Dry farming El Cajete Pumice: Pueblo farming strategies in the Jemez Mountains, New Mexico

Rory Gauthier, Robert Powers, Cynthia Herhahn, Mike Bremer, and Fraser Goff

2007, pp. 469-474. https://doi.org/10.56577/FFC-58.469

in:

Geology of the Jemez Region II, Kues, Barry S., Kelley, Shari A., Lueth, Virgil W.; [eds.], New Mexico Geological Society 58 th Annual Fall Field Conference Guidebook, 499 p. https://doi.org/10.56577/FFC-58

This page is intentionally left blank to maintain order of facing pages.

DRY FARMING EL CAJETE PUMICE: PUEBLO FARMING STRATEGIES IN THE JEMEZ MOUNTAINS, NEW MEXICO

RORY GAUTHIER[1], ROBERT POWERS[2], CYNTHIA HERHAHN[3], MIKE BREMER[4], AND FRASER GOFF[5]
[1]National Park Service, Bandelier National Monument, NM 87544
[2]National Park Service, Santa Fe, NM, 87504
[3]Office of Contract Archeology, University of New Mexico, Albuquerque, NM, 87131
[4]USDA Forest Service, Santa Fe National Forest, Santa Fe, NM, 87505
[5]Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87131

Abstract — Often overlooked, El Cajete Pumice greatly influenced the ancestral Pueblo people who populated the southern Jemez region from AD 1200 to AD 1600. The El Cajete eruption, which occurred some 55,000 years ago, is one of the latest in a series of volcanic events beginning some 16 million years ago. El Cajete pyroclastic pumice fall blanketed the south and the southeast side of the Jemez Mountains and, beginning in the 1200s, ancestral Pueblo populations began to settle and farm areas of pumice deposits. Unlike many other contemporary farming strategies, pumice soils were not often subjected to constructed facilities such as terraces, check dams or grid gardens, suggesting that unique properties of the soil made it ideal for agriculture. We postulate that pumice-bearing soils hold more moisture, and pumice on the ground surface will act as mulch, making it ideal for farming by conserving soil moisture. Conserving soil moisture is necessary for farmers in this environment who rely solely upon rainfall to water their crops. For nearly five hundred years, El Cajete "pumice patches" enabled Pueblo farmers to survive on the slopes of the Jemez Mountains.

INTRODUCTION

For the past 12 millennia, certain geologic resources have attracted people to the Jemez Mountains (Fig. 1). The great obsidian sources may have been the original draw, although chert from Cerro Pedernal or the dacite outcrops on the southeast fringe of the Jemez Mountains may have also lured people to the area. For the last 800 years, it appears that pumice enticed Pueblo farmers to the region. Archeologists have known about mineral resources for making stone tools since the late 1800s (Bandelier, 1892; Hewett, 1938; Lange and Riley, 1966) but nearly all archeologists have ignored the one mineral resource that may have had the greatest influence on the ancestral Pueblo people who lived in the southern Jemez Mountains – El Cajete Pumice.

Why pumice? Stone-washed jeans, pumice building block and the need for abrasives were still eight centuries away when the ancestral Pueblo populations began to rely on a unique geologic feature of the southern Jemez Mountains, the El Cajete Pumice. Once the great civilizations in the Four Corners area began to wane, population in the areas around the Jemez Mountains began to grow, small hamlets containing original occupants were augmented by people from the north and west, and these early farmers were exploiting the floodplains along the Rio Grande, Rio Jemez, and several areas along the Rio Santa Fe and Rio Tesuque (Wendorf and Reed, 1955; Cordell, 1979; Stuart and Gauthier, 1981). From approximately AD 900 to AD 1100 settlements and most farmed areas were concentrated along these permanent water courses. However, beginning in the mid 1100s there was a decided push into the foothill regions surrounding the major drainages such as the Jemez Plateau and Pajarito Plateau (Powers and Orcutt, 1999; Kohler, 2004, Kulisheck, 2006). In the southern Jemez region, nearly all of these newly established settlements had one thing in common – they were situated in areas of pumice soils.

Farming in the Southwest is challenging. Water is the limiting factor but the length of the growing season and nutrient-poor soils are also factors. For Pueblo farmers, these limitations were partially met by an intimate knowledge of the environment (including soil types and field exposure) and, where necessary, constructing soil moisture and soil retention features of stone. In this paper, we will discuss the agricultural success of Towa, Keres and Tewa ancestors who once dry-farmed the volcanic-derived soils on the mesa tops in the southern Jemez Mountains.

