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THE GEOLOGICAL AND GEOARCHAEOLOGICAL SIGNIFICANCE OF CERRO PEDERNAL, RIO ARRIBA COUNTY, NEW MEXICO

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Abstract.—Cerro Pedernal is an isolated basalt-capped peak of substantial geologic and geoarchaeological significance. The peak is located on the Colorado Plateau near the boundary of the Rio Grande rift. Oligocene-Miocene stratigraphic units on Cerro Pedernal correlate to thicker sections within the rift and document initiation of rift-basin subsidence before 25 Ma. Cessation or near cessation of sedimentation on the nascent rift margin led to hypothesized extensive weathering and formation of pedogenic calcrete horizons that were later buried by volcaniclastic deposits that overlapped the rift margin. Diagenesis of vitric volcaniclastic detritus likely led to silica replacement of the calcareous soils to form the Pedernal chert, which was commonly used for lithic-tool manufacture for more than 13 millennia of human occupation in northern New Mexico. Heavily utilized chert quarries in the Cerro Pedernal-San Pedro Parks region were important lithic-material sources, but so were redeposited cobbles of chert that are ubiquitous in alluvial deposits on the Colorado Plateau and in the Rio Grande rift. The combination of primary and secondary chert sources has confounded efforts to determine the exact source locations of artifact raw materials. Fire, along with simple prying tools and hammerstones were likely used to dislodge large chert pieces for tool manufacture. Preliminary working of cores and bifaces produced large volumes of irregular flakes and rejected pieces that were mistaken by some early workers as finished products of more ancient tool-making cultures.

INTRODUCTION

Rising to an elevation of 2986 m, the pinnacle of Cerro Pedernal is a widely recognized and visible landmark in northern New Mexico (Fig. 1). Referred to in the accounts of Spanish explorers and American surveyors, and made famous as a common landscape element in Georgia O'Keefe's paintings, the narrow, flat-topped peak is also significant to diverse geological and archaeological studies.

This paper summarizes current knowledge of two aspects of northern New Mexico geology that center on Cerro Pedernal and localities close to the peak. First, Cerro Pedernal preserves an erosional remnant of Rio Grande rift-basin stratigraphy that overlaps onto the Colorado Plateau. Stratigraphic correlation of the Cerro Pedernal strata to sections in the Cañones-Abiquiu area provides insights into the history of rift-basin subsidence and sediment accumulation. Second, the peak is the type locality of the Pedernal member of the Abiquiu Formation, an enigmatic succession of siliceous layers that have served as a significant regional source for lithic tool manufacture since the appearance of the first humans in New Mexico. The Spanish name for the peak ("pedernal" translates as flint, in English) calls attention to this curious rock occurrence. The durability of the chert during weathering and transport causes it to be widespread as cobbles in alluvial deposits of northern New Mexico, which aids provenance study of the sediment and provides innumerable secondary contexts for human use.

GEOLOGIC SIGNIFICANCE OF CERRO PEDERNAL

Cerro Pedernal is located within a band of en-echelon normal faults that form the western margin of the Abiquiu embayment within the Española basin of the Rio Grande rift (Fig. 2). A Tertiary section that includes Eocene El Rito Formation, Oligocene-lower Miocene Abiquiu Formation, middle Miocene Tesuque Formation, and upper Miocene Lobato Basalt is flat lying and rests disconformably on Mesozoic strata at the base of the butte. The lack of stratal tilting and the absence of large-displacement faults to the west of Cerro Pedernal support placement of the peak at the eastern margin of the Colorado Plateau. The capping 7.8 Ma Lobato Basalt lava flow (Manley and Mehnert, 1981), erupted nearby in the Jemez Mountains to the southeast (Fig. 2), preserves more than 400 m of Oligocene and Miocene rocks that are better known from thicker sections within the Rio Grande rift in the Abiquiu area.

Rift-Basin Subsidence History

Manley and Mehnert (1981) and Baldridge et al. (1994) called attention to the fault displacement of roughly 7.5-10 Ma Lobato

FIGURE 1. View of Cerro Pedernal from the north. Miocene basalt caps a pinnacle of poorly exposed lower and middle Tertiary strata that rise above a base of Mesozoic rocks. Photo courtesy of Lisa W.Huckell.

