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Tectonic development of late Pleistocene (Rancholabrean) animal-trapping fissures in the Middle Jurassic Todilto Formation, north-central New Mexico

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Abstract

Open fissures in the Middle Jurassic Todilto Formation near San Ysidro, Sandoval County, New Mexico, trapped large late Pleistocene mammals whose articulated bones are preserved in the fissure fill. The fissures probably originated as the result of two tectonic events—compression that led to closed conjugate fractures during the Laramide orogeny followed by extension associated with development of the Rio Grande rift. During the later event the conjugate shears were opened and additional extensional, open fractures were formed.

Introduction

Pleistocene vertebrate fossils are known in New Mexico from 138 open (or stratified) sites and 23 caves (Harris 2005; Morgan and Lucas 2005). However, fissure-fill deposits containing Pleistocene vertebrate fossils were unknown in New Mexico before the discovery reported here. In 2005 gypsum miners at the White Mesa mine near San Ysidro (Fig. 1) discovered partial to complete articulated skeletons and isolated bones in fissure-fill deposits developed in the Middle Jurassic Todilto Formation (Pino, pers. comm. 2005). A field party from the New Mexico Museum of Natural History (NMMNH), aided by the miners, collected these fossils. Here, the bone-bearing fissure fill is described, and a brief structural analysis is presented to explain the origin of these unusual animal-trapping fissures. The paleontology of the site will be treated in a separate companion article in *New Mexico Geology*.

Study area

NMMNH locality 6112 is in the floor of the White Mesa mine, operated by the American Gypsum Company on Zia Pueblo Reservation property in Sandoval County, New Mexico. There, gypsum is mined from the ~30-m-thick (~100-ft-thick) Tonque Arroyo Member of the Middle Jurassic Todilto Formation (Figs. 1–2). NMMNH locality 6112 is a group of fissure-fill deposits (Figs. 2A–D) that are approximately 12 m (40 ft) below the Recent surface. Large mammal fossils are contained in at least three fissures within a 30-m (100-ft) radius (Fig. 2D). The principal bone-containing fissure trends N70ºW. Gypsum