GEOLOGY AND VOLCANOLOGY

The Jemez Mountains volcanic field has been active for the last ca. 16 m.y., erupting more than 2000 km^3 of domes, flows, and pyroclastic deposits of basalt, andesite, dacite and rhyolite (Smith et al., 1970; Gardner et al., 1986). Valles caldera formed at 1.25 Ma, blanketing the lower elevations of the Jemez Mountains with the Tshirege Member of the Bandelier Tuff, a rhyolitic ignimbrite (Smith and Bailey, 1966; Self et al., 1986; Phillips et al., in press). The Bandelier Tuff forms most of the prominent mesas in the Jemez Mountains including those of the Pajarito Plateau (Goff et al., 2002).

After formation of Valles caldera, a series of ring-fracture rhyolites erupted inside the caldera depression (Fig. 2). The El Cajete eruption (55 ± 6 ka) is one of the youngest of the postcaldera rhyolites and originates from El Cajete crater in the southern caldera (Toyoda et al., 1995). El Cajete deposits are overlain by the Banco Bonito rhyolite, the youngest eruption in the Jemez Mountains (ca. 40 ka; Goff and Gardner, 2004). Collectively, the Banco Bonito, El Cajete, and Battleship Rock rhyolites form the El Cajete Series of Self et al. (1988).

The El Cajete deposits consist primarily of pyroclastic fall with subordinate pyroclastic flows and surges (Wolff et al., 1996; Goff and Gardner, 2007). Because the wind blew to the south and east during most of the pyroclastic fall eruptions (plinian eruptions) the fall deposits form a blanket throughout the southeastern Jemez Mountains, which thins away from the vent (Fig. 2).

