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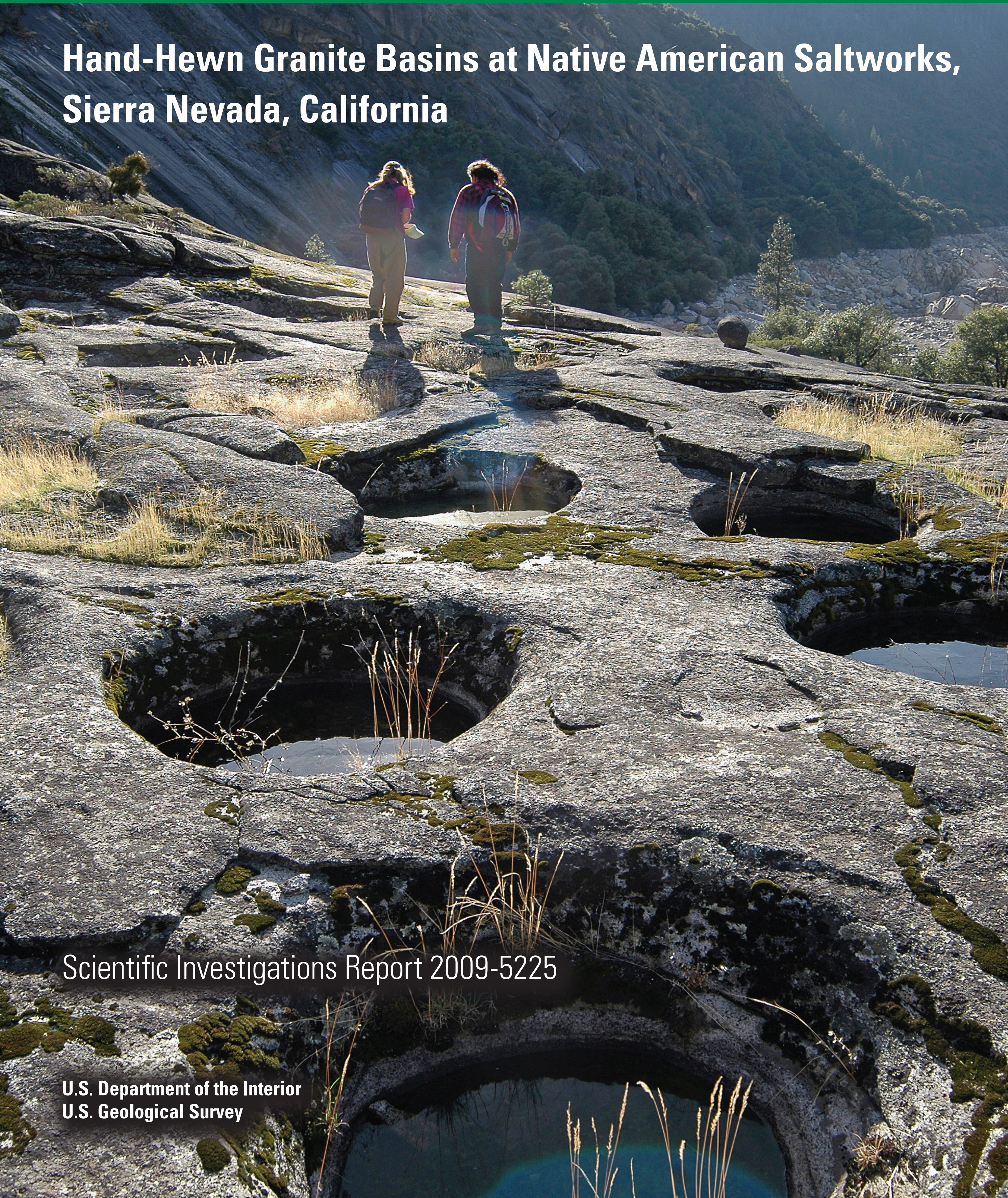
Hand-Hewn Granite Basins at Native American Saltworks, Sierra Nevada, California



Scientific Investigations Report 2009-5225

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FRONT COVER—View toward the southwest at the basin site in the Sierra Nevada, showing about a dozen granite basins carved in the glaciated bedrock of the main terrace, which is studded with 325 basins. Photograph by Tyler Childress.

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By James G. Moore and Michael F. Diggles

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Hand-Hewn Granite Basins at Native American Saltworks, Sierra Nevada, California

By James G. Moore and Michael F. Diggles

Abstract

This site in the northern Sierra Nevada contains about 369 circular basins carved in fresh, glaciated granodioritic bedrock, with 325 basins crowded together in an area of 2,700 m^2 on the main terrace. These terrace basins have a median average diameter of 125 cm (80 percent between 100 and 160 cm) and a median depth of 75–80 cm. They show a strong congruity to similar granitic basins in the southern Sierra Nevada apparently of Native American origin that are generally shallower.

The basins are not of natural origin, as indicated by uniformity in size and nonoverlapping character of the basins; their common arrangement in lineaments; details of the shape of the basins; features in common with granite basins in the Southern Sierra Nevada; and, most compelling, the clustering of all the basins adjacent to (within 20 m of) two saline streams fed from a nearby salt spring. Native Americans apparently excavated them for the purpose of collecting saline water to evaporate and make salt for their use, and also as an animal attractant and a trade commodity.

The flow of the salty streams delivers about 2.9 metric tons of salt per summer season to the basin area, and evaporation rates and the holding capacity of the basins indicate that about 2.5 tons of salt could be produced per season. This correspondence shows that the Indians made enough basins to exploit the resource. The site is the most impressive prehistoric saltworks yet discovered in North America and represents a unique departure from traditional hunter-gatherer activities to that of manufacturing.

The actual grinding of so many basins in granite could not have been done without the labor of a concentrated population. It is believed that the work was accomplished over a long time by many people and with the use of fire to help disaggregate the bedrock.

Introduction

Hundreds of meter-size basins are carved in glaciated granitic bedrock in a canyon on the west slope of the northern Sierra Nevada (figs. 1, 2, 3).

Previous fieldwork has suggested that these are naturally produced potholes formed by the action of flowing water. In this study we map, measure, and examine the basins to develop data that bears on their origin. This work indicates that the basins have been laboriously excavated in granodiorite by Native Americans to contain and evaporate water from a nearby salt spring to produce salt as a commodity.

The site occurs on land administered by the U. S. Forest Service, which has authorized this study. Because of the archaeologically sensitive nature of the site, location details have been omitted in accordance with U. S. statute: Archaeological Resources Protection Act of 1979 (16 U.S.C. 470). This report focuses on the geologic, not the archaeological, perspective.

Figure 1. Aerial view looking southeast across glaciated terrain toward the upper salty pond. The main terrace at the base of the cliff in the middle foreground is studded with 325 meter-size basins.

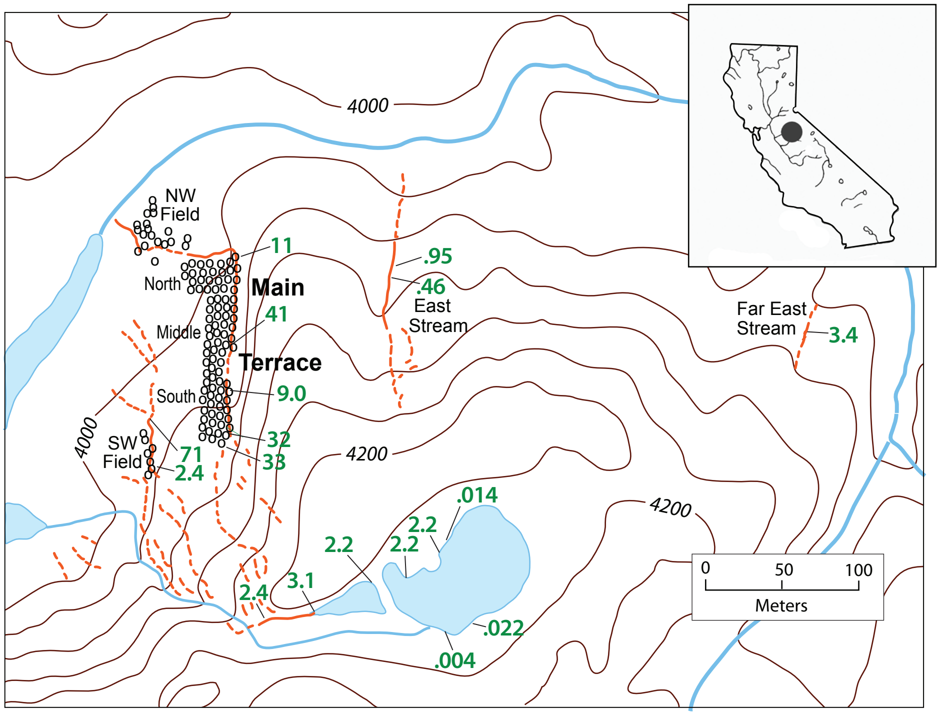

Figure 2. Map showing location of basins (circle pattern) in three neighboring fields. Existing salt streams (solid red) and ephemeral salt streams (dashed red) are shown with conductivity measured in May, 2009 in millisiemens/cm (green). Base from USGS 7.5 minute quadrangle. Contour interval 40 feet (12.2 m).

Previous Work

Meter-size granite basins have been described in the southern Sierra Nevada for more than a century and are known to occur in a 180-km-long belt extending north from Lake Isabella to the South Fork of the Kings River. Their restricted size and elevation range, their common association with Indian middens and grinding mortars, their south- and west-facing aspect, the concentration of specific shapes in different localities, and their location in a food-rich belt with pleasant summer weather all suggest that they were made by Native Americans for food processing (Moore and others, 2008).

Other localities of a few basins each are known to the north, including one near Yosemite (Presnall, 1930), one on the Stanislaus River, (S. Davis-King, written commun., 2008), and one in the watershed of the South Fork of the American River (Linda Pollack, written commun., 2009). The last site is the only one yet known north of the site discussed here.

The first mention of the site under discussion was made by Henry W. Turner, who conducted fieldwork in the region in 1891, 1895, and 1896 while working on a U.S. Geological Survey Geologic Atlas Folio. In Turner's report on the basins he shows a photograph of 47 basins with two men, each standing in a separate basin. Turner states that there are some 250 "potholes," from 6 inches [15 cm] to 6 feet [180 cm] apart, with well-rounded, smooth interiors. He noted that "they seldom or never coalesce and the regularity of their arrangement is noticeable." Water from a nearby salt spring collects in some of the basins where it is commonly covered with a "thick layer of very pretty hopper-shaped crystals" [of salt]. A man who was living with the Indians at the time of Turner's visit in 1891 told him that the Native Americans made the holes for the purpose of collecting salt.

Turner also noted "It would not, however, be a very difficult matter for the Indians to have made them [the basins]. If a fire is built on the granite it flakes off very readily, and by repeating this operation for some time and using utensils in addition, cavities could be made."

