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INVESTIGATION OF A SUSPECTED METEORITE IMPACT AT UPHAM, NEW MEXICO

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ABSTRACT—A circular feature in the Jornada del Muerto Basin in southern New Mexico has been interpreted in this investigation as a probable meteor impact crater. The feature has a diameter of about 12.6 km, and is split by Sierra County Road A013 that follows the historic 1598 El Camino Real. The site is on the gentle eastern slope of the Caballo Mountains. A dense band of vegetation, over about 60 percent of the circumference, defines the shape. The best evidence for an impact site, besides satellite photographs, is a magnetometer survey "snapshot" across one well-defined edge that depicts a disturbed mega-breccia bedrock in abrupt lateral contact with a uniform deposit, possibly lacustrine crater fill. More subtle indications of a structure include an erosional scarp and possible evidence of karst sinkholes on the southwest perimeter and subsidence of a slump block on the northern perimeter. The impact may have occurred in the interval between the deposition of the marine Cretaceous Crevasse Canyon Formation and the closed basin deposits of the Paleocene/Eocene Love Ranch Formation that overlie the northern side of the feature. Three isolated volcanic outcrops dated about 29 to 35 Ma border the southern and eastern perimeters. It is estimated a few hundred meters of Tertiary deposits and Cretaceous bedrock have been removed by erosion since the uplift of the Caballo Mountains during the Rio Grande rift, effectively removing any direct surficial evidence of an impact. A discussion is presented of arguments for and against this being an impact crater.

INTRODUCTION

A circular feature, which can only be seen on satellite photos (Fig. 1), was discovered by the author in November 2007 while investigating the potential for aggregate for use in construction of the nearby Americas Spaceport. This feature is located in the Jornada del Muerto basin in Sierra County, New Mexico, divided by County Road A013.

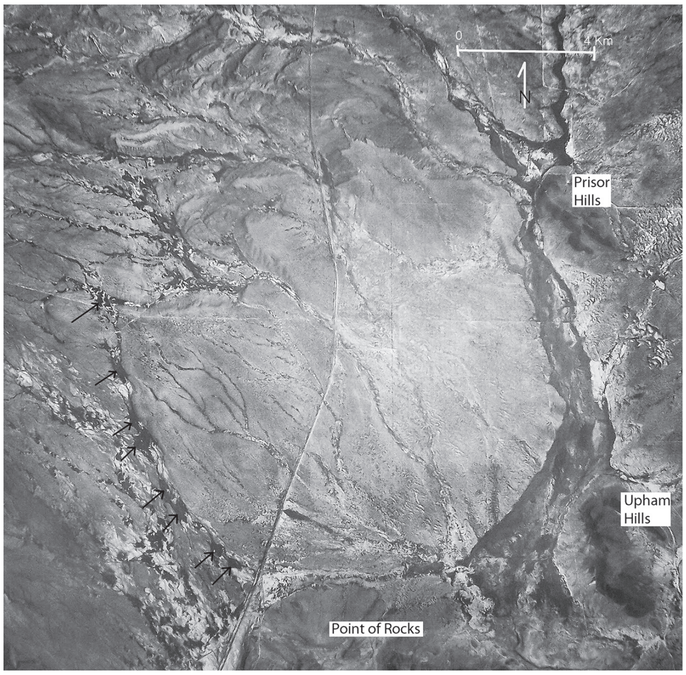


FIGURE 1. Satellite mosaic photograph of circular feature in Sierra County, New Mexico. From: Earth Data Analysis Center, Upham Quad, 2005. County Road A013 and BNSF Railroad corridor runs toward Engle, NM. The drainage on the right is Jornada Draw in the center of the basin. Also shown are three volcanic ridges that are remnants of the Uvas field: Point of Rocks at southern edge; Upham Hills at southeastern edge; and Prisor Hills at northeastern edge.

The circular feature, herein referred to as the footprint, has a diameter of approximately 12.6 km (Figs. 1-2). The center lies near the abandoned Upham Ranch house, which has the coordinates of 32˚53'20"N, 106˚59'59"W (Fig. 3). This location was registered as the Lindsey "circular feature" with the Earth Impact Data base web site in 2008 (University of Brunswick, 2008). The lands within the footprint consist mostly of Bureau of Land Management (USBLM) public lands with about 17 percent being New Mexico State lands while only about 1.5 sections (square miles) consist of private land. The footprint area includes parts of Townships 16 and 17S, and Ranges 1 and 2W in portions of the following U. S. Geological Survey Quadrangle maps: Upham, Prisor Hill, Alivio, and Upham Hills.