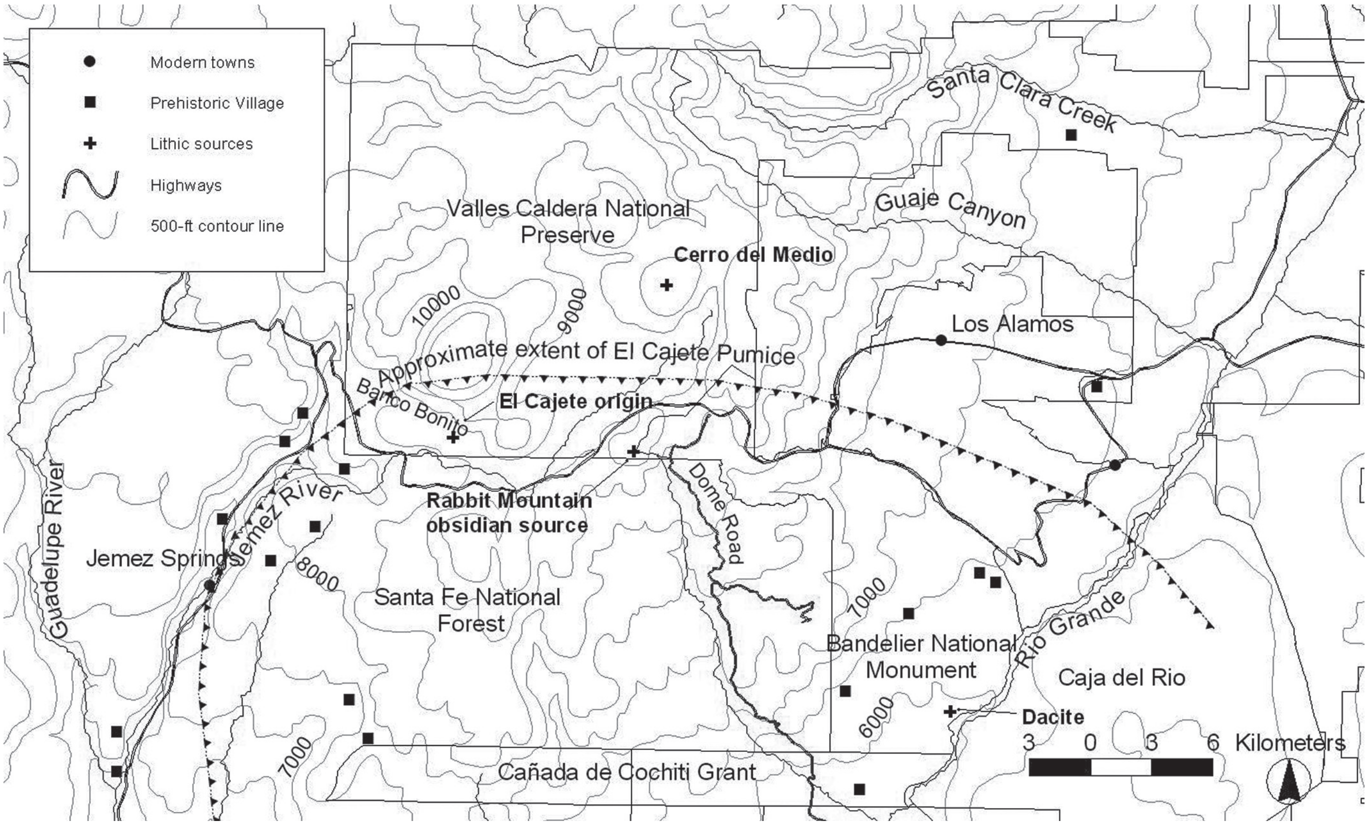

FIGURE 1. Location map of the Jemez Mountains region showing the Jemez Plateau, Pajarito Plateau and the location of select prehistoric villages.

Maximum pumice clast size diminishes away from the vent (from roughly 0.3 m to ≤1 cm). The fall deposits are relatively well sorted and contain up to 2% of lithic fragments, presumably from excavation of vent walls during eruption. Erosion has stripped the pumice off of precaldera domes. On the Pajarito Plateau, erosion has partially stripped the El Cajete from the underlying Bandelier Tuff, commonly forming relatively thick fans and aprons (usually ≤10 m thick) along eroded cliffs of the ignimbrite.

SETTLEMENT OF THE PAJARITO AND JEMEZ PLATEAU

A brief history of Keres and Tewa use of the area

The initial Pueblo occupation on the southern portion of the Pajarito Plateau consists of literally hundreds of small, short-lived villages, located on the mesa tops. This portion of the Pajarito Plateau gradually slopes from west to east, and most of the settlements are located between 1675 to 2290 m in elevation. Today, along this elevation gradient, annual precipitation ranges from about 45 to 30 cm at the Rio Grande. During wet and dry years, the range in precipitation can be even more dramatic. During the first 150 years of Pueblo settlement on the Pajarito Plateau, the inhabitants of these small villages frequently moved uphill or downhill along the mesa crests, thereby manipulating elevation to take advantage of more rainfall or a longer growing season (Steen, 1977; Powers and Orcutt, 1999). By establishing fields in the higher elevation areas, the crops would receive more rainfall, but would have a shorter growing season. Fields located at lower elevations would have an ample growing season but may not receive enough moisture to ensure a successful harvest (Gauthier and Herhahn, 2005). Survival for Pueblo farmers during this period (roughly AD 1150 to 1325) was based upon the ability to move frequently and to place fields in several different environmental settings in order to spread out the risks of dry farming an area not really conducive to such an activity.

By AD 1325 nearly all of the small villages were abandoned and fewer and larger villages were constructed. This occurred not only in the southern Jemez, but throughout central New Mexico, along the Rio Grande Valley and west to the Acoma-Zuni regions (Cordell, 1984; Adler, 1996; Powers and Orcutt, 1999). On the Pajarito Plateau and within Bandelier National Monument, the villages of Tyuonyi, Yapashi, San Miguel and others were founded at this time (Fig. 2). Many of these sites are quite large, containing hundreds of rooms, multiple plaza areas and kivas.

Often surrounding these large villages are small structures referred to by archeologists as field houses, which were shelters used during the growing season. These small structures can be located some distance from the large mother village and are situated in areas that were farmed. Surveys within Bandelier National Monument first noted the relationship between field house structures and pumice soils (Powers and Orcutt, 1999; Gauthier and Herhahn, 2005). These areas of El Cajete pumice soils found in the southeastern part of the Jemez can be several hundred acres

