GLACIATION NEAR LASSEN PEAK, NORTHERN CALIFORNIA

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Abstract.—Lassen Volcanic National Park in northern California was mostly covered by icecap glaciers during the Tahoe and Tioga Glaciations, and at least once during pre-Tahoe time. Glacial deposits of various ages have been subdivided chiefly by weathering profiles in till, specifically by the relative amounts of clay formation, the presence and thickness of weathered rinds on volcanic stones at or near the ground surface, the depth of oxidation, and the color hues of the oxidized zone. During each glaciation the major ice-accumulation area in the western part of Lassen Volcanic National Park was on the slopes of the old Brokeoff Volcano, a Pleistocene andesitic stratovolcano which covered an area of more than 100 square miles. Lassen Peak is a dacite dome that evidently was erupted during late Tioga time, perhaps about 11,000 years ago. In latest Tioga time, small glaciers formed on the flanks of Lassen Peak and on adjacent mountains at altitudes above 8,000 feet, whereas during the Tioga icecap glaciation the regional snowline near Lassen Peak was probably at about 7,000 feet.

Surficial deposits near Lassen Peak in northern California record at least three major glacial episodes during which a sizable icecap glacier covered much of the area. The glacier that was formed during the last major glaciation was the largest ice mass between the Sierra Nevada icecap (see Wahrhaftig and Birman, 1965, fig. 3), 60 miles to the south, and an icecap that formed on the High Cascades of Oregon a little more than 100 miles north of Lassen Peak (see Crandell, 1965, fig. 3). I noted evidence of widespread glaciation in the western part of Lassen Volcanic National Park while making an appraisal, with Donal R. Mullineaux, of potential geologic hazards in the park. A review of pertinent literature indicated that little was known of the extent and sequence of glaciation in this region; consequently, 2 weeks were spent during July 1970 examining glacial deposits and preparing a reconnaissance map of glacier extents (fig. 1).

The region studied includes a glaciated area of about 100 square miles. It is the western part of an even larger glaciated area of at least 400 square miles which extends about 20 miles east of Lassen Peak. The glaciated area east of Lassen Peak, however, was not examined during this study.

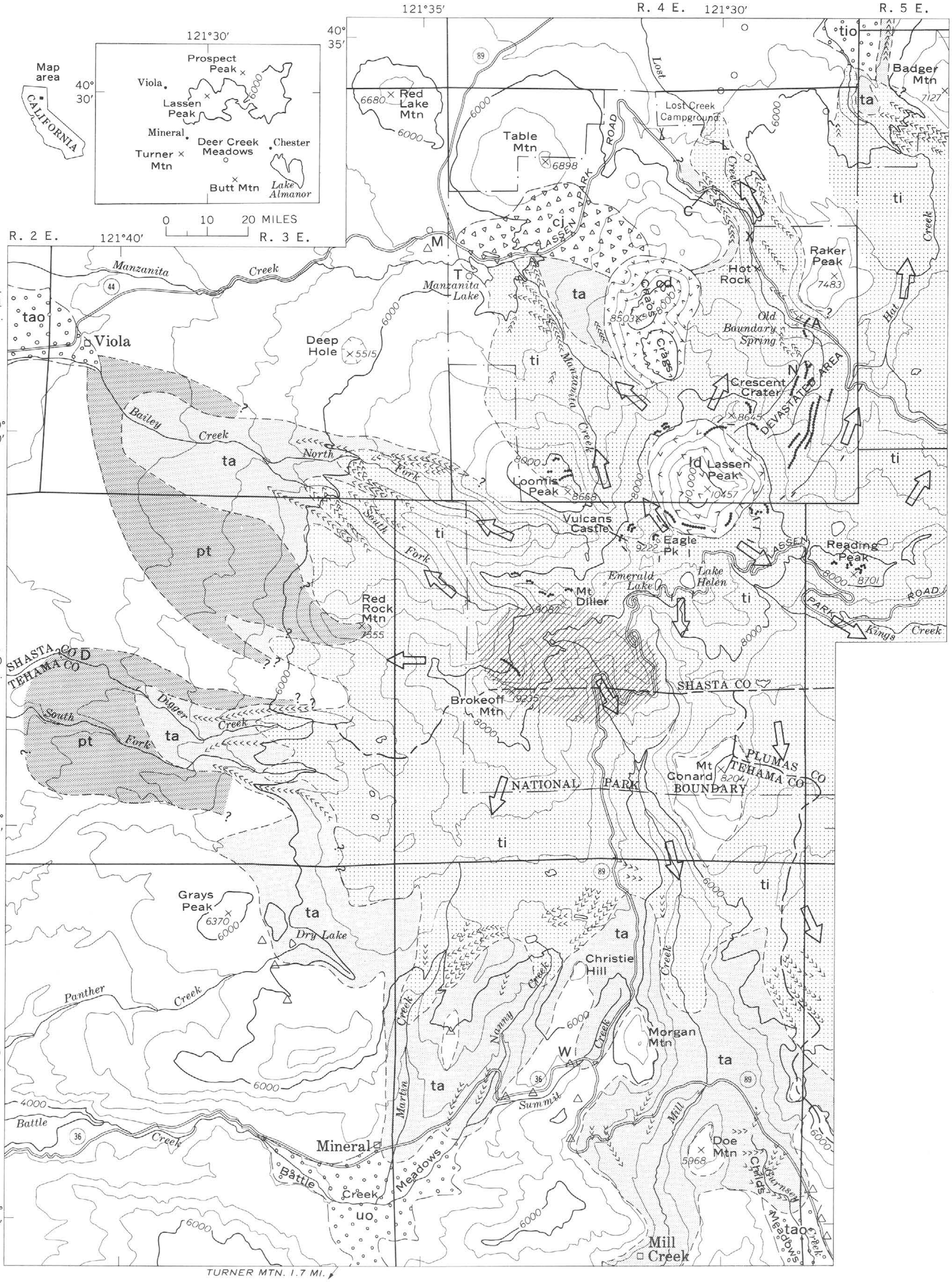
High volcanic peaks in the western part of Lassen Volcanic National Park are bordered on the west by a volcanic plateau (Macdonald, 1966; Lydon and others, 1960). The most significant topographic feature of the area with respect to glaciation is the old Brokeoff Volcano, an andesitic stratovolcano of Pleistocene age (Williams, 1932). The base of the volcano has a diameter of at least 12 miles and perhaps as much as 15 miles. The top of the cone may once have reached an altitude of as much as 11,000 feet (Williams, 1932, p. 244), but the summit area collapsed or was removed by erosion some time before the last major glaciation. Brokeoff Mountain (alt 9,235 ft) and Mount Diller (alt 9,087 ft), the highest surviving remnants of the old volcano, lie just south and north, respectively, of the former summit area. Loomis Peak (8,658 ft), Reading Peak (8,701 ft), and the peak adjacent to Crescent Crater (8,645 ft) are dacite domes and flows which postdate Brokeoff Volcano but predate the last major glaciation. Lassen Peak (10,457 ft) is a dacite dome that was formed on the north flank of Brokeoff Volcano during a late phase of the last major glaciation. The Chaos Crags consist of several dacite domes that were erupted approximately 1,200 years ago (Crandell and others, 1970).

