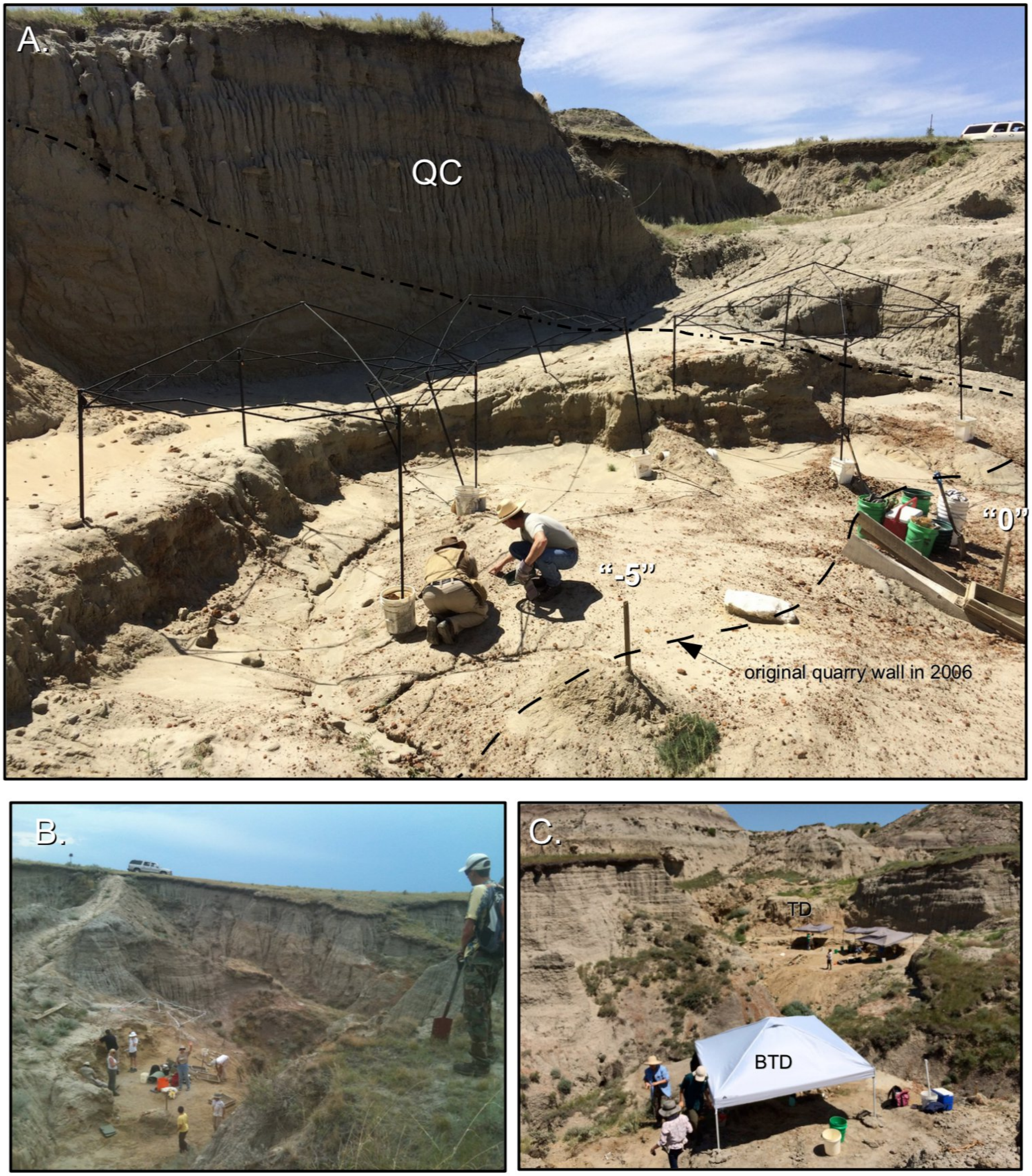


Figure 8- TD Quarry Photos. Serious excavation work at the TD Quarry began in 2009 and has been going ever since. Thousands of vertebrate fossils from fish, amphibians, reptiles, dinosaurs and even mammals have been collected. A) This image shows the quarry in 2018 facing south. Much of the overburden consists of thick layers of Quaternary Colluvial deposits (QC) that have filled in a previous erosional surface tens of thousands of years old. B) This photo shows the quarry in 2010 looking southwest. A large ramp was constructed in 2010 from overburden removed from the site connecting the two sides of the main ravine. C) This photo, taken in 2019 shows a view of the quarry facing East. In recent years the quarry has expanded across the other side of the main ravine at a site we call BTD.

The bone bearing horizons of the Tooth Draw Deposit are as follows:

"A Horizon"

The "A horizon" is the uppermost bone bearing strata in the TD deposit. It consists of layers of yellow gray to buff colored, fine-grained lithic arenite sandstone, interbedded with layers of pale to dark, yellow-orange and reddish-brown, ironstone pebble conglomerate and dark gray to pale purple mudstone pebble conglomerate. Large, secondary siderite ironstone concretions are common here, often forming in the sandstones around bits of organic debris or mud clasts. Carbonized impressions of leaves and woody detritus are often found in these concretions, but they do not usually form on the bones themselves.

Thickness of this lens varies greatly across the exposed outcrops. It has an average of 50-60 cm thick towards the middle of the TD quarry, but it rapidly disappears to the east. Towards the west and northwest, however, the A horizon appears to thicken and become more extensive. It appears to have a low-angled, scoured contact with the B horizon. The geology of BTD, TDS and TDW suggests that it may be the most consistent and laterally extensive horizon, present in all of the sites.

Bones in the A horizon are less frequent, but when found, are usually better preserved and more complete. The majority of elements here are smaller, but rare 25 cm+ specimens show up from time to time. Elements here show standard weathering and abrasion due to stream transport.

"B Horizon"

The B horizon consists of a well-sorted, light yellow-gray (Munsell 5Y 8/1 to 9/2), thinly laminated, well cemented, fine grained, lithic arenite sandstone with rare, but occasional clasts of mudstone and ironstone pebbles. Every once in awhile a larger cobble to boulder sized clast of ironstone or mudstone shows up, but this is rare as it is 90% sandstone. Due to its highly cemented nature, it is more resistant to erosion and is often difficult to remove without the aid of a rock hammer and chisel. It is generally 30-35 cm thick and forms a sharp, low angled scour contact with the overlying A horizon in most places along the TD quarry wall.

Towards the east end of the TD quarry, the grain size of the B horizon gradually increases to a coarser grained sandstone and well sorted, mudstone granule dominated conglomerate we call the B+. This layer goes from predominantly non-fossiliferous and massive to finely laminated, having an abundance of winnowed, small micro-vertebrate material. Fish scales, teeth, vertebrae, crocodile teeth, small turtle shell fragments, shed ornithischian teeth, micro-vertebrate elements are the most common remains in this area of the horizon.

One layer in particular, along the lower B/C contact, is very light in color and heavily cemented. This layer forms an erosion resistant bed of thinly laminated, very fine-grained lithic wacke sandstone. This often splits along the lamina revealing a carbonized plant hash of sub-centimeter sized lignite stems, seeds and woody bits. The composition of this layer is estimated to be roughly 40% quartz, 40% feldspars and about 20% lithic fragments (claystone, mudstone, black to dark gray quartzite(?) organics and others). Fine, sand-sized particles of muscovite are also a minor component. Although it has produced no vertebrate fossils thus far, it is often found overlying larger bones along the B/C contact.

Another distinct layer in the middle of this horizon includes the “Mid B” layer, which has a thin gravel bed with occasional ironstone or mudstone pebbles. It is poorly sorted and is usually less than 10 cm thick. Clasts are sub-rounded to sub-angular with some imbrication indicating stream flow. This layer is not laterally extensive or traceable beyond the TD Quarry. It is thickest over the densest pocket of bones and then pinches out to both east and west.

Fossils are largely absent in the B horizon sandstone. From time to time a micro fossil will turn up in the sand layers, but on average the greatest chance of finding any fossils in this horizon is along the Mid B gravel lens, the B+ layers or just below the laminated layer. The laminated layer happens to be the thickest and most well cemented above the most narrow portion of the TD deposit, as the underlying floodplain mudstone rises upwards toward it.

“C Horizon”

One of the most fossil-rich layers in the Tooth Draw Deposit includes the “C Horizon” . This is a 20-30 cm thick band of clast supported, yellowish-orange (Munsell 10YR 7/8) to reddish-brown (Munsell 7.5 YR 5/4-6/6) ironstone pebble conglomerate. Clasts are generally well sorted, sub-elongated and sub-rounded indicating significant stream transport. They are tightly packed with a sandy matrix and not much cement. Clasts range in size from approximately 3 to 5 cm in length and 2 to 4 cm in width, but larger clasts of pebbles and the occasional cobble or boulder sized mudstone or ironstone clast (Figure 9) show up every once in awhile. This is a rarity, however, as most clasts are well-sorted and pebble-sized.

The contact with the overlying B horizon is usually sharp and distinct. The same can be said for the contact with the underlying D horizon, especially when weathered during a strong rainstorm. As one moves east or west of the “hot zone” of the TD Quarry, however, the contact becomes less distinct and the upper threshold is blended, having more sand going west and more claystone going east. This blended zone is often called the C/D contact as the contact between the two zones become less sharp.

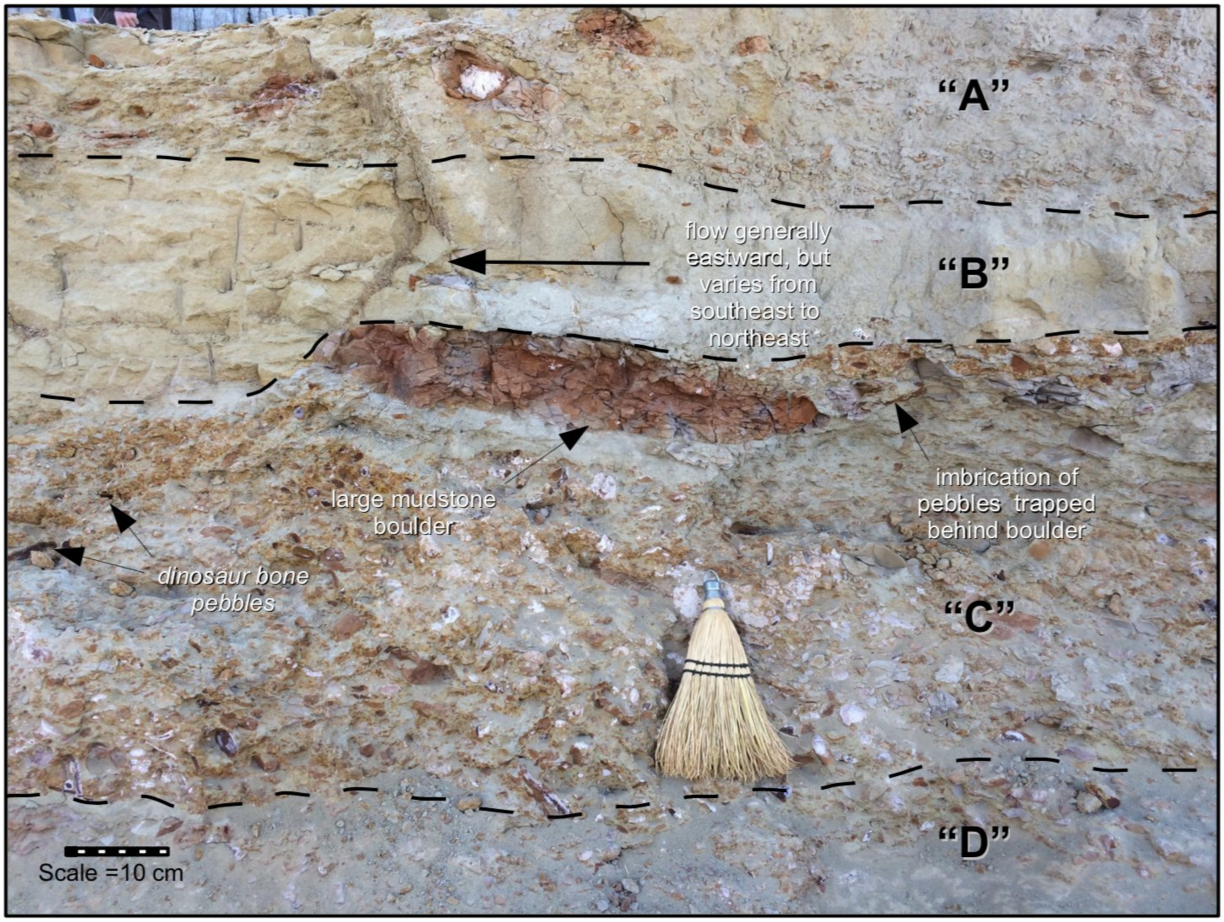


Figure 9- "C- Horizon" Boulder. The C horizon conglomerate consists of tightly packed, mostly moderately well sorted, pebble-sized clasts of ironstone within a sandy matrix. The clasts are usually well-rounded and appear to have been deposited in a swift flowing river. They show imbrication patterns that usually indicate that the current direction was from west to east. The photo above shows a large, sub-rounded boulder of mudstone that was swept up in the river channel. This indicates that flow rates were still fairly significant even after the hyperconcentrated flow event that formed the D horizon began to wane. Photo is looking towards the southwest.

Vertebrate fossils in the C horizon are quite common. Small vertebrae, turtle shell fragments, ornithischian bone fragments/pebbles, short sections of hadrosaur tail tendon, ornithischian shed teeth, metasequoia cones and garfish scales are quite abundant and can be found tucked between and around the ironstone pebbles. Most importantly, the C horizon includes the largest numbers of 2 to 6 cm sized Tyrannosaurid teeth (Figure 10). Most of these are identified as *Nanotyrannus*, but more robust adult and juvenile *Tyrannosaurus* teeth can be found here as well. Elements and teeth found in this horizon are often stream abraded and tumbled, indicating significant stream transport and re-working. They are usually laying horizontal to contact, but some imbrication of pebbles and elements are apparent.

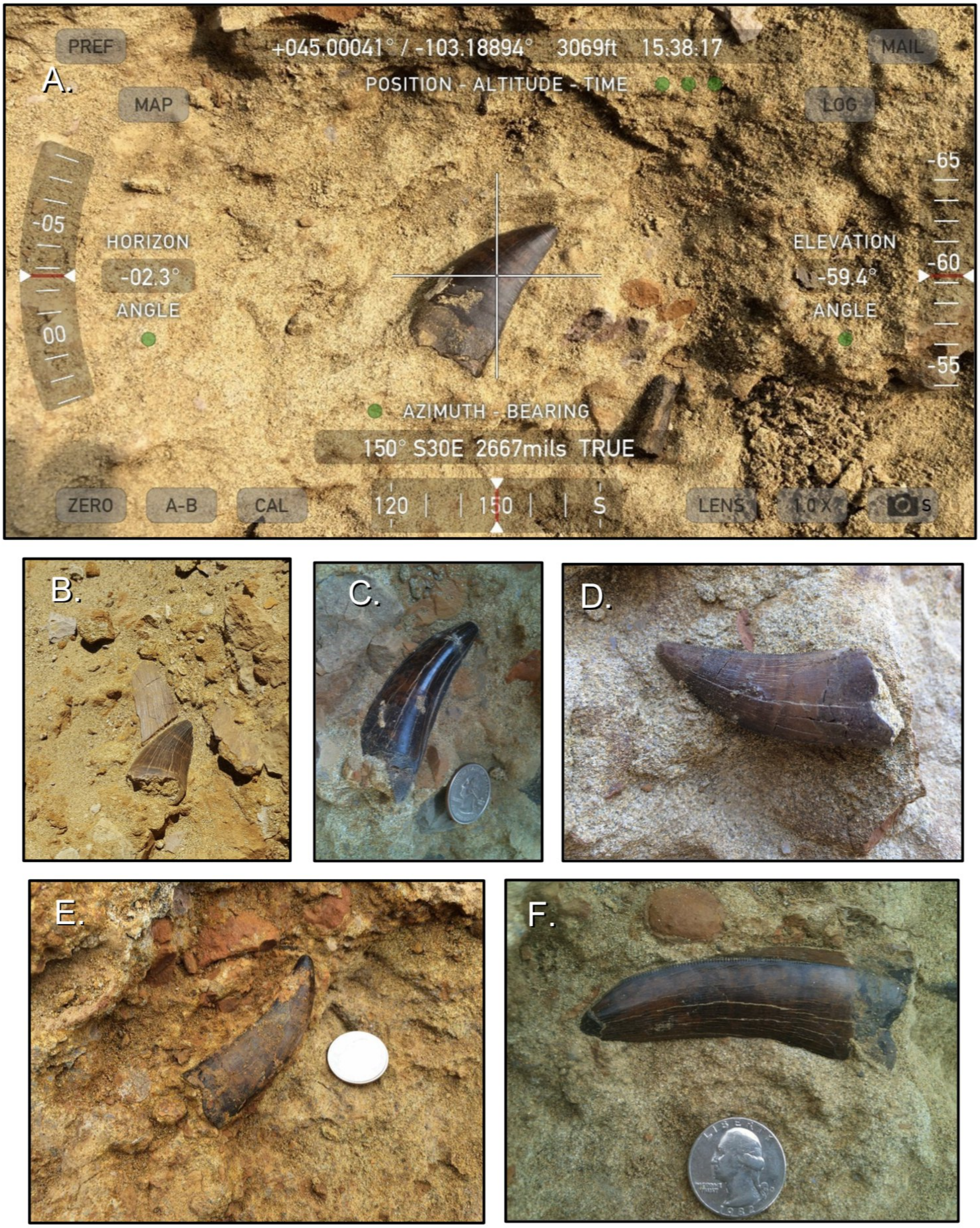


Figure 10- Tyrannosaur Teeth. Tyrannosaur teeth are one of the most common, logged elements from the Tooth Draw Quarry and what give the site its name. Most of the teeth are concentrated in the C and D horizons with many 2- 6 cm. specimens of Nanotyrannus found in the C horizon. A) Nanotyrannus right maxilla tooth in the C/D contact. B) Nanotyrannus tooth in the C horizon. C) Large adult Tyrannosaurus rex dentary tooth. D) Average sized left dentary tooth Nanotyrannus. E) Adult Nanotyrannus or young T. rex from the C horizon. F) Large adult T. rex left dentary tooth from the B/C contact.

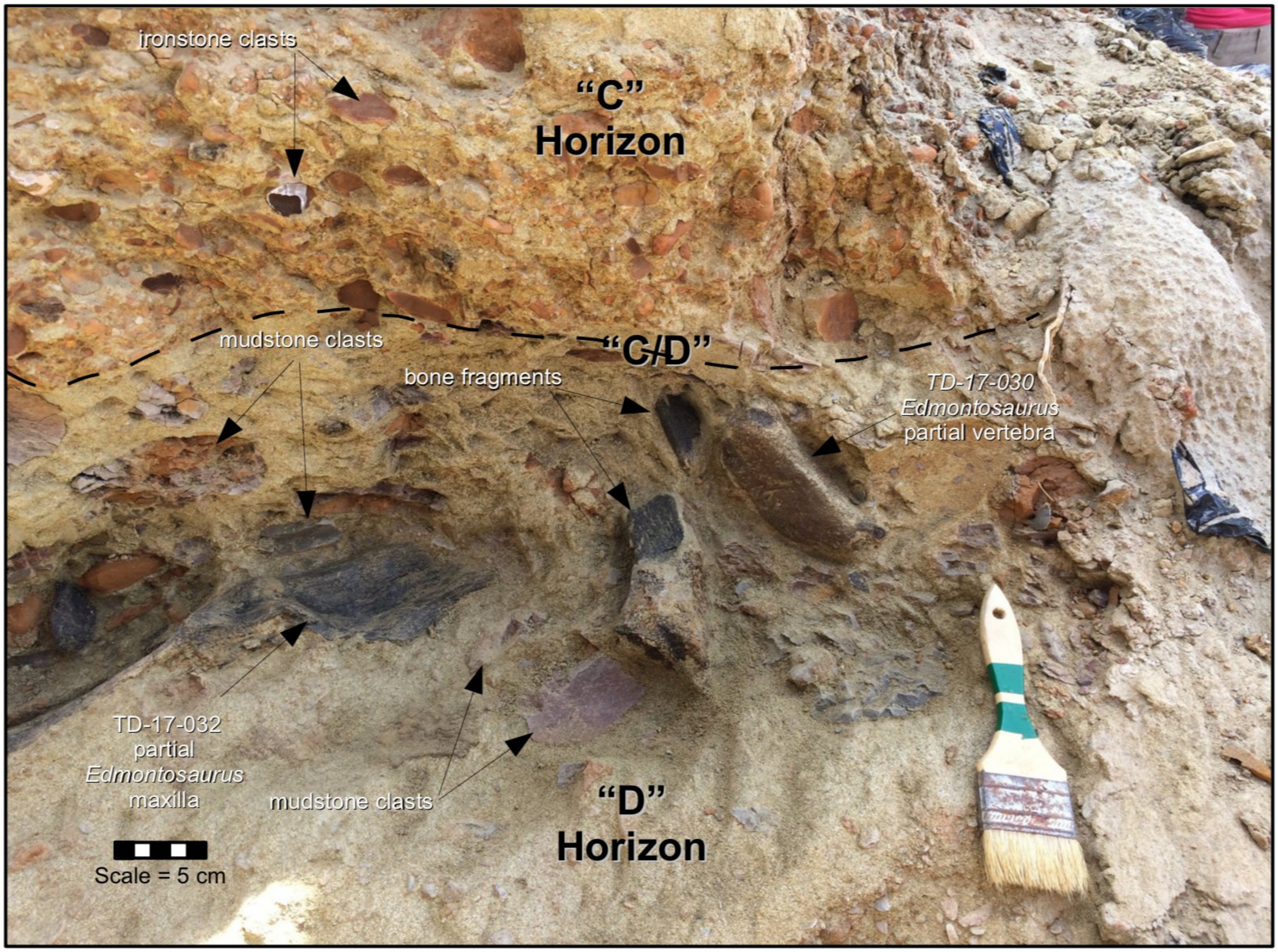


Figure 11- C/D Horizon Bone Fragments. Excavation of the Tooth Draw Quarry is slow and difficult as many layers contain an abundance of densely pack bone, teeth and shell that need to be carefully worked around. Pre-depositionally broken ornithischian bone fragments/pebbles are very common. Many of the elements are deposited at steeply dipping angles with imbrication patterns indicating turbulent hyper-concentrated flow rates.

Occasionally, larger or more complete bones can be found in the C horizon as well. These are often along the upper C horizon along the B/C contact. Typically, these include large limb bones and vertebrae from *Edmontosaurus* or *Triceratops*. These elements do not appear to be from single individuals and no articulation or clear association has been found thus far.

"D Horizon"

The main, bone-bearing layer of the Tooth Draw Quarry is the "D" horizon (Figure 11). This zone consists of a 25-30 cm thick bed of matrix-supported, very poorly-sorted, mudstone pebble conglomerate. Clasts are sub-rounded to sub-angular and range in size from granules to boulders. They are generally a pale purple (Munsell 5P 6/2) to pale pink (Munsell 5 RP 8/2) to dark gray (Munsell N3) and often show oxidation halos indicating what appears to be secondary geochemical alteration of the mudstone. Ironstone pebbles occur from time to time, but this layer is overwhelmingly dominated and characterized by very poorly sorted mudstone clasts in a yellow brown, sandy matrix.

The largest clasts are boulder sized, often 30-50 cm in diameter (Figure 12). They are massive and show strong iron oxidation halos. Despite their size, they often have rounded to sub-rounded features indicating some weathering and stream transport prior to final deposition. Cobble-sized clasts of mudstone and ironstone occur in large quantities as well. This extreme size variation, lack of any internal structure or lamination and irregular orientations suggest very rapid, turbulent flow and/or a paleotopographic relief greater than previously thought for the Hell Creek.

The sandy matrix is essentially a lithic arenite. This consists of sub-rounded to sub-angular, fine to coarse grains of quartz, feldspar, and darker lithic bits. Some of the darker grains appear to be bits of claystone or ironstone. Some of the darker bits are lignite and chips of bone. Some appear to be well rounded, coarse grains of dark grey quartzite. Further work on the mineralogy is necessary, however, to evaluate its true nature, trace element composition, and origin.

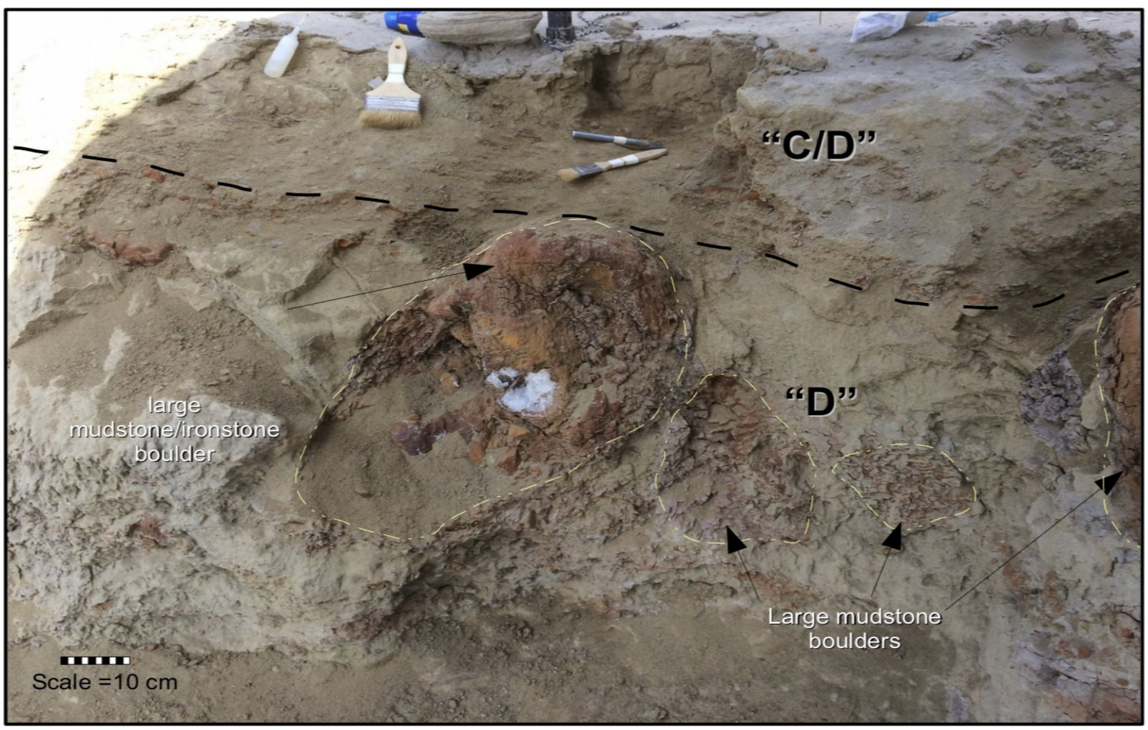


Figure 12- "D- Horizon" Boulders. The D horizon conglomerate consists of poorly sorted, pebble-boulder sized clasts of mudstone and ironstone (likely derived from the original F horizon" within a sandy matrix. The mudstone clasts are usually well rounded to sub-rounded and often show strong oxidation halos and secondary diagenesis to ironstone. The boulder in this photo started off as a mudstone, and was later modified in parts to ironstone concretion. Orientation of the boulders is chaotic and flow velocities were likely very high. This all suggests that the D was deposited in a hyper-concentrated flow event, perhaps as a result of a natural levee or cut-bank collapse.