Surprisingly, Turner concluded it was "most likely that all the pot-holes were formed by the action of water, probably in some way connected with the glacier that formerly filled the canyon." In his report he emphasizes this concept with the statement "It may be presumed that these potholes formed by a glacial river falling from this granite cliff." Hence he opted for a natural origin for the basins, despite the considerable evidence he provided supporting the notion that they were made and used by Native Americans. Perhaps he was daunted by the prospect of such a large-scale enterprise of basin excavation, an effort that would require decades if not centuries.

Methods

After the basin region was photographed from the air, a number was assigned to each basin before work began on the ground (figs. 4, 5, 6). Despite the fact that field study showed

Figure 3. Views taken 118 years apart from the same point looking south down the length of the main basin terrace. Older photograph is by H.W. Turner (U. S. Geological Survey, Denver library photograph collection). The basins are carved into granitic bedrock through distinct exfoliation fractures parallel to the topographic surface. In addition to trees, note the greater sediment basin fill and the more abundant dark lichens in the more recent photograph.

some basins had not been identified and numbered on the photographs (some were hidden under boulders and grass) and that features other than basins (grassy patches, bedrock knobs, boulders, and glacial erratics) were mistakenly numbered, we have left unchanged the numbers in our database to minimize confusion. The numbers remain the primary reference points on the maps and database. These aerial-photograph maps were scaled by comparison with the applicable U.S. Geological Survey 7.5-minute topographic quadrangle (scale 1:24,000) and by ground measurements with a steel tape between basins recognizable on the aerial photos.

Because the main terrace basin field (fig. 4) contains 325 basins, it has been divided into three areas to facilitate study and measurement. The north area extends from the field's northern extent south to a prominent northeast-trending, basin-free bedrock ramp (about 15 m long and 3 m wide), which slopes down to the northwest. The middle area extends from this ramp south to the westward tip of a major rockfall on the east side of the field. The slide moved down from a steep scarp on the east and traveled west halfway across the main terrace. The south area extends from the tip of the rockfall south to the southern extent of the field.

In addition to the main terrace field, two other zones or fields of basins have been identified (fig. 2). Separate maps cover the southwest field (fig. 5) and northwest field (fig. 6). All of the basins were not investigated or measured because of time constraints. However, at least one basin was measured in every sequentially numbered group of four.

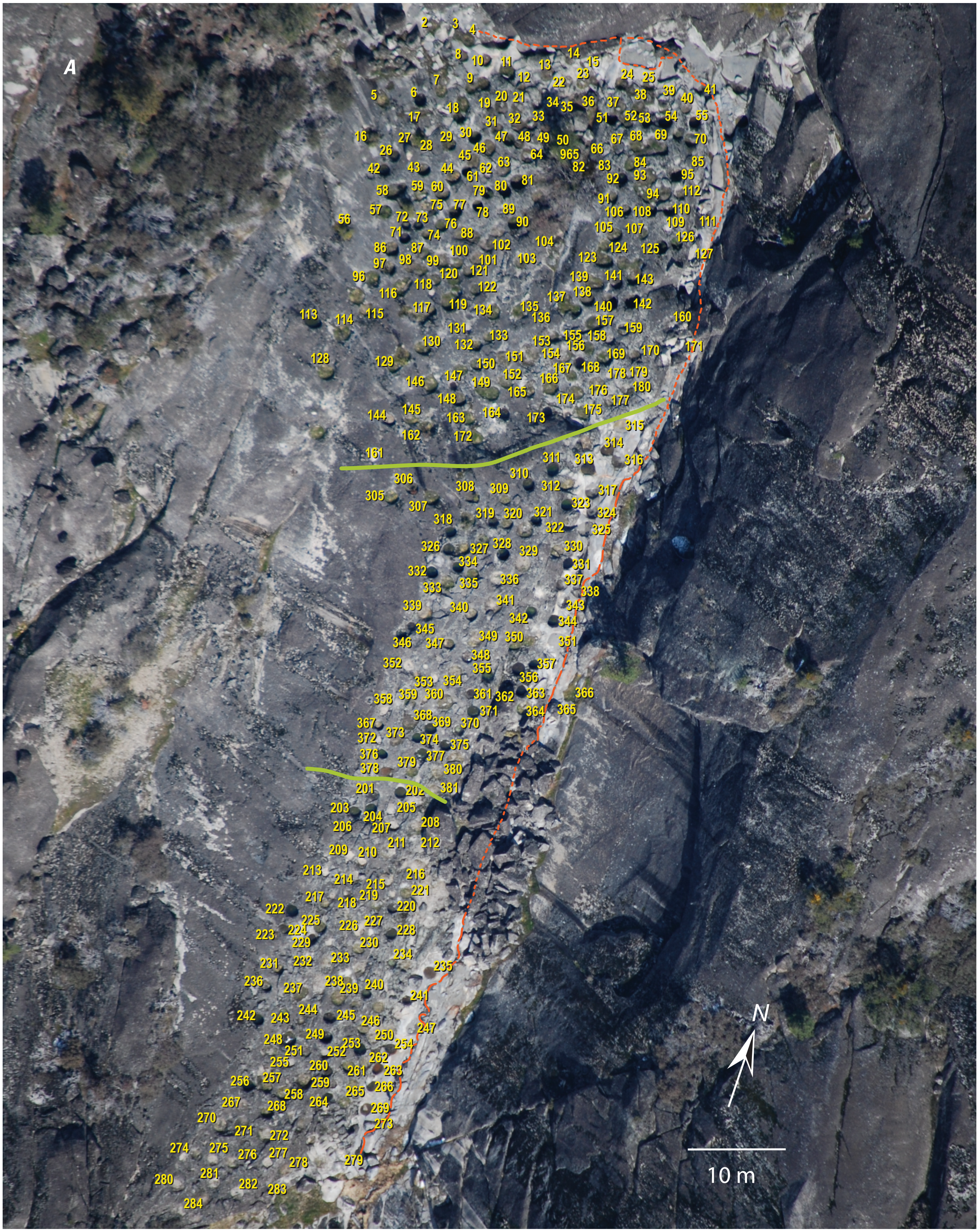

Figure 4. Aerial view of main terrace field with 325 granite basins. *A*, Reference numbers (yellow) define individual basins. North, middle, and south parts of terrace are separated by two green lines. Small north-flowing stream of salty water (red dashed line) has bleached the rock and killed lichens along its course. Rockfall between middle and south parts postdates glaciation, but is primarily older than the basins. Scale is approximate. *B*, Main terrace showing azimuth toward the overhanging wall of selected basins and the horizontal amount (in cm) of overhang, which is on the upslope side of the basin

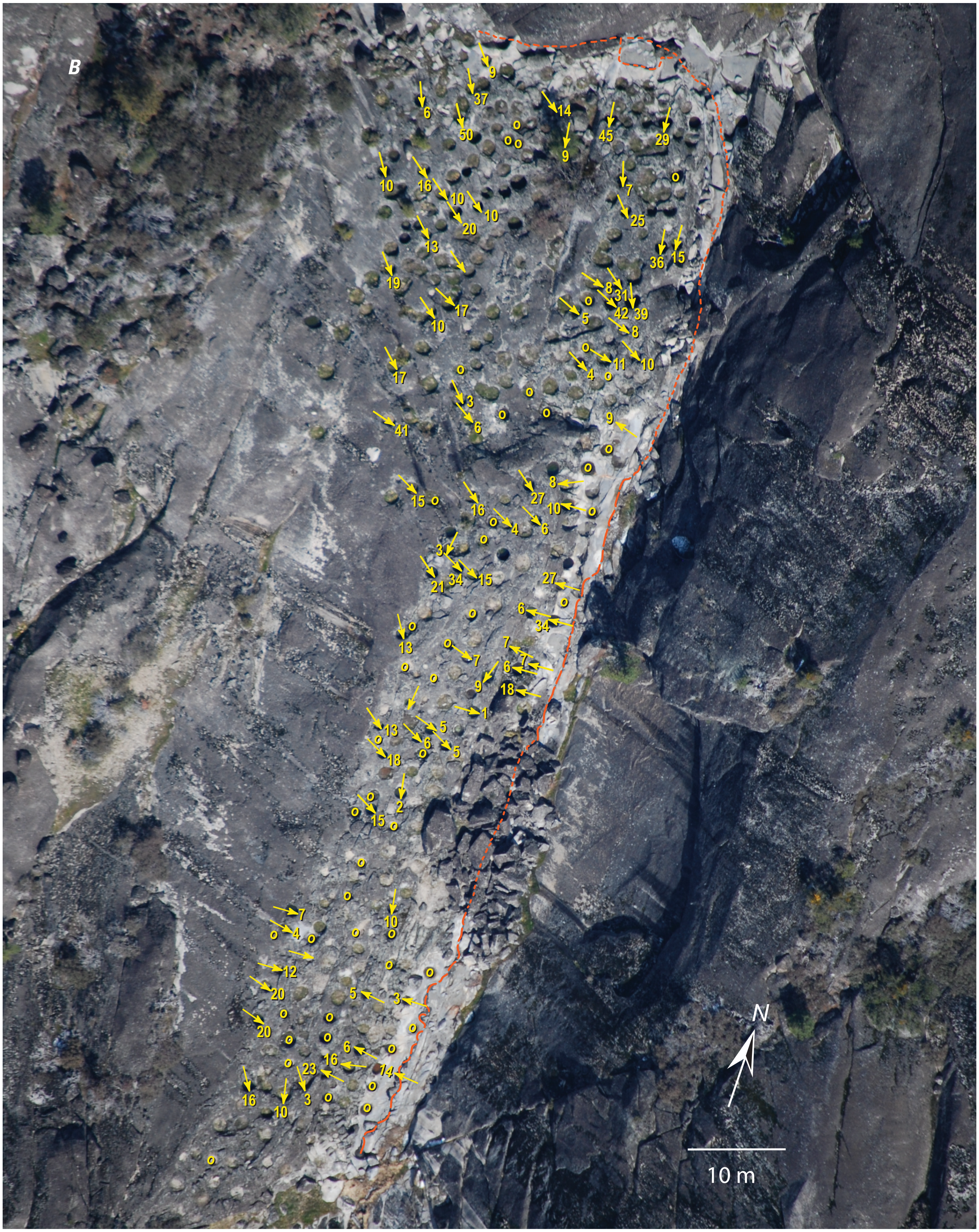

Figure 4—Continued.

