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Andrew B. Heckert, Kate E. Zeigler, Spencer G. Lucas, Justin A. Spielmann, Patricia M. Hester, Ronald E. Peterson, Rodney E. Peterson, and N. V. D'Andrea

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GEOLOGY AND PALEONTOLOGY OF THE UPPER JURASSIC (MORRISON FORMATION: BRUSHY BASIN MEMBER) PETERSON QUARRY, CENTRAL NEW MEXICO

ANDREW B. HECKERT[1], KATE E. ZEIGLER[1], SPENCER G. LUCAS[1], JUSTIN A. SPIELMANN[2], PATRICIA M. HESTER[3], RONALD E. PETERSON[1], RODNEY E. PETERSON[1], AND N. V. "DAN" D'ANDREA[1]

[1]New Mexico Museum of Natural History, 1801 Mountain Road NW, Albuquerque, NM 87104-1375; [2]Dartmouth College, Hinman Box 4571, Hanover, NH 03755; [3]U.S. Bureau of Land Management, 435 Montaño NE, Albuquerque, NM 87107

Abstract.—The Upper Jurassic Peterson quarry, located in Bernalillo County, central New Mexico, is New Mexico's most extensive and productive Jurassic dinosaur locality. The quarry is developed in the upper part of the Brushy Basin Member of the Morrison Formation, approximately 26 m below its contact with the overlying Jackpile Member. Fossil bones occur low in a 1.1-m-thick sequence of well-indurated, trough-crossbedded, subarkosic sandstone. Preserved elements range from scattered bones to articulated assemblages of bones from a single individual, and the long bones are preferentially oriented along a generally east-west-trending axis. The occurrence of associated-to-articulated bones in a trough-crossbedded sandstone underlying a floodplain mudstone suggest deposition of the fossils in the mixed fill of an abandoned channel in a typical Brushy Basin Member fluvial system. Particularly important dinosaurs from the Peterson quarry include a large (1100 mm estimated femoral length) *Saurophaganax*-like allosaurid theropod and the anterior portion of a sauropod skull and lower jaws similar to *Diplodocus*. Camarasaurid teeth are also relatively common at the quarry and some can be assigned to *Camarasaurus*. Excavations at the quarry are an excellent example of partnerships between the Bureau of Land Management and a natural history museum. To date at least 6000 volunteer hours have been donated excavating the quarry, and volunteer preparation may double that total.

INTRODUCTION

Previous authors have often noted that New Mexico's record of Jurassic vertebrates lacks the rich Morrison Formation quarry faunas known from other western states such as Wyoming, Utah, Colorado, and Oklahoma (e.g., Lucas and Hunt, 1985; Hunt and Lucas, 1993; Lucas and Heckert, 2000). Mineral exploration in the Grants uranium district yielded some fragmentary dinosaurs (e.g., Smith, 1961), but few of these specimens found their way into museums. Until 10 years ago, almost all known New Mexican Morrison Formation localities were isolated occurrences of an incomplete, single dinosaur (Rigby, 1982; Gillette, 1991). These are very different from the rich bonebeds at, for example, Como Bluff, Garden Park, Dinosaur National Monument, Cleveland-Lloyd, and the Stovall quarries that have made the Morrison Formation famous worldwide (e.g., Dodson et al., 1980; Foster, 2000, 2003). Here, we describe the stratigraphy, taphonomy, and vertebrae fauna of New Mexico's first true Morrison Formation dinosaur bonebed, which has yielded multiple elements preserved from at least three taxa and perhaps several individuals. This locality, New Mexico Museum of Natural History and Science locality 3282, is in the Brushy Basin Member of the Morrison Formation in Bernalillo County, central New Mexico (Fig. 1). Locality 3282, known informally as the "Peterson quarry," is by far New Mexico's strongest candidate at this time to yield a large and important sample of Morrison Formation dinosaurs, and excavations there have already netted almost 60 jackets of large dinosaur bones (Fig. 2). In this article we document the history of study of the quarry, its stratigraphy and taphonomy, and highlight some of the most significant fossils recovered from the quarry. In this paper, NMMNH refers to the New Mexico Museum of Natural History and Science and BLM to the U.S. Bureau of Land Management.

HISTORY OF STUDY

The general area of the Peterson quarry was initially discovered by one of us (Rodney Peterson) while prospecting for uranium in the 1960s. Collectively, the Petersons and Dan D'Andrea began leading the first of more than 100 trips to the site in 1989. The quarry was approved as an excavation under a BLM permit issued to the NMMNH for the collection of vertebrate fossils from

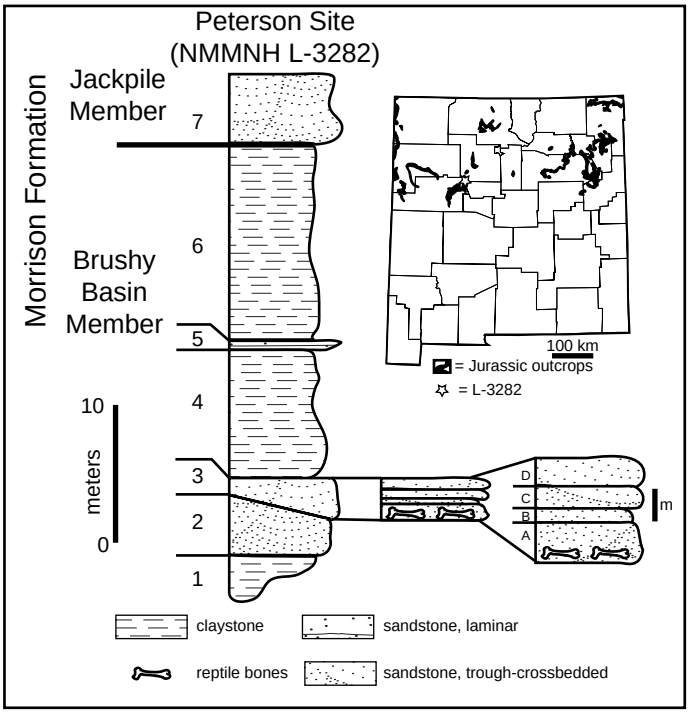


FIGURE 1. Location map and stratigraphic section of the Peterson quarry (NMMNH locality 3282).