Basalt flows and the intrusion of contemporary dikes along faults; they proposed that principal rift-basin subsidence in the Abiquiu embayment initiated at about 10 Ma. Smith et al. (2002) point out, however, that the basalt flows preserve a northward paleoslope from the Jemez Mountains that was eroded on southwest-dipping rift-basin fill (Fig. 2). The angular unconformity between the basalt and underlying strata implies that most basin subsidence occurred before basalt extrusion.

Figure 3 illustrates the correlation of Cerro Pedernal stratigraphy to the stratigraphic section in the Cañones area in the western Rio Grande rift and only 5 km east of the peak. The correlation of rift-basin stratigraphy mapped by Manley (1982) and Moore (2000) to the undeformed section at Cerro Pedernal highlights evidence for the pre-basalt rifting history. Middle Miocene strata of the Tesuque Formation thicken dramatically from about 65 m at Cerro Pedernal to 330 m southeast of Cañones, indicating substantial movement on the Gonzales and Cañones faults (Figs. 2 and 3) before eruption of the Lobato Basalt. The underlying Abiquiu Formation consists of two thick members, a lower member of Precambrian-clast gravel and conglomerate, and an upper member of volcaniclastic sandstone and conglomerate (Smith, 1938; Vazzana, 1980; Moore, 2000). The lower member thickens only slightly between Cerro Pedernal and Cañones, whereas the upper member is roughly 25% thicker at Cañones (Fig. 3).

Recognition of stratigraphic subdivisions within the upper member defined by changing volcanic provenance (Smith, 1995), allowed Moore (2000) and Smith et al. (2002) to further determine that the thinner section at Cerro Pedernal lacks the lowermost parts of the upper member that are present in outcrop near Cañones and farther east near Abiquiu. Clasts of the 25 Ma Amalia Tuff and sandstones with abundant quartz and alkali feldspar eroded from the tuff and coeval volcanic rocks of the Latir

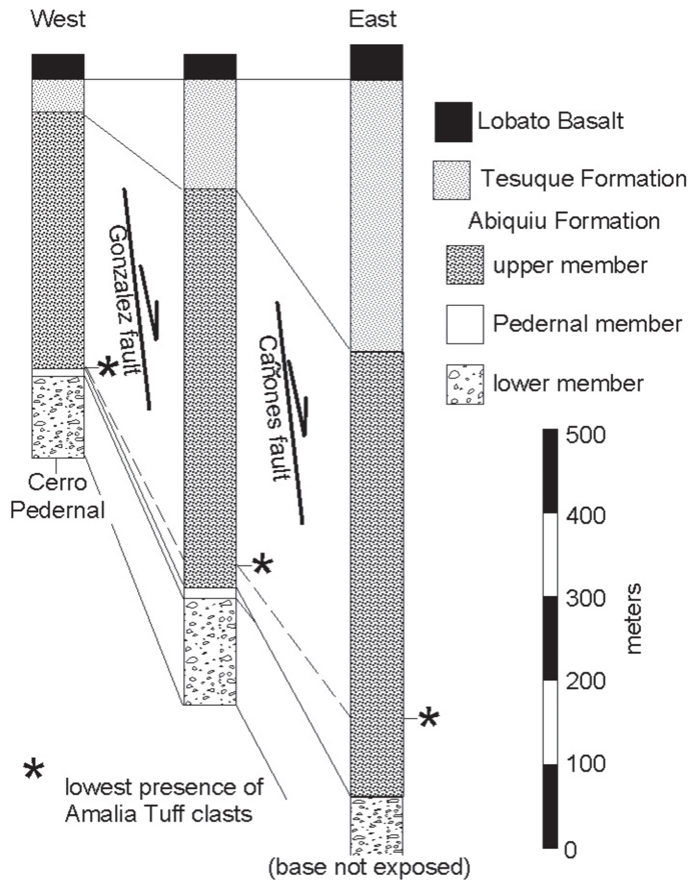

FIGURE 3. Correlation of Oligocene and Miocene rocks eastward from Cerro Pedernal shows abrupt thickening of strata across rift-margin faults, except for the Pedernal member, which is restricted to the footwall of the Cañones fault. Thickening across faults implies syndepositional movement on rift-margin faults. The restricted distribution of the Pedernal member, along with condensation of the lowest strata of the upper member implied by the lowest appearance of Amalia Tuff clasts, is consistent with an initial pedogenic origin for the Pedernal member.