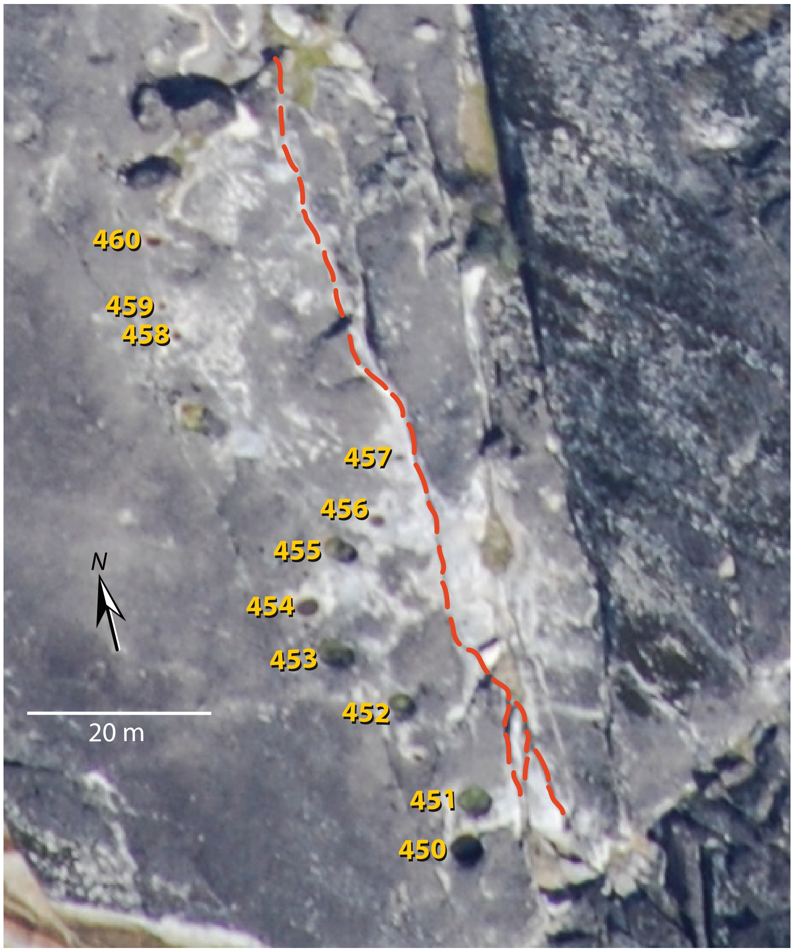

Figure 5. Aerial view of southwest field of basins. Dashed red line is salty stream flowing in May 2009, and white areas outline previous saline streams. North half of field has small incipient basins perhaps in early stages of construction. Two large glacial erratics are at north end of field.

Measurements of the basins were made with graduated staffs. The depth of those filled with soil, debris, and water was determined by measurement with pointed steel rods (5 and 10 mm in diameter) inserted vertically down through the soil until apparent rock bottom was encountered. The depth was measured from a horizontal staff laid on the basin rim across the basin center paralleling a topographic contour. Therefore, the upslope wall of the basin extends above this horizontal staff, and the downslope wall and lip of the basin extend below the staff. Hence on sloping terrain, the depth measurements are an average depth and are those from which the approximate volume of excavation of the basin may be calculated. However, in most basins the lip is lower than the horizontal reference staff, so that the water-holding capacity of the basin is considerably smaller (commonly one-half) than that of the calculated excavated volume.

Profiles of a few nearly empty basins were determined by fixing a horizontal staff in a downslope direction across the center of the basin and measuring downward to the basin floor at 5-cm intervals. The basin walls were examined for overhangs, and where found the maximum amount of overhang was determined by measuring horizontally into the zone of greatest concavity from a vertical rod that just touched the tip of the overhanging wall. The azimuth toward the greatest overhang was measured by compass.

The temperature and salinity of water in the salt streams, pits, and ponds were measured with a conductivity meter utilizing a probe 2 x 5 cm in size.

Measurement of saline water flow in the two principal salty streams was facilitated by construction of temporary weirs made of small sandbags. The impounded water behind the weirs was funneled through a two-meter-long, 2.5 centimeter pipe. The capacity of stream flow was measured by determining the volume of water issuing from the distal end of the pipe during a fixed time. Water samples collected from the principal salt stream on the terrace field were analyzed in the laboratories of the U.S. Geological Survey.

The water level in two pits was measured for three days in late May, during which time most basins were nearly full of rainwater. Evaporation was also evaluated by noting the

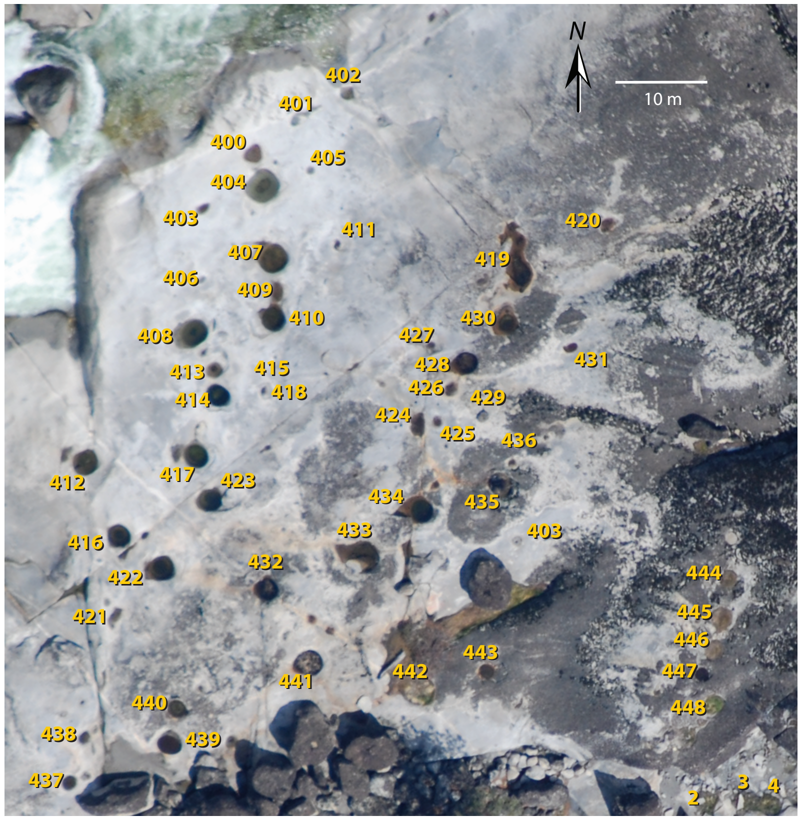

Figure 6. Aerial view of northwest field of basins between river and main terrace. A northeast-trending line of several mortars appear as tiny dots right of the photograph center (just to the left of basin 424). Four grass-filled basins occur in southeast corner.

water level in selected basins in late May, early August, and late September. However, at the September trip, all basins not adjacent to the salty stream were dry.

Geology

The basins are all excavated in a relatively uniform, fresh granodiorite with a specific gravity of 2.71 and a silica content of about 66 weight percent. The rock contains about 15 percent dark minerals, principally biotite and conspicuous hornblende prisms. It also contains rather widely spaced phenocrysts of K-feldspar up to 2 cm in size that contain numerous inclusions of other minerals (poikilitic). This granodiorite is part of the Sierra Nevada batholith, probably Cretaceous in age. It apparently belongs to a large intrusive mass, because the nearest mapped basic and metamorphic wall rock occurrences are 5 km southwest and 12 km east of the site, respectively (Strand and Koenig, 1971).

A glacier descended the adjacent canyon during the last glacial period. The area just east of the basins displays the smooth, rounded outcrop of a glaciated hummock, roche moutonnee, streamlined on the upstream (stoss) side and cliffed on the downstream (lee) side (fig. 1). The general shape of the canyon with its relatively smooth high walls (750–1,000 m) indicates that a major trunk glacier occupied the canyon during the Quaternary Period. The canyon changes downstream from a relatively straight U-shaped canyon to a curvy, V-shaped valley 6.2 km west of the basin site, and this change probably marks the western terminus of the most far-reaching canyon trunk glacier.

The granodiorite is cut by three systems of joints (or fractures). Two are subvertical, the most prominent trending north and a second trending east-northeast. On the lee (west) side of the roche moutonnee, glacial plucking has exposed the steep west-facing scarp of a prominent north-trending joint face. This scarp, which bounds the main terrace field on the east, has an average dip of about 65° west and is 25–35 m high. Glaciation has stripped the main terrace to smooth bedrock except for a few scattered glacial erratics. The principal salty stream drains north in a low swale at the base of the scarp on the east side of the main terrace basin field (figs. 1, 2). On this terrace at the base of the joint face, 325 basins are crowded together in an area measuring 120 m north-south and 20–30 m east-west.

In addition to these two subvertical joint sets is a family of subhorizontal extensional exfoliation joints, which are subparallel to the generalized upper rock surface (the ground surface). They are believed to have formed as the original deep-seated granitic massif was progressively exhumed by erosion and came closer to the surface into a regime of lower pressure. The rock mass expanded most in a direction perpendicular to the exposed surface, causing expansion fractures to develop parallel to the surface. Such exfoliation joints (especially where they are unaffected by other sets of subvertical joints) form the domes common in the Sierra Nevada, such as Half Dome in Yosemite.

A west-directed rockfall from the steep, west-sloping joint face has deposited a group of boulders about 25 m wide that extends 15 m out onto the terrace (fig. 4). Assuming that the basins are naturally formed by moving water, then: (1) they are not younger than the rockslide, because none of the rockslide boulders are rounded or otherwise modified by the turbulent water that would be required to produce waterworn pothole basins, and (2) they are not older than the rockslide, because the rockslide boulders generally do not overlie basins or fill any basins. Only one basin underlies the rockfall debris and it is beneath the outermost edge of the largest (5 m long) and most distal boulder. A careful examination of exposed bedrock between boulders does not reveal any other basin there. Apparently most of the slide covered no basins nor filled any basins with debris, and therefore the slide predated the basins. These facts support the notion that the potholes were selectively excavated around the rockslide after its fall and that the distal boulder was originally deposited in an unstable position, so that it later toppled partly over a basin at its base that had been newly excavated.

Tracing the water from the small salty streams in the region is hampered, because commonly the flow is below the surface in both subvertical joints and subhorizontal sheeted fractures bounding exfoliation slabs. The saline water is apparently poisonous to lichens, because no lichens grow in or adjacent to the salty streams or basins filled by them (fig. 7*A*), yet the lichens are ubiquitous away from the salt. However, since the lichens do not grow where ephemeral salty streams have flowed, the courses of these streams leave dramatic white stripes on the bedrock (figs. 7*B,C*).

On the basis of these stripes, ephemeral salty streams have been traced to the west end of the upper pond, 150 m southeast of, and 30 m above, the southeast corner of the terrace basin field (figs. 1,2). This pond waxes and wanes in size with the seasons. In January and March 2009 the pond was large, at its highest level, so that its east-west dimension

Figure 7. Bleached granodiorite adjacent to salty streams. *A*, Looking south along salty stream on main terrace at base of scarp. Note rounded weathering of bedrock adjacent to stream on left. Healthy lichens and more angular bedrock on right occur away from salt. *B*. Bleached and lichen-free rock at ephemeral salty stream south of main terrace. *C*. Bleached salty stream course along east saline stream. Note large glacial erratic.