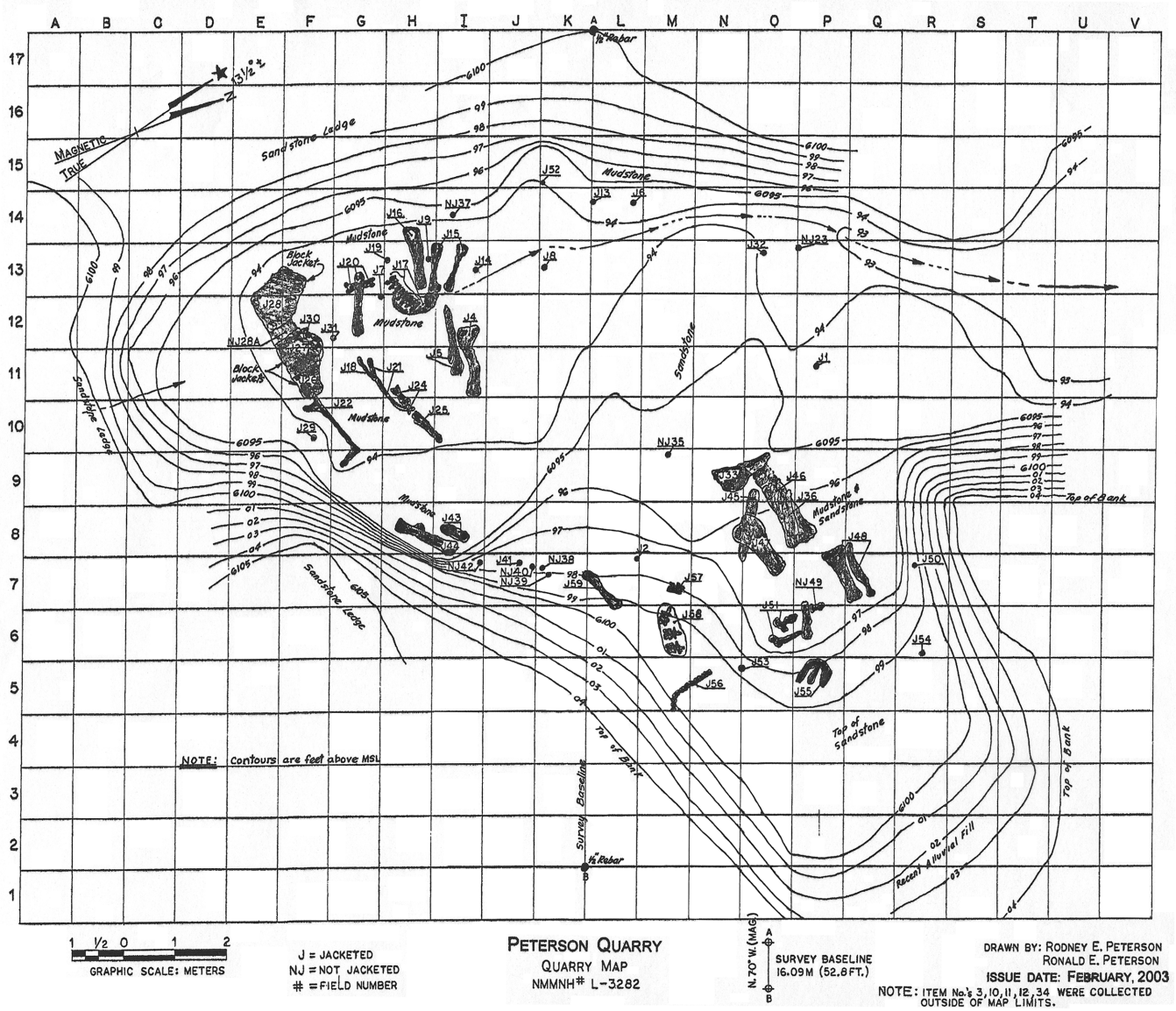


FIGURE 2. Detailed quarry map prepared by Rodney E. Peterson and Ronald E. Peterson. Grid squares are 1 m^2. J#s refer to jacketed specimens, NJ#s refer to specimens removed without jacketing.

public lands, required an analysis under the National Environmental Policy Act (NEPA) and was addressed under an environmental analysis. Because the initial site was discovered within an arroyo (Fig. 3B), additional permitting (404 permit) was required from the U.S. Army Corps of Engineers. Since 1989, the junior authors (Petersons and D'Andrea) and other NMMNH volunteers have dedicated more than 6000 hours of labor documenting and excavating almost 60 jackets and more than 100 bones from the quarry, with excavations continuing under the direction of the Petersons at this time. Importantly, the BLM provided assistance and heavy excavation equipment to extend quarry operations to the east (out of the arroyo) in the mid 1990s (Fig. 3C). This extension of quarry activities has been critical to the ongoing success of the quarry, and has resulted in some of the most important recent discoveries, including camarasaurid teeth and well preserved, possibly articulated sauropod bones (e.g., jackets 46-60; Fig. 2). In large part because of the many jackets extracted from the quarry, the BLM has also provided additional storage, in the form of a 30-by-60-foot outbuilding, at NMMNH.

