UNM

EVIDENCE FOR A MAJOR IMPACT SITE IN THE SANGRE DE CRISTO MOUNTAINS, NEAR SANTA FE, NEW MEXICO

A FIELD GUIDE

Field Trip Leaders
Horton Newsom, Institute of Meteoritics
Wolf Elston and Eric Tegtmeier, E & PS Department

A field trip held in connection with the E&PS alumni reunion in honor of Professors Emeriti R.Y. Anderson, W.E. Elston and L.E. Woodward

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EVIDENCE FOR A MAJOR IMPACT SITE IN THE SANGRE DE CRISTO MOUNTAINS, NEAR SANTA FE, NEW MEXICO: A FIELD GUIDE Field trip leaders:

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BACKGROUND

In the rainy spring of 2005, a mud slide blocked NM 475, the well-traveled road ascending the east flank of the Sangre de Cristo Range, from Santa Fe to Hyde State Park and the Santa Fe Ski Basin. The pile of mud and rocks left by a road-clearing bulldozer became an irresistible attraction to TinTin, a little terrier taking Tim McElvain, a retired petroleum geologist, for a walk. On retrieving his muddied dog, Tim's eyes were drawn to fragments of schist with curved surfaces, covered by converging striations. As a long-time student of impact processes, he recognized them as fragments of shatter cones, uniquely formed by the passage of impact-induced hypervelocity shock waves. Looking around, he saw rain-washed road cuts covered with centimeter-to-meter sized shatter cones, equal in size and development to those of well-known impact localities like Sudbury, Ontario, and Vredefort, South Africa (Fig.1).

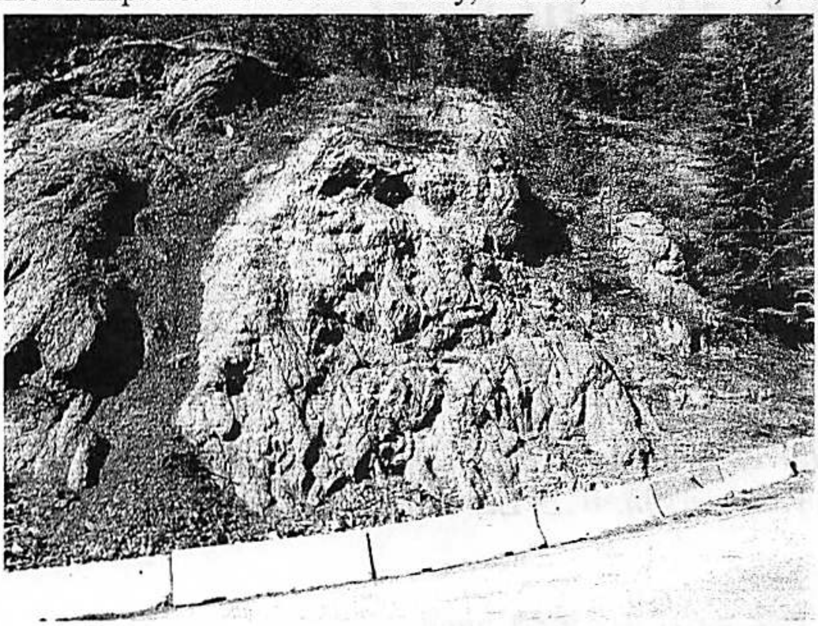

Figure 1. Shatter cone outcrop on Hyde Park road.

GEOLOGIC SETTING AND HISTORY

In the foothills of the Sangre de Cristo Range, Paleozoic carbonates lie unconformably on fault blocks of Proterozoic biotite schist and granite gneiss cut by pegmatites. The lowest carbonate beds are unfossiliferous but have tentatively been identified as Mississippian; Pennsylvanian fossils appear higher in the section. Following Proterozoic deformation and metamorphism, the region was disturbed by tectonic movements associated with the rise of the late Paleozoic Ancestral Rockies, the late Cretaceous-early Tertiary Laramide orogeny, and the late Tertiary uplift of the present mountains relative to the Rio Grande Rift to the west. In evaluating the evidence for impact, the complex tectonic history of the region must be taken into account.