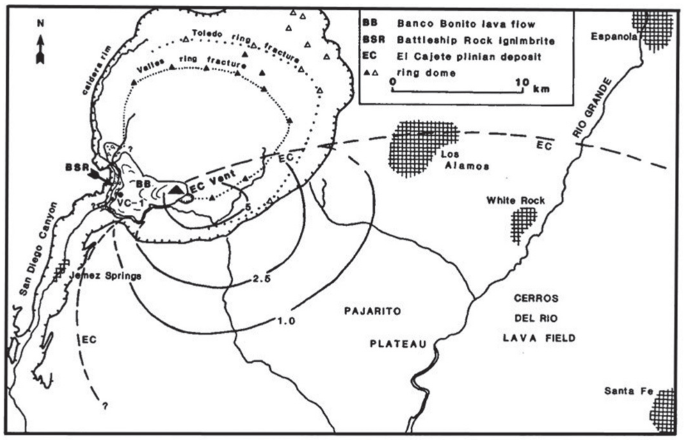

FIGURE 2. Location and distribution map for the El Cajete Series volcanic eruptions in relation to the Valles caldera (from Self et al., 1986). Dashed line labeled EC shows the approximate extent of El Cajete pumice fall deposits erupted from El Cajete crater (EC vent). Isopachs of El Cajete pumice fall deposits are in meters. Post-Valles caldera ring fracture lava domes are shown as solid triangles and post-Toledo caldera ring domes are shown as open triangles. VC-1 is site of Continental Scientific Drilling Program core hole in the southwestern Valles caldera.

in size, ranging down to a scant acre. However, even the smallest pumice fields will often have an associated field house.

A brief history of Jemez Pueblo (Towa) use of the area

Limited use of the area by Paleoindian groups (ca. 12,000 yrs BP) is presumed based on the low occurrence of Jemez obsidian found at nearby excavated sites. Winter (1983) hypothesized that populations were accessing Jemez obsidian source areas during their seasonal movements. Later Archaic groups (ca. BC 5000 to AD 600) were also utilizing the Jemez area for hunting and to procure obsidian, chert, and dacite for making stone tools (Acklen et al. 1987). The most significant development during this period is the introduction of maize (corn) into the area at approximately BC 1000, found at Jemez Cave (Vierra and Ford 2006).

The earliest ancestral pueblo occupations are found along the lower reach of the Rio Jemez and consist of small clusters of pit house structures or later, the appearance of small pueblos containing five to 40 rooms. Beginning sometime after AD 1200, and lasting until AD 1600, numerous large ancestral Jemez villages were established on the southwest fringe on the Jemez Plateau. These sites represent what is traditionally known as the florescence of preconquest Jemez Pueblo culture.

During this time (ca. AD 1200) rapid population growth appears to have resulted from migration into the area by people from the San Juan Basin, Mesa Verde and Montezuma Valley regions. Together with population increase, people developed large systems of agricultural fields and field houses to grow the crops necessary to sustain life in larger communities. Through time, villages continued to increase in size, with some sites containing more than 600 rooms. Community layout consisted of large massed room blocks surrounding multiple plazas with kivas (Fig. 3).

Settlement during the historic period was heavily influenced by the Spanish conquest of the upper Rio Grande at the end of the 16th century (Kulisheck 2005, p. 248-252). Site size decreased as populations were affected by conquest and its attendant characteristics such as disease and resettlement. During the 1600s, occupation persisted at the largest of the Jemez phase sites but settlement in much of the area decreased while it appears that groups began to move back to earlier sites in the lower reaches of the Rio Jemez. This phase appears to represent the initial stages of adaptation by the people of the Jemez to the conquest. By the 1700s, occupation of large sites in the Jemez declined significantly and they were "abandoned," in the sense that people were not maintaining habitations in them. However, as people resettled in the area of Cañon, at the confluence of the Rio Jemez and Rio Guadalupe, and in the area of modern Walatowa, their ties to the mesa tops did not decline. Strong connections with their ancestral homes are still maintained in the form of oral traditions, history and ceremonies.