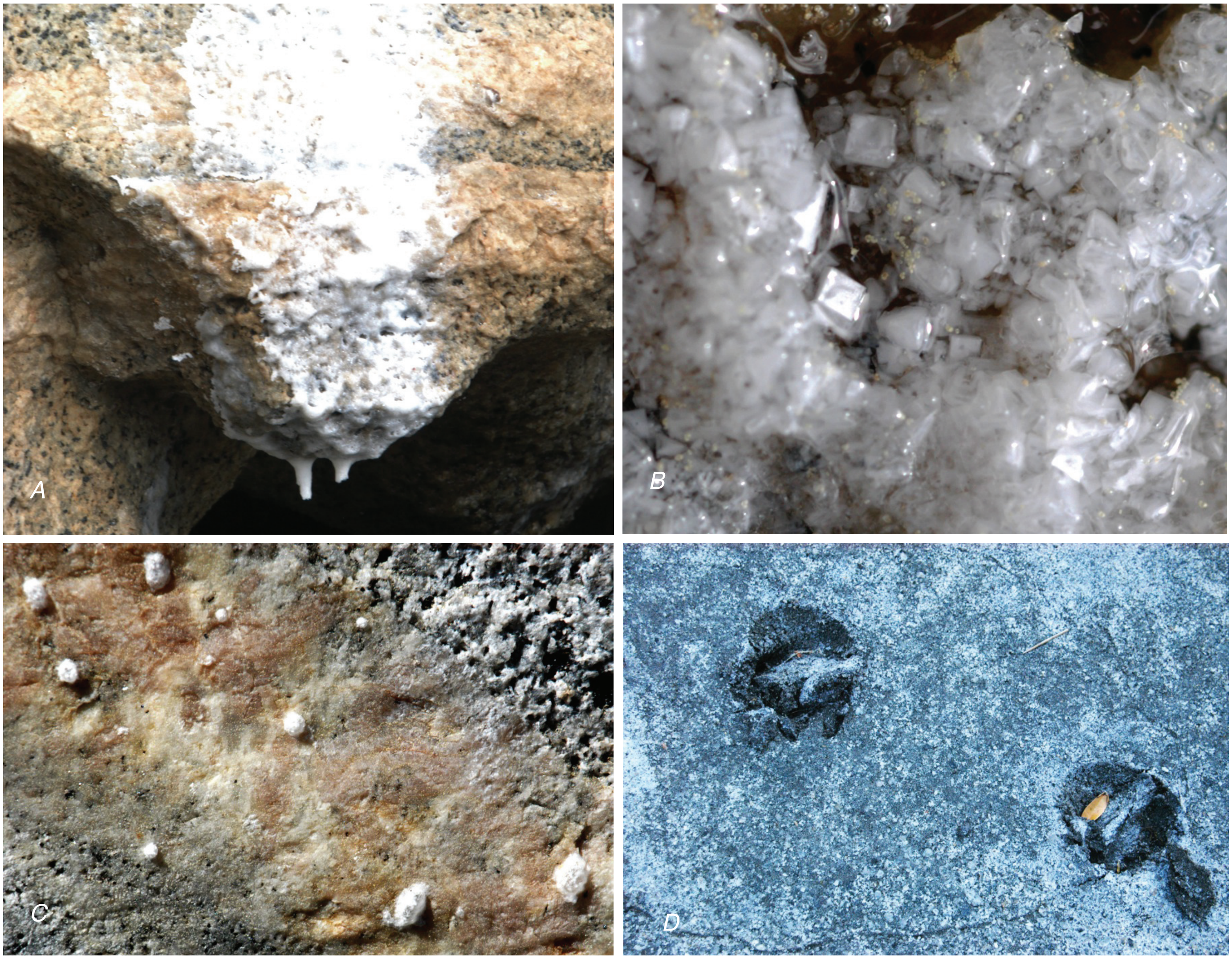

Figure 8. Features of salt deposits. *A*, Salt stalactites (longest is 1 cm) produced where thin veneer of salty water drips and evaporates. *B*, Salt crystals on edge of salty stream. Size of cubes is about 1 mm. *C*, Salt blisters (largest about 1 cm in size) formed where salty film evaporates on rock. *D*, Muzzle marks (about 7 cm in diameter) imprinted in salty sand where a deer thrust its nose into sand to suck salt.

was 150 m and it merged completely with the small arm of the pond on the west. In May the arm on the west was separated from the main pond by a bar covered with reeds, as shown in figure 2. In September, the western arm had dried to a dry reed-covered field and the main pond had shrunk to a shallow pond 40 m in diameter, surrounded by tall reeds.

Measurements in May indicate that the main east part of the pond was fresh but the west arm was salty near its outlet. In September the actual orifice of the briny spring was not located, but it apparently occurs near the region of the west arm, because this was the highest terrain where salty water was detected earlier in the season. Conductivity measurements indicate that the water in the salty stream on the main terrace became more concentrated from January to September, apparently because less fresh water from the eastern pond was mixing with the saline spring water.

The saline spring water drains west, divides, and feeds the salt streams of both the main terrace and the southwest field of basins; the northwest field of basins is fed from the northern extension of the terrace salty stream (fig. 2).

The nature of the conduits that feed the east stream and the small salty stream farther to the east is not known. Apparently subterranean fissures conduct saline water northward from the west pond area under the glaciated hummock to these sites.

The saline stream gulch on the east side of the main terrace shows a lichen kill zone as much as 6 m wide and a half meter above the stream level that is conspicuous on aerial photographs (fig 4), yet the salty stream flowing at its bottom is only 2–10 cm wide and 1–2 cm deep. The extended width of this lichen-free zone is apparently the result of a much larger salty water flow than that observed during our excursions in May, August, and September 2009, when the salty stream was small. The much higher indicated flows may result either from seasonal (perhaps winter) combined salt and fresh water flow from the upper pond or from a more copious salt-spring flow in the recent past.

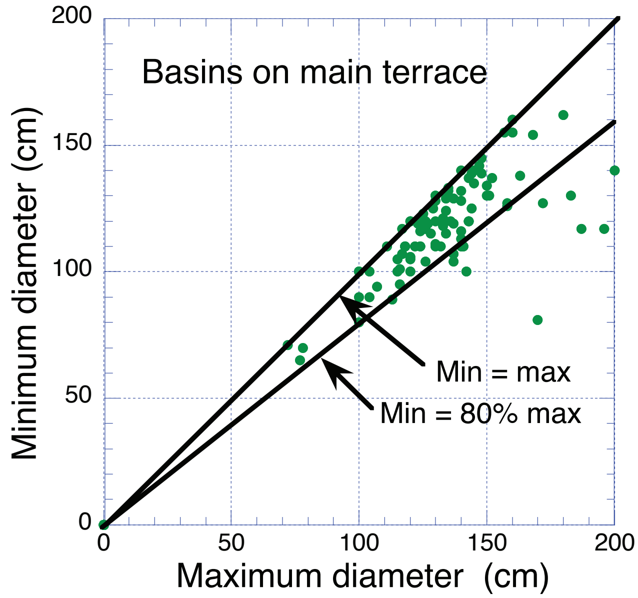

Figure 9. Maximum and minimum measured diameters of basins on the main terrace.

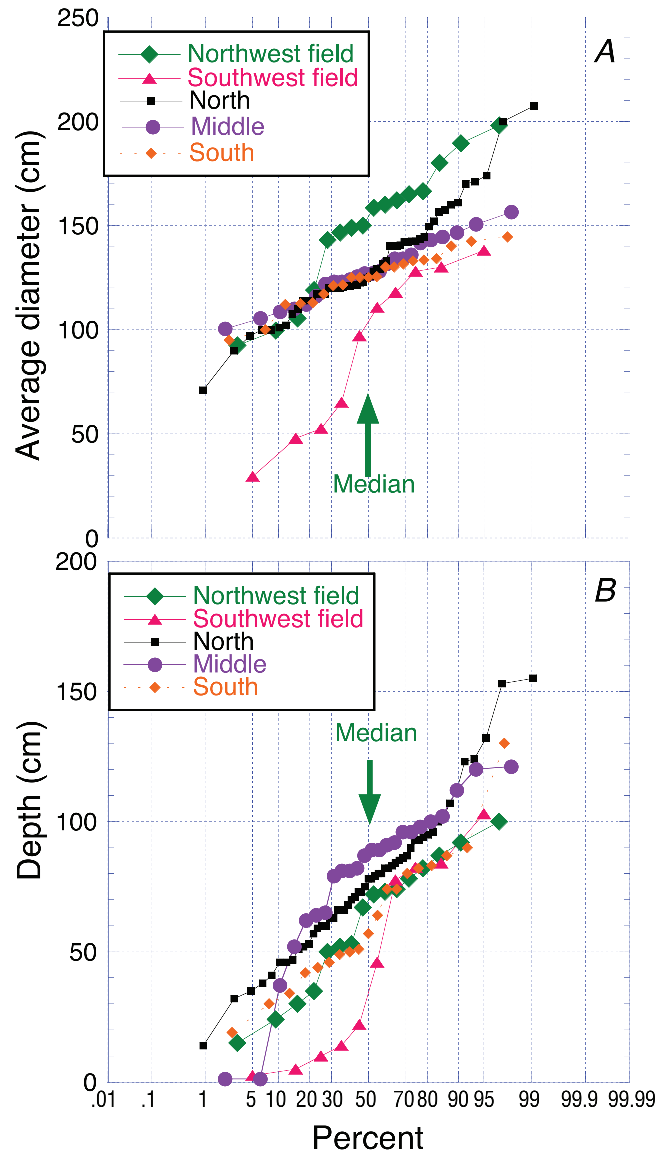

Figure 10. Size of basins from the main terrace field (north, middle, and south areas) and from the two neighboring northwest and southwest fields. Cumulative probability curves show (*A*) the average diameters and (*B*) the depth of basins. Each of the three parts of the main terrace contains basins remarkably congruent in diameter, with a median average diameter of 125 cm. Those in the northwest field are larger and those in the southwest are smaller. Basins of the southwest field tend to be the shallowest.

Along the salty streams, especially the one on the main basin terrace, the adjacent lichen-free granitic rock slabs are distinctively weathered and rounded, contrasting with lichen-covered rock just meters away, which are more angular (fig. 7*A*).

In places where the briny streams are small and evaporation high, various forms of salt are deposited. Salt stalactites form where dripping brine evaborates (fig. 8*A*). Commonly a thin white crust of salt is evident on the margins of (or traces of dry) small salty streams, and it displays minute pyramidal and hopper-shaped crystals of halite (fig. 8*B*). In some places evaporation of films of salt water form widely spaced salt blisters (fig. 8*C*).

The salty sand, especially that along the salty stream in the northeastern part of the main terrace, attracts wildlife. Commonly in the morning fresh deer tracks were observed in the sand. One morning we encountered fresh deer muzzle imprints where the animals had apparently thrust their noses into the sand to suck salt (fig. 8*D*). Deer remains have been noted for the past several years near the main upper pond, apparently where the animals attracted to the salt were taken by mountain lions (Edward Berry, oral commun., 2009).

