Origin of Meter-Size Granite Basins in the Southern Sierra Nevada, California

Scientific Investigations Report 2008-5210

U.S. Department of the Interior
U.S. Geological Survey

Cover—Rainwater pond in granite basin at Quail Flat site. Water is 110 cm in diameter and 20 cm deep; upper white rim is 148 cm in diameter.

Origin of Meter-Size Granite Basins in the Southern Sierra Nevada, California

By James G. Moore, Mary A. Gorden, Joel E. Robinson, and Barry C. Moring

Scientific Investigations Report 2008-5210

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

This report and any updates to it are available online
at: http://pubs.usgs.gov/sir/2008/5210/

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Produced in the Western Region, Menlo Park, California
Manuscript approved for publication, October 29, 2008
Text edited by Peter Stauffer
Layout and Design by Jeanne S. DiLeo

Contents

Figures

Blank page

Origin of Meter-Size Granite Basins in the Southern Sierra Nevada, California

By James G. Moore[1], Mary A. Gorden[2], Joel E. Robinson[1], and Barry C. Moring[1]

Abstract

Meter-size granite basins are found in a 180-km belt extending south from the South Fork of the Kings River to Lake Isabella on the west slope of the southern Sierra Nevada, California. Their origin has long been debated. A total of 1,033 basins have been inventoried at 221 sites. The basins occur on bedrock granitic outcrops at a median elevation of 1,950 m. Median basin diameter among 30 of the basin sites varies from 89 to 170 cm, median depth is 12 to 63 cm. Eighty percent of the basin sites also contain smaller bedrock mortars (~1-2 liters in capacity) of the type used by Native Americans (American Indians) to grind acorns. Features that suggest a manmade origin for the basins are: restricted size, shape, and elevation range; common association with Indian middens and grinding mortars; a south- and west-facing aspect; presence of differing shapes in distinct localities; and location in a food-rich belt with pleasant summer weather. Volcanic ash (erupted A.D. 1240±60) in the bottom of several of the basins indicates that they were used shortly before ~760 years ago but not thereafter. Experiments suggest that campfires built on the granite will weaken the bedrock and expedite excavation of the basins. The primary use of the basins was apparently in preparing food, including acorns and pine nuts. The basins are among the largest and most permanent artifacts remaining from the California Indian civilization.

Introduction

Numerous round, meter-size basins are found on the west slope of the southern Sierra Nevada. They are carved in granitic bedrock (fig. 1) and are abundant in a belt extending 180 km south from the South Fork of the Kings River to a site

Figure 1. Examples of granite basins. *A*, Nelson Cabin site; hammer is 30 cm long. Some rain water remains in bottom, and pine needles mark the high-water mark. *B*, Three rock basins at Alpine Creek site; that on right contains some water. Hammer is 30 cm long. *C*, Man near two granite basins. Three grinding mortars are visible in foreground at Methusula site near Balch Park (Dulitz, 2000).

[1]U.S. Geological Survey, Menlo Park, California 94025

2 Southern Sierra Archaeological Society, PO Box 44066, Lemoncove, California 93244

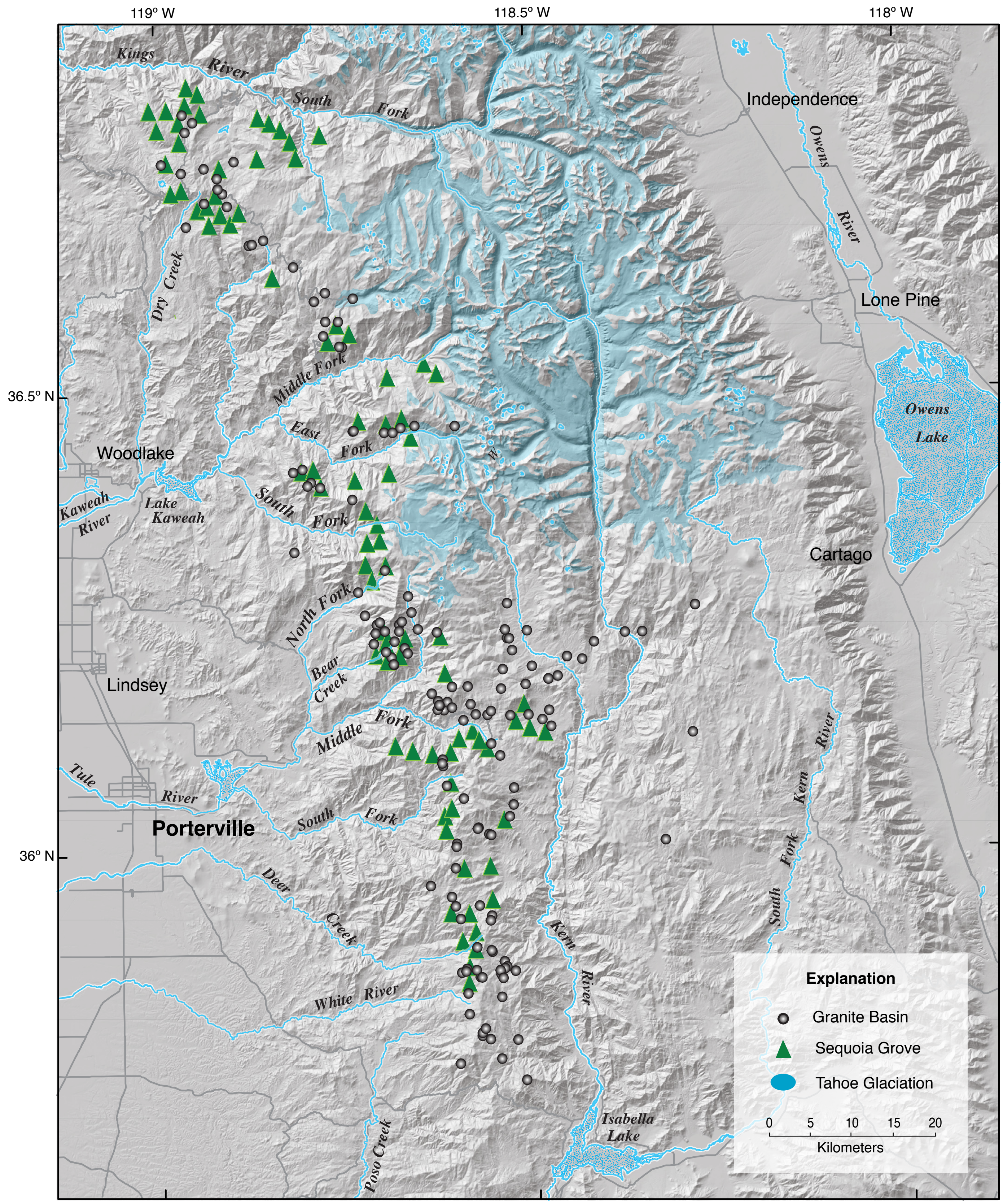

Figure 2. Granite basin sites (gray circles) and giant sequoia groves (green triangles). Extent of the earliest and most extensive documented glaciation (Tahoe) is shown by blue color (after Moore and Mack, 2008).

west of Lake Isabella (fig. 2). Most of the northern part of the belt is in Sequoia National Park, and much of the southern part is in the southern section of Giant Sequoia National Monument. These basins commonly occur in clusters or lineaments on bedrock outcrops and are concentrated near streams, mostly in the elevation range of 1,700–2,300 m (figs. 3, 4). They are clearly higher in elevation than the core Indian habitation areas in the lowlands (Elsasser, 1972).

In the 1970's Mary Gorden of the Southern Sierra Archaeological Society began an inventory of basin sites (Gorden, 2007), and nomenclature was standardized in collaboration with Louise Hastrup. The inventory has been supplemented more recently by data from the Southern Sierra Archaeological Society, the California Division of Forestry and Fire Protection (Sandelin, 2000), and investigators of the National Park Service and Sequoia National Forest. Much of the descriptions and conclusions in this report rely on the inventory, which contains data on 1,033 basins at 221 sites. In this report we analyze and summarize the data now available on the basins and propose what process produced them and for what purpose.

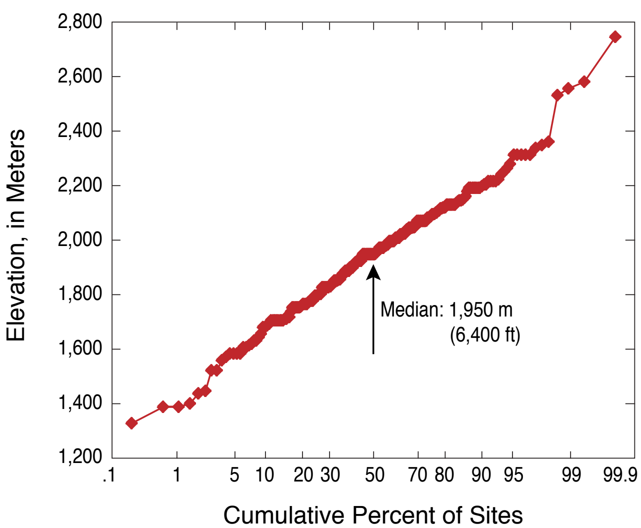

Figure 3. Elevation distribution of 221 basin sites shown as cumulative percent. Median elevation is 1,950 m (6,400 ft).

