Jacks birthday sit, a diverse dinosaur bonebed from the cretaceous two medicine formation of Montana by David Joseph Varricchio

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biological Sciences
Montana State University

Abstract:
Jack's Birthday Site, a diverse vertebrate assemblage from the Upper Cretaceous Two Medidne Formation of western Montana, was taphonomically investigated and compared with other predominantly iguanodontoid bonebeds from the area. The large bone sample at Jack's Birthday Site allowed statistical evaluation of the preservational and compositional variation within the site. Evidence, including sedimentary fades, plant and invertebrate fossils, and bone orientation and condition, indicates Jack's Birthday Site represents part of a small, shallow floodplain lake. Lithologies and fossil preservation vary from northwest to southeast over a distance of 50 m, representing a transition from lake through shoreline to marginal shoreline/floodplain environments.

The vertebrate assemblage contains ten dinosaur taxa and a variety of non-dinosaurs and indudes two taphonomic fractions. The first, consisting of attritional, predominantly isolated and allochthonous elements, represents a time-averaged assemblage. The other consists of assodated, parautochthonous remains restricted to a single horizon. Taxa represented by associated remains indude three iguanodontoids, Hypacrosaurus, Prosaurolophus, and Gryposaurus, and the theropod Troodon. Associated individuals of these taxa have non-random distributions within the site and observed taxonomic dustering may reflect group behavior and/or event mortality. The four or more Troodon represent the first described multiindividual troodontid occurrence.

Other predominantly iguanodontoid assemblages, like Jack's Birthday Site, are single highly concentrated bone horizons occurring in silty mudstones. Most are primarily parautochthonous with some degree of skeletal assodation and likely represent mass-mortality. The size-frequency profile of the Camposaur bonebed supports a catastrophic origin. Jack's Birthday Site differs in its diversity, the other localities being nearly monospecific, and its size-frequency profile for iguanodontoids which suggests strongly selective mortality and/or preservation. These plus the site's variable preservation indicate that Jack's Birthday Site is a much more time-averaged assemblage.

Both hadrosaurids and lambeosaurids appear to have been gregarious. Lack of association between small (total length <3 m) and larger individuals suggests that juvenile growth rates may have been as rapid as large ungulates. Size-frequency profiles for Maiasaura peeblesorum suggest seasonally synchronous reproduction and high juvenile mortality.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Jack's Birthday Site, a diverse vertebrate assemblage from the Upper Cretaceous Two Medicine Formation of western Montana, was taphonomically investigated and compared with other predominantly iguanodontoid bonebeds from the area. The large bone sample at Jack's Birthday Site allowed statistical evaluation of the preservational and compositional variation within the site. Evidence, including sedimentary facies, plant and invertebrate fossils, and bone orientation and condition, indicates Jack's Birthday Site represents part of a small, shallow floodplain lake. Lithologies and fossil preservation vary from northwest to southeast over a distance of 50 m, representing a transition from lake through shoreline to marginal shoreline/floodplain environments.

The vertebrate assemblage contains ten dinosaur taxa and a variety of non-dinosaurs and includes two taphonomic fractions. The first, consisting of attritional, predominantly isolated and allochthonous elements, represents a time-averaged assemblage. The other consists of associated, parautochthonous remains restricted to a single horizon. Taxa represented by associated remains include three iguanodontoids, *Hypacrosaurus*, *Prosaurolophus*, and *Gryposaurus*, and the theropod *Troodon*. Associated individuals of these taxa have non-random distributions within the site and observed taxonomic clustering may reflect group behavior and/or event mortality. The four or more *Troodon* represent the first described multi-individual troodontid occurrence.

Other predominantly iguanodontoid assemblages, like Jack's Birthday Site, are single highly concentrated bone horizons occurring in silty mudstones. Most are primarily parautochthonous with some degree of skeletal association and likely represent mass-mortality. The size-frequency profile of the Camposaur bonebed supports a catastrophic origin. Jack's Birthday Site differs in its diversity, the other localities being nearly monospecific, and its size-frequency profile for iguanodontoids which suggests strongly selective mortality and/or preservation. These plus the site's variable preservation indicate that Jack's Birthday Site is a much more time-averaged assemblage.

Both hadrosaurids and lambeosaurids appear to have been gregarious. Lack of association between small (total length <3 m) and larger individuals suggests that juvenile growth rates may have been as rapid as large ungulates. Size-frequency profiles for *Maiasaura peeblesorum* suggest seasonally synchronous reproduction and high juvenile mortality.