The structure is defined by contrasting vegetation that suggests abrupt changes in the conductivity of groundwater in near surface materials. The satellite image begs the question: is it a structure or an accident of geomorphic processes?

GEOLOGIC SETTING

The footprint lies on the western side of the Jornada del Muerto Basin, which is bounded by the east-tilted Caballo Mountains, and the west-tilted San Andres Mountains. This rift basin, imprinted over a Laramide synclinal basin, lies in the middle of the Basin and Range province. The gentle slope of the western edge of the footprint, about 6.5 km from the toe of the Caballo Mountains, gradually yields to playas and the shallow, meandering Jornada Draw that forms the axis of the valley and the eastern edge of the footprint. The most prominent topographic feature is the Point of Rocks volcanic hills stretching along the southern side of the footprint, one of three isolated, mostly erosional remnants of Tertiary Uvas volcanic rocks that approximately bound the southern and eastern sides of the footprint (Figs. 1-2). Seager (2005) shows the trace of the Jornada Draw fault approximately trending along the main drainage of the Jornada Draw and appearing to coincide and overlap what is interpreted to be the eastern perimeter of the

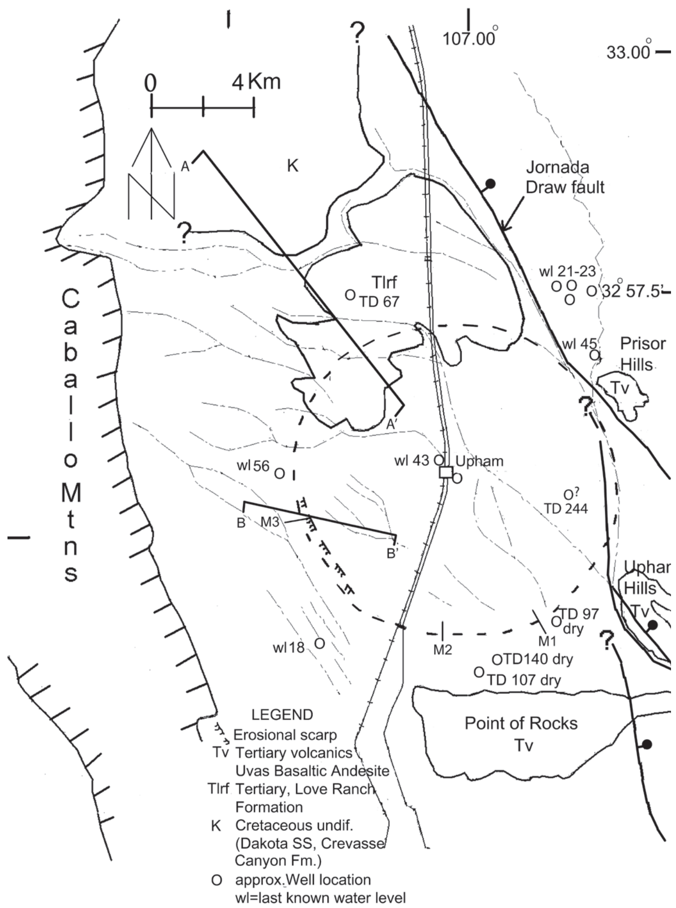


FIGURE 2. Geologic sketch map of southern Sierra County, New Mexico showing circular feature. Reference: USGS/NMBGMR map, 2003 The circular feature, shown as a dashed line, is overlain by Tertiary Love Ranch Formation (Tlrf) on the north edge. Magnetometer survey lines indicated as M1-M3. The marked eastern border of the Caballo Mountains is formed mostly by upturned Permian Yeso Formation. The escarpment interpreted as an eroded edge of a crater fill is indicated at the 8:00 position.

footprint (Fig. 2). The fault connects Rio Grande rift Quaternary basaltic volcanoes to the north of the footprint area.

Stratigraphy

Steeply-dipping hogbacks of resistant Permian limestone and Cretaceous strata mark the eastern foothills of the Caballo Mountains. Precambrian granitic basement rocks form the core of the western side of the Caballo Mountains and also the core of the east side of the San Andres Mountains, but lie about 1000 m below the Jornada del Muerto basin, emphasizing the synclinal nature of the underlying structure (Seager, 1986). The basement rock lies approximately 1000 m below the basin surface in the vicinity of the Upham Hills based on well logs (Seager, 1986).

Bedrock includes Pennsylvanian limestone, Permian Abo Formation, Yeso Group, and San Andres Limestone, and Cretaceous Dakota Sandstone, Mancos Shale, and Crevasse Canyon Formation (Seager and Mack, 2003). All Phanerozoic geologic time periods are represented in the mountains bordering the valley except for Triassic and Jurassic periods (Clemons and Osburn, 1986).