Nature of the Granite Basins

Number

In the main terrace field (fig. 4) at the base of the joint face, 325 basins are carved in glaciated granodiorite bedrock in an area 120 m north-south and 20–30 m east-west, with an area of about 2,700 m^2. This field is divided into three areas. The north area has 180 numbered sites, 10 of which are not basins, with 5 basins unnumbered, equaling 175 basins. The middle area has 81 numbered sites, 7 of which are not basins, with one unnumbered, equaling 75 basins. The south area has 84 numbered sites, 13 of which are not basins, with 3 unnumbered, equaling 74 basins. In addition, one very large basin occurs 7 meters above the salt stream on the cliffed joint face east of basin no. 325. The basins cover an area of about 2,700 m^2, so that on average one basin occurs in each 8.3 m^2.

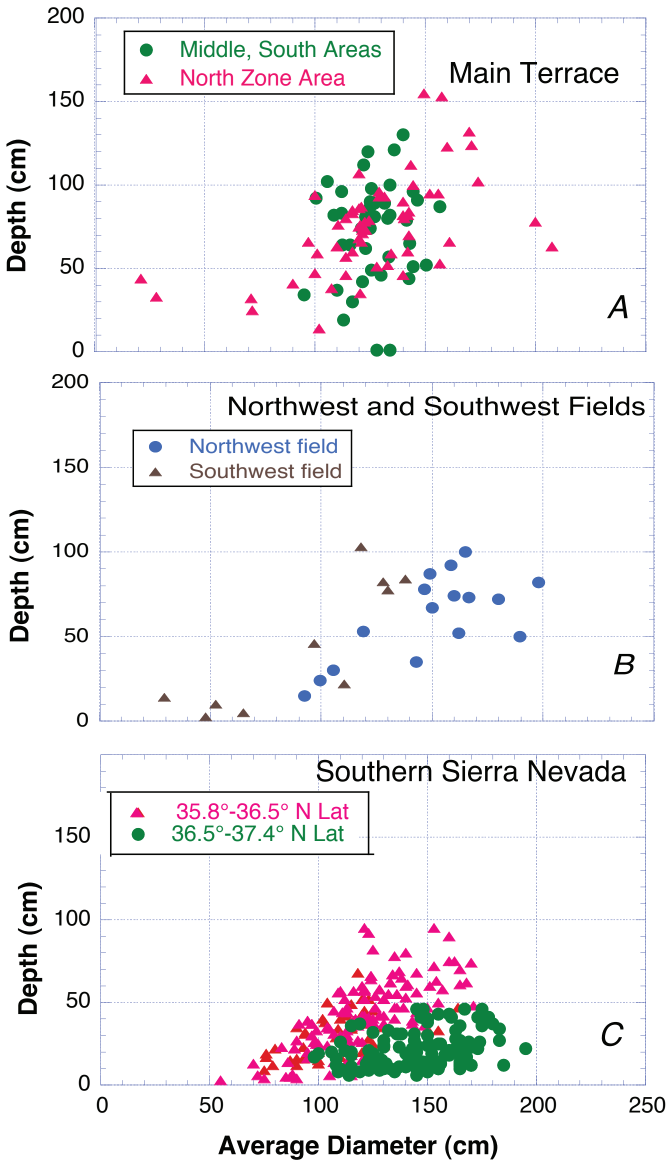

Figure 11. Average diameter and depth of measured basins. *A*, From the main terrace field (north, middle and south areas). *B*, From the two main neighboring fields (northwest and southwest). *C*, From two populations of granitic basins from the southern Sierra Nevada.

Assuming an average diameter of 125 cm, each basin covers 1.23 m^2, and all the basins together cover 15 percent of the area of the terrace field.

In addition, two other basin fields neighbor the main terrace field (fig. 2). The southwest field contains about 11 basins 50 m southwest of the main field (fig. 5). The northwest field contains about 33 basins northwest of the main terrace field (fig. 6). It extends from the northern part of the terrace field to the river, and the lower basins are periodically inundated during high water. The total for the three fields is 369 basins.

Shape and Size

The basins are quite circular in plan, with a low ellipticity. Among 91 basins measured on the main terrace, most have their minimum diameter greater than 80 percent of their maximum diameter (fig. 9). Most basins are simple circular pits in the granite that are separate from their neighbors, but some come remarkably close (within a few cm). On the main terrace, 14 basins intersect, 12 are doublets, and 2 are triplets.

The basins in the north, middle, and south areas of the terrace field are remarkably similar to one another in average diameter, each group having a median average diameter of 125 cm (fig. 10*A*). Eighty percent of the average diameters of the north area basins are between 100 and 160 cm. In contrast, median average diameters of basins in the northwest field are larger, at 1.55 m, and those in the southwest field are smaller, at 1.05 m (fig. 10*A*). The depth of basins shows more variance. The median depth on the main terrace ranges from 60 cm in the south part, through 90 cm in the middle part, to 80 cm in the north part (fig. 10*B*). At a diameter of 125 cm, a hemisphere has a depth of 62.6 cm. Hence, the median south basin is close to a hemisphere, whereas the median middle and north basins are somewhat,deeper than hemispheres.

The median basin depth in the northwest field is similar, at about 70 cm, but the median basin depth in the southwest field is considerably shallower, at 30 cm.

The general uniformity in the size of the basins is conspicuous and is quite unlike the size distribution encountered in natural potholes. When compared with measurements of basins in the southern Sierra, again a significant correspondence is evident, with the majority of the average diameters being between 100 and 150 cm (fig. 11). The southern Sierra basins are, however, distinctly shallower (fig. 11). Moreover, they show a marked regional geographic control, with those between 35.8° and 36.5° N latitude being smaller and deeper than neighboring ones to the north between 36.5° and 37.4° N latitude (fig. 11*C*; Moore and others, 2008).

Basins of the southern Sierra generally show a distinct trend toward an increase in diameter with an increase in depth. In contrast, the basins in this study are more constant in diameter regardless of depth (fig. 11). Apparently after their desired diameter was attained, the terrace basins were simply deepened and not widened. This may have occurred because of the limited area available.

The basins are all carved through a system of sheeted fractures that separate onionskin exfoliating shells paralleling the generalized topographic slope. These fractures are commonly 10 to 20 cm apart, but they become noticeably farther apart and tighter with depth (figs. 3, 12*A*). Commonly the uppermost fracture is open enough so that water may leak into or out of basins, but deeper ones seem more impervious. Where the uppermost fracture intersects the surface it isolates individual slabs (fig. 7*A*). These slabs move intermittently downslope as a result of surface processes. Some slab fragments overlap basin edges or have tumbled into the basins.

Figure 12. Features of meter-size basins. *A*, Basin filled with sand and growing plants showing truncation of exfoliated sheets. *B*, Basin undercut toward the upslope side (toward top of photograph). *C*, Two basins on north margin of north part of main terrace now partly covered by a large block that has fallen from rocky ridge. *D*, Looking southwest over edge of main terrace, showing trees growing in basins. Boulders in background are glacial erratics. *E*, Basins almost merging at top and two that have merged, forming a doublet at lower right of center. *F*, Twin basins at lower left and triplet basin at right center. *G*, Alignment of basins at northwest part of main terrace.

Arrangement in Lineaments

On the main terrace the basins are commonly arranged along multiple straight or curved lines (fig. 12*G*). Many of these lineaments, of 4 to 7 basins, are north-trending. They are subparallel to the length of the terrace and to the joint cliff on its east side. However, a system of well-developed northeast-trending lineaments is present on the west side of the north area. Some of these include as many as a dozen basins (fig. 12*G*).

In addition, basins appear to be arranged bounding other natural obstructions, such as an east-trending line against the north bedrock wall bounding the terrace on the north. Also, lineaments occur paralleling both sides of the northeast-trending ramp that separates the north and middle parts of the main terrace. Such alignment of basins is not typical of potholes carved by the milling action of stones in a stream.

Intergrown Basins

About a dozen compound basins, where two or three basins are merged together, are present in the main terrace field. Most are doublets; two are triplets. The partial circles of individual basins can generally be recognized in these intergrown constructs. Commonly, distinct cusps are recognizable between two partial circular basins where they come together (figs. 12*E, F*). This shape indicates that these irregular elongate basins were clearly made by the intersection of two independent circular basins, and even after intersection they continued to be excavated as separate basins rather than as a single elongate or oval basin.

The multiple basins all occur in the north part of the terrace field. Perhaps this was the first area where basins were excavated and they underwent construction for the longest period, causing crowding and intersection of basins.

Overhanging Walls

Many of the basins have overhanging walls on one side (figs. 4*B*, 12*A*). Measurement of the direction of undercutting indicates that it invariably occurs on the uphill slope (figs. 4*B*, 13). The basins that are not undercut commonly occur where local topography is relatively level. The direction and amount

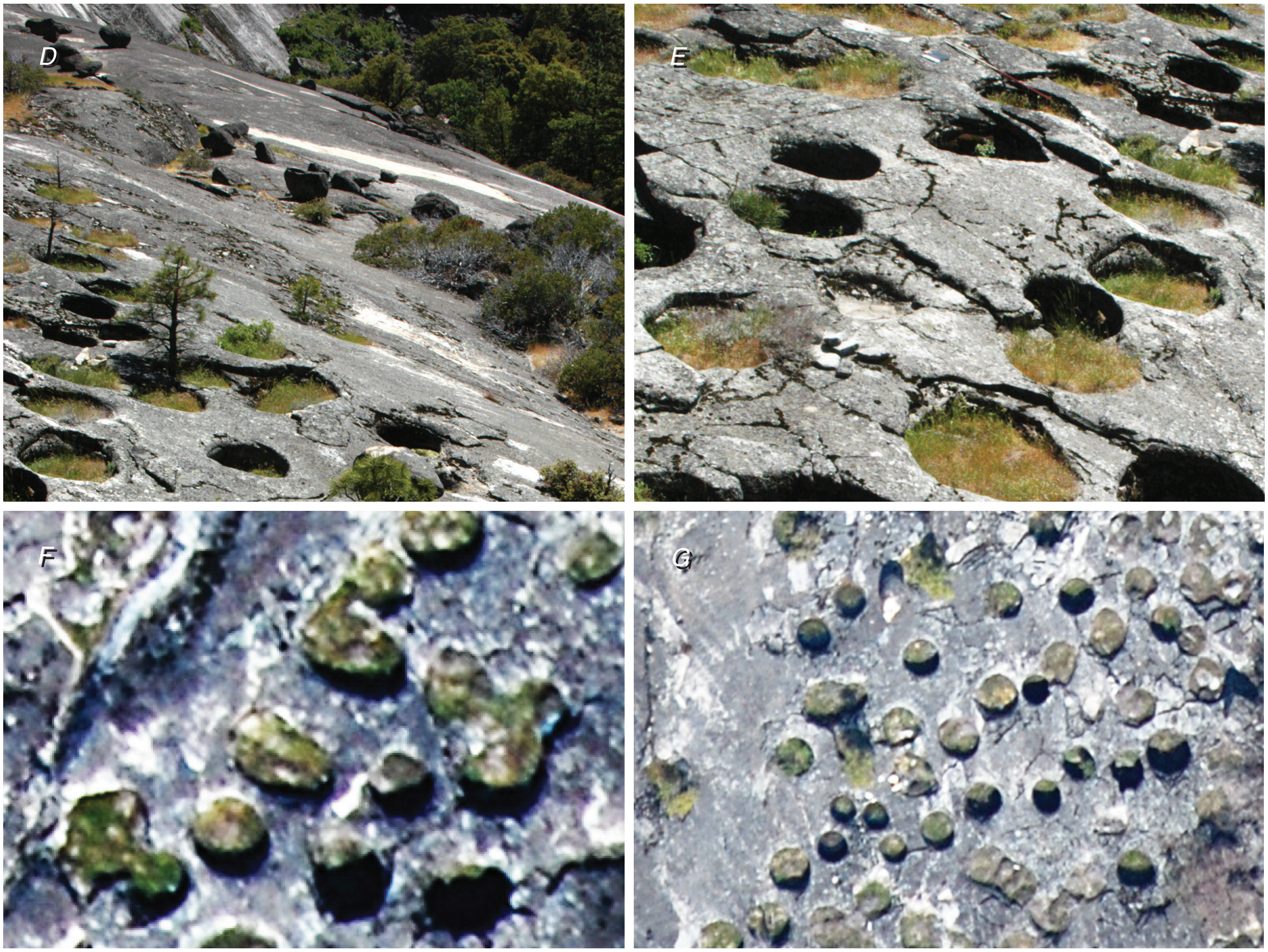

Figure 12—Continued.

of undercutting is therefore systematically arranged depending on the local slope (fig. 4*B*).