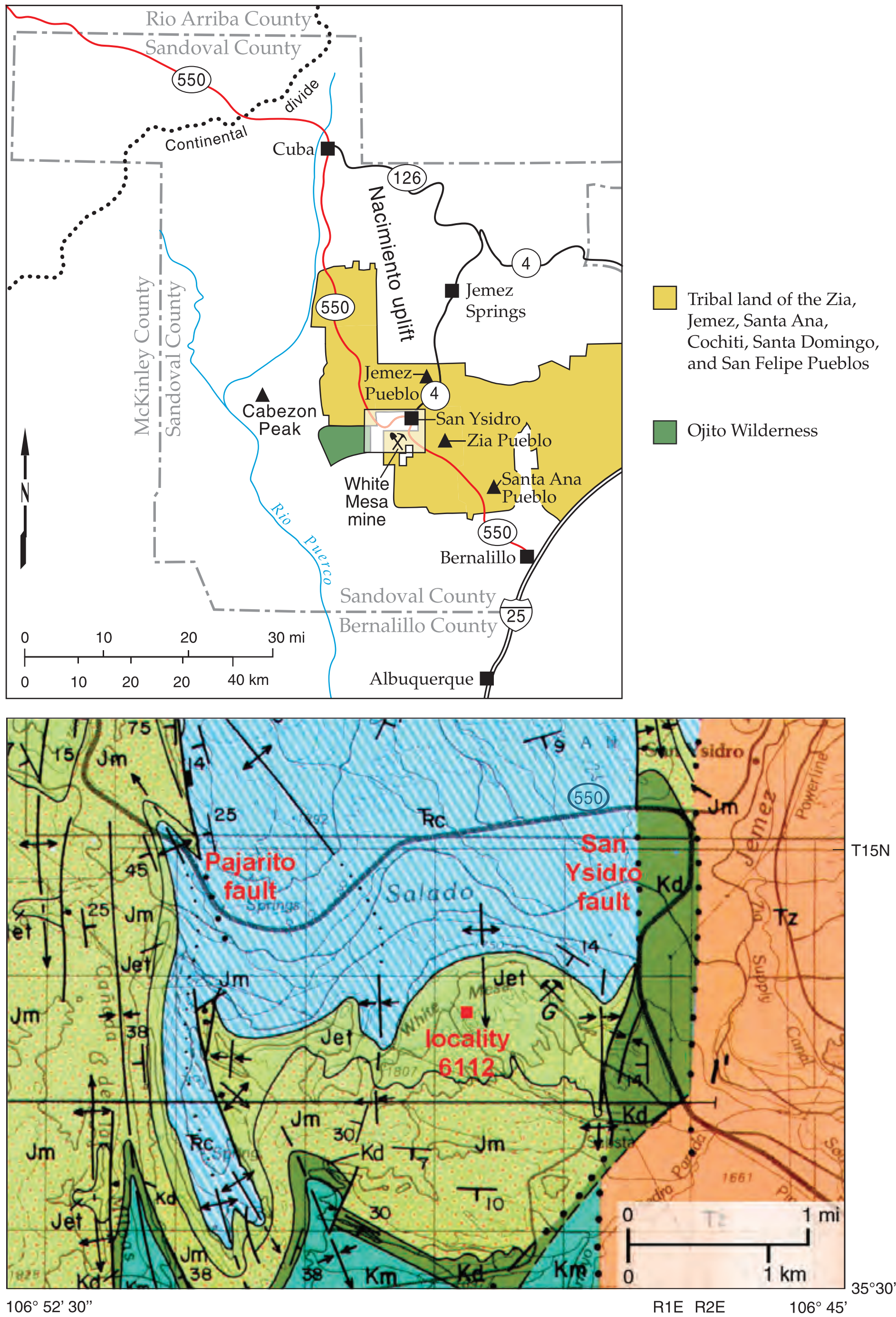

FIGURE 1—Maps showing the location and geology (Woodward 1987) of the study area. Structures dashed where approximate and dotted where concealed. Ball on downthrown side of faults. **Tz** = Tertiary rift fill, **Km** = Cretaceous Mancos Formation, **Kd** = Cretaceous Dakota Formation, **Jet** = Jurassic Entrada and Todilto Formations, **Jm** = Jurassic Morrison Formation, **T̶Rc** = Triassic Chinle Group, **G** = White Mesa mine.

