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Shatter cone and microscopic shock-alteration evidence for a post-Paleoproterozoic terrestrial impact structure near Santa Fe, New Mexico, USA

Siobhan P. Fackelman [a], Jared R. Morrow [b,*], Christian Koeberl [c], Thornton H. McElvain [d]

[a] Earth Sciences Department, University of Northern Colorado, Greeley, CO 80639, USA
[b] Department of Geological Sciences, San Diego State University, San Diego, CA 92182, USA
[c] Department of Lithospheric Studies, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria
[d] 111 Lovato Lane, Santa Fe, NM 87505, USA

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ABSTRACT

Field mapping, morphologic description, and petrographic analysis of recently discovered shatter cones within Paleoproterozoic crystalline rocks exposed over an area >5 km^2, located ~8 km northeast of Santa Fe, New Mexico, USA, give robust evidence of a previously unrecognized terrestrial impact structure. Herein, we provisionally name this the “Santa Fe impact structure”. The shatter cones are composed of nested sub-conical, curviplanar, and flat joint surfaces bearing abundant curved and bifurcating striations that strongly resemble the multiply striated joint surfaces (MSJS) documented from shatter cones at Vredefort dome. The cones occur as a penetrative feature in intrusive igneous and supracrustal metamorphic rocks, are unusually large (up to 2 m long and 0.5 m wide at the base), display upward-pointing apices, and have subvertical, northeastward-plunging axes that crosscut regional host-rock fabrics. Key characteristics of superficially similar, but non-shock-generated conical and striated features are inconsistent with the properties of the Santa Fe cones. In thin section, sub-millimeter-scale, dark, semi-opaque to isotropic veneers on cone surfaces and veinlets within cone interiors closely resemble previously described shock-induced melt features. Microscopic grain alteration, restricted generally to within 1 mm of the cone surfaces, includes random fractures, fluid micro-inclusions, sericite replacement in feldspar, rare kink bands in mica, optical mosaicism, and decorated planar fractures (PFs) and planar deformation features (PDFs) in quartz. The PFs and PDFs are dominated by a basal (0001) crystallographic orientation, which indicate a peak shock pressure of ~5–10 GPa that is consistent with shatter cone formation. Regional structural and exhumation models, together with anomalous breccia units that overlie and crosscut the shatter cone-bearing rocks, may provide additional age constraints for the impact event. The observed shatter cone outcrop area suggests that the minimum final crater diameter of the Santa Fe impact structure was ~6–13 km.

1. Introduction

Of the approximately 174 presently confirmed Earth impact craters and structures, only five are located in the western United States, a number that is statistically low given the crater density recorded elsewhere on the North American continent (http://web.eps.utk.edu/ifsg.htm; http://www.unb.ca/passc/ImpactDatabase/index.html). The active tectonic history of the western United States, which is characterized by widespread episodes of compressional and extensional deformation, erosion, sedimentation, and volcanism (Burchfiel et al., 1992), especially hampers the preservation of impact structures. In such an active tectonic regime, the likelihood of complete crater preservation decreases dramatically with increasing age. Known terrestrial impact events in these active settings are evidenced by buried, partially eroded, or tectonically dismembered craters or by isolated occurrences of proximal to distal impactite deposits that may or may not be linked to a preserved source crater. With the exception of the young and well-preserved Barringer crater, Arizona, four of the five confirmed impact events in the United States west of the Interior Plains province are evidenced by craters that are buried (Cloud Creek, Wyoming — Stone and Therriault, 2003), highly eroded (Upheaval Dome, Utah — e.g., Kriens et al., 1999; Buchner and Kenkmann, 2008), or tectonically dismembered (Beaverhead, Montana — Hargraves et al., 1990, 1994; and Alamo, Nevada — e.g., Warme and Kuehner, 1998; Morrow et al., 2005; Pinto and Warme, 2008).

During fieldwork conducted in 2005, one of us (McElvain) discovered anomalous, large, nested cone-like structures within road cut and natural exposures of tectonically complex Paleoproterozoic intrusive igneous and metamorphic rocks in the southern Sangre de Cristo Mountains northeast of Santa Fe, New Mexico, USA (Figs. 1, 2). Subsequent

* Corresponding author.
E-mail address: jmorrow@geology.sdsu.edu (J.R. Morrow).