To date, the fauna of the Peterson quarry has been mentioned in summary articles by Hunt and Lucas (1993), Lucas et al. (1996), Foster (2000) and Lucas and Heckert (2000) and is indexed in Foster's (2003) paleoecological synthesis of the Morrison Formation fauna. Williamson and Chure (1996) described the partial pelvis, hind limb, and caudal vertebrae of a large allosaurid from the Peterson quarry, but did not address the stratigraphy or taphonomy of the site. Recently, we (Peterson et al., 1999a,b; Heckert et al., 2000) have begun to summarize data on the stratigraphy and taphonomy of the Peterson quarry, and we present those results in more detail in the following sections. Importantly, we provide a new quarry map (Fig. 2) documenting another nine jackets removed since our earlier report (Heckert

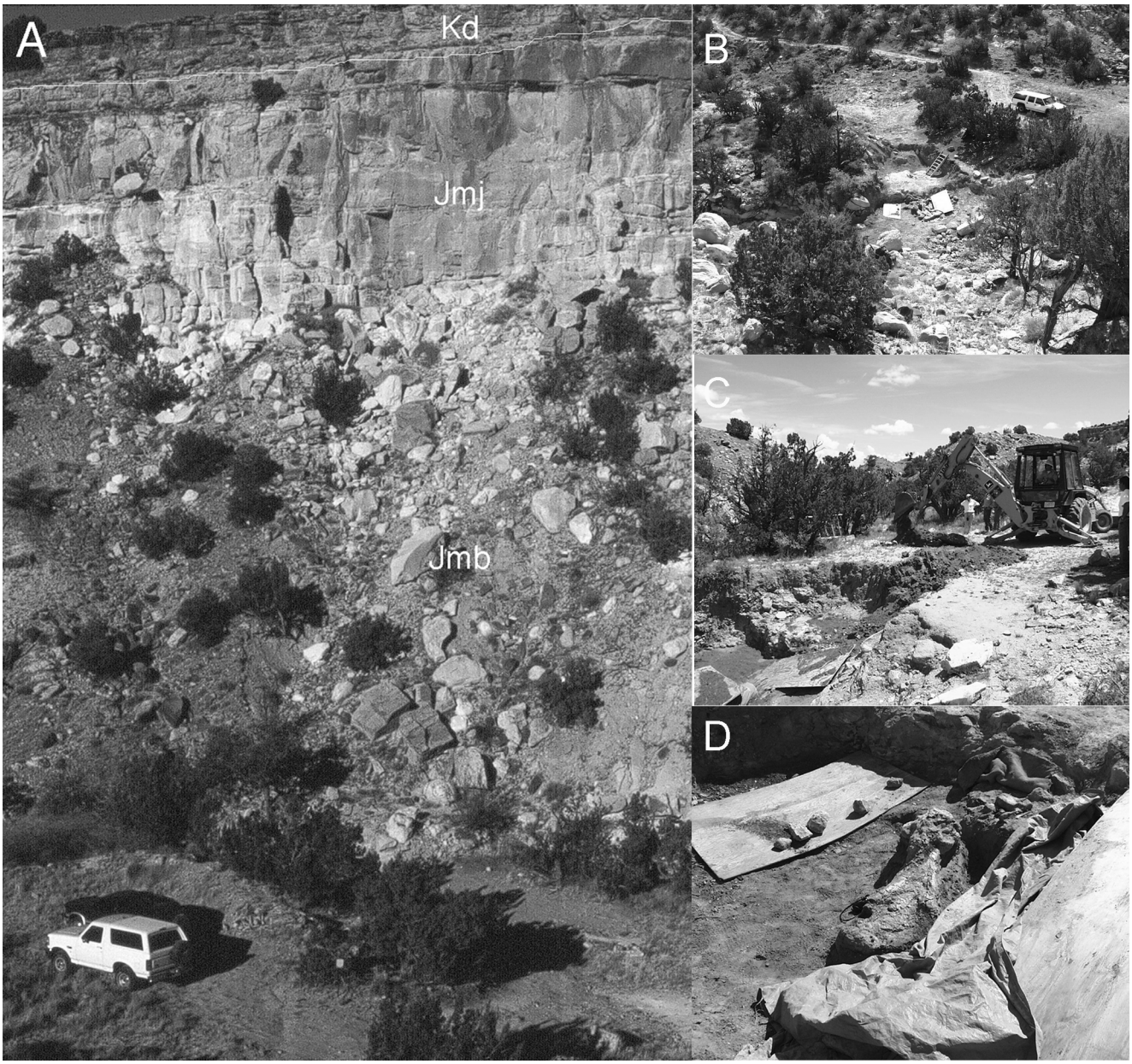


FIGURE 3. Outcrop photographs of the Peterson quarry. A. Overview of the quarry (below junipers to right of vehicle) showing the stratigraphy of the area; B. overview of quarry operations from the opposite side of the valley, ladder and lumber are in the quarry area; C. BLM backhoe operator removing overburden in the eastern quarry; D. sauropod bone exposed in the field. Abbreviations: Jmb, Brushy Basin Member, Jmj, Jackpile Member, Kd, Cretaceous Dakota Formation.

et al., 2000). As of this writing, 15 of the 60 jackets (including unjacketed blocks, e.g., "NJ 54" on Figure 2) have been prepared or are under preparation, and 21 specimens have been catalogued into the collections of the NMMNH (Table 1).

STRATIGRAPHY

In western and north-central New Mexico, the Morrison Formation consists of three members (in ascending order): Salt Wash, Brushy Basin, and Jackpile (Anderson and Lucas, 1996, 1997; Lucas and Anderson, 1998; and references cited therein). Of these, the Salt Wash and Brushy Basin members are readily correlated throughout the Morrison outcrop belt in the Western Interior (Anderson and Lucas, 1998). The Peterson quarry is located in the Brushy Basin Member of the Morrison Formation, as are almost all large Morrison Formation dinosaur quarries (Turner and Peterson, 1999; Foster, 2003). The quarry lies in the floor of an arroyo approximately 26 m below the contact of the Brushy Basin Member with the overlying Jackpile Member of the Morrison Formation (Fig. 1, 3A).

