Geology and stratigraphy of the Seismosaurus locality, Sandoval County, New Mexico

by Hilde L. Schwartz, P. O. Box 156, Dixon, New Mexico, 87527
and Kim Manley, 4691 Ridgeway Dr., Los Alamos, New Mexico 87544

Abstract

The Brushy Basin Member of the Morrison Formation (Upper Jurassic) is widely exposed in western North America and is well known for its diverse and abundant dinosaur fauna. Before 1985, however, the Brushy Basin in central New Mexico had yielded few fossils and was thought to be relatively barren of dinosaur remains. A group of new fossil sites reverses this view. They contain the remains of several different dinosaur taxa, including the gigant sauropod Seismosaurus. The new localities are in the southeastern San Juan Basin, in an area that is both structurally and sedimentologically complex. Mapping shows that the fossil sites do not occur along a single horizon but are distributed through at least 65 meters of section, occurring in a variety of facies.

Introduction

Since 1985, several important paleontological sites have been discovered in the Morrison Formation approximately 50 km northwest of Albuquerque, New Mexico. The general location of the sites is shown in Fig. 1; precise locality data is not shown. In the interest of fossil protection, but is on file at the New Mexico Museum of Natural History (NMMNH). These sites have yielded dinosaur remains, including those of a supergiant sauropod, Seismo-
General stratigraphy, age, and structure

The Upper Jurassic Morrison Formation of the Western Interior is a complex, widespread sequence of continental fluvial and lacustrine sedimentary rocks that is well known for its abundant dinosaur fauna (e.g., Ostrom and McIntosh, 1966; Dodson et al., 1980). In central New Mexico, the Morrison is approximately 230 m thick and consists of four members, in ascending order: the Recapture, the Westwater Canyon, the Brushy Basin, and the Jackpile Sandstone Members (Flesch, 1974, 1975; Owen et al., 1984). These units were mapped by Santos (1975) and are well described in Flesch (1974, 1975) and Flesch and Wilson (1974).

Most of the fossil sites discussed below are in the Brushy Basin Member, the most widely exposed and fossiliferous unit of the Morrison Formation; one site is in the uppermost portion of the underlying Westwater Canyon Member. The Brushy Basin in this part of New Mexico is exposed in broad canyons whose slopes are commonly covered by an overburden of sandstone rubble and rotated, landslipped blocks of well-indurated sandstone.

Near the Seismosaurus site, the Brushy Basin consists of approximately 80 m of variegated claystones, siltstones, sandstones, and rare limestones, punctuated by resistant ledges of well-indurated sandstone (Fig. 2). Many of the claystones are altered volcanic ash beds, as indicated by relict shard textures in beds that have been altered to clinoptilolite or by their bentonitic clay composition. The ledge-forming sandstone beds in the Brushy Basin range in thickness from several centimeters to several meters and are dominantly coarse-grained arkosic arenites. They are cemented for the most part by siliceous minerals (mainly chaledony) and minor calcite. Authigenic clays are also present in many horizons. Individual sandstone beds are lenticular, but some extend far enough to be useful as local marker horizons. Highly polished, subangular to subrounded pebbles and cobbles (ranging from 1 cm to 15 cm), of exotic lithologies, also occur in the Brushy Basin. Their origin and significance is currently being studied by Manley (1989, 1991a,b; Johnston et al., 1990). Overall, the Brushy Basin deposits in the study area represent fluvial channel, floodplain, pond, and playa lake facies (Flesch, 1974; Bell, 1986; Turner and Fishman, 1991).

Preliminary K/Ar dates from the Brushy Basin Member near the Seismosaurus locality indicate a minimum age of sedimentation of 154 ± 2.4 Ma (Waldegabriel and Hagan, in press). 40Ar/39Ar ages for the Morrison Formation at Montezuma Creek, Utah and Dinosaur National Monument, Utah range from 153–145 Ma (Kowallis et al., 1991), and it is unknown to what extent the Morrison Formation may be time-transgressive.

Structurally, the Brushy Basin and Westwater Canyon Members exposed in the study area are dominated by low westerly and southwesterly dips (<10°) and are cut by several NNW- to ENE-trending faults that are predominantly down to the southwest. These faults are high angle and have offsets of as much as 60 m. Sandstone lenses in the Brushy Basin Member contain numerous small fractures with slickenside surfaces, along which net motion has been negligible.

Fossil sites

All the fossil sites described are in T15N, R1W and R1E. To date, more than a dozen dinosaur bone sites have been discovered in the area; of these, nine have been documented and studied. The latter are designated Seismosaurus I (SSI), Seismosaurus II (SSI), Seismosaurus III (SSIII), McConnell I (MCI), McConnell II (MCII), Martini I (MTI), Cary–Jim I (CKI), Cary I (CI), and Lat I (LI). Other localities within a 5 km radius from the main, Seismosaurus I site have yet to be mapped and studied.

