Geologic Report

SHERWIN CANYON AREA, SIERRA NEVADA, CALIFORNIA

Robert R. Curry
1972

Prepared for the United States
Forest Service

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GEOLOGIC REPORT

Sherwin Canyon Area, Sierra Nevada, California

by

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INTRODUCTION

This study covers the environmental geology of the area delimited in the map appended to the U.S. Forest Service contract requisition number 4-72-497; order number 1647-R5-72, issued February 22, 1972, for Inyo National Forest. The area in question is located along the eastern escarpment of the Sierra Nevada approximately 1 mile south of the town of Mammoth Lakes, California, and bounded on the east by Sherwin Canyon and on the west by the crest of Gold Mountain above Mammoth Creek. The study is based upon published information and field work conducted by the author. Field investigations of this site have been conducted predominantly in the years 1964 through 1971, although some work upon which this report is based was done by the author in approximately 1945.

PHYSIOGRAPHY AND GENERAL SITE DESCRIPTION

The Sherwin Creek site, as it has been called by the U.S. Forest Service, encompasses the major escarpment of the eastern side of the Sierra Nevada where it bounds the Long Valley volcano-tectonic depression in east-central California. This portion of the eastern escarpment of the Sierra Nevada differs from those to the north and south along most of the 600 km length of the range in that it trends east-west along the southern margin of a semicircular physiographic re-entrant into the otherwise linear fault-bounded Sierran escarpment. The re-entrant is called the Mammoth Embayment and is the locus of volcanic and tectonic activity wherein that portion of the area north and east of the escarpment represents a collapse caldera filled with Quaternary volcanic extrusive rocks. Mammoth Mountain (11,053 feet), located about 5 km west of the Sherwin Creek site, is a recent composite volcano lying at the extreme western margin of the Long Valley caldera where it intersects the major bounding faults of the Sierran escarpment.

Topographic maps that cover this area include the U.S. Geological Survey's Mt. Morrison Quadrangle, 1953, at a scale of 1:62,500 and the 20-foot contour-interval plane-table map produced by Kesseli in his 1941 University of California Press paper (1941b). Place names within the study area used in this report have been taken from these two sources as well as the work of this author (Curry, 1966, 1968a, 1968b, 1969, 1971). The map accompanying the report by Kesseli (op cit) is the most detailed topographic map available for the lower portion of this region. Nearly the entire area is included in the field of U.S.G.S. aerial photo EMG-7-149 of 9-10-63 and is bounded by photos 7-150 and 7-148 for stereographic coverage.