Most, if not all, of the dinosaur bones are found in a 1.1-m-thick sandstone lens that overlies and fills scours in less well indurated, underlying sandstone (Figs. 1-2). The bone-bearing sandstone is a well indurated, yellowish-gray, fine- to coarse-

TABLE 1. Inventory of catalogued specimens from the Peterson quarry (L-3282)

Specimen #	Taxon	Elements	Jacket #
26083	Allosauridae	Partial skeleton - femur, tibia, fibula, and phalanges	4, 5, 14, 15, 17
26084	Diplodocidae	Partial skull and mandible	NJ (Not Jacketed) 8
27340	*Camarasaurus* sp.	(1) left ischium (proximal)	36
33694	?	(1) rib fragment	42
34844	Sauropoda	(numerous) small fragments	50
35383	Sauropoda	(1) skull fragment	NJ 54B
35384	Sauropoda	(1) tooth	NJ 54A
35385	Sauropoda	(2) teeth	NJ 54D
35386	Sauropoda	(2) teeth and (5) fragments	NJ 54C
35819	Theropoda	(1) rib	?
35820	Sauropoda?	(1) probable vertebra	43
35958	Allosauridae?	(1) incomplete distal phalanx	?
37746	Sauropoda?	(1) fragment of large flat element	early jacket (# lost)
37747	Sauropoda?	(4) skull (?)/dentary (?) frags	early jacket (# lost)
37748	Dinosauria?	(1) fragment of an ungual?	
37876	Dinosauria	(11) associated rib frags.	1 (26 on map)
37877	Dinosauria	(4) associated vertebral frags	2 (29 on map)
37878	Theropoda?	(2) vertebral and assoc. frags	32
37879	Sauropoda?	(1) neural spine(?)	?
38575	Sauropoda	(1) fibula	16
39598	*Camarasaurus*	(1) tooth	NJ 54
39768	Diplodocidae?	(1) left ulna	20
39769	Allosauridae	(1) caudal vertebra	20
39770	Diplodocidae?	(3) incomplete vertebrae	24

grained, subangular, poorly sorted subarkose. This unit is trough-crossbedded with some clay-pebble conglomerate clasts at the bases of trough sets. Some thin (< 5 cm thick), discontinuous, sub-meter-scale mudstone lenses are also present. Overlying the bone-bearing sandstone is a 2.2-m-thick series of 0.6-0.9-m-thick sandstone beds of broadly similar lithology. All are subarkosic, although grain size and sorting vary widely. Heckert et al. (2000) provided a detailed description of the measured section illustrated in Figure 1.

TAPHONOMY

The taphonomy of the Peterson quarry can be evaluated using two sets of data, the sedimentological and the biological. Sedimentological data includes the sedimentology of the deposit itself, the alignment and abrasion states of the bones, hydraulic sorting of the fossil material and density of fossil material in the deposit. The biological data set includes the degree of skeletal articulation, weathering stages of the bones, scavenger marks (if present), fracture patterns, minimum number of individual calculations, age profiles of the taxa (when possible), and identification of any plant material present.

Sedimentological Data

The Peterson quarry is near the top of a 1.1 m thick sandstone lens that overlies and scours into a lower sandstone and is overlain by an additional 2.2. m of similar sandstone that is in turn overlain by a thick mudstone-dominated interval (Figs. 1, 3A). The bone-bearing sandstone lens is a well indurated, poorly sorted subarkose that contains faint trough crossbeds. Subangular to subrounded intraformational clay pebbles occur at the bases, of some of the crossbed sets. There are also thin (cm-scale), discontinuous mudstone lenses within the sandstone. These data indicate that the Peterson quarry fossil material was deposited in a fluvial system. Given the proximity of the bones to the lithologic transition from the sandstone to a mudstone, and the presence of discontinuous mudstone lenses within the sandstone, the fluvial system was probably aggrading its bed, prior to avulsing.

The bones, if they are considered as clasts that are acted upon by fluvial forces, can be indicators of current direction and strength. The bones in the Peterson quarry show a preferential east-west alignment, and many of the bones have a moderate (<10 degrees) dip to the northwest (Fig. 2). Thus, the current that acted upon the bones was strong enough to orient them and was flowing either east to west or vice versa. As there is no indication of deformation of the quarry layer, the dip of the bones to the northwest is probably due to the bones lodging against the end of a bar within the channel, which would indicate that flow was to the east.

The bones show little evidence of bone abrasion, but we note here that in many cases, the state of preservation of the fossil material is poor enough that evidence of abrasion may not be visible. However, a lack of strong abrasion of the bones would indicate that the bones were not transported within the stream for long distances. The irregular surfaces and poor preservation of material situated slightly above the other bones (and closer to the modern stream course) could be due to two different processes. It is possible that these fossils, due to their proximity to the modern channel, have interacted to a greater degree with groundwater and surface waters, leading to this odd preservational appearance. The other possibility is that these fossils, while still fresh, were lying upstream of the rest of the bones and were subsequently reworked over the other material (e.g., Behrensmeyer, 1988). This second stage of transport would probably be enough to cause further damage to the bones.

Many of the bones that have been recovered from the quarry are large limb bones, or semi-articulated groups of smaller bones, such as vertebrae (Fig. 2). The larger bones have a moderate to low surface area to volume (SA:V) ratio, and if we were to utilize the Voorhies Groups (Voorhies, 1969), we would initially think that these bones were moved by a low to moderate velocity current. However, Voorhies' flume experiments were conducted using bovid bones, which are obviously not in the same size class as the Jurassic dinosaur (sauropod and allosaurid) bones studied here. Thus, given the large size of these bones, we may assume that the current that oriented them was quite strong. This assumption is further supported by the lack of individual smaller elements such as small limb bones (metapodials), cervical ribs, chevrons, and other small vertebral elements. These smaller,

lighter elements were winnowed away by the strong current, leaving a lag deposit of heavier bones and partial carcasses.