CHAPTER 1

INTRODUCTION

Dinosaur bonebeds such as the Late Jurassic Cleveland-Lloyd and Dry Mesa quarries provide hundreds of specimens and a wealth of information on morphology and taxonomy. These rich assemblages also stimulate much speculation about their origin. At the Cleveland-Lloyd Quarry near Cleveland, Utah more than 40 individuals of the large and presumably carnivorous *Allosaurus* are found mixed with a variety of far less numerous dinosaurs (Madsen, 1976). Do these *Allosaurus* represent a group killed in a catastrophic event, animals trapped through cycles of miring and predation, or simply attritional mortality at a favored locale? At the Dry Mesa Quarry south of Grand Junction, Colorado, the disarticulated remains of seventeen species of dinosaurs are preserved within a channel sandstone (Britt, 1991). Do the relative abundances of these dinosaurs accurately reflect the once living dinosaur community or simply hydraulic transport and sorting?

Taphonomy is the study of fossil preservation, of how material moves from the biosphere to the lithosphere (Efremov, 1940). Much of taphonomy concerns the loss of data due to destructive processes such as weathering, trampling, and lithostatic crushing and the resulting discrepancies between a living community and a death assemblage. Nevertheless, by documenting

information loss, taphonomy exposes processes. Bone damage represents both a loss of morphological data and a record of the modifying agents. Tooth-marked bone reflects carnivore behavior. Thus, taphonomy can provide information not only concerning the history of specimens, but also about past environments and their physical, chemical and biologic attributes (see Wilson, 1988).

At the most basic level, bonebeds reflect the interplay between the rates of sedimentation and bone accumulation (Kidwell, 1986). For example, when sedimentation is minimal or absent, background attritional mortality can eventually produce a fossil concentration which may then have the look of a single event horizon. In contrast, high sedimentation rates may swamp even higher than normal mortality, leaving fossils spread out vertically through a stratigraphic sequence. Where animals die within or adjacent to depositional environments, bone accumulation rates reflect mortality rates to the extent that post-mortem modification allows. An even greater discrepancy likely occurs between the two rates where transportation to a depositional environment is required. Sorting, mixing and reworking by hydraulic transport and selective behavior by biotic collecting agents such as scavengers may potentially obscure the relationship between mortality and bone accumulation. Fundamental to the interpretation of bonebeds is an assessment of the amount of time and transport they represent.

Taphonomic interpretations depend on both geologic and paleobiologic data. Geologic data comprise relevant stratigraphy and sedimentology, including the shape, thicknesses, lateral relationships and contacts of units; grain size, sorting and mineralogy; and sedimentary structures. Paleobiologic

data consist of taxa represented; their abundance both by individual and element counts and size/age composition; degree of articulation through association of skeletons; site geometry; bone density and orientation; type, abundance and size of skeletal parts; and abundance and stage of bone modification such as abrasions, weathering damage, breaks, borings, etchings, and trample, tooth and gnaw marks. Invertebrate, plant and trace fossils and their preservation also provide significant information.

Rogers (1993) and Behrensmeyer and Cutler (1994) suggest that bonebed abundance and attributes vary non-randomly through space and time. Tectonic setting, climate and the evolution of traits imparting a susceptibility to mass mortality (e.g. body size, herding behavior), apparently influence bonebed occurrences.

In the summer of 1988 a rich dinosaur bonebed was discovered in the Upper Cretaceous Campanian Two Medicine Formation of Glacier County, Montana. Found by John "Jack" Horner on June 15th, his birthday, the locality, Museum of the Rockies (MOR) TM-068, became known as Jack's Birthday Site (JBS).

The occurrence of a bonebed in the Two Medicine Formation was not unusual. Previous excavations by the Museum of the Rockies included several paucispecific ceratopsian and iguanodontoid bonebeds (see Rogers, 1990). From the initial surface collections however, Jack's Birthday Site appeared both unusually extensive and diverse. Theropods, those dinosaurs generally considered carnivorous and rare at all other Two Medicine sites, appeared exceptionally abundant.

Excavation began shortly after the site's discovery. To evaluate the site's geologic and biologic significance, full taphonomic investigation commenced in the field in 1989 and continued through 1992. Taphonomy of Jack's Birthday Site is decribed (Chapter 2) and then compared with other Two Medicine bonebeds (Chapter 3).

CHAPTER 2

TAPHONOMY OF JACK'S BIRTHDAY SITE

Introduction

Preservation in fossil vertebrate assemblages can range from nearly complete, the burying of a Miocene rhinoceros herd including stomach contents in a volcanic ash (Voorhies and Thomasson, 1979; Voorhies, 1985), to fragmentary, a microfossil accumulation of isolated bones and teeth in a channel lag (Brinkman, 1990). Both yield paleobiological information. The former records information on posture and herd demographics in an almost photographic fashion. The latter, when compared to hydraulically similar localities, reveals the spatial and temporal pattern of species distributions. Many bonebeds show a range of preservation, a mix of articulated skeletons to isolated bones or both parautochthonous and allochthonous elements. The precise paleobiological meaning of such bonebeds often remains unclear.