Previous Work

Local residents, foresters, sheepherders, cattlemen, hikers, and fishermen have long known of the basins. Early explorers and residents were unable to learn from the Native Americans then living about the history of the basins, how they were formed, and if they had a practical use (Stewart, 1929).

One of the earliest reports on the basins is that of Barton (1881; see fig. 5), who stated that "some ancient people have scalloped out holes in the rock, large enough, in some cases, to hold eight or ten barrels of water" (as quoted by Wallace, 1993). Barton believed them to be man-made and commented that apparently "work had been done with a chisel" (as quoted by Stewart, 1929).

In a pioneering report based on 1925 fieldwork in Sequoia National Park, Stewart (1929) described 42 basins from 5 clusters near Park Headquarters in Giant Forest, and provided measurements of their size and descriptions of their excavated contents. The team that investigated the basins at that time included geologist François Matthes, known for his exhaustive study of the origin of Yosemite Valley (Matthes, 1930). The team concluded that the basins were manmade. A letter from Matthes to C. Hart Merrium dated March 21, 1926, states, "I took pains to examine a number of basins of this type in different localities (Giant Forest, Redwood Meadows, etc.) with a special view to ascertaining whether by any chance they might be produced by natural processes, but am convinced that they are of artificial making" (Plotnicov and Elasser, 1961). Matthes, shortly before his death in 1947, reportedly changed his opinion and opted for a natural origin for the basins (Plotnicov and Elsasser, 1961). This reversal in thought is partly responsible for the debate that has continued—whether the basins are of natural or man-made origin (fig. 5). Three reports have attributed the origin of the basins to pits formed by weathering (Hall, 1930; Plotnicov and Elsasser, 1961; Otter; 1979); two to potholes created by millstones in a subaerial or subglacial stream (Schutt, 1962; Barnes, 1984); four to unspecified natural processes (Elsasser, 1972; Mundy, 1990; Foster and others, 1991; Dillon, 1992); six to an unknown origin (Pusateri, 1962; Weinberger, 1981; Wallace, 1993; Dulitz, 2000; Sandelin, 2000; and Gorden, 2007); and four to a manmade origin (Barton, 1881; Stewart, 1929; Gehr and others, 1979; this study). Dillon (1992, p. 72) states, "With only one or two notable exceptions, the consensus of opinion amongst most Sierra Nevada archaeologists is that in every case the large hemispherical bedrock basins are of natural, not cultural, origin." Several of those authors who support a natural origin also suggest that the Indians selected campsites that had natural basins, made use of them, and possibly modified them.

Location, Vegetation, and Associated Features

Most of the inventoried basins occur in a belt or zone on the west slope of the southern Sierra extending south from the South Fork of the Kings river to a point west of Lake Isabella—from lat 37.4° to 35.75°N—a distance of 180 km (fig. 2). The basins at 221 sites in this zone are those considered in this report. Scattered basins are also reported north of the zone, including one site near Yosemite (Presnell, 1930). The median elevation of the mapped sites in the main belt is 1,950 m (6,400 ft), and 80 percent of the sites tabulated occur between 1,700 and 2,200 meters (fig. 3). The width of the basin belt generally varies from a few kilometers to about 7 km, but near its center at lat 36.02°N it broadens to a width

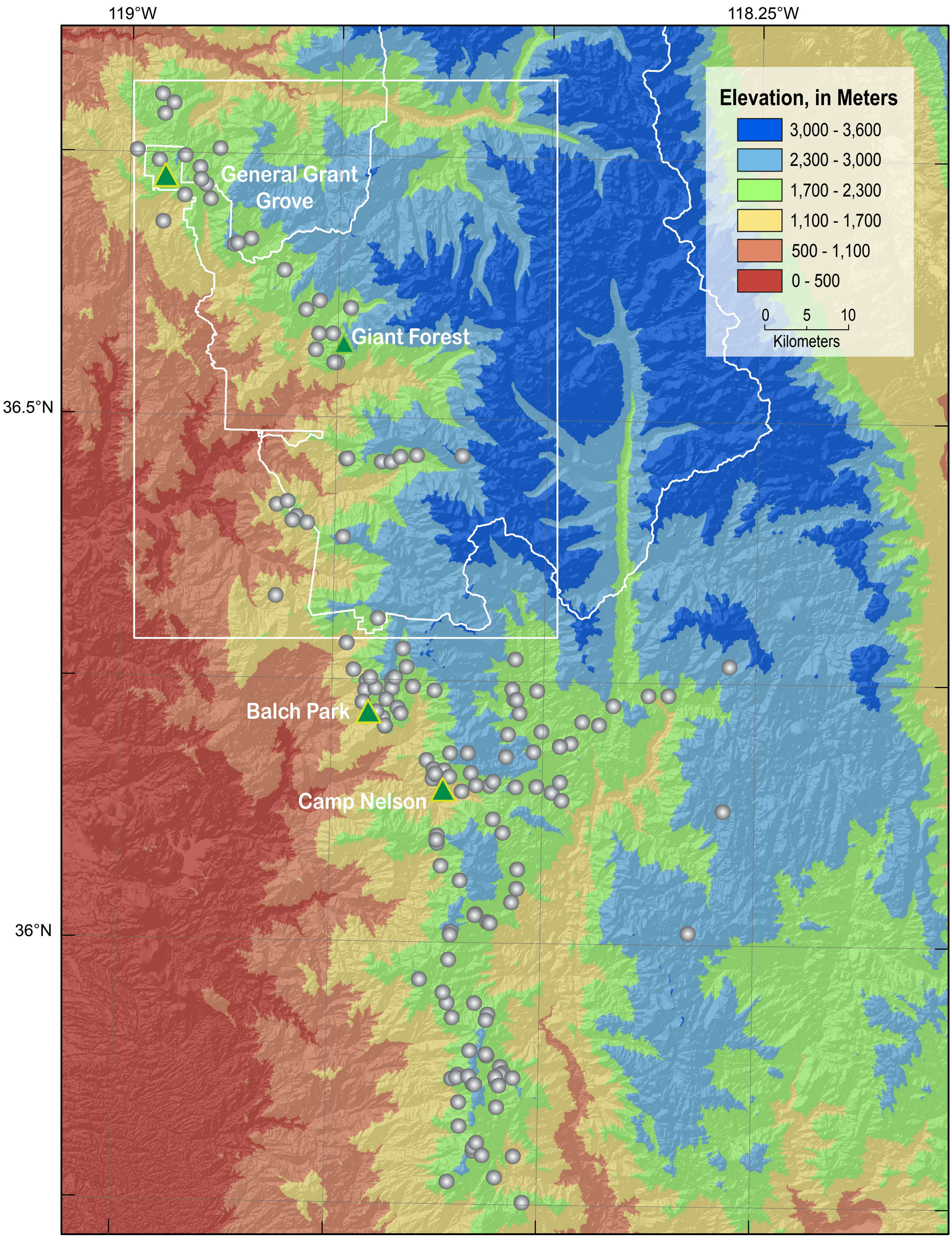

Figure 4. Map of basin sites (gray circles) showing general restriction to elevation range of 1,700-2,300 m. Rectangle is area of figure 8, and boundary of Sequoia and Kings Canyon National Parks is shown (irregular white line).

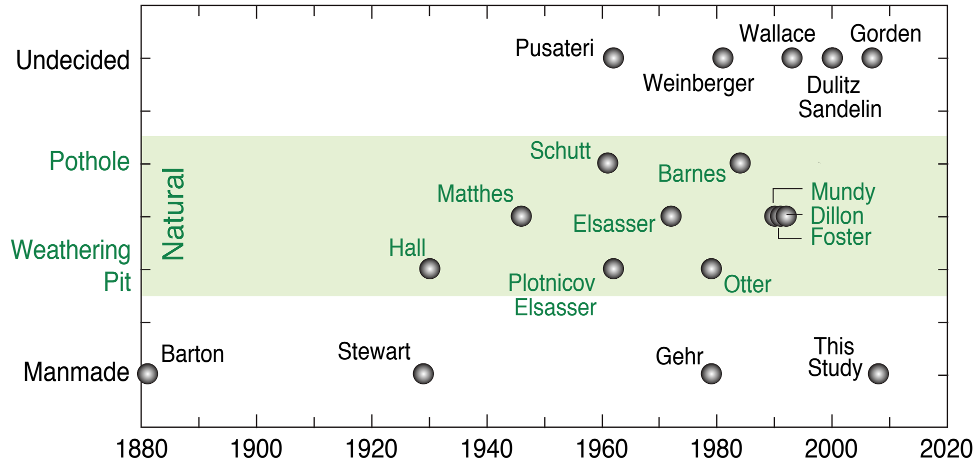

Figure 5. Proposed origins of granite basins as reported in publications spanning 130 years.

of 30 km, partly in the relatively flat country where the Little Kern and Kern Rivers join (figs. 2, 4).