McRae Formation

The McRae Formation of Cretaceous age may be overlapped by the Tertiary Love Ranch Formation within about 3 km of the northern edge of the footprint (Seager and Mack, 2003). This Laramide basin deposit is mainly restricted to the vicinity of the Elephant Butte Reservoir. Dinosaur fossils in the McRae Formation suggest that deposition may span the Cretaceous-Tertiary boundary, dated about 65.5 Ma (Lozinsky et al., 1984; Wolberg et al., 1986; Gradstein et al., 2004).

Love Ranch Formation

The age of the Love Ranch Formation, which locally shows no evidence of an impact structure, is significant to the investigation of an impact crater because it overlaps the northern edge of the footprint (Figs. 2, 4) and could be as old as Paleocene, but most of it is Eocene (Seager, 2002, 2005; Seager and Mack, 2003). The deposit is described as being as much as 600 m thick in a drill hole about 8 km east of Upham (Seager, 1986). The deposits consist of fanglomerates, sandstone, and shale, becoming finer grained upward in section with increasing volcanic debris in the upper part. The granitic debris that is contained in the Love Ranch is evidence for the existence of the Rio Grande uplift, which briefly exposed the granitic basement rock, on what is now the southern end of the Caballo Mountains, during the onset of the Laramide orogeny. This fault-bounded uplift was eroded away about as fast as uplift occurred, with the sediment being deposited north and eastward across the present Jornada Basin (Seager et al., 1986). The Precambrian granitic clasts in the Jornada Del Muerto valley occur in the lower part of the deposit.

A specimen with visible feldspar clasts from a Love Ranch Formation sandstone outcrop (Fig. 5), close to Sierra County Road A013 and overlapping the footprint, revealed only a mixture of

FIGURE 3. Upham, New Mexico is an abandoned ranch house near the center of circular feature. Road in foreground is Sierra County Road A013. The volcanic hills in the distance are Upham Hills just beyond the eastern edge of the circular feature.

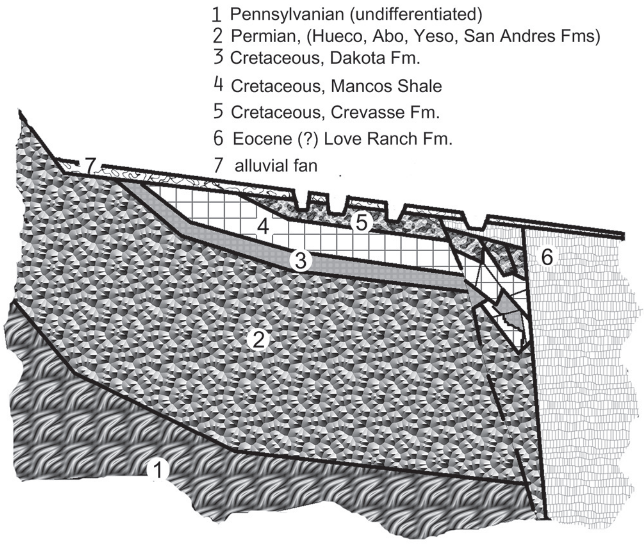


FIGURE 4. Interpreted geologic cross section. The section shows the relationship of the Love Ranch Formation to possible crater fill and a slump block on the north-northeastern perimeter. This is based on the apparent lateral contact between Cretaceous Dakota Sandstone and the Love Ranch Formation across Yoast Draw drainage system. A fanglomerate forms mesa tops over both Cretaceous and Eocene Love Ranch Formations.

granitic materials with a preponderance (75 percent) of volcanic glass in the 1.0 mm size (Gold Hill Geological Research, 2008). No tektites or shocked quartz were found in the sample.

Volcanic-debris clasts increase in abundance in the upper part of the Love Ranch Formation as it grades conformably upward into the Eocene Palm Park Formation, consisting of andesitic debris, which is exposed near Point of Rocks. The base of the Palm Park has been dated as old as 51 Ma (Kottlowski et al., 1969).