Mono- to paucispecific bonebeds preserve a wide variety of dinosaurs representing most of the major groups. Among theropods, such assemblages include the ceratosaurs, *Coelophysis bauri* and *Syntarsus rhodesiensis* (Colbert, 1964, 1989; Raath, 1990; Rowe and Gauthier, 1990), and *Deinonychus antirrhopus* (Ostrom 1969, 1990). Monospecific mass accumulations such as

the Trossingen, Germany *Plateosaurus* assemblage are characteristic of prosauropods (Weishampel, 1984; Weishampel and Westphal, 1986; Galton, 1990).

Ornithischians known by associations of a few individuals include: *Tenontosaurus tilletti, Iguanodon bernissartensis, Leptoceratops gracilis* and *Protoceratops andrewsi* (Brown and Schlaikjer, 1940; Sternberg, 1951; Norman, 1986; Forster, 1990). Numerous Late Cretaceous hadrosaurid, lambeosaurid and ceratopsian bonebeds have each produced hundreds of bones representing tens of individuals (Gilmore, 1929; Currie and Dodson, 1984; Hooker, 1987; Wood et al., 1988; Nelms, 1989; Lehman, 1990; Rogers, 1990; Christians, 1991). (Note: Hadrosauridae and Lambeosauridae are used in this text sensu Horner, 1990.)

These low-diversity assemblages, commonly interpreted as the products of mass mortality events, may represent biological aggregations. Based on these accumulations, workers envision "herds" for many species: *C. bauri* (Colbert, 1990); *S. rhodesiensis* (Raath, 1990); *Iguanodon* (Norman and Weishampel, 1990); the hadrosaurids, *Maiasaura peeblesorum* (Hooker, 1987) and *Edmontosaurus annectens* (Christians, 1991); and numerous ceratopsians (Currie and Dodson, 1984; Wood et al., 1988). Juvenile *T. tilletti* may have formed groups as an important survival strategy (Forster, 1990). Ostrom (1969) suggested pack-hunting for the dromaeosaurid *D. antirrhopus*, while von Huene (1928) viewed *Plateosaurus* as a gregarious migrator. Recently, mass assemblages have been critical for the interpretation of morphology, allowing for the recognition of dimorphism and explanation of various cranial

structures as social or sexual display features (Colbert, 1989; Lehman, 1989, 1990; Raath, 1990; Rowe and Gauthier, 1990; Sampson, 1993).

The criteria generally used to recognize mass mortality are relatively simple: a predominance of one species and concentration of bones on a single horizon. Uniformity of preservation and the demographics of the assemblage may support this interpretation. Nevertheless, attritional mortality in environments with one predominant taxon or with size- or taxonomically-selective mortality may result in near monospecific assemblages. Rogers (1990) noted that three monospecific parautochthonous assemblages from the Two Medicine Formation may have resulted from the aggregation and death of individuals, not herds, attracted to waterholes in times of drought. Conditions at the Hot Springs Mammoth Site (Agenbroad, 1984) preferentially trapped only the largest animals, resulting in an attritional assemblage dominated by subadult to mature mammoths. The abundance and physical attributes of *Plateosaurus*, rather than mass mortality, may account for the predominance of this species on some horizons at Trossingen (Weishampel, 1984; Weishampel and Westphal, 1986; Sander, 1992). Therefore, the interpretation of monospecific assemblages warrants some caution.

Multispecific dinosaur bonebeds, common to both the Jurassic (Dodson, et al., 1980) and Cretaceous (Currie and Dodson, 1984; Wood et al., 1988), usually represent attritional allochthonous accumulations within channel sands (Lawton, 1977; Wood et al., 1988; Britt, 1991; Fiorillo, 1991a). Notable exceptions include the Cleveland-Lloyd Quarry, a presumed predator trap (Madsen, 1976), and Scabby Butte, a catastrophic mix of hadrosaurid and ceratopsian material (Langston, 1976). Recent discovery of a rich dinosaur

bonebed, Jack's Birthday Site, in the Two Medicine Formation of Montana, allowed the opportunity to consider the taphonomic and biologic meaning of a multispecific but primarily parautochthonous assemblage.