The shatter cones occur in all types of Proterozoic crystalline rocks but seem to be confined to a relatively small area east of Hyde State Park. However, further investigations have brought to light a variety of unconventional breccias and shattered basement rocks. Their full extent is not known, but they extend for about 8 road miles along NM 475 and for longer distances parallel to I-25, southwest of Santa Fe. These are minimum dimensions consistent with a sizable impact structure of equal to or greater than 15 km in diameter, compared to 2 km for the famous Meteor Crater in Arizona.

PREVIOUS AND CURRENT INVESTIGATIONS

In retrospect, a zone of unusual breccias had been mapped in the 1950s by Frank Kottlowski (later to become Director of what is now the NM Bureau of Geology). The area was covered in a 1990s MS thesis by Adam Read (UNM, currently NM Bureau of Geology), with interpretations based on multiple tectonic events. Present investigations are still in a very early stage, with more questions than answers. So far, they have resulted in an MS thesis on the shatter cones by Siobhan Fackelman (Northern Colorado University). At UNM, several lines of laboratory investigations, including argon-argon dating, petrology, geochemistry, and paleomagnetism are in progress and Eric Tegtmeier is completing a senior thesis involving reconnaissance field work, with generous support from Tim McElvain. Tim McElvain is searching quartz grains for planar deformation features, the best-established diagnostic impact phenomenon.

QUESTIONS

Unresolved issues under investigation include:

(1) Size and geometry of the proposed impact structure.

(2) Time of proposed impact. Shatter cones are confined to Proterozoic crystalline rocks and so are most breccia varieties. In most places, what appear to be undisturbed Paleozoic sedimentary rocks seem to lie on brecciated Proterozoic rocks with apparent depositional contact. However, at a few contact exposures, there is evidence for shearing or of clasts of brecciated Paleozoic rocks mingled with Proterozoic breccia clasts. Are the Paleozoic rocks in place, or are they allochthonous slide blocks?

Figure 2. Gneiss clast with dark reaction rim several cm thick, encased in fractured limestone.

Figure 2 illustrates some of the complexities. At this locality, the contact between brecciated Proterozoic crystalline rocks and Mississippian? limestone has been disturbed. Meter-sized blocks of Proterozoic and Mississippian? rocks are intermingled. The brecciated granite gneiss clast with alteration halo in Figure 2 represents a rare variant, being apparently enclosed in brecciated limestone. The enclosing limestone has hairline ($\leq$ mm) fractures, partly filled with grains of granite gneiss in which some quartz grains are fractured in at least two directions (Fig. 3). The crucial questions: Was the disturbance related to the impact (suggesting a maximum age of Mississippian for the event) or to a later tectonic movement? How and when where granite gneiss grains injected into limestone? Are the fractures in quartz from these grains (Fig. 3) true planar deformation features?

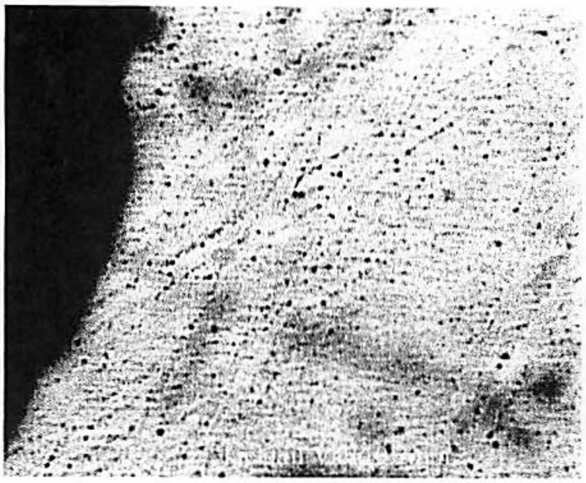

Figure 3. Possible planar deformation features in quartz.

(3) Nature of the breccias. In some places, the crystalline basement rocks are pervasively shattered down to centimeter size, in others blocks of meter size appear jostled and intermingled. without major displacement between blocks. They are cut by dike-like breccia bodies with evidence for movement by fluidization. What are the relationships between breccia types to each other, and to the shatter cones? In previous studies, these breccias have generally been associated with faults of a tectonically complex region. This may well be correct; large impacts can produce breccias by reactivating pre-existing faults, as well as by creating new ones.

(4) Are fractures in quartz grains true planar deformation features, or are they the result of deformation within the range of tectonic forces?