In the north area of the main terrace, basins are undercut toward the south and southeast, reflecting the overall north and northwest slope in that area. In the middle and south areas of the terrace field the basins on the west side are generally undercut toward the east and southeast, but those on the east side (but west of the gulley occupied by the salt stream) are undercut toward the west. A north-trending ridge in the middle of the terrace accounts for these basins being undercut toward the higher terrain of the ridge. The greatest amount of undercutting is about 30–40 cm, and such extreme values occur where the regional slopes are steepest, primarily in the north part of the north area. Even though a lack of undercutting is favored by the basins on a gentle slope, the basins that do not have overhanging walls still show steeper walls on the uphill side (fig. 13*A*).

The same effect also occurs in the southwest field. There the overhanging walls of four basins all occur on the southeast side, reflecting the northwest topographic slope in this region.

Basin profiles show that the basins were excavated into the slope such that the axis of symmetry of each basin is about perpendicular to the slope, rather than vertical (fig. 13). This shape may be a natural result of pounding directly into the rock surface. Moreover, this geometry optimizes the thickness, and hence coherence, of the lip at the downslope rim of the basin, which controls the volume of water that the basin can hold. Fracturing of this lip would cause more water to drain from the basin, permitting it to hold less water for a given volume of excavation.

Another factor contributing to the overhang may be that if fire were used to enlarge the basins, heat from fire at the bottom center of a basin would necessarily more strongly affect the higher basin wall on the uphill side. More lateral excavation would be favored in the fire-softened rock of that sector.

Bedrock Mortars

Bedrock mortars (~ 15 cm in diameter) of the type associated with acorn grinding are common in the general vicinity of the basins. These mortars are distinctly smaller than the meter-size basins, and depressions of intermediate size are rare (fig. 6). A noteworthy lack of mortars occurs on the main terrace, where hundreds of meter-size basins dominate. Only 4 mortars were observed amongst the 325 basins. An additional five occur in a cluster adjacent to the field on the west, 7 m west of basin 144. This fact emphasizes the single-minded purpose of activity on the terrace—to make salt by evaporation in the basins.

Mortars are present at the southwest and northwest fields, where they are associated with basins notably more widely spaced than those of the main terrace. Many of these basins are shallower than those of the main field. In this respect, they more closely resemble the basin groups in the southern Sierra (figs. 11*B*, *C*), which also are almost always associated with abundant mortars (Moore and others, 2008).

Changes Since Excavation

The general aspect of the terrace in Turner's 1891 photograph (fig. 3) reflects a long cessation of major salt-making activity. Sediment, grass, brush, and trees are in the basins, and no trace of Indian activity or equipment is visible. Presently most of the basins are partly or wholly filled with sediment. Much of the sediment is sandy, but some has a muddy component, especially in those that contain water. More sediment is evident in the the modern photograph as compared with that taken by Turner 118 years earlier (fig. 3). This change supports the notion that cleaning of the basins had been more active up until Turner's visit, presumably to enable them to be employed for salt-making.

Various forms of vegetation now occur in the basins, depending on sediment and water content. Most have lichens on their walls that are similar to those on surfaces between basins. Sediment in the basins hosts grass and bushes, and some basins have small trees several meters tall and up to 12 cm in diameter. Some of those basins that contain fresh water for part of the summer have reeds or floating aquatic plants. No apparent lifeforms grow in those with salty water, but this habitat should be closely examined.

The internal surface of many of the basins is somewhat weathered and eroded, especially, along the lines of intersected sheet joints (figs. 7*A*, 12*A*). These features suggest a marked antiquity for basin construction, but any age determinations must await detailed excavation and systematic dating.

Basins are partly covered by large blocks in two places, indicating block movement after basin formation, because the basins could not have been easily excavated in their present position. In the north part of the main terrace, three basins are partly covered by the downslope movement of a large block north of basin 13 (fig. 12*C*). Seventy-five meters to the south, the distal 6-m-long block of the rockfall largely covers basin 208. In both cases the covered basins are notably shallow, indicating that block movement took place before excavation was mature.

Exfoliated granitic slabs have migrated downslope into several of the basins, ending either totally within the basins or partly overlapping the edges of the basins. This movement has occurred wholly after construction of the basins and their abandonment for manufacturing salt, because it would interfere with that process. Detachment and movement of the slabs apparently resulted from a combination of several processes. Freezing and thawing of moisture beneath the slabs can lift them and facilitate downslope movement. Earthquakes can rattle and vibrate the plates causing them to move downslope. Strong winds and heavy rain can act on them and affixed ice to initiate movement. Animals can kick them, and plant roots can wedge them downslope. However, the lack of any apparent movement of such slabs in the area of the photographs of figure 3 taken 118 years apart supports the notion of the antiquity of the saltmaking operation.

Large pestle-like rocks that may have been employed in abraiding and excavating the basins were rarely seen. Only a few possible partly rounded candidates have been found, but others may be present buried in the basins.

Water

Composition

The salt springs at this site produce a water rare in the Sierra Nevada because it is much richer in Na, Ca, and Cl than that of most other mineral springs. A sample collected January 20, 2009, showed the following characteristics (R.H. Mariner, U.S. Geological Survey, written commun., 2009):

Temperature 7.2 °C
Specific conductance 33.4 millisiemens/cm
pH 8.2
Alkalinity as HCO_3 41

Its elemental concentration in milligrams per liter (mg/L) as compared to average seawater:

	Salt Spring	Ocean water
Ca	1,600	420
Mg	4	1,300
Na	5,610	10,700
K	98	390
Li	19	0.2
SO_4	162	2,700
Cl	12,100	19,250
As	1.7	0.003

The water is marked by a much higher calcium, lithium, and arsenic content and a lower magnesium and sulfate content relative to seawater. The $CaCl_2$ is somewhat bitter and, being more soluble than NaCl, would be among the last of the salts to crystallize.

The high arsenic content (1.7 milligrams per liter) is considerably elevated over new safe limits set by the Environmental Protection Agency (EPA) at 0.01 mg/L. Hence, the arsenic in the spring water is 170 times higher than the EPA Maximum Contaminant Level (MCL) for arsenic in drinking water.

These analytical data indicate that the water is ancient and was derived from deep-seated saline water contained in pregranitic marine sediments (connate water). The elemental differences from seawater can be accounted for by water-rock interaction during storage at elevated temperatures and during ascent of the spring water.

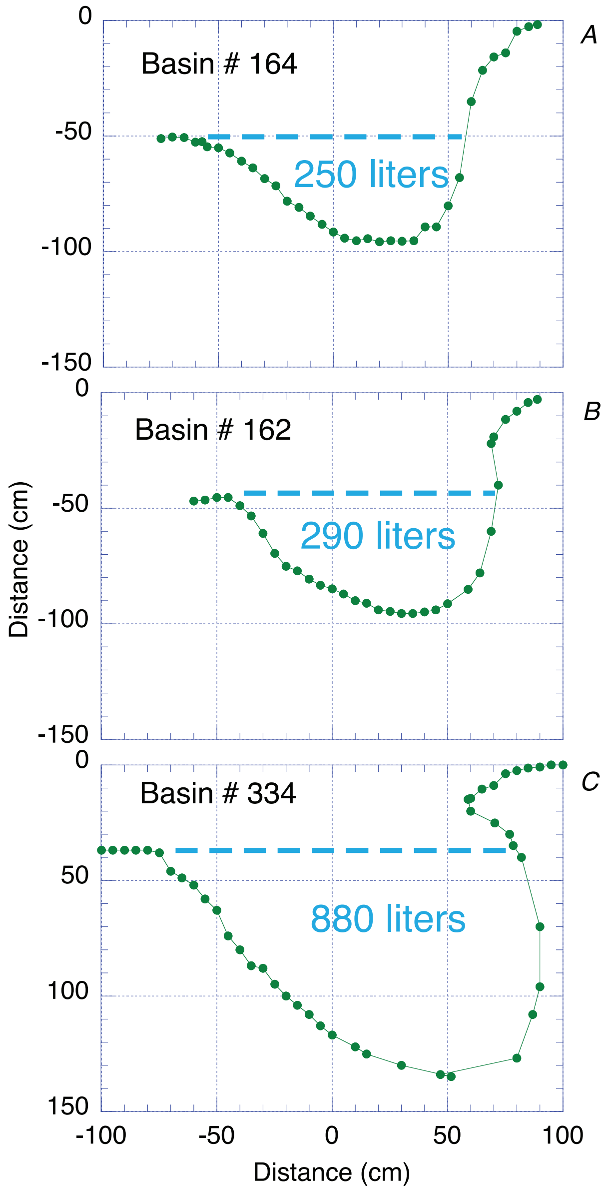

Figure 13. Profiles through the centers of three basins along the fall line. A, Basin 164 in north area, not undercut. B, Basin 162 in north area, undercut 3 cm. C, Basin 334 in middle area, undercut 30 cm. Note that the axes of symmetry of all profiles are arranged more normal to the surface slope than to the vertical. The water-holding capacity of the basins is considerably less than their excavated volumes, especially when considering surface-parallel exfoliation fractures 10–20 cm apart.

Tritium analyses were made on saline water collected in May from the main terrace stream to evaluate whether it was indeed deep-seated or related to surface waters. Tritium (^3H) has been elevated in surface water since atmospheric atomic explosions began in the 1940s. A sample of the water from the stream on the main terrace contained a low tritium concentration at 0.5 ± 0.3 tritium units (TU) at 1 sigma. Modern precipitation in the area contains 3–4 TU, indicating that a small amount of modern precipitation has mixed with tritium-dead spring water in the salty stream.