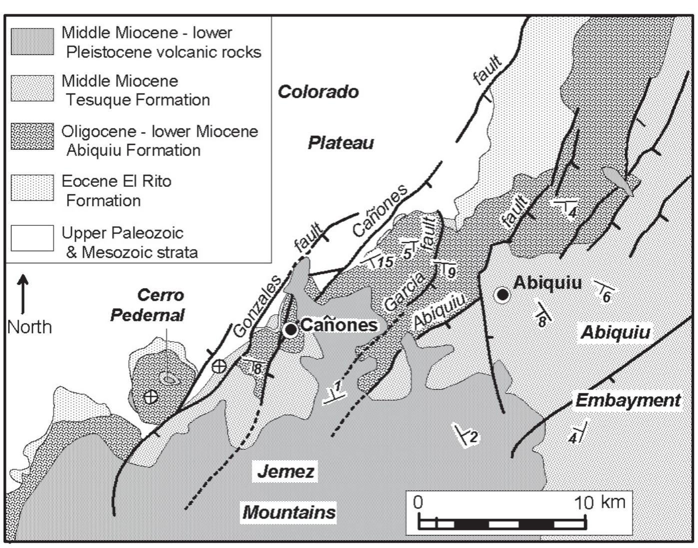

FIGURE 2. Generalized geologic map of the Abiquiu region showing the location of Cerro Pedernal near the boundary between the Colorado Plateau and the Abiquiu embayment of the Rio Grande rift (after Smith et al., 2002).

volcanic field (north of Taos, NM) occur at the base of the upper member at Cerro Pedernal (Smith et al., 2002; Fig. 3). This same marker horizon is about 15 m above the base of the upper member near Cañones and is more than 80 m above the base near Abiquiu (Smith et al., 2002). These observations imply that basin subsidence and rift-margin faulting were underway during Abiquiu Formation deposition, which commenced in this area before eruption of the 25 Ma Amalia Tuff (Smith et al., 2002).

Deposition of approximately 400 m of Abiquiu Formation outside of the rift at Cerro Pedernal also implies aggradation mechanisms other than rift-basin subsidence. Moore (2000) and Smith et al. (2002) provide the results of simple flexural-loading and sediment-transport models that can partially account for deposition of the Abiquiu Formation by two mechanisms. First, the loading of the crust by construction of the coeval San Juan and Latir volcanic fields (in southern Colorado and north-central New Mexico, respectively) likely produced a flexural moat of sufficient dimensions to produce sediment accommodation space in the Cerro Pedernal area. Second, the inundation of rivers by large volumes of volcanically produced pyroclastic sediment would likely lead to regrading of river profiles that would cause modest aggradation in this region. This volcanism-driven aggradation allowed sedimentation to extend beyond the nascent rift margin, whereas stratigraphic thickening into the rift, relative to the section at Cerro Pedernal, demonstrates the contemporaneity of deposition and rift-basin subsidence (Smith et al., 2002).

Nature and Origin of the "Pedernal Chert"

In Abiquiu Formation outcrops west of the Cañones fault, the Pedernal member is present between the lower and upper members (Fig. 3; Bryan, 1938, 1939; Smith, 1938; Church and Hack, 1939). The Pedernal member is a 4- to 8-m thick interval of gravel that resembles the lower member but is notable for the presence of one to four, discontinuous, irregular bodies of chalcedonic and cherty silica with varying proportions of associated calcite. Figure 4 presents the approximate extent of the Pedernal chert member as mapped by Church and Hack and others (Banks, 1990; LeTourneau, 2000). Most of the chert is massive with scattered pebbles but in places also consists of nodular cement within gravel. The siliceous layers compose the informally known "Pedernal chert." The siliceous horizons are best exposed as outcrop ledges more than 2 m thick near the tapered base of Cerro Pedernal (at an elevation of ~1900 m), but continue southwestward around the western margin of the Jemez Mountains and form much of the summit plateau of the Sierra Nacimiento at the San Pedro Parks (at an elevation of 3100-3200 m; Fig. 4; Church and Hack, 1939). Although sedimentary deep-sea chert and chert replacement of limestone are common rocks, the Pedernal chert is very unusual as a nonmarine occurrence of stratiform silica.