ROAD LOG

As NM 475 rises into the Sangre de Cristo uplift, it intersects progressively deeper structural levels, as follows (in miles):

0.0 Santa Fe: Intersection of NM 590 (Washington St.) and NM 475 (Artist St. Sign: Hyde State Park). Follow NM 475.

1.5 Pass gate for the Santa Fe Institute. On left, shattered granite gneiss cut by fractured post-metamorphic pegmatite dikes.

2.2 Biotite schist blocks in brecciated granite gneiss.

3.3 Ten Thousand Waves spa and resort.

Figure 4. Nun's curve at mp 4.1 showing the contact of brecciated basement with the overlying Mississippian sediments?

4.1 Nun's Curve. **Caution, slow down!** The curve takes its name from a tragic accident, in which some nuns were killed! On the right (south), excellent exposures of meter-sized blocks of schist and gneiss, jostled and intermingled in a complex manner, overlain by Mississippian (?) carbonates (Fig. 4). The contact appears to be depositional but locally shows evidence of shear. In the distance to the left, the same contact can be seen on a high ridge, cut by faults. The locality of intermingled brecciated gneiss and brecciated limestone (Figs. 2, 3) is below us, at the bottom of the intervening canyon.

4.2 Cross Little Tesuque Canyon, head of unmarked Little Tesuque Trail. We will return to this spot for Stop 3.

4.6 Left (north), Memorial (to a fatal bus accident) Breccia Tower. This breccia dike has many of the features we will see at Stop 3.

5.4 Head of Chamisa Trail 183. We will return to this spot for Stop 2.

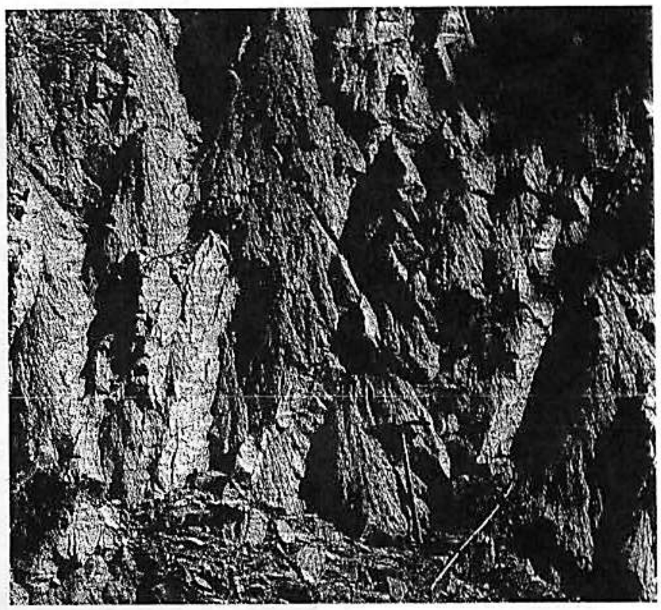

Figure 5. Shatter cone outcrop, large hammer for scale.

5.7 **Stop 1. Main shatter cone site. _Please do not take samples_**; you can get those at Stop 2. The rocks here are faulted and jointed, but not crushed or significantly rotated. Shatter cones are nested, from cm-to m-size (Fig. 5). In biotite schist, they tend to be incomplete and flattened in the plane of schistosity. They are best developed in granite gneiss, a more homogeneous rock. Surficial horse-tail striations are characteristic. It has long been held that, statistically, the orientations of shatter cones converge on the point of origin of shock waves, i.e. the impact target. The original measurements of this effect, at Vredefort, made several structural assumptions, which have recently been challenged. If the original observations hold up, the point of origin at this locality is now high in the sky, a victim of erosion. However, rotation by post-impact faults must be considered.

6.8 Little Tesuque Campground.

7.0 **Lunch Stop, Hyde State Park.** Please go to designated picnic area. Along the road, for about 1.3 mi beyond this point, the rocks (mainly granite gneiss) are crushed to cm size and weather to grus. Exposures are poor. Over the next 1.0 mi, there is a transition from crushed rock to rock that is jointed but otherwise solid. It remains that way that way all the way to the Sky Basin, 14.5 mi from mile 0.0.

After lunch, please turn around and retrace the route.