The distribution of glaciers during the last two glaciations shows a close relation to Brokeoff Volcano, rather than to Lassen Peak which is topographically the highest point in the region today. During each glaciation icefields on the slopes of Brokeoff fed glacier lobes that extended down each major valley from the volcano. A high area mostly underlain by post-Brokeoff dacite domes and lava flows, which trends northeastward from Brokeoff Mountain to the site of Lassen Peak, seems to have been an ice divide from which glaciers flowed to both the southeast and northwest (fig. 1). Ice that mantled these high areas in the western part of the park evidently merged with ice that covered a plateau to the east to form a single massive icecap.

There are no glaciers on Lassen Peak today, although snowbanks persist on north-facing slopes and on the summit throughout most summers. Existing glaciers on Mount Shasta (alt 14,162 ft), 70 miles north-northwest of Lassen, all originate at altitudes above 12,000 feet; thus, Lassen Peak is well below the present regional (climatic) snowline.

Most precipitation in the Lassen Peak area occurs during the period October through April, when the southward shift of the Pacific high-pressure area permits moisture-bearing storms to move southeasterly inland from the Aleutian low-pressure

U.S. GEOL. SURVEY PROF. PAPER 800-C, PAGES C179-C188



Map area
CALIFORNIA
Prospect Peak
Viola
Lassen Peak
Mineral
Deer Creek Meadows
Chester
Turner Mtn
Butt Mtn
Lake Almanor
0 10 20 MILES
R. 2 E.
R. 3 E.
R. 4 E.
R. 5 E.
T. 31 N.
T. 30 N.
T. 29 N.
Red Lake Mtn
Table Mtn
Lost Creek Campground
Badger Mtn
Manzanita Creek
Manzanita Lake
Deep Hole
Chaos Crags
Hot Rock
Raker Peak
Old Boundary Spring
Crescent Crater
DEVASTATED AREA
Lassen Peak
Loomis Peak
Vulcans Castle
Eagle Pk
Reading Peak
Lake Helen
Emerald Lake
Mt Diller
Red Rock Mtn
Bailey Creek
North Fork
South Fork
Brokeoff Mtn
SHASTA CO
TEHAMA CO
PLUMAS CO
Digger Creek
NATIONAL PARK BOUNDARY
Mt Conard
LASSEN PARK ROAD
Kings Creek
Hat Creek
Grays Peak
Dry Lake
Panther Creek
Christie Hill
Morgan Mtn
Nanny Creek
Martin Creek
Summit Creek
Battle Creek
Mineral
Battle Creek Meadows
Mill Creek
Doe Mtn
Childs Meadows
Gurnsey Creek
TURNER MTN. 1.7 MI.

Figure 1.