FARMING STRATEGIES

Archeological studies in the northern Rio Grande-Jemez Mountains region indicate that most prehistoric farming was dry farming, relying solely upon precipitation falling directly on the fields for a successful harvest. It is remarkable in this environment of frequent and persistent droughts that one could survive as a farmer. In order to do so, a variety of microenvironments were exploited, specific soil types and exposure were farmed, and a number of features were constructed to conserve soil moisture, limit soil erosion, and in some cases, "harvest" winter snowfall (Anschuetz, 1998; Dominguez 2002). Elevation and exposure of fields is also important. On the Jemez Plateau (west facing exposure, possi-

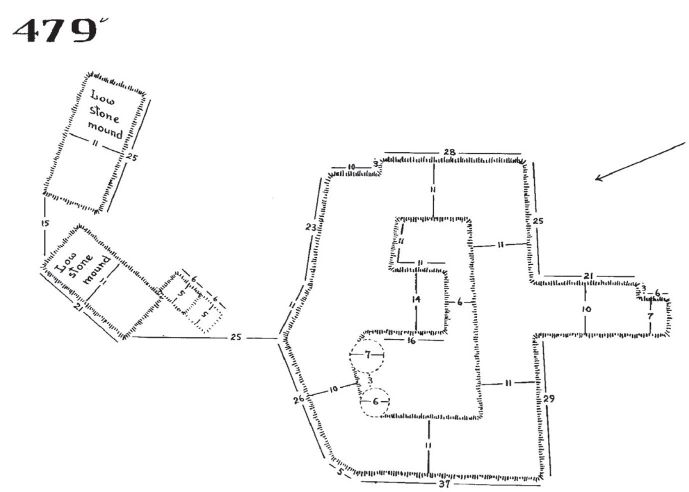

FIGURE 3. Floor plan of Totaskwinu, an ancestral Jemez village occupied from AD 1450 to 1550. The village contains an estimated 300 rooms. Measurements are in paces. Map by H.P. Mera, on file Laboratory of Anthropology, Santa Fe, New Mexico. Arrow points north.

bly warmer and drier), some farming areas were located at elevations greater than 2400 m (Ramenofsky, 2005, 2006), while on the Pajarito Plateau (east facing, possibly cooler and wetter), the maximum elevation for farming is around 2350 m.

A second observation, based on knowledge of the larger northern Rio Grande Valley is equally important: compared to other areas with large ancestral Pueblo populations, prehispanic agricultural features in Bandelier and adjoining areas in the southern Jemez Mountains are relatively rare. In surrounding areas, such as the Chama, Ojo Caliente, and Santa Cruz river valleys, around modern Cochiti Pueblo, the Caja del Rio plateau, and in the Galisteo Basin, extensive prehispanic fields with terracing, grid gardens, cobble piles, and cobble mulching indicate that farmers invested substantial amounts of labor to construct features with primary functions of harvesting, trapping, and conserving soil moisture (Buge, 1984; Maxwell and Anschuetz, 1992; Herhahn, 1995; Lightfoot and Eddy, 1995; Anschuetz, 1998; Dominguez, 2002). Although terrace and gridded field systems do occur in Bandelier and the Jemez, these features are less extensive, and few are found in pumice soils (Orcutt, 1999). These observations suggest that pumice soils have properties that made labor-intensive construction of moisture-trapping features such as terraces and cobble mulching unnecessary under most conditions. The most obvious exception to this are the terraces found on the pumice soils of the Banco Bonito (Ramenofsky, 2005, 2006). It is possible that the construction of terraces and other rock features on pumice soils at the high elevations of the Banco Bonito is driven more by the need for thermoregulation than soil moisture retention. Studies on terracing and other rock agricultural features in the American Southwest and in the Andes of South America have shown that terraces and rock features create more favorable microclimates for plant growth in areas prone to frosts (Donkin, 1979; Cordell et al., 1984; Erickson, 2000).

HOW PUMICE SOILS WORK

Perhaps surprisingly, archeologists studying the Jemez Mountains have only recently become interested in Pueblo agriculture. Interest in soils forming in pumice deposits (referred to here as pumice soils) and questions about the desirability of pumice as an ingredient in agricultural soil, are even more recent. Because of this, few answers are in hand. In fact, we are still learning what questions to ask.

At Bandelier National Monument, where pumice soils are widely distributed in small, discontinuous "pumice patches", archeologists have recently commented on the close relationship between ancestral Pueblo farming sites and these pumice-derived soils (Gauthier and Herhahn, 2005). A random sample of pueblos and field houses found over forty percent are located on, or within a very short distance of one or more pumice patches (Orcutt, 1999). Personal observation indicates this percentage may be higher and suggests that pumice patches were used as agricultural fields (Gauthier and Herhahn, 2005).