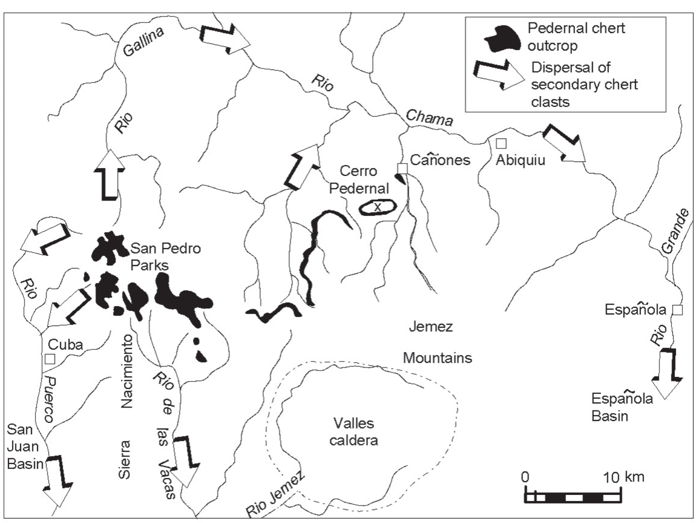

FIGURE 4. Map showing the distribution of Pedernal chert outcrops and pathways for fluvial distribution of Pedernal clasts (modified from Church and Hack, 1939).

The siliceous horizons are very heterogeneous in thickness, color, and texture. Individual layers range from 20 cm to more than 2 m thick. Upper and lower contacts are undulatory and are sharp in some places but gradational through a nodular-chert zone in other places. As Bryan (1939, p. 17) described it:

> "The chert is commonly white to pearly gray in color though in places the color may vary considerably. Near the base and sometimes near the top the chert shows bands 1/4" to 1/2" thick and is black in color. In places near the top, weathering has changed the color to pink, red, or yellow. The red color also occurs as flecks or spots in the white to pearly gray mass. Generally the yellow color is associated with clear, very translucent phases of the chert. This translucent type usually occurrs in small masses near the top of the bed."

Most exposures consist of vitreous chert (equant, microcrystalline quartz) and chalcedony (fibrous quartz) dominated by translucent gray and yellowish gray colors with patches and swirls of more opaque red, maroon, and black coloration. Discontinuous micritic calcite, in horizons as much as 50 centimeters thick, is present in the lower parts of, or beneath, most siliceous layers. Petrographic observations by Vazzana (1980) and Moore (2000) show evidence of replacement of micritic calcite by both chalcedony and chert, with subsequent infilling of vugs by chalcedony, drusy quartz, or sparry calcite.

Although cropping out only in a narrow stratigraphic interval over an area of only 300 km^2, chert pebbles and cobbles from this unit are notable in rift-basin and younger valley-fill alluvial deposits southward into the Albuquerque basin, westward into the San Juan basin, and eastward into the Española basin (Fig. 4). The persistence of the siliceous clasts attests to the resistance to weathering and the hardness of Pedernal chert.

No researchers have systematically studied the siliceous horizons of the Pedernal member, although Vazzana (1980) and Moore (2000) provided some important observations and data as part of broad studies of the Abiquiu Formation. Vazzana (1980) described mineralogical and whole-rock-geochemical variations within sandy gravel below a Pedernal chert horizon that he ascribed to a buried weathering profile. Along with the widespread replacement of micritic calcite by silica, Vazzana (1980) and Moore (2000) interpret the evidence of weathering to indicate pedogenic modification of the upper part of the lower member of the Abiquiu Formation. In this hypothesis, Oligocene weathering and soil formation produced several very mature aridisols with subsurface calcrete horizons. Following burial by the volcaniclastic upper member, ground water leached silica from the rhyolitic, vitric detritus and then reacted with the buried calcretes to largely replace the calcite with silica.

If true, the altered pedogenic calcrete is consistent with stratigraphic evidence for development of the rift-basin margin during Abiquiu Formation deposition (Fig. 2). The Pedernal member is only present west of the Cañones fault and in areas where the lower part of the upper member is absent, based on the stratigraphic analysis of Moore (2000) and Smith et al. (2002). The mutual exclusion of the Pedernal member and the complete sections of the upper member led Smith et al. (2002) to conclude that early rift faulting excluded significant deposition from relatively high-standing structural blocks along and west of the rift margin, where soils formed during hiatuses in slow accumulation of gravel eroded from the Sierra Nacimiento. Increased volcaniclastic sedimentation following eruption of the Amalia Tuff buried the relief along the rift margin.