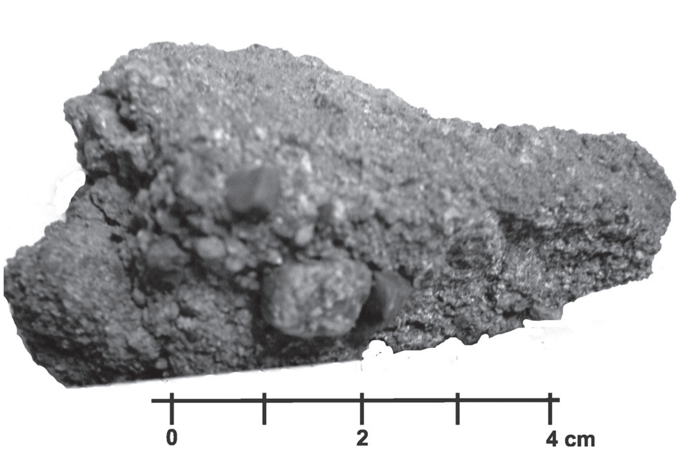


FIGURE 5. Hand sample of Love Ranch Formation sandstone that crops out near north edge of footprint. Clasts of feldspar are visible.

Tertiary Volcanic Remnants

The southern and eastern periphery of the footprint is roughly outlined by three separate groups of Tertiary volcanic exposures. These three volcanic ridges are the Point of Rocks on the south, Upham Hills to the southeast and the Prisor Hill to the northeast, and lie at distances of 2 to 3 km from the edge of the footprint (Figs. 1-2). The Point of Rocks volcanic hills are fairly extensive, being about 10 km east-west, and about 3 km wide, and with elevations as much as 215 m above the basin floor.

These occurrences were described by Seager (1975, 2005) as Uvas Basaltic Andesite, part of the broad Uvas volcanic field about 35 km to the south. The Uvas field has been dated as late Oligocene, 27 to 28 Ma (Seager et al., 1984). Seager (2002) describes the outcrops as dikes with possible plugs that feed some of the basaltic andesite flows, and the Point of Rocks was most probably originally topped by a cinder cone.

Adjacent Structures

Yoast Draw, about 3 km north of the footprint, appears to be a structural boundary between a broad slope to the north, underlain by Cretaceous strata and a belt of scattered mesas bordering the footprint that is underlain by the Love Ranch Formation south of the draw. The northern slope has been mapped as the southern limb of a low anticline (Seager and Mack, 2003). The 3-km wide belt underlain by Love Ranch Formation consists of scattered mesas that are variably tilted southward as much as 10 degrees, indicating that this area is part of a broad slide. It is likely that the Yoast Draw drainage system is the faulted border of a structural depression that has preserved the Love Ranch Formation. Figure 4 interprets this depression as a possible slump block marginal to a crater edge that existed prior to deposition of the Love Ranch deposits that included undisturbed fresh water limestone, and where continued movement of the block could explain the southward tilting and slides of the Quaternary fanglomerate.

Topography and Drainage

The only significant topographic relief that defines the footprint perimeter other than the vague meanderings of the Jornada Draw is in the southeastern quadrant where a 15-m high erosion scarp extends for about 2.5 km on the inside edge of the footprint (Fig. 2, 6). The scarp forms a low plateau where the inside of the footprint to the east has the same slope as that of the thinly covered bedrock surface upslope to the west (Figs. 6-7). It is speculated that runoff across the gravelly crater fill was diverted by exposed, ruptured bedrock or by karst sinkhole development in underlying Cretaceous or Permian strata, and subsequently a Cretaceous shaley layer upslope of the edge was stripped, representing a loss of about 15 m, to expose the dip slope of a resistant limestone stratum now covered by a thin layer of alluvium. The vegetation changes seen on aerial photos create the appearances of false topography elsewhere.

FIGURE 6. The 15 m high erosional escarpment, shown at the 8:00 position. Looking east, the truck on the trail is shown at the point interpreted as the edge of circular feature based on vegetation alignment. Magnetometer survey M3 was conducted on this alignment.

RESULTS OF INVESTIGATIONS

Magnetometer Survey

Magnetometer surveys (Fig. 2) were conducted at three points across the perimeter of the footprint with lines on the order of 2.25 km (Sunbelt Geophysics, 2008). The location of the first survey (M 1) was determined by an unusually sharp contrast in vegetation that permitted accurate locations on the ground when compared with mapped ranch facility features (Figs. 8-9). Following the results of the first magnetometer survey that showed a pronounced anomaly that coincided with the footprint edge, a tight grid of about 200 m on centers in an area of about 600 x 800 m was focused on this anomaly (Fig. 9). The computer drawn "snapshot" appears to show mega breccia and crater fill. The second traverse (M 2) with the magnetometer was a few hundred meters east of the Sierra County Road A013 and BNSF Railroad R/W. Although having a similar abrupt change in field strength magnitude at the interpreted crater edge as the first survey, the magnitude was reversed. Variable conditions here suggest that the reversal might be caused by cathodic protection of the two pipelines along the railroad easement or by its close proximity to the geologically younger Point of Rocks magmatic intrusion into the brecciated edge. A third traverse (M 3) crossed the vegetation cluster along a trail just west of the high point of the western side escarpment (Fig. 6). Anomalies that might define the edge were not found in this line; however, it is believed that this confirms that the area was completely within a filled area that did not distinguish crater fill from suspected karst sinkhole fill that may have formed along the edge of the footprint.