8.6 (same as 5.4) **STOP 2.** Please park at Chamisa trail head. During a Sunday afternoon stroll along the Chamisa Trail in about 2002, Wolf Elston noticed a weathered outcrop a short distance from the highway, with peculiar slickensides between patches of moss and lichens. "Look!" he cried to his accompanying son Steve and daughter-in-law Marion "these slickensides are odd; they're oriented any which way. They almost look like shatter cones.!" Then he said to himself: "Get real, Wolf, there's no impact site in the Sangre de Cristos! Forget it!" And he did. Somewhere in this tale there must be a moral. – On the south side of the highway, you can collect samples of partial shatter cones in schist from a pile of rocks left by Highway Department road construction.

9.8 (same as 4.2) **Stop 3. Park (carefully) in wide spot on the left (south) side of the road,** then examine the road cut on the north side (Fig. 6). Relationships between crystalline rocks are similar to those at the Nun's Curve (mile 4.1). Meter-sized blocks or zones of granite gneiss breccia stained red by a hematitic matrix interfinger with brecciated biotite schist, with sheared contacts; the entire complex is cut by minor faults. Breccia clasts are in the centimeter-to-decimeter range; angular in granite gneiss, more rounded in schist. The rocks have clearly been shaken and broken but the amount of movement is uncertain. There is no evidence for more than a few meters of relative movement between adjacent blocks, but neither is there in certain slide blocks that have moved for many kilometers

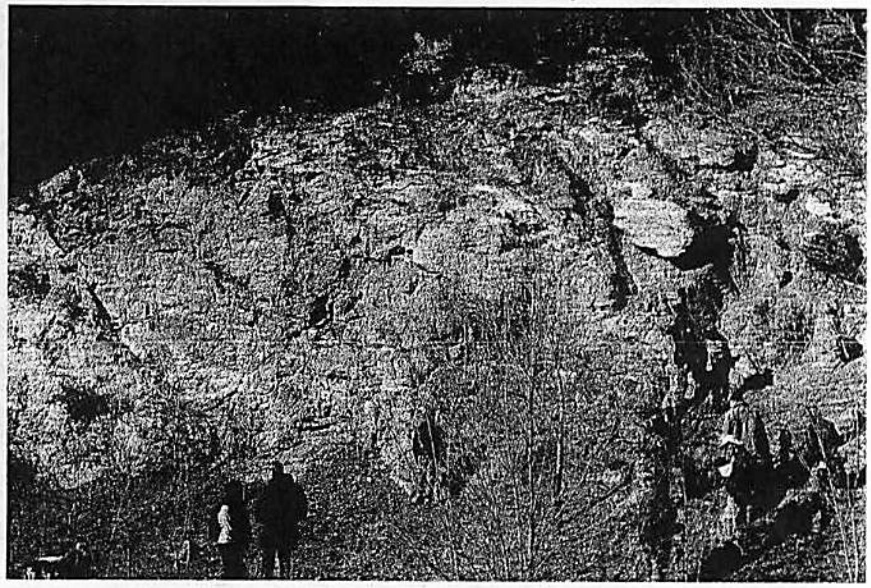

Figure 6. Roadcut at mile 2.2 with intermingled gneiss biotite schist and pegmatite.

After examining the road cut, follow the Little Tesuque Trail downhill for about 50 m, to a towering dike-like body of red granite gneiss breccia, about 10 m wide (Fig. 7). Many of these bodies have been found, generally with northerly trend. Much of the surrounding bedrock consists of granite breccia, but these dike-like bodies have evidence of cross-cutting relationships and lateral zoning. Going inward, clasts are comminuted at the contact. Over the next several decimeters, there is a zone of rounded clasts, followed by a zone in which rounded biotite schist clasts of decimeter-to-meter size are surrounded by a centimeter-wide envelope of comminuted granite gneiss fragments (Fig. 8). The interior consists of angular-to-subangular clasts of granite gneiss, commonly fitted like pieces of an exploded jig-saw puzzle,. On every scale, the matrix consists of hematite-stained granite gneiss fragments, progressively comminuted to the limits of resolution There are no slickensides or fault gouge, but the contact zones suggest movement in a fluidized medium. If so, in which direction was the movement? From above?