The nine sites discussed below are separated by a maximum distance of 2.8 km, with five of them located within a radius of 1 km. The stratigraphic interrelationships of all the sites could not be directly measured because of erosion and faulting; one group of sites, SSI, SSII, SSIII, MTI, CKI, CI, and LI, is closely spaced and not separated by faulting. Faults separate this group from the MCI and MCII sites, however. The relative stratigraphic positions of these two groups of sites were determined by establishing the irrelationship to the base of the overlying Jackpile Member. Because the Brushy Basin and Jackpile Sandstone may be intertonguing over several meters of vertical section and because the basal contact of the Jackpile Sandstone is locally channelled into the Brushy Basin, these measurements allow for only an approximate correlation.

Fig. 2 illustrates the stratigraphy of the Brushy Basin and uppermost Westwater Canyon Members in the study area and the stratigraphic positions of the fossil sites. The "Seismosaurus" localities: SSI, SSII, and SSIII are, respectively, 26, 31, and 35 meters below the Jackpile Sandstone. McConnell I is approximately 18 m below the base of the Jackpile Sandstone and McConnell II 5 m below the base. The Martini I site is 46 m below SSI and 72 m below the Jackpile Sandstone. Sites CKI and LI occur at about the same stratigraphic level, approximately 32 m below the Jackpile Sandstone. Locality CI lies approximately 39 m below the Jackpile Sandstone. The contact between the Brushy Basin Member and underlying Westwater Canyon Member is not sharp but vertically interfinger through a stratigraphic interval of approximately 20 m. The lower boundary of the Brushy Basin is placed at the top of the highest thick, continuous sandstone unit, in accordance with Flesch (1974).

Site descriptions

Seismosaurus I (SSI)

The largest excavated site and main source of Seismosaurus remains thus far is locality SSI. It is near the top of a peninsular mesa that rises 40 m above the surrounding valley floor and is capped by a thick, well-indurated sandstone bed. SSI has yielded
the articulated remains of a single *Seismosaurus* individual, including vertebrae, ribs, chevrons, parts of the innominate bone, and gastroliths (Gillette, 1986, 1991). The bones trend into a hillside and excavation is continuing in search of more. Three of the caudal vertebrae have been prepared and are on display at the NMMNH. Because of its paleontological significance and accessibility, SSI has been studied in greater detail than the other seven sites in the area.

The bones at SSI are enclosed in several different horizons of moderately indurated, buff to grey, arkosic arenite. The sandstone is coarse grained and moderately sorted; its constituent framework grains consist mainly of quartz (80–85%) and feldspar (plagioclase).
gioclase, microcline, and orthoclase, 15-20%). The quartz grains are subrounded to subangular and contain abundant inclusions. Quartz overgrowths and clay rims are common. Feldspar grains are generally subangular and range in preservation from nearly pristine to completely altered. Both fresh and altered grains commonly exhibit twinning, zoning, or perthitic texture.

Minor detrital grains in the SSI sandstone include heavy minerals (predominantly zircon) and rock fragments. The rock fragments are mainly volcanic materials, consisting of feldspar laths and quartz phenocrysts in a dark, fine-grained matrix. Light-colored mottling in the matrix of some of the fragments suggests relict shard textures. Rare sedimentary rock fragments (chert and silicified siltstone) and igneous rock fragments (polycrystalline quartz with muscovite) also occur in the sandstone. Bone fragments make up a significant percentage of the detrital grains in the SSI sandstone near the contacts between dinosaur bone and matrix as well as in sediment-filled cracks in larger bones.

Diagenetic alterations in bone and matrix at SSI were recognized using petrographic and scanning electron microscopes. Cementation is prevalent, occurring as grain coatings, void fillings, and overgrowths. Clay (smectite) rims are common around detrital grains, pore spaces, and voids in both sandstone and bone, and fill in approximately 45-85% of the sandstone porosity. Locally, a second generation of chalcedony cement and quartz overgrowths is volumetrically important in pore space reduction (approximately 15-55%). The largest pore spaces in the bone are the haversian canals, which are tubes that lie parallel to the long axis of a bone. In living bone, the canals are filled with blood vessels, connective tissue, and nerve filaments, but these organic materials decay and wash out of bone with time and burial. Haversian canals in the interior, spongy parts of *Seismosaurus* bone are cemented exclusively by chalcedony. Variable sorting of the sandstone accounts for discrete, concretionary lenses (pore spaces largely filled with chalcedony) in the quarry area, some of which are associated with fossil bone. A later generation calcite cement is also present locally in the sandstone and bone; its distribution is related to the location of large (to several centimeters thick) root and caliche-filled cracks that criss-cross the sandstone at the SSI quarry (Fig. 3).

A microstratigraphic section of the quarry wall at SSI (Fig. 3) shows the internal structure of the *Seismosaurus*-bearing sandstone. Planar laminations, trough cross-stratification, scour and fill, and repeated fining-upwards sequences predominate, suggesting that the deposit represents a fluvial channel sandstone bed (Fisk, 1944; Folk and Ward, 1957; McGowen and Garner, 1970). Crossbedding at the quarry site shows that current directions were generally to the east and northeast. Scroll bars, representing parts of the point bars of large rivers (Fisk, 1944; Sundborg, 1956), are selectively cemented and weathering out across the upper surface of the *Seismosaurus* mesa, several meters strati-
graphically above SSI. They also have an overall east-west orientation and are part of a resistant sandstone that is continuous across several kilometers. Trough cross-bedding, scroll bars, and the sheet-like geometry of the sandstones at SSI all suggest that the *Seismosaurus* died on or near the banks of a large meandering river.