The Peterson quarry is a rich assemblage, with an average of 2-3 bones per square meter (Fig. 2). Given that much of the material is associated or articulated, and the relatively high density of bones, the material was not transported far before deposition. The sedimentological data point to a fossil assemblage that was transported a short distance by a moderate to high velocity current prior to channel avulsion. Some time after the deposition of the Peterson material, the stream abandoned this particular channel. Thus, from a sedimentological point of view, the Peterson quarry is a lag deposit.

Biological Data

Most of the material in the Peterson quarry is either partially articulated or associated. At least two strings of articulated vertebrae have been recovered, as well as the sacral region, hind limbs and caudal vertebrae of an allosaurid (Figs. 2, 4; Williamson and Chure, 1996; Heckert et al., 2000). This high degree of element association indicates that the carcasses were only partially decayed prior to deposition. Thus, the animals had not been dead long enough to be completely scattered by scavengers, nor had the material been transported enough for the skeletons to be completely pulled apart.



FIGURE 4. Peterson quarry allosaurid fossils (all are NMMNH P-26083). A. incomplete right ilium and caudal vertebrae in lateral view; B. left femur in posterior view; C. left tibia in lateral view. D, right ischium in medial view; E. left ischium in medial view; F-G. left pedal phalanx II-1 in E, dorsal and F, lateral views; H-I. left pedal phalanx II-2 in G, lateral and H, dorsal views. J-K. left pedal phalanx III-2 in I, dorsal and J, lateral views. L-M. left pedal phalanx II-3 in K, lateral and L, dorsal views. Scale bars = 6 cm for A-D and 2 cm for E-L.

Most of the bones are in a relatively poor state of preservation, so that positive identification of weathering stages is not entirely possible. Also, individual bones were often exposed for several months during excavation and prior to jacketing and removal. Thus, many of the bones, while probably relatively unweathered as fresh skeletons, appear to be poorly preserved as fossils. Given the articulation states and short transport of partially articulated skeletons, it is unlikely that the bones were exposed for periods long enough to weather the bones to any substantial degree.

There are no scavenger marks, such as tooth or bite marks, on the bones, though we again note the caveat of the poor preservational state of the bones surface on many of the prepared specimens (and the large volume of unprepared material). Once again, given the high degree of articulation and association, it is unlikely that vertebrate scavengers interacted with the material enough to leave definitive marks on the bones.

All of the bones are badly fractured in multiple places. The fractures are all perpendicular to the bones' long axes, with no spiral or jagged fracture patterns. These types of fracture, with flat surfaces, are indicative of post-fossilization fracturing, which is usually due to sediment loading or to decompressive stresses when the bones are first unearthed. As mentioned previously, the lengthy exposure of many of the elements prior to removal also aids in the fracturing of the bones. Thus, none of these bones were fractured prior to burial of the skeletons. This is simply an indication that the carcasses were not trampled or stepped on by other large vertebrates before they were covered with sediment.

Minimum number of individuals (MNI) are usually calculated from the maximum number of a sided element (e.g., 12 left and 5 right femora would lead to an MNI of 12 individuals (Badgley, 1986)). In the case of the Peterson quarry, we may also use the associated and articulated pockets of skeletal elements to represent individuals. Thus, there is at least one allosaurid (based on the partial skeleton), one diplodocid (based upon a single skull recovered) and one camarasaurid (based upon isolated, but locally associated teeth). All the sauropod postcranial elements are referable to either the diplodocid or the camarasaurid. To date, there is no duplication of sauropod elements among the prepared fossils.

We did not attempt to construct age profiles for any of the taxa because there are not enough individuals to construct a histogram that could indicate the approximate ages of all individuals in the quarry. However, given further excavation and preparation, it may be possible to construct age profiles and determine whether or not this is a catastrophic accumulation of a population of animals, or simply the attritional accumulation of random individuals who died of predation or disease.

Through the time of this publication, no fossil plant material had been recovered from the quarry. This is not unexpected if the assemblage has indeed been transported by moderately high velocity currents. Any lightweight, buoyant plant material would have been quickly winnowed out of the deposit.

The biological data thus indicate that at least three partially decayed corpses, one of an allosaurid and two of sauropods, were washed into a stream channel. Given the more articulated state of the allosaurid, we suspect that this corpse was either added shortly after the sauropod remains or that the sauropod carcasses were older and had had more time to begin to decay and dissociate. The carcasses were not exposed to scavenging and weathering for very long prior to their burial. Because we have not recovered enough material to reconstruct age profiles, it is not possible at this time to determine whether these carcasses may be part of a much larger catastrophic assemblage, or if they were simply three carcasses that were washed together into a single deposit.

Comparison

The Peterson quarry can be compared to a similar accumulation at Dinosaur National Monument (DNM) in western Colorado. The mass accumulation at DNM is thought to have developed as a channel-lag deposit (Morris et al., 1996). These elements were deposited within a confined channel during a series of depositional events and are all strongly oriented. The environment of deposition has been inferred to be a meander in a fluvial system where bone accumulated during episodes of confined flow (Morris et al., 1996). Interestingly, many of the bones at DNM are well preserved on their lower side, but the upper side is almost entirely destroyed, which indicates that the material was half-buried in sediments, so that the upper half weathered away, while the lower half was preserved (Gilmore, 1932; Lawton, 1977).

At DNM, the bones were deposited near the base of an active channel. The Peterson quarry material, on the other hand, was probably washed into a channel as the mixed fill that is associated with a channel that was being abandoned as the stream avulsed across the landscape. We note that, in general, the sedimentology of the Peterson quarry and the orientation of the elements in three dimensional space match well with the taphonomic data from other fluvial Morrison deposits (Dodson et al., 1980; Foster, 2003).