Location and Methods

Jack's Birthday Site is located in badlands along Badger Creek in Glacier County, Montana within the Blackfeet Indian Reservation (Fig. 1A). Excavation commenced in late June, 1988. The bonebed crops out on three sides of a north-south trending ridge and initial excavations consisted of two west-side quarries, Lower and Middle (Fig. 2). Three additional quarries, South, Brad, and East, opened in 1989, extended work to all three sides of the ridge. Small crews continued to dig on both east and west sides from 1990 to 1992. Excavation of 140 m^2 of bonebed represents roughly 200 work days. All excavations and exposures suggest lateral continuity for the bonebed. Based on visible bonebed exposure on each side of the ridge, and assuming lateral continuity, total preserved area of the site is over 3000 m^2.

Full taphonomic investigation began in 1989. Excavation was carried out with hand tools, and an effort was made to collect all potentially identifiable bones and a sample of unidentifiable fragments. Washing and screening of matrix was minimal (<100 kg of matrix); therefore, a bias against microvertebrates may exist in the overall sample. Microfossils include some small limb bones and gastropods, but the washing process rendered most unidentifiable. The large sample size (>1600 skeletal elements), large area

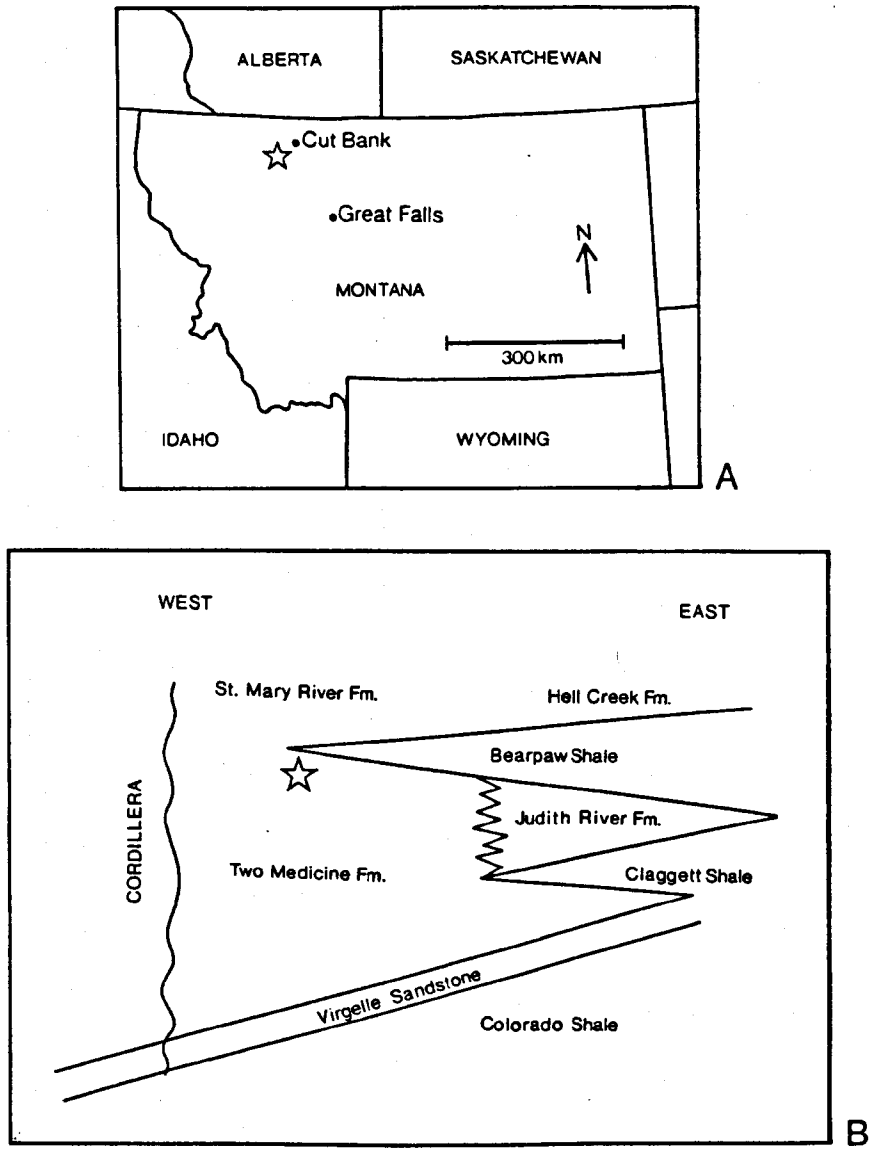

FIGURE 1. Location of Jack's Birthday Site (star), Museum of the Rockies locality TM-068, sec. 11, T31N, R8W, in Glacier Co., Montana (A) and in a stylized cross section of the Upper Cretaceous strata of north central Montana (B), modified from Horner et al. (1992).