ARCHAEOLOGICAL SIGNIFICANCE OF CERRO PEDERNAL AND PEDERNAL CHERT

The ethnologist J.P. Harrington (1916), who reported that the Tewa Indians knew the peak as tsiping, or "flaking stone mountain," first drew anthropological attention to Cerro Pedernal. His informants were somewhat confused as to whether it was a source for obsidian or some other material, although archaeologist J.A. Jeancon told Harrington that his excavations at a nearby pueblo ruin had produced very little obsidian but considerable "calcedony (sic) and other varieties of flaking stone" (Harrington, 1916, p. 123). Some 20 years later, Hibben (1937) was apparently the first archaeologist to describe evidence of prehistoric quarrying of chert on the south side of peak. He observed the prominent ledge outcrops and also reported numerous ancient pits, with accompanying accumulations of flaking debris and workshops. In addition, he noted that material from the quarry was abundant down the Rio Chama to its confluence with the Rio Grande.

Additional research carried out during that same decade by Kirk Bryan and his then-student John Hack led to more detailed description of the extent of the Pedernal chert and to a fuller appreciation of the kinds of evidence for its use by prehistoric stone workers. In particular, Bryan (1938; also see Church and Hack, 1939) reported extensive outcrops of the chert extending westward as far 30 kilometers into the San Pedro Parks area. Quarry pits were reported to cover an area some 40,000 square meters (10 acres) in size (Bryan, 1938; see Church and Hack, 1939, fig. 6 for an illustration) in the San Pedro Parks (Fig. 4).

Clearly this material was obtained over a large area, and probably by cultures spanning the last 13 millennia. In fact, we now know that its first use was by Clovis Paleoindians—a complete Clovis point of Pedernal chert was reported from the area near Bandelier Monument some 45 km southeast of Cerro Pedernal on the east flank of the Jemez Mountains (Fig. 5; also see Powers and Orcutt, 1999), and a fragment of another Pedernal chert Clovis point was reported by Acklen (1997) from a site south of Abiquiu about 15 km east of Cerro Pedernal. Folsom points of Pedernal chert have been reported from the Middle Rio Grande (LeTourneau, 2000; Huckell and Kilby, 2002). Turnbow (1997) reported numerous Middle and Late Archaic Pedernal chert projectile points from Jemez Mountain sites, and Roxlau et al. (1997) documented extensive use of the chert for other flaked stone tools in the region. Pedernal chert was also abundant at large pueblo sites along the Rio Chama (Hibben, 1937; Warren, 1974), and occurred at Puebloan sites in the Jemez Mountains as well (Turnbow, 1997; Roxlau et al., 1997).

In addition to the large area within which the primary outcrops of Pedernal chert are found, it can also be obtained in the form of cobbles from Tertiary and Quaternary alluvium over a significant portion of the Rio Puerco, Rio Jemez, and Rio Grande valleys. It occurs as large blocks, cobbles, and pebbles. This distribution in secondary contexts confounds assignment of particular artifacts of Pedernal chert to the primary source outcrops, because there is clear evidence that prehistoric people exploited these cobbles. However, we have observed that in the middle Rio Grande valley, Pedernal chert cobbles seem to represent a comparatively narrow portion of the range of color variation seen in the primary source areas—the more colorful varieties (yellow, red-spotted, purple, variegated) are rare to absent, and those of darker colors (brown, black) are abundant. This remains to be fully documented, but may provide an additional means (along with the presence of stream-tumbled exterior surfaces) to differentiate at least some primary and secondary occurrences of Pedernal chert.

Quarrying at Primary Outcrops of Pedernal Chert

While it is abundantly clear that the chert was in great demand for tool manufacture, few studies of its quarrying at the primary

FIGURE 5. Clovis spear point manufactured from Pedernal chert and collected in Bandelier National Monument on the eastern flank of the Jemez Mountains. The point is 7.64-cm long from base to tip (Bandelier National Monument Collection specimen BAND 5024). Photo courtesy of Lisa W. Huckell.

source locales have been undertaken since the 1930s. Much of the chert can be obtained simply by collecting the eroded blocks scattered below the ledge outcrops of it, or by breaking and prying pieces from the ledges.