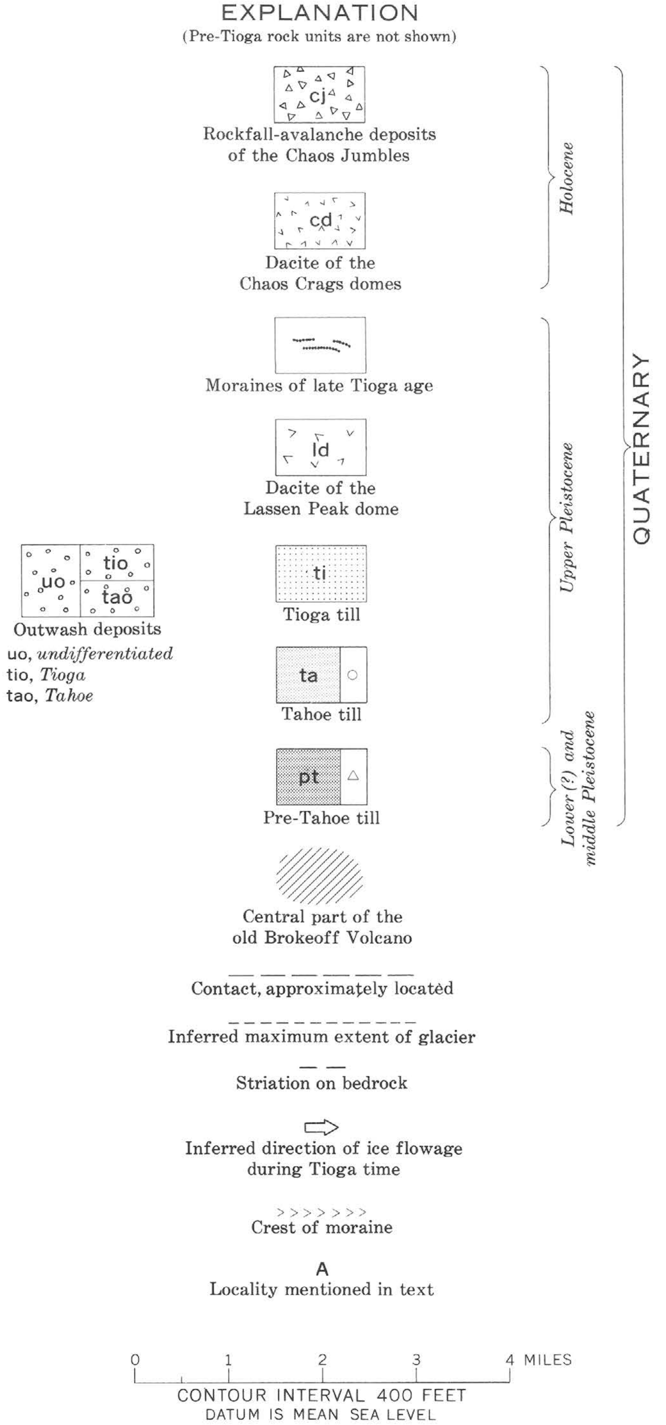


Figure 1.—Reconnaissance geologic map showing extent of Pleistocene glaciation in the western part of the Lassen Peak region.

area. Summers are cool and dry. The average annual precipitation at Mineral (alt about 4,900 ft) from 1950 to 1969 was 55.49 inches, and the average January and July temperatures were 30.8°F and 62.6°F. During the same period, Manzanita Lake (alt about 5,900 ft) had an average annual precipitation of 43.42 inches, and average January and July temperatures of 29.1°F and 63.0°F. According to an isohyetal map of northern California (U.S. Environmental Sci. Services Adm., 1959), Mineral and Manzanita Lake are in or near the zone of maximum precipitation in this part of the Cascade Range, and normal annual precipitation decreases in all directions from those localities except to the south.

The part of the Lassen Peak area that is below an altitude of about 8,000 feet is covered by a dense coniferous forest. The forest is dominated by red fir, Jeffrey pine, lodgepole pine, and mountain hemlock down to an altitude of about 6,000 feet, and by incense cedar, ponderosa pine, sugar pine, Douglas fir, and white fir at lower altitudes. Areas in which the forest has been destroyed by fire are thicketed by dense brush which includes manzanita, tobacco brush, and Sierra chinquapin (Gillett and others, 1961).

The part of the Lassen Peak area that lies west of the maximum extent of glaciation is characterized by reddish-brown lateritic soils. None of the soils on the glacial deposits, which probably are all noncalcic Brown Forest soils, are as red, thick, or clayey as the lateritic soils in the adjacent region.

GLACIAL SEQUENCE

Glacial drift in the area studied is subdivided into four units principally on the basis of weathering profiles and moraine morphology. From oldest to youngest these units are referred to as pre-Tahoe drift, Tahoe Drift, and Tioga Drift; in addition, moraines that were formed in late Tioga time are distinguished as a separate unit and are referred to as moraines of late Tioga age. The drift of the last major glaciation can be correlated with some confidence with the Tioga Drift of the Sierra Nevada, but drift called Tahoe in this report may include deposits that are correlative with the Mono Basin Drift of the Sierra Nevada, as well as Tahoe; thus, Tahoe is used in the sense of drift which is older than Tioga but which seems to be younger than the last major interglaciation. The pre-Tahoe drift of this report is thought to be older than the last major interglaciation.

Weathering profiles constitute the principal evidence of the last major interglaciation, on which part of this subdivision is based. The Tahoe and Tioga tills bear relatively immature soils that lack a well-defined and conspicuous zone of clay enrichment (B horizon). Weathered rinds on stones of intermediate and basic composition are no more than 2 mm thick in Tahoe till and are commonly absent in soils on till of both ages. By comparison with the glacial chronologies of other regions (see Birkeland and others, 1971, and references therein), the time represented by the development of the post-Tioga soil probably is between 10,000 and 15,000 years, and of the post-Tahoe soil between 30,000 and 40,000 years. The soil developed on the oldest part of the Tahoe till recognized in the Lassen Peak area is not greatly dissimilar to that on the youngest part of the Tahoe. In contrast, the extent of clay weathering, depth of oxidation, and oxidized colors all suggest that soils on pre-Tahoe till represent a weathering interval of great duration. It seems likely that these pre-Tahoe soils were formed during one or more major interglaciations whose lengths were probably at least 100,000 years.

The relative age of a soil in the western part of Lassen Volcanic National Park can be approximated from the hue of the oxidized zone. None of the soils on glacial deposits are as red as the lateritic soils on volcanic rocks west of the park, in which hues of 10*R* or 2.5*YR* are typical (color notations are those of the Munsell system (Munsell Color Co., 1954)). Oxidized zones in glacial deposits of pre-Tahoe age have hues as red as 5*YR*, and the hues of soils on the Tahoe and Tioga tills are typically 7.5*YR* and 10*YR*, respectively. These color differences are thought to be due principally to weathering processes and not to lithologic differences in parent materials.

PRE-TIOGA GLACIATIONS

Pre-Tahoe drift

Glacial drift in which there has been extensive weathering and in which the original morphology of moraines has been very extensively modified is here called pre-Tahoe drift. Soils developed on pre-Tahoe till typically have a well-developed clayey B horizon, and stones in the till generally are extensively weathered to clay. The oxidized zone in pre-Tahoe till extends to depths of more than 15 feet. The moist color of the oxidized zone in till is commonly reddish brown (5*YR* 4/4) to yellowish red (5*YR* 4/6) or reddish yellow (7.5*YR* 6/8). Most small pebbles can be easily cut through with a pick mattock at depths of as much as 10 feet, and rock granules streak and smear out on the face of the cut. Unweathered till of pre-Tahoe age was not seen.