Conductivity measurements provide a quick method of assessing the salinity of the water. Salinity of waters flowing in the salt stream on the main terrace ranged in May, 2009, from 9 to 41 millisiemens per centimeter (mS/cm) (fig. 2). That in the southwest field stream was 2 to 71 mS/cm, that in the east stream was 0.5 to 1 mS/cm, and that in the far east stream, 3 mS/cm. In the early morning of September 20, 2009, measurements of the water in the stream on the east side of the main terrace increased in conductance systematically downstream for 100 meters from about 30 to 60 mS/cm.

For comparison, tap water is generally below 0.2 mS/cm, and water is generally acceptable for drinking up to 0.3 mS/cm. Most people would agree that water above 0.7 mS/cm is unpalatable. Ocean water is about 50 mS/cm.

In general the water in the stream on the main terrace increased in salinity from winter into summer in 2009. The sample collected in January (analyzed above) is the most dilute, with 19.6 grams per liter (g/L) of salt, that collected in May contained 28.6 g/L, and the average of three samples collected in September contained 31.5 g/L. Apparently the January sample was diluted by surface water. We employ a value of 30 g/L for resource estimates. Total evaporation of a basin filled with 250 liters of this water would cause 7.5 kg of salt to crystallize.

The salinity of standing water in the basins of the main terrace field is generally fresh where the basins are more than 5 m distant from the saline stream flowing on the east side. This indicates that the great bulk of the basins have been totally flushed of salt if they had ever been used to concentrate it.

Water Flow

Determination of the water flow in the saline streams can provide constraints on the size of the salt resource. Therefore, in September 2009 weirs were constructed on the saline stream of the main terrace and on the small stream passing through the southwest field. Analysis of measurements indicates that about 800 liters per day flowed in the main stream and a much smaller 30 liters per day flowed in the southwest stream. Hence, if the main terrace water were apportioned over the 325 basins, each basin would receive 2.5 liters per day. Likewise, for the 11 basins of the southwest field, each would receive 2.7 liters per day. The fact that the number of basins constructed matches the available salt resource suggests that basins were made in accordance with the available supply of salt.

Effect on Bedrock

The granodiorite in which the basins are excavated is clearly affected by the waters of the salt spring. Most noticeable is the complete absence of lichen on the granite near the salty brook flowing north from the spring at the base of the east-bounding scarp (fig. 7*A*). The brine is apparently toxic to all lichen. The light color of the lichen-free granite is clearly visible on the aerial photographs (figs. 4, 5), and forms a zone about 5 m wide.

Moreover, the light-colored granodiorite in this zone appears somewhat corroded. The edges of joint blocks and the septa between the basins are more rounded, and fewer angular corners are present as compared with the “fresh,” lichen-covered granodiorite distant from the salty stream (fig. 12*A*).

A possible cause of this affect may be the crystallization of water-soluble salts in pore spaces between the minerals making up the granodiorite. Apparently the presence of salt, as repeatedly growing and dissolving crystals in rock interstices, has partly disaggregated the rock surfaces, thereby enhancing the rounded weathering.

Experiments of repeated cycles of soaking of rock in a saturated sulfate solution and then drying has proved to be quite effective in disintegrating granite (Kessler and others, 1940). The grains of the rock were wedged apart by formation of sulfate crystals between the rock-forming minerals. Such action may account for the corrosion of the rock adjacent to the briny stream where it is saturated by salt water and dried periodically, depending on diurnal, seasonal, and weather changes. Conceivably the Indians may have exploited this same process. As the saline water dried in the basins, salt crystallization weakened the rock surficially and thereby promoted deepening of the hole.

Evaporation Rates

Measurements of water level in two granite basins during 3 days in the middle of May, 2009, indicated a lowering of the water level (presumably caused by evaporation) of about 1 cm per day. A similar result was determined by measuring a series of horizontal strand lines on the walls of some basins in May. The strand lines are thought to represent a daily deposition of minute quantities of floating pollen, and it is believed that they result either from daily wind agitation or more rapid evaporation in the day relative to the night. They also indicate a lowering rate of about 1 cm per day for a 10-day period prior to our mid-May visit.

The main salt-making season is assumed to be 122 days in the warm months of June, July, August, and September. This is the period with the highest temperature, highest sun angles, and greatest evaporation rates, and it is almost free of rain and snow. Long-term monthly measurements at the two closest stations with U.S. Weather Bureau evaporation pan data (Class A pans) show a mean evaporation of 18.3 cm for June, 23.4 cm for July, 21.3 cm for August, and 15.8 cm for September. These four months therefore total 78.8 cm averaging 0.65 cm per day. Generally the summer is nearly free of precipitation, which totals about 130 cm in the fall, winter, and spring.

The median basin on the main terrace is 125 cm in diameter at the top edge, but because the water level is below the lip of the basin the ponded diameter would be closer to 100 cm (see fig. 13). However, the effective maximum diameter for evaporation would be much less for two reasons. First, the presence of sheeted joints would commonly cause water to leak below the lip of the basin. Second, in order to evaporate to dryness, the water level would have to be held at a series of lower levels much of the time. A crude estimate of the effective diameter of the evaporating water in each basin is 60 cm giving an average surface area of 2,800 cm^2.

At this level, the basins would each evaporate (at a rate of 80 cm per season) 224 liters per season and all 369 basins would evaporate 82,700 liters per season. With 30 grams per liter of salt, they would produce 2.5 metric tons per season.

Strategy of Saltmaking

The methodology and strategy of salt manufacturing at this site must have included the coordinated effort of a large workforce, probably directed by a single manager. The work included the construction of the basins, diverting saline streams most effectively, cleaning the basins and filling them with saline water, harvesting and storage of salt, and perhaps even transporting and marketing the finished product.

The process would require particular attention and exhaustive labor at the beginning and end of the warm months so as to optimize production. The commands to begin and cease production need be explicit because of the climate-dependant nature of the enterprise. Salt-making would be initiated as early as possible when the chance was good that most rain had ended. At that point the winter rainwater and snowmelt that had filled all the basins would be removed, probably by bailing, and the basins cleaned. The recovered fresh water should be carried away from the terrace area so it would not seep back into other basins.

Immediately thereafter, water from the saline streams would be carried to the basins for evaporation. Much of this work could be done with watertight baskets, but perhaps wooden scoops or troughs were used to transfer water from the stream to some of the basins. This work would have to done both day and night so as not to lose any salt water downstream into the river. The basins could be filled in such a way as to optimize early the area exposed to the sun so as to evaporate the greatest volume. In the beginning, production could be maximized by adding a small amount of water into all the basins. As the hot season progressed, water would steadily be added to increase the water volume in each basin.

A keen understanding of evaporation rates and weather patterns would be required to decide when to desist adding salt water to the basins. Stopping too soon would curtail production by not fully utilizing available solar energy. Stopping too late could jeopardize a part of the production when the first rainstorms dissolved the crystallizing salt. The final drying cycle should be long enough to allow the water in each basin to totally dry so that the salt could be harvested. Upon complete evaporation, the salt that precipitated on the bottom of each basin floor would be scraped in piles and collected in baskets or skin bags.

Experience in saltmaking may have led to special techniques to enhance the quantity and quality of the finished product. A strategy of transfer of waters of different concentration between basins may make the best use of basins best suited for storage or evaporating. The straining of salt crystals from saturated brine could be designed to produce optimum amounts of NaCl, and to free the product of the final liquor or bitterns enriched in undesirable elements such as calcium and potassium. The ability to hold concentrated brine over the winter, conceivably in roofed-over basins could provide a concentrated feedstock to begin the next season.

As noted above, the flow of saline water in the main terrace stream is about 800 liters per day, containing 30 grams per liter of salt. Hence the total resource available for the 4-month warm season is 2.9 metric tons of salt. Our estimate of evaporation from the 369 basins would produce 2.5 tons of salt per season. The close correspondence of the available supply of salt with the amount of salt that could be produced by evaporation is significant. It strongly suggests that just enough basins were constructed to totally exploit the resource. The average salt requirement for an adult is about 2 grams per day. Therefore, a triblet of 200 persons would require 0.15 tons per year, thereby freeing more than two tons for trade.

Salt-Making by Indigenous Peoples

Salt (NaCl) is essential to animal life. All body fluids, including blood, lymph, milk, saliva, semen, sweat, and urine, are saline solutions, and sodium is the primary electrolyte in human and animal bodies. Plants, on the other hand, contain a much more limited salt content. Salt deprivation in animals causes dehydration and desiccation, because water is expelled to maintain adequate salinity for cell function. Therefore, salt has always been a commodity of the greatest importance and has been the basis of many systems of commerce (Kurlansky, 2002).

Native Americans living near the Pacific Coast obtained salt from evaporated seawater on rocks and in coastal ponds, kelp, and marsh grass. Interior Indians obtained salt from rare salt springs, desert saline waters, and playa sediments, by burning salt grass (*Distichlis spicata*; Heizer, 1958), and from animal flesh and blood.

A study of all available references on trade among California Indians utilized notations on the trade commodities of each tribe in question. This work revealed that salt was the most oft-cited exported and imported commodity between tribes (Davis, 1961). The next four commodities in order of importance were: basketry, hides and pelts, marine shell beads, and acorns. Salt was a coveted resource for preparing and preserving food, as an attractant for deer and other animals, and as a valuable trade item.

Several salt deposits or salt seepages are present on the east side of the Coast Range north of Clear Lake, the largest in Salt Spring Valley 3.5 miles north of the town of Stonyford and a mile west of Big Stony Creek. The salt occurs on the floor of Salt Spring Valley where it is concentrated in sandy layers upon evaporation of brackish seepages issuing from the base of hills south and east of the valley (Barret, 1908). During the hot summer months, salt crystallizes on the sediment surface and may reach a thickness of 10 cm. The northeastern Pomo tribe exercised property rights over the salt, which they scraped from the salt-rich sediment and refined.

The salt was a valued resource and item of trade, and the Pomo people also received payment from other tribes for the privilege of collecting it (Barret, 1908). In defending this important resource, the Pomo engaged in a series of salt wars. The last battles ended around 1840, when the first white settlers occupied the valley.

People of the Kamia tribe leached salt out of salt-impregnated sediment in the Imperial Valley of California. The resulting brine was then boiled to precipitate salt (Heizer and Whipple, 1971). Salt was obtained from Mono Lake, Death Valley, and other saline lakes and playas east of the Sierra Nevada.

Indigenous people in other regions of the world make salt today in individual basins similar in size to those of this site. In Niger, Africa, salty water is bailed with buckets into circular clay-lined basins for evaporation (Steinmetz, 2008). In Cusco, Peru, near the village of Salinas thousands of small Incan salt pans still are used to evaporate spring-fed salty water in the sun to make salt.

The Case Against a Natural Origin for the Basins

The uniformity in diameter and depth of the basins (figs. 4, 10, 11) and the rarity of their overlapping (figs. 4, 12*G*) make them unlike those produced by natural processes, such as milling of rotating stones in a stream or weathering by water standing in depressions on horizontal outcrops. In general, natural basins show a much broader range of diameter and depth and usually have a wide assortment of small, irregular depressions.