One possibility is that the pumice allows these soils to store more moisture. In most soils, water and air are trapped in pore spaces surrounding individual soil particles and within soil structural aggregates composed of organic and mineral particles. Sandy soils have less surface area than finer soils with smaller silt and clay particles. Because particle surface area is inversely proportional to particle diameter, soils composed of finer particles have more pore space and a greater capacity to store water (Troeh and Thompson, 2005). Given the relatively high proportion of coarse pumice clasts, pumice-derived soils would at first glance appear to be a poor medium for storing water. However because pumice is essentially rhyolitic froth composed of thousands of small, thin-walled, interconnecting vapor cavities, its capacity to store water is much greater than its clast diameter would suggest. This is convincingly demonstrated by putting a pumice nodule in a glass of water. At first, the pumice floats on the surface of the water, but after several hours, as the water displaces the air in the pumice vesicles, the pumice sinks to the bottom of the glass. Rather than just storing water between soil particles and within aggregates, pumice also stores water within clasts.

Nonetheless, several important questions about pumice water storage remain unanswered. It is not yet known how much water pumice absorbs compared to other types of soil, or how long the moisture is retained. Even more critical for agriculture, it is uncertain how much of the stored moisture is available for use by plants. Studies of volcanic ash-derived soils in other areas have demonstrated that while these soils do store substantial quantities of water, much of this water may not be available for plant use (van Breemen and Buurman, 2002). Whether water absorbed by El Cajete pumice is similarly limited is unknown.

A second potential benefit of soils containing pumice is their insulative quality as a surface mulch. Elsewhere in the northern Rio Grande region Puebloan farmers mulched their fields with gravel and cobbles, which they excavated and then spread over the ground surface. Studies of these fields suggest that the primary purpose of the mulch was to conserve soil moisture and moderate soil temperature (Lightfoot and Eddy, 1995; White et al., 1998). By planting in soils with a surface pumice layer, it seems likely that Bandelier farmers would have realized the same benefits without any of the labor.

While investigation of the water holding and mulching properties of pumice soils are only beginning, demonstration of the inferences presented here will help to explain why Puebloan farming sites were so frequently situated near pumice patches. This is not to say that pumice soils were the solution to every 12th through 16th century farming challenge, or that all pumice patches were created equal. Relatively pure pumice deposits with little finer soil material have few roots, suggesting that moisture, minerals and organic material needed for plant growth are not present. In contrast, pumice soils with finer materials display abundant root growth. Depth of pumice soils may also be an important factor. In areas where pumice deposits are relatively thick, their permeability may have allowed water to percolate beyond the roots of prehistoric corn plants before much moisture was absorbed. For this reason, areas with a relatively shallow pumice stratum underlain by a less permeable clay-rich layer may have been more productive (Sandor, 1995). Likewise, moisture in the form of winter and spring snow melt may have been more effective than summer rainfall, since the slower, more sporadic seepage of melting ice would allow more water to be absorbed. Like most other aspects of the natural environment to which prehistoric people adapted, pumice soils combine economically useful as well as less productive qualities. A current study of prehistoric fields at Bandelier is not only attempting to determine what crops were grown (through pollen and phytolith analyses) but is comparing the soil water content, structure, texture, nutrient availability, and other critical properties of both pumice and nonpumice soils. We are optimistic that the results of this and future studies will increase our understanding of the role of pumice in the unique prehispanic cultural landscape of the Jemez Mountians.

CONCLUSIONS

For archeologists, the Jemez Mountains are famous for source areas of stone for making stone tools. All southwestern archeologists know about Jemez obsidian or Pedernal chert or Bandelier dacite and how these resources fit into the prehistoric economies. However, only recently has the importance of pumice soil been realized. The unique vesicular properties of pumice allow pumice deposits and soils to store and conserve rain and snow melt for dry farming. For nearly five centuries these unique soils played a key role in the survival of Pueblo populations occupying the slopes of the Jemez Mountains.

ACKNOWLEDGMENTS

The authors thank Linda Cordell, School of Advanced Research; David Stuart, University of New Mexico; and Jonathan Sandor, Iowa State University for their review and valuable comments on this paper.

REFERENCES

Adler, M.A., ed., 1996, The prehistoric Pueblo world, A.D. 1150-1350: Tucson, University of Arizona Press.

Anschuetz, K.F., 1998, Not waiting for the rain: integrated systems of water management by pre-Columbian Pueblo farmers in north-central New Mexico [Ph.D Dissertation]: Ann Arbor, University of Michigan.