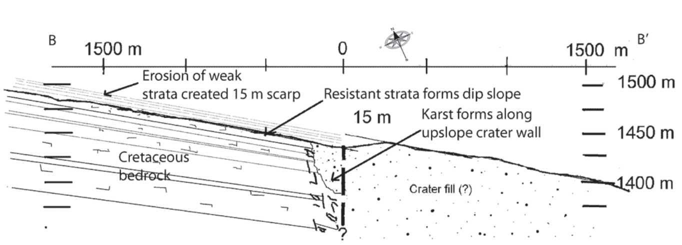


FIGURE 7. The profile show the slopes up dip and down dip from the interpreted footprint edge suggesting it was controlled by dip slope structure of the underlying Cretaceous strata. It is interpreted that the toe of the scarp has karst sinkholes filled with material similar to crater filling.

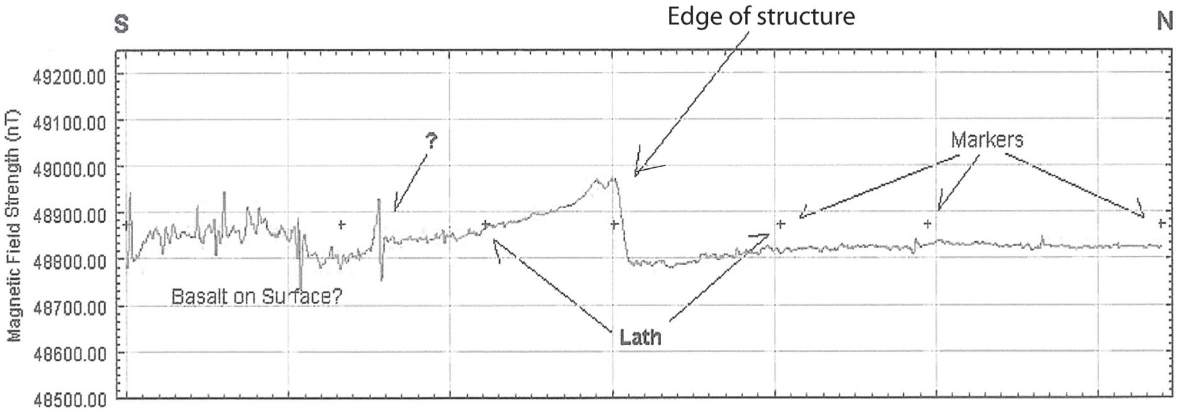
Review of Water Well Logs

An inventory was made of the water wells in the area to determine what might be shown in the well logs relative to the crater filling versus the bedrock outside the crater (New Mexico Office of the State Eng., 2008). A well field recently (2007-08) located for Americas Spaceport Authority, in an area within 2 km of the crater edge on the northeastern quadrant of the footprint, has provided the only lithology logs within the vicinity. The location of the wells is shown in Figure 2. The depth to groundwater in this area (section 5, T16S, R1W) is only about 23 m. Only four wells are within the footprint area, with water levels recorded when the wells were drilled or redrilled. It is believed these were originally associated with the railroad. The oldest dates to 1900. The only wells with lithology logs are the ones near the Spaceport, with one exception: the 140 m dry well (it apparently had a windmill) at the southern edge (position 5:30) has logged 25 ft (8 m) of basalt at 62 m. An exploratory gas drill hole inside the footprint near the eastern edge that was made to a depth of 244 m in 1966 could provide important information (Fig. 2). It reported a water level at 99 m, but apparently was not completed as a well and did not have a lithology log.