Generally the basins occur in groups of 2-4, but their numbers range from 1 to 31 at a single site. The most crowded sites (10 percent of all sites) contain more than 11 individual basins (fig.6). Typical bedrock mortars of the type used by Native Americans to grind acorns are commonly associated with the basins (fig. 1*C*). Of 221 basin sites, 176 (80 percent) also have mortars on the same bedrock outcrop. Where both occur at the same site, in most cases there are more mortars than basins (fig. 6).

The topographic information employed for elevation data in the map region (fig. 2) is the U.S. Geological Survey National Elevation Dataset gridded at 30-m spacing. Using these data, we calculated the aspect of each basin site (the direction that the 30-meter-size slope containing the site faces). The result of this determination is that the most common aspect for the basin sites is toward the south and west (fig. 7). Of a total of 216 basin sites, 9 percent face within 40° of north (from 320° to 40° azimuth) and 39 percent face within 40° of south (from 140° to 220°). We believe that the most reasonable explanation for this preferred aspect is that the Native Americans chose their campsites (with rock basins) in areas of sunny exposure. Because of snow cover and other weather patterns, such locations could be occupied earlier in the spring and later in the fall.

The elevation belt of the basin sites is similar to that of the giant sequoia (*Sequoiadendron giganteum*) groves (fig. 2). It also contains most of the desirable campgrounds and cabins that residents of the San Joaquin Valley use to avoid the summer heat. These include Grant Grove, Giant Forest, Mineral

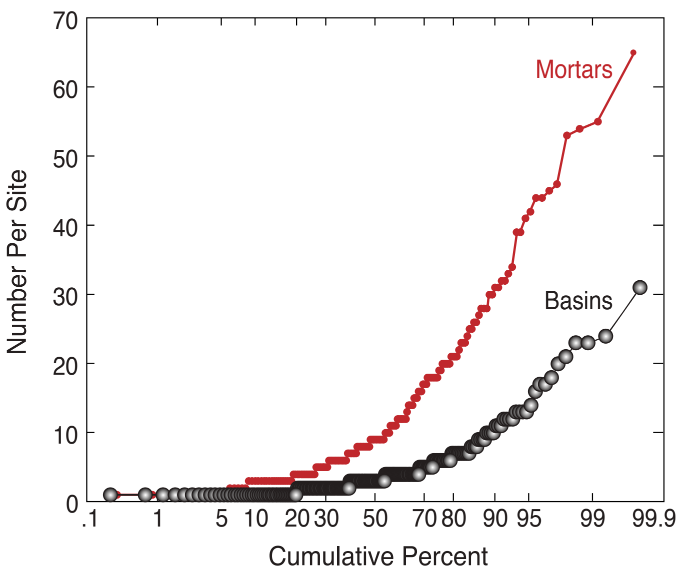

Figure 6. Numbers of basins and mortars per site for the entire belt of sites, plotted as cumulative percent. The median number of basins per site is about 3, and the median number of mortars about 9. The ratio of mortars to basins per site is variable, but the median ratio is about 3 to 1.

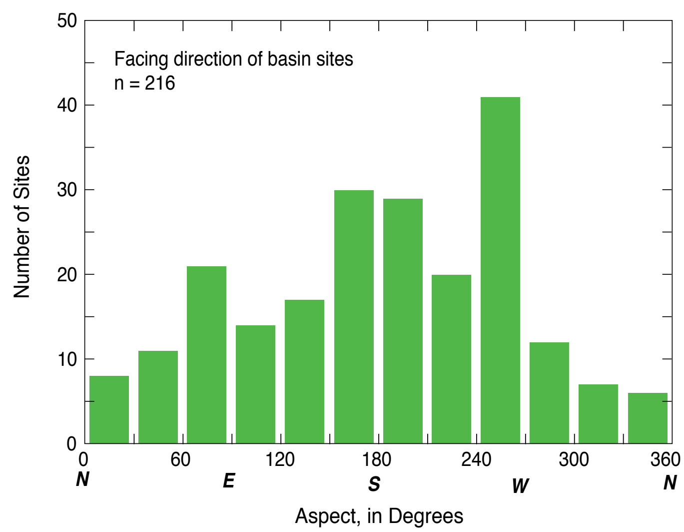

Figure 7. Distribution of aspect of basin sites, showing the direction that the topographic slope faces at each of 216 sites. South and west exposures predominate over north and east.

King, Mountain Home, Balch Park, Camp Wishon, Camp Nelson, and Johnsondale. The monthly means of the maximum daily temperatures for Porterville in the San Joaquin Valley are: June, 34°C; July, 37°C; August, 36°C; and September, 33°C. The monthly means of the maximum daily temperatures for Giant Forest in the basin belt are: June, 22°C; July, 26°C; August, 26°C; and September, 22°C. This 10°C+ difference in mean maximum temperature inspires a migration to the mountains in the spring and summer after melting of the heavy winter snow.

Generally, the axis of the belt of basin sites is remarkably close to that of the Sequoia groves. However, in the north, the basin belt south of the South Fork of Kings River occurs west of numerous groves. On the other hand, numerous basins occur east of groves in the lower Little Kern River area. The basins also extend an additional 14 km south of the

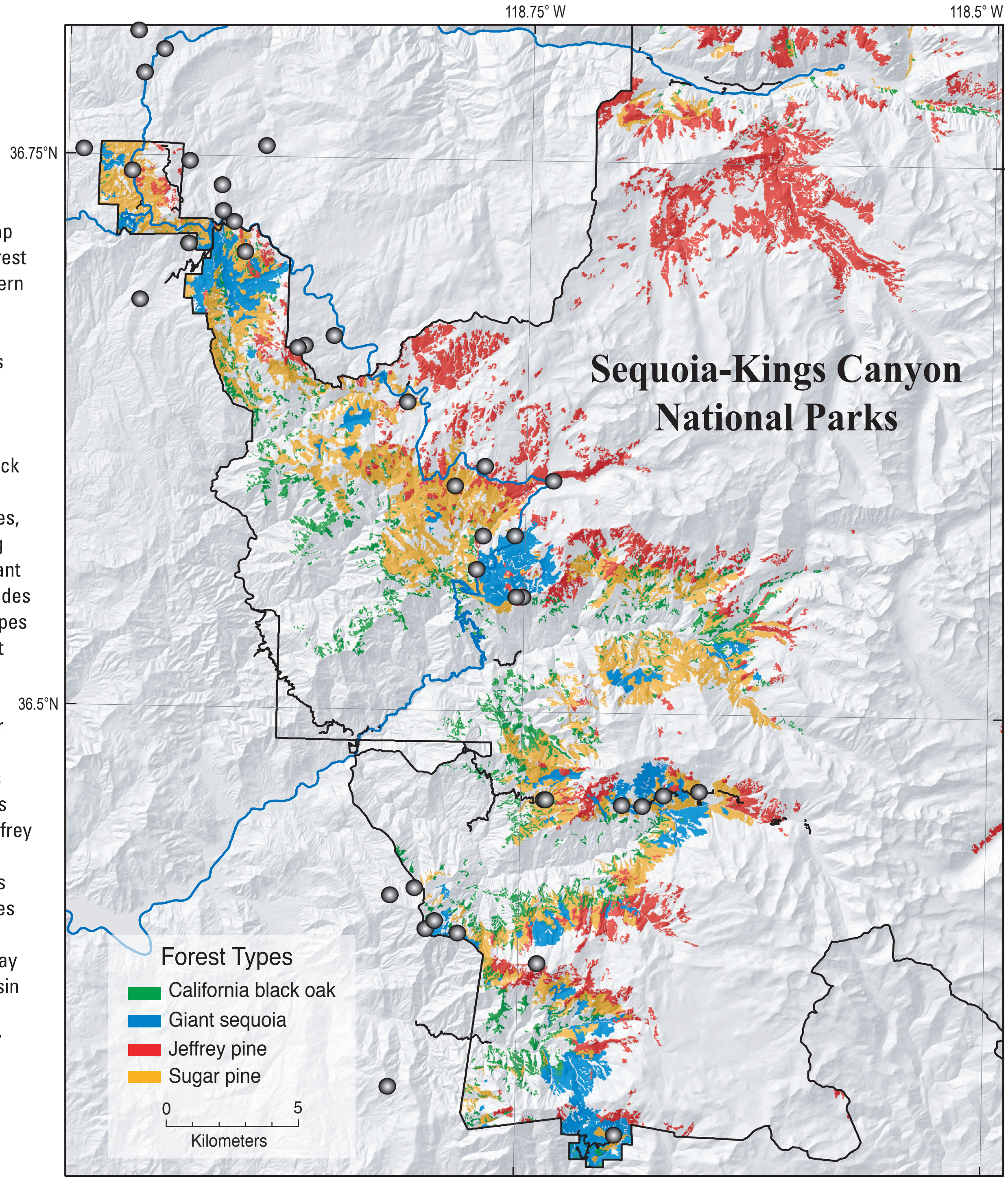

Figure 8. Map of selected forest types in southern Sequoia and Kings Canyon National Parks (modified from National Park Service, 2007). "California black oak" includes two forest types, each including black oak; "giant sequoia" includes three forest types including giant sequoia, one of which also includes sugar pine; "Jeffrey pine" includes six forest types containing Jeffrey pine; "sugar pine" includes two forest types containing sugar pine. Gray circles are basin sites. Area of map shown by rectangle in figure 4.

southernmost grove (Deer Creek Grove at lat 35.88°N) and end at lat 35.75°N.