Fossils within the D horizon are plentiful and include some of the most significant specimens found to date. Tucked in between the mudstone and clay stone cobbles are a mix of broken and disarticulated, large ornithischian elements, turtle shell fragments, unidentified, water-worn, bone pebbles, and dinosaur teeth. Elements are often pre-depositionally broken on one or both ends, with jagged, angular breaks, occasional fine parallel scratch marks, and frequent tooth marks. Larger elements such as vertebrae, ribs or limb and pelvic bones are often found with steeply dipping, random orientations, suggesting rapid and turbulent deposition. Scattered in and around the larger broken elements are more complete bones, which show very little abrasion or breakage. These include the bones of turtles, crocodiles, mammals and smaller dinosaurs such as small theropods and small ornithopods. In fact, as a general rule (not always the case), there appears to be an inverse relationship between the size of the element and its condition, with smaller bones often in much better condition than larger ones (Figure 13).

Plant fossils are occasionally seen as well. These include, partial leaf impressions, stems and woody carbonaceous bits (found when splitting mudstone or ironstone clasts), the occasional ironstone metasequoia cone, and more common 2-4 cm long fossilized root traces. The root traces have a thin, outer rind of light gray claystone, surrounding a tube filled with yellow sand. These are often found as clasts in both the C and the D horizon and are usually sub-centimeter in size. These likely originated in the F horizon. "Petrified" wood is also found from time to time, usually as iron-stained, claystone castings or carbonized impressions in ironstone itself. From time to time, larger "logs" are found, but these are merely elongated carbon impressions in the rock. They seldom have any real thickness of lignite or three-dimensional shape to them as seen on other sites on the ranch. In a few cases, particularly within the main "hot zone", larger, more defined tree "logs", stretching several meters (Figure 14) were discovered. These appear to have caused a log jam, helping to trap some of the bones. To date, most of this plant material has been unidentified.

"E Horizon"

The E horizon is generally a light colored, thin-bedded (0-20 cm thick), fine-grained lithic arenite sandstone devoid of fossils that can be found at the bottom of the bed. It was originally discovered in the middle of the quarry under some of the largest pockets of bones and was a good indicator that you had gone through the main bone bed. It is poorly cemented, but firm and dense. As a result, it is much easier to dig through by trowel (unlike the B horizon). The sandstone is very porous and given the nature of its upper and lower bounding surfaces (mudstone below and clay pebbles above) it tends to hold a lot of water. This layer tends to thicken up and become more complex to the west and thins out to the east. This sand is largely unfossiliferous, but occasional small microfossils (fish, amphibian, reptile) show up every once in awhile.

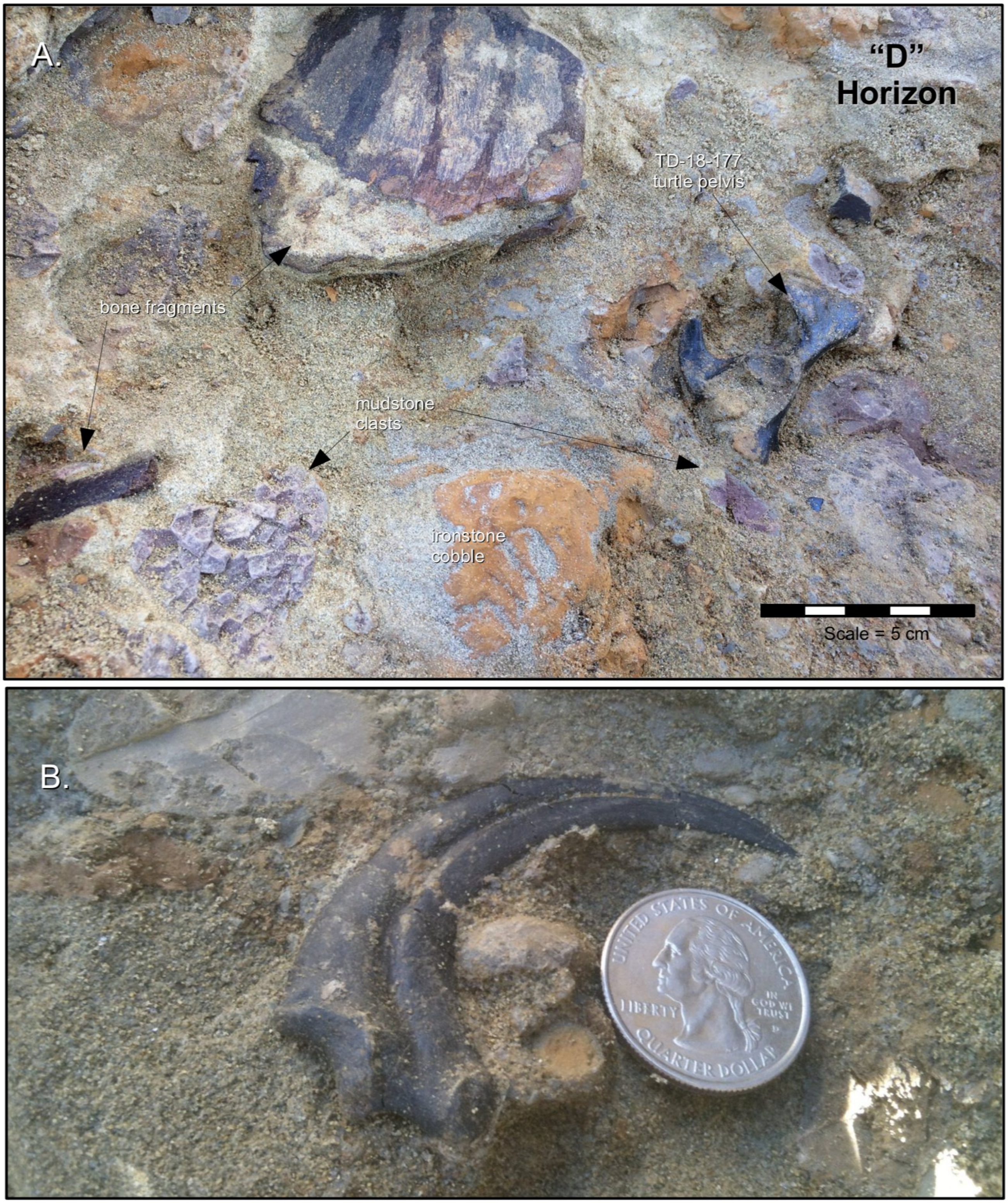


Figure 13- Fossils of the D Horizon. There appears to be an inverse relationship between the size of the element and its condition, particularly in the D horizon. Smaller elements from *Thescelosaurus*, small theropods, turtles, crocodiles, etc. tend to be in much better condition and far more complete than larger elements of *Triceratops* and *Edmontosaurus*. This implies less stream transport and a more local population. A) Image shows a complete turtle pelvis in excellent condition. B) TD-15-203 Dromaeosaurid manus ungual (claw) likely from an *Acheroraptor*, from the bottom of the D horizon in pristine conditon.

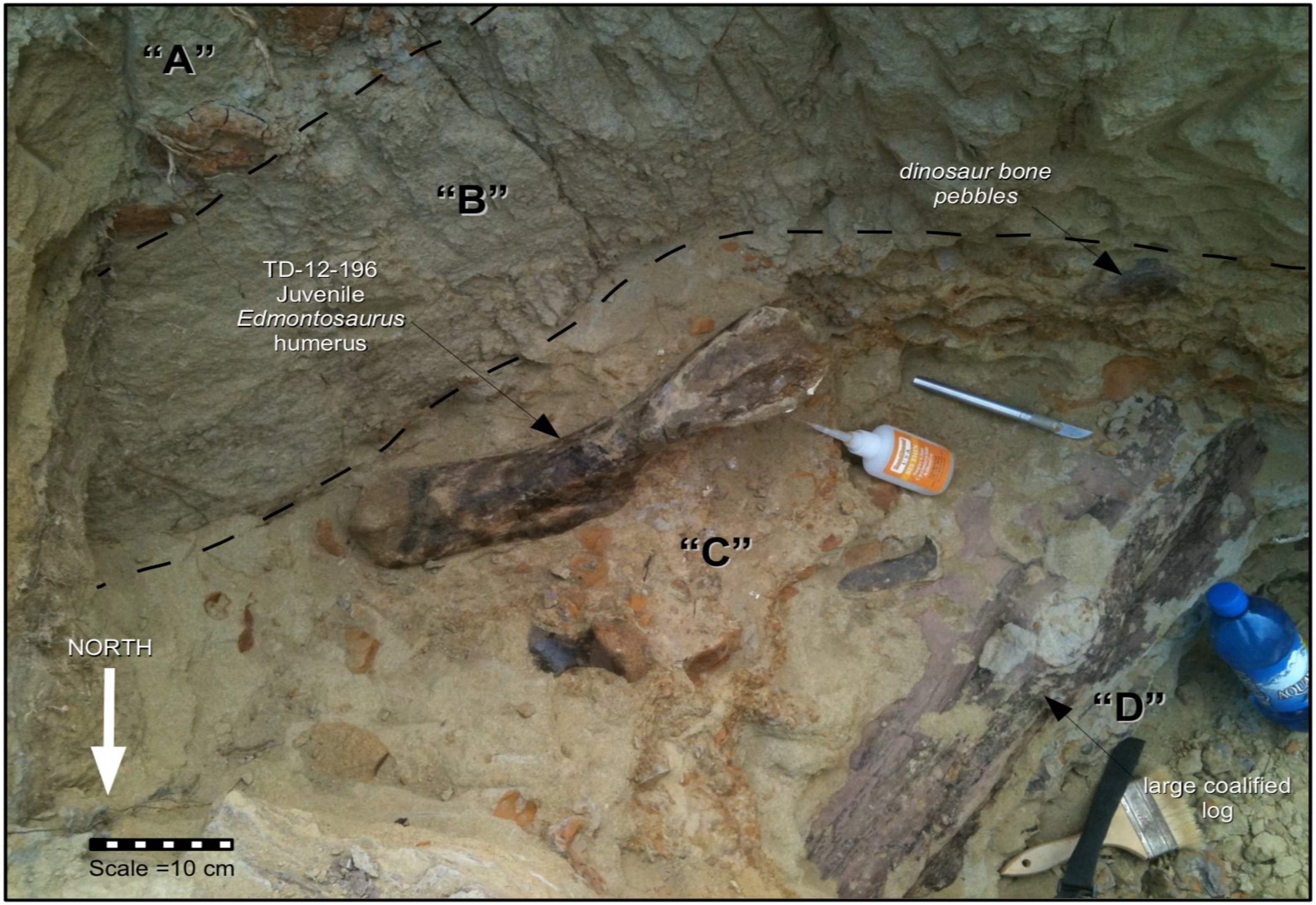


Figure 14- Juveniles and Plant Fossils. (Top down) Juvenile elements of *Thescelosaurus* and *Edmontosaurus*, including some which are likely neonates, are found frequently in the C and D horizons. This image shows a juvenile *Edmontosaurus* humerus in good condition with some abrasion to the distal condyles. Plant fossils also show up from time to time as well. Metasequoia cones are commonly found along with fossilized root traces, rhizoliths, ironstone casts of petrified wood and rare leaf impressions. In the above image we can see the carbonized remains of a large log that stretched for several meters. This may have caused a log jam, helping to trap more bones in the hyper-concentrated flow.

In the main Tooth Draw Quarry and towards the northwest, the “E horizon” is overlain in places by another gravel lens we call the E-1 horizon. This gravel lens squeezes in between the complex D horizon and the un-cemented and simple arenite sands of E. Abundant, but smaller, turtle and micro vertebrate remains can be found within this bed. It appears that the E-1 may continue at least as far as the BTD Site to the northwest.

In rare cases, particularly on the east end of the tooth Draw Quarry, we find another very thin (under 10 cm thick), well-sorted, ironstone pebble conglomerate lens we call the E2 horizon. This also contains an abundant assortment of disarticulated small vertebrate material and often small tyrannosaurid and dromaeosaurid teeth.

“F Horizon”

The F horizon is a medium to dark gray, to pale purple, mudstone that is over 2 meters in thickness. This is the basal floodplain mud, into which the river system scoured and eroded. Vertebrate remains are seemingly absent from this zone, but occasional plants, woody carbonaceous bits, and root traces can be found here. The root traces suggest minor soil development, but the lack of concretions or bioturbation suggests it was either short lived or that the upper portions were completely scoured away. The clay pebbles, cobbles, boulders and iron concretions found in the overlying layers likely originated within the muddy banks and levees of the F horizon.

SYSTEMATIC PALEONTOLOGY

To date the remains of at least 21 different genera of dinosaurs and over 45 different genera of other vertebrates have been recovered from the Tooth Draw Deposit (Figure-15A,B,C). Many of these are considered rare by most workers in the Hell Creek. Some are exceptionally well preserved with almost no stream abrasion, suggesting that burial was rapid and that they were from a more local community. Others show significant abrasion and weathering indicating that they came from a more distant community. Others still, show pre-depositional breaks, bite marks and other taphonomic indicators that imply feeding activity not far from the eventual site of burial.

The following genera have been recovered from the Tooth Draw Quarry itself, with notes on any specimens of significance:

DINOSAURIAN FAUNA OF THE TOOTH DRAW QUARRY

Taxon	Identification Based Upon
CLASS REPTILIA	
SUBCLASS DINOSAURIA	
ORDER SAURISCHIA	
SUBORDER THEROPODA	
Family Tyrannosauridae	
Tyrannosaurus	Teeth, dentary, manus ungual, vertebrae
Nanotyrannus	Teeth, manus ungual
Family Ornithomimidae	
Ornithomimus sp.	Manus and pes unguals, caudal vertebrae
Family Caenagnathidae	
Anzu	Manus and pes unguals
Family Dromaeosauridae	
Dakotaraptor	Teeth
Acheroraptor	Teeth, unguals(?)
Saurornitholestes	Teeth
Richardoestesia	Teeth
unnamed tooth taxon	Teeth
Family Troodontidae	
cf. Troodon	Teeth, metatarsals and pes unguals
Pectinodon	Teeth
Family Alvarezsauridae	
cf. Albertonychus	Manus ungual
incertae sedis	
Paronychodon	Teeth
unidentified theropoda	Partial limb elements, unguals, vertebrae
ORDER ORNITHISCHIA	
Family Hadrosauridae	
Edmontosaurus	Teeth, cranial, axial, and appendicular elements
Family Ceratopsidae	
Triceratops	Teeth, cranial, axial, and appendicular elements
Torosaurus	Frill sections
Leptoceratops	Teeth, appendicular elements
Family Pachycephalosauridae	
Pachycephalosaurus	Teeth, cranial, axial, and appendicular elements
Dracorex	Cranial, axial
Family Thescelosauridae	
Thescelosaurus	Teeth, cranial, axial, and appendicular elements
Family Nodosauridae	
Denversaurus	Teeth and scutes
Family Ankylosauridae	
Ankylosaurus	Teeth and scutes
unidentified ornithischians	Cranial and axial elements

OTHER VERTEBRATE FAUNA OF THE TOOTH DRAW QUARRY

Taxon	Identification Based Upon
CLASS CHONDRICHTHYES	
ORDER BATOIDEA	
Family Rhinobatoidei	
Myledaphus	Teeth
ORDER HYBODONTIFORMES	
Family Hybodontidae	
Lonchidion	Spines
CLASS OSTEICHTHYES	
INFRACLASS CHONDROSTEI	
ORDER ACIPENSERFORMES	
Family Acipenseridae	
Acipenser	Scales/Spines
INFRACLASS HOLOSTEI	
ORDER AMMIIFORMES	
Family Ammiidae	
Kindleia fragosa	Vertebrae
ORDER LEPISOSTEIFORMES	
Family Lepisosteidae	
Lepisosteous	Teeth, scales cranial and axial elements
ORDER TELEOSTEI	
indet.	Vertebrae
CLASS AMPHIBIA	
ORDER CAUDATA	
SUBORDER AMBYSTOMATOIDEA	
Family Scapherpetonidae	
Scapherpeton	Vertebrae
Opisthotriton	Vertebrae
ORDER URODELA	
Family Sirenidae	
Habrosaurus	Vertebrae
CLASS REPTILIA	
ORDER EOSUCHIA	
Family Champsosauridae	
Champsosaurus	Teeth cranial, axial, appendicular elements
ORDER CROCODILIA	
SUBORDER EUSUCHIA	
Family Crocodilidae	
Subfamily Crocodilinae	
Borealosuchus	Teeth, cranial, axial, appendicular elements
Thoracosaurus	
Subfamily Alligatorinae	
Brachychampsa	Teeth, cranial, axial, appendicular elements
ORDER TESTUDINATA	
Family Baenidae	
Peckemys	Skull
Plesiobaena	Shell
Neurankylus	Shell
Saxochelys	Skull
Family Adocidae	

Adocus	Shell
Family Chelydridae	
indet. Tullochelys?	Shell
Family Nanhsiungchelyidae	
Basilemys	Appendicular elements, shell
Family Trionychidae	
Aspideretoides	Appendicular and axial elements, shell
Axestemys	Appendicular elements, shell
Apalone sp.	Shell
Gilmorermys	Appendicular elements, shell
likely others	
ORDER SQUAMATA	
Family Varanidae	
Paleosaniwa	Fused fronto-parietal
Cemetarius	Dentary
ORDER PTEROSAURIA	
SUBORDER PTERODACTYLOIDEA	
Family Ornithocheridae	Phalanges
CLASS AVES	Partial femur
CLASS MAMMALIA	
SUBCLASS ALLOTHERIA	
ORDER MULTITUBERCULATA	
Superfamily Ptilodontoidia	
Family Ectypodidae	
Mesodema	Teeth and cranial elements
SUBCLASS METATHERIA	
ORDER MARSUPIALIA	
Family Didelphidae	
Didelphodon	Teeth and cranial elements

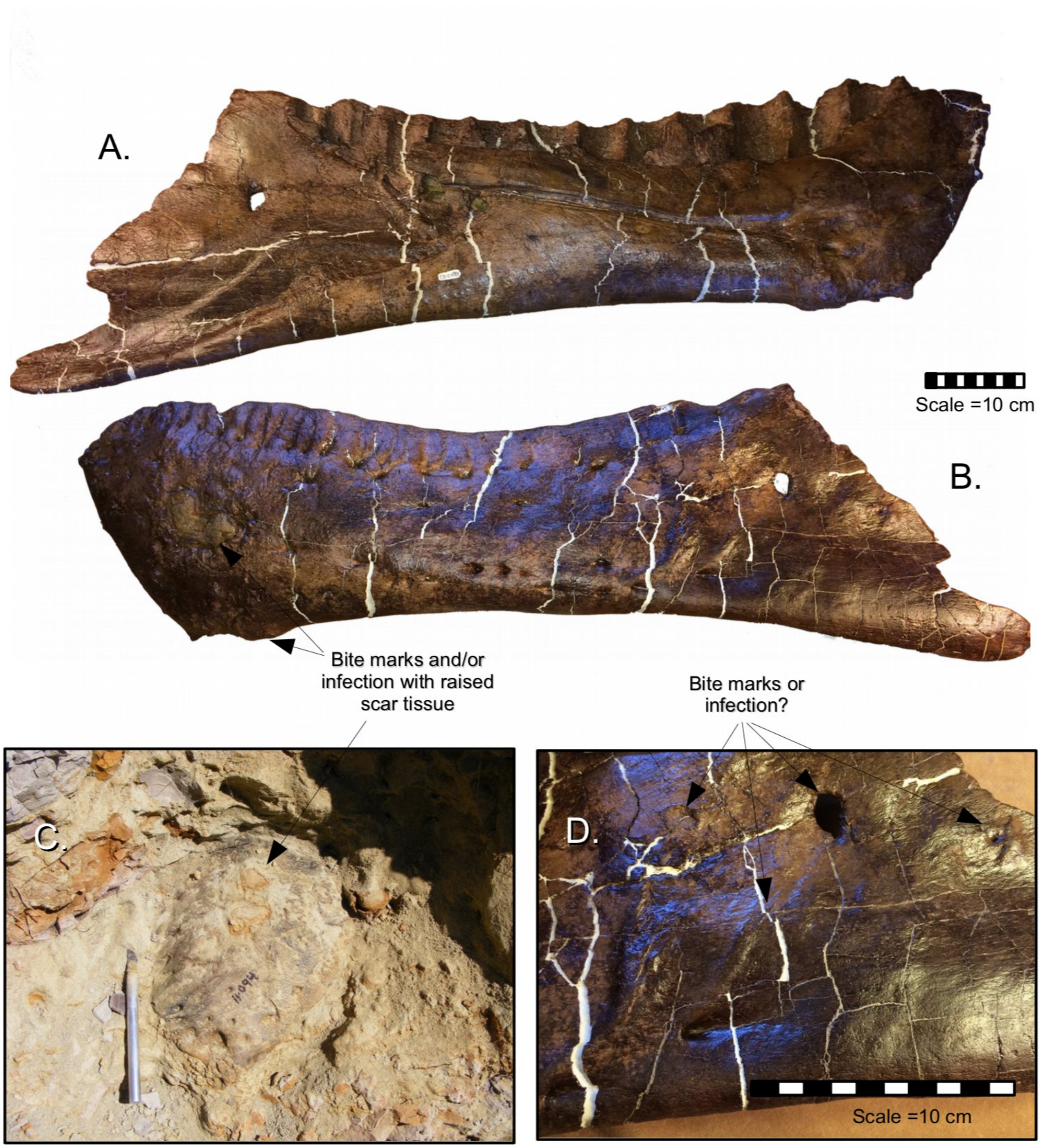
Figure 15- Faunal List. Other taxa of the Tooth Draw Quarry. Thousands of microfossils have been recovered from the Tooth Draw Quarry since 2006. Much of this material has not been prepared or identified. ABOVE: Fish vertebrae, teeth, spines and miscellaneous skull material are frequently encountered in several TD horizons. The above specimen is likely from a teleost, but further work is necessary to confirm its true affinities.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY TYRANNOSAURIDAE
GENUS *Tyrannosaurus* Osborn, 1905
SPECIES *Tyrannosaurus rex* Osborn, 1905

Tyrannosaurus is represented by over 260 isolated teeth and at least 14 elements discovered within the Tooth Draw Quarry. Elements include a complete left dentary (TD-11-094/FDM-xx?) (Figure 16), a manus ungual, two metatarsals, pes phalanx, a few caudal vertebrae and several large fragments. Aside from the broken and water-worn fragments, their preservation was generally good to excellent with minor abrasion due to stream transport. These elements, however, were widely spaced and from different bone layers, so likely from different individuals. Several other *Tyrannosaurus* elements have been found in other areas of the Tooth Draw Deposit, including one corner of TDW where a partial tibia, phalanx, gastralia, and several large limb fragments were found in close association from the same horizon. It is hoped that further excavation in this area of the deposit may yield a partial skeleton, but thus far, no articulated or conclusively associated skeletons, of any species, have been found.

The left dentary (PARC-TD-11-094/FDM-xx?) is the largest and most important *Tyrannosaurus* element recovered to date (Figure 16). This specimen measures 92 cm in length, which is only a few centimeters shorter than BHI 3033 (aka "Stan"). This places it solidly in the adult size range, likely from a 35 ft. long + individual. The dentary was found laying horizontally along the C/D contact layer in the middle of the TD quarry. It has some abrasion and is missing a small portion of the caudal region of the supradentary (between #12,13,14 alveoli), but is otherwise complete. Despite its excellent condition, erupted teeth were absent. These were likely lost during stream transport. CT scans conducted in 2013 did, however, reveal the presence of at least three unerupted teeth in tooth positions #2, and #3 and #7. There were 14-15 alveoli (tooth sockets) present in the dentary suggesting that it came from what Larson, 2008, considers *Tyrannosaurus "x"*.

Several pathologies were also noted on the jaw, including two large, sub-circular holes on the lateral anterior end that appeared to have been a nucleus for secondary iron concretion development. These measure 4.0 cm and 3.5 cm in diameter and both are filled by fe-concreted sand. A mass of raised and frothy scar tissue lines this area and continues below the injury to the ventral edge of the jaw below. While the nature of this injury is not entirely clear, it is suspected of being either a) a bite mark from another Tyrannosaur, b) a loss of bone due to a Tricomonosis parasitic infection (Wolff et. al., 2009) or c) from a broken tooth and/or severe dental abscess draining out the side via a complex fistula. According to Wolff et. al., 2009, 15% of the 61



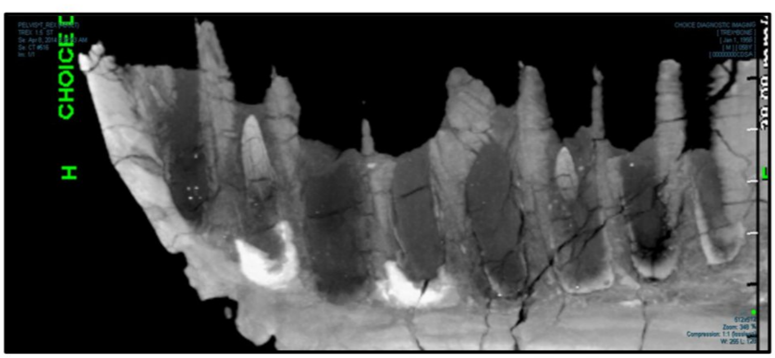


Figure 16- Tyrannosaurus Left Dentary. One of the most significant dinosaur specimens recovered to date, includes this pathologic left dentary. This element shows two large and serval small bite marks with raised scar tissue, suggesting antagonistic behavior between Tyrannosaurids. This specimen was sold to the Fukui Prefectual Dinosaur Museum in Japan in 2018. A) Lingual View. B) Labial or Lateral View. C) Field photo. D) Closeup of posterior bite marks or parasitic infection. E) CT scan of dentary showing unerupted teeth.

tyrannosaur specimens they studied had such lesions, but their locations were towards the caudal regions of the lower jaw, particularly the surangular and caudal portions of the dentary. They write, "*Despite the superficial resemblance of the tyrannosaurid mandibular lesions to abnormalities that may stem from crocodylian poxvirus, abscesses, granuloma, bite-wound gingivitis, and bite trauma, the trichomonosis-type lesions in tyrannosaurids differ in their location and distribution at the caudal end of the mandible*" (page 2, Wolff et. al., 2009) . From this they concluded that most, if not all of these lesions, represented Tricomonosis infection not bite marks. The injury on TD-11-094, however, is unique in that it occurs near the anterior portion of the jaw, not the caudal. The lesions are sub-circular in shape and of the right size and position to be caused by a bite from a large T. rex clipping the jaw with its front #2, #3, or #4 dentary or maxillary teeth. Similar pathologies have recently been found in a tyrannosaurid dentary from New Mexico that were also interpreted to be bite marks due to conspecific antagonsitic behavior (Dalman and Lucas, 2020). Later, infection may have triggered tooth loss and it is possible that this infection (bite or otherwise) led to the death of the animal.

Towards the caudal end of the dentary there is also another cluster of pathologic injuries with raised scar tissue that are found in a line. These are much smaller than the two in the front and may be a separate bite mark from an earlier time or the early stages of a *Tricomonosis* infection. The two primary "dents" are 11 mm and 14 mm in length, respectively, and are roughly almond-shaped. They are four cm apart. Further work on this jaw is necessary to determine the exact cause of this injury.

Teeth of *Tyrannosaurus* can be found in all of the bone bearing layers of the Tooth Draw Deposit (Figure 17) . The abundant *Tyrannosaurus* teeth at the Tooth Draw Quarry are in fact, what originally gave this site its name. These range from mature adults (12 cm +) to juveniles (1 cm +/-) and most are in good condition. The majority are shed, "spitter" teeth, missing all but the very top of the root. They are usually, a yellow brown to chocolate brown in color with various degrees of enamel and serration present. Many show wear facets, where the tooth struck an opposing one in life. Many others have pre-depositional breaks to their tips or bases, missing either tip or base. A few appear to have acid etching or corrosion along the top edge of the root, suggesting that they may have been either swallowed during feeding or had significant geochemical corrosion prior to final deposition.