PALEONTOLOGY

At least three, and possibly four, large dinosaurs are present in the fauna of the Peterson quarry. Unambiguous fossils include the partial skeleton of a large allosaurid theropod (Williamson and Chure, 1996; Fig. 4), a diplodocid sauropod (Heckert et al., 2000) and a camarasaurid (Fig. 5G-H). Additionally, several sauropod dorsal vertebrae from the site (Fig. 5A) resemble the enigmatic sauropod *Amphicoelias*, which would be a first New Mexican occurrence for this rare Morrison Formation taxon. In the following paragraphs we document the nature and significance of the allosaurid and the sauropods.

Allosaurid

Williamson and Chure (1996) described a partial pelvis, hind limbs, and caudal vertebrae of a large allosaurid theropod. As they documented, this specimen, NMMNH P-26083, consists of the posterior half of the right ilium, paired, nearly complete ischia, incomplete left femur, left tibia and fibula, several left phalanges, two sacrals? and four caudal centra as well as four chevrons (Fig. 4). Williamson and Chure (1996) noted that the elements of P-26083 are larger than any known *Allosaurus* and similar in proportion to *Saurophaganax*. A statistical analysis of

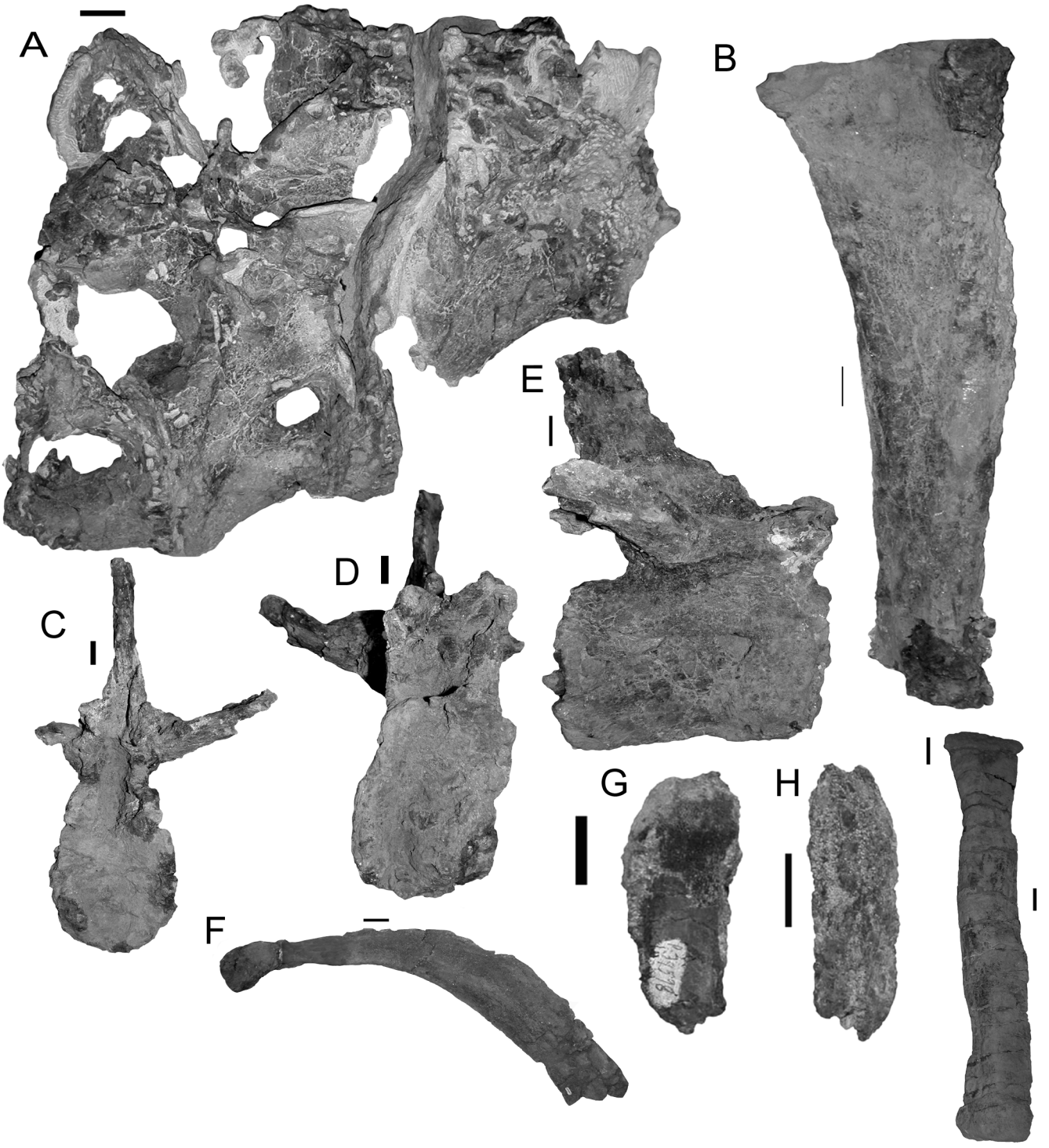


FIGURE 5. Peterson quarry dinosaur fossils. A. matrix block with three sauropod vertebrae (P-39770) in sequence; B. sauropod left ulna (P-39768) in anterior view. C-E. theropod caudal vertebra, (P-39769, but possibly part of P-26083), in C, anterior, D, posterior, and E, right lateral views. F. left ischium? (P-27340) in left lateral view. G-H. camarasaurid tooth (P-39598) in G, labial and H, lingual views. I. left fibula (P-38575) in anterior view. Scale bars = 6 cm for A-B, F, and I and 2 cm for C-E, and G-H.

the Cleveland-Lloyd quarry sample of *Allosaurus* undertaken by Rinehart et al. (2002) further demonstrates that the Peterson quarry theropod is much too large to pertain to even an extremely large, old individual of *Allosaurus*. However, no features of the preserved material of P-26083 are autapomorphies of *Saurophaganax,* and there is no overlap of this material with the comparably sized allosaurids *Epanterias amplexus* Cope and *Torvosaurus tanneri* Galton and Jensen (Williamson and Chure, 1996).