Detailed vegetation mapping in Sequoia and Kings Canyon National Parks (National Park Service, 2007) provides a basis to compare location of the basins with distribution of forest types (fig. 8). This area has the advantage that it has undergone no logging since creation of the parks in 1890. In addition to the giant sequoia, the belt of basins is associated with white fir (*Abies concolor*), red fir (*Abies magnifica*), incense cedar (*Calocedrus decurrens*), Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lamberiana*), and California black oak (*Quercus kellogii*). The tree species in this area that produce edible pine nuts, a valuable food source to the Indians, are primarily the sugar pine and also the Jeffrey pine and ponderosa pine. Forests containing these pines are closely associated with the basin belt, especially the sugar pine (fig. 8), which is the largest of the pines and has the longest cone of any conifer, 25-50 cm in length. The black oak, which provides the acorns most prized by the Indians, occurs up to the belt elevation (fig. 8). Acorns were no doubt processed in the mortars. The proximity of the large-cone pine nut trees to the basin sites, and the fact that basins are absent in all the other regions of California where oak trees and mortars are common, suggests that the basins were used in pine-nut processing.

Geology

Generally the north part of the basin belt is close to, but slightly west of the mapped western limit of the Tahoe stage glaciation in the Sierra (fig. 2). This glaciation is the earliest (and most extensive) that has been mapped on the west slope of the southern Sierra (Moore and Mack, 2008). In two small areas the basins are near the lower courses of major trunk glaciers that extended to relatively low elevation. Some basin sites are near the terminus of the glacier occupying the canyon of the Marble Fork of the Kaweah River. Also, several basin sites occur at the north margin of the glacier occupying the canyon of the East Fork of the Kaweah River. However, the great majority of the basin sites are unassociated with the areas of glaciation. The area of glaciation extended south to about lat 36.25°N, but, significantly, the belt of basins extends an additional 57 km south.

The basins are excavated entirely in medium- to coarse-grained granitic rock, granodiorite and granite in the classification of Streckheisen (1973). No basins are reported in metamorphic rocks, a rock type in which river potholes are common. Most of the basins in the northern third of the belt, north of Giant Forest at lat 36.55°N, are carved in the Giant Forest Granodiorite, a rather dark granodiorite that contains about 17 volume percent dark minerals (hornblende and biotite), has a SiO_2 content of 60-66 weight percent, and was emplaced 102–97 million years ago (Moore and Sisson, 1987; Sisson and Moore, 1994). However, a few basins in the extreme north (Princess Campground, Pennys Pride, and Azalia Campground) occur in a much lighter colored rock, the granite of Grant Grove, which contains only 5 percent dark minerals, has a SiO_2 content of 71-76 weight percent, and was emplaced in the interval 128–106 million years ago (Moore and Nokleberg, 1992). No difference in character is noticed in the basins hollowed out of these two somewhat different rock types. The Case Mountain area (lat 36.4°N) has basins in the granodiorite of Case Mountain, a coarse-grained granodiorite with 1–9 volume percent dark minerals and SiO_2 content of 69-73 weight percent.

The rocks hosting basins south of Giant Forest in the southern half of the basin belt are not as well known, because detailed published geologic mapping is not available. Several of the basins in the region near the southeastern corner of the Mineral King 15-minute quadrangle (lat 36.2°N) are carved in the porphyritic biotite granodiorite of Castle Rock, which contains ~12 volume percent dark minerals (D. C. Ross, U. S. Geological Survey, written commun., 1988). This rock is characterized by scattered large crystals of potassium feldspar 1-4 cm in size.

Volume of the Basins

Most of the basins closely approach a round shape in plan, and oval ones are not common. The basins range in volume from 40 to 1,400 liters. A distinct gap exists between the volume of the basins and that of the associated bedrock mortars, the larger of which are about 1-2 liters in volume.

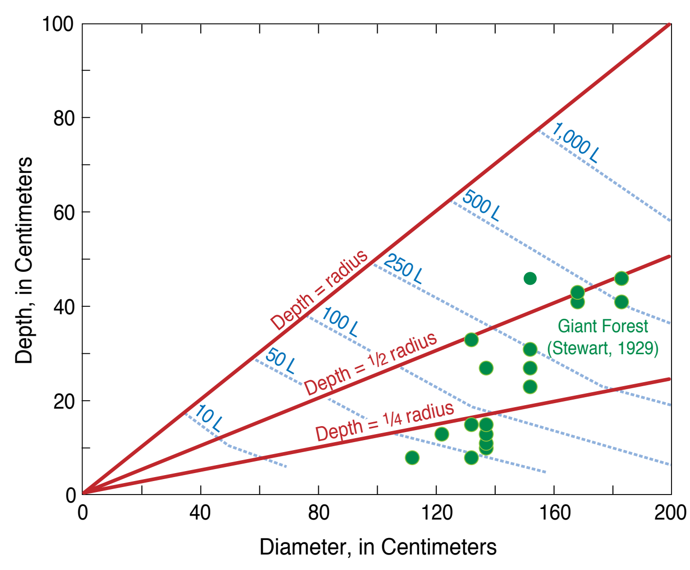

Figure 9. Plot of diameter versus depth of basins. Lines of equal basin volume (blue lines) are based on the assumption that the basins are the shape of a spherical segment (volume = $1/6\,\pi\,h\,[3a^2 + h^2]$, where a is the radius and h the depth). The volumes of Giant Forest basins range from about 45 to 600 liters. Red lines show selected diameter-to-depth ratios.

Some of the basins attain a depth that is equal to their radius, and hence they approximate a hemisphere in shape. However, such deep basins are not common, and most have a depth ranging from one-eighth to one-half of the radius. A good approximation of the shape of the basins is a segment of a sphere, that is, the part of a sphere cut off by a plane. A few basins may be either flatter or more pointed on the bottom than is a spherical segment, but generally this shape provides a good approximation of the volume of the basins (fig. 9). Such a segment has a volume equal to $1/6\ \pi\ h\ (3a^2 + h^2)$, where a is the radius and h is the depth of the spherical segment representing the granite basin. In this way, the volume of the basins can be approximated by reference to their diameter and depth. The largest basin has a volume about 1,400 liters, the median maximum volume of basins at the 30 sites with more than five basins each is about 300 liters, and the overall median volume is about 130 liters.

Size and Shape of the Basins

The diameter and depth of basins are variable at sites with multiple basins, as well as between the separate sites within the main 180-km-long belt of sites. Within each of 30 groups of basins at which five or more basins occur, the diameter-depth plots commonly show a range of 50 cm or more in diameter and as much as 40 cm in depth, but these plots usually define a distinct trend line, such that the larger basins are closer in shape to a hemisphere than the smaller basins, which are flatter—less deep in proportion to their diameter (fig. 10). This relationship seems to hold for all of the sites. It may result because the smaller, shallower basins at each site are those in an early stage of construction. If the trends are projected back to zero depth on the plots, the resulting diameter is about 50 cm. In the Mountain Home State Forest area, Dulitz (2000) has shown that the smallest basins have a diameter of about 55 cm. He concludes this indicates, “the basins start development with a diameter of about this size and are not formed by the enlargement of a small diameter hole.” The diameter-depth plots show a general tendency for northern sites to be shallower than southern sites (fig. 10).

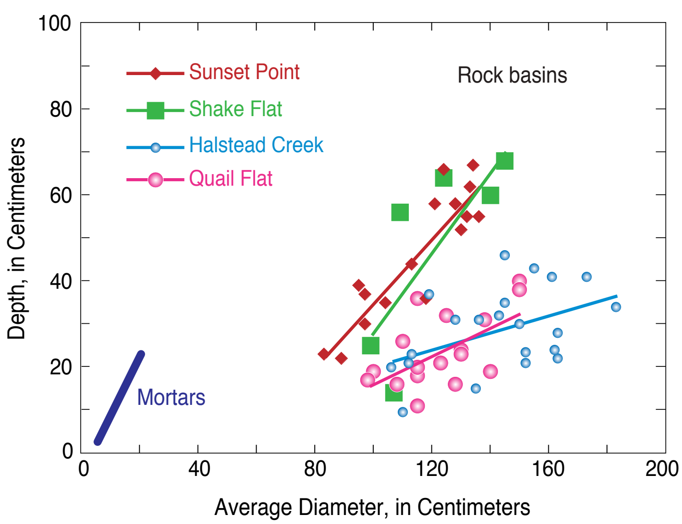

Figure 10. Average dimensions (diameter and depth) and trend lines of all of the basins in each of four sites. The Halstead Creek and Quail Flat sites are considerably north of the Sunset Point and Shake Flat sites. All trend lines (least squares) project to about 50 cm diameter at zero depth, suggesting that the basins began their growth at that diameter. The depth, when projected to a diameter of 125 cm, is about 25 cm for shallow northern sites and 50 cm for deep southern sites. A major gap occurs between the dimensions of mortars (navy blue bar) and the much larger basins.