The quarry pits near Cerro Pedernal and the San Pedro Parks suggest, however, that prehistoric toolmakers recognized that higher quality material could be obtained through more labor-intensive methods that entailed excavating from the ground surface down through the flat-lying exposures of the chert. In all probability they accomplished this using fire, a process described by Fowke (1902) for the Flint Ridge quarries in Ohio, and as observed in Australia by Binford and O'Connell (1984). The process entails clearing away loose earth and debris to expose the fractured surface of the rock and then building a fire on it. The rapid rise and subsequent fall of heat generated by the fire exceeds the elastic limits of the chert, causing it to fracture and shatter. Stone hammers and wooden or antler picks are then used to break and wedge out the shattered chert until unaffected stone is reached; the firing process is then repeated, commonly until the entire thickness of the chert horizon is removed. If, as is the case with the Abiquiu Formation, the chert is underlain by poorly consolidated material, then this underlying material can be removed to create a working face from which the chert can be quarried. Again, fire is used to fracture large blocks of chert from the lower part of the bed. The fractured blocks are removed from the pit; those suitable for flaking are reduced by percussion techniques on the spot or taken to nearby workshops. Small and thermally compromised chert blocks is discarded.

Bryan (1938, p. 344) described the quarry pits as "1 to 5 feet deep and 2 to 10 feet across. Some are filled with broken pieces of stone, others almost empty." Because none of the pits have been excavated, we have no knowledge of the specific manner of their creation and use. In addition, the time period or periods when they were in use remains uncertain. Finally, in addition to the quarry pits, there are numerous scattered workshops to which blocks of material were carried for further flaking and refinement; hammer stones and other knapping tools are also present at these localities (Warren, 1974).

Quarry Products

The kinds of technological activities undertaken at the Pedernal chert quarries are similarly poorly known. The tremendous quantities of flakes, broken or discarded bifaces, cores, and thermally or mechanically shattered fragments of chert that are scattered around the quarried outcrops demonstrate that considerable flaking was done once the chert was obtained—but what products were created and then taken away?

The answer to this question probably depends to a considerable degree on the social and technological organization of the societies that existed in the region. The highly mobile hunters and gatherers of the Paleoindian and Archaic periods (ca. 11,500-1500 radiocarbon years BP) probably used the source in different ways than did the later Ancestral Puebloan people, who lived in more or less permanent villages at no great distance from it.

For example, recent work at the Boca Negra Wash Folsom site west of Albuquerque shows that Pedernal chert was second only to Jemez Mountains obsidian among utilized lithic materials (Huckell et al., 2002). Most of the Pedernal flakes are small and show features suggesting that they were struck from bifacially flaked pieces. The fact almost none of the flakes display any cortex suggests that Folsom flint knappers probably chose to make and transport either large flakes or bifaces of varying size. Folsom tools were frequently designed to be used and resharpened many times, and the projectile points for their spears were best made from pieces of material some 8-10 cm in length by 3-5 cm in width. Furthermore, because the points break frequently and may not be reparable, the manufacture of new points is a recurrent demand. The tool manufacturers' choices were constrained further by the need to minimize the weight of transported pieces while maximizing the potential utility of those pieces; carrying away large blocks of the chert would have been an unlikely solution. Therefore, their activities probably entailed the creation of flakes and small bifaces that could be made into projectile points, knives, and scrapers as needed; intermediate products, and perhaps some finished ones, were likely what they carried away from the source.

Conversely, Ancestral Puebloans, whose technological organization centered on making more expedient tools and whose settlements were nearby, might well have chosen to make and transport large cores for later flake production at their villages (Hibben, 1937). Their tools were usually simple, sharp-edged flakes, used without modification after being detached from the core. Also, the small arrow points they used could be created from small, thin flakes. One large tool made by Puebloan people in the Rio Chama area is the flaked ax, which does require a large piece of material (Warren 1974, fig. 4).

The "Los Encinos Culture"

The differing demands for chert tools over time should also be reflected in the material left behind, based on what products were being produced. However, there is substantial debate about how to interpret the stone objects recovered from quarries: Do they represent finished tools of some antiquity or are they much younger implements abandoned early in the manufacturing process?