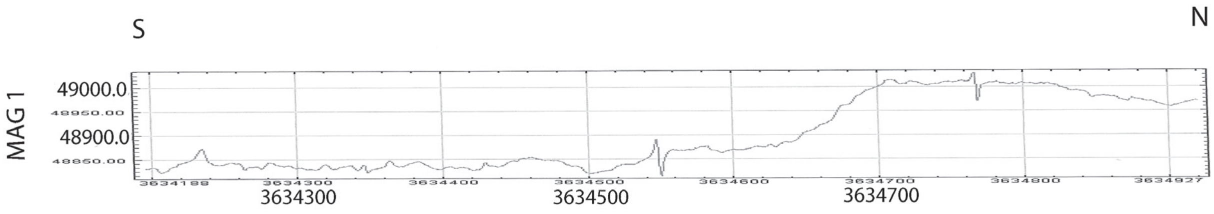
The most significant anomaly in water levels is in the southern periphery of the footprint where three wells drilled (redrilled?) below 100 m are now dry with windmills abandoned, while one well in the southwest in Barbee Draw has water as shallow as 18 m. The proximity of dry wells to the Point of Rocks volcanic field suggests that groundwater flow has been diverted southward near the 7:00 position, perhaps related to subsurface magmatic intrusions.

EVIDENCE FOR AN IMPACT CRATER

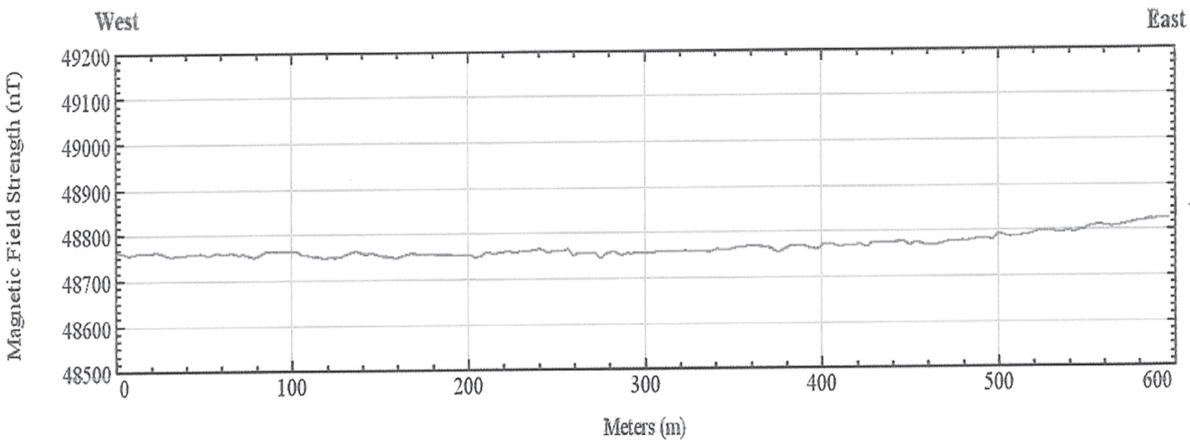
The distinctive edge shown on satellite photographs is the primary argument for a meteorite crater. The most likely "other causes" for the nearly 13-km diameter feature would be either: a maar, a hydrovolcanic (phreatomagmatic) explosion caused by rising magma encountering an aquifer; or a volcano-tectonic collapse structure caused by evacuation of a magma chamber below a volcano. The diameter of a maar is constrained by the maximum depth of overburden over an aquifer at 100 m (Self et al., 1996). The largest known maar anywhere (Zuni Salt Lake, New Mexico) is about 1980 m in diameter and 122 m deep (Wohletz and McQueen, 1984; Tilling, 1985), which is only about one sixth the size of this feature (Figs. 1-2). Another reason that opposes a maar as the cause is that local Uvas basaltic andesite volcanic



M1 @ southeast edge



M2 @ southedge



M3 @ WSW quadrant

FIGURE 8. Magnetometer surveys M1, M2 and M3. From Sunbelt Geophysics, 2008. The software printout of the survey lines shows the length in meters vs. the magnetic field strength. M1 taken near the 5:00 position shows an abrupt change where a lath marker anticipated the edge of the foot print would be. Figure 9 shows this location in a "snapshot" of the expected crater edge. M2 was taken near the 6:00 position and shows a similar boundary condition but with the field strength is reversed from that of M1. The M3 survey was taken on a trail across the scarp edge near position 8:30 shown in photo Figure 6 and topographic profile Figure 7.