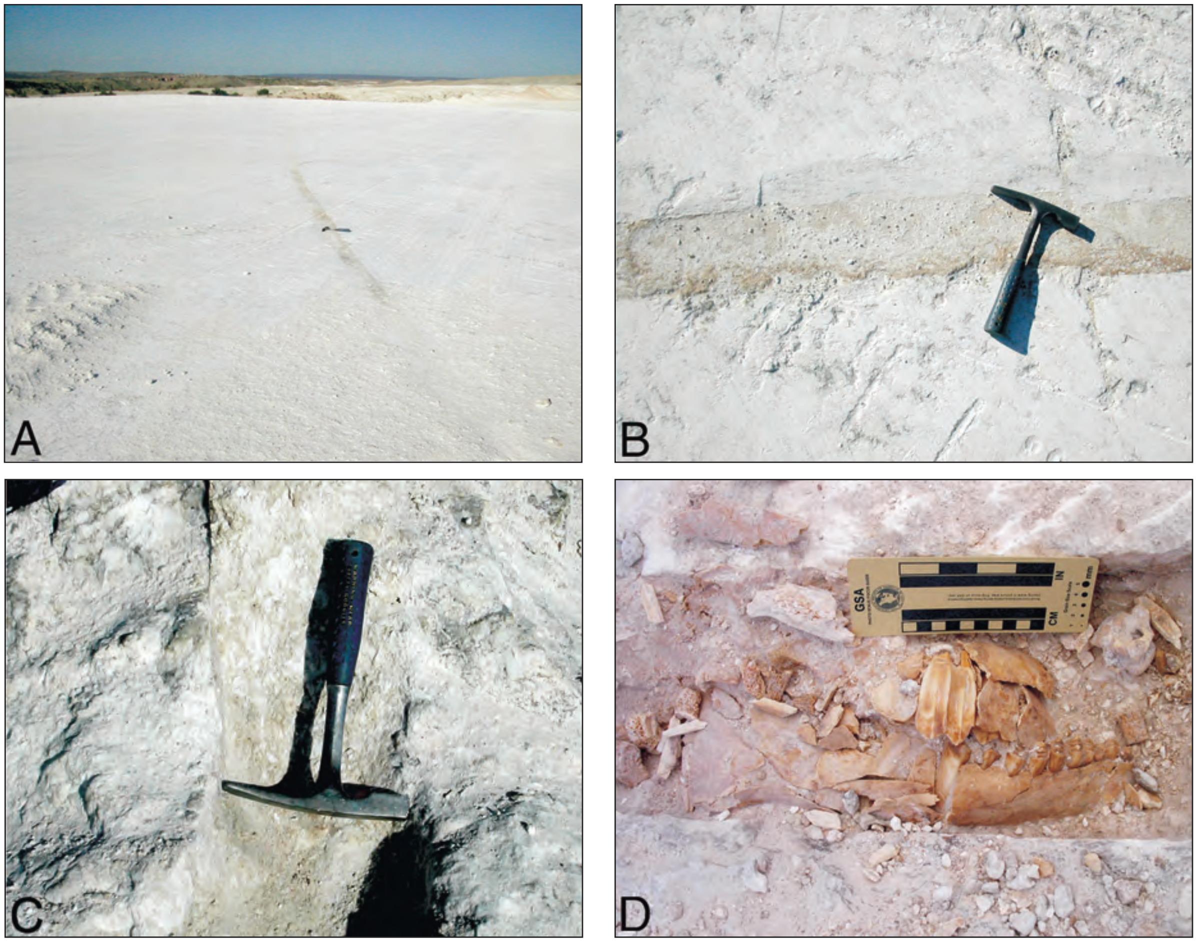

FIGURE 2—Selected photographs of fissure fills at White Mesa mine. **A**—Overview of a northwest-southeast-trending, linear fissure fill in Jurassic Todilto gypsum (looking southeast). **B**—Close-up of fissure fill showing vertical orientation and well-defined boundaries. **C**—Vertical view of the top of the fissure fill showing gypsum breccia (white spots) in tan sandy-silty matrix. **D**—View of *Bison* skull and jaws in fissure fill. Rock hammer in **A–C** is 28 cm long; scale in **D** in inches (above) and centimeters (below).

karst structures, joints, and fissures are common in the area. Some of these fissures were open to the surface in late Pleistocene (Rancholabrean) time and trapped various animals. To date, the site has produced articulated skeletal material comprising at least two camels (*Camelops hesternus*), a bison (*Bison antiquus*), a horse (*Equus* sp.), and a deer (*Odocoileus* sp.), all of late Pleistocene (Rancholabrean) age.

Tectonic setting

White Mesa is located in a structurally complex area (Fig. 1) near the southern terminus of the Nacimiento uplift (Woodward 1987). Rise of the Nacimiento uplift began during the compressional Laramide orogeny and may have continued during the Neogene extension of the Rio Grande rift. The mesa is bounded on the east by the San Ysidro fault, which is locally the Rio Grande rift boundary fault. This fault lies 1.2 km (0.75 mi) east of locality 6112 and juxtaposes the Cretaceous Dakota Formation on the east with the Jurassic Entrada, Todilto, and Morrison Formations to the west. The east-dipping Pajarito reverse fault (Woodward 1987; Woodward and Ruetschilling 1976) or the Nacimiento fault of Cather (2004) that defines the western boundary of the Nacimiento uplift has many associated south-plunging folds approximately 3 km (1.9 mi) west of locality 6112. White Mesa is on a low, broad, south-plunging anticline associated with these folds.

Fissures and fissure fill

In 1998 while prospecting for fossils in the Todilto Formation near San Ysidro, one of the authors (LFR) documented large open fissures of unknown depth. These ~ north-south-oriented fissures were located on a south-plunging anticline ~6 km (3.7 mi) northwest of locality 6112. The surficial expression of these fissures is a large steep-sided funnel-like structure whose sides become steeper as depth increases. We suppose that the Pleistocene fissures were probably similar.