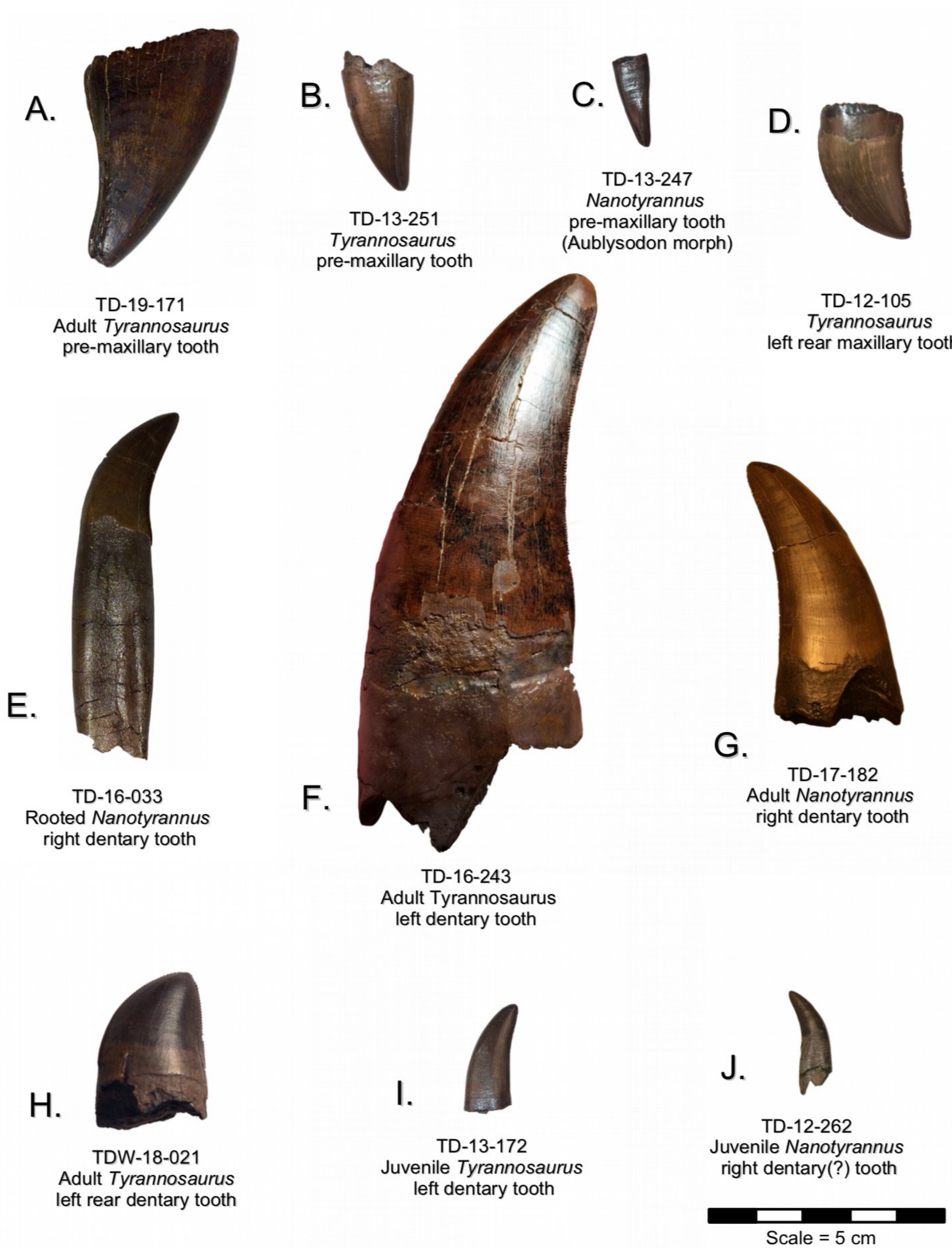


Figure 17- Tyrannosaurid Teeth from the Tooth Draw Quarry.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY TYRANNOSAURIDAE
GENUS *Nanotyrannus* Bakker et. al., 1988
SPECIES *Nanotyrannus lancensis* Bakker et. al., 1988

One of the most common elements recovered in the Tooth Draw Deposit are *Nanotyrannus* teeth (Figure 17). To date, 422 *Nanotyrannus* specimens have been recovered from the Tooth Draw Quarry alone with dozens more found in other portions of the Tooth Draw Deposit. *Nanotyrannus* teeth can be found within all of the bone bearing beds of the site, but show a high concentration in the C horizon as reworked or stream transported components. They are often stream sorted with the majority in the 2-6 cm size range. Larger and smaller *Nanotyrannus* teeth are also present, but the average sized tooth is around 2.5 – 3.0 cm in height. Most of these teeth are shed "spitter" teeth, showing evidence of abrasion and stream transport, but several, extremely well preserved, teeth have been found with complete roots, suggesting the possibility of more complete jaw remains somewhere within the deposit.

Nanotyrannus teeth are considered separate from *Tyrannosaurus* teeth, based upon their morphology and serration count. T. rex teeth, regardless of size and inferred tooth position, typically have an average of 2-3 denticles/mm on both anterior and posterior carina. They are robust teeth with sub-rounded to D-shaped cross sections. Carina tend to be more straight lined and tips tend to be more blunt or rounded. *Nanotyrannus*, on the other hand, have an average of 4 denticles/mm on both anterior and posterior carina (anterior denticle count/mm = posterior denticle count/mm), regardless of crown height or inferred jaw position. They are labiolingually compressed teeth with a "compressed oval-shaped" base. Their carinas often have a slight sigmoidal curvature to them, serrations seldom reach the base on the anterior carina, while serrations do reach the base on the posterior. Wear facets are very common and when unworn, tips are often narrower and sharper than those of *Tyrannosaurus*. Teeth traditionally referred to the tooth taxon *Aublysodon* are also frequently found, but are hereby considered to be juvenile *Nanotyrannus* pre-maxillary teeth.

Even though Nanotyrannus teeth are very common, skeletal elements of *Nanotyrannus* (or juvenile *Tyrannosaurus*), are largely absent. Only two specimens, loosely considered "*Nanotyrannus*", have been found thus far. These include a gracile Tyrannosaurid rib head with a pre-depositional broken shaft from TDW and a large manus ungual from TD (Figure 18). The manus ungual is in good condition with only light stream abrasion. It is slightly elongated and more straight when compared to *Tyrannosaurus* manus unguals. This specimen compares well to casts of the manus unguals, made from the unpublished "Bloody Mary" specimen of "Dueling Dinosaurs" fame.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY ORNITHOMIMIDAE
GENUS *Ornithomimus sp.* Marsh, 1890

Ornithomimid elements are a rare component of the Tooth Draw Deposit. To date, only 22 specimens have been conclusively identified as Ornithomimid. The taxonomy of Ornithomimids in the Late Cretaceous has been widely debated (Russell, 1972; personal communication Ken Carpenter, 2019). Some workers refer to the Hell Creek Ornithomimid as *Ornithomimus velox (Marsh, 1890)* and others refer to it as either *Ornithomimus sedens* (Marsh, 1892; Derstler, 1994) or *Struthiomimus sedens*. Some have suggested that both Ornithomimus and Struthiomimus are present in the Hell Creek (personal communication Dale Malinzak, 2021). At this time, however, all ornithomimid material collected at the TD Quarry are simply considered *Ornithomimus sp*. until this taxon is better understood. Identifiable remains include multiple, unassociated caudal vertebrae, several phalanges and both manus and pes unguals (Figure 18). The condition of this material is considerably better than many of the other genera represented in the deposit, showing very little abrasion or evidence of stream transport. The majority of this material has been discovered in the D horizon of the Tooth Draw Quarry though other specimens have been found in both the A and the C.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY CAENAGNATHIDAE
GENUS *Anzu,* Lamanna et. al., 2014
SPECIES *Anzu wyliei* Lamanna et. al., 2014

Anzu is another rare component of the Tooth Draw Deposit. In 15 years of excavation only 8 elements have been recovered that can clearly be assigned to this genera. These include one cervical vertebra, a few phalanges and three very diagnostic manus unguals. One of the unguals shows a distinct, roughed, pitting that is interpreted to be from osteophagus insect borings (Figure 18). This was found within the more well-sorted “C” horizon and has likely seen a good deal of pre-depositional weathering and stream transport. The other two unguals were found just a short distance from one another during the summer of 2019. Both came from the D horizon and were in significantly better condition than the one found in the C. Given their close association it is hoped that other bones of *Anzu* lie nearby, but chances for a more complete specimen are unlikely. From previous field work on the first two specimens (Stein, 2000; Lammanna et. al., 2014) *Anzu* is a genera that likely preferred a different habitat than the one exhibited by the river system of the Tooth Draw Deposit. The first two specimens were found in a unique depositional environment within a greenish grey siltstone surrounded by carbonaceous shale and lignite. Possible stomach contents found with the second specimen included a mix of small vertebrate remains, organic plant matter and small gastropod shells. This implies that Anzu was an omnivore with a diverse diet that may have preferred a more swampy environment.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY DROMAEOSAURIDAE
SUBFAMILY DROMAEOSAURINAE
GENUS Dakotaraptor DePalma et. al., 2015
SPECIES *Dakotaraptor steini* DePalma et. al., 2015

While multiple, isolated specimens of small theropods have been recovered from the Tooth Draw Deposit, clearly identifiable *Dakotaraptor* elements remain elusive. So far, *Dakotaraptor* is represented solely by shed "spitter" teeth (Figure 19). These teeth exhibit a more laterally compressed morphology with, labiolingually compressed, oval-shaped to broader, almond shaped cross sections. They typically have smooth sides, but occasionally show strong horizontal, parallel whorls within the enamel. Anterior serrations are finer than posterior, which is a diagnostic trait of most dromaeosaurids (Currie et. al., 1990; Turner et. al., 2012; Gates, 2013; DePalma et. al., 2015), but not dramatically so as in *Acheroraptor* or *Saurornitholestes*. As described, by DePalma et. al., 2015, their serration counts average 4-6 denticles/mm on the anterior carina and 3-5 denticles/mm on the posterior carina. This can be expressed by the following equation: anterior denticle count/mm = posterior denticle count/mm - 1 or 2 denticles. Crown heights tend to be tall compared to their fore-aft basal length, though this is not always the case, with this ratio likely dependent on tooth position. Anterior carinas typically have serrations that do not reach the base, often truncating ⅓ to ½ of the way down (DePalma, 2015). Posterior carinas, on the other hand, are relatively straight and serrations usually reach the base. Identification is difficult without directly measuring the serration and noting its rounded shape under magnification. As a result, large *Dakotaraptor* teeth are often confused with small *Nanotyrannus* teeth.

Dakotaraptor teeth have been found in all of the bone bearing horizons of the Tooth Draw Deposit, but are more common in the C,D, and E1 horizons. Thus far, all specimens are shed teeth with no roots. Usually they are in good condition showing some abrasion due to stream transport. *Dakotaraptor* teeth are more common in the TD Quarry, than *Saurornitholestes*, *Richardoesteia*, *cf. Troodon* or *Pectinodon* teeth, but slightly less common than *Acheroraptor*.

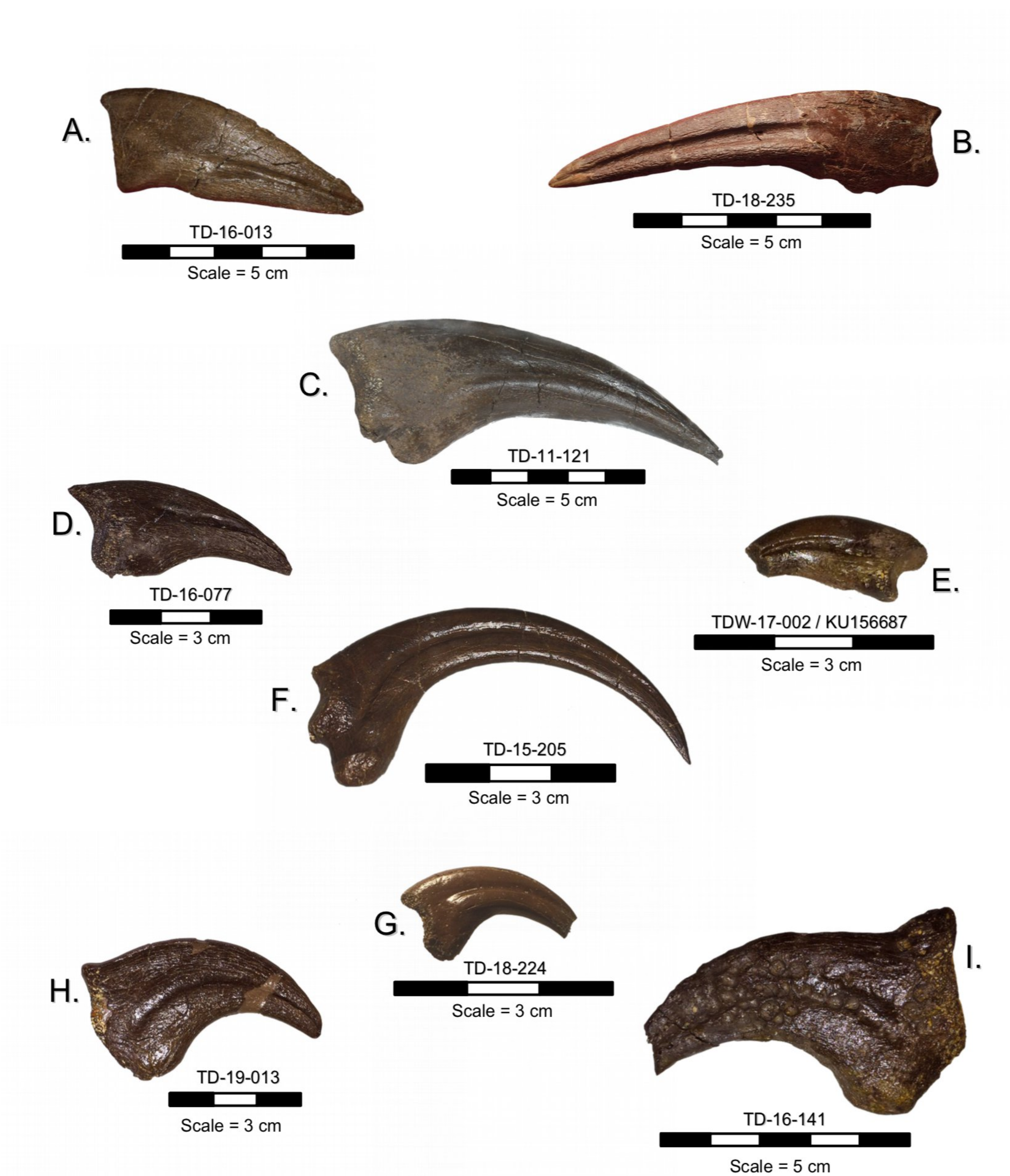


Figure 18- Theropod Unguals. A number of small theropod specimens have been found in the Tooth Draw Deposit. Some of these may have been from a local population living along the ancient river system, but others may have lived a considerable distance upstream. Most theropod specimens consist of pre-depositionally broken limb elements, but some, like claws, are better preserved and more diagnostic. A) Ornithomimid pes ungual. B) Ornithomimid manus ungual. C) Nanotyrannus manus ungual D) cf. Troodon pes ungual E) cf. Albertonychus manus ungual. F) Acheroraptor manus ungual. G) Acheroraptor pes ungual. H) Anzu manus ungual. I) Insect bored Anzu manus ungual.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY DROMAEOSAURIDAE
SUBFAMILY VELOCIRAPTORINAE
GENUS *Acheroraptor* Evans et. al., 2013
SPECIES *Acheroraptor temertyorum* Evans et. al., 2013

Acheroraptor is another elusive dromaeosaurid from the Hell Creek Formation that has only been described from teeth, a single isolated maxilla and an associated dentary from the Hell Creek Formation of Montana (Evans et. al., 2013). Teeth are distinguished from *Dakotaraptor* by the higher serration count of 6-7 denticles/mm anterior and 4-5 denticles/mm posterior (anterior denticle count/mm = posterior denticle count/mm - 2 or 3) (Figure 19), extreme labiolingually compressed nature, strong curvature, blade-like shape, short, well rounded denticles and the presence of subtle, longitudinal, apicobasal ridges as described by Evans et. al., 2013. These slight ridges almost give the tooth a faceted look, reflecting light as the specimen is turned slightly. They are even more laterally compressed than *Dakotaraptor* and they are the most common dromaeosaurid tooth in the Tooth Draw Quarry.

Despite the lack of a well described skeleton to reference, some small theropod elements from the Tooth Draw Quarry were tentatively assigned to *Acheroraptor* based on their size and morphology. These included some metatarsals, several phalanges and several unguals. One in particular, (PARC-TD-15-205) is an extraordinarily well preserved manus ungual from the D/E horizon of the main TD Quarry (Figure 18). It measures 8.7 cm. along the dorsal curve, is very gracile and is complete from the tip to the base. It shows no evidence of stream transport, despite its small and fragile nature. It compares favorably with other velociraptorine manus unguals and appears to be less "stoutly constructed" than *Saurornitholestes* as described by Sues, 1978.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY DROMAEOSAURIDAE
SUBFAMILY SAURORNITHOLESTINAE
GENUS *cf. Saurornitholestes* Sues, 1978

Saurornitholestes langstoni is known from several partial skeletons, skulls, isolated elements and teeth from the Campanian aged Dinosaur Park Formation (Sues, 1978; Longrich, 2008; Sankey, 2008; Larson and

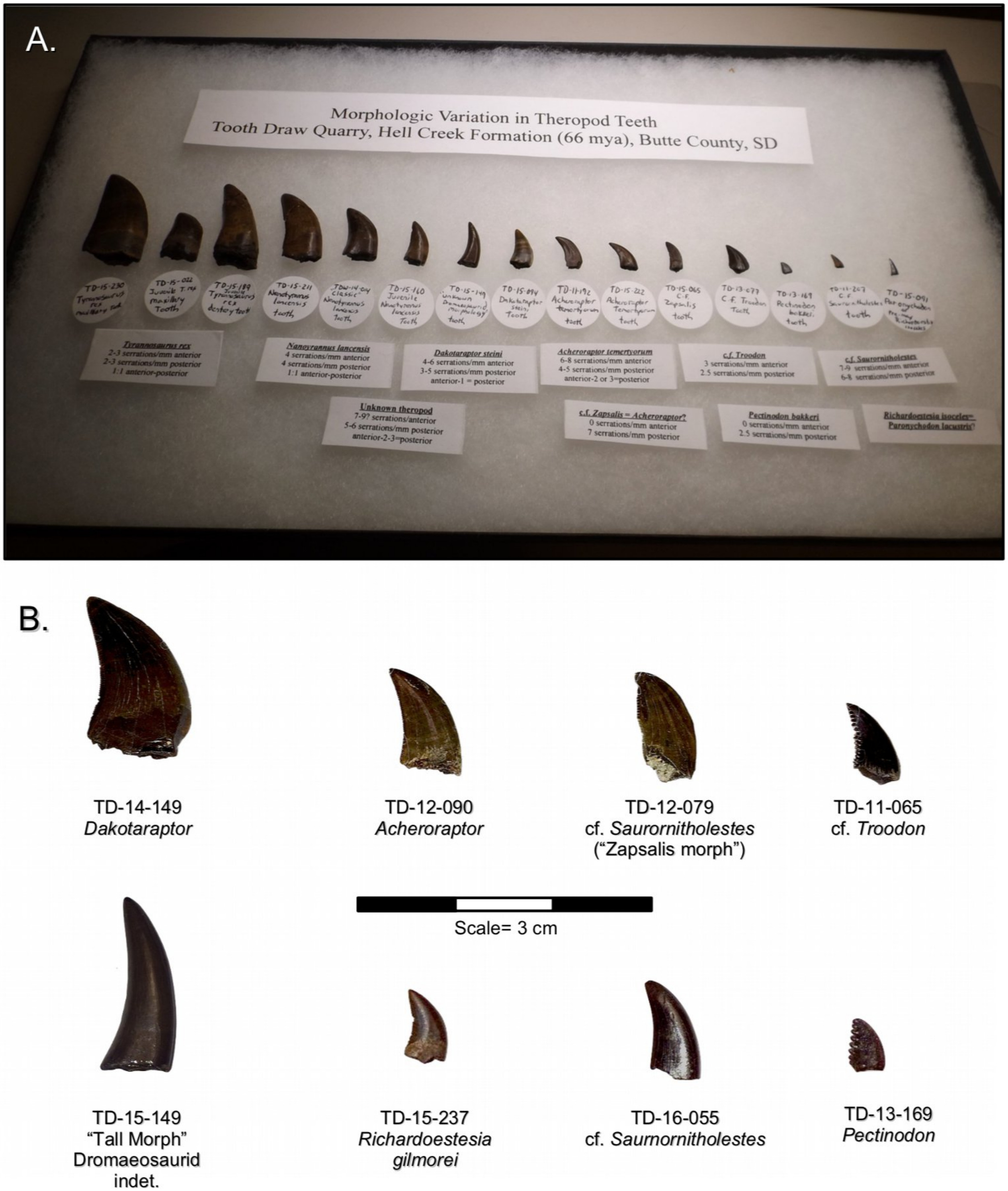


Figure 19- Small Theropod Teeth. Dromaeosaurid skulls, skeletons, and isolated bones are very rare in the Hell Creek Formation due to the depositional setting and their fragile nature. As a result, most are only known from teeth and a handful of isolated elements. Based on teeth from the Tooth Draw Deposit and elsewhere it appears that there are at least four or possibly five dromaeosaurids and two troodontids present in the Hell Creek. These include, *Dakotaraptor*, *Acheroraptor*, *cf. Saurornitholestes*, *Richardoestesia gilmorei*, An undescribed dromaeosaurid, *cf. Troodon* and *Pectinodon*. A) Display showing the morphologic variation in teeth from the Tooth Draw Quarry. B) Representative tooth specimens from the major genera showing a diverse small theropod population.

Currie, 2013; Evans et.al., 2013; Currie and Evans, 2019). Its presence (or the presence of something closely related to it) has, however, been reported in other rock units for years (Larson and Currie, 2013; Williams and Brusatte, 2014; Currie and Evans 2019; etc.), including the much later, Maastrichtian, Hell Creek Formation. Teeth that match these descriptions, have also been found in the Tooth Draw Deposit. These specimens are hereby referred to as *cf. Saurornitholestes* until more diagnostic material is found and described.

The teeth of *cf. Saurornitholestes* are very similar to those of *Acheroraptor*, in that they are both similar sized, blade-like, strongly curved, medio-laterally (labiolingually) compressed teeth with fine serrations on the anterior carina and coarser serrations on the posterior carina. Due to these similarities they are often confused leading to frequent misidentification. Compounding the problem is a complete lack of partial skeletons and skulls from the Hell Creek, from which to base analysis. At this time, c*f. Saurornitholestes* teeth are differentiated from *Acheroraptor* by their finer anterior serrations, usually running between 7-9 serrations/mm anterior and 5-7 serrations/mm posterior (anterior denticles/mm = posterior denticles/mm - 2 or 3), smooth sides and a lack of any longitudinal, apicobasal ridges or flutes on labial surfaces (Figure 19) (Currie and Evans, 2019). Currie and Evans (2019), also noted that *Saurornitholestes* teeth have "apically hooked" denticles on their posterior serration meaning that individual denticles are not rounded and bilaterally symmetrical, but rather longer on their dorsal margins. Unfortunately, this character is very difficult to see without magnification, often leading to misidentification.

Another frequently reported tooth from the Hell Creek Formation is *Zapsalis* (Larson and Currie, 2013; Currie and Evans, 2019). Teeth referred to as *Zapsalis* often have a strange, quite diagnostic shape with distinct apicobasal longitudinal ridges and flutes on both labial and lingual sides, unserrated anterior carinas (frequently), very fine posterior serrations, a basal constriction on the gum line and flattened lingual sides (Currie and Evans, 2019). These were originally described in 1876 by E. D. Cope from isolated teeth recovered in the Judith River Formation. As shown by Currie and Evans, 2019, these teeth are likely premaxillary teeth from *Saurornitholestes* and not a separate taxon, at least in the Dinosaur Park Formation. Though, they admit that *Zapsalis* may still be a separate genus, not yet described in full, within the Judith River formation. In the Hell Creek they are hereby referred to as premaxillary teeth from *cf. Saurnonitholestes (aka. "Zapsalis morph").*

Rare specimens of teeth matching the description of *Saurornitholestes* and *Zapsalis*, have been found within all horizons of the Tooth Draw Quarry (Figure 19), but are generally found while excavating the E1 and E2 beds. Due to their small size they are generally discovered by either screening with a fine screen or by surface collecting after a strong rain. Other elements, including several partial, hollow theropod limb bones may also be from this animal.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY DROMAEOSAURIDAE
GENUS *c.f. Richardoestesia*

The holotype of *Richardoestesia* was originally found by C.H. Sternberg in 1917 and later described in 1924 by Charles Gilmore (Gilmore, 1924; Currie et. al., 1990; Williamson and Brusatte, 2014). The original specimens consisted of two isolated dentaries from the Campanian Dinosaur Park Formation, that were originally thought to be oviraptorid, but were later reassigned (Williamson and Brusatte, 2014). Like *Saurornitholestes*, it is another taxon that has been attributed to isolated teeth in multiple rock formations. While these may be closely related to the holotype *Richardoestesia*, they are likely from different taxa due to their wide geographical and chronological extent. Larson and Currie (2013) argued that the specific name *Richardoestia gilmorei* should only refer to specimens from the Dinosaur Park Formation and that similar teeth from the Hell Creek should be called something else. They suggested that any teeth similar to this be considered a *Richardoestesia morphotype*. Longrich (2008), considered *R. isoceles* and *R. gilmorei* the same taxa with the different morphs originating from different parts of the dentition. Others have even questioned whether the triangular morph, *Richardoestesia isoceles* are really from a dromaeosaurid or even from dinosauria. For the purposes of this paper, the Hell Creek taxon is referred as *cf. R. gilmorei* and is considered a dromaeosaurine whilst *cf. R. isoceles* is considered a separate taxon of unknown affinities, until more complete skulls with teeth can be found and described.

cf. Richardoestesia teeth are occasionally found in the Tooth Draw Deposit, usually along the E1 or E2 boundaries (Figure 19). Due to their small size, they are often missed during excavation and recovered by screening or "re-discovered" during surface collecting. These include teeth that are the *Richardoestesia gilmorei* morphotype (Currie et. al., 1990); Larson and Currie, 2013) and the more triangularly shaped *Richardoestesia isoceles morphotype* (Sankey, 2001). Of the two, *R. isoceles* is more rare with less than five confirmed specimens recovered in 15 years of excavation.

Richardoestesia gilmorei teeth tend to be very small (0.5-0.6 cm average) in height, with a fore-aft basal length (FABL) to height ratio of about 0.67. They tend to have a strong anterior curvature, but often a more straight posterior curvature. In the TD Quarry their anterior carina are either devoid of serration or very finely serrated and their distal serration is between 5-7 denticles/mm though the type specimens described by Currie had 5 denticles/mm (Currie et. al., 1990). They differ from small *Acheroraptor* teeth by having no apicobasal or longitudinal ridges/facets. They differ from *Saurornitholestes* by exhibiting an even finer serration on the posterior carina and usually no serration or very faint serration on the anterior carina.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY DROMAEOSAURIDAE
GENUS Indet.