END OF LOG

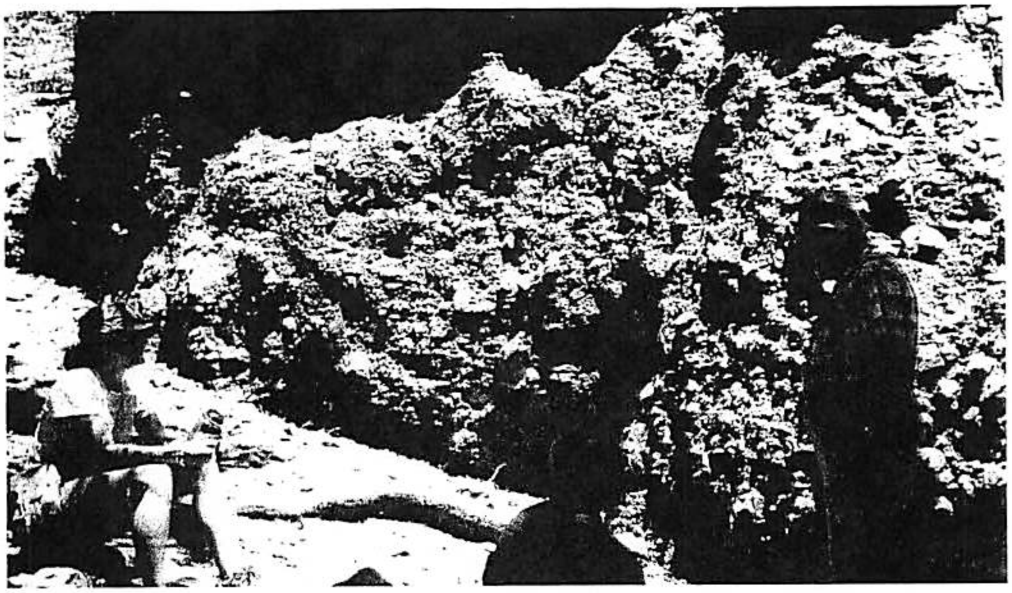

Figure 7. Breccia tower on Little Tesuque Creek trail.

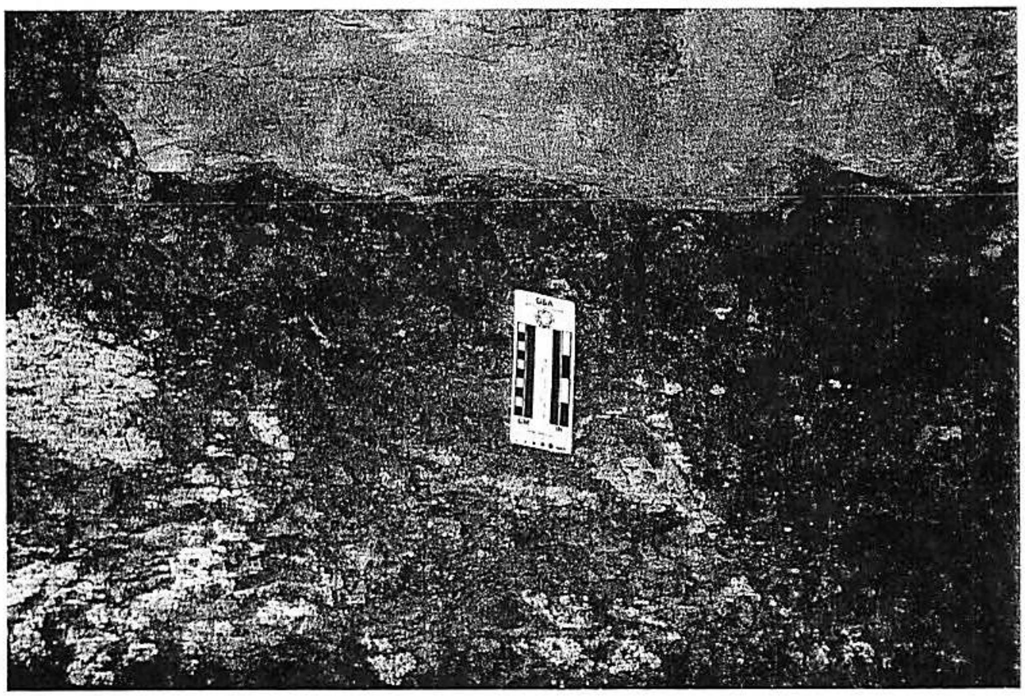

Figure 8. Rounded biotite schist clasts of decimeter-to-meter size are surrounded by a centimeter-wide envelope of comminuted granite gneiss fragments