The most deeply weathered pre-Tahoe till that was recognized underlies a lava flow in a roadcut along State Highway 36 about 3 miles northeast of Mineral (loc. W, fig. 1). Most cobbles and boulders of andesite are weathered to clay throughout the exposed thickness of the till, which is about 8 feet. The lava flow is shown as part of the Brokeoff Andesite on Williams' (1932) geologic map of the Lassen Volcanic National Park area.

Pre-Tahoe till rarely displays any morainal topography, although broad smooth till ridges in some places probably are lateral moraines that have been greatly modified by erosional processes. Such a moraine lies on the north side of Digger Creek 6 miles west of Brokeoff Mountain (loc. D, fig. 1).

Pre-Tahoe till which has been buried by younger unconsolidated deposits crops out in the banks of Manzanita Creek 0.3 mile west of Lassen Volcanic National Park (loc. M, fig. 1). The dark-yellowish-brown clayey till contains cobbles and boulders of volcanic rock which have clayey weathering rinds as thick as 4 inches. The till is overlain by a compact, gray, unweathered, lithic sand that is as much as 4 feet thick. The sand is horizontally bedded and locally crossbedded, and it dips a few degrees westward. It may be the deposit of an ash cloud which accompanied a hot block-and-ash flow. The sand is overlain by a pumice-flow deposit containing charcoal which is more than 32,000 years old (radiocarbon sample W-2259, Meyer Rubin, written commun., 1969).

Pre-Tahoe outwash sand and gravel deposits which are partly weathered to clay were noted at several places, but are not shown on figure 1. The most widespread deposits recognized are in the area south of Bailey Creek and west of the outer limit of the pre-Tahoe till. Other deposits are present in the Mill Creek valley downstream from the community of Mill Creek, and on the east side of the Gurnsey Creek valley at Childs Meadows and at Deer Creek Meadows (index map, fig. 1).

A large pre-Tahoe glacier lobe derived from the Brokeoff icefields moved northwestward down the Bailey Creek valley. It is represented by drift near Viola, at a distance of about 8 miles from Brokeoff Mountain. Another glacier lobe, represented by the outcrop of till along Manzanita Creek west of the park, may have been of similar size; however, younger volcanic rocks have obscured the original extent of the drift there and in the area farther east.

Although scattered outcrops of pre-Tahoe drift were recognized southwest and south of the western part of the park, not enough were found to permit reconstruction of glacier lobes in those sectors. The valley of Mill Creek, which heads within the deeply eroded central part of old Brokeoff Volcano, contains pre-Tahoe drift between the community of Mill Creek and a point 4.5 miles farther downvalley. Some of this drift, however, may have been deposited by local glaciers that originated on Turner Mountain (alt 6,893 ft) and adjacent high ridges 1–2 miles west of the Mill Creek valley, rather than by ice from the Brokeoff Volcano. The valley of Gurnsey Creek contains scattered outcrops of pre-Tahoe till at least as far south as Deer Creek Meadows, which is 7 miles southeast of Childs Meadows (fig. 1). Although the till at Deer Creek Meadows probably was deposited by northward-moving glaciers that originated on the north flank of Butt Mountain and along the ridge to the west (index map fig. 1), till northwest of Deer Creek Meadows may have been formed by a glacier heading in the icecap to the north.

Tahoe Drift

Glacial drift which is substantially less weathered than pre-Tahoe drift but which is somewhat more weathered than Tioga Drift is here included in the Tahoe Drift. Some Tahoe till has a zone 1–2 feet below the ground surface which is slightly to moderately plastic and which is interpreted to be a slight textural B soil horizon, but the soil lacks the extensive alteration to clay that characterizes pre-Tahoe till. Stones of andesite or basalt in the upper foot of the soil may have weathered rinds as much as 2 mm thick. Oxidation extends to depths ranging from about 3 to 8 feet, but depths of 4 to 6 feet are most common. The oxidized till is generally strong brown (7.5*YR* 5/6) or dark brown (7.5*YR* 4/4), whereas the unoxidized till is gray.

The range in degree of weathering in the Tahoe till of the Lassen region suggests that it includes deposits of more than one age. For example, till in some moraines is oxidized to a depth of only 3–4 feet, and stones in the oxidized zone have weathered rinds no more than 1 mm thick. The till of adjacent moraines in the same general area, which are here included in the Tahoe Drift, may have oxidation depths of 7–8 feet, and stones near the ground surface may have rinds as much as 2 mm thick.

Tahoe till crops out beneath Tioga till in a streambank on the west side of Lost Creek 1 mile east of Lost Creek Campground (loc. L, fig. 1). The Tahoe till is more than 7 feet thick and is oxidized to a depth of about 6 feet; it is directly overlain by unoxidized Tioga till. This buried oxidized zone is thicker than that on some Tahoe till that has been exposed at the ground surface since it was deposited. The buried till presumably represents a relatively old part of the Tahoe Drift, and it may, in fact, be of Mono Basin age.

The only chronological control on the age of the Tahoe Drift in the Lassen Volcanic National Park area is from charcoal more than 32,000 years old which was obtained from the pumice-flow deposit described previously. The compact unweathered gray sand beneath the pumice-flow deposit overlies Tahoe till near the west edge of Manzanita Lake. Outcrops of the sand and till can be seen in a gully which was once an outlet for the lake and which is located just beyond the southwest edge of the lake (loc. T, fig. 1). Bouldery till exposed in the walls of this gully is oxidized to a depth of 4–6 feet. The till west of the lake forms a west-sloping ramp which probably is the front of a Tahoe end moraine. Just south of the southwest arm of the lake there is a low lateral moraine of Tahoe till whose upvalley end seems to be overlapped by a dacite lava flow. The flow was mapped as the "dacite flow of the Manzanita Lake area" by Macdonald (1963) and assigned an age of late Pleistocene. The flow is older than the Tioga Glaciation.

The oxidized zone on the Tahoe till exposed in the gully evidently was formed prior to 32,000 years ago, but it seems to be as thick as oxidized zones on some Tahoe till that has been exposed to weathering processes since it was deposited. The buried oxidized zone suggests that the till in the gully outcrop is of either early Tahoe or Mono Basin age and thus is at least 70,000 years old.