Several other dromaeosaurid teeth have been found in the Tooth Draw Quarry that do not seem to match the descriptions of any of the known Hell Creek taxa. One morphology in particular I call the "tall morph" dromaeosaurid (Figure 19). These are strongly curved, fang-like teeth, quite tall, with a CH:FABL ratio of 2.6 or higher. They are smooth sided, extremely medio-laterally flattened, and often quite sharp. Both the anterior (7-9 denticles/mm) and posterior carina (5-6 denticles/mm) are finely serrated (anterior serration denticles/mm= posterior serration denticles/mm – 2 or 3 denticles). At this point it is still unclear whether or not this "tall morph" represents a distinct and separate dromaeosaurid taxa or whether it is a simply a different morph in an anterior tooth position (premax tooth or maxilla 1-3), from one of the other four main dromaeosaurid taxa present.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY TROODONTIDAE
GENUS *cf. Troodon*

The history of the genus *Troodon* is long, complex and largely above the scope of this paper. *Troodon* was first described by Joseph Leidy in 1856 from a single tooth found in the Judith River Formation. Since this time, similar teeth have been reportedly found in multiple, Late Cretaceous rock units (Sankey, 2008; Larson and Currie, 2006; Larson, Brinkman and Bell, 2010). These teeth are quite diagnostic in that they have very coarse serration on their posterior (2-3 denticles/mm) and anterior (2-3 denticles/mm) carinas. The serration is jagged and sharp with apically pointed denticles. Multiple authors have reported their discovery in the Hell Creek and Lance Formations (Derstler, 1994; Sankey, 2008; Longrich, 2008; Gates et. al., 2015) and since Troodon was named from a significantly younger rock formation, it is likely from a separate genus and species. For the purposes of this paper, any teeth found with *Troodon*- like morphology have been assigned to *cf. Troodon*.

Cf. Troodon is represented by multiple, isolated shed teeth from various horizons in the Tooth Draw

Quarry. Several isolated theropod elements, also recovered from the Tooth Draw Deposit have been tentatively assigned to *cf. Troodon* pending the discovery and description of more complete Hell Creek material for comparison. These include several gracile metatarsals and phalanges from TD and a pes ungual from the TDW (Figure 18). These match descriptions of other, more complete Troodontids from other rock units (see also *Talos* in Zanno et. al., 2011; *Stenonychosaurus* in Van Der Reest and Currie, 2017). These elements were found in the C and the along the D/E contact.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY TROODONTIDAE
GENUS *Pectinodon* Carpenter, 1982
SPECIES Pectinodon bakkeri Carpenter, 1982

A second Troodontid tooth taxa is also known from the Hell Creek Formation. This taxon is known as *Pectinodon bakkeri* (Carpenter, 1982). *Pectinodon* teeth have a distinct morphology that is quite different from those traditionally identified as *cf. Troodon*. The teeth of *Pectinodon* are usually very small (<0.5 cm), labiolingually flattened with very coarse denticles on the posterior carina (2-3 denticles/mm) and no denticles on the anterior carina. The denticles on the posterior carina are more rounded and are mostly directed perpendicular to the gum line, as opposed to the very sharp and apically directed denticles of *Troodon*. Most authors have concluded that *Pectinodon* is a valid genus and separate it from *Troodon* (Longrich, 2008; Zanno et. al., 2011; Larson and Currie, 2013). Some, however, suggest that both troodontid tooth taxa are from the same genus and the difference in morphology is due to ontogeny or tooth position (personal communication Ken Carpenter, 2017). Until further, more complete material is recovered in the Hell Creek to clarify the issue, I consider them to be separate taxa.

Pectinodon is a very rare component of the Tooth Draw Deposit, known from only a single tooth (Figure 19). It measures 4.5 mm in height and has a FABL of 2.3 mm. This tooth was discovered while screening, so its placement to horizon within the quarry is unknown. Further analysis of wet screened material will likely reveal more teeth of *Pectinodon*.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY ALVAREZSAURIDAE
GENUS *cf. Albertonykus* Longrich and Currie, 2009

Albertonychus is an enigmatic, lightly built, small theropod described from the upper beds of the Late Cretaceous, Horseshoe Canyon Formation, Alberta, Canada (Longrich and Currie, 2008; Larson, Brinkman and Bell, 2010). It is an Alvarezisaurid, a group of very bird-like dinosaurs united in having extremely lightweight bones, long legs and a reduced forelimb ending in a single ungual (Longrich and Currie, 2008). These rare and unique dinosaurs have been described from Late Cretaceous rocks in both North and South America as well as Asia. Isolated remains of Alvarezsaurids in the Hell Creek and the Lance Formations have been reported by a few authors including Holtz, 1994 and Hutchinson and Chiappe, 1998 (Longrich and Currie, 2008).

Two unguals, collected in the Tooth Draw Deposit, have been tentatively assigned to *cf. Albertonychus* based on the presence of two ventral foramen, a ventral sulcus, and their general morphology. One is retained in the PARC as TD-16-149 and another donated to the University of Kansas as KU-156687 (TDW-17-002) (Figure 18). These were originally mis-identified in the field as a turtle ungual and small unknown theropod pes ungual respectively. Photographs shown to other colleagues then suggested that they were Alvarezsaurid (personal communication, Henry Mendoza, 2017). If these are indeed Alvarezsaurid then several of the smaller unidentified theropod elements may also be from this rare genus.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER SAURISCHIA
SUBORDER THEROPODA
FAMILY Incertae sedis
GENUS *cf. Paronychodon* Cope, 1876

Paronychodon has been an enigmatic tooth taxon since its original description by Cope in 1876. Shed teeth attributed to it have been described from multiple rock formations (including the Hell Creek Formation), from various geographic locations and chronologic times (Estes, 1964; Carpenter, 1982; Currie et. al., 1990; Sankey et. al., 2002; Larson and Currie, 2013). To date, no skull or skeletal material associated with these teeth has yet to be discovered, leading different scientists to refer it to multiple different dinosaur and non-dinosaur taxa (Currie et. al., 1990). Cope originally described these teeth as "having the general character of Plesiosaurus, Elasomosaurus, etc." (p.256, Cope, 1876). Other workers moved *Paronychodon* to dromaeosauridae (Currie et. al. 1990).

Teeth that can be referred to the tooth taxon *cf. Paronychodon* have been recovered from the Tooth Draw Deposit, but they are rare. These are generally small (<1.0 cm crown height), unserrated, conical teeth with multiple well developed apicobasal ridges and usually a flattened side. They are similar to the *Zapsalis* morph aka, premaxillary teeth of *Saurornitholestes* (Currie and Evans, 2019), and thus, likely an unserrated premaxillary tooth of one of the previously mentioned dromaeosaurids.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY HADROSAURIDAE
GENUS *Edmontosaurus*
SPECIES *Edmontosaurus annectens*

The majority of ornithischian elements found within the Tooth Draw Deposit have been identified as *Edmontosaurus annectens* (Figure 20). These constitute approximately 23.2% of all logged specimens recovered from the Tooth Draw Quarry (n=532), not including shed *Edmontosaurus* teeth and fragments, which were very abundant and rarely counted. This closely matches the percentage of Edmontosaurus partial skulls and skeletons recovered from the Hell Creek (22.8%), but is significantly less than the percentage of isolated bones and teeth (46.3%) as reported in the latest 2019 Hell Creek Dinosaur Census (Stein, 2019). Edmontosaurus specimens have been found in all bone bearing strata of the deposit, but are frequently found in the C, and D horizons. Specimens recovered include most elements of the skull and body, but vertebrae and pieces of vertebrae (centrums, spines, neural arches, etc.) are by and large the most frequently encountered (n=217).

Elements of *Edmontosaurus* are typically broken and highly abraded. Breaks are often jagged, sometimes oblique and occasionally show evidence of spiral fracture. Often limb elements are missing one or both ends, vertebrae missing tops of spines, and/or other evidence of pre-depositional damage. Many of the dinosaur bone fragments and "bone pebbles" are likely from *Edmontosaurus* as they often match the thin-walled texture of *Edmontosaurus* bone. Bite marks are sometimes found associated with these breaks indicating feeding activity as the probable cause of some of this.

All ontogenetic stages are represented in the collection (Figure 21). Limb bones ranged from several with a 90+ cm length, indicating the presence of large, full grown adults, to those under 15 cm in length, indicating the presence of neonates or, at the very least, very young juveniles. Some of the largest metatarsals exceeded 27 cm, while at least one metatarsal discovered was less than 8 cm in length. Interestingly, there is often a reverse relationship between the size and the condition of *Edmontosaurus* bones in the deposit. Smaller elements tend to be better preserved with more complete ends and less abrasion, while many of the larger elements tend to be missing sections, have strong pittings and etchings and/or show more intense abrasion.

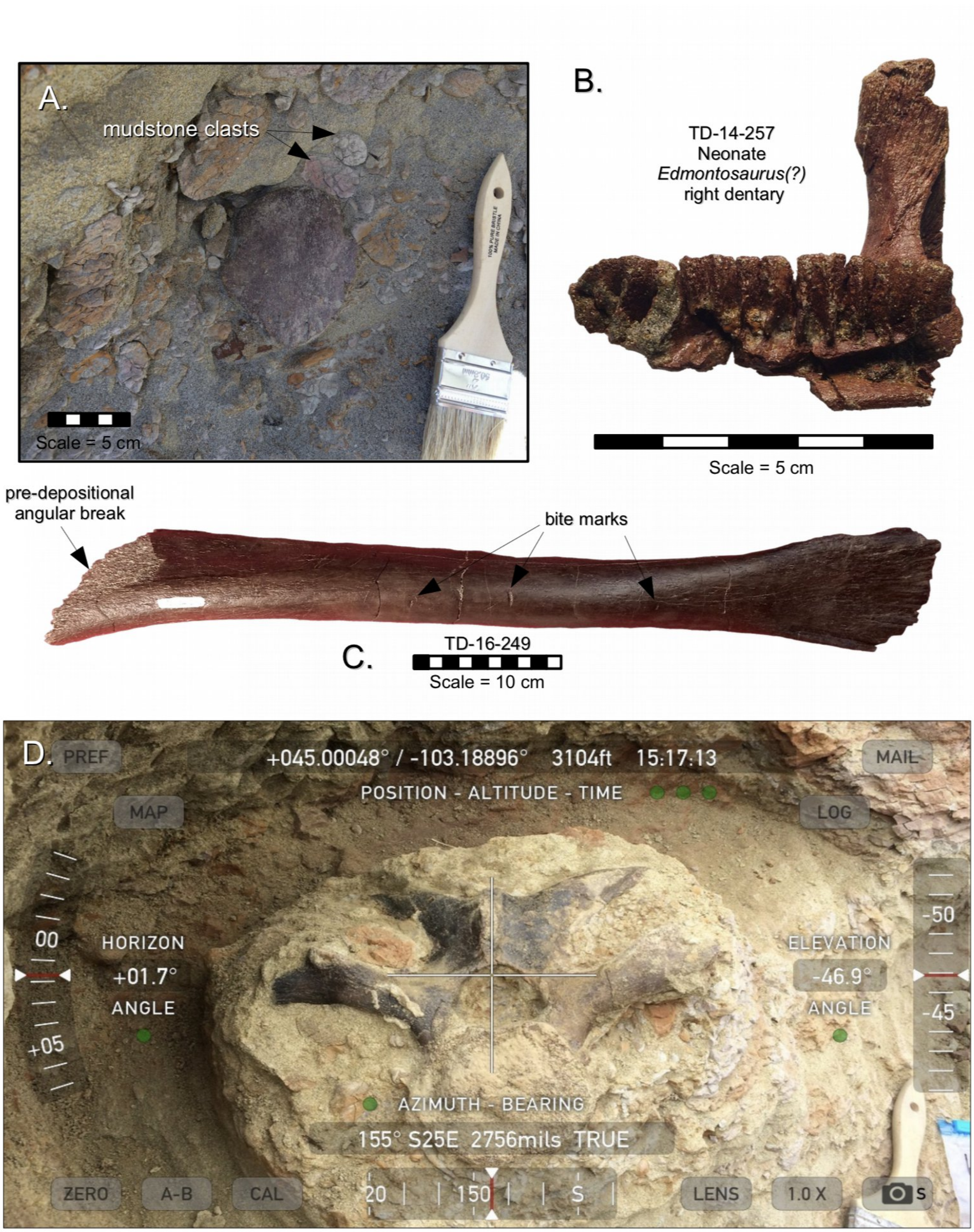


Figure 20- Edmontosaurus. The most common dinosaur discovered in the Tooth Draw Quarry is the Latest Cretaceous hadrosaurid, *Edmontosaurus*. *Edmontosaurus* bones, teeth and ossified tendon can be found in every horizon of the deposit, and range from neonate to mature adults. So far, all elements are disarticulated and unassociated, but there is always the possibility of something more complete showing up. A) Pes ungual from the D horizon. B) Neonate right dentary from the D horizon C) Partial fibula showing oblique irregular, pre-depositional fracture and bite marks. D) Mostly complete cervical vertebra from an adult, found within the D horizon.

Figure 21- *Edmontosaurus* Age Variation. *Edmontosaurus* elements range in size from full grown adults to neonates. A) TD-13-037, a Juvenile to neonate left humerus and B) TDW-19-064, an adult right humerus compared.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY THESCELOSAURIDAE
GENUS *Thescelosaurus*
SPECIES *Thescelosaurus neglectus*

One of the most common genera encountered in the Tooth Draw Deposit is the small, basal ornithopod *Thescelosaurus* (Figure 22). Bones and teeth of *Thescelosaurus* are particularly plentiful in the Tooth Draw Quarry (n=310), where they represent 13.5% of the collected dinosaur remains. They rank third behind only Tyrannosaur teeth and *Edmontosaurus* material, ranking ahead of the normally more plentiful *Triceratops*. Elements are from all areas of the body, including multiple pelvic, pectoral axial, and major limbs. Like *Edmontosaurus*, vertebrae and portions of vertebrae (centrums, neural arches) are the most plentiful (n=80), but pes elements, including multiple phalanges, unguals, and metatarsals are a close second (n=65). Multiple disarticulated skull elements have also been recovered, though no complete skulls have been found to date. The majority of *Thescelosaurus* specimens have been found in the D horizon.

Figure 22- ***Thescelosaurus***. One of the most common species found in the quarry is the small basal ornithischian, *Thescelosaurus neglectus*. Specimens range from neonate to adult with a large collection of juvenile to subadult material. *Thecscelosaurus* specimens tend to be in better condition than *Edmontosaurus* with less abrasion and almost no weathering. They are abundant in the D horizon and likely from a local population. A) Collection of metatarsals, phalanx's, and unguals. B) Left scapula. C) Right illium. D) Adult right femur compared to a left neonate femur.

Thescelosaurus bones are generally in good condition, with lighter abrasion and more moderate, pre-depositional damage. Like the other ornithischians in the study, the smaller elements tend to be better preserved than the larger ones. Elements are usually not pitted or corroded like many *Edmontosaurus* or *Triceratops* bones. Many appear to even show some loose association of common and similarly sized elements, though nothing has been found in articulation. All ontogenetic stages are represented by the collection, from mature adults to very young juveniles and neonates. For example, the largest femur from the quarry measures over 30 cm and the smallest is less than 9 cm in length. Their frequency, their condition, as well as concentration in the D horizon, suggest that they are from a more localized fauna.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY CERATOPSIDAE
GENUS *Triceratops* Marsh, 1889

Disarticulated, ceratopsian bones, teeth and fragments are found within all strata of the Tooth Draw Deposit, though most are found within the A and the C horizons. Most of this material has been tentatively assigned to *Triceratops,* but it is possible that some of it could be from *Torosaurus,* a similar genera reported from the Hell Creek, by other authors (Marsh, 1891, Farke, 2011; Longrich, 2012; Stein, 2017).

Recovered elements (n=190) consist of vertebrae, rib sections, metatarsals, metacarpals, unguals, phalanges, some rare pelvic bones and the more commonly discovered, disarticulated skull material. This includes multiple, partial frill sections, horn cores, portions of braincases, rostral sections, epoccipitals, and unidentified skull material. Interestingly, only two partial, major limb elements (femurs, tibias, humeri, etc.) of ceratopsians have been found to date. Like those of *Edmontosaurus*, many elements show significant pre-depositional weathering, abrasion and breakage. This pre-depositional damage indicates significant stream transport.

All ontogenic stages appear to be represented by the material (Figure 23). These range from neonate(?) to mature, based upon their size, rugosity, and lack of or presence of fused sutures. For example, epocipitals range in size from juveniles measuring a mere 4.7 cm wide to older adults measuring up to 30 cm wide. *Triceratops* bones in the quarry, like those of *Edmontosaurus,* show an inverse relationship between size and condition. The larger, adult bones tend to be more broken up and incomplete, while those of juveniles or younger adults tend to be more complete.

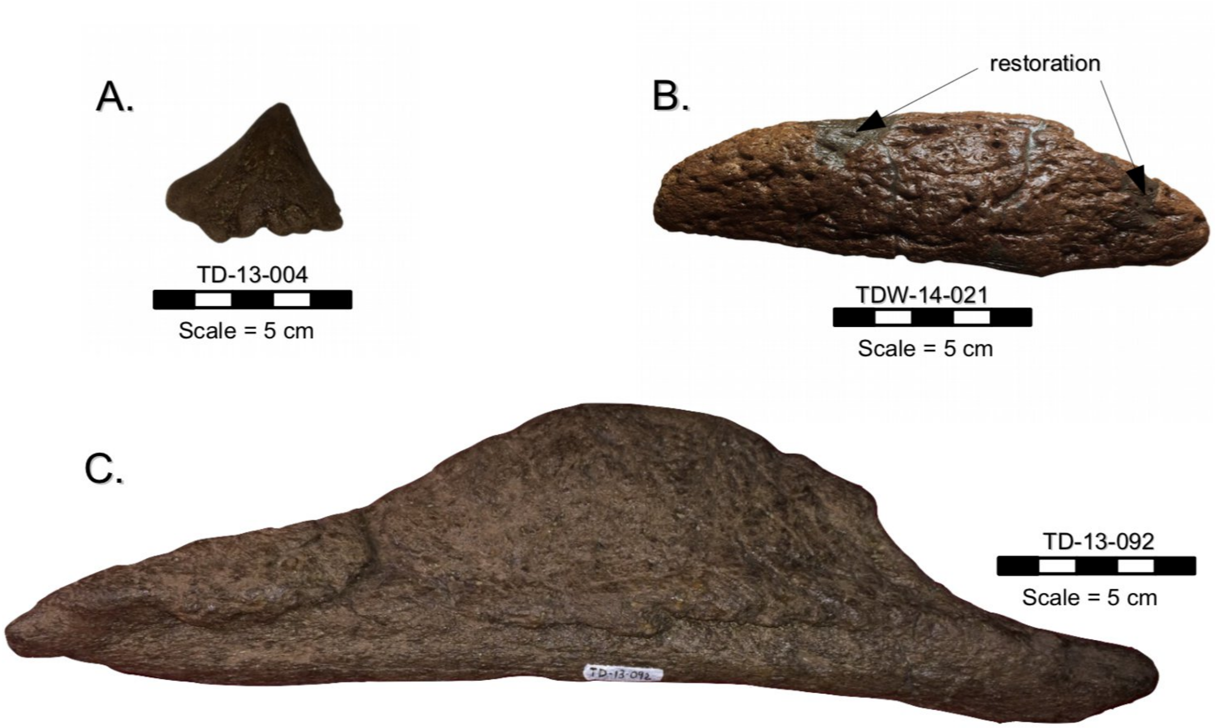


Figure 23- Triceratops Epocipitals. *Triceratops* is the most commonly found dinosaur in the Hell Creek, but only the third most common ornithischian from the Tooth Draw Quarry, behind both *Edmontosaurus* and *Thescelosaurus*. The majority of specimens consist of adult material from the skull and mostly water-worn fragments of skull. Others, however, are from very young juveniles. In this image we can see three epocipitals from the edge of the frill. A) Young juvenile. B) Subadult. C) Mature Adult.

One of the most significant juvenile specimens recovered includes a left dentary from a very young individual (Figure 24). This dentary does not have any teeth, but it is in otherwise excellent condition. The specimen is quite robust for its size, and there are at least 14 alveoli along the broken tooth row. It measures only 14.8 cm long and is identical to, but measures about 1.2 cm less, than UCMP 154452, the "smallest known Triceratops skull", as described by Goodwin et. al., 2008.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY CERATOPSIDAE
GENUS *Torosaurus* Marsh, 1891

While the vast majority of ceratopsian elements have been identified as *Triceratops*, a few have been tentatively identified as *Torosaurus*. These include two partial parietal bars and assorted frill fragments which appear to indicate the presence of a large fenestra. These tend to be thinner and less rugose than the larger pieces of *Triceratops* frill recovered thus far. Additional work on these is planned for the future.

Figure 24- Juvenile Triceratops Dentary. One of the more scientifically significant specimens from the quarry includes this juvenile Triceratops dentary. Like many of the more complete and unweathered specimens it was found in the lower portions of the D horizon. Although no teeth were found, the bone texture and surface is in exceptional condition. Its size is 1 cm smaller than the "smallest known Triceratops" skull described by Goodwin et. Al, 2008, making it the smallest presently known from the Hell Creek. A) Field photograph of TD-15-233. B) Labial/lateral view of dentary. C) Lingual view of TD-15-233.

Figure 25- Leptoceratops. *Leptoceratops* material is rare in the Hell Creek Formation, but more specimens are being found now that field workers are looking for them. A) Left ulna of suspected *Leptoceratops*. B) In the Tooth Draw Quarry, Leptoceratops is mostly represented by rare, but diagnostic teeth. Teeth typically have a single root, instead of the two seen on *Triceratops*.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY CERATOPSIDAE
GENUS *Leptoceratops sp.* Brown, 1914

Leptoceratops was a small, primitive ceratopsian that was originally described from a few partial skeletons and skulls from the Edmonton Group of Alberta, Canada in 1914 (Brown, 1914;). Unlike the more advanced ceratopsians, *Leptoceratops* lacked horns of any kind. Its frill was fairly simple and its bones were more gracile then most other ceratopsids of the day. Since Brown's early discoveries, several partial skeletons and skulls as well as teeth, either attributed to *Leptoceratops* or closely related to *Leptoceratops*, have been discovered in multiple Late Cretaceous rock units of Western North America (Ostrom, 1978; Ott, 2002; Arbour and Evans, 2019). The Hell Creek is no exception (Malinowski, 2014; Stein, 2019). Several good specimens, recovered from the Hell Creek, including jaws with teeth are also in private collections, but these have yet to be described (personal communication Frank Francino, 2020). It appears to have been a very rare component of the Hell Creek Formation, but it is being reported more and more frequently.

Shed *Leptoceratops* teeth have been sporadically found within the Tooth Draw Deposit over the last few years (Figure 25). Most of these are heavily abraded, worn “spitter teeth” with only partial roots. They can be distinguished from other ceratopsians by their possession of a single root, instead of a forked root, like

Triceratops or *Torosaurus*. The suspected *Leptoceratops* teeth are a very small component of the collection and likely reworked from far upstream. A few other elements may also be *Leptoceratops* including one ulna with a very broad olecranon process.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY PACHYCEPHALOSAURIDAE
GENUS *Pachycephalosaur indet.*

Pachycephalosaurid remains have also been recovered from the Tooth Draw Quarry (n= 46), but their numbers are a small percentage of the collection (2.0% of dinosaurs). Teeth, vertebra, ribs, limb elements, unguals and skull fragments (including hornlets) are all represented (Figure 26). Unguals tend to be more rounded towards the tip and more broad towards the posterior when compared to *Thescelosaurus*. Ribs are stouter and strongly curved. Two other specimens, in particular, are a pair of robust, slightly bowed (inwards), femurs with an slight s-shaped twist, and triangular (though both are worn), weakly pendant 4th trochanter. Portions of the distal condyles are missing, but it appears that the lateral condyle is larger than the medial. These features are reported as diagnostic of Pachycephalosaurids (Maryanska and Osmolska, 1974; Sereno, 2000; Ryan and Evans, 2005). While these may simply be very large and distorted *Thescelosaurus* femurs, their morphology does compare favorably to the femurs of the Triebold specimen (nicknamed “Sandy”- currently at the National Museum of Japan), the only known pachycephalosaurid from the Hell Creek, with a significant percentage of post-cranial elements (Triebold, 1999; Glut, 1997; Stein, 2019).

Fragments of broken and tumbled skull material tend to be the most commonly found items. These are highly abraded, however, and show significant stream transport. Elements of pachycephalosaurids have been recovered in all horizons of the quarry, but they are more predominant in the C and the D horizon.

Identification of individual elements to genera has been difficult due to the lack of well preserved post cranial skeletons in the Hell Creek for comparison. Though some would consider all Hell Creek specimens as *Pachycephalosaurus*, most from the TD Quarry can best be described as *Pachycephalosaurid indet.* at this time.