**Seismosaurus II (SSI)**

SSI is 0.2 km southeast of, on the same mesa as, and 5 m stratigraphically below SSI. It consists of several piles of bone fragments. The fragments are parts of large bones that eroded (apparently in place) from a sandy shelf composed of poorly indurated, buff sandstone. The fossiliferous sandstone was deposited directly above a well-indurated, dark sandstone bed (with abundant 1-cm-sized calcite concretions), and is interpreted to be a paleochannel deposit.

**Seismosaurus III (SSIII)**

An isolated limb bone was excavated from the SSIII locality. The bone was found in situ in an olive-green claystone, approximately 4 m stratigraphically below SSI. The claystone lies between two channel sandstones and is itself an overbank deposit. SSIII is located approximately 0.2 km northeast of SSI, on a ledge on the north side of the same peninsular mesa.

**McConnell I (MCI)**

MCI consists of an accumulation of disarticulated skeletal elements, including ribs, teeth, vertebrae, one tooth, and one gastrolith in situ. The bones represent at least two individuals, a sauropod and a carnosaur (Gillette, 1991). They are at the base of a short, steep slope in a silty olive claystone that crops out 2.8 km southeast of SSI. The MCI stratum is part of a thick floodplain-overbank sequence that is near the top of the Brushy Basin Member.

**McConnell II (MCII)**

Only 0.1 km south-southeast of MCI, the MCII site is stratigraphically 13 m higher than its neighbor. One large bone and numerous bone flakes and fragments (unidentified to date) are exposed here. They are eroding from a dark reddish-brown siltstone bed that is part of the same floodplain-overbank complex as MCI.

**Martini I (MTI)**

The MTI site is 1.4 km east of SSI in a sandstone and small pebble conglomerate of locally derived clasts that is exposed in the middle of a long, steep, rubble-covered slope. The fossiliferous horizon is part of a channel-point bar facies. MTI is approximately 70 m below the base of the Jackpile Sandstone, in a zone of interfingerings between the Brushy Basin and the Westwater Canyon Members. Several large dinosaur bone fragments have been collected from the site.

**Cary–Kim I (CKI)**

One large bone fragment, resting in float on a rubble-covered slope, was found at CKI. This bone was clearly not in situ, and thus only its lowest possible stratigraphic position is known. The hillside at CKI is capped by a moderately well indurated sandstone considered equivalent to that capping the mesa at SSI, which provides some measure of control on the upper limit of the site's stratigraphic position.

**Cary I (CI)**

Various bones and bone fragments are exposed in situ at CI. They are eroding from an olive claystone that crops out 0.8 km south of SSI. Thin, discontinuous limestone outcrops near and stratigraphically just above CI also contain broken fragments of dinosaur bone. These beds represent floodplain deposits that interter with pond or lake-margin sediments.

**Lat I (LI)**

Site LI, about 0.3 km south-southeast of SSI, contains many large fragments of dinosaur bone. The fragments are along one horizon, along 25 m of hillside, but are not in situ; their depositional setting is thus indeterminate. Although one large bone fragment was found in a landslid sandstone block, the rest of the bones lie on a reddish claystone. The hillside at LI is capped by a well-indurated buff sandstone; it lies between 5 and 8 m above the level at which most of the bones are found.

**Conclusions**

The Brushy Basin Member of the Morrison Formation in the southeastern San Juan Basin is much richer in dinosaur remains than was previously believed. Both sauropods (at least *Seismosaurus* and *Caniasaurus*), and possibly others) and a theropod have been identified. Nine documented fossil localities within the study area (approximately 2.24 km²) occur over 65 m of vertical section. They are found in both fine-grained and sandy units, representing a range of paleoenvironments from distal floodplain and pond to fluvial channel and channel top: the fossiliferous sediments may have accumulated near the southern margin of a large alkaline, saline lake ('Lake Kooloobidi'), under semiarid to arid climatic conditions (Turner and Fishman, 1991).

For the most part, the dinosaur remains in the study area represent isolated partial skeletons (articulated and disarticulated) and isolated bones (both complete and broken). In the Morrison Formation to the north of New Mexico, isolated partial dinosaur skeletons and bones occur mainly in floodplain and overbank environments, while mass skeletal accumulations are found mainly in paleochannel deposits (Dodson, et al., 1980). The lack of mass accumulations of dinosaur bone in Morrison Formation paleochannels in the southeastern San Juan Basin suggests that paleoenvironmental conditions varied widely across the Morrison depositional basin (and Lake T'oo'dichi') during the Late Jurassic.

The local abundance of dinosaur bone in this area shows that the Morrison Formation in central New Mexico has great potential for further vertebrate paleontological studies, particularly with respect to taphonomy and paleoecology, and deserves further investigation.

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**References**


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