Moraines of Tahoe age are well preserved but have been substantially smoothed by erosional processes. Drainage on moraines is generally well integrated, and closed depressions are rare. The basin of Dry Lake, which is a marsh most of the year, is the only lake basin recognized on the Tahoe Drift.

Prominent lateral moraines of Tahoe age are present in the valleys of Bailey and Digger Creeks west of the park. Tahoe till, however, extends considerably farther west; thus, either the lateral moraines were formed during retreatal stands of the Tahoe glaciers or they represent a different part of the Tahoe Glaciation than does the till in front of them.

Glaciers of Tahoe age were somewhat smaller than some of the pre-Tahoe glaciers but were substantially larger than the Tioga glaciers. The approximate lowest altitudes, in feet, reached by glaciers in some valleys are shown for comparison as follows:

Valley	*Pre-Tahoe glaciers*	*Tahoe glaciers*	*Tioga glaciers*
North Fork Bailey Creek	4,400	4,600	5,700
South Fork Bailey Creek	.....	.....	5,600
Digger Creek	4,000(?)	4,700	5,500
South Fork Digger Creek	.....	.....	5,700
Martin Creek	.....	4,900	5,400(?)
Nanny Creek	.....	4,900	5,600(?)
Mill Creek–Childs Meadows	.....	4,850	.....
Mill Creek	.....	<4,400(?)	4,900
Lost Creek	.....	<5,500	5,600

The similarity in lowest altitudes reached by Tahoe glaciers in valleys on the west and south sides of the park suggests that a general scarcity of Tahoe Drift at comparable altitudes on the north side of the park is due, in part, to burial of once-extensive drift by younger lava flows. This suggestion is supported by the similarity in the lowest altitudes reached by Tioga ice north, west, and south of the park. Along Lost Creek, for example, Tahoe till is found downvalley to an altitude of about 5,500 feet, and it is bordered on the north by a pyroxene andesite lava flow that does not seem to have been glaciated, although the same flow is locally overlain by Tioga till at higher altitudes farther to the southeast. The lava flow was assigned an early Pleistocene age by Macdonald (1963, 1964). Its relations to glacial deposits suggest that the flow is of post-Tahoe age.

Tahoe outwash gravel can be recognized by a lack of the deeply weathered stones that characterize pre-Tahoe deposits and by the presence of thin rinds on stones, which are absent on stones in gravel of Tioga age. Tahoe outwash deposits were noted in the area north of Bailey Creek west of Viola, and beneath Battle Creek Meadows at Mineral. An outwash valley train of Tahoe age extends down the valley of Gurnsey Creek from the terminal moraine at Childs Meadows at least as far as Deer Creek Meadows, south of the area mapped.

TIOGA GLACIATION

The Tioga Glaciation is represented in Lassen Volcanic National Park by deposits of at least two distinct glacial episodes. During the earlier episode widespread Tioga Drift was deposited by ice originating in an icecap glacier. During the later episode small cirque glaciers developed at altitudes above 8,000 feet; the deposits that resulted are referred to here as moraines of late Tioga age. The Lassen Peak dome evidently was erupted between the two glacial episodes. The soils on till formed during each episode are similar; hence, both tills are assigned to the Tioga Glaciation.

Tioga Drift

Tioga Drift consists of deposits of till and outwash sand and gravel which were formed during the last major glaciation of the Lassen Peak region. A shallow zone of oxidation, which is rarely more than 2.5 feet deep, and a lack of weathered rinds on stones distinguish Tioga till from Tahoe till. Oxidized Tioga till is dark yellowish brown (10*YR* 4/4) to pale brown (10*YR* 6/3). Soils developed on the till do not have a zone of clay enrichment that is discernible in the field. Moraines are sharp crested and well defined and have constructional topography. Closed depressions are common on the Tioga till, and lakes and ponds are abundant in areas covered by Tioga glaciers. Many lakes are in basins excavated in rock by ice (for example, Lake Helen and Emerald Lake), but a few are dammed by moraines (for example, Summit Lake, which is about 2 miles northeast of Reading Peak).

Tioga till is especially well exposed in a cut through a lateral moraine along the Lassen Park Road 1 mile southeast of Lost Creek Campground (loc. C, fig. 1). The till is compact and gray and is oxidized to a depth of 2.5 feet. The moraine merges northward with a terminal moraine complex. Tioga recessional end moraines are present in the Lost Creek valley near the highway bridge across Lost Creek and a short distance south of Hot Rock.

The Hat Creek glacier of Tioga age split into two small lobes near its terminus. A massive outwash fan of very coarse gravel which lies north of the terminal moraines is probably chiefly of Tioga age, but it may include some deposits of Tahoe age.

A Tioga terminal moraine was not recognized in the Manzanita Creek valley, and if one is present it probably lies beneath the rockfall-avalanche deposits of the Chaos Jumbles, which are only a few centuries old. The most conspicuous lateral moraine in the valley is a long north-sloping ridge which holds Manzanita Creek along the east valley wall in a position several hundred feet higher than the central and lowest part of the valley. Inconspicuous recessional moraines curve out from this lateral moraine into the central part of the valley southeast of Manzanita Lake, and other recessional moraines are present farther south in the valley.

Although lobes extended several miles beyond the outer margin of the Tioga icecap glacier on the north, ice lobes were short on the south and west sides. Closely spaced recessional end moraines parallel the outer limit of Tioga ice on the plateaus adjacent to Mill Creek and on the upland just east of Martin Creek.