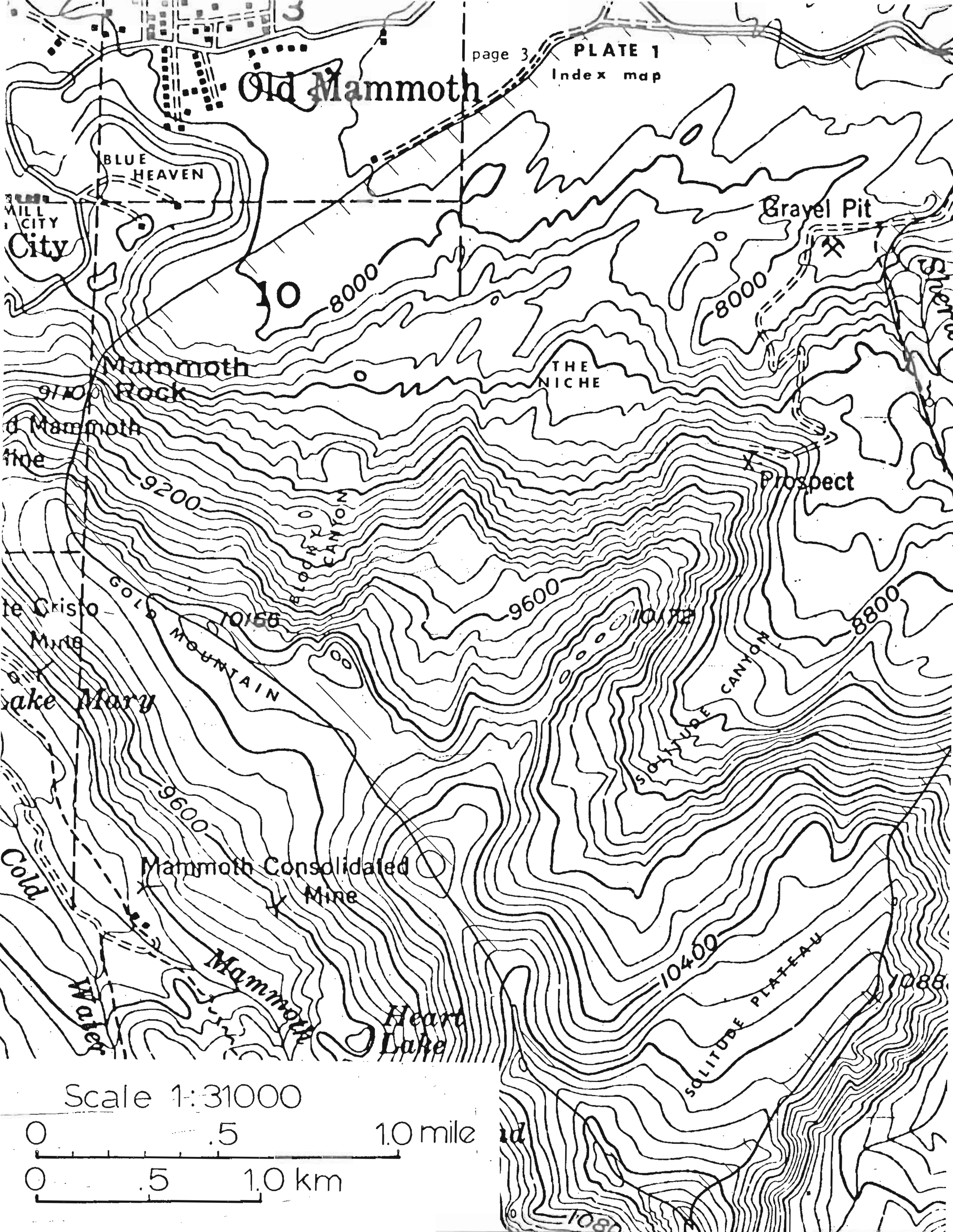
As may be seen from the topographic map (Plate 1), the lower portions of the study region, between elevations of approximately 7760 feet and 8400 feet are largely a series of glacial and glaciofluvial deposits filling downfaulted valleys north of the main escarpment. The escarpment, a probable fault-line scarp, is an erosionally modified bedrock mountain front with about 2000 feet of surface relief and approximately 2000 to 4000 feet minimum additional subsurface relief, now buried by volcanic and glacial deposits (Pakiser, 1964, Pl. 4). The upland areas are residual portions of a composite Tertiary erosion surface, of probable Eocene through Pliocene age with local relief within the study area of an additional 2000 feet. The highest elevation within the delimited study area (see Plate 1) is 11,600 feet for a total relief in the study area of 3840 feet.

The lowland glacial and volcanic terrane north of the escarpment consists of a series of hummocky and undulating morainal ridges with areas of marshy closed depressions and stagnant ice topography (see section on Quaternary deposits and glacial history). The escarpment itself is a partly forested rubble, scree, talus, and rock-glacier covered mountain front into which three cirque-headed canyons have been eroded. These are, from west to east, Blocky Canyon, The Niche, and Solitude Canyon. Total lateral erosion of the presumed original fault-bounded escarpment, has been on the order of 1.5 km (1 mile). The upland surface, termed the Solitude Plateau, is a blocky rubble covered erosion surface with a shallow to deep frost-rived mantle (see section on Surficial Geology). The surface has been deformed since its formation from one with an original paleo-slope to the SSW to one that now trends downward toward the NW in the direction of Mammoth Mountain.

STRUCTURAL GEOLOGY & GEOLOGIC HISTORY

The present geologic landscape and landforms of the region have evolved in the following way: The Sierra Nevada became a distinct uplifted mountain range by the end of the period of intrusion of granitic rocks in the late Cretaceous and early Tertiary, approximately 70 million years ago. At this time, the material comprising today's major summit peaks of the Sherwin Creek impact site were probably at about sea level buried beneath 2000 to 4000 feet of uplifted metamorphic rocks. Further uplift continued for at least about 60 million years, into the Pliocene Epoch. During the latter part of this time, perhaps 10-14 million years ago, the actual rocks exposed near the higher areas of the Solitude Plateau surface became exposed through slow erosion of the overlying bedrock by fluvial (stream) erosion. Throughout this bulk of the Tertiary time, the Sierra was a gently rolling uptilted mountain block, with the highest local elevations probably being in the area now occupied by the Long Valley depression. Streams drained westward and southwestward across the Solitude Plateau from highlands that have now been downdropped and buried in the Long Valley Caldera.