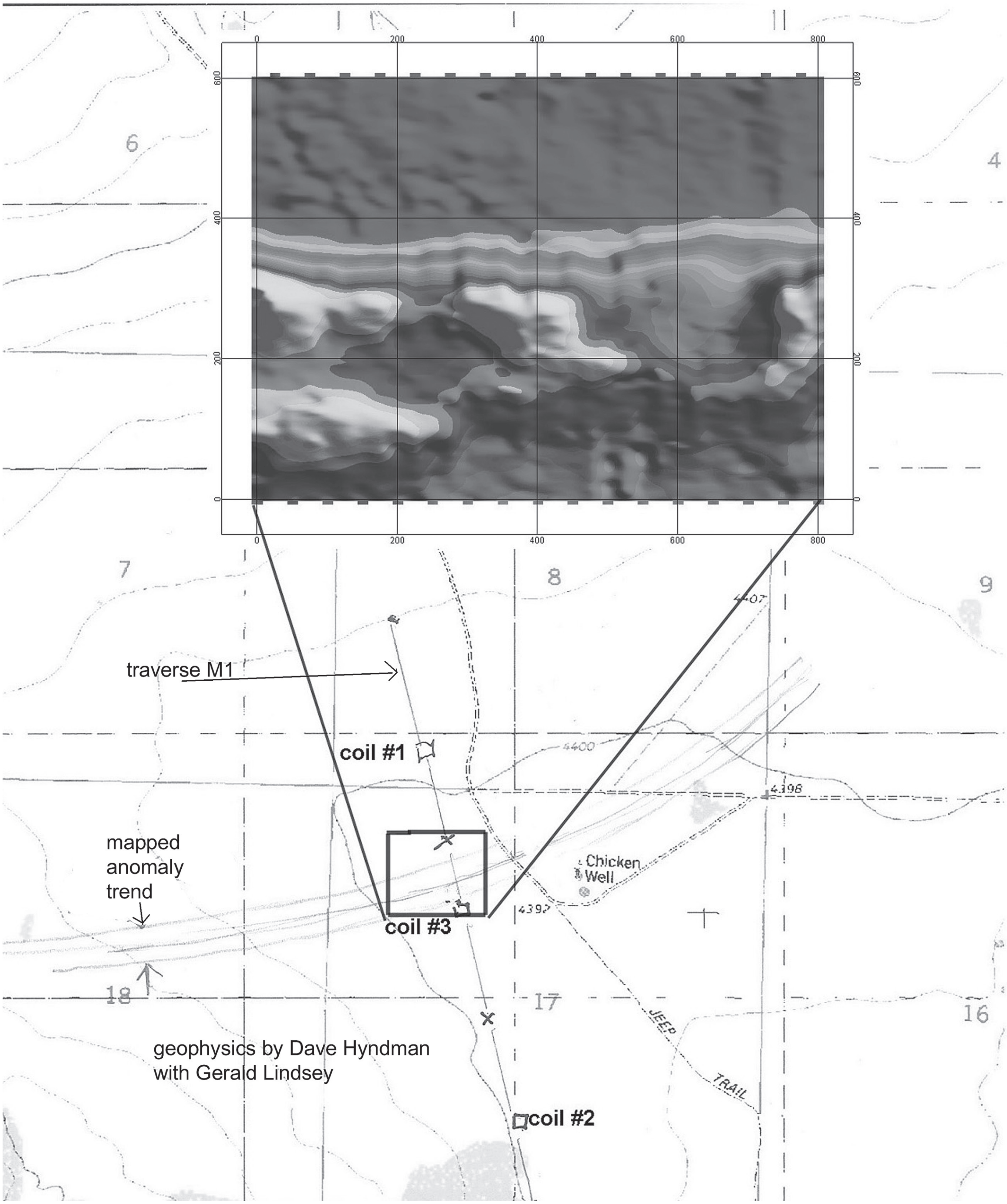


FIGURE 9. Magnetometer survey line M1working map. This line was surveyed by Sunbelt Geophysics (2008) at a point that was solely defined by vegetation changes. A sharp drop in field strength magnitude (north to south) at the anomaly trend was surveyed by a 300 m grid that resulted in the computer drawn image. The "coil" surveys were experimental. The "snapshot" image suggests the south side consists of mega breccia bedrock separated by a sharp structural boundary from uniform deposits that could be lacustrine crater fill on the north.

activity has been dated no older than 35 Ma; this is at least 25 million years younger than the time constraints of the overlapping Love Ranch deposits. It is similarly unlikely that a volcano-tectonic structure similar to the Valles Caldera in the Jemez Mountains could have occurred here for the above reason in addition to there being no volcanic center here that would have depleted a magma chamber.

The vegetation belt that defines the perimeter is believed to be the result of near surface groundwater barriers that occur at the interface of relatively fine-grained crater fill and the highly disturbed bedrock shown on Figure 9, which may have resulted from an impact. Locating the initial magnetometer survey line (M1) across the southern edge of the footprint was possible as a result of the distinct contrast in vegetation seen on satellite photos that allowed the circular line to be extended into an area with existing mapped features.