Here, we briefly highlight a few additional details of P-26083. All of the specimens associated with NMMNH P-26083 were

found in close association over a 2 by 4 meter area at the western edge of the quarry excavations (Fig. 2). These bones were excavated in a series of plaster jackets, with both the sacrum and vertebral material in one jacket (Jacket 17) and ischia and limb bones in individual jackets (J). Notably, the tibia (J5; Fig. 4D), fibula (J5, Fig. 4C), ischia (J15) and femur (J4; Fig. 4B) were all aligned approximately east to west (Fig. 2). Therefore, as noted in the preceding section on the taphonomy of the quarry, paleoflow was apparently sufficient to push and slightly disarticulate (but not disassociate) the allosaurid skeleton. At least two sauropod long bones (NMMNH P-38575—J16, J20; Fig. 5I) were also associated with the allosaurid skeleton. Recent preparation of jacket 20 recovered a relatively small theropod caudal centrum (NMMNH P-39769—Fig. 5C-E) that may pertain to NMMNHN P-26083 as well. This centrum is weakly amphicoelous with a tall neural canal and tall neural spine that is inclined posteriorly (Fig. 5C-E). The transverse processes are directed laterally and similarly inclined posteriorly so that, when intact, the vertebra would have had a triangular shape in dorsal view. Two depressions on the surface of the right side of the centrum superficially resemble small pleurocoels, but are not present on the left side and thus are probably a result of postmortem crushing associated with burial of the specimen.

Very little of the preserved theropod material includes features identified as synapomorphies of the Allosauridae in recent phylogenetic analyses (e.g., Holtz, 1994, 2000; Harris, 1998; Sereno, 1999). However, the femoral head is directed dorso-medially (is at a greater than right-angle with the femoral shaft—Fig. 4B), a possible synapomorphy of the Allosauridae (Holtz, 2000). Instead, the specimen has generally been assigned to the Allosauridae based on its gross similarity to *Allosaurus* (Madsen, 1976) rather than based on any particular suite of allosaurid synapomorphies (Williamson and Chure, 1996; Heckert et al., 2000).

Sauropods

There are at least two taxa of sauropod dinosaurs present at the Peterson quarry, and sauropod fossils dominate the site numerically. However, with the exception of the incomplete diplodocid skull and teeth described by Heckert et al. (2000), most of the preparation completed to date has been on the allosaurid, which appears to be the most unique dinosaur from the Peterson quarry. Consequently, the known sauropods have been identified primarily by teeth. Indeed, no dorsal or proximal caudal sauropod vertebrae have been completely prepared as of this writing. However, sauropod dinosaurs are actually the most common fossils at the quarry, and almost all fossils collected since 1994 (jackets 24 and more recent) pertain to sauropod dinosaurs. In the following paragraphs we provide brief descriptions of the known sauropod fossils from the Peterson quarry. We note here that in spite of recent work on sauropod phylogenetics (e.g., Upchurch, 1998; Wilson and Sereno, 1999), the vast majority of professional literature that is useful for identifying disarticulated sauropod material was written in the first half of the previous century (e.g., Osborn and Mook, 1921; Gilmore, 1925, 1932, 1936). Hopefully in the future modern dinosaur workers generally, and sauropod workers in particular, can work to make more comprehensively illustrated monographs, along the lines of McIntosh et al. (1996).

An incomplete diplodocid skull and lower jaws was recovered from a float block early in the excavations of the Peterson quarry. This specimen was first illustrated by Lucas et al. (1996) and described in detail by Heckert et al. (2000). To date, very little of the prepared material appears to represent diplodocids. A possible exception is the three semi-articulated posterior dorsal centra currently under preparation at NMMNH (Fig. 5A). This specimen, collected in jacket 24 (Fig. 2), consists of a partial dorsal vertebra in close articulation with a second vertebra, and a third vertebra that is slightly displaced dorsally and posteriorly. All three centra bear large lateral pleurocoels that are deepest on the posterior side of the lateral surface of the centrum. The neural arches, spines, and transverse processes are present on all three vertebra, and most complete on the two anteriormost vertebrae. However, they are poorly preserved, at least somewhat crushed, and apparently incomplete. This hampers attempts to identify the vertebrae, although the elongate centra, which appear amphicoelous or nearly so, much more closely resemble those of diplodocids (Gilmore, 1936; McIntosh, 1990) than other Morrison sauropods, and are definitely not referable to *Camarasaurus* (Osborn and Mook, 1921; McIntosh et al., 1996). Similarly, the neural spines are much too tall to pertain to a brachiosaurid (Janensch, 1950; McIntosh, 1990). Interestingly, if the vertebrae are amphicoelous, they may pertain to the rare Morrison Formation sauropod *Amphicoelias*, so named because of the amphicoelous nature of its dorsal vertebrae (Cope, 1877; Osborn and Mook, 1921).

We interpret another isolated element (NMMNH P-39768; Fig. 5B) as a left ulna of a sauropod. This specimen, as preserved, measures 107.5 cm proximal to distal, 31.4 cm mediolaterally at the proximal head, and 13.5 cm mediolaterally at its midshaft. There is a well-developed process projecting from the proximal end of the bone that well-matches the olecranon process of a sauropod ulna. The bone is otherwise long and relatively gracile, much more so than in the diplodocid *Apatosaurus* or in *Amphicoelias* (Hatcher, 1902; Osborn and Mook, 1921; Gilmore, 1936), but is comparable to that of *Diplodocus* (Gilmore, 1932; McIntosh, 1990) and also somewhat resembles that of the rare taxon *Dystrophaeus* (Gillette, 1996). Therefore, we provisionally identify this element as the left ulna of a diplodocid sauropod, possibly *Diplodocus*.