Aside from milling and weathering, another model for the formation of basins is based on deformation of subhorizontal extensional exfoliation joints. Local irregularities in such joints may cause the uparching of an exfoliation shell. This uparching can detach a shell from the one beneath producing a “blister.” Such a blister can weather away and develop a basin, and scattered basins apparently formed in this way occur on Stone Mountain, Georgia (Hopson, 1958). Again, this mode of origin seems unlikely for the closely packed basins on the main terrace. Such an array of blisters would require a seemingly unreasonable and uncommon pattern of tightly-spaced arches in the exfoliated sheets.

Moreover, most of the basins cut through not just the uppermost exfoliation shell, but two or three (fig. 12*A*).

Virtually all of the basins at this general site are within 20 m of presently active salty streams, including those at the main terrace field as well as those of the two other sites: the southwest field and the northwest field (fig. 2). No basins occur unassociated with saline water, pointing to their construction and use as saltwater evaporators. The equivalence of the amount of saline water available to each basin on the main terrace (2.5 liters per basin per day) as compared to each basin in the southwest field (2.7 liters per basin per day) points to intelligent management of the basins constructed on these basin fields of such disparate size (325 basins as compared to 11 basins). Also, the fact that the 2.9 tons of salt delivered in the summer by the stream closely compares with the 2.5 tons that could be evaporated indicates that enough basins were constructed to exploit the resource.

The common occurrence of overhanging sides only on the uphill wall of basins is not reasonably explained by natural processes such as falling water. This same feature occurs in the southwestern field, far removed from the cliff bounding the main terrace on the east. The cliff could be a possible source of the falling water on the main terrace, but it could not interact with basins in the southwest field.

The similarity in size and shape of these basins to those in the southern Sierra (fig. 11) is notable, especially because the southern basins are excavated in nonglaciated bedrock while those in the north are carved in glaciated bedrock. A communication over a distance of 350 km apparently existed between the people that constructed basins at the various sites because it is unlikely that the idea of excavating similar such basins would have been conceived independently. The northern basins seem more mature, considering their crowding and greater depth, thereby suggesting that they were early and served as a model for those made later in the south.

Where two or three basins intersect one another and form a compound depression, the individual basins still maintain their circular shape (figs. 12*E*,*F*). Even after joining, the cusps between remain unmodified. If the individual basins were each milled down by whirling stones in an eddying water current, why, when the growing basins intersected, would the combined depression not grow as a unit and approach a circular shape with the cusps eroded? Instead, each basin appears to have been deepened individually, both before and after they joined together. This suggests human rather than natural causes in their enlargement.

The arrangement of more than a dozen basins along lineaments, commonly subparallel (fig. 12*G*), is not common in naturally occurring depressions. In places the basins seem almost to form rectangular patterns.

In general the basins appear to be younger than the rockfall, which has fallen from the east scarp and moved about halfway across the middle of the main terrace. If the basins were naturally eroded and younger than the rockfall, then boulders of the rockfall would certainly have been eroded and otherwise affected by the same processes that created the basins. The fact that they are not rounded or eroded indicates the youth of the basins, which appear purposely excavated around the margins of the earlier rockfall.

Making the Basins

Excavating the well-known small bedrock mortars—by pounding, pecking, and grinding with a pestle stone—is a long, laborious task. Experiments have shown that to create a typical mortar, 15 cm in diameter and deep and having a volume of about a liter, would take seven 8-hour days of continuous pounding of stone on stone (Osborne, 1998; Moore and others, 2008). Because the average excavated volume of the basins at the site is 500 liters, their excavation at this rate would take about 10 years of continuous work by one person.

The effect of fire in cracking, weakening, and spalling rock is well known (Agricola, 1556, p. 118–121). Heating rock will “soften” it, thus hastening basin excavation (Stewart, 1929). Microscopic examination of heated samples of rock shows it to be minutely cracked. The extensive cracks pass around most mineral grains, tending to disaggregate the rock and thereby inducing a reduction in strength. The cracking is apparently caused by internal stresses set up by the differing thermal expansion of mineral grains (Tarr, 1915).

Experiments have shown that when fresh granodiorite is heated by placing glowing charcoal on it for several hours, excavation of a cavity is about six times faster than when pounding unheated rock (Moore and others, 2008). Hence the granite basins could have been more easily quarried if a hot fire was built on the outcrop and within the basins to crack and weaken the underlying stone. The rather uniform size of the basins may have been controlled by the optimum size of the fire used to aid in excavation. A smaller fire would require constant attention to add fuel, and a larger fire would require too much wood. A likely fuel for these fires would be the large amounts of drift wood carried down the adjacent river in the Spring floods.

Most of the basins are carved through one or more exfoliated slabs separated by fractures. The slabs become farther apart downward, so the rock is less jointed and more impermeable with depth and will hold water better. Some of the shallow incipient basins are watertight because they have not penetrated the first slab. However, once that slab is pierced, the water will leak out, and the hole will have to be deepened considerably into the next layer before it will again hold water.

Future Work

In addition to archaeological examination of the basins and associated dwelling places, several geologic, hydrologic, geophysical, and biologic studies could enlarge our understanding of the nature of the salt-producing enterprise and therefore of the people who conducted it.

Excavation and auguring of selected basins could provide post-basin-construction stratigraphic information. Layers of pollen, volcanic ash, and charcoal may provide age constraints. A basin of particular interest is the one east of basin number 325, seven meters above the general terrace level, that is carved in the face of the east cliff. It is difficult to climb to, and therefore unusable for salt-making, but it occupies a commanding position overlooking the terrace. Conceivably it is a shaman's site and its excavation may reveal special artifacts.

The presence of fish bones in the basins or nearby middens might support the notion that salt was used to preserve salmon that migrated up the nearby rivers. Or fish may have been preserved in brine-filled basins. Conceivably salt was exported to the southern Sierra tribes to be used in their basins for preserving fish and meat.

Geochemical-geophysical methods could be employed to constrain the age and origin of the basins. These could possibly include K-Ar and Ar-Ar methods for determining the age of included volcanic ash, and radiocarbon methods for determining the age of charcoal and organic remains. Hydration dating could put limits on the age of obsidian artifacts. Cosmogenic analyses might constrain the age of basin construction. Paleomagnetic determinations might determine whether the basin areas were subjected to an elevated temperature that would point to the use of fire in basin excavation.

Additional and more detailed mapping and profiling of individual basins could provide data on their precise morphology and its variation. This could include stereoscopic photogrammetry and lidar surveys in basins cleared of debris.

The nature of the sandy sediment within the basins, the salt-saturated sand along the salt stream, and the sand pockets underlying small grassy spots below the terrace should be examined. Perhaps these sediments represent the material that was removed from the basins during their excavation.

Close examination of the distribution of lichens may help in unraveling past history of surface features. All lichens are absent from the areas subjected to salt streams, which apparently are toxic to them. The resulting white aspect of the rock has been employed to map the ephemeral streams. The broad white areas in the trough occupied by the small salt stream on the east side of the main basin terrace indicates that this stream was much wider and perhaps as much as a meter deep in the past. However, a few lichens apparently of a single species have advanced back into the upper part of this zone. Could this be due to a seasonal fluctuation in release of salt water from the upper salt pond or does it indicate that the salt streams are now waning from a higher flow in the past? Year-round monitoring of stream flow and configuration, pond levels, and salinity may help us understand the dynamics of the saline water distributary system.

Since the basins are presumably much younger than the glaciation of the bedrock into which they are carved, the lichen assemblage is perhaps different in the basins. Lichens may also point to differences in the age of the general bedrock surfaces and of blocks within rockfalls. Lichens are less prevalent on the main terrace in the 1891 photograph of Turner than in the modern photograph (fig. 3), indicating that much of their growth has been in the last 118 years. Perhaps they were partly abraded and inhibited by the extensive human traffic in the vicinity during the heyday of salt making.

A careful tracing of saline streams from the upper pond down over steep, cliffed terrain to the main terrace field, where the water is commonly hidden in joints and fractures, would clarify the course of the salt water. The apparent saltwater flow parallels, but then diverges north from the several ephemeral mapped streams that drains the pond toward the west (fig. 2). Perhaps Indians diverted the flow of saltwater toward the north so as to feed the main terrace field, and to prevent its loss down the west gulch. Examination of the salt-water streams may indicate whether their courses were artificially modified in order to supply the saltworks.

Evaporation studies could refine our ideas on the nature of the salt-making process and the amount of salt that could be produced. As yet no rigorous evaporation measurements have been made on site. Measurement with fixed staffs in several water-filled basins over an extended period could evaluate the water budget in the basins due to the combined effects of precipitation, seepage, and evaporation. Auxiliary metal evaporation pans, ground and air thermometers, and rain gages could further isolate important processes. The overall solar heating of bedrock in summer may be a factor in enhancing evaporation.

Exploratory trenching late in the season adjacent to the marshes of the main upper pond—the source of the salt—might reveal a paleontological bonanza. The repeated occurrence of deer remains in this region indicates that predators, such as mountain lions, habitually take deer there that are attracted by the salt.

The techniques used by Native Americans to freely make so many basins in solid, fresh granite remains a puzzle. Almost certainly fire was used to heat and partly disaggregate a surface layer and render the rock more friable (Moore and others, 2008). A controlled experiment could test this idea in the field and refine our knowledge of the optimum methods of heating as well as the time required for excavation of a basin (Sandelin, 2000).

Conclusions

This site is the most impressive prehistoric saltworks yet discovered in North America. It represents a unique departure from traditional hunter-gatherer activities to that of manufacturing. About 369 meter-size circular basins are carved in fresh glaciated granodioritic bedrock. No fewer than 325 basins occur on the main terrace where some 160 tons of fresh granodiorite was pulverized and removed during excavation of the basins. The basins have a median diameter of 125 cm (80 percent between 100 and 160) and a median depth of 75–80 cm. Many of the basins have a holding capacity of about 250 liters. All the basins are clustered near two of four saline streams fed from a salt spring, which discharges about 800 liters of water per day containing about 30 grams per liter of salts. The salt water is similar to seawater in salinity except for a higher content of calcium.

The evidence indicates that the basins are not of natural origin, but were excavated by Native Americans for the purpose of collecting water from the nearby salt streams to evaporate and make salt for their use, as an animal attractant, and as a trade commodity. This anthropogenic origin of the basins is indicated by their uniformity in size and nonoverlapping character, their common arrangement in lineaments, their similarity with apparent manmade, elevation-restricted, granite basins in the southern Sierra, but most compelling by their invariable clustering within 20 m of streams carrying saline water from an adjacent salt spring.

The composition and volume of the main terrace salt stream indicates that on the supply side it delivers about 2.9 metric tons of salt during the four month summer evaporation season. On the production side based on evaporation rates and the holding capacity of the basins, we estimate that 2.5 metric tons of salt could be manufactured per season at the site. This balance of supply and production strongly suggests that enough basins were excavated by the local tribal group to totally utilize the available salt resource.

The actual grinding of so many basins in granite could not have been done without great labor. It is believed that the work was accomplished over a long time by many people and with the use of fire to help disaggregate the bedrock.

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