Beginning in the Pliocene, the great gentle arch of the Sierra Nevada extending from the San Joaquin Valley possibly all the way across the White


page 3
PLATE 1
Index map
Old Mammoth
BLUE HEAVEN
MILL CITY
City
10
8000
Gravel Pit
8000
Mammoth Rock
THE NICHE
Prospect
9200
BLOODY CANYON
GOLD MOUNTAIN
9600
8800
SOLITUDE CANYON
9600
Mammoth Consolidated Mine
Mine
Heart Lake
10400
SOLITUDE PLATEAU
Scale 1: 31000
0 .5 1.0 mile
0 .5 1.0 km

Mountains and into Nevada began to break up into a series of mostly fault-bounded linear depressions. Owens Valley began to form, as did the depression now occupied by Mono Lake and Long Valley. The eastern margin of this down-warping and faulting is not everywhere well defined but the western margin now constitutes the major eastern Sierran escarpment and is still active today. By approximately 3 million years ago, the escarpment that we see today south of the town of Mammoth Lakes had begun to form. Within the site and nearby, to the north along the Deadman area, and to the east near McGee Mountain, volcanic rocks began extruding from the fault zone along the escarpment. Streams draining westward to the San Joaquin Valley were cut off by the faulting and new drainage patterns became established with flow to the east and north. The steeper became the escarpment, the greater the erosive energy of the small streams draining the highland areas, and the greater the resultant modification of the fault-line escarpment.

Averaged over the last 3 million years, this downfaulting of the eastern side of the Sierra Nevada has occurred within the Sherwin Canyon area at rates of about 1-1.5 feet per 1000 years. All available evidence suggests that this faulting has been more or less continuous, and that the faulting along the major range-front fault today in this site continues today at the same rate (Curry, 1968b).

During the earlier Pleistocene, about 1.5 million years ago, the down-dropping Long Valley fault block began to be the site of considerable volcanic activity which culminated 700,000 years ago with the outpouring of the extensive Bishop Tuff and the isolation and collapse of the separate Long Valley caldera. Then quieter basalt eruptions began to flow from fissures beneath the present site of Mammoth Mountain, flowing into both the Middle Fork of the San Joaquin and into the Mammoth Creek Valley, depositing up to several hundred feet of olivine basalt along the northern limits of the study site between 630,000 and 192,000 years ago. In the past 400,000 years, Mammoth Mountain has erupted in a series of quartz latite flows interspersed with explosive activity and pumice eruptions. Repeated glacial episodes have modified the canyons of the escarpment portion of the study site and glaciers have deposited debris in the north portion of the study site. These deposits are intermixed with those of the Mammoth Creek basalts and the Mammoth Mountain quartz latites.

Warping of the Solitude Plateau surface has probably been going on very slowly for at least 2.7 million years, judging from the elevations of glacial deposits of various ages along the flanks of Gold Mountain. As this warping progressed, erosion of the eastern escarpment in the vicinity of the town of Old Mammoth eventually beheaded Mammoth Creek, which had previously flowed into the San Joaquin River, allowing it to take its present course into the Long Valley depression. This stream capture occurred sometime between 2.7 and 700,000 years ago.

More detailed geologic histories of this site are given on page 13-20 of Curry (1971) and page 7x-12x of Curry (1968b). General geologic history is reviewed also by Schumacher, et al, 1959.

One major range-front fault is inferred to extend along the northern margin of the escarpment in this impact study site (Rinehart & Ross, 1964, Pl. 1; Curry, 1971, Pl. 1). This fault is obscured by late Pleistocene glacial deposits and rock glaciers so its exact location is not known. It is probable, based upon its character just east of the study site in Sherwin Canyon, that the fault is in fact a fault zone 100 to 200 meters wide, with basin-side-downward normal motion with a cumulative offset through the zone of 1 foot per 1000 years. I can find no surface expression of activity of this fault within historic (100-year) times. An additional fault in the Paleozoic basement rocks of the site is mapped by Rinehart and Ross (1964, Pl. 1), but it is not active today and not a portion of the present active structural system of the region.