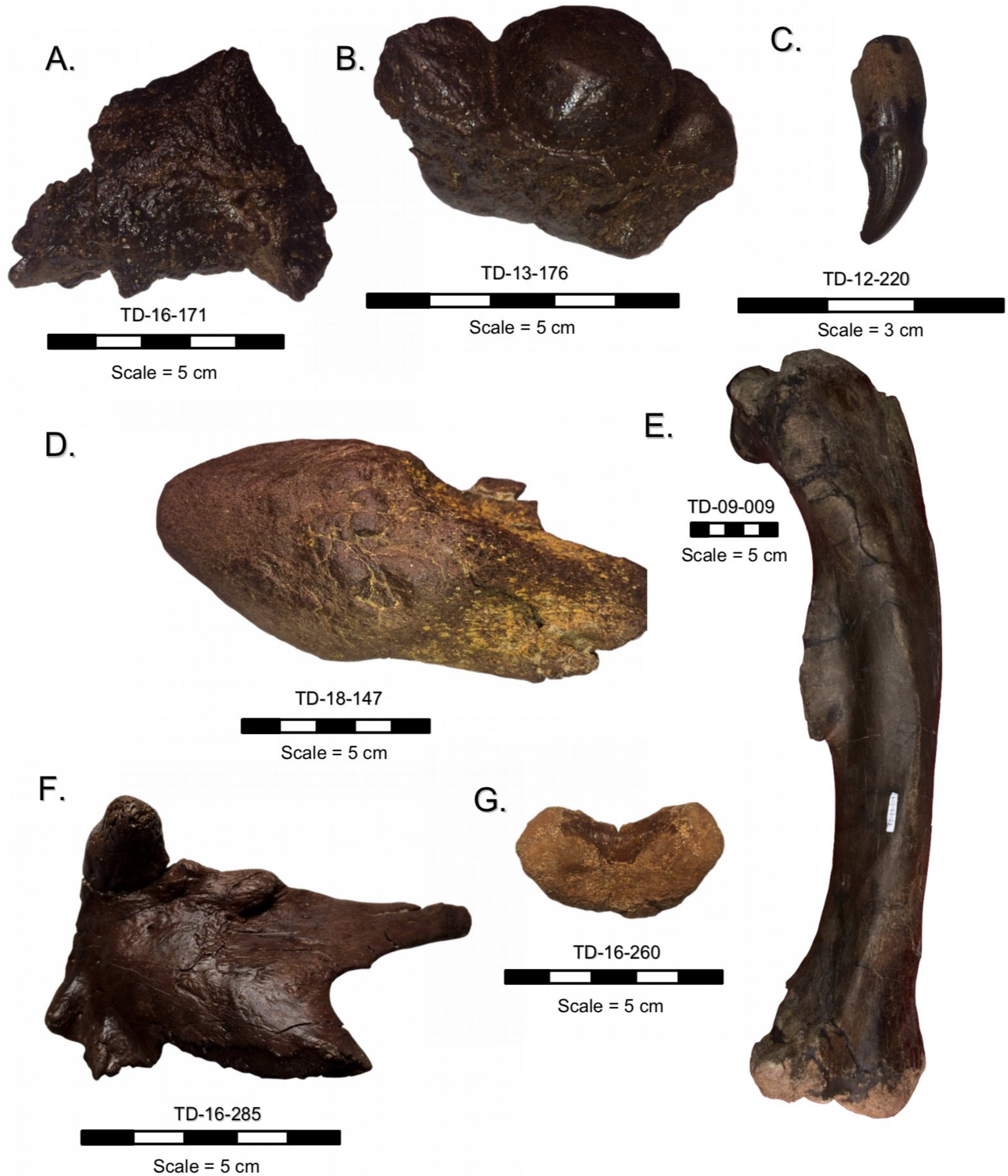


Figure 26- Pachycephalosaurus. Pachycephalosaurid material is generally considered rare in the Hell Creek Formation and it is no exception in the Tooth Draw Deposit. Most Pachy material consists of isolated skull elements with a distinct cross section. A) Hornlet from nasal area. B) Hornlets from postorbital region? C) Pachycephalosaur pre-maxilary tooth. D) Possible large hornlet from rear of skull. E) Femur from large adult Pachycephalosaurid. F) Unknown skull element possibly from Pachycephalosaurid. G) Atlas intercentrum possibly from *Dracorex*.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY PACHYCEPHALOSAURIDAE
GENUS *Dracorex* Bakker et. al., 2005
SPECIES *Dracorex hogwartsia* Bakker et. al., 2005

Dracorex hogwartsia is a very rare Pachycephalosaurid known from a single skull and a few associated cervical vertebrae (Bakker et. al., 2005). Due to the limitations of the material it is difficult to say with any certainty that disarticulated cranial or postcranial remains from the Tooth Draw Quarry can be directly identified as *Dracorex*. To further complicate matters there is considerable disagreement on the validity of the genus (see Goodwin et. al. and Sullivan, 2006, for discussion). That said, a few cranial elements including a suspected atlas-intercentrum (TD-16-260) was discovered, that, while more dorsoventrally flattened, bears a striking similarity to the holotype described by Bakker et. al., 2005 (Figure 26). It measures 4.8 cm wide and is in fair condition with moderate abrasion. This was discovered along the base of the D/E contact.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY ANKYLOSAURIDAE
GENUS *Ankylosaurus* Brown, 1908
SPECIES *Ankylosaurus magniventris* Brown, 1908

Ankylosaurs have a fragmentary record in the Hell Creek Formation. Less than a dozen articulated or associated skeletons are known from this unit to date. Most of these are only associated collections of dermal armor and only seven are in public institutions (Stein, 2019). Aside from a few partial skeletons originally described by Brown in 1908 and redescribed by Carpenter in 2004, most Ankylosaurs in the Hell Creek are known only from isolated pieces of their armor (scutes) and shed, spitter teeth. Ankylosaur remains in the Tooth Draw Quarry are no exception.

A total of 62 Ankylosaurid and Nodosaurid specimens have been found within the Tooth Draw Quarry (Figure 27). The majority of these are broken, highly abraded, pieces of dermal armor that are not identifiable to genus. They are usually in fair to poor condition and well tumbled indicating significant stream transport. A few, however, are complete enough and in good enough condition to be identifiable as *Ankylosaurus*.

According to Carpenter, 2004, *Ankylosaurus* scutes can be differentiated from *Edmontonia* (*Denversaurus*), by several key characteristics. These include a flatter and smoother surface, thin walls and the presence of a low, well rounded keel that is offset from the center (Carpenter, 2004). Several specimens fit this description.

CLASS REPTILIA
SUBCLASS DINOSAURIA
ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA
FAMILY NODOSAURIDAE
GENUS *Denversaurus* Bakker, 1988
SPECIES *Denversaurus schleshmanni* Bakker, 1988

While it is clear that Nodosaurs were part of the Hell Creek/Lance ecosystem, there is considerable debate over their taxonomy (Bakker, 1988; Carpenter, 1990; Burns, 2015; Personal communication Carpenter 2019). Six known partial specimens have been recovered to date (Stein, 2019), but only two have had significant portions of the skull and post-crania (the rest are merely piles of osteoderms). The first good partial skeleton consisted of a partial skull with associated osteoderms originally described as *Edmontonia* by Barnum Brown and then later redescribed by Bakker, as *Denversaurus* (Bakker, 1988). The second is currently undescribed, but more complete, found by BHI, and later sold to a museum in Japan (Stein, 2019). Several authors, including Carpenter (1990), suggest that this material should be considered *Edmontonia,* a closely related genus from Canada and earlier rock units. Others, such as Burns (2015) have argued that it is more than likely a separate genus and that *Denversaurus* is valid. Until more complete material is discovered and described, the Hell Creek genus is considered *Denversaurus,* a very closely related, but distinct genera.

As stated above, Nodosaurid material has been found within the Tooth Draw Quarry, though it is fairly rare by comparison (less than 2%) (Figure 27). Like its cousin *Ankylosaurus*, *Denversaurus* material consists of worn teeth and fragmentary scutes which exhibit a level of breakage and abrasion consistent with significant stream transport.

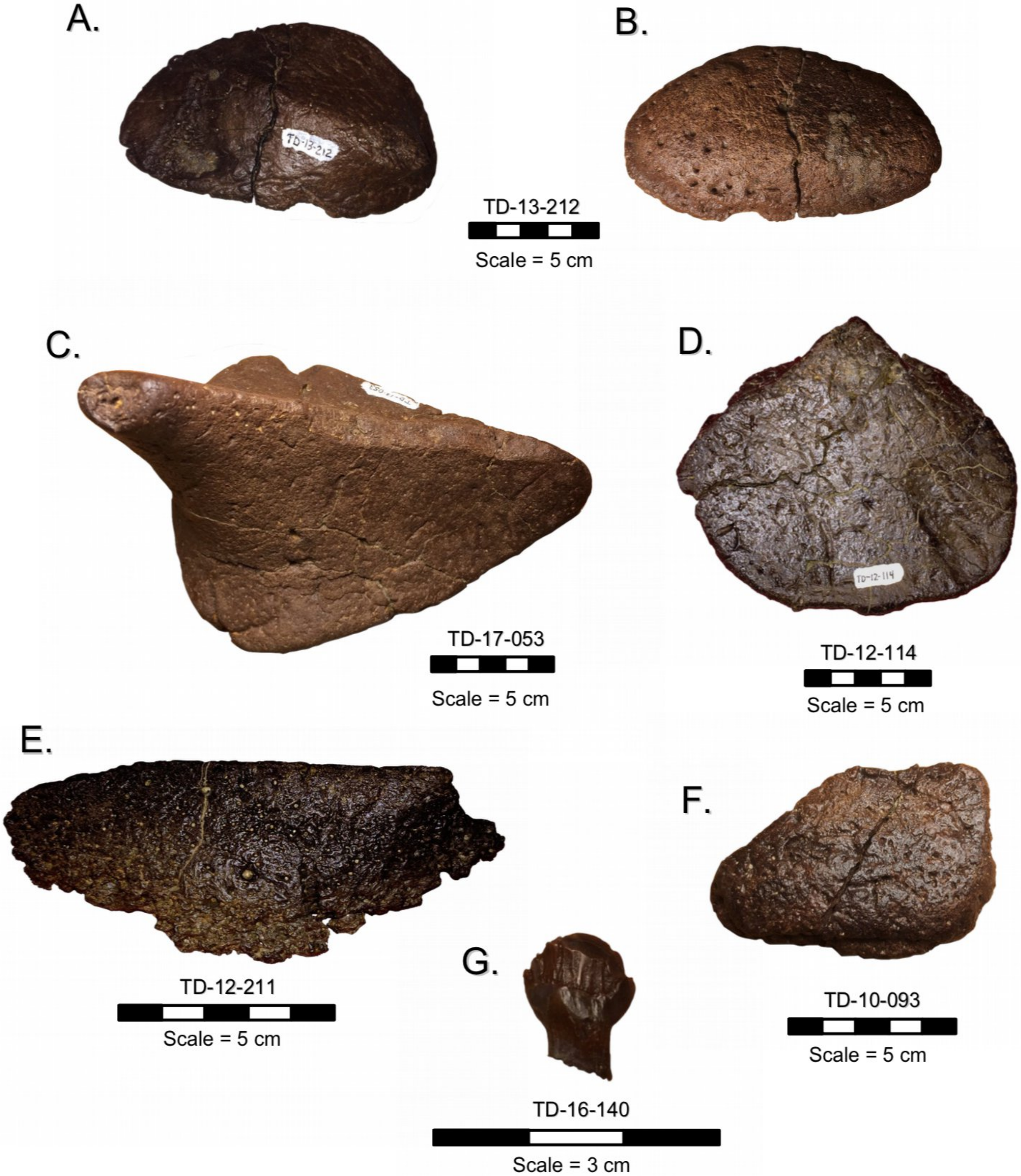


Figure 27- Ankylosaurs and Nodosaurs. The armor plated dinosaurs are usually represented by rare teeth and isolated scutes. Specimens of both *Ankylosaurus magniventris* and *Denversaurus Schleshmanni*. have been recovered in most of the horizons at Tooth Draw. A) *Ankylosaurus* scute in dorsal view. B) *Ankylosaurus* scute in ventral view. C) Lateral spike from *Denversaurus*. D) Dorsal scute from *Denversaurus* in ventral view. E) Posterior (?) *Denversaurus* scute in dorsal view. F) Dorsal scute from *Denversaurus* in dorsal view. G. Worn Nodosaurus tooth.

CLASS CHONDRICHTHYES
ORDER RAJIFORMES
FAMILY Rhinobatoidei incertae sedis
GENUS *Myledaphus* Cope 1876
SPECIES *Myledaphus pustulosus* Cook et. al., 2014

Isolated teeth from the euryhaline (can tolerate both fresh and saltwater) guitarfish *Myledaphus*, are commonly found throughout the Hell Creek Formation (Hoganson et. al., 2002; Brinkman et. al., 2005; Cook et. al., 2014; Hoffman et. al., 2018). According to Pearson et. al., 2002, they make up some 16.5% of the total specimens recovered from microfossil localities in their study area (Pearson et. al., 2002; Hoffman et. al., 2018). The distinctive, hexagonally shaped teeth can be found in every bone bearing horizon of the Tooth Draw Deposit. These are typically discovered while dry screening debris or by surface collecting after a good rainstorm. The average size of teeth recovered are approximately 0.5 cm, but specimens smaller than 1 mm and specimens approaching 1 cm in diameter have all been collected.

CLASS CHONDRICHTHYES
ORDER HYBODONTIFORMES
FAMILY Hybodontidae
GENUS *Lonchidion* Estes, 1964

Tiny, dorsal spines of the hybodont, freshwater shark are occasionally found in the Tooth Draw Quarry but their numbers are low. To date, no teeth have been identified.

CLASS OSTEICHTHYES
INFRACLASS CHONDROSTEI
ORDER ACIPENSERFORMES
FAMILY Acipenseridae Bonaparte, 1831
GENUS *Acipenser albertensis* Lambe, 1902

The fossil record of Sturgeon is generally considered poor by most authors (Hilton and Grande, 2006). Miscellaneous scutes, spines and skull elements, however, have been reported from the Hell Creek and its sister formation, the Lance, for some time (Estes, 1964). In general, the Hell Creek Formation does not preserve fish very well, with only a few sites yielding complete, articulated fish (DePalma et. al., 2019). Though very little work has been done on the fish fossils in the Tooth Draw Deposit, *Acipenser* scutes, fragmentary skull elements and possible spines are occasionally discovered during the excavation and preparation process. These are usually small and thin and not terribly abundant compared to the other fish remains. *Acipenser* appears to have been present, but a very minor component of the Tooth Draw fauna.

CLASS OSTEICHTHYES
INFRACLASS HOLOSTEI
ORDER Ammiformes
FAMILY Ammiidae
GENUS *Kindleia sp.*

Specimens of Amiid, or bowfin fish, are also discovered in the Tooth Draw Deposit. These consist of distinctive vertebrae, miscellaneous scales, tooth batteries and skull elements. Several genera of Amiid fish are known from the Hell Creek Formation, including *Amia*, *Kindleia*, and *Melvius*. At present, the material from the Tooth Draw Deposit is thought to be from *Kindleia*, though work on fish remains is preliminary at best.

CLASS OSTEICHTHYES
INFRACLASS HOLOSTEI
ORDER LEPISOSTEIFORMES
FAMILY LEPISOSTEIDAE
GENUS Lepisosteous

One of the most common fish remains in the Hell Creek Formation are the bony scales of the genus *Lepisosteous*. Garfish were well suited to the rivers of the Hell Creek ecosystem as these are a very common component of both microfossil localities and in macrofossil bone beds in the Deer's Ears Buttes area. *Lepisosteous* scales are very abundant in the Tooth Draw deposit, and it is a rare occasion that one digs for more than two minutes without finding one during excavation. Teeth and skull elements are also discovered in the quarry. Like the other fish, previously mentioned, very little work has been done on them.

CLASS AMPHIBIA
ORDER CAUDATA

Amphibian remains are occasionally discovered in the Tooth Draw Quarry, usually via dry screening the debris. Like many of the other microfossils in the assemblage, very little work has been done on them. The majority of identifiable remains include isolated atlantes and trunk vertebrae, currently identified as the ambystomatid salamanders *Scapherpeton* and *Opisthotriton*. *Habrosaurus* is another genus that rarely shows up as isolated vertebrae. So far, there have been no anuran fossils recovered to date.

CLASS REPTILIA
ORDER SQUAMATA

Lizards are represented by rare, but significant elements including isolated vertebrae, teeth, limb and pelvic elements and most importantly the fused pareitals of *Paleosaniwa* (TD-12-044) and a mostly complete left dentary of *Cemetarius* (TD-13-171) (Figure 28). The fused parietals of *Paleosaniwa* measure 3.5 cm in length from the edge of the frontal suture along the midline. A comparison to illustrations of a complete specimen of the similar *Saniwa ensidens* FMNH PR2378 (Riepple and Grande, 2007), suggests that the overall skull length of the individual that TD-12-044 represents, would be approximately 18-20 cm and have a total body length of 1.1-1.25 meters.

Specimens of squamates are generally rare, but well preserved with little abrasion or stream transport and usually found within the C or D horizons.

CLASS REPTILIA
ORDER EOSUCHIA
FAMILY CHAMPSOSAURIDAE
GENUS *Champsosaurus*
SPECIES *Champsosaurus*

Champsosaurus elements are also commonly found, but less so than many other bone beds I have worked. Teeth, vertebrae and ribs are the most commonly found elements. These are all disarticulated and are evenly distributed throughout the deposit and strata. Vertebral centra are generally in the smaller size ranges, seldom exceeding 2.5 cm in maximum length.

CLASS REPTILIA
ORDER CROCODILIA

Crocodile teeth and osteoderms tentatively referred to *Brachchampsa* and *Borealsuchus* are commonly found in the quarry on a daily basis. The overwhelming majority of these elements are in the smaller size ranges, with teeth, on average, less than 1.5 cm and scutes less than 3.0 cm max length. Teeth and osteoderms above those levels are much rarer. It is unclear whether this is due to fluvial sorting or if it indicates a much larger quantity of younger/smaller animals within the river basin. Given the large sizes of the theropod teeth, the latter may be the case. Only a few teeth and osteoderms reach lengths of very large crocodiles, including one of the largest scutes I have ever seen in the Hell Creek (See Figure 28) and a few teeth that exceed 3 cm in length. Some of these larger teeth show strong longitudinal grooves and curvature similar to described specimens of *Thoracosaurus*.

Limb elements, vertebrae and skull bones are also found frequently. These too are from smaller individuals (also see Figure 28). Posterior portions of the cranium dominate, including parietals, squamosals, and post-orbitals. This material has not been identified to genus to date.

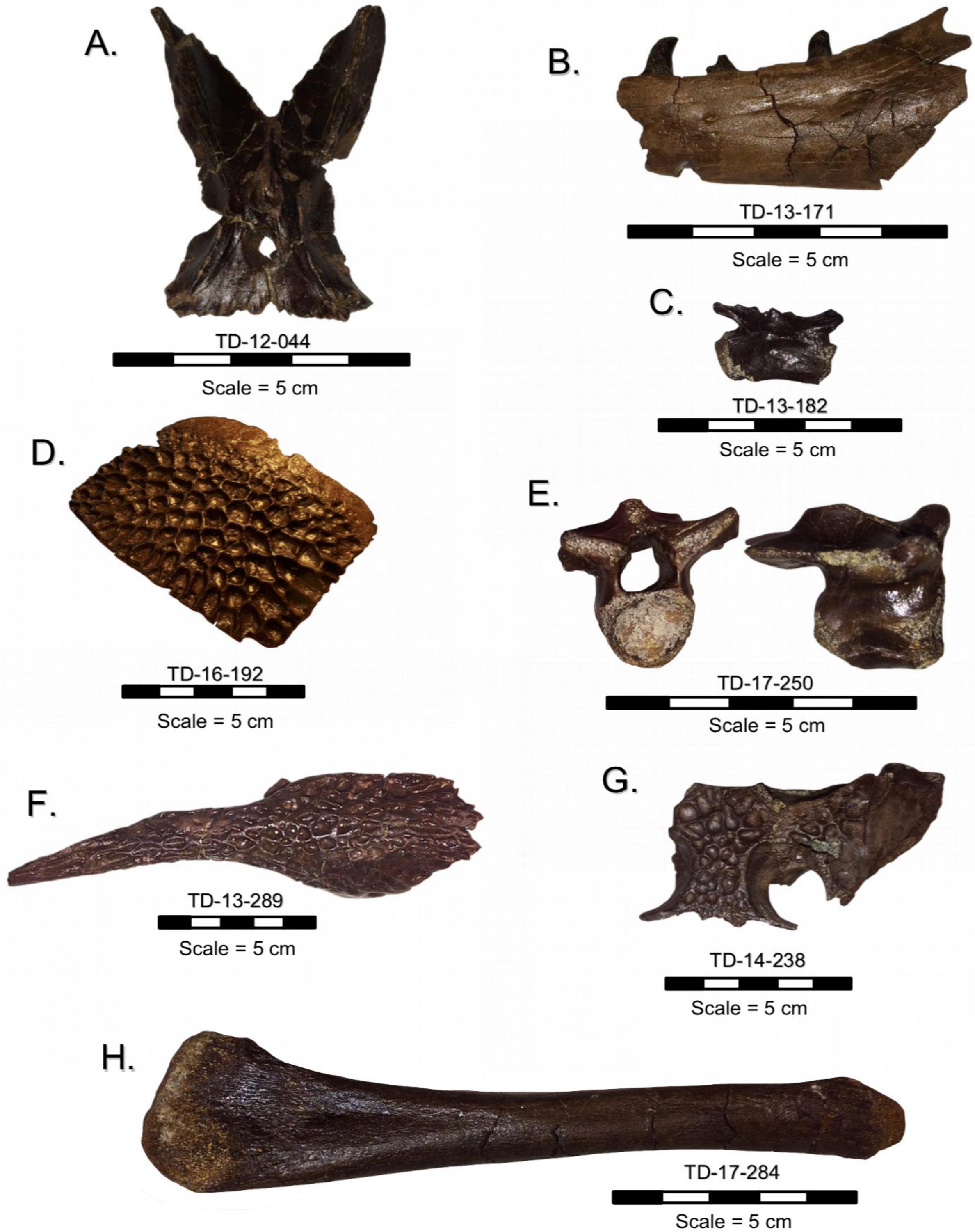


Figure 28- Lizards and Crocodillians. A) fused parietals of the varanid lizard *Paleosaniwa* in dorsal view. B) Left dentary of *Cemetarius* in lateral view. C) Caudal vertebrae unknown. D) Large *Thoracosaurus* or *Borealosuchus* scute. E) Crocodile vertebra. F) Crocodile postorbital. G. Parietal crocolilian (*Brachychampsa*?) H) Tibia of *Champsosaurus*.

CLASS REPTILIA
ORDER TESTUDINATA

Turtles were a major component of the Hell Creek ecosystem and their isolated shells, cranial, axial and appendicular elements are found in great abundance at many sites (see Triebold, 1997; Pearson et. al., 2002; Brinkman, 2005; Joyce and Lyson, 2011 and 2015; Holroyd et. al., 2014; Joyce et. al., 2019; Lyson et. al., 2019). They have a diverse fauna, with over 24 genera considered valid by most authors (Holroyd et. al., 2014; Joyce et. al., 2019). Turtle shell fragments, in particular, are frequently encountered at just about every Hell Creek bone bed or microsite I have ever worked. The Tooth Draw Deposit, is no exception, with an abundance of material that has yet to be completely prepared, analyzed or counted. Officially, there are 215 logged turtle specimens in the collection from the main Tooth Draw Quarry, but the actual number recovered is considerably higher. Turtle material is one of the most frequently encountered vertebrate remains in the deposit.

Despite the high number of turtle specimens, identification of elements to genus is often difficult and work preparing and sorting the collection is still ongoing. At present, the collection is dominated by three major types of turtles. These include trionychtids (*Axestemys*, *Aspideretoides*, *Apalone sp.*, and *Gilmoremys*), baenids (*Peckemy*s, *Saxochelys*, *Neurankylus* and others), and nanhsiungcheyids (*Basilemys*) (Figures 29-31). Large, disarticulated *Axestemys infernalis* (personal communication Tyler Lyson, 2020) shell sections are very common throughout, but concentrated in the C and D horizons. Disarticulated elements, marginals, and costals of the large, tortoise-like *Basilemys* are also surprisingly common throughout all horizons and sites. While no complete skeletons have been recovered, isolated turtle elements, humeri, scapula-coracoids, femurs, and pelvic elements are frequently found. So far, three, mostly complete skulls have also been recovered. Two of these (TD-17-063/TD-12-290) have been identified as *Saxochelys gilberti* (Personal communication Tyler Lyson, 2020; Lyson et. al., 2019) and one as *Peckemys brinkmani* (TMP 2015.005.0020).

Several other groups of turtles also appear to be present, but their numbers are fewer. These include the snapping turtles (Chelydridae- *Tullochelys* ?) and cryptodiran turtles (Adocidae- *Adocus*). Most of these specimens are highly fragmentary and identified mostly from shell morphology and sculpturing. As more work continues on the turtle portion of the collection it is expected that other genera will be identified.

Large turtle shell sections from the D horizon, are often lying on their sides or at canted angles, instead of flat-lying. Their disarticulated nature and chaotic orientations suggest that deposition of the D horizon was swift, turbulent and sudden. Specimens within the D horizon are generally in good condition with little abrasion, whereas specimens in the A and C horizons often show a considerable amount of stream abrasion and pre-depositional breakage. Some even show the same insect borings exhibited in many of the *Edmontosaurus*

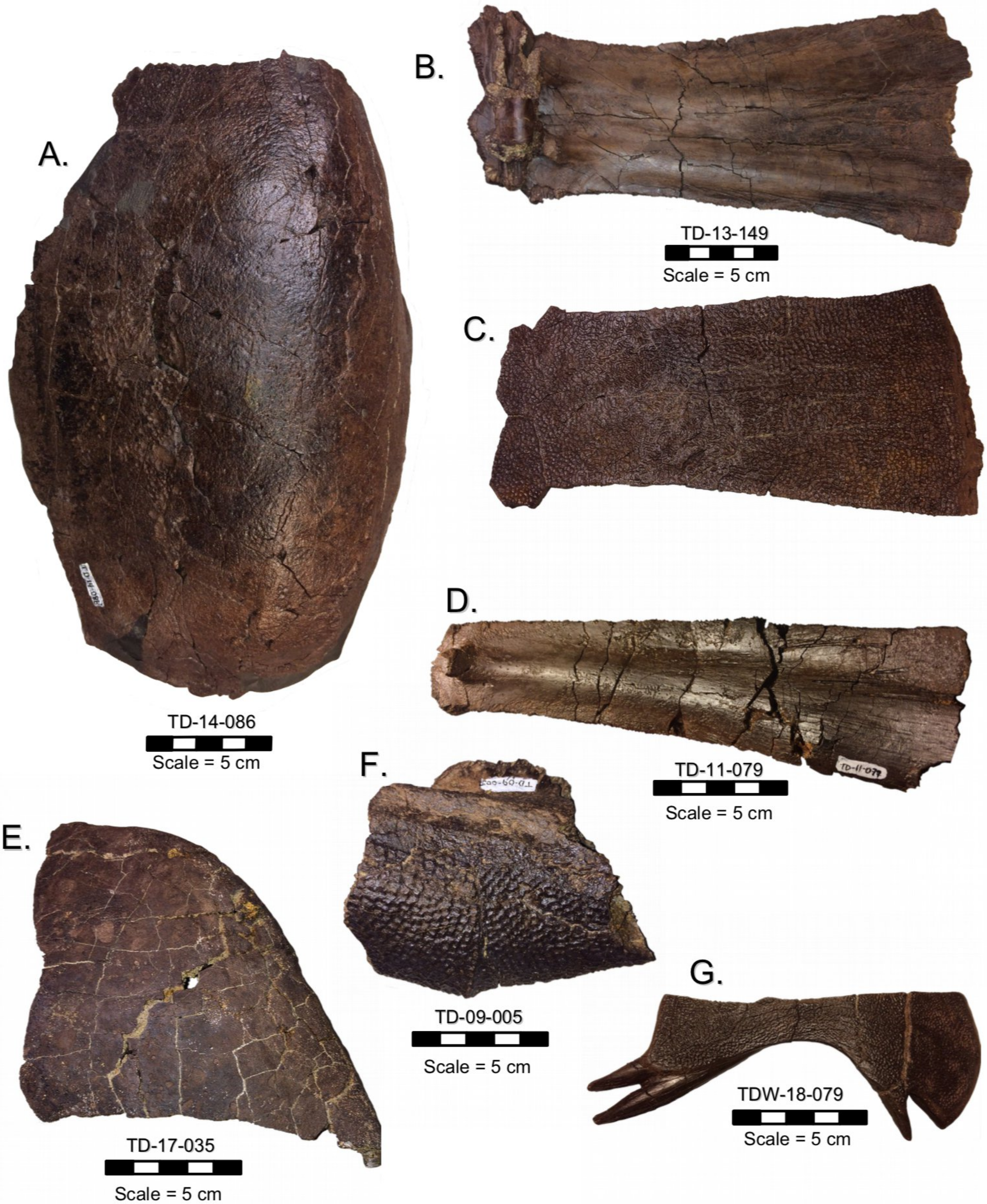


Figure 29- Turtle Shell. One of the most common vertebrate fossils recovered in the TDD are fragments of turtle shell. There are some 28 genera of turtle that can be found in the Hell Creek, with at least 12 confirmed, and likely more in the TDD. Work on turtles is still ongoing and will eventually be a paper in itself. A) Baenid turtle carapacel, *Neurankylus*. B,C,D) *Axestemys infernalis* costals in ventral, dorsal and ventral views. E) Baenid turtle shell. F) *Basilemys* marginal. G). *Gilmoremys* plastum.