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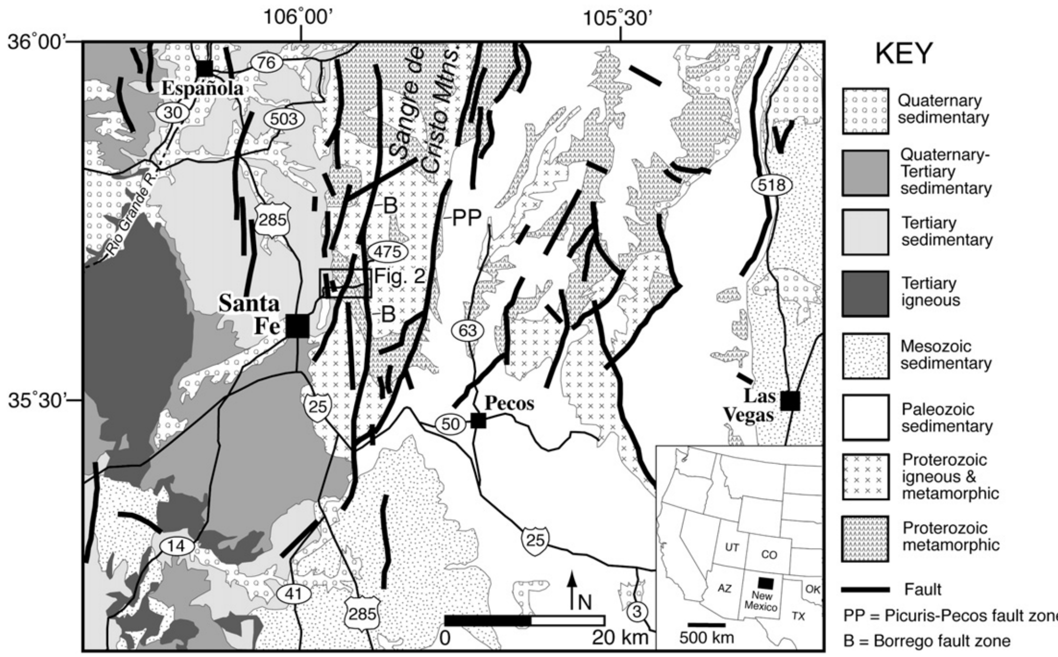

Fig. 1. Locality and generalized geologic map of study region, showing area depicted in Fig. 2 (rectangle). Major highways and cities are shown. Key defines major lithologic types and corresponding map patterns. Geology is simplified from Geologic Map of New Mexico (New Mexico Bureau of Geology and Mineral Resources Staff, 2003).

detailed mapping, measurement, and petrographic analysis of the cone structures, including work conducted as part of a graduate student research project (Fackelman, 2006), strongly indicates that these structures are shatter cones from a previously unrecognized, but highly eroded or tectonically dismembered terrestrial impact structure (Fackelman et al., 2006; McElvain et al., 2006; Fackelman et al., 2007; Newsom et al., 2007). In the region, unusual, structurally complex breccias and megabreccias overlie and crosscut the Precambrian crystalline rocks containing the shatter cones. These anomalous breccias are currently under study (e.g., McElvain et al., 2006; Newsom et al., 2007) to further establish a possible genetic link with the impact event. In this paper, we provide initial results documenting the occurrence and morphology of the shatter cones and the shock-related alteration and micro-deformation within the shatter cone-bearing rocks.

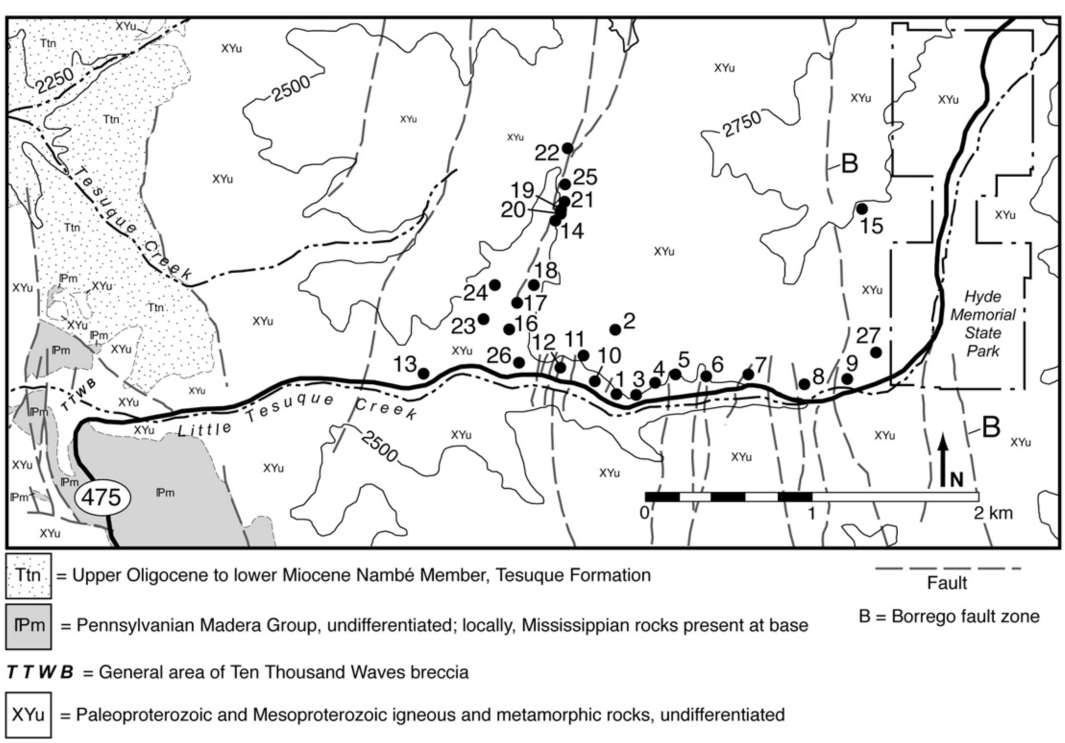

Fig. 2. Map of study area, showing shatter cone localities (numbers; see also Appendix A), generalized topography, generalized bedrock geology, and New Mexico State Highway 475. Topographic contours are meters above sea level; contour interval is 250 m. General outcrop area of Ten Thousand Waves breccia (McElvain et al., 2006; Newsom et al., 2007) is also shown. Geologic data after Bauer et al. (1997) and Read et al. (2000).