BEDROCK GEOLOGY

The bedrock geology of the Sherwin Canyon impact site has been mapped by Rinehart and Ross (1964) and the map (Plate 2) is derived from their work plus field work by the author. The majority of the area is underlain by the Round Valley Peak granodiorite (Krv), a rather uniform equigranular (1-2 mm grain size) intrusive igneous rock of Cretaceous age. Within the study region, this rock crops out from the vicinity of Mammoth Rock to the highest point on the Solitude Plateau and contains numerous dark-grey fine-grained dioritic inclusions, the largest of which is found near the high point on the interfluve between The Niche and Solitude Canyon and is shown on Plate 2. This granodiorite is very well jointed within the study area. The joint planes delimit nearly equant granitic blocks, ranging in size up to several meters on an edge but dominantly in the range of 0.2 to 1.0 m. The regional joint sets are a near vertical joint set trending north-south and another near east-west set dipping from 80° N to 80° S. A third joint set is subparallel to the Solitude Plateau Tertiary erosion surface and its joint density decreases with depth below that surface such that, at the Plateau surface, tabular joint blocks averaging about 0.2 m thick predominate while at the base of the eastern escarpment the predominant joint block dimension is a 1-2 m cube. The striking joint density in these granitic rocks near the eastern escarpment, together with the orthagonal relationships between the joint sets has created the unique conditions favoring rock-glacier formation throughout the later Pleistocene in Sherwin Canyon.

The Round Valley Peak granodiorite was intruded into the metasedimentary and metavolcanic rocks of Paleozoic and Mesozoic age that are commonly called the Mt. Morrison roof pendant, referring to the fact that they are believed to be remnants of the rocks into which the Sierra Nevada granitic rocks were intruded. This sequence of ancestral rocks, which originally filled basins and low-lying areas at the site of the present Sierra Nevada, consist of a series of Ordovician (500 million years) through Permian (225 million years) sedimentary rocks overlain by Triassic through Jurassic (225-135 million years) volcanic rocks - all of which have been metamorphosed into marbles, slates, hornfels, and quartzitic rocks.

Within the study area, these country rocks generally strike NW and dip to the SW, usually steeply. The oldest unit exposed in the study area is the Pennsylvannian Bright Dot formation, which crops out near Mammoth Rock. Here it is a grey silicous calc-hornfels. Mammoth Rock itself is an example