Tioga snowline

The regional (climatic) snowline during a glacial episode can be approximated from the average altitude of cirque floors formed during that episode. The floors of west- and north-west-facing cirques at Turner Mountain, about 11 miles south of the summit of Brokeoff Mountain, are at an altitude of about 6,200 feet. Although I did not visit that area, aerial photographs of the Turner Mountain area reveal several small lakes in the cirques as well as moraines whose morphology resembles that of Tioga moraines elsewere. Cirque floors near Lassen Peak indicate a snowline that probably was at an altitude of about 7,000 feet. Table Mountain, 7 miles north of the summit of Brokeoff, evidently has not been glaciated, despite a sizable summit area between altitudes of 6,500 and 6,900 feet. Badger Mountain, 10 miles northeast of Brokeoff, also seems to be unglaciated, although it has an extensive area at an altitude of nearly 7,000 feet. Prospect Peak, which has a summit altitude of about 8,300 feet, probably was not glaciated in Tioga time. Thus, the Tioga snowline in the Lassen Peak region evidently rose northeastward at a gradient of at least 70 feet per mile and probably was above 8,300 feet at a distance of 15 miles northeast of Brokeoff Volcano.

The eastward rise of the snowline near Lassen Peak is similar to that inferred for other areas in northern California which have a roughly similar climate today (table 1). On the east side of the Sierra Nevada near Truckee, 100 miles southeast of Lassen Volcanic National Park, Birkeland (1961) found that the climatic snowline was at an altitude of 8,200–8,400 feet during Tioga time. The snowline rose eastward from the Sierra Nevada to the Carson Range of western Nevada on a gradient of 72 feet per mile. Eighty miles west-northwest of the park the average altitude of cirque floors in the Trinity Alps is about 6,500 feet (Sharp, 1960, p. 338), and a map showing contours on climatic firn limits in northern California suggests that the snowline rose southeastward across the Trinity Alps on a gradient of 20–25 feet per mile (Wahrhaftig and Birman, 1965, p. 309).

Table 1.—*Climatological data from the Trinity Alps, Lassen Volcanic National Park, and Truckee area, California*
[Data from U.S. Environmental Science Services Administration (1959)]

Location	Normal annual precipitation (inches)	Mean temperatures (°F) January Max	January Min	July Max	July Min
Trinity Alps	40–>44	44–48	24–28	>92–<96	>44–<48
Lassen Volcanic National Park (western part).	>48–<56	40–44	16–20	>80–<84	44
Truckee area	28–48	36–40	8–12	76–80	40

Eruption of Lassen Peak dome

The Lassen Peak dome was probably erupted during a late phase of the Tioga Glaciation, after the Brokeoff icecap had largely or wholly disappeared. The absence of extensive thick ice after the dome was erupted is demonstrated by the extensive taluses of the dome rock which bury the flanks of Lassen Peak; Williams (1932, p. 316) attributed these taluses to "fracturing of the dome during its actual emplacement." If Williams is correct, the presence of the voluminous taluses surely indicates that Lassen postdates the Brokeoff icecap of

Tioga age, because otherwise the loose rock would have been carried away by the glacier. In addition, the trends of some glacial striations on surfaces of pre-Lassen dacite around the base of Lassen also show that the dome postdates the Brokeoff icecap. Northwest-trending striations at the southwest base of Lassen Peak, just north of Eagle Peak, are especially significant, because if Lassen had been present when they were formed, glaciers descending the flank of the dome would have produced west- or southwest-trending striations at this locality. The flanks of the dome are, indeed, indented by shallow cirques, but I believe these to have been formed during the brief glacial episode which postdated the disappearance of the Tioga icecap.

Moraines of late Tioga age

Small moraines located in high cirques in the western part of Lassen Volcanic National Park represent an episode of glacier growth which followed the eruption of the Lassen Peak dome. Such a moraine on the north side of Brokeoff Mountain extends from an altitude of about 8,300 feet down to at least 7,800 feet. Others, on Vulcans Castle, Reading and Loomis Peaks, Mount Diller, and elsewhere (fig. 1), lie between 8,100 and 8,900 feet. Till in the moraines on the north side of Reading Peak (fig. 2) is oxidized to a depth of at least 2 feet and is overlain by pumice erupted from vents at the site of the Choas Crags about 1,200 years ago.

Similar high moraines lie at the downslope margins of shallow cirques on the southeast flank of Lassen Peak at about 8,900 feet (fig. 3), on the south flank at about 9,100 feet, and on the southwest flank at about 8,800 feet. Till in the moraines is oxidized yellowish brown (10*YR* 5/6) to a depth of 2–2.5 feet, and the moraines are overlain by the 1,200-year-old pumice.

The largest reentrant on the flanks of Lassen Peak dome lies on the northeast side (fig. 4). The reentrant is shallow and does not have the form of a typical cirque, but nevertheless I believe it to be primarily the result of glacial erosion and to have formed during the glacial episode represented by the high cirque moraines elsewhere in the area. Downslope from the reentrant, lateral moraines along Lost Creek (figs. 1 and 4) record a Lassen Peak glacier which, at its maximum extent, was about three-quarters of a mile wide and nearly 3 miles long. The lateral moraines lead down to an end moraine at an altitude of about 6,300 feet near Old Boundary Spring. Till in the end moraine at the west edge of the Devastated Area (loc. A, fig. 1) is oxidized to a depth of about 2 feet.

Alluvium and mudflows of late Tioga age

A thick sequence of mudflows interbedded with alluvial deposits fills a northeast-trending valley (loc. N, fig. 1)

Figure 2.—Moraines of late Tioga age at an altitude of about 8,200 feet on the north side of Reading Peak. View is to the north. Figure of man (circled) on moraine crest at left shows scale.