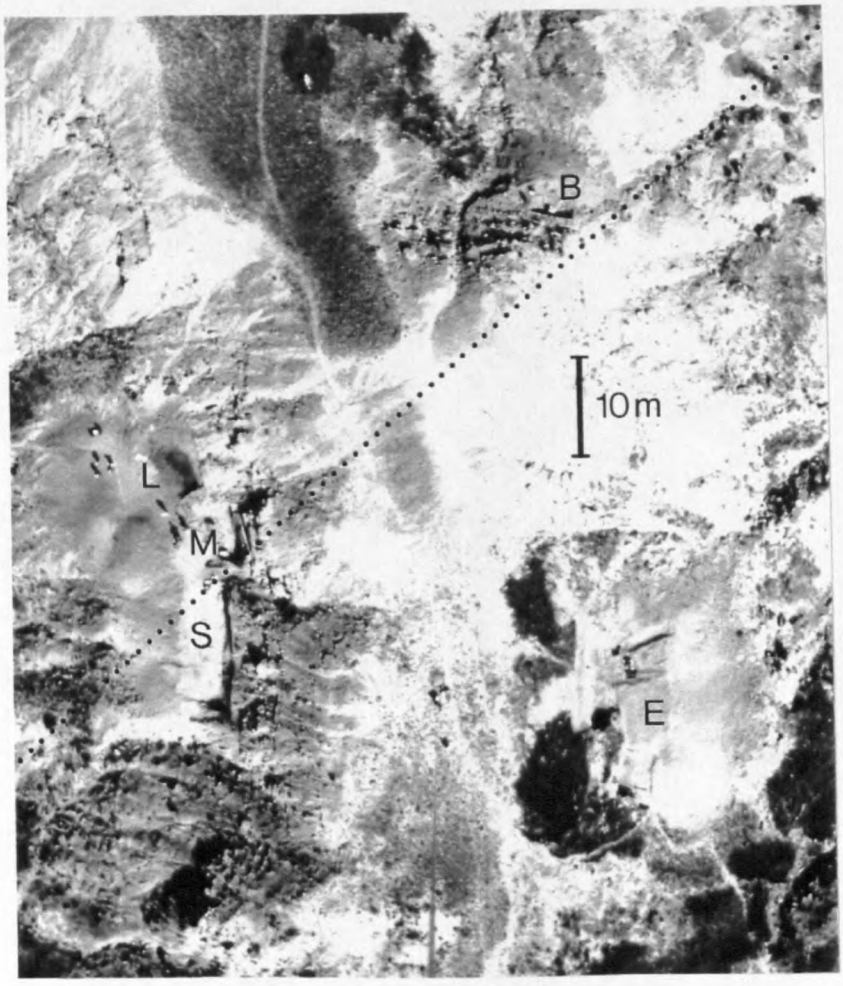

FIGURE 2. Aerial photo from hydrogen balloon of Jack's Birthday Site showing the quarries: **B**, Brad; **L**, Lower; **M**, Middle; **S**, South; and **E**, East. To the northwest, Brad, Middle and Lower, represent part of a lake basin and the dotted line marks the southeast limit of all small through medium-scale sedimentary bedding and plant preservation. The greatest density of bone and wood occur along this line in Brad and Middle and may represent a strand line. Bone weathering and breakage increase significantly from northwest to southeast. Hadrosaurid remains are concentrated in Brad, Lower and Middle, *Hypacrosaurus* in South and East, and *Troodon* in South. Vertical line at bottom center is the tether for the balloon and the white dot at end of tether is Dr. Johnson.

excavated, and contrast in color and hardness between bone and matrix likely minimized any bias in the macrovertebrate (elements >1 cm^3) fraction.

As each element was uncovered in the field, excavators noted bone condition: degree of completeness, wear and weathering, and the presence of fractures and tooth marks. After preparation in the lab, specimens were re-examined for these same features.

Specimens were mapped using a meter-square grid system. Orientation (i.e trend and plunge) of linear bones, ossified tendons and plant fragments were measured using a Brunton compass. Additionally, in 1989, workers plotted specimens in three-dimensional space using a dumpy level, with large or steeply inclined elements measured at two or more points. Also in 1989, Dr. Jerry Johnson conducted a trial experiment of two documentation techniques used in archaeology. This involved low-level photography using both a 5 m bi-pod and an unmanned hydrogen balloon (Fig. 2). All specimens are curated in the Museum of the Rockies (MOR) paleontological collections in Bozeman, Montana.