Recently, excavations at the Peterson quarry have yielded several spatulate teeth (e.g., Fig. 5G-H). NMMNH P-39598, as preserved, measures 7.64 cm basal to occlusal, 2.44 cm anterior to posterior, 1.13 cm lingual to labial at its crown, and 2.30 cm lingual to labial at its root. Spatulate teeth are known from non-diplodocid Morrison sauropods, most commonly *Camarasaurus* and *Brachiosaurus* (e.g., McIntosh, 1990 and references therein). We refer these teeth to *Camarasaurus* because they possess the broader, more spatulate shape typical of that genus (e.g., Gilmore, 1925), as opposed to the less-well defined "spoon-shaped" teeth of *Brachiosaurus* (e.g., Janensch, 1935/36). As with the diplodocid teeth described in detail by Heckert et al. (2000), these teeth are neither numerous enough nor well-enough preserved to evaluate tooth wear (e.g., Fiorillo, 1998), although the enamel is relatively well-preserved on the specimen we illustrate here.

Another possible camarasaurid element is NMMNH P-27340 (Fig. 5F), which bears at least some resemblance to the ischium of a young *Camarasaurus* (R. Wilhite, written comm., 2001). The specimen, as preserved, measures 91.5 cm anterodorsal to posteroventral, 12.7 cm dorsoventrally near the proximal end, and 18.7 cm dorsoventrally near the distal end. However, we refrain from assigning this specimen to *Camarasaurus* pending further study.

Another sauropod element from the Peterson quarry (P-38575) has tentatively been identified as a fibula (R. Wilhite, written comm., 2001). The specimen, as preserved, measuring 105.5 cm proximal to distal, 21.3 cm mediolaterally at the proximal head, and 16.0 cm mediolaterally near the midshaft. Its long, slender shaft and almost completely unexpanded ends are typical of *Diplodocus* or, possibly, *Barosaurus*. The fibula is much more gracile than that of *Apatosaurus*, *Camarasaurus*, or *Brachiosaurus* (McIntosh, 1990).

As shown in Figure 2, most of the last 40 or so jackets removed from the Peterson quarry are large limb and rib bones doubtless associated with sauropod dinosaurs. To date, relatively few of these jackets have been prepared, and none could be reliably identified in the field. However, these jackets clearly contain numerous hind limb elements, several of which may be articulated (e.g., a possible tibia and fibula in jacket 48, just east of a probable femur in jacket 46). We anticipate that further collecting at the Peterson quarry and preparation of the material already collected will allow future refinement of the composition of the quarry fauna.

SIGNIFICANCE AND DISCUSSION

In spite of the intense efforts of the last decade, much remains to be understood about the Peterson quarry. For example, the only known limits to the bonebed are related to exposure—as more overburden is removed, more fossils are inevitably discovered, especially to the south and east. Thus, we can only guess at how extensive the quarry may be. Importantly, preservation appears to improve to the south and east, out of the modern-day arroyo and into less weathered rock. Consequently, we expect that many of the sauropod fossils in jackets 21-60, alluded to previously, will provide well-preserved, identifiable material in the relatively near future.

Clearly, the Peterson quarry represents a fluvially-dominated accumulation of bones. The coarse grain size, trough crossbedding, and alignment of long bones a meter or more in length all speak to a substantial fluvial system, probably one that aggraded during the final stages of channel abandonment. The presence of this deposit and numerous similar sandstone bodies in the Brushy Basin Member in the region demonstrate that the Brushy Basin Member in New Mexico represents the deposits of a typical fluvial system with isolated coarse-grained channels separated spatially by fine-grained floodplain deposits. Thus, there is no reason to believe that a large lacustrine system (Lake T'oo'dichi' of Turner and Fishman, 1991) deposited the Brushy Basin Member of the Morrison Formation of northern New Mexico.

In a comprehensive review, McIntosh (1990) documented fewer than 10 diplodocid skulls from the Morrison Formation of the United States. These include two of *Diplodocus longus*, two of *D. carnegii*, and one of *Apatosaurus louisae*, considerably fewer than sauropod species known from postcrania from this same interval, even given the oversplit state of Morrison Formation sauropod taxonomy, in which McIntosh (1990) recognized as many as ten species of diplodocids. The last decade has not substantially added to this record, which was developed over 120 years of collecting, although another skull of *Apatosaurus* is now known from Como Bluff (Connely, 1997), and a private collector has successfully recovered skulls of *Apatosaurus*, *Diplodocus*, and *Camarasaurus* from the Howe Quarry in Wyoming (Ayer, 1999).

Consequently, any sauropod skull fossil from the Morrison Formation is potentially the first record of a particular taxon. Therefore, NMMNH P-26084 is important because it is both the only sauropod skull and jaw material recovered from the Jurassic of New Mexico and one less than 20 Morrison Formation diplodocid skulls known. The preserved skull is too incomplete to assign to a specific genus, but the numerous sauropod postcrania from the locality should, when prepared, facilitate genus-level identification of both the diplodocid and the camarasaurid from the Peterson quarry.

To date, perhaps only a quarter of the material recovered from the Peterson quarry has been prepared. Clearly, as more of this material is prepared, our knowledge of this fauna will continue to increase. For example, in just the last few years we have added *Camarasaurus* to the quarry fauna. However, the uniqueness of the site in preserving both sauropod skull material, as well as a large allosaurid, has already vindicated the extensive effort of various agencies, including BLM and NMMNH, to support this excavation.

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All excavation, fossil recovery, and data collection at the Peterson quarry has been conducted by volunteer crews working over the last 11 years, so that over 6000 volunteer hours have been dedicated to collecting dinosaur bones from this site under the direction of the Petersons. NMMNH volunteers prepared the fossils we illustrated and described. Ray Wilhite identified some of the sauropod elements described here. The United States Bureau of Land Management, particularly Mike O'Neill, have provided tremendous logistical support of efforts at the Peterson quarry, which is located on lands administered by BLM. Discussions with A.K. Behrensmeyer and other visitors at an earlier presentation of this material (Peterson et al., 1999b) influenced the ideas presented here.

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