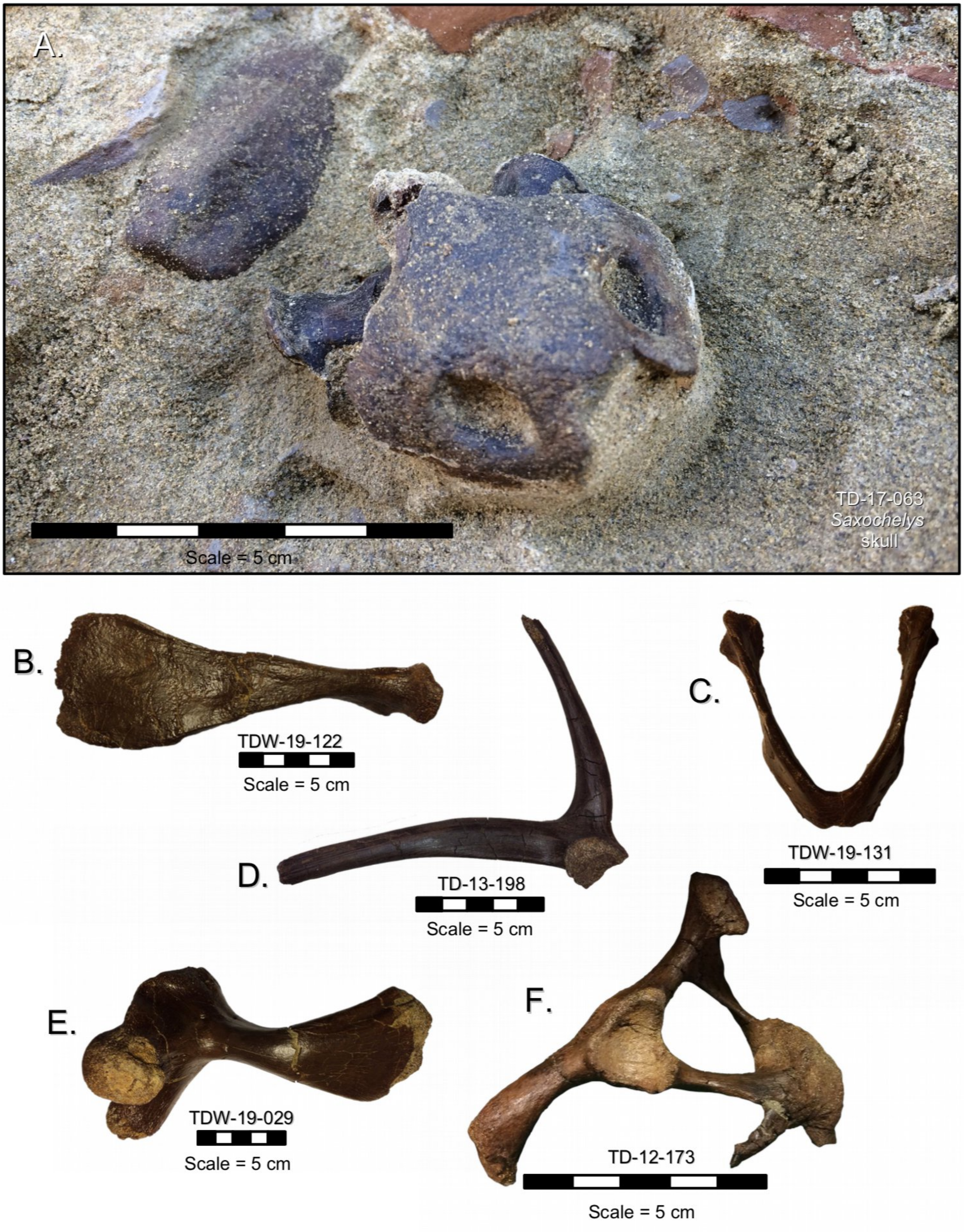


Figure 30- Turtles #2. A) Field photograph of Saxochelys skull. B) Trionictid turtle scapula. C) Axestemys infernalis lower jaw. D) Coracoid, unknown. E) Basilemys humerus. F) Pelvic girdle Basilemys.

Figure 31- Turtle Skull. A few, complete turtle skulls have been recovered from the quarry to date, with likely more to come. This is the skull of Saxochelys in A) dorsal, and B) ventral views (personal communication Tyler Lyson, 2020)

and *Triceratops* bones found in the deposit, suggesting that many of the turtle fossils in the upper A, B, and C layers were also subaerially exposed for a long period of time prior to washing into the river system.

CLASS REPTILIA
ORDER PTEROSAURIA
SUBORDER PTERODACTYLOIDEA
FAMILY ORNITHOCHERIDAE
GENUS *Indet.*

Pterosaur bones are hollow, thin-walled and extremely fragile. As a result, they are very rarely found in the Hell Creek Formation. Despite this, a few isolated fragments and elements have been reported by other authors (Triebold 1997; Pearson et. al., 2002; Bartlett, 2004; Henderson and Peterson 2006; DePalma 2010) and one partial, undescribed skeleton has been found (Personal communication Robert Depalma 2010; 2020). These finds indicate the presence of at least one large Azhdarchid (Henderson and Peterson, 2006) and one Pteranodontid (Personal communication Robert DePalma, 2010/2020) in the Hell Creek. It is likely that there were more. A few partial pterosaur wing phalanges have also been recovered from the Tooth Draw Quarry, but they are not complete enough for generic identification. Pterosaurs were probably a very significant member of the ecosystem, they simply were too delicate for preservation in the turbulent rivers of the Hell Creek ecosystem.

CLASS AVES
SUBCLASS Indet.

Bird fossils are also very rare in the Hell Creek Formation. Only a handful of isolated, partial elements recovered from the Tooth Draw Quarry can clearly be placed in Aves. One in particular, is the anterior ¼ of an unidentified aves femur. This specimen is hollow and crushed, but has a complete femoral head. It measures 3.6 cm long to the break and 0.9 cm maximum width at the shaft. The femoral head is well defined, deep and bulbous. Further work is necessary to identify this specimen to family and genus.

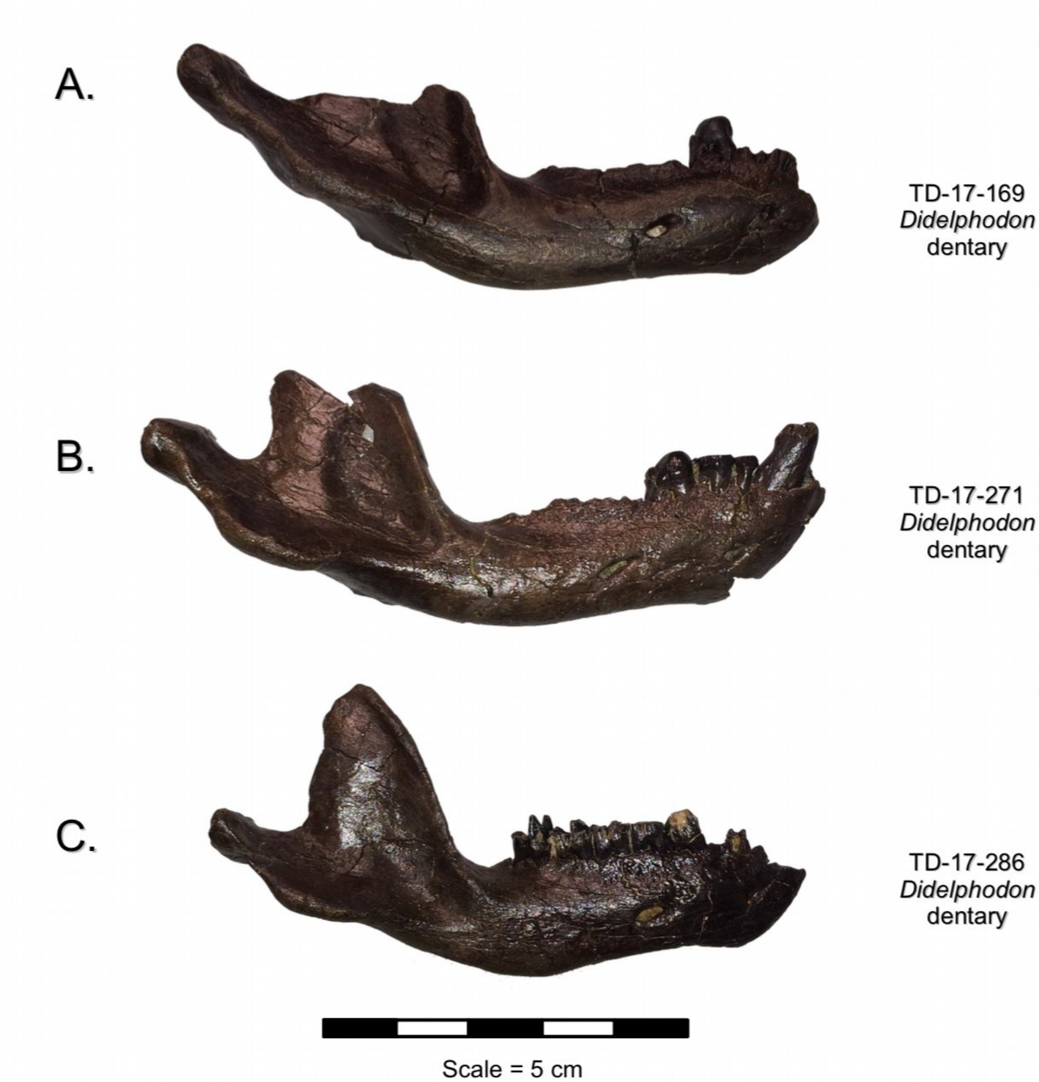


Figure 32- Didelphodon. Mammal teeth and partial jaws are encountered in the quarry on a routine basis. Some of these, from the D horizon are the largest and best preserved in the Hell Creek. The image above shows three different *Didelphodon* jaws all from the D horizon.

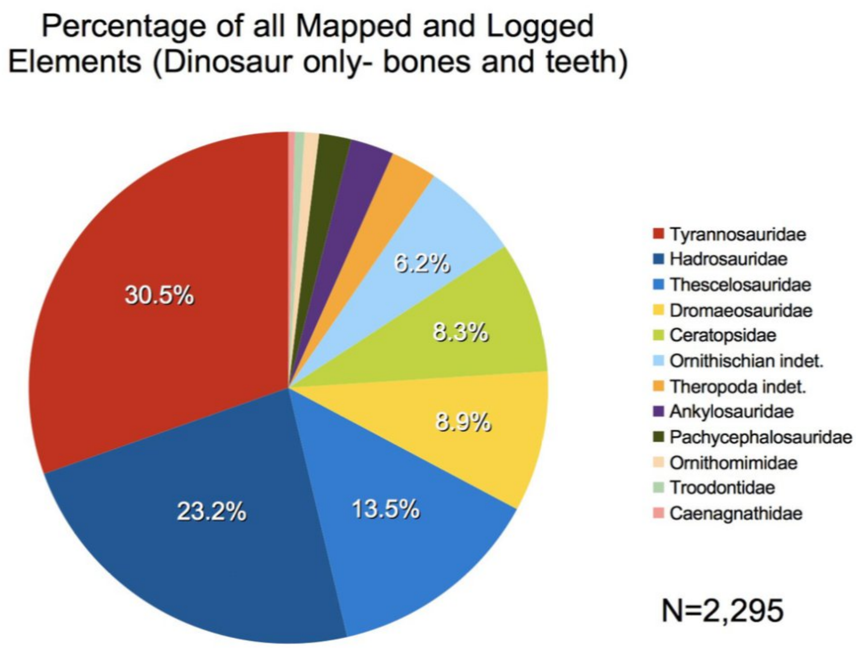
CLASS MAMMALIA
SUBCLASS METATHERIA
ORDER MARSUPIALIA
FAMILY DIDELPHIDAE
GENUS *Didelphodon*
SPECIES Didelphodon

Several mammal fossils, particularly isolated teeth and jaw bones, have also been recovered from the Tooth Draw Deposit. The most common mammal remains found in the Tooth Draw Quarry are mandibles and teeth of the Stagodont marsupial Didelphodon (Figure 32). Didelphodon mandibles tend to be larger than average Hell Creek specimens and in good condition with little to no stream abrasion. The better than average preservation suggests a localized community. Additional mammalian genera, identified by teeth have also been recovered, but little work has been done on them to date.

TAPHONOMY

Site Census:

Several thousand vertebrate specimens have been collected from the Tooth Draw Deposit, but this analysis will only focus on mostly complete, identifiable bones and teeth, collected from the Tooth Draw Quarry from 2006-2019 (Appendix A; Table 1 and 2). The total number of logged and mapped specimens from this sample is: N=2,835. With an NISP (for Dinosaurs)= 2,295. Of this, 1,013 specimens, or 44%, were identified as theropod and 1,282, or 56%, were identified as ornithischian. There is some bias here, however, as several hundred shed *Triceratops* and *Edmontosaurus* teeth, and hundreds of bone fragments were given away and not logged or counted. Despite this bias, there is clearly a larger than normal percentage of theropod teeth in the dataset. Theropod teeth accounted for 39.4% of the entire dataset. Of this, there have been to date, 700 shed tyrannosaurid teeth, comprising 30.5% of all mapped and logged specimens. Dromaeosaurid teeth were also fairly common totaling over 180 specimens, or 8.9% of the collection. Large, complete *Triceratops* teeth on the other hand, totaled only 47 (though smaller spitter teeth were not counted), or 2.1%. Large, mapped *Edmontosaurus* teeth were even less. In most channel lag deposits that I have worked, theropod teeth are not normally found in such high concentrations or percentages.



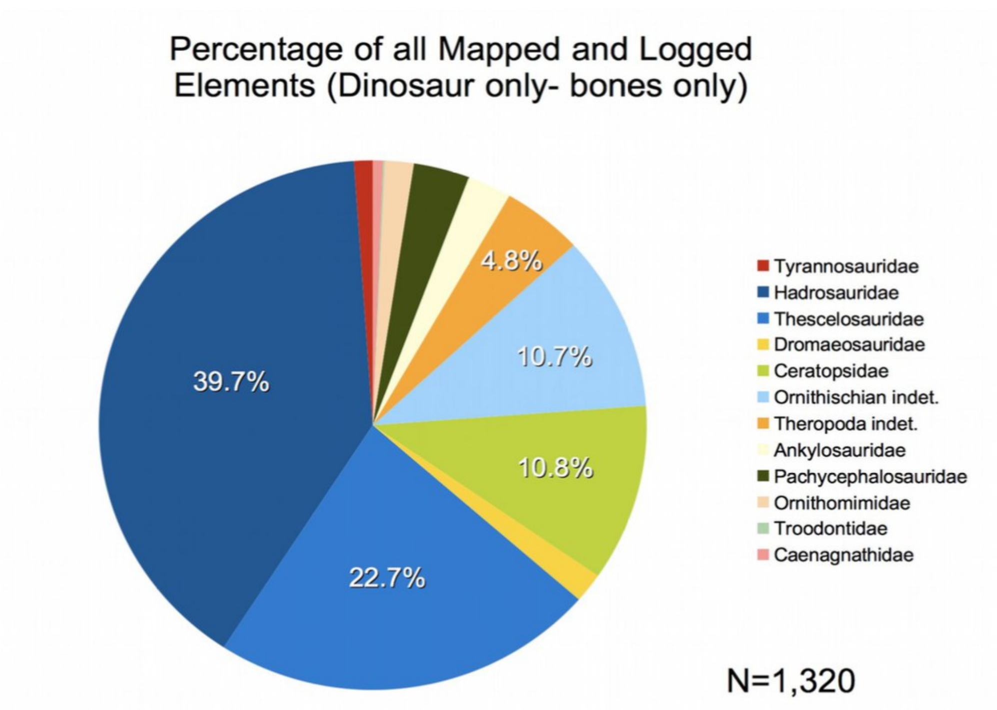


Figure 33-34. Pie charts showing relative percentage of elements by family. Mapped and logged elements show a significantly above average amount of theropod teeth and a ecosystem dominated by *Thescelosaurus* and *Edmontosaurus*.

The next most common genera in the quarry are isolated bones and teeth of Edmontosaurus. Edmontosaurus remains made up about 23.2% of the total dinosaur collection, (Figure 33) which is consistent with percentages of recovered hadrosaur remains in the entire Hell Creek/Lance reported collections (Stein, 2019).

Over 310 specimens were identified as *Thescelosaurus, or 13.5%* of the dinosaur genera, making it one of the most common species in the quarry. These were also much higher than most normal channel lags that I have worked. *Thescelosaurus* is seldom seen in bone beds of the Hell Creek in this number. This is much higher than ceratopsian elements (8.3%) and much higher than pachycephalosaurids, ankylosaurids or nodosaurids. These high numbers, and concentration in the D horizon suggest that this is from more of an autochthonous population.

Removing teeth from the dataset, changes the equation entirely (Figure 34). This reduces the total sample to only N= 1,320, with theropods reduced to only 10.2% of recovered elements. This is likely a much closer representation to the actual population along the river system, further illustrating how much above background the tooth sample is. Both *Edmontosaurus* and *Thescelosaurus* make a large leap to 39.7% and 22.7% of the total collected elements, once teeth are removed, further illustrating the large, above background concentration of these two genera. Ceratopsians round out the top three with about 10.8% of the collected bones. As, no genera's elements exceed the 50% mark, and there have been elements from at least 21 dinosaur genera (and likely more) and over 48 total recovered genera from the quarry, the Tooth Draw Deposit is considered a high diversity, multitaxic bone bed.

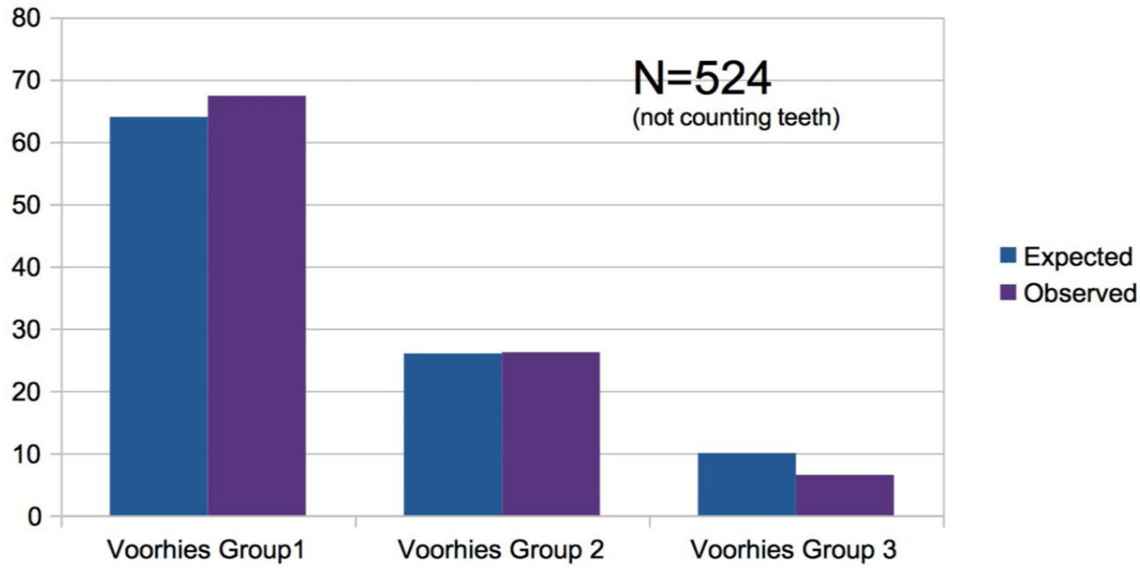
Minimum number of individuals (MNI)

Determining the minimum number of individuals in a multitaxic bone bed, with complete disarticulation of elements and an abundance of shed teeth is difficult, to say the least. It is easy to both over estimate the number and underestimate it. A total of five right humeri, four right scapula, and seven *Thescelosaurus*, right femurs or portions of right femurs have been recovered to date, giving an MNI of 7 for *Thescelosaurus*. There have also been enough femora of different size, ontogeny, and/or strata to give Hadrosaurs an MNI of 7 as well. Given the extent of the bone bed, however, these numbers are likely underestimated.

Skeletal Representation:

A review of the different types of elements represented by the collection and their relative percentages can be found in Table 3. As stated previously, teeth were by and large the most common fossils mapped and

Edmontosaurus



Thescelosaurus

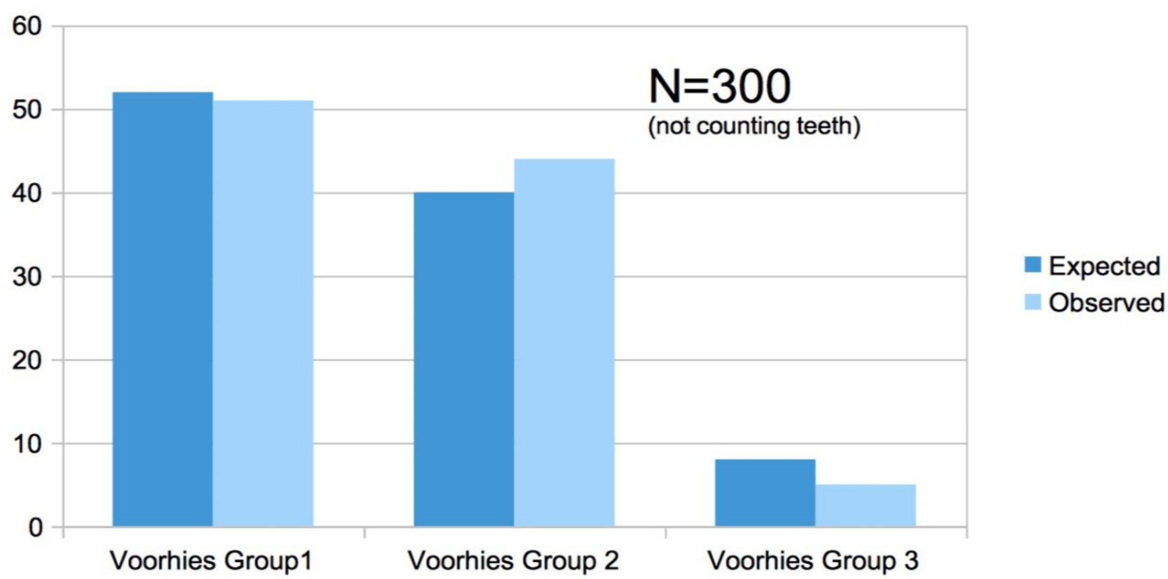


Figure 35-36- Voorhies Group Analysis. A review of all element types, sorted into Voorhies groups, from Group I (most easily transported in a fluvial setting) to Group III (most resistant to transport in a fluvial setting) (See Voorhies, 1969; Behrensmeyer, 1975), produced a graph that matched the percentages of elements in the skeletons of both *Edmontosaurus* and *Thescelosaurus* with only minor variation. This implies that at least these two genera are an autochthonous (local) population whose elements have not been preferentially sorted, winnowed out or lagged behind. The slightly higher percentage of V-I elements for *Edmontosaurus* suggest that some of these were washed in from further upstream.

logged in the quarry, at well over 42.5% of the collection. This is distantly followed by vertebrae and portions of vertebrae such as disarticulated neural arches and isolated centra, which made up 16.1% of the collection. Larger limb bones made up only 5.2% of the total, which would suggest that significant transportation of elements was likely. However, if we remove teeth from the equation, and re-sort elements into Voorhies groups I, II, and III (Voorhies, 1969; Behrensmeyer, 1975; Rogers et. al., 2007; Foster et. al., 2018) we can see a grouping that suggests at least some of the species were likely not transported far from their place of death, ie. they were autochthonous populations.

A total of 776 elements or 58.8% of the collection fell into the lighter and more easily stream transported, Voorhies Group I elements. At first glance, this may seem like a high percentage, but given the large number of vertebrae and ribs in the average dinosaur skeleton it is actually expected. 383 elements or 29.1% fell into Voorhies Group II and 161 elements or 12.2% fell into the less likely to be removed Voorhies Group III. Since group III was not terribly high it suggests there was not much winnowing out of elements and since group I did not overwhelmingly dominate, it suggests the deposit is not that far from its point of origin.

A Voorhies analysis was also done on both *Edmontosaurus* and *Thescelosaurus* elements recovered from the quarry (See figures 35-36). These both showed a normal distribution of elements into all three Voorhies groups. Thescelosaurus was spot on for group I with slighterly higher than expected group II and slightly lower group III. This indicates that the Thescelosaurus elements are from a local source with little transportation, stream sorting or winnowing. *Edmontosaurus* elements showed a slightly higher than expected percentage of lighter weight Voorhies 1 elements suggesting that some lengthy stream transport and winnowing may have occurred, but Group 2 was spot on and group three was only slightly less than expected.

Ceratopsians and Pachycephalosaurs, on the other hand, consisted primarily of partial skull fragments with much smaller amounts and percentages of group I, II and even group III elements. In fact, only a few limb bones and very few manus and pes bones have been recovered to date. This suggests that most ceratopsian and pachycephalosaur parts likely washed in from far upstream.

Ontogenic Representation:

An estimation of maturity, based upon relative size, was conducted on 514 elements in the PARC collections. All life stages are represented in the collection, from neonates fresh out of the egg to mature individuals of above average size (Figure 37). Elements of *Thescelosaurus*, *Edmontosaurus* and *Triceratops* have all been found which suggest neonate or at least very young individuals were present. Their preservation suggests that this was a local population and upon time of death, these genera were not merely migrating

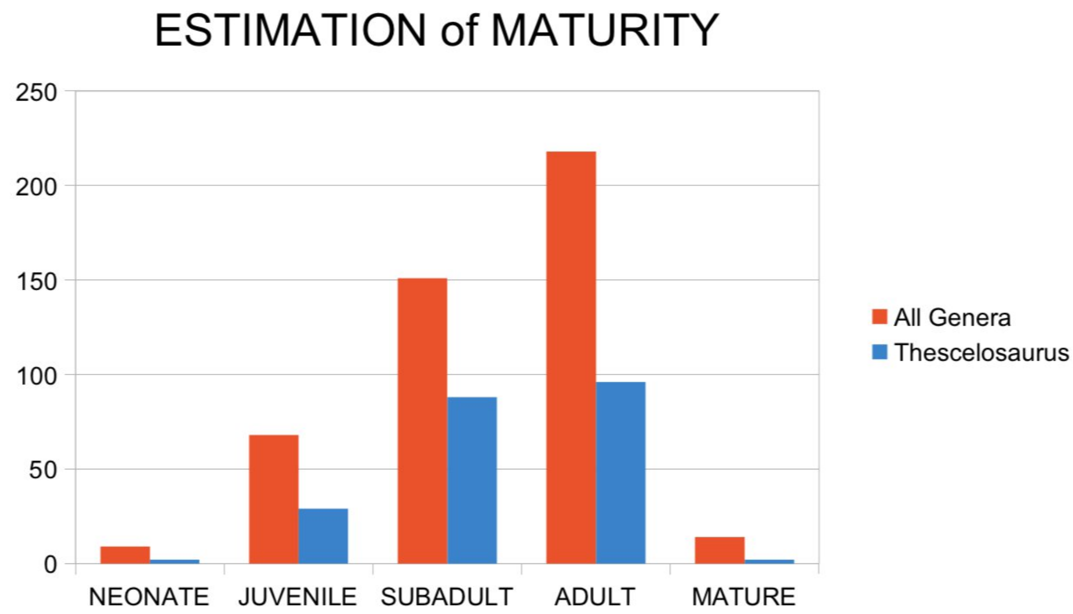


Figure 37- Age Distribution of Elements. A detailed taphonomic review of 514 elements in the collection showed elements from all life stages, with adults and sub-adults being the most commonly found elements.

through. Based upon the wide diversity of teeth and tooth sizes, the same can be said for the tyrannosaurs. As expected, the analysis produced a normal bell curve distribution, with adult sized elements being the most commonly found and mature and neonate elements at the lower ends of the curve. While the large amount of "lower than average size", "sub-adults" in the collection (particularly with *Thescelosaurus*) might indicate a more catastrophic demise for some individuals, there may be other reasons for the this discrepancy, including: size variation due to sexual dimorphism, species or individual variation or some reason due to the local habitat.