A few incipient basins have been noted in several of the basin clusters. These appear to be basins in the early stage of construction, which have a normal diameter but are extremely shallow. Stewart (1929) describes a feature in the Giant Forest region that is 65 x 95 cm in horizontal dimensions but has negligible depth and only a faint, slightly etched outline.

No basins are known that display a prominent bump in the center; such bumps are common in potholes formed by stream action. They form where cobbles rotate and erode around the circumference of the growing depression and leave a vertical protuberance standing in the middle.

When all of the 30 sites for which there are several measured basins at each site are compared, the median diameter among the sites ranges from 89 to 170 cm and the median depth among the sites ranges from 12 to 63 cm (fig. 11*A*). The overall median diameter and depth are 125 cm and 25 cm, respectively. A trend of increasing size northward is distinct, and one of decreasing depth northward is less distinct.

The relation of depth to diameter is characteristic of individual areas and changes systematically from one geographical area to another. One measure of the ratio of depth to diameter for each group of basins is the projected depth where the diameter equals the overall median of 125 cm. This projected depth, determined by a best fitting least squares line, ranges from 7 to 60 cm (fig. 11*B*).

The typical shape of the basins varies geographically in the southern Sierra. For example, two basins near lat 36.2°N average about 50 cm in depth at 125-cm diameter, whereas two near lat 36.6°N (44 km to the north) average about 25 cm in depth at that diameter (fig. 10). On this basis, the region can be divided north to south into three districts: north, lat 37.4°–36.5°N (north of Middle Fork of Kaweah River); middle, lat 36.5°–36°N (between Middle Fork of Kaweah River and South Fork of the Middle Fork of the Tule River); and south, lat 36°–35.7°N (south of the South Fork of the Middle Fork of the Tule River). Distinct differences are evident when the characteristics of basins are examined for each district. The median dimensions of basins in the north district tend to be greatest in diameter and shallowest, those in the middle district are medium in diameter and deepest, and those in the south district are smallest in diameter and medium in depth (fig. 11*A*).

Similarly, with the depth normalized to a diameter of 125 cm, the north district contains the shallowest basins, while the middle and south districts contain basins that are deeper, with those of the middle district being slightly deeper yet (fig. 11*B*). Basins in the middle district tend to have a greater maximum volume than those north and south, because of their greater depth (fig. 11*B*).

These differences are difficult to explain by natural causes and suggest that the basins are manmade, with the differences resulting from the culture of the tribelets that made them. Since basins of the middle district are the deepest and most voluminous, we infer that they were the first to be made and underwent construction and refinement for the longest period.

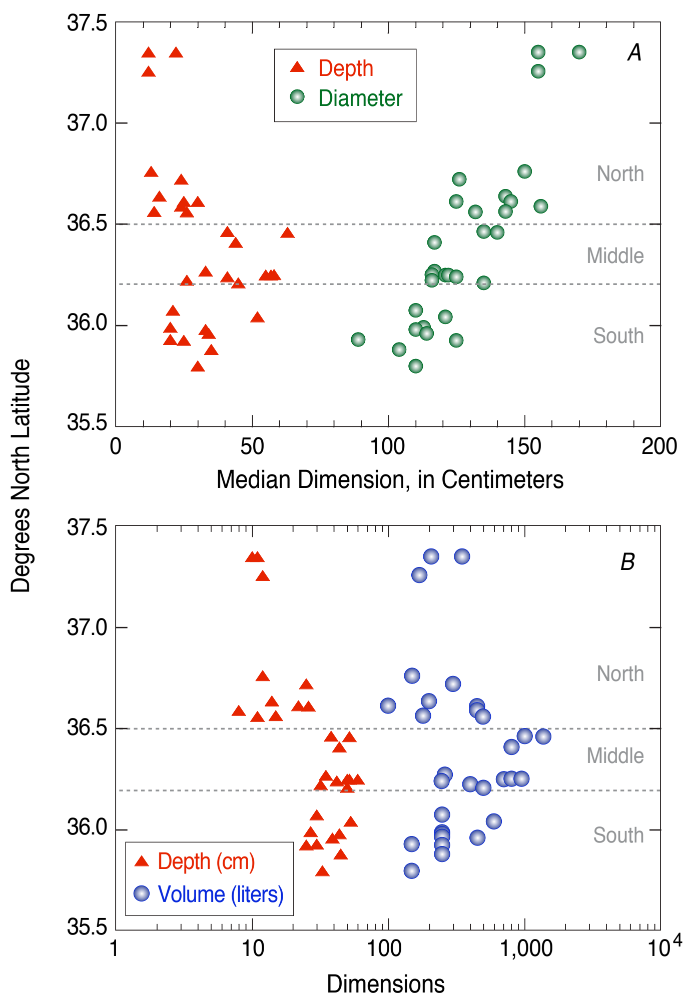

Figure 11. North-south variation of basin dimensions. Arrows separate three latitude-defined districts of basin sites with different basin shapes. North district is north of the Middle Fork of the Kaweah River and south district is south of the South Fork of the Middle Fork of the Tule River. The middle district is between the north and south districts. *A*, Latitude of 30 basin sites with median diameter and median depth of basins at each site. *B*, Latitude of 30 basin sites with depth (normalized to a diameter of 125 cm) and maximum volume of basins at each site.

Age of the Basins

A few constraints can provide some information on the age of the basins. They must postdate the settlement period if they were indeed made by Native Americans. Archaeological investigation in the Mountain Home State Forest uncovered cultural material similar to that in use during the Late Prehistoric Period in the southern Sierra Nevada (Dillon, 1992; Wallace, 1993). This material included pottery, steatite vessels and beads, triangular arrowheads, and mortars using cobble pestles. This phase of Native American history is believed to have begun around A.D. 1200–1300 (Moratto, 1984). However, other artifacts in this area apparently reach back into the Archaic Period, perhaps as early as 2500-2000 B.C.; a single radiocarbon age at the Sunset Point site indicates an age of 6000 B.C. (Dillon, 1992).

In general, the basins look older and more weather-beaten than the mortars. The basins commonly truncate exfoliated shells of granite 10 cm or so thick (fig. 1). At one site a large boulder of vein quartz was apparently washed up onto the rock outcrop by the rise of a nearby creek. This boulder has since disintegrated into a pile of angular fragments averaging 5-10 cm in size that has partly migrated into one of the basins filled with forest litter. Clearly this basin has not been used for a considerable time.

Excavation of undisturbed basins in the Giant Forest area in 1925 revealed a basal white layer identified as rhyolitic volcanic ash (Stewart, 1929; Wood, 1977). Subsequent examination at numerous sites on the west slope of the Sierra in meadowland soils led to the identification of two volcanic ash layers that originated from explosive eruptions in the Mono Lake area northeast of the basin belt. The older ash erupted between A.D. 680 and 940 from Panum Crater, in the Mono Craters, and the younger ash erupted between A.D. 1180 and 1300 (dated at A.D. 1240±60) from the Deadman Creek Domes area (Wood, 1977).

The older ash is limited to regions north of Sequoia National Park, but the younger one occurs over much of that Park (Wood, 1977) and has been identified in sinkholes in the Redwood Canyon region of the Park (Tinsley, 1982), located 16 km northwest of the Giant Forest area. Consequently, this younger ash is considered to correlate with that found in the Giant Forest basins, indicating that these basins were formed before A.D. 1240±60. It should be noted, however, that the ash has not been resampled or recovered from any basins since the original work of Stewart (1929). Because that ash lay on bedrock at the very bottom of the basins with no forest litter below it, yet was covered by forest debris when they were excavated in 1925, the basins were evidently in use when the ash was deposited. They had not been used since, however, because such use would have removed the ash (Stewart, 1929). The original construction of the basins may have been very early, but they were in use at A.D. 1240±60, nearly 800 years ago and were abandoned at that time or shortly thereafter. A possible reason for their abandonment was the environmental disturbance caused by the ashfall (Stewart, 1929).

Natural Versus Manmade Origin

Some workers have called on natural processes to produce the basins. In the forefront of these explanations is the role of running water forming bedrock potholes, where turbulent water rotates loose rocks in streambed irregularities, thereby grinding cylindrical holes in bedrock. A variant of this model, which can account for the presence of basins distant from a steam course, is the notion that water flowing beneath a glacier or at the edge of a glacier can activate rotating stones that mill the basins (Turner, 1892; Gilbert, 1906; Barnes, 1984; Schutt, 1962).

Another class of natural processes produces weathering pits, particularly where an existing depression traps rainwater. Wetting and drying (perhaps abetted by organically derived acids) and freezing and thawing can over time attack and disaggregate rock. Fragmental material is then removed from the deepening cavity by wind gusts, permitting the depression to accumulate more water (Stewart, 1929). This process generally produces shallow irregular depressions and is best suited to horizontal, not domical, bedrock exposures. A related process calls on granite disintegrating beneath a layer of overlying sand or soil that undergoes cycles of wetting and drying, causing the underlying bedrock to be attacked in favorable places (Twidale, 1982).

Many of the proposals for a natural origin add the condition that Native Americans took advantage of existing natural depressions made by one of the above processes and enlarged and deepened them to serve their own purpose.