At locality 6112 the fissure fill consists of brecciated fragments of gypsum in a matrix of poorly consolidated, silty, grayish-orange (10 RY 7/4), fine- to medium-grained gypsum sandstone with sparse quartz grains. The gypsum fragments are mostly 1–3 cm (0.4–1.2 in) in diameter, but the largest are 10 cm (4 in) or more. The proportion of gypsum breccia to sand varies considerably throughout the

FIGURE 3—Rose diagram of 44 fissure trends within 100 m (328 ft) of locality 6112 shows three principal components.

deposit. The brecciated fragments make up ~25–75% of the fill and are generally matrix supported. Some stratification is evident; beds that are more or less sandy show lateral continuity.

The trends and widths of 44 fissures in the White Mesa mine floor at the level of locality 6112 were measured. All were within a 100-m (328-ft) radius of that locality and were nearly vertically oriented (dip ~90º). A rose diagram of the trends of the measured fissures (Fig. 3) shows three principal components; these are approximately north-south, N60ºW, and N60ºE. Many of the fissures show short angular jogs along their length, and a few have short, curved segments. There is considerable branching and crossing of the fissures.

Fissure widths range from 1.3 cm to 33.7 cm (0.5 to 13.25 in) and average 9.5 cm (3.75 in), with a standard deviation of 7.2 cm (2.8 in). Widths are randomly distributed with respect to the three principal azimuths (Fig. 4). A few of the narrower fissures are open and unfilled in spots. Many vertical joints and small fissures were evident in the gypsum highwalls of the mine a few hundred meters north and west of locality 6112; several of these were 10–25 m (33–82 ft) tall. They give the impression that a small amount of extension could open them to the surface.

As it would be impossible to fit a full-grown camel or bison into even the widest of these fissures, we think that the animals lodged in the wider upper portion of the fissures and that the bones fell to full depth after decomposition of most of the animal's bulk. It is possible that the fissures were originally wider than we observed today and were closed by mobilization of the gypsum. However, we do not find any evidence of this at the site. The bones show no sign of crushing from fissure closing, and there is no foliation or other evidence of compression in the fissure fill.

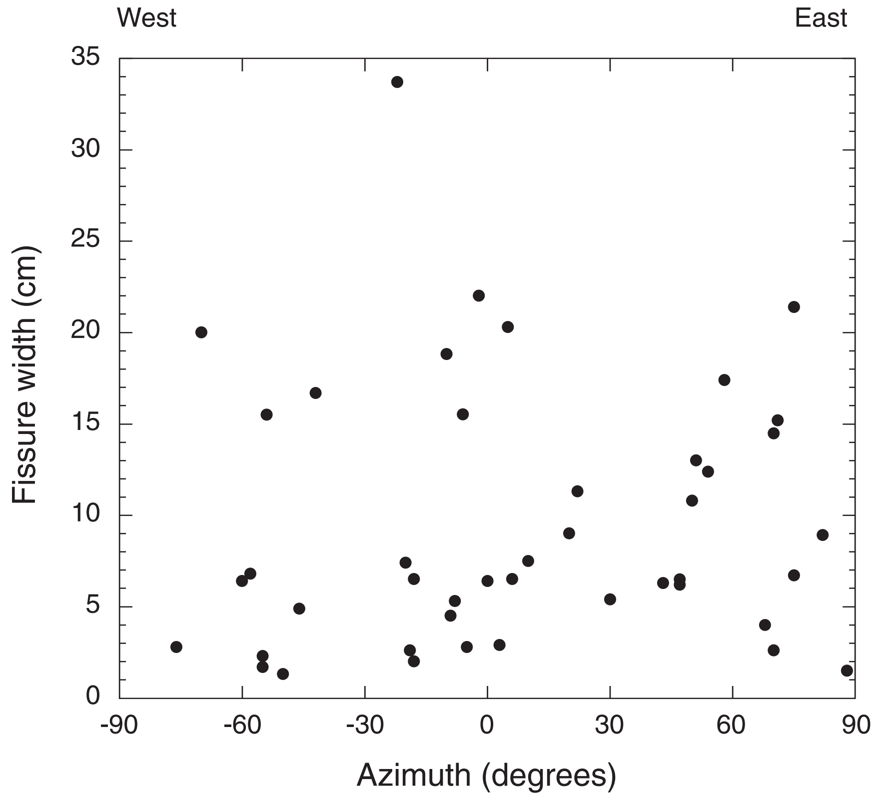

FIGURE 4—Scatterplot of fissure widths versus azimuth shows approximately random distribution of widths among the three principal groupings (i.e., N60ºW, north-south, and N60ºE).