PLATE 2

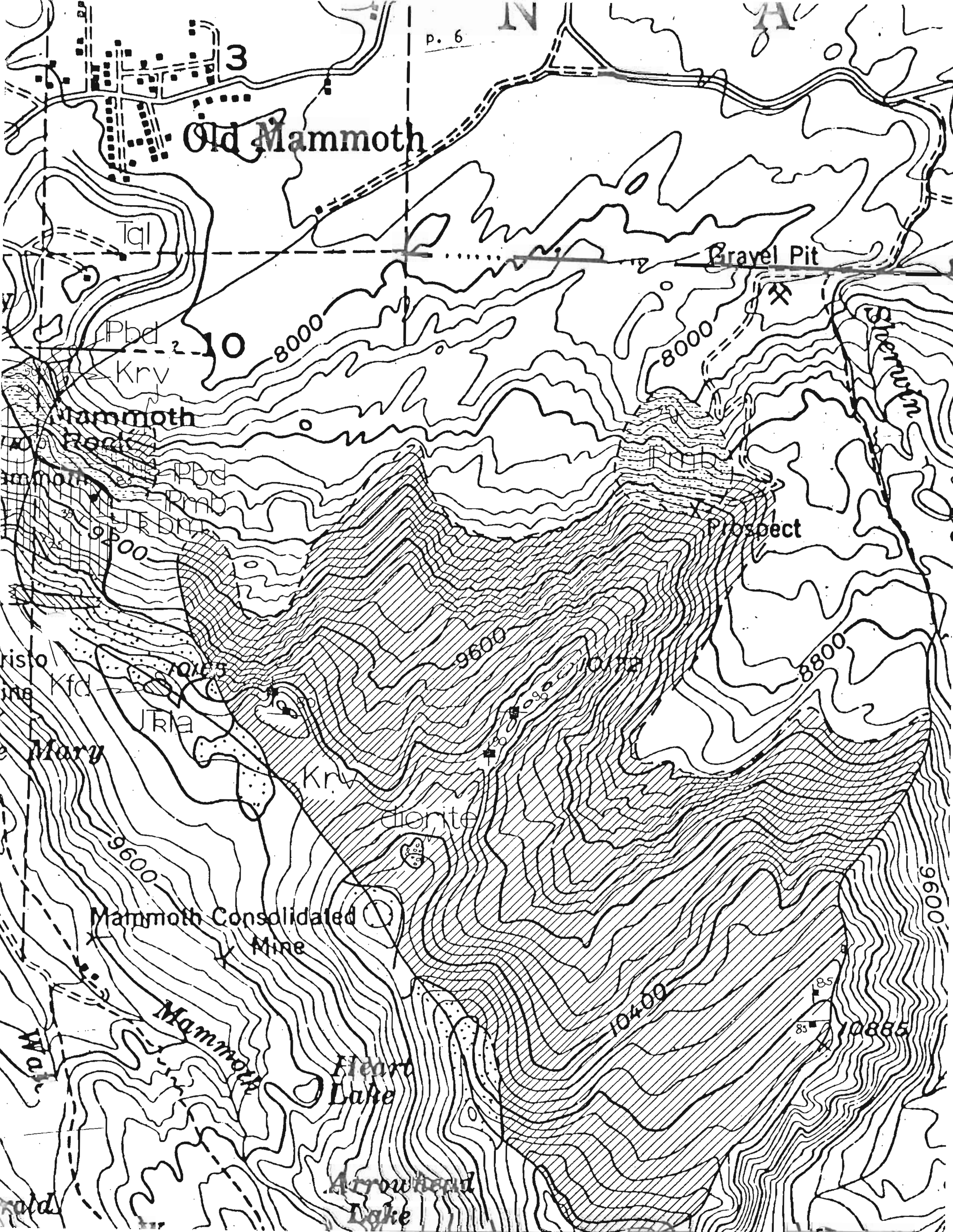
BEDROCK GEOLOGY

- Kfd — Cretaceous felsic dikes and masses
- Krv — Cretaceous Round Valley Peak granodiorite
- JTRla — Jurassic and/or Triassic Latite of Arrowhead Lake. Pyritic hornfels mineralized zone where stippled
- JTRbm — Jurassic and or Triassic Volcanic breccia of Mammoth Rock
- Pmb — Pensylvannian Mt. Baldwin marble
- Pbd — Pensylvannian Bright Dot formation
- Fault with dot on downthrown side. Dashed where approximate, dotted where infered

Scale 1:31000

0 .5 1.0 mile

0 .5 1.0 km



p. 6
3
Old Mammoth
Tql
Gravel Pit
8000
10
Pbd
Krv
Mammoth
Rock
Pbd
Pmb
8000
Pmb
Prospect
Kfd
Jkla
Mary
9600
Krv
diorite
8800
9600
Mammoth Consolidated
Mine
Mammoth
Heart
Lake
10400
10885
9600
Arrowhead
Lake

of the next younger unit, the Mount Baldwin marble. This Pennsylvannian unit is a fine-grained dark-grey crinoid-bearing marble with streaks and nodules of chert and occasional recrystallization, especially near its contact with the granodiorite which intrudes it. Another outlier of this marble bedrock unit is exposed in the study area at the head of the Pappas Prospect road, about 1 mile west of lower Sherwin Lakes.