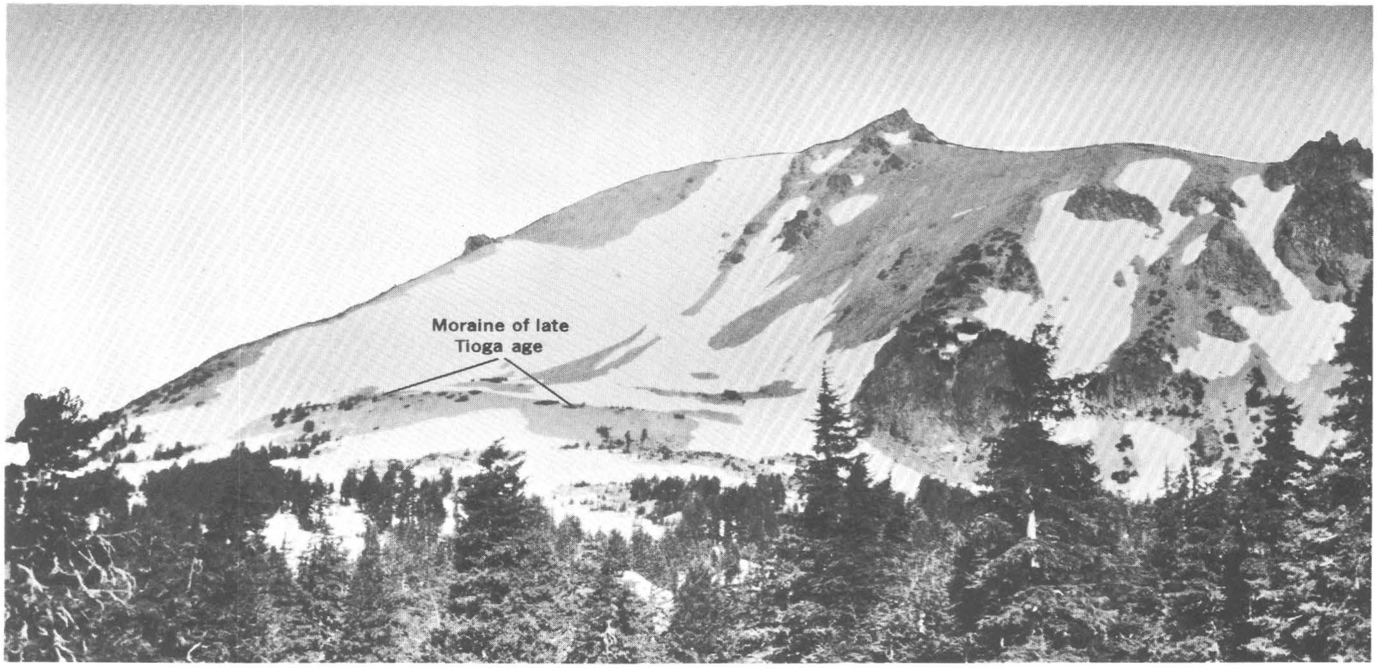


Figure 3.—End moraine of late Tioga age at an altitude of about 8,900 feet on the southeast side of Lassen Peak.

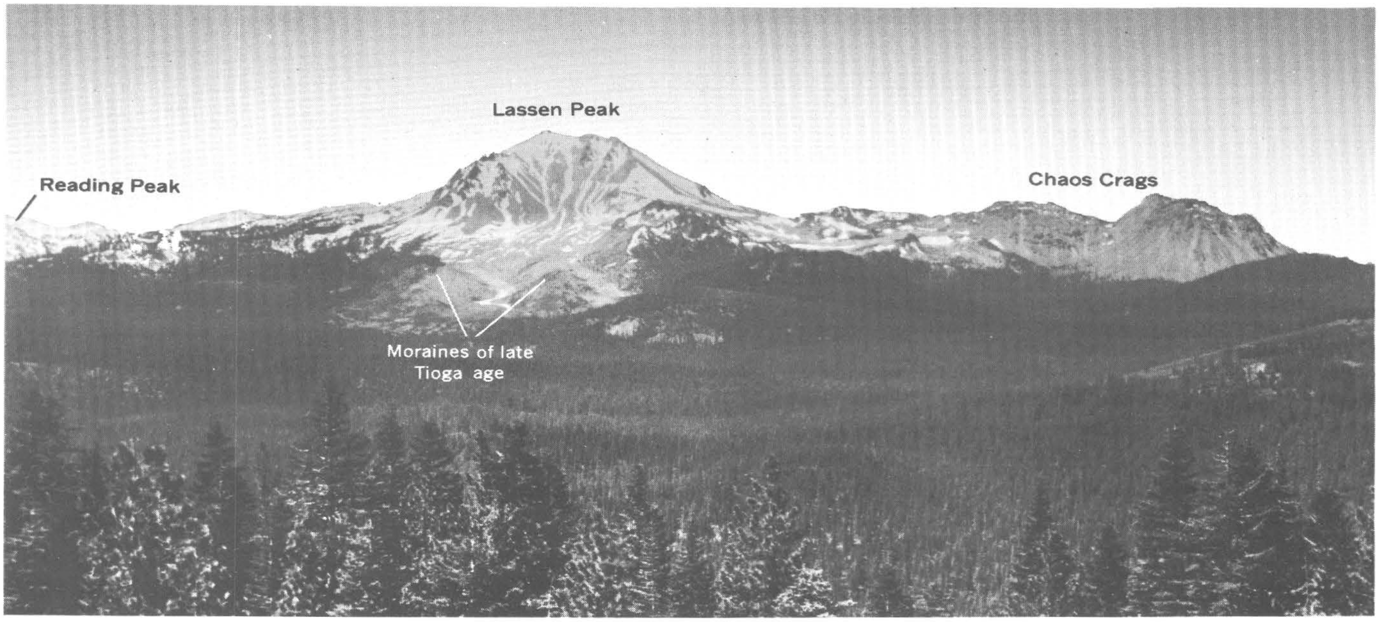


Figure 4.—Lateral moraines of late Tioga age flanking Lost Creek on the northeast side of Lassen Peak.

between lateral moraines of late Tioga age along Lost Creek. In places the fill deposits overlap and bury the moraines. The deposits a·e continuously exposed in gully walls 40–50 feet high, and their total thickness may be substantially greater than this amount. No other valley that heads on Lassen Peak contains a similar fill.