Regional Setting

Rogers et al. (1993) provide a recent review and dating of the Campanian Two Medicine Formation. Age of the formation, based on $^{40}Ar/^{39}Ar$ values from bentonites, falls between 86 and 74 Ma. Correlatives of the formation include: eastward in Montana, the Eagle, Claggett, Judith River and Bearpaw Formations; and in southwestern Alberta, the Belly River and

Bearpaw Formations (Russell, 1970; Koster and Currie, 1987; Shurr et al., 1989; Fig. 1B).

Montana Late Cretaceous paleogeography consisted of western mountains shedding sediments eastward onto a low coastal plain bordering the Western Interior Seaway (McGookey, 1972; Gill and Cobban, 1973). Floras indicate that the Two Medicine region was within a transition zone between warm or sub-humid tropical and temperate climates (Dodson, 1971; Wolfe and Upchurch, 1986; Crabtree, 1987). This boundary marks a switch from southern evergreen to northern deciduous forests (Krassilov, 1981). The following evidence supports a seasonally semi-arid climate with a long dry season for the Late Cretaceous of Montana: tree rings, unexpected in a thermally equable region (Dodson, 1971; Crabtree, 1987); a substantial number of evergreens with leathery leaves without drip tips (Crabtree, 1987); impoverished palynological assemblages (Jerzykiewicz and Sweet, 1987); fusain or charcoal, evidence of fires (Carpenter, 1987); caliche paleosols (Lorenz, 1981; Jerzykiewicz and Sweet, 1987); desiccated (septarian) carbonate nodules; sandstone bodies of episodic (ephemeral) rivers; abundant clay-flake rip-up clasts; and fresh, unstable volcanic rock fragments (Lorenz, 1981).

The rich dinosaur fauna from the Two Medicine Formation includes massive ceratopsian, hadrosaurid and lambeosaurid bonebeds (Gilmore, 1917; Rogers, 1990, 1993), hypsilophodont and hadrosaurid nesting grounds (Horner and Makela, 1979; Horner, 1982; Horner and Weishampel, 1988), and numerous isolated specimens (Gilmore, 1917, 1930, 1939; Horner, 1983).

Jack's Birthday Site

The Two Medicine Formation along Badger Creek consists primarily of mudstone and some sandstone. Relatively common caliche horizons contrast with rare lacustrine platy shale and siltstone. Mudstones typically are massive and represent floodplain deposition. The abundance of mudstone relative to sandstone reflects the proximal basin subsidence experienced by this area during the Campanian (Lorenz, 1981). Sandstones are generally either thin (<2 m thick), fine-grained and well sorted with pervasive climbing ripples or thick (2-8 m), medium-grained, moderately-sorted and lenticular (width/height ratios between 5:1 and 30:1) with trough and planar-tabular crossbeds (Lorenz, 1981).

Bone, though found at various levels throughout Jack's Birthday Site, is concentrated within a green-gray, calcic, massive, and poorly-sorted mudstone. The fossiliferous horizon lies roughly 100 m below the Two Medicine Formation-Bearpaw Shale contact (Horner et al., 1992) and 14 m above a prominent bentonite (Fig. 3) which may correlate with TM-4, a volcanic ash recently dated at 74.1 Ma (Rogers, et al., 1993).

A poorly sorted, fine-grained sandstone underlies the main bone horizon in the northwest quarries, (Brad, Lower, and Middle) (Figs. 2, 4). This thin, <20 cm thick, sandstone coarsens upwards so that the upper 5 cm contain an abundance of small (1-10 cm), well-abraded bone fragments, isolated caliche nodules and rip-up clasts. The sharp, flat upper contact with the overlying mudstone may represent a crevasse splay, an omission or