The basins commonly occur near the top of domical outcrops, a site unlikely for streambed potholes. The restricted size of the basins, their near circularity, and their separation from their neighbors make them unlike river potholes, which commonly range greatly in size and shape and are intergrown with one another. Some potholes are deep and cylindrical in shape, with depth greater than diameter, and some are cylindrical and inclined with overhanging walls (Turner, 1892). Such features almost never are seen in the basins, which approach a shallow spherical segment in shape. Potholes commonly have a central basal protuberance. This feature, formed by boulders rotating by stream action in the bottom of the growing pothole, does not occur in the basins.

The basins are generally larger than 55 cm in diameter and apparently start development with a large diameter (fig. 10). None occur in the size range between the smallest basins, with a diameter of about 40 cm, and the largest mortars, with a diameter of about 22 cm (fig. 10). The basins, therefore, are not formed by the enlargement of a small-diameter hole, as would be the case for river potholes.

Most of the basins are west of the terrain covered by ice in the last glacial periods, although a few are near the western margin of the ice. More than half of the basin belt is south of the apparent ice limit (fig. 2), thereby demonstrating that they are not features formed by stream flow beneath or marginal to glacial ice.

The basins do not show the irregular outlines of weathering pits, and they are not restricted to the horizontal or depressed part of an outcrop where water would naturally pond. In fact, some basins occur on the flank of a domical outcrop and have the uphill side distinctly higher than the downhill side. They do not show the overhanging lips or localized control by joints and fractures (Migon, 2006) common in weathering pits. They are, however, all capable of holding a considerable volume of liquid.

We believe that the preponderance of evidence indicates that the basins are manmade. The regional restriction of the basin belt to a narrow elevation range near nut-producing pines and at the upper limit of acorn-producing oaks argues for the desirability of this zone for summer harvesting camps (figs. 2, 4, 8). Other evidence concerns the basin shape, size, and associated features.

The basin sites are restricted to an elevation belt of 1,700-2,200 m, with a median of 1,950 m (6,400 ft). This forested belt includes the most pleasant elevation for summer camping and contains an important nut-bearing tree, the sugar pine (fig. 6). It also lies adjacent to, but slightly higher than, black oak forests, which provide the most desirable acorns for food purposes. The predominant location of basin sites is on the southern and western slopes, sunny locations that can be occupied first after spring snowmelt and latest before fall rains and cool temperatures.

A few extremely shallow basins of normal diameter show only a faintly scored but quite circular outline. These appear to be incipient basins in the earliest stage of manual formation. Other basins show a slick inner surface, apparently smoothed by hand.

Three general categories of basin shape can be differentiated (fig. 11). Generally these groups are geographically separated within the overall basin belt. This grouping suggests that some intelligence established the basin shape in a given area, possibly the differing traditions of separate tribal groups.

At eighty percent of the basin sites, typical bedrock mortars, undoubtedly of Native American origin, occur together on the same outcrop. Generally, more mortars occur per site than basins, with an overall ratio of 3 to 1 (fig. 6). Archaeological excavations near several of the basin sites have revealed middens containing artifacts that indicate a camp of some size was maintained at the site for a considerable length of time (Wallace, 1993; Dulitz, 2000). Obsidian chips are commonly found scattered in and near the basins.

Several groups or triblets of Native Americans lived in the general region of the basin belt. The Yokuts occupied the low Sierra foothills and San Joaquin Valley on the west, and the Owens Valley Paiutes occupied the region east of the Sierra. In between, on the west slope of the Sierra, lived the

Monachi (Western Mono) in the north and the Tubatulabal in the south. These last two tribelets bordered one another near the course of the Middle Fork of the Kaweah River (Kroeber, 1925; Elsasser, 1972). The most marked difference between the three basin districts occurs between the middle and north districts (fig. 11), which also meet near the Middle Fork of the Kaweah River (lat 36.5°N). We suggest, therefore, that the different tribelets (or their predecessors) who made the granite basins controlled the differences in their shape. The most refined basins, those that are smallest and deepest, occur in that district occupied by the Tubatulabal tribelet at the time of European contact. Both triblets spoke Shoshonean languages, but the differences in vocabulary led Kroeber (1925) to believe that the Tubatulabal had a longer separate history and had resided in their area adjacent to the Kern River several times longer than their Monachi neighbors to the north. Perhaps significantly, the name Tubatulabal is a Shoshonean word meaning "pine nut eaters" (Kroeber, 1925).

Excavation of the Basins

Considering that the granite basins are manmade, one would assume that they were hollowed out in the same fashion as were the neighboring bedrock mortars—by pounding, pecking, and grinding with a pestle stone. However, studies have shown that this method of boring a hole in granite is extremely laborious and slow. Careful experiments with continuous pounding (42,000 strikes) for five hours with a hard stone produced a hole 11 cm in diameter and 2 cm deep. Continued pounding (67,200 strikes) for a total of 8 hours enlarged the hole to a depth of 3.5 cm and a total volume of 140 mL (Osborne, 1998; fig. 11). This pounding at a quarrying rate of 17.5 mL/hr was so bone-jarring that one individual could continue only for about one hour at a time. The final hole was considerably shallower than the typical acorn mortars, which are about 15 cm deep (fig. 12) with a volume of about a liter (McCarthy and others, 1985). Work to create a typical mortar would, therefore, take seven 8-hour days of continuous pounding of stone on stone. (A longer time would be required if the mortar contained acorn meal.) Because the median volume of the maximum-sized basins at the 30 sites reported here (fig. 11*B*) is 300 liters, the excavation of such a basin at this rate would take about five years of continuous work. Moreover, living at the basin sites is only possible for half of the year because of snow cover. Hence, an enormous, decade-long effort would be required to make each basin, if the traditional pounding and grinding method used to quarry the mortars were employed.

Heating the rock will expedite excavation of the basins (Stewart, 1929). The effect of fire in cracking, weakening, and spalling rock is well known. Forest fires are implicated in degrading native art by spalling off sheets of decorated rock (Johnson, 2004); bedrock is spalled from the ceiling and walls of tunnels from the heat generated by burning vehicles (Larsen, 2006); and mining and quarrying operations commonly make use of fire to fracture rock (Gage and Gage, 2005). Stone buildings subjected to fire may fail because of degradation and loss of strength of the stone, and the heated stone is commonly unsatisfactory for rebuilding because of its reduced strength.

Heating experiments conducted on building stones show that coarse-grained rocks are less resistant to heating than fine-grained rocks and that granite is less resistant to heating than limestone and sandstone. Tar (1915) prepared cubes of several types of granitic rock, 2 inches on a side, and heated them in a furnace to known temperatures. The principal minerals in the rocks were quartz and feldspar, and to a lesser degree, biotitic, and hornblende. After quenching in either air or water, all of the heated rocks were tested for crushing strength. The unheated granites ranged in crushing strength from 25,100 to 34,960 pounds per square inch (1,770–2,460 kg/cm^2). The average of the granitic rock samples showed a loss of 29 percent in strength after heating to 500°C and a loss of 63 percent in strength after heating to 750°C (Tarr, 1915). Little difference was noted in strength loss between the air-quenched and water-quenched samples.

Microscopic examination of the heated samples showed that they were minutely cracked. The extensive cracks, which passed around most mineral grains and across the larger grains, tended to disaggregate the rock and induce its reduction in strength. The cracking was apparently caused by internal stresses set up by the differing thermal expansion of mineral grains (Tarr, 1915). The thermal expansion of quartz is twice that of feldspar.

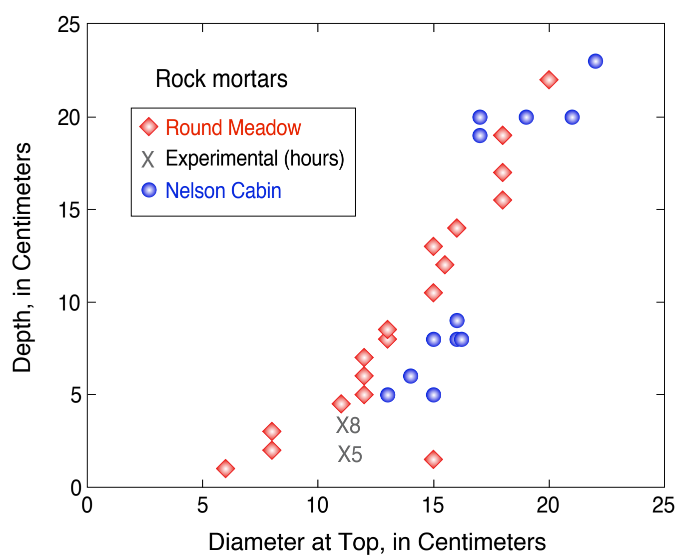

Figure 12. Dimensions of an experimental mortar compared with two groups of bedrock mortars, one at Round Meadow in Giant Forest (Stewart, 1929) and one at Nelson Cabin site at lat 36°16′N. Diameter as measured at the top of the mortar holes is larger than the main shaft. Five and eight hours of continuous pestle pounding produced the experimental mortar (Osborn, 1998).

We have heated hand samples of granodiorite in a box furnace to 500°C and 700°C for half an hour and then air-cooled the specimens. When cooled samples were struck sharply with a geologist's 24-oz (0.7 kg) hammer, they shattered into several fragments, a behavior quite unlike untreated samples, which are much more difficult to break. When the fragments were forcefully rubbed together, they shed a sandy, grus-like material.