Discussion

The fissures do not appear to be of geomorphic origin. We see no evidence of their formation by solution. The opposing sides of the fissure walls appear as if they would fit perfectly back together if closed, indicating that little or no material has been dissolved within the joints. The corners of the various jogs and intersections are sharp and show no sign of dissolution. White Mesa is bounded on three sides by cliffs. Mass wasting along these margins could open fissures close to the edge of the mesa. The main concentration of fissures is, however, 500 m (1,640 ft) from the closest mesa boundary. This boundary is to the north and trends east-west. Because we see no fissures parallel to this boundary, we conclude that extensional stress due to mass wasting did not generate the fissures. Anhydrite formation in the gypsum could produce stress and possibly fracture the rock. Kelley (2006) found in the Chama Basin that dewatering during anhydrite formation in the Todilto gypsum probably caused brecciation and formation of fluid release structures in the Todilto and its overlying beds. Anhydrite is present in the mine. The closest deposit is approximately 200 m (656 ft) north of and 5 m (16 ft) stratigraphically higher than the main fissure area. Again, we see no relationship between the anhydrite formation and the fissures; none was present in the gypsum mined from above locality 6112, and there were no dewatering structures present near the locality.

Taken in the context of the tectonic setting, the three components of the fissure orientations (Fig. 3) probably show two tectonic events. Local north-trending folds are associated with the rise of the Nacimiento uplift and may indicate east-west compression of the area in Laramide time. The ~N60ºE and ~N60ºW components of the fissure trends are interpreted to be conjugate shears generated by this east-west compression (Bles and Feuga 1986). Presumably, these conjugate joint sets remained closed and tight until rift-associated extension of the area occurred.

Local rifting began in the late Miocene to early Pliocene and was very active in the Pleistocene, when east-tilting and faulting occurred in the Albuquerque and Santo Domingo Basins (Baltz 1978). The north-trending fissures (Fig. 3) parallel the nearby San Ysidro fault and thus appear to be extensional fractures formed by pull-apart associated with the Rio Grande rift. A minor component of right slip has been reported along the Rio Grande rift approximately 25 km (16 mi) north of White Mesa (Woodward and DuChene 1975) and approximately 40 km (25 mi) southeast of White Mesa on the east side of the rift (Woodward and Menne 1995). It is possible that some of the northeast-trending fissures at White Mesa were initiated as extensional joints during rifting and were not necessarily conjugate shears of Laramide age. Regardless of when these fractures initially formed, their opening and infill were coeval with rifting. Many short curves and jogs in the previously existing Laramide conjugate shears probably locked them to some extent and prevented them from fully accommodating all of the extension. New north-trending joint sets therefore opened to accommodate the rifting.

Other workers have noted rift-related fissure fills nearby. Campbell (1967) and Slack and Campbell (1976) documented many sandstone dikes east of the Ignacio monocline (south of the present study area). They interpreted these northeast-southwest-trending dikes as penecontemporaneous infillings of tension gashes generated by the early to middle Miocene pull-apart of the Rio Grande rift.

Conclusions

The most parsimonious explanation of the White Mesa fissures is that most of the northeast-southwest and northwest-southeast fractures began as conjugate joint pairs formed by Laramide compression. Subsequent rifting generated the remainder of the joints (north-south) as tension gashes and provided the extensional stress to open all of the joints to form fissures. These open fissures acted as natural traps in the late Pleistocene as indicated by the articulated fossil bones, and probably continue to do so at present.

Acknowledgments

Gypsum miners David and Lambert Pino discovered the fossils and helped tremendously in their recovery. We are grateful to the Pueblo of Zia Environmental Management Office, which contacted NMMNH concerning this important find. Harold Reid, Zia Pueblo environmental manager, arranged access to the working mine area for collection of the fossil material. Sean Connell, New Mexico Bureau of Geology and Mineral Resources, John B. Rogers, and Dirk Van Hart reviewed this article and improved its content with their suggestions.

Notice

White Mesa mine is located on Zia Pueblo tribal land and may not be entered without permission of the governor's office and the American Gypsum Company onsite operations office.

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