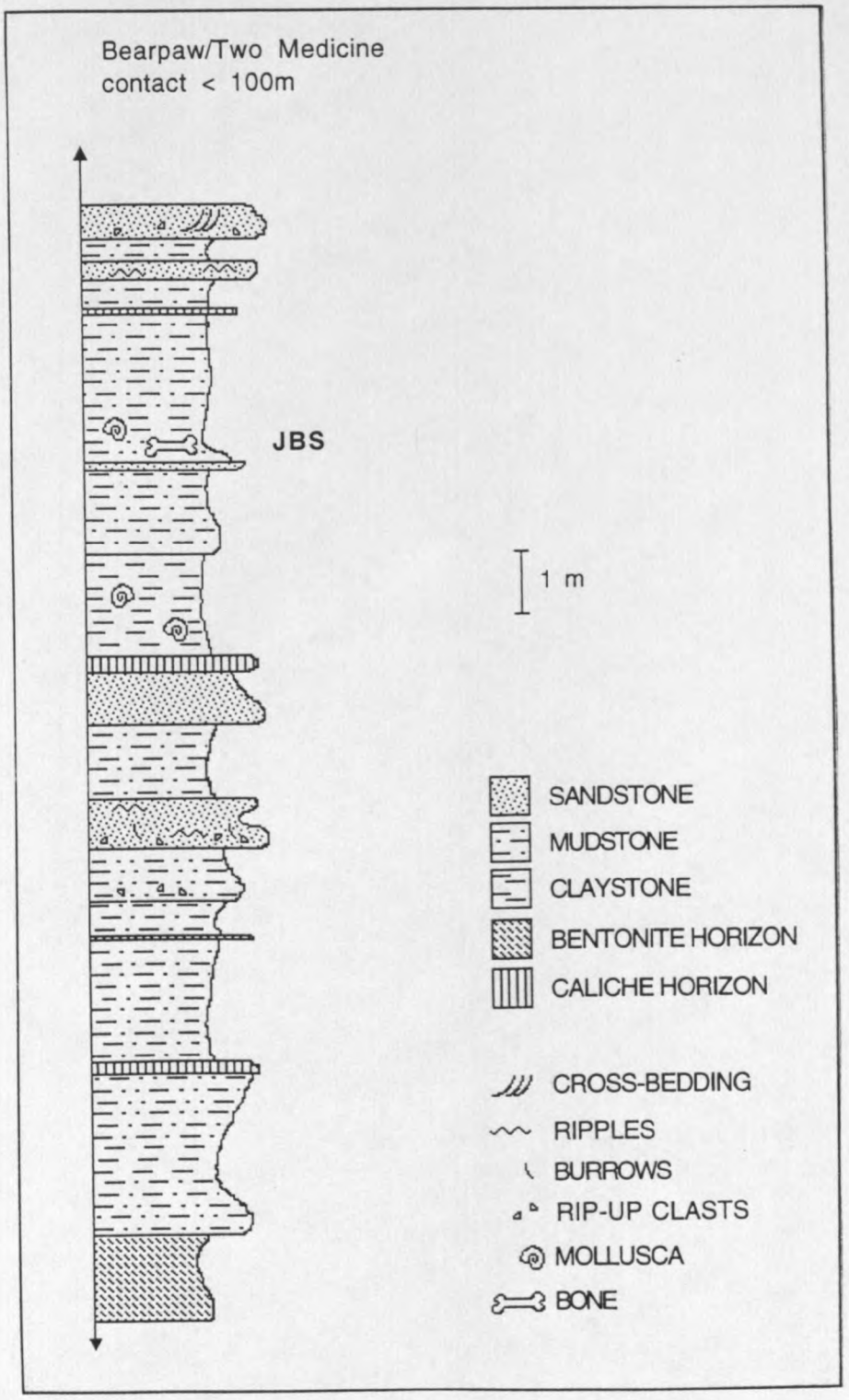

FIGURE 3. Stratigraphic column through Jack's Birthday Site (JBS). Prominent bentonite at base may correlate to an ash horizon, TM-4, dated at 74.1 Ma (Rogers, et al., 1993).