In the late 19th and early 20th centuries, archaeologists in the eastern US frequently offered up "primitive-looking" bifaces and other tools reminiscent of European Paleolithic specimens (such as handaxes) as evidence of great human antiquity (Pleistocene) in North America, termed the "American Paleolithic" (Meltzer and Dunnell, 1992, Meltzer, 1994). To a significant degree, their argument rested on the assumption that similarity in form was best explained by similarity in age. However, others (particularly Holmes, 1894, 1919) pointed out that some tools, especially bifacially flaked ones, passed through several morphological changes in the manufacturing process from "primitive" beginning stages to more fully refined and carefully shaped ones as the final product was completed. Further, the same basic flaking technique—direct percussion with a stone hammer—was employed in the making of truly ancient Old World implements and in the initial stages of work at lithic quarry sites, thereby promoting the appearance of similarity. Ultimately, archaeologists came to accept that particularly at lithic raw material quarries and workshops, primitive did not necessarily equate to ancient.

In the western US, however, this debate continued well into the 20th century, with researchers reporting artifacts reminiscent of Old World Paleolithic types from surface contexts at raw material sources in Arizona (Bartlett, 1943), Wyoming (Renaud, 1938), and New Mexico, including at the Pedernal quarries. As early as 1939, Bryan identified and discussed several artifacts—principally large bifaces of irregular shape and flakes he identified as "Levallois" (a recognized Old World Lower and Middle Paleolithic flaking technology)—as being representative of a potentially ancient industry that he called the Los Encinos culture (Bryan, 1939). Counter to Holmes' ideas that these were discarded blanks, Bryan (1950: 22-25) argued that they were tools, possibly axes, and showed sufficient dulling of the edges and partial dissolution of calcite nodules to suggest that they were of some considerable age. To further support their presumed antiquity, he noted that he had recovered some examples from what he identified as the intermediate alluvium in a three-deposit sequence of alluvial units along the Rito de los Encinos, a tributary of the Rio Chama on the west side of Cerro Pedernal. Bryan used the stratigraphic evidence to propose a post-Pleistocene, but pre-Puebloan age for his Los Encinos culture. No further stratigraphic studies in the area have been conducted, so the actual ages of the alluvial units remain poorly known. He continued to suggest that quarries such as those at Cerro Pedernal were not solely places at which tool blanks were made and carried away, but places where apparently a suite of large tools were also put to use (Bryan, 1950). While Bryan was doubtless correct that some activities beyond basic lithic tool production may have occurred in the vicinity of Cerro Pedernal, his Los Encinos culture never attracted archaeological support, let alone verification of great age or distinctiveness.

CONCLUSIONS

The Tertiary stratigraphy at Cerro Pedernal, preserved beneath a tiny cap of resistant basalt, provides key insights into the early development of the Rio Grande rift. These strata thicken abruptly eastward from Cerro Pedernal, on the Colorado Plateau, across faults that form the en echelon western boundary of the Rio Grande rift. In particular, the thickening of volcaniclastic strata in the upper member of the Abiquiu Formation implies that rift-basin subsidence relative to the Colorado Plateau began prior to eruption of the 25 Ma Amalia Tuff.

The origin of the Pedernal chert, which forms the middle member of the Abiquiu Formation, is probably related to pedogenic and diagenetic replacement processes. Although further study is required, we adopt the hypothesis of Vazzana (1980) and Moore (2000) that the chert horizons originated as pedogenic-calcite horizons that were later mostly replaced by silica derived from aqueous alteration of vitric volcaniclastic detritus in the overlying upper member. The restricted distribution of the chert to areas west of the Cañones fault is consistent with relative uplift of the Colorado Plateau margin as rift-basin subsidence began in the late Oligocene. Large volcaniclastic sediment loads caused aggradation that overfilled the nascent rift margin (Smith et al., 2002), leading to further sedimentation above the buried soils in the Cerro Pedernal-San Pedro Parks region.

Cerro Pedernal and the entire Pedernal chert deposit is probably the largest and most significant prehistoric lithic quarry in New Mexico (Banks, 1990). As such, and with evidence of use over 13,000 or more years, it is clearly important for archaeologists to be able to use it in studies of lithic technological organization, patterns of prehistoric land use, and as evidence of mobility and trade. However, uncertainties about geological origin of the chert, its diverse visual and textural properties, widespread occurrence in secondary geological contexts, and the paucity of focused geological and archaeological study over the past 70 years, currently limit its utility for many archaeological research problems. To remedy this situation, new, detailed geological and archaeological research is needed to improve understanding of its development, the history of exposure and redistribution by natural processes, and the details of its use by humans.

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