In another experiment, glowing charcoal briquettes were heaped on a large slab of fresh Carson Pass porphyritic granodiorite 1.37 m long, 1.04 m wide, and 18-30 cm thick. After several hours of heating, pounding with a stone pestle excavated a shallow basin. At this point the depression was 14 cm in diameter and about 1 cm deep and held 60 mL of water before overflowing. A second period of heating used 3.2 kg of glowing charcoal that was replenished twice to heat the same depression for 3.5 hours. A thermister probe was inserted beneath the charcoal atop the rock. Temperature measurements indicated that the base of the coals was over 200°C for the entire period, was above 300°C for more than 2 hours, and attained a maximum temperature of 550°C. After 20 minutes of pounding with a granite pestle, the volume of the depression was increased to 95 mL. Hence excavation was at the rate of 107 mL/hr, six times faster than Osborne's (1998) rate with unheated rock of 17.5 mL/hr.

From this information we conclude that the granite basins could have been more easily quarried if a hot fire was built on the outcrop and within the basins, in order to minutely crack and weaken the underlying stone. A campfire can attain temperatures comparable to those employed in the experiments. Aluminum cans (melting point of 660°C) melt in a hot campfire. Iron can be heated to a red glow in the hottest core of a fire, indicating a temperature of ~700°C. However, even after several hours of heating, high temperatures would affect only about 1 cm of the rock because of its insulating properties. After heating the rock, the time needed to produce a basin by the traditional pounding and grinding would be greatly reduced, but of course time and energy would be required to maintain a fire and heat the rock. The fire could burn at night and the pounding done in the daytime. In any event, sustained labor over a long period would still be required to hollow the basins.

After a basin was made, containment of the fire would be easier and the heat more concentrated. The size of the basins is comparable to that of a campfire that could produce a good bed of coals without constant attention. If, indeed, the basin was used periodically to contain a fire, as would be needed for heating cooking stones, burning pitch off pine cones, roasting meat, or perhaps for ceremonial purposes, then the heating from each fire would hasten the disintegration of the granite and accommodate the subsequent deepening of the basin.

Uses of the Basins

Many uses have been suggested for the basins, including water or steam bathing, tanning of hides, storage of food and water, and food preparation. The common juxtaposition of the basins with mortars strongly suggests that their chief purpose was in food preparation, because the primary use of the mortars for grinding acorns is well established. Preparing enough food to last through the winter was essential for survival.

The black oak ranges higher in elevation than other oaks and is commonly found at 1,200-1,800 m in the lower reaches of the basin belt. Its acorns were among the most desirable types of oak acorns because their low tannin content required less leaching. The acorns were first shelled. For green acorns, the women commonly did this directly with their teeth. If dry, acorns were cracked in a shallow mortar by a single blow with a stone (Gayton, 1948). On other occasions, dry acorns were soaked in a waterproof basket to soften the tough shells to prepare them for easy opening by the teeth. The kernels were next removed from the shell and dried and the nutmeats ground in mortars to produce a fine meal to expedite leaching. The meal was then mixed with water and the batter was placed in a reservoir in which fresh water was added to remove the tannic acid and render the batter edible. In some cases hot water was poured over the meal. The reservoir commonly pictured is a depression in sand, which is about a meter in size, close in size to the rock basins (Morrato, 1984, his figure 1.1). Water was changed or added in the basin several times until bitterness disappeared from the meal. After leaching, the meal was removed from the basin taking care to prevent mixing with the sand. It was spread out in the sun to dry for later use, or cooked to a mush in a waterproof basket by adding hot stones, or baked into cakes. An early resident of the Springville area reported the use of a rock basin for hot-stone cooking of acorn mush (Wallace, 1993).

The basins could be used during the three processes of acorn preparation—soaking, leaching, and cooking. They could serve the same purpose as the waterproof baskets used by Native Americans for containment of water and other liquids, and for cooking, without the problems of leakage, wear, and burning. The leaching process would be conveniently close to the mortar grinding activity. Because of their great volume, they would require fewer changes of the leaching water and could make use of water warmed by the sun for more efficient leaching. They would have the distinct advantage during leaching of keeping the meal free of sand. The meal could then be removed from the basins with a basket strainer. After leaching the meal could be hot-stone boiled in a basin to produce mush or baked wok-fashion on the side of a basin to produce cakes. A fire maintained in one of the basins would facilitate the heating of cooking stones and baking of acorn cakes. Watertight baskets would be needed to carry water to the basins from a nearby stream, except when they were filled by rainwater. Water could be continually added to the basins, always using the freshest water for the final leach.

Indians harvested pine nuts in the autumn from sugar pines (Gayton, 1948; Corliss, 1989) and probably also from Jeffrey pines and ponderosa pines. Sugar pines are particularly abundant in the basin belt, and carbonized sugar pine nuts were excavated from an Indian campsite at Sunset Point (Dillon, 1992). Sugar pine cones were obtained by men climbing trees and picking cones by twisting, cutting with a sharp rock, or knocking them off with a club. The cones were not permitted to ripen on the tree because when they matured and opened the seeds would be scattered irretrievably. Each cone would be a prize, containing on average 150 seeds weighing a total of about 32 g and containing 190 Kcal of nourishment (Farris, 1982). The women collected the cones in piles and burned off the pitch. Then the nuts were released from the cone by "setting the butt down on a rock and striking the tip with a heavy stone. They split into about three sections and the nuts fell out. . . The nuts to be eaten were first parched with coals on a basket tray. Care was needed to prevent scorching. Sometimes after being cooked, they were pounded in a mortar hole, the greasy mass then being rolled into balls and eaten as an accompaniment to acorn mush." (Gayton, 1948).

The basins could be used to store the cones, and as a place to split and pound them in order to collect and save the released seeds. The basins could also provide a receptacle to burn the pitch off cones or to serve as an oven to heat the cones, causing them to release nuts (Dillon, 1992). Kroeber (1925) mentions, in referring to habits of the Tubutalabal tribelet, that pine nuts were ". . . cached in circular stone-lined pits about five feet in diameter and two and one-half feet deep, located near the piñon gathering areas." The granite basins, which were of this size, would be ideal for such storage and could be rendered more rodent proof. Fires in the basins would be convenient to provide coals for parching and hot stones for boiling. These fires would also disaggregate the underlying stone, thereby facilitating the further deepening of the basins.

Conclusions

A total of 221 sites of meter-size granite basins are found in a 180-km belt extending south from the South Fork of the Kings River to a site west of Lake Isabella on the west slope of the southern Sierra Nevada. Most basins occur in clusters on bedrock outcrops at an average elevation of 1,950 m. Individual sites have 1 to 31 basins, and 80 percent of the sites also contain bedrock mortars of the type used by Native Americans to grind acorns. The north half of the basin belt is close to the western limit of the earliest and most extensively documented glaciation on the west slope of the southern Sierra, but the south half is not adjacent to any known past glacial action.

The median basin diameter among the basin sites ranges from 89 to 170 cm, the median depth ranges from 12 to 63 cm, and the volume from 40 to 1,400 liters. The median maximum volume of basins at the 30 sites measured in detail is about 300 liters. In median diameter and depth, basins in the north district of the overall belt of sites tend to be greatest in diameter and shallowest, those in the middle district are medium in diameter and deepest, and those in the south district are smallest in diameter and medium in depth. The boundary between the north and middle district is close to the boundary of the lands occupied by the Monache and Tubutalabal tribelets, respectively.

The basins do not appear to be natural features—neither waterworn bedrock potholes nor weathering pits. Features that suggest a manmade origin for the basins are the following: (1) restricted size, shape, and elevation range, (2) common association with Indian middens and grinding mortars, (3) a south- and west-facing aspect, (4) the concentration of different shapes in distinct localities, and (5) their location in a food-rich belt with pleasant summer weather. A volcanic ash that erupted from the Mono Lake area at A.D. 1240±60 has been found in the very bottom of several of the basins, indicating that they were used shortly before that time but not thereafter.

It is likely that the basins were made by grinding and hammering with stones (as with the smaller mortars), probably after heating the rock up to about 500°C with campfires. Such heating would weaken the stone and greatly reduce the time and effort needed to deepen the basins.

The common association of mortars with basins strongly suggests that the primary purpose of the basins was in processing of food, primarily acorns and pine nuts. Acorn-bearing black oaks and pines that bear nuts—sugar, Jeffrey, and ponderosa—grow abundantly near the basin zone. Acorns were normally processed in a water-containing vessel three times: for soaking to soften shells, leaching to remove tannin, and cooking (hot-stone boiling of mush or baking of cakes). Traditionally, the soaking and cooking were done in watertight baskets and the leaching in sand basins. The granite basins could serve all three purposes. Likewise, the basins would be useful for processing pine nuts—storing cones and nuts, burning the pitch off cones, and splitting cones to release and collect the nuts.