Bandelier, A.E., 1892, Final report of investigations among the Indians of the southwestern United States, carried on mainly in the years from 1880 to 1885, Part II: Papers of the Archaeological Institute of America, American Series, No. 4. Cambridge.

Buge, D.E., 1984, Prehistoric subsistence strategies in the Ojo Caliente Valley, New Mexico, *in* Fish, S.K., and Fish, P.R., Prehistoric agricultural strategies in the Southwest: Anthropological Research Papers 33, Arizona State University, Tempe.

Cordell, L.S., 1979, Cultural resources overview of the middle Rio Grande Valley, New Mexico: U.S. Government Printing Office, Washington, D.C.

Cordell, L.S., 1984, Prehistory of the Southwest: San Diego, Academic Press.

Cordell, L.S., Earls, A.C., and Binford, M.R., 1984, Subsistence systems in the mountainous settings of the Rio Grande Valley, *in* Fish, S.K., and Fish, P.R., eds., Prehistoric agricultural strategies in the Southwest: Anthropological Research Papers 33, Arizona State University, Tempe, p. 233-241..

Dominguez, S., 2002, Optimal gardening strategies: maximizing the input and retention of water in prehistoric gridded fields in north central New Mexico: World Archaeology, v. 34, p. 131-163.

Donkin, R.A., 1979, Agricultural terracing in the aboriginal New World: Viking Fund Publications in Anthropology No. 56, Wenner Gren Foundation for Anthropological Research, New York.

Erickson, C.L., 2000, The Lake Titicaca Basin: a pre-Columbian built landscape, *in* Lentz, D., ed., Imperfect balance: landscape transformations in the Precolumbian Americas: New York, Columbia University Press.

Gardner, J., Goff, F., Garcia, S., and Hagan, R., 1986, Stratigraphic relations and lithologic variations in the Jemez volcanic field, New Mexico: Journal of Geophysical Research, v. 91, p. 1763-1778.

Gauthier, R., and Herhahn, C., 2005, Why would anyone want to farm here?, *in* Powers, R.P., ed., The peopling of Bandelier: new insights from the archaeology of the Pajarito Plateau: School of American Research Press, Santa Fe, p. 27-33.

Goff, F., and Gardner, J.N., 2004, Late Cenozoic geochronology of volcanism and mineralization in the Jemez Mountains and Valles caldera, north central New Mexico, *in* Mack, G.H., and Giles, K.A. eds., The geology of New Mexico, a geologic history: New Mexico Geological Society, Special Publication 11, p. 295-312.

Goff, F., and Gardner, J.N., 2007, Valles caldera–second-day road log from Los Alamos to Valles Grande, southern caldera moat, resurgent dome, northern caldera moat, and barbeque at old Baca ranch headquarters: New Mexico Geological Society, 58th Field Conference, Guidebook. p. 53-78.

Goff, F., Gardner, J.N., and Reneau, S.L., 2002, Geology of the Frijoles 7.5-minute quadrangle, Los Alamos and Sandoval Counties, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map OF-GM 42, scale 1:24,000.

Herhahn, C.L., 1995, 14th Century dry farming features in the northern Rio Grande Valley, New Mexico, *in* Tull, H.W., ed., Soil, water, biology, and belief in prehistoric and traditional southwestern agriculture: New Mexico Archaeological Council, Special Publication 2, C and M Press, Denver, p. 77-84.

Hewett, E.L. 1938, Pajarito Plateau and its ancient people, hand book of archaeological history, 2nd edition, revised 1953: Albuquerque, University of New Mexico Press, and Santa Fe, School of American Research.

Kohler, T., ed., 2004, Archaeology of Bandelier National Monument: village formation on the Pajarito Plateau, New Mexico: Albuquerque, University of New Mexico Press.

Kulisheck, J., 2006, Population and settlement trends in the Jemez Province, A.D. 1250 to 1600: Paper presented at the 71st Annual Meeting of the Society for American Archaeology, San Juan, Puerto Rico.

Lange, C.H., and Riley, C.L., 1966, The Southwestern journals of Adolph F. Bandelier, 1880-1882: Albuquerque, University of New Mexico Press and Santa Fe, School of American Research and the Museum of New Mexico Press.

Lightfoot, D.R., and Eddy, F.W., 1995, The construction and configuration of Anasazi pebble-mulch gardens in the northern Rio Grande: American Antiquity, v. 60, p. 459-470.