The results of the magnetometer "snapshot" using a tight grid survey show all of the features that would be expected for an impact crater edge: the outside edge of megabreccia disrupted bedrock; and the very abrupt "crater-wall" contact with uniform-structured deposits that would be expected for closed-basin deposition. This interface confirms the presence of a groundwater barrier that would affect vegetation preference and growth. Although two subsequent survey lines did not show this dramatic fractured bedrock edge, the results could be explained by the variable local geology. Because the site was a segment of the circular pattern visible on satellite photo, this indicates that it is unlikely to be a fault, particularly when compared with the trace of the Jornada Draw Fault with which it intersects.

The M 3 survey line across the 8:00 position shows no change across the footprint edge. This would be expected if it were crossing a filled sinkhole where the deposit is the same material as the crater fill. The several clusters of dense mesquite growth in the southwestern quadrant (positions 6:30 to 9:00, Fig. 1) suggest locations of filled karst sinkholes. The subsurface conditions of Permian and Cretaceous carbonate layers and shallow groundwater would be conducive to sinkhole formation. A famous case of sinkholes related to impact craters is the Yucatan Chicxulub crater where sinkholes (cenotes) were belatedly discovered to outline the crater edge.

Besides the vegetation contrast on the edge, there is one artifact of a probable impact in the form of the 15-m high escarpment that is not visible on satellite photos. This feature (Figs. 2, 6) in the southwestern quadrant is positioned at about the 9:00 to 7:00 position, and is interpreted as being the result of differential erosion between the erosive resistant fanglomerate footprint fill relative to a 15 m thick shaley bedrock upslope that occurred directly upslope from the footprint. This erosion differential could have been initiated by development of karst sinkholes at the footprint edge.

The lack of crater rims and a central peak that are characteristic of craters of this size is not a negative argument because of the loss of hundreds of meters of thickness of bedrock stripped by erosion from the surface over millions of years. It could also be argued that such features would not have persisted in a Cretaceous marine environment or in a closed basin lake during deposition of the Love Ranch deposits. Because hundreds of meters of Cretaceous and Love Ranch Formation deposits have been eroded from the site, it appears that the circular feature structure persists at depth and is not the result of surficial geomorphic processes.

The deposits of Eocene Love Ranch Formation are preserved in a belt about 3 km around the northern edge and bounded on the north by Yoast Draw. North of the drainage only Cretaceous sandstone and shale occur. The position of the depression, now mapped as a growth syncline, could alternately be considered as a secondary artifact of an impact because it has the characteristics of a peripheral slump block such as might occur at the margin of deep impact craters.

The location of water wells and water depth indicate that the contrast in conductivity at the perimeter is both a barrier and a potential recharge zone that greatly influences the flow of groundwater.

ARGUMENTS AGAINST AN IMPACT

There are no surficial manifestations of a meteor strike. The perimeter does not have a rim showing upturned bedrock, and, for crater diameters greater than 4 km, it is expected there would be a central peak formed by rebound.

There is no evidence presented of altered minerals such as shocked quartz (coesite and suevite), melt particle tectites and shatter cone structures that are proof of an impact. There could be an occurrence of iridium several times the amount of background levels.

The proximity of the Uvas type volcanic centers strongly suggests it is of volcanic origin, such as a hydromagmatic explosion known as a maar that occurs when rising magma intercepts an aquifer. Such structures occur in the Potrillo volcanic field west of Las Cruces.

The magnetometer data could also be the results of a circular fault.

CONCLUSIONS

The magnetometer survey has identified the interpreted edge of a filled and buried crater. The results appear to show a crater filling of very uniform sediments and an outside edge consisting of highly fractured bedrock. Three factors indicate that the circular outline is a bedrock structure and not a basin fill geomorphic accident: the removal of hundreds of meters of Cretaceous and Tertiary Love Ranch strata; the dip slope west of the footprint and the abrupt, and the narrow vegetation outline of the circular feature indicative of bedrock groundwater conditions. If this argument is accepted, the argument that it is a maar, a phreatomagmatic explosive crater, is unlikely because the largest know maar is only one sixth the size of this 12.5 km feature and at potential depths of less than 200 m would have been nearly "erased" by the subsequent erosion of the Dakota Sandstone and Crevasse Canyon Formation strata. The apparently unaffected Love Ranch Formation that overlaps the northern quadrant is younger than the circular feature. The age of the Love Ranch Formation age has been defined as Paleocene/Eocene but this does not necessarily provide the oldest date of an impact. These preliminary assessments based on surface investigations will require subsurface investigations to validate these interpretations.

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