The fill deposits along Lost Creek consist mostly of coarse lenticular mudflows 5 feet thick or less, although a few are as much as 15 feet thick. The mudflow deposits contain angular to subround fragments of pink and gray dacite, some of which are as large as 6 feet in diameter, in a matrix of gray and reddish-gray sand and granule gravel. Beds of fluvial sand and gravel interbedded with the mudflows are a few inches to several feet thick. The interbedded mudflows and alluvium dip 5°–10° NE., parallel to the trend of Lost Creek in the Devastated Area. Oxidation at the top of the sequence extends to an average depth of about 2 feet, and some beds of relatively high permeability within the sequence are also oxidized.

The interbedded mudflows and alluvium have not been radiometrically dated, but correlation with other deposits farther downvalley suggests an age limit. A sand and gravel deposit exposed in the west bank of Lost Creek (loc. X, fig. 1) may be correlative with the fill in the Devastated Area. The sand and gravel underlies, and is thus older than, a bed of peat, the base of which has been radiocarbon dated at about 5,400 years (sample W-2231, Meyer Rubin, written commun., 1969). The apparent absence of mudflow deposits downvalley from the Devastated Area may be the result of individual mudflows terminating within a mile or two of their source.

The depth of oxidation on the mudflows and alluvium is similar to that on the adjacent lateral moraines and on the high cirque moraines; all these deposits are therefore thought to be of about the same age. The mudflows and alluvium may have been formed when rock debris was moved downslope by glacial melt water during retreat of the late Tioga glacier that formed on the northeast flank of Lassen Peak.

CORRELATIONS

Recent detailed studies of glacial deposits in northern California include those of Sharp (1960) in the Trinity Alps and Birkeland (1964) in the Truckee area. Correlations with both areas can be suggested on the basis of soil development and moraine morphology. Some glacial drift in the Lassen Peak area may be correlative with deposits recognized so far only in the Bridgeport and Mono Lake areas of California, which are 195 and 220 miles southeast of Lassen Peak, respectively.

According to Sharp, the Pleistocene stratigraphic sequence in the Trinity Alps includes three drifts of Wisconsin age and one or more drifts of pre-Wisconsin age (table 2). Pre-Wisconsin (Swift Creek) till consisting of serpentine-rich rock

Table 2.—*Correlation chart*

Lassen Peak area (this report)	Trinity Alps (Sharp, 1960)	Truckee area (Birkeland, 1964)	Mono Lake area (Sharp and Birman, 1963)
Moraines of late Tioga age		Frog Lake Till	
Tioga Drift	Morris Meadow moraines	Tioga Till	Tioga moraines Tenaya moraines
Tahoe Drift	Rush Creek moraines Alpine Lake moraines(?)	Tahoe Till	Tahoe moraines Mono Basin moraines
Pre-Tahoe drift	Swift Creek glacial deposits	Donner Lake Till Hobart Till	 Sherwin Till

debris has a deep-red, clay-rich soil, and the oldest serpentine-bearing till thought by Sharp to be of Wisconsin age (Alpine Lake) has a brownish-red clayey soil. Soils on the younger Wisconsin (Rush Creek and Morris Meadows) tills were not described by Sharp, and he stated that he did not find soils to be widely useful in differentiating the glacial deposits. The morphology of the Morris Meadows moraines described by Sharp suggests that they correlate with the Tioga moraines of the Lassen Peak area, as does also the fact that the Morris Meadows represents the last major glaciation of the Trinity Alps. The Rush Creek moraines represent the next older Trinity Alps glaciation, which suggests that they are of Tahoe age. Their subdued morainal morphology is consistent with this correlation. Sharp's Swift Creek glacial deposits are clearly of pre-Tahoe age, and the color and clayey nature of the Alpine Lake moraines suggest that they are at least as old as the oldest Tahoe till of the Lassen Peak area; possibly they are of Mono Basin age.

The sequence near Truckee described by Birkeland (1964) includes the Tioga and Tahoe tills which are separated from the Donner Lake and Hobart tills by one or more major interglaciations. According to Birkeland the soil on the Donner Lake till is 6–7 feet thick, includes a well-developed B horizon, and is brown or strong brown. In contrast, soils on the Tahoe and Tioga tills are similar to one another in that textural B horizons are lacking and hues in the oxidized zones are more yellowish than in the older tills. According to Birkeland (1964) the Tahoe till seems to represent a single major glacial advance. An expansion or rebirth of glaciers in cirques during late Tioga time resulted in the formation of the Frog Lake till at altitudes between 7,400 and 7,900 feet. This till may be of the same age as the moraines of late Tioga age at Lassen.

The parts of the Tahoe Drift of the Lassen Peak area that are somewhat more deeply weathered than others may be correlative with the drift of the Mono Basin Glaciation which has been recognized at the east base of the Sierra Nevada 100 miles southeast of Truckee (Sharp and Birman, 1963). Sharp and Birman regarded the Mono Basin as a glaciation intermediate in age between the Sherwin and Tahoe and tentatively correlated it with the Illinoian Glaciation of the central United States. According to Smith (1968, p. 306–307), however, "* * * the deposits of the Mono Basin Glaciation of Sharp and Birman (1963) are correlated with the first half of the early Wisconsin deposits in Searles Lake, and the Tahoe Glaciation correlated with the second half of those deposits." Smith inferred that the Mono Basin Glaciation extended from about 130,000 to about 70,000 years ago. Birkeland and Janda (1971, table 1) have also suggested, from morphological and soils evidence, that the Mono Basin deposits are closer in age to the Tahoe till than to the Donner Lake till.

Several authors (Morrison, 1965, p. 272; Smith 1968, p. 307; Birkeland and Janda, 1971, p. 2498) suggest that the Tenaya (table 2) represents an early phase of the Tioga

Glaciation, rather than "a separate and distinct glacial phase" as indicated by Sharp and Birman (1963, p. 1080). If drift of Tenaya age is present in the Lassen Peak area, it probably has been included in the Tioga Drift on figure 1.

The pre-Tahoe drift of the Lassen Peak area cannot yet be correlated with assurance with any one of the old tills of other areas in northern California.

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