The 180-km-long belt of granite basins at mid elevations on the west slope of the Sierra Nevada is indeed a remarkable feature. More than 1,000 basins averaging 130 liters in volume were apparently excavated by a civilization that left few other lasting relicts. The quarrying of this 130,000 liters (325 tons) in solid granite represents an enormous expenditure of energy. The basins are among the largest and most permanent artifacts remaining from the California Indian civilization.

Acknowledgments

Special recognition is due the numerous workers who contributed information on the basins as part of a multiagency program that includes members of the Southern Sierra Archaeological Society, the California Division of Forestry and Fire Protection, Sequoia National Forest, the U.S. National Park Service, and the U.S. Geological Survey. Thomas Sisson aided in field mapping as well as heating experiments to assess rock strength. Silvia Haultain provided data and advice on vegetation types in Sequoia National Park. John Gallaway, Gail Mahood, Jack Stewart, and Muriel Myers reviewed the manuscript and offered valuable advice. We are grateful for this help.

References

Barnes, E.K., 1984, Sierra sub-glacial potholes; their significance in California geology, with a note on archaeology: Research paper on file at Sequoia National Park [cited in Dulitz, 2000].

Barton, Orlando, 1881, Early history of Tulare County; important facts gathered from reliable sources preserved in ink: Letter to H. H. Bancroft as reported in Visalia Daily Times, 17 October 1905.

Corliss, D.W., 1989, Native food resources and archaeological sites in the Tule River drainage, Tulare County, California: U. S. Forest Service, Tule River Ranger District, Oct. 1989, 53 p.

Dillon, B.D., 1992, Excavations at the Sunset Point Site (CA-TUL-1052) Mountain Home Demonstration State Forest, Tulare County, California: California Division of Forestry Archaeological Reports, no. 11, p. 69-108, reprinted by Coyote Press, Salinas, California.

Dulitz, D., 2000, Rock basins in Mt. Home State Forest and immediate vicinity: Manuscript on file at California Division of Forestry Archaeology Office, Sacramento, and posted on the California Division of Forestry Archaeology Program Web Site.

Elsasser, A.B., 1972, Indians of Sequoia and Kings Canyon National Parks: Three Rivers, Calif., Sequoia Natural History Association, 56 p.

Farris, G.J., 1982, Pine nuts as an aboriginal food source in California and Nevada; some contrasts: Journal of Ethnobiology, v. 2, p. 114-122.

Foster, D.G., Kauffman, E., Jenkins, R., and Betts, J., 1991, Archaeological testing at the Salt Creek Ridge Site (CA-TUL-472); a southern Sierra rock basin and bedrock mortar encampment on Case Mountain, Tulare County, California: California Department of Forestry and Fire Protection, Archaeological Reports No. 5, 22 p.

Gage, M., and Gage, J., 2005, The art of splitting stone; early rock quarrying methods in pre-industrial New England, 1630–1825 (2nd ed): Amesbury, Maryland, Powwow River Books, 88 p.

Gayton, A. H., 1948, Yokuts and western Mono ethnography, Tulare lake, Southern Valley, and Central Foothills Yokuts: Berkeley, University of California Press, Anthropological Records, v. 10, no. 1, 142 p.

Gehr, E., Conton, L, Parella, D., and Stott, J., 1979, Cultural resources survey and evaluation of Range 31 E, Tule River Indian Reservation: Tuscon, National Park Service, Western Archaeological Center, 20 p.

Gilbert, G.K., 1906, Moulin work under glaciers: Geological Society of America Bulletin, v. 17, p. 317-320.

Gorden, M., 2007, Granite basins in the Sierra Nevada mountains of California (abs.): Society for California Archaeology, 2007 annual meeting, March 22-25, San Jose, California, p. 73.

Hall, A.F., 1930, A guide to Sequoia and General Grant National Parks: Berkeley, Calif., National Parks Publishing House, 151 p.

Johnson, Clay, 2004, Archaeological sites and fire-induced changes, *in* Runswig, R.H., and Butler. W.B., eds., Ancient and historic lifeways in North America's Rocky Mountains: Proceedings of the Rocky Mountain Anthropological Conference, Estes Park, Colorado, 16 p.

Kroeber, A.L., 1925, Handbook of the Indians of California: Washington, D.C., Bureau of American Ethnology, Smithsonian Institution, 995 p.

Larsson, Kristina, 2006, Fires in tunnels and their effect on rock: Lulea, Sweden, Lulea University of Technology, Research Report, 48 p.

Matthes, F.E., 1930, Geologic history of the Yosemite Valley: U.S. Geological Survey Professional Paper 160, 137 p.

McCarthy, H., Hicks, R.A. and Blount, C.M., 1985, A functional analysis of bedrock mortars; western Mono food processing in the southern Sierra Nevada, *in* Cultural Resources of the Crane Valley Hydroelectric Project Area: Pacific Gas and Electric Company, p. 303–356.

Migon, Piotr, 2006, Granite landscapes of the world: Oxford Press, 384 p.

Moore, J.G., and Mack, G., 2008, Limits of Tahoe glaciation in Sequoia and Kings Canyon National Parks, California: U. S. Geological Survey Scientific Investigations Map 2945, scale 1:125,000.

Moore, J.G., and Nokleberg, W.J., 1992, Geologic map of the Tehipite Dome quadrangle, Fresno County, California: U. S. Geological Survey Geologic Quadrangle Map GQ-1676, scale 1:62500.

Moore, J.G., and Sisson, T.W., 1987, Preliminary geologic map of Sequoia and Kings Canyon National Parks: U. S. Geological Survey Open File Report 87–651, scale 1:125,000.

Moratto, M.J., 1984, California archaeology: Orlando, Fla., Academic Press, Inc., 757 p.

Mundy, W.J., 1990, The 1985 and 1986 Generals Highway Archaeological Survey, Sequoia National Park, California: Yosemite Research Center, National Park Service, Publications in Anthropology, no. 10, 26 p.

National Park Service, 2007, Vegetation map for Sequoia and Kings Canyon National Parks: National Park Service, Sequoia and Kings Canyon National Parks, Three Rivers, CA 93271 [http://science.nature.nps.gov/nrdata/, last accessed May 15, 2008].

Osborne, R.H., 1998, The experimental replication of a stone mortar: Lithic Technology, v. 23, no. 2, p. 116-123.

Otter, F., 1979, The view from Hatchet Peak; 'bathtubs' probably natural: Tule River Times, September 6; and The view from Hatchet Peak; does weathering explain bathtubs?: Tule River Times, September 13.

Plotnicov, L. and Elsasser, A.B., 1961, Additional notes on the granite basins in Sequoia National Park: Report to National Park Service, p. 24-37.

Presnell, C.C., 1930, Unusual rock basins in Yosemite: Yosemite Nature Notes, v. 9, p. 107-108.

Pusateri, S.J., 1962, Rock basins of Sierra; natural or made by man?: Woodlake, Calif., Woodlake Echo, a series of three articles on August 9, 16, 23 appearing also in Exeter, Calif., Exeter Sun [cited in Barnes, 1984].

Sandelin, L.C., 2000, Inventory project of the rock-basin sites of the southern Sierra Nevada of California: California Department of Forestry and Fire Protection Special Report, February 14, 2000, 10 p.

Schutt, H.G., 1962, Prehistoric Rock Basins: Visalia, Los Tulares, Quarterly Bulletin of the Tulare County Historical Society, v. 54, p. 1-2.

Sisson, T.W., and Moore, J.G., 1994, Geologic map of the Giant Forest quadrangle, Tulare County, California: U. S. Geological Survey Geologic Quadrangle Map GQ-1751, scale 1: 62,500.

Stewart, G.W., 1929, Prehistoric rock basins in the Sierra Nevada of California: American Anthropologist, new series, v. 31, no. 3, p. 419-430.

Streckeisen, A., chairman, 1973, Plutonic rocks—classification and nomenclature recommended by the IUGS Subcommission on the systematics of igneous rocks: Geotimes, v. 18, no. 10, p. 26-30.

Tarr, W.A., 1915, A study of some heating tests, and the light they throw on the cause of the disaggregation of granite: Economic Geology, v. 10, p. 348-367.

Tinsley, J.C., 1982, Tephrochronology of sinkhole deposits in the Redwood Canyon karst, Sequoia and Kings Canyon National Parks: Washington, D.C., Cave Research Foundation Annual Report, p. 23-25.

Turner, H.W., 1892, Glacial pot-holes in California: American Journal of Science, v. 44, p. 453-454.

Twidale, C.R., 1982, Granite landforms: Amsterdam, Elsevier, 372 p.

Wallace, W.J., 1993, The great Indian bathtub mystery solved?: California Division of Forestry Archaeological Reports, no. 13, p. 373-378, reprinted by Coyote Press, Salinas.

Weinberger, Gay, 1981, Indian slides and "bathtubs"—archaeological enigmas of the southern valley and foothill Yokuts: Southern Sierra Archaeological Society Meeting, Bakersfield, April, 1981.

Wood, S.H., 1977, Distribution, correlation and radio-carbon dating of late Holocene tephra, Mono and Inyo craters, eastern California: Geological Society of America Bulletin, v. 88, p. 89-95.

Moore and others—**Origin of Meter-Size Granite Basins in the Southern Sierra Nevada, California**—Scientific Investigations Report 2008-5210