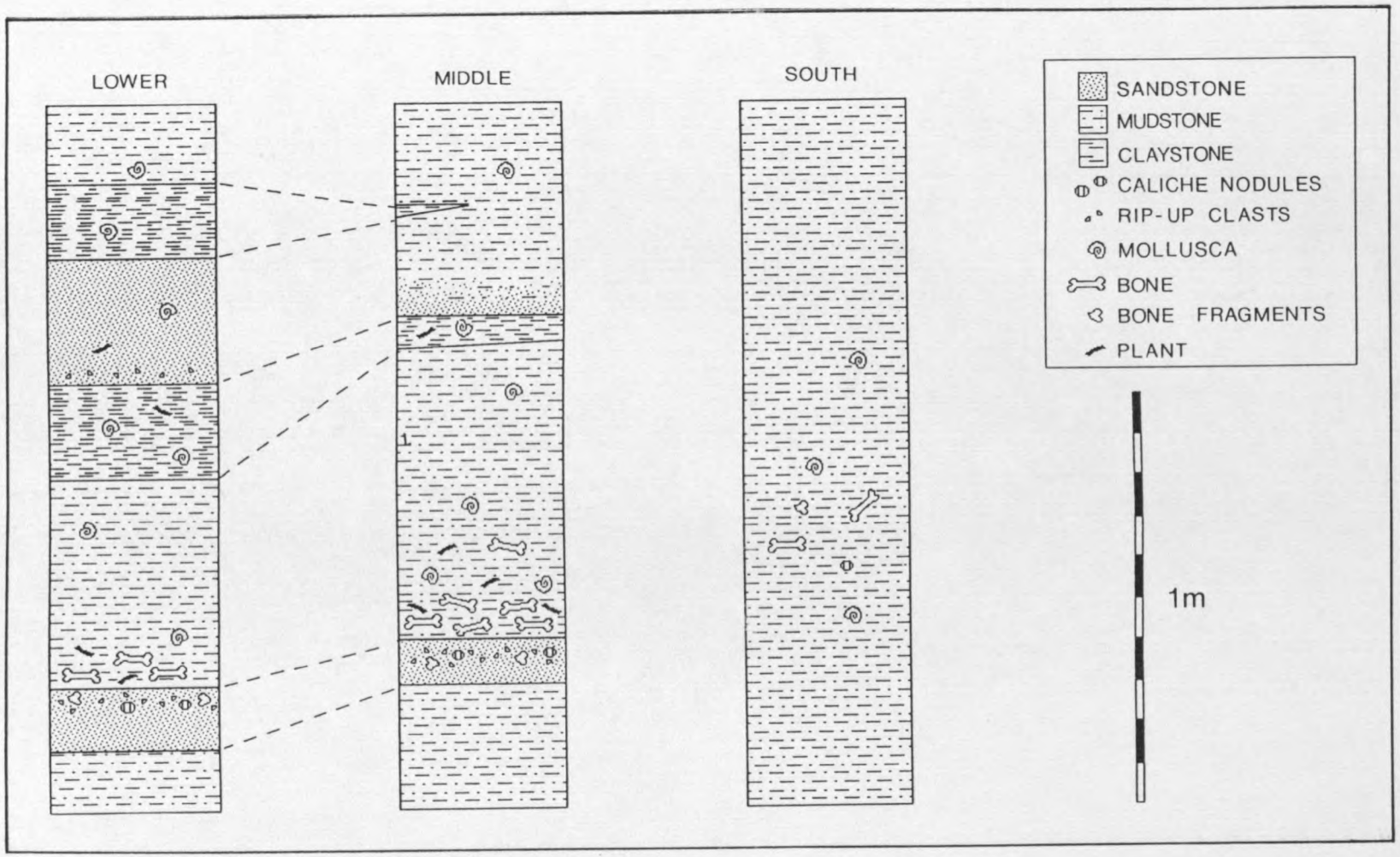

FIGURE 4. Stratigraphic profiles for the three west side quarries, Lower, Middle, and South (see Fig. 2). Columns are roughly 10 m apart along a N20°W trend. Bones mark main bone concentration only.

winnowed surface. This unit both pinches and grades laterally to the southeast into a mudstone continuous with the main bone-bearing mudstone.

In the northwest quarries (Fig. 2, 4), the main bone-bearing mudstone is about 0.5 m thick. Concentrated in the basal 30 cm of the unit, most bones lie in contact with the underlying sandstone. In contrast, in the southeast, the bone-bearing mudstone is roughly 5 m thick. This results from the units in the northwest that under- or overlie the bone-bearing mudstone (for example, the basal sandstone) pinching out and/or grading laterally to the southeast into the massive mudstone (Fig. 4). This lithologic change occurs rapidly within the Middle and Brad quarries (Fig. 2). Despite this lateral variation, a bone layer 30 cm thick persists as a continuous horizon from 25 m north of the Lower quarry south to the limits of the South and East quarries (Fig. 2). The mudstone unit extends in visible exposures some 100 m beyond the limit of the excavations and the bonebed. At least two unexcavated bone horizons of unknown extent sit within the 3 m beneath the main bonebed.

The bone-bearing mudstone is poorly-sorted. Grain-size analysis reveals that silt- and sand-sized grains, mostly highly-angular quartz, make up over 10% by weight of the unit. This unit in the northwest quarries contain compressed, coalified wood, showing conchoidal fractures and a vitreous luster. Pieces range in size up to 0.1 - 0.2 m by 1.5 m. Plant remains are absent from the southeast quarries.

The bone-bearing unit contains abundant gastropods and includes both aquatic forms such as physids, pleurocerids and viviparids, and terrestrial ones (Table 1). Shells are complete, unabraded, but distorted by lithostatic compaction. Opercula occur separately. An aquatic pulmonate,

TABLE 1. Jack's Birthday Site gastropod assemblage.

COUNT	PERCENTAGE	
31	16%	Pleuroceridae, three species, including cf. *Lioplacodes williamsi* and *Lioplacodes* cf. *L. judithensis*
6	3%	Viviparidae, probably *Campeloma*
71	38%	Physidae, *Physa* cf. *P. copei*
16	9%	unidentified aquatic forms, two species
64	34%	unidentified terrestrial forms, two species
188	100%	TOTAL