Maxwell, T.D., and Anschuetz, K.F., 1992, The Southwestern ethnographic record and prehistoric agricultural diversity, *in* Killion, T.W., ed., The gardens of prehistory: settlement and subsistence in greater Mesoamerica: Tuscaloosa, University of Alabama Press, p. 35-68.

Orcutt, J.D., 1999, Demography, settlement, and agriculture, *in* Powers, R.P., and Orcutt, J.D., eds., The Bandelier archeological survey, volume I: Intermountain Cultural Resources Management Professional Paper no. 57, National Park Service, Santa Fe, p. 219-308.

Powers, R., and Orcutt, J., eds., 1999, The Bandelier archaeological survey, vols. I and II: Intermountain Cultural Resources Management, Professional Paper no. 57, National Park Service. Santa Fe.

Phillips, E.H., Goff, F., Kyle, P.R., McIntosh, W.C., and Dunbar, N.W., in press, $^{40}Ar/^{39}Ar$ age constraints on the duration of resurgence at the Valles caldera, New Mexico: Journal of Geophysical Research.

Ramenofsky, A. F., 2005, UNM Archaeological Field School report 2005: lower Dome Mesa and Banco Bonito survey: SFNF Report #2005-10-008B; VCNP Report 2006-007. NMCRIS Activity # 95061. Museum of New Mexico, Santa Fe.

Ramenofsky, A., 2006, Agricultural intensification on the Jemez Plateau: from Coalition through Early Historic: Paper presented at the 71st Annual Meeting of the Society for American Archaeology, San Juan, Puerto Rico.

Sandor, J.A., 1995, Searching soil for clues about Southwest prehistoric agriculture, *in* Toll, H. W., ed., Soil, water, biology, and belief in prehistoric and traditional Southwestern agriculture: New Mexico Archaeological Council, Special Publication 2, C and M Press, Denver

Self, S., Goff, F., Gardner, J., Wright, J., and Kite, W., 1986, Explosive rhyolitic volcanism in the Jemez Mountains: vent locations, caldera development, and relation to regional structure: Journal of Geophysical Research, v. 91, 1779-1798.

Self, S., Kircher, D.E., and Wolff, J.A., 1988, The El Cajete Series, Valles caldera,

New Mexico: Journal of Geophysical Research, v. 93, p. 6113-6127.
Smith, R.L., and Bailey, R.A., 1966, The Bandelier Tuff: a study of ash-flow eruption cycles from zoned magma chambers: Bulletin of Volcanology, v. 29, p. 83-104.
Smith, R., Bailey, R., and Ross, C., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I -571, scale 1:125,000.
Steen, C.R., 1977, Pajarito Plateau archaeological survey and excavations: Los Alamos Scientific Laboratory, Report LASL-77-4, 60 p.
Stuart, D., and Gauthier, R., 1981, Prehistoric New Mexico: background for survey: New Mexico Historic Preservation Bureau, Santa Fe.
Toyoda, S., Goff, F., Ikeda, S., and Ikeya, M., 1995, ESR dating of quartz phenocrysts in the El Cajete and Battleship Rock Members of Valles Rhyolite, Valles caldera, New Mexico: Journal of Volcanology and Geothermal Research, v. 67, p. 29-40.
Troeh, F.R., and Thompson, L., 2005, Soils and soil fertility, 6th edition: Ames, IA, Blackwell Publishing.
Van Breeman, N., and Buurman, P., 2002, Soil formation, 2nd edition: Dordrecht, Netherlands, Kluwer Academic Publishers.
Vierra, B., and Ford, R., 2006, Early maize agriculture in the northern Rio Grande Valley, New Mexico, *in* Staller, J., Tykot, R., and Benz, B., eds., Histories of maize: New York, Academic Press.
Wendorf, F., and Reed, E., 1955, An alternative reconstruction of northern Rio Grande prehistory: El Palacio, v. 62, p. 200-227.
White, C.S., Dressen, D.R., and Loftin, S.R., 1998, Water conservation through an Anasazi gardening technique: New Mexico Journal of Science, v. 38, p. 251-278.
Wolff, J.A., Gardner, J.N., and Reneau, S.L., 1996, Field characteristics of the El Cajete pumice deposit and associated southwestern moat rhyolites of the Valles caldera: New Mexico Geological Society, 47th Field Conference, Guidebook p. 311-316.