Distribution of Elements:

All major elements, fragments and teeth greater than 5 cm. were mapped in the field and later digitized (see Figures 38-39). No two bones or teeth were ever found in true articulated positions. On rare occasions, however, similar elements (particularly vertebrae, ribs, manus or pes elements), from similarly sized individuals were found with possible, loose association along the same bedding plane/horizon. This suggests that some of the elements are likely from the same individuals and from a more local, autochthonous population. This was particularly true with *Thescelosaurus* elements, which were often found scattered, but associated on the D horizon. In some instances, along the C and D horizon particularly, elements were found clustered around some

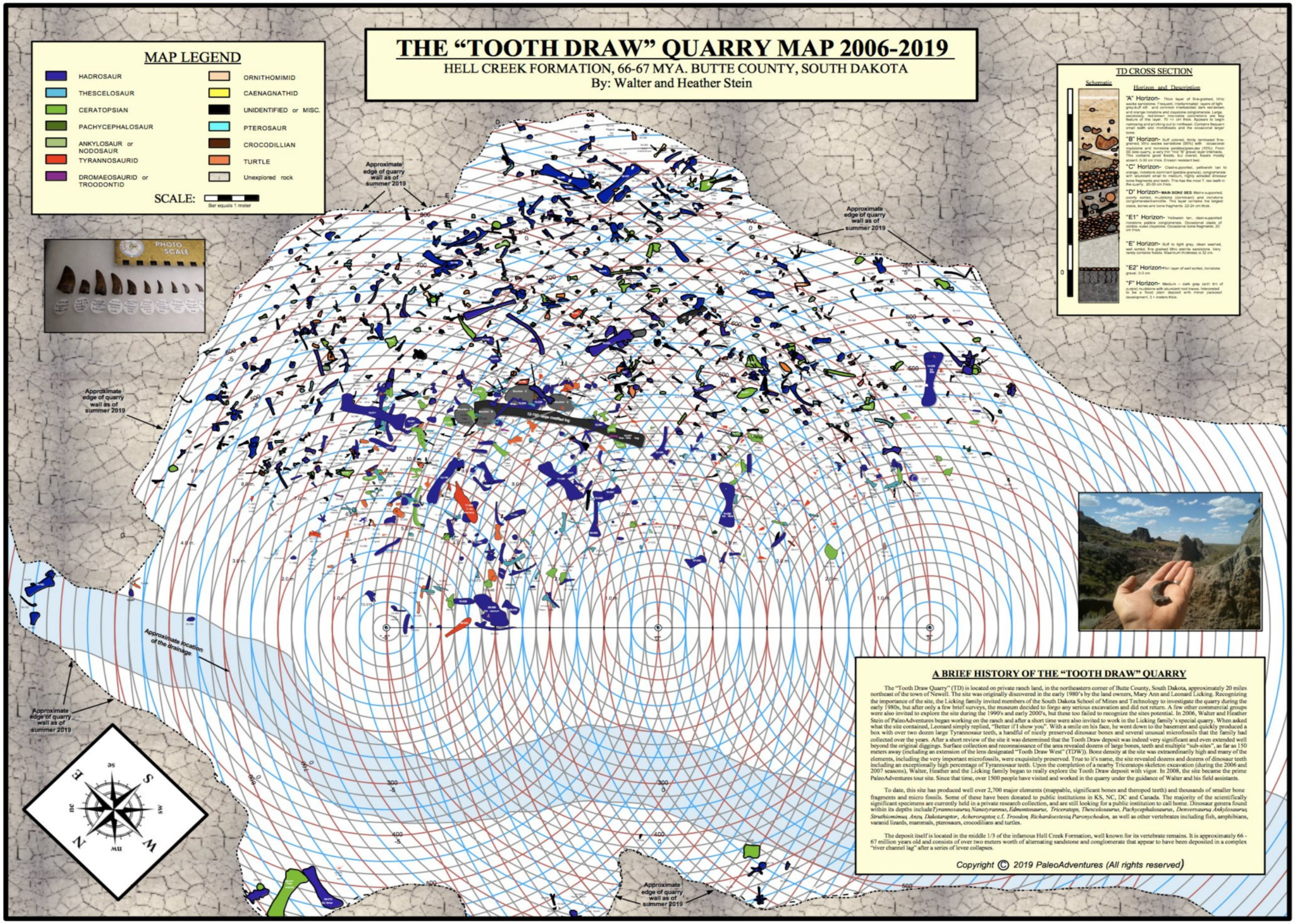
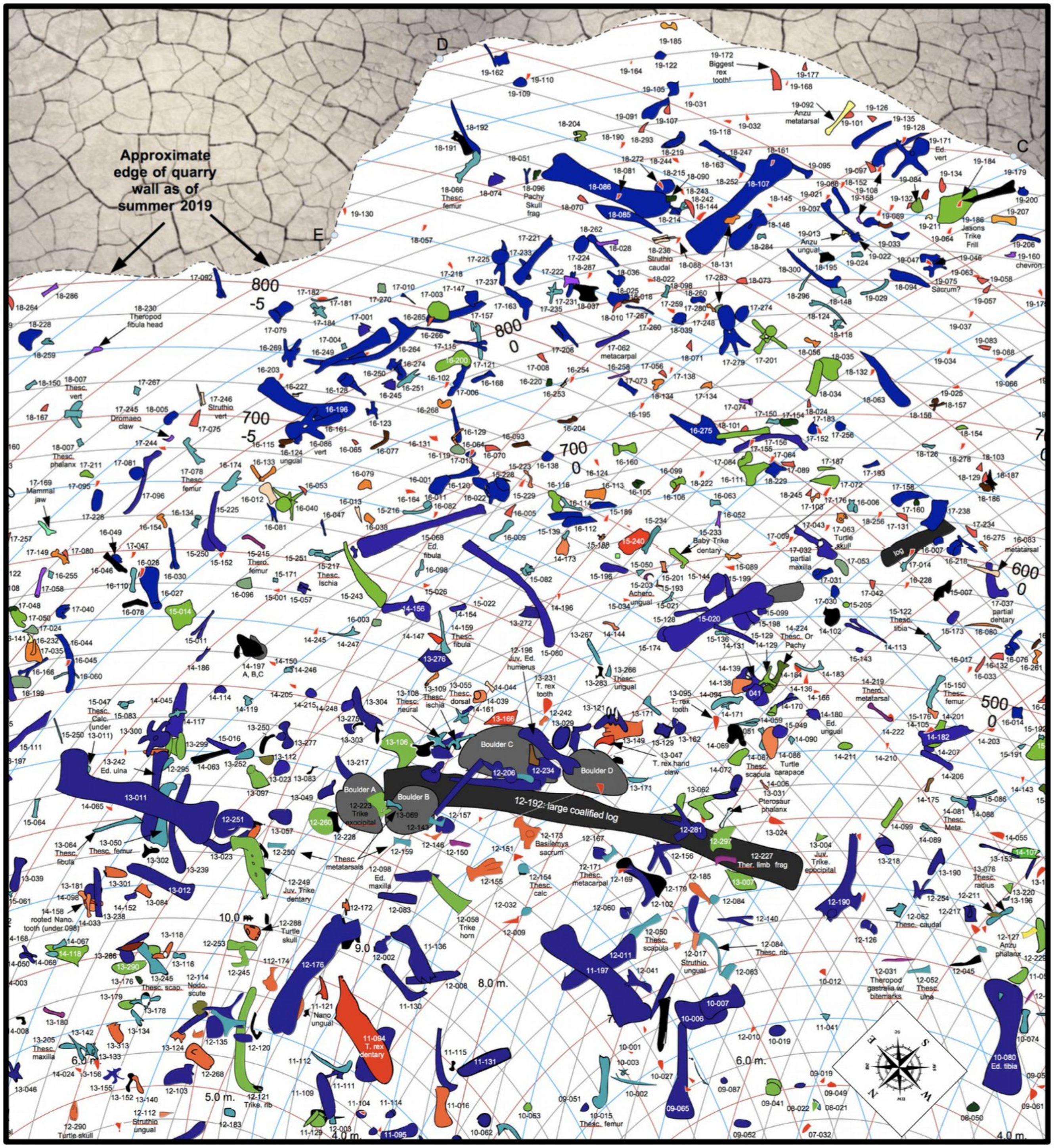


Figure 38- Tooth Draw Quarry Map. Thousands of bones and teeth have been recovered from our quarries since we began in 2006. All elements greater than 5 cm in length or important microfossils were logged in our annual field book and mapped for future reference. Specimens were mapped using the radial-arc technique and later digitized in Apache Open Office. The map is color coded by genera and is available as a pdf for any researchers upon request.



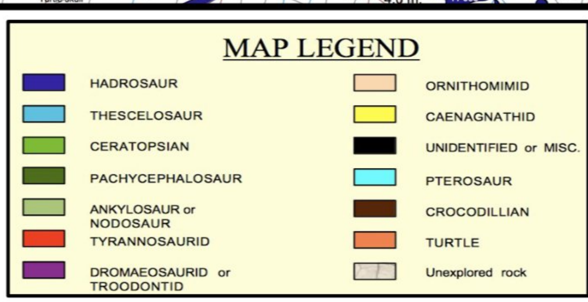


Figure 39- Close-up Tooth Draw Quarry Map. The above graphic shows a detailed, zoomed-in portion of the larger quarry map. To date, no articulated elements have been found in the quarry, however, some of the *Thescelosaurus* bones from the D horizon are in close association. This suggests that there are likely several disarticulated, but recoverable individuals present. The conditions, orientations and dispersal within the strata also suggest that some of those individuals are from a more local community and others are from much farther upstream.

of the larger mudstone boulders and carbonized fossil wood impressions. These "log jams" of boulders and plant remains appear to have trapped some elements while acting as a barrier around which others flowed.

Bone fragments with angular breaks and bone pebbles with well rounded edges were also found in every strata of the Tooth Draw Quarry. These were particularly plentiful in the C and D horizons. It is likely that some of this material is from a feeding site only a short distance upstream while others may have been transported from many miles away.

Preferred Orientations:

While the geology and bone imbrications suggest a general southeastern flow, an analysis of preferred bone orientations for 582 long bones greater than 10 cm in size, plotted on a rose diagram, produced an average eastward (northeastly to southeasterly) flow direction (Figure 40). Elements in the D horizon, however, often showed chaotic orientations with extreme dips/plunges in a random fashion. This was not seen in any other horizon. This implies a more rapid and turbulent flow rate for the D horizon, but a more stable, calmer flow rate for the A, B, C and E horizons.

Vertical Distribution:

While elements, fragments and teeth have been found in all horizons of the Tooth Draw Quarry, vertical distribution is by no means uniform (see section on geology). The largest elements and teeth were typically found in the D horizon or along the C/D contact. The lower part of the D, known as the D/E contact, contained some of the smallest, most interesting and better preserved elements, whereas the C contained an abundance of better sorted teeth and bones with clear fluvial transport. The A was a hodgepodge of sporadic bones, often with an abundance of abrasion, and only the occasional tooth. The A horizon is more typical of most of the Hell Creek channel lag deposits that I've worked.

In order to better refine the observations, A subset of 826 bones and teeth collected from 2016-2019 were sorted based on the horizon where they were found. Of the 474 bones collected during this timeframe, 338 or 71% were collected from the D horizon. *Edmontosaurus* and *Thescelosaurus* elements dominated the D horizon with at least 74% of all *Thescelosaurus* bones and 82% of all Edmontosaurus bones found in the D. By comparison, only 2 *Thescelosaurus* elements and 3 *Edmontosaurus* elements were found in the A during that 4 year sample.

Tyrannosaur teeth were found in all horizons of the deposit, including large numbers in the C and D layers. 40% of all recovered teeth came from the D and 40% came from the C. Tyrannosaur teeth recovered

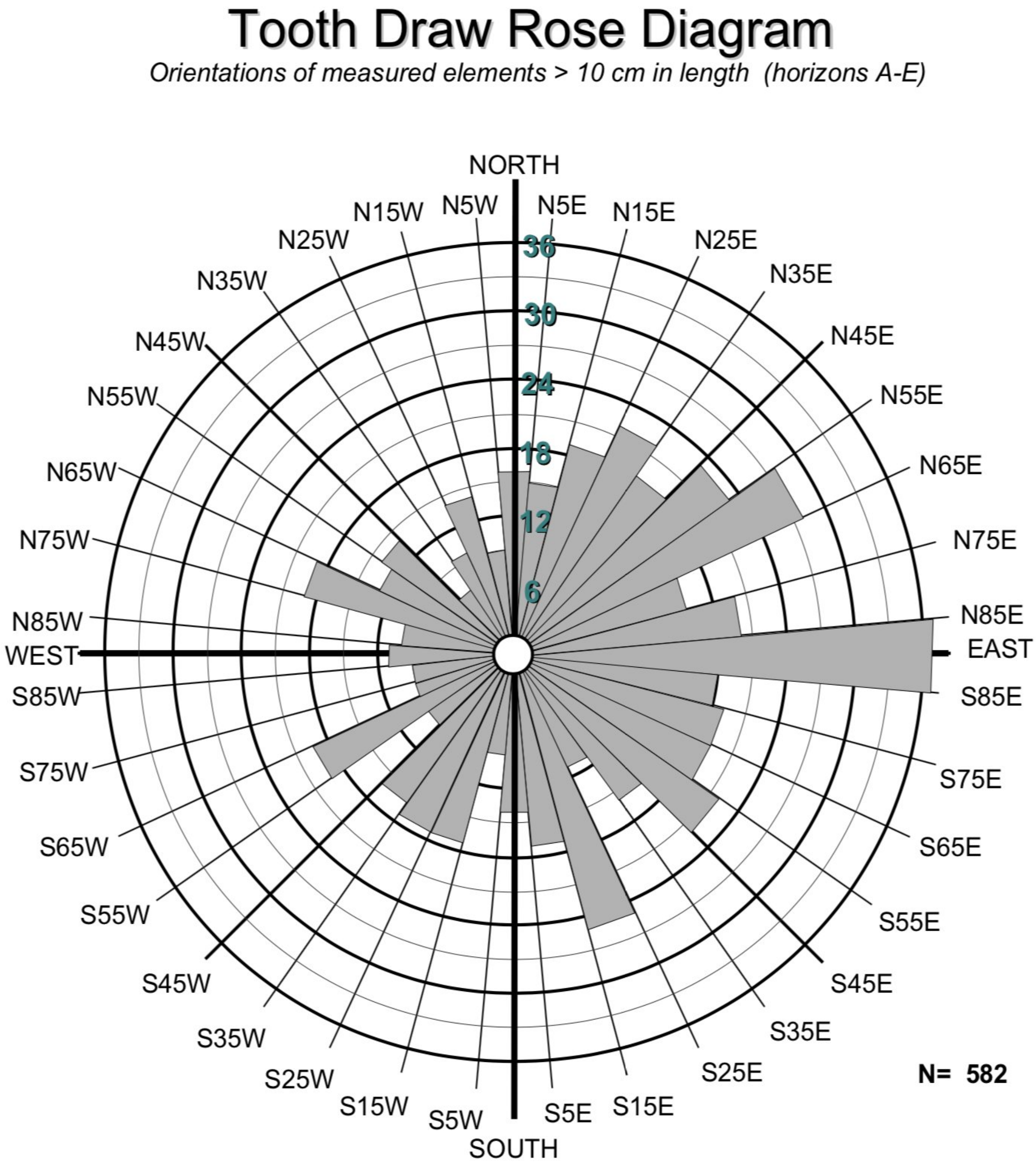


Figure 40- Rose Diagram. A review of 582 mappable elements with lengths greater than 10 cm were compiled into a rose diagram to determine if there was any preferred orientation to the bones distribution. The geology and imbrication of elements suggests a general flow direction varying from northeast to southeast. Elements along the D horizon, however, were often more chaotic with elements sometimes dipping in every direction. This implies a rapid, turbulent flow in an easterly direction.

from the D horizon included both the largest and smallest teeth in the deposit, implying the feeding behavior was exhibited by all age groups and over an extended period of time. Teeth in the C horizon appeared to be sorted by size (or density), as most teeth from this layer were about the same size as the surrounding clasts of ironstone. Another larger cluster of Tyrannosaur teeth was found within the E horizon, but these consisted solely of those identified as *Nanotyrannus* (20 specimens). The significance of this, if any, is unclear at this time.

Condition and Modification of Elements:

Elements recovered from the Tooth Draw Quarry frequently exhibited a variety of post mortem modifications. Bite marks, gnaw marks, pitting, scratches, corrosion, abrasion and both pre-depositional breakage and pre-depositional weathering are often discovered in the field and during preparation. In order to understand the timing and extent of this modification a subset of 514 bones from the PARC collection was reviewed in 2019-2020.

Breakage

Approximately 56% of all elements studied showed some degree of pre-depositional breakage. Limb bones were frequently found missing ends, ribs were missing shafts or heads, vertebrae were frequently found disarticulated, missing centra, neural arches, or transverse processes. Angular fragments and well rounded bone pebbles were commonly found and particularly plentiful in the C and D horizons. This breakage was predominately found on *Edmontosaurus* and *Triceratops* bones, but *Thescelosaurus* was also not spared, to a lesser extent.

Several different types of bone breakages were identified, sometimes on opposite ends of the same element. These included helical (spiral) fractures, oblique and oblique irregular fractures, transverse and transverse irregular fractures, longitudinal fractures, sawtoothed fractures and even rare impact fractures. Oblique irregular fractures were the most common, found on 73% of the bone with pre-depositional breakage. Transverse and transverse irregular fractures were found on 17% of all bones with pre-depositional damage. These were usually found on spines, transverse processes or ribs. Helical (spiral) fractures were found on 15% of all bones with some form of pre-depositional breakage, usually on limb elements. Sawtoothed breaks (6%) and columnar breaks (3%) were sometimes found as well. The oblique, spiral and sawtoothed breaks indicate that many if not all of these bones were fresh when broken (Lyman, 1984; Bonnichsen, 1979; Britt et. al., 2009). The oblique irregular and spiral breaks indicate twisting or torsional stresses. These are pre-depositional modifications that could not possibly arise from simple weathering and stream transport.

Tooth Marks

Of the 514 bones closely observed in this study 9.3% showed bite marks or suspected bite marks (Figure 41 and 42). These marks were often near pre-depositional breakages and likely directly related to them. Bite marks came in several different configurations including impact and drag, scrape or grazing cuts (showing scratches from serrated edges), and "gnawing" or repeated biting in one area. The majority of the most well defined bites are from medium to small carnivores. Clear cut puncture and pull marks from Tyrannosaurs have not been found to date, but gouges of adult T. rex size have been seen and suspected marks along broken edges are sometimes observed. None of the 48 bones with bite marks showed signs of scar tissue or healing. The clearest and deepest of the markings suggests feeding was done by multiple species and size ranges over an extended period of time.

Insect Borings

Borings and gnaw marks from osteophagus insects are also commonly seen on many of the bones recovered from the Tooth Draw Quarry. At least 125 of the 514 bones used in this preliminary study (24%) showed some indication of bio-erosion (Figures 43 and 44). *Edmontosaurus* and *Triceratops* bones show the highest levels of pitting, often with complex clusters and groupings. *Thescelosaurus* elements rarely have these marks, but they do occur from time to time. Small and large theropods were also not immune to this, as both an *Anzu* hand claw and a Tyrannosaurus foot claw were recovered with extensive pitting. These marks suggest that many, if not most of the bones in the quarry, were subaerially exposed for an extended period of time.

Marks such as these are not uncommon in the fossil record and reports of invertebrate feeding traces have been found in other multitaxic bone beds of Jurassic age (see Britt, et. al., 2009; McHugh, 2020). It is currently unclear as to what insect might be causing this damage, but dermestid beetle larvae, which can cause similar pitting in modern bone (personal communication Hasiotis, 2017), are a possible culprit. Borings are generally rounded to sub-rounded in shape and can be found as single pits or as complex clusters. Ribs and limb bones seem to have been particularly targeted, though all different types of elements have been found with them. Additional work on these marks is planned for the future.

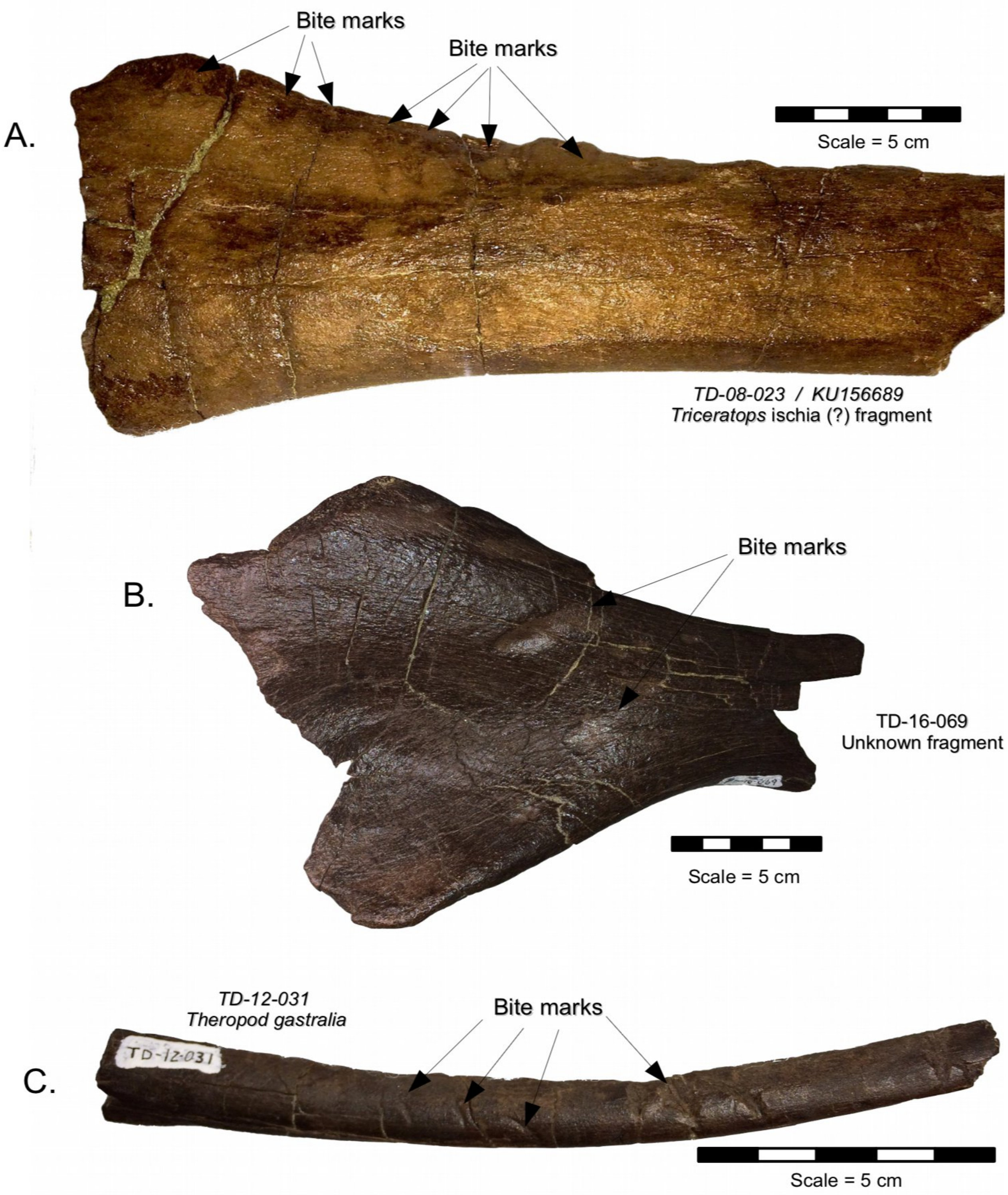


Figure 41- Bite Marks. Approximately 9.3% of the bones examined during the taphonomic study exhibited bites marks of one kind or another. A) Shows a Triceratops ischium(?) fragment with a spiral break and gnaw marks from a mid sized carnivore. B) Shows an unknown large bone fragment with widely spaced gouges likely caused by Tyrannosaurus. C) A partial theropod gastralia with transverse irregular fractures on both ends and bite marks from a small theropod.

Figure 42- Bite Marks and Breakage. A)/B) This figure compares TD-12-249, an unknown ceratopsian left dentary from the Tooth Draw Quarry, with C) JHRY-15-021 an adult *Triceratops* left dentary found on another ranch. The dentary from Tooth Draw exhibits a moderate to heavy degree of weathering, abrasion, oblique irregular breakage, and multiple bite marks from a mid to large theropod. This demonstrates the high degree of bone modification to many of the elements recovered from the quarry.

Scratch Marks

5.1% of the 514 bones used in the taphonomy study showed light, but distinct parallel scratch marks. These scratch marks were typically found on the shafts of limb bones, occasionally in sets, with some going in one direction and another overprinting in a second direction. In other sites the presence of scratch marks have been used to suggest trampling and extreme bioturbation (Eberth, Rogers and Fiorillo, 2007) and this might be the cause here. However, no footprints, evidence of trampling or dino-turbation has been found at any zone within the TDD to date. So, if these scratches are a result of trampling, this trampling must have occurred at the original site of death upstream from the TD Quarry. If the marks are not caused by trampling activity then another possible cause could be the violent deposition of the debris flow/hyper-concentrated flow itself. According to Eberth, Rogers and Fiorillo, (2007) this is theoretically possible.

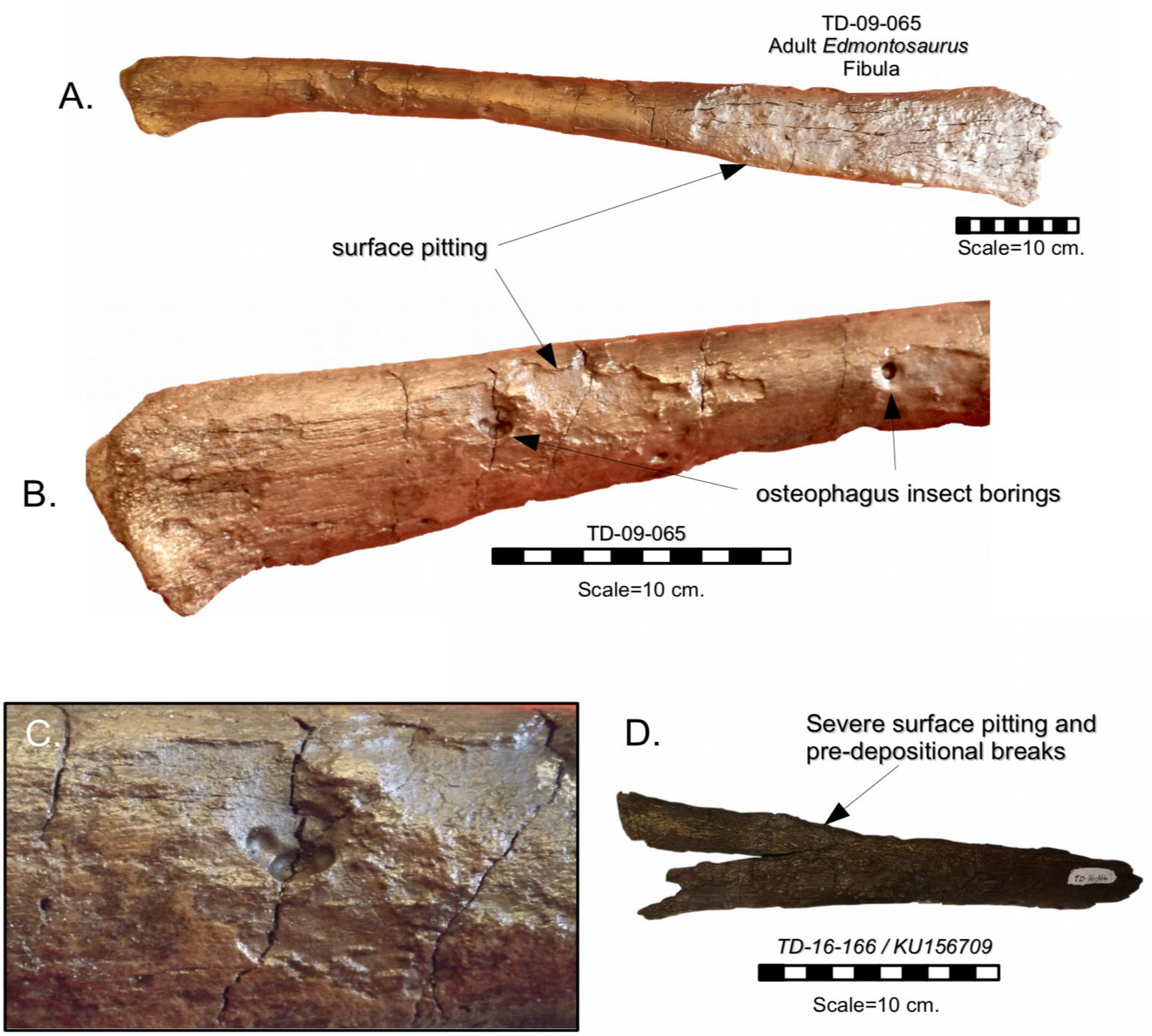


Figure 43- Insect Borings. Gnaw marks, borings and etchings likely caused by osteophagus insects (possibly dermestid beetles) are commonly found on many of the elements discovered in the Tooth Draw Quarry. These marks show up very frequently on Edmontosaurus bones indicating that the elements were sub-aerially exposed for a significant amount of time prior to subsequent deposition and burial. A) Adult *Edmontosaurus* Fibula with gnaw marks and borings. B) Close up of distal end of A. C) Extreme close up of etching and boring on distal end. D) A severely pitted *Edmontosaurus* chevron bone.

Weathering, Abrasion and Corrosion:

Pre-depositional weathering of elements seems to have been a major factor in the condition of much of our sub sample. Of the 514 bones closely looked at, at least 275 (53.5%) of them exhibited at least "weathering stage 1" , indicating 0-3 years of subaerial exposure prior to burial (see Behrensmeyer, 1978; Shipman 1981; Eberth, Rogers and Fiorillo, 2007). At least 36 of the elements (7%) exhibited signs (cracking, splitting, spalling) of "weathering stage 2", indicating approximately 2-6 years of subaerial exposure prior to burial. Only a few exhibited signs of extended exposure beyond stage 2.

Many elements, however, exhibited no evidence of weathering. These were typically, the better preserved *Thescelosaurus* and more complete small theropod elements. This suggests that some of the animals that died and were buried in the deposit, were buried quickly and likely from a more autochthonous (local) community. Others may have been sitting out on the floodplain for an extended period of time.

The vast majority of elements did show at least some signs of abrasion indicating loss of tissue and stream transport prior to burial. Many elements showed rounded and abraded ends with loss of some softer bone structures. Much of that abrasion was considered light, but at least 150 bones (29%) exhibited signs of moderate abrasion and 17 (3%) exhibited signs of heavy abrasion (modified from Shipman, 1981). All of this indicates that most of the elements have traveled some distance from the original site of death and some have travelled a considerable distance. This means that there is an overprint of a more distant community on top of the more local one (Parautochthonous deposit).

Corrosion or bone loss, due to acidity of habitat, burial sediment, surface or ground water, or as a result of ingestion and predatory activity is another bone modification that should be noted in the sample. Unfortunately, this type of modification is very difficult to differentiate from weathering and abrasion which can mimic it and/or certainly obscure it. (Eberth, Rogers and Fiorillo, 2007). It is possible that some of the moderate to heavy abrasion and bone loss is a result of corrosive activities and given the high degree of broken bones and bone pebbles some of this might be a result of feeding and ingestion. At least some of the Tyrannosaur teeth found in the quarry have corroded surfaces particularly along the margin between the base of the cusp and that of the upper root. Others show dentine loss in patches where enamel has been removed by corrosive processes. These teeth have been interpreted as passing through the gut of Tyrannosaurs and being etched by stomach acids as the animals were feeding. If this has happened, then many of the broken and etched fragments of bone in the quarry may also have undergone a similar process. Additional work is necessary to confirm or deny this hypothesis.

DISCUSSION:

At first glance the Tooth Draw Deposit looks like a number of standard channel lags in the Hell Creek Formation. This is likely why so many workers decided to forgo any serious excavation efforts. Once dissected and intensely excavated, however, the deposit shows a very unique and complex depositional setting and a very diverse and interesting faunal assemblage. This assemblage of bones and teeth show a variety of bone modifications that aid in the interpretation of the site and also adds to its significance.

Depositional Setting

One of the biggest mysteries of the quarry is its depositional setting. The poorly sorted, matrix-supported conglomerate of the D horizon with complete disarticulation and dispersal of both large and small elements suggests something other than standard riverine deposition. The presence of so many matrix supported and well rounded, "mega-clasts" suggests an extremely rapid, turbulent, and sudden flow regime. This is more than just a rapidly flowing river, as such matrix supported, large clast sizes should not be present in what is normally thought of as a lowland forest/floodplain environment, well away from any topographic highlands. While the bottom of the deposit does show an eroded surface, the known architecture of the deposit does not indicate a deeply incised channel bed either, so where did the boulders and cobbles come from and how did they accumulate here?

The first possibility is that the D horizon was laid down in a single event as a debris flow. Debris flows have been suspected in the deposition of several bones beds (Andrews and Alpagut, 1990; Van Itterbeeck et. al., 2005; Rogers, 2005; Eberth et. al., 2006; Lauters et. al., 2008; Britt et. al., 2009; Scherzer and Varricchio, 2010), but none are a perfect match for the observed geology at TDD. While the bone bed geology and taphonomy of the Jurassic Morrison Formation, Dalton Wells Quarry comes close (as described by Eberth, 2006; Britt et. al., 2009) to TDD, and bone bed geology at TDD is compatible with debris flows associated elsewhere (Nemec and Steel, 1984), a number of things at the TDD are inconsistent with a standard debris flow model, including, the lack of any topographic highlands, along with the absence of a muddy matrix. The conglomerate of the D horizon does contain a large amount of fine sands, but almost no mud or silt. The site certainly shows a melange of clasts, bones and woody debris at random angles and sharp dips, suggesting a sudden flow and rapid deposition, but without finer particles that flow was considerably "cleaner" than a standard debris flow, moving en-masse. Bone modifications do not indicate a sudden catastrophic event that captured whole, living animals and trapped them there either. So, if the bed was laid down in a reasonably sudden event, how does this occur without muds and without preserving articulated animals?

The next hypothesis for the formation of the main bone bed is what is known as a "hyper-concentrated flow". Hyper-concentrated flows are "turbulent, two phase, gravity driven, flows of water and sediment, intermediate in suspended-sediment concentration between normal sediment laden streamflow and debris flow or mudflow" (Pierson, 2005). According to Pierson (2005):

> *"Hyper-concentrated flows characteristically have sand concentrations that greatly exceed the fines concentrations". "... If sediment continues to be added to a hyper-concentrated mixture, however, a point is eventually reached whereby sand and gravel grains in the suspension begin to significantly interact with each other and frictional forces between grains hinder selective settling from the fluid*

suspension when the flow slows or stops (Druitt, 1995; Major, 2003). Frictional contact between grains prevents the larger and denser grains from settling faster than the surrounding finer and lighter grains. Consequently, all the grains settle at the same rate and the result is an unsorted, unstratified deposit."

This might explain the lack of lamina/structure, poor sorting and possibly the lack of finer grains. A hyper-concentrated flow, full of sand-sized particles, would be able to pick up and move larger bones, boulders and debris, giving some loose preferred orientation towards the east, but the poorly sorted matrix settled without finer muds and silts which were carried further away. This explains the deposit to some degree, but was the concentration of bed-load and suspended sediment high enough to be considered "hyper-concentrated" (Beverage and Culbertson, 1964; Nemec and Steel, 1984; Pierson, 2005) and is there any other examples in ancient settings we can compare to?

Hyper-concentrated flows have been suspected in the deposition of only a few dinosaur bone beds across the world; as wide ranging as Australia (Seegets-Villiers, 2017) to Alaska (Flaig, Fiorillo and McCarthy, 2014). The hyper-concentrated flow deposits from the Alaskan bonebeds, like the Tooth Draw Deposit were both far from a topographic highland on a distal, coastal floodplain, but markedly different in their bone bed geology. The Tooth Draw deposit shows a basal, poorly sorted conglomerate with no evidence of a mudstone or claystone second phase cap, whereas the Alaskan sites show much finer grained silts and the anticipated finer grained upper mudstone/claystone (Flaig, Fiorillo, and McCarthy, 2014). It is possible that if the TDD represents a hyper-concentrated flow event, that the upper fines were either washed further along or that they were removed during the reworking of the upper D horizon into the better sorted, ironstone dominated "C" horizon as the flow stabilized.

If the amount of debris was large enough to be considered, hyper-concentrated, then what was the triggering mechanism? In order to have such a flow, you normally need a combination of several factors: 1) high topographic relief or some sort of gravity induced flow, 2) High volumes of water under rapid flow, 3) severe soil erosion, and 4) low vegetative ground cover (Xu 1993; Pierson, 2005). All of these factors produce rivers with an exceptionally heavy sediment load (Xu, 1993). According to Nemec and Steel, (1984) debris flows and hyper-concentrated flows are found adjacent to or within alluvial systems on modern coastal plains, so this is possible.

Several hypotheses exist as a trigger mechanism for this type of flow, at the Tooth Draw Deposit. They include: 1) cut bank collapse 2) catastrophic natural levee failure, 3) catastrophic failure of a natural dam or build-up of debris behinds a stream blockage and 4) a catastrophic meander-breach. As stated before, the topographic relief in the lowland forests and distal coastal plain of the Hell Creek Formation was likely not very steep. Cut banks were likely on par with some of the broad river systems of the modern southeast coastal plain (Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina). It is highly unlikely that such large mudstone boulders would have traveled far. They are also petrologically near identical to the underlying “F horizon” mudstone, their likely source. Forrest fires leading to advanced soil erosion, could potentially trigger high sediment volumes and the TDD does show some evidence for large tree and plant matter in the quarry. This material, however, is not extensive nor is it coalified as would be expected in an area devastated by fire. Volcanic ash deposition is also another way that rivers might become clogged or forced to change course, but the absence of any bentonite muds in the deposit itself (other than the mudstone clasts/boulders) does not support this. Major flooding often causes natural blockages within modern river systems which then cause rivers to become diverted or change direction (Kyuka et. al., 2020), but is this enough to create the geologic profile seen at TDD? It is unclear whether any of these processes would result in the creation of a gravity-induced, hyper-concentrated flow on par with what is seen at the Tooth Draw Quarry.

Paleontology and Ecologic Setting

Elements and teeth collected from the Tooth Draw Quarry show a wide range of conditions and taphonomic modifications. These range from nearly pristine, complete elements with no abrasion to well rounded and tumbled bone pebbles showing significant fluvial transport. The lack of any dominant condition implies that elements have vastly different sources and taphonomic histories. *Thescelosaurus* elements, for example, are usually in very good condition with only slight abrasion and weathering. They seldom are found with teeth marks or insect borings. *Edmontosaurus* elements include a mix of very well preserved to very poorly preserved remains suggesting that the *Edmontosaurus* fraction is a mix of both local and distant populations. There is often an inverse relationship between the size of the element and its condition, ie. smaller elements tend to show the least amount of weathering, abrasion and bone modification. Since elements and teeth in the D horizon and especially along the lower D and D/E contact seem to be in the best conditions it is postulated that those are from a more local community with little transport. These include elements of *Thescelosaurus*, *Edmontosaurus*, *Pachycephalosaurus*, young *Triceratops*, *Ornithomimus sp.*, *Nanotyrannus* (teeth), *Acheroraptor* and small unidentified theropods. This assemblage also includes elements of *Didelphodon*, *Basilemys*, and other vertebrates.

Bone breakages, bite marks and the abundance of tyrannosaur teeth in both the D and the C horizons imply that tyrannosaurs were routinely hunting and scavenging along the river system just upstream from the deposit. There are very few sites in the Hell Creek Formation that can match the high numbers of tyrannosaur teeth recovered from this site and this does not appear to be a coincidence (simply as a result of reworking or stream transport). The presence of a high number of oblique irregular, spiral and saw-toothed fractures imply that torsional twisting, ripping and breaking of bones from fresh carcasses was being employed during feeding over the course of several seasons. This type of activity would naturally create a lot of angular bone fragments and this is exactly what we find in both the C and D horizons. Some of this material may have been the result of normal fluvial weathering and transport, some by reworking, some as a result of tumbling during hyper-concentrated flow, but much of this material appears to be directly related to feeding activity.

Many animals utilize bone and bone marrow as a source of additional nutrients and that list included *T. rex*. According to Gignac and Erickson, 2017, T. rex was not only built for such activity, but that there is strong evidence to support osteophagy in tyrannosaurs. Tyrannosaur coprolites have been found with fragments of bone, ingested by either accident or intent (Chin et. al., 1998; Chin et. al., 2003). *Tyrannosaurus* had one of the largest bite forces in the animal kingdom. Estimates of bite force vary considerably (Erickson et. al., 1996; Gignac and Erickson, 2017), but most place it well within ranges that are easily capable of rupturing and fracturing bone (Gignac and Erickson, 2017). At the TDD we see multiple lines of evidence to suggest that this deposit was near a feeding site and that repeated biting of bone (either accidentally or to use bone as an additional food resource) at this site was done. These include: 1) The high amounts of recovered Tyrannosaur teeth, 2) The high presence of bite marks and suspected bite marks, 3) The presence of angular breaks including oblique irregular, transverse irregular, helical and saw-toothed fracture types, 4) The presence of a large amount of worn and/or pre-depositionally broken teeth, 5) The presence of large quantities of angular and sub-angular bone fragments and 6) The presence of corrosion on teeth and possibly bones as a result of stomach acid. Each of these things supports the concept that TDD represents a "displaced" feeding site. It suggests that many of the elements of the C and D horizon were accumulated by two processes: one biotic through feeding and a second through abiotic sedimentary means. This was later overprinted with material that washed in from further along the river drainage.

Since recovered tyrannosaurid teeth are from all sizes, tooth positions, and age ranges, and that a majority of bones show at least stage 1 weathering (and many show stage 2), it suggests that this feeding activity occurred over multiple seasons and by multiple individuals. At this time it is unclear whether this was simply just a fertile hunting ground with abundant game, an area near a mass death of *Edmontosaurus* or if carcasses were brought to the area to feed family units over a long period of time. Given that there has also been some tooth-marked Tyrannosaur bones found in the TDD, some of this activity might have even resulted in *Tyrannosaur* vs. *Tyrannosaur* competition, territorial battles or even cannibalistic feeding. All of these behaviors have been suggested by other authors (Molnar and Farlow, 1990; Molnar, 1991; Tanke and Currie, 1998; personal communication Peter Larson; Stein and Triebold, 2003/2013; Peterson et. al., 2009; Longrich et. al., 2010; Carbonne, 2011; Hone and Tanke, 2015; Dalman and Lucas, 2020 and others).

The large scale of this feeding activity suggests that multiple individuals took part over several seasons. This implies that tyrannosaurs may have been gregarious to some extent or at least cohabited the same area over a short timespan. Several monotaxic bone beds from other rock units, where multiple individual tyrannosaurs have been recovered, have shown that some genera (*Albertosaurus* , *Daspletosaurus, Teratophoneus*) did congregate in groups for at least part of the year (Currie, 1998; Currie et. al. 2005; Eberth and Currie, 2010; Titus et. al., 2021). A single track site from the upper Cretaceous of British Columbia, Canada also shows three concurrent tracks made by tyrannosaurs walking in the same direction, implying gregarious behavior (McCrea et. al., 2014). Cooperative hunting or pack hunting has been suggested by several authors as a result of these discoveries (Currie, 1998; Currie et. al. 2005; Eberth and Currie, 2010; Titus et. al., 2021). If tyrannosaurs were indeed feeding or hunting cooperatively, it could explain the large quantities of teeth from various ontogenic stages. While nothing at the TDD conclusively shows pack hunting behavior, the evidence suggests that tyrannosaurs in the Hell Creek Formation may have been far more gregarious than previously thought.

The presence of a large amount of small theropod teeth, particularly the dromaeosaurs *Acheroraptor* and *Dakotaraptor* suggest that they might also have also been involved in the hunting and scavenging of carcasses in this area. The presence of 1) multiple tooth morphologies 2) rare genera and 3) rare small theropod elements, particularly along the D/E contact, indicates that small theropod diversity was likely quite high with multiple tiers of top and mid-level carnivores.

The large numbers of elements showing osteophagus insect borings is another interesting component of this site. These borings suggest sub-aerial exposure for several seasons and a diverse array of insects that may have feasted on the dung and carcasses left by tyrannosaurs and other predators.

Turtles and other vertebrates were also a large component of the ecosystem. Many of the shell fragments are from very large individuals. Many of these also show evidence of insect borings and modifications. Given their broken and disarticulated nature these may have been washed into the site during the hyper-concentrated depositional event. Disarticulated *Basilemys*, tortoise elements are also frequently found particularly along the D/E contact suggesting that they were part of a local community and common to this area.

Combined, all of this suggests a very dynamic and diverse ecosystem along the river floodplain with *Tyrannosaurus* as the top predator and scavenger. *Edmontosaurus* would have been the dominant herbivore and main prey for tyrannosaurs. Ceratopsians like *Triceratops and Torosaurus* would have been a less common, but still dominant herbivores in the area and another source of food for tyrannosaurids. *Nanotyrannus* and larger dromaeosaurs like *Dakotaraptor* would then be second tier cooperative hunters likely competing for and targeting small ornithischians like *Thescelosaurus,* young *Edmontosaurus*, *Ornithomimus sp.* and several pachycephalosaurs. Smaller dromaeosaurs like *Acheroraptor* and *Saurnornitholestes* were present as well.

These likely fed on very young ornithischians, and other small game, including things that came to scavenge carcasses (mammals, pterosaurs, birds, crocodiles, other small theropods). Both *Anzu* and at least one and possibly two large ornithomimids were clearly present, but in lower numbers in the TDD community. Troodontids, alvarezsaurids and likely other smaller theropods acted primarily as insectivores, hunting the area at night. Crocodilians, varanid lizards, mammals and others acted as opportunistic lower tier hunters and scavengers, along with osteophagous insects that feasted on whatever was left.

CONCLUSION:

Approximately 66-67 million years ago, nearby where the Tooth Draw Quarry would eventually be found, a large population of *Edmontosaurus* and *Thescelosaurus* from all age groups, lived along an ancient river system (Figure 45). The *Edmontosaurus* ranged in size from full grown adults to neonates. Some may have been using the river systems to migrate and were simply passing through and others may have been endemic to the area, feeding on the lowland vegetation. Ceratopsians and pachycephalosaurs likely passed through this area as well, but in far fewer numbers. Tyrannosaurs, including both *Tyrannosaurus rex* and *Nanotyrannus lancensis*, were present and actively competed for food along the river system. While their main food source was likely *Edmontosaurus and Thescelosaurus*, the occasional wandering *Triceratops* were surely targeted when available. Some niche-partitioning of the two is likely, with tyrannosaurs hunting and scavenging larger prey and *Nanotyrannus* focusing on hunting mid-sized game. Scavenging activities by tyrannosaurs were likely extensive, including possible utilization of bone as a nutrient source (osteophagy). The remaining material was secondarily scavenged by smaller dromaeosaurs and carnivores whose diversity, based upon teeth, was likely higher than previous estimates. Troodontids and alvarezsaurids were the primary insectivores, hunting at night the insects that were drawn to the decaying prey. Any remaining carcasses, bone, dung etc. remained subaerially exposed for a period of up to three years, further being broken down by osteophagous insects that chewed into the bones perhaps even laying their eggs in what was left.

Then, during a period of heavy rainfall and severe flooding, perhaps after forest fires or volcanic ash deposition, the nearby incised river channels began to undercut their river banks and tear through their natural levees. As sediment swollen rivers meandered across the plain both predator and prey moved out of the lowland area seeking higher ground. The extreme flow may have created large boulders and cobbles of clay and mud that were soft enough to be eroded by the rapidly flowing waters along with displacing ironstone concretions excavated from poorly drained soils. What may have begun as a simple crevasse-splay (floodwaters cresting a natural levee and spilling out onto topographic low spots forming the finer grained E horizon), eventually

Figure 45- The Ecology of the Hell Creek Formation at Deers Ears Buttes, South Dakota. The data recovered from the Tooth Draw Deposit indicates a diverse fauna of dinosaurs and other vertebrates living near the edge of an ancient and ever-changing river system. The lowland forrest was locally dominated by the dinosaurs *Edmontosaurus* and *Thescelosaurus*. The large super-predators of *Tyrannosaurus* and *Nanotyrannus*, along with smaller theropods like *Acheroraptor* and *Dakotaraptor* would stalk their prey along this river system, feeding on any animals they could hunt or scavenge. It is important to remember, that not only dinosaurs lived in this amazing ecosystem. The rivers were teeming with life, including fish and salamanders, turtles, varanid lizards, champsosaurs, and crocodiles. Mammals scurried along the banks and both birds and pterosaurs flew overhead. This was not an environment in slow decline, but an amazing world full of vibrance and majesty. Illustration courtesy of Chris DiPiazza.

became a torrent as one of these hypothetical levees burst apart rolling and tumbling a hyper-concentrated flow of bones, boulders, trees, sands and gravel onto the adjacent floodplain. As it violently flowed over the floodplain it would scour the surface, picking up bones and teeth along the way and re-depositing them into any lowland areas down-surge. Eventually, as flow rates slowed, and a new channel began to stabilize, portions of the upper D horizon were scoured, winnowed of fine-grained muds and clays, and was sorted into heavier ironstone clasts. This new channel began to slow even more, eventually filling with sand creating the B horizon. Afterward, during more increased flow rates and more migration of the nearby river system, a channel cut into both the B and C depositing the channel lag of horizon A.

This rapid and turbulent deposition (horizon A-E) captured at least two separate communities of fossil bones and teeth. One, which did not travel far and thus, was more local (autochthonous) and another that shows a significant level of stream transport and thus a more distant and reworked assemblage (allochthonous). Both were likely attritional assemblages, deposited over multiple seasons. Combined, the site is considered parautochthonous with both an abiotic and biotic genesis.

Over the last fifteen years of work, the Tooth Draw Deposit has produced thousands of isolated bones and teeth from a diverse array of animals. Unlike most private sites, the bulk of the scientifically significant specimens have been retained in a single collection that rivals that in size of those found in many institutions. The deposit itself is a high diversity, multitaxic bone bed with a complex history of development, laid down in multiple stages. Work is ongoing and future papers are intended to elaborate on individual characteristics.

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APPENDICES

Taphonomy Summary Table Theropods

Family	Total number of identified specimens/ family (NISP)	% of the whole dinosaur sample (%N) N=2,295	Predominant element types by percentage	Ontogenetic stages present in the sample	Minimum number of individuals (MNI)	Average Weathering Stage	Average Breakage Type	Average Condition	Average Abrasion	Observed bone modifications (bite marks, borings, etchings, etc.)
Tyrannosaurids	700	30.5%	Teeth= 98.0%	Juvenile to adult	Dozens by teeth 3 by size, strata and/or ontogeny	0-1	Shed teeth some with chipped or missing tips to none on elements	Good	None-light	Some elements tooth marked, some teeth show evidence of acid etching.
Dromaeosaurids	204	8.9%	Teeth=88%	Subadult to adult	Dozens by teeth 5 by strata / ontogeny	0-1	Shed teeth, mostly complete	Good	None-light	none
Troodontids	13	0.6%	Teeth=85%	Insufficient data	N/A	0	Shed teeth, mostly complete	Good	None-light	none
Ornithomimids	22	0.9%	Caudal vertebra =45.5%	Adult	2 by ontogeny	0	none	Fair	None-light	none
Caenagnathids	8	0.4%	Manus elements =75%	Adult	2 by condition and strata	0-2	none	Fair	None-light	None on most one ungual with insect borings
Misc Theropoda indet.	67	2.9%	Partial limb bones =35.8%	Insufficient data	N/A	1	Oblique Irregular-Frequent breakage of thin processes. Both ends often missing	Fair	Light to moderate	none
TOTAL/AVERAGE	1,013	44%	Teeth	Adult	dozens	0-1	None to oblique	Fair-good	None-light	none to infrequent

Table 1- Taphonomy Summary Table Theropods.

Taphonomy Summary Table Ornithischians

Family	Total number of identified specimens/ family (NISP)	% of the whole dinosaur sample (%N) N=2,295	Predominant element types by percentage	Ontogenetic stages present in the sample	Minimum number of individuals (MNI)	Average Weathering Stage	Average Breakage Type	Average Condition	Average Abrasion	Observed bone modifications (bite marks, borings, etchings, etc.)
Ceratopsids	190	8.3%	Fragmentary skull elements= 38.4%	Neonate to mature	4+ by ontogeny, stratigraphy dozens by teeth	1-3	Oblique irregular fractures	Fair	Light to heavy	Occasional borings and bite marks
Hadrosaurids	531	23.2%	Vertebrae= 40.8%	Neonate to mature	7 by left and right femurs and ontogeny	1-3	Frequent pre-depositional breaks including spiral and oblique fractures, missing ends	Fair	Light to heavy	Abundant and frequent insect borings, parallel fine scratches, tooth marks, severe fragmentation of bone
Basal Ornithischians Thescelosaurids	310	13.5%	Vertebrae= 25.8% Pes= 21%	Neonate to mature	7 by right femur	0-1	Oblique irregular to transverse irregular	Good	None- light	Minor abrasion and breakage of thin processes or ends. Rare bite marks
Pachycephalosaurids	46	2.0%	Fragmentary skull elements= 58.7%	Adult	N/A	0-1	Oblique irregular to transverse irregular	Fair-Good	Light to heavy	Light borings and rare bite marks
Ankylosaurids and Nodosaurids	62	2.7%	Scutes= 54.8%	Adult	N/A	0-2	N/A	Good	Light to heavy	none
Ornithischian indet.	142	6.2%	Appendicular fragments= 69.7%	Insufficient data	N/A	1-3	Oblique irregular to transverse irregular	Poor	Light to heavy	Abundant and frequent insect borings, fragmentation of bone
TOTAL/AVERAGE	1,282	56%	Teeth, fragments and vertebrae	Neonate to mature	dozens	1	Oblique irregular to transverse irregular	Fair-Good	Light to heavy	Abundant modification and insect borings. Severe fragmentation of bone.

Table 2- Taphonomy Summary Table Ornithischians.

BONE MODIFICATION SUMMARY COMBINED

Taphonomy Study	Total Breakage	Total Scratch marks	Total Bite marks	Total Abrasion	Total Stage 1 Weathering +	Total w/ Insect Borings or Bioerosion
N= 514	55.6%	5.1%	9.3%	91.1%	53.5%	24.3%