The next younger bedrock unit is the Volcanic Breccia of Mammoth Rock. This unit, of Triassic and/or Jurassic age, is located south and above Mammoth Rock and is separated from the Mt. Baldwin marble by a fault contact. Here about 1,200 feet of rhyolitic volcanic strata are exposed. They are generally massive with angular blocks as much as a foot across and much included sedimentary rock particles, evidently derived from the stratigraphically lower marbles and hornfels within the roof-pendent section. Locally the unit is crudely bedded with dips to the SW. Stratigraphically above this unit, and making up the crest of Gold Hill, is the rusty red Latite of Arrowhead Lake. This rock, of probable Triassic and/or Jurassic age, is typically dark grey where freshly exposed and unaltered, but throughout the Impact Study plot, this unit is altered to what Rinehart and Ross (1964, p. 33) call a pyritic hornfels zone--yielding the characteristic brick-colored unit. This rock is believed to have intruded those above and below it at shallow depths, then was uptilted, metamorphosed and altered, and then was in turn intruded by the granodiorite.

After the granodiorite of Round Valley Peak was intruded, more volatile igneous constituents intruded it and its surrounding host rocks, giving rise to the felsic dikes and small masses noted along the crest of Gold Hill in the Latite of Arrowhead Lake.

No other bedrock units are exposed in the study site, but it is probable that at least one Quaternary volcanic flow unit exists beneath the glacial sediments along the northern fourth of the impact area. The depth of burial is unknown. Immediately west of the area boundaries are two other volcanic rocks of considerable import to the regional geologic picture. At the northern terminus of Gold Hill and indeed exposed as a residual boulder mass within the study plot at the crest of Gold Hill, are relicts of the Mammoth Mine basalt of 3.06 million years age. This unit in these small exposures is the type name-bearing section for the Mammoth geomagnetic polarity event. This short period of reversed dipole magnetic polarity just over three million years ago is recognized through the world and these rocks represent the single key timing mark upon which this portion of the radiometric and geomagnetic time scale of the entire earth is based (Cox, 1969). Just north of this unit, on the hill called Panorama Dome just south of the Old Mammoth townsite, some of the early flows of quartz latite from what is now Mammoth Mountain are exposed. These are not dated radiometrically but are probably less than 400,000 years old.

ECONOMIC DEPOSITS AND RESOURCES

The area of the Sherwin Canyon Impact study has had considerable exploration for economic mineral deposits. The location and development of the original towns around Old Mammoth, Mill City and Lake City beginning in 1878 are directly related to the mineralization of the altered Latite of Arrowhead Lake along Gold Hill, then called by some Red Mountain. Almost no portion of this unit, where exposed in the study area, is without a history of prospect work and mineral claims. The three major gold/silver mines, the Old Mammoth Mine, the Monte Cristo Mine and the Mammoth Consolidated Mines all have drifts that either enter beneath the study area or penetrate close to its boundary. Descriptions of the Old Mammoth mine drifts (Rinehardt & Ross, 1964, p. 98) indicate that it certainly enters the westernmost salient of the impact area and the others are reported close to the granodiorite contact. These mines have produced gold, silver, lead and copper from northwest-trending steeply-dipping quartz veins near the granodiorite contact from a ore consisting chiefly of native gold, auriferous pyrite, chalcopyrite, sphalerite, pryyhotite, arsenopyrite, and magnetite. Tucker (1927), Sampson and Tucker (1940, and Mayo (1934a) have supplied the basic information on these mineral deposits. From their data, the ore being shipped in 1939-41 was reported to have asseyed about 0.3-0.5 ounce gold per ton and 9 ounce silver per ton from Gold Hill. Numerous quartz veins can be seen in the study area at the summit of Gold Hill on the Solitude erosion surface where it is made up of the brick-red latite. The source of the mineralizing fluids was probably the granodiorite intruded into these rocks in the Cretaceous. There is no reason to doubt that considerable mineral value remains within Gold Hill and that some of it could be recovered from the impact study area. At times of abandonment or collapse, values of veins being mined in this area in the 1920's and early 1930's ran from $9 to $12 per ton for gold and there is no indication from field reports, old newspaper accounts of the Mammoth newspapers, or published geologic studies that any of these veins were decreasing in value at the times of cessation of mining. Ease of accessability, recreational value, and speculation on patented mining claims all suggest that the Gold Mountain area will continue to draw latent economic interest in the future, even though current values and recovery costs would not likely lead to potentially economic development options.

The only other significant mining development within a mineralized area of the impact site is that of the Pappas Prospect at 8800 feet elevation at the head of the Pappas Prospect road a mile west of lower Sherwin Lakes. This bulldozer-trenched area reveals schleeite-bearing tactite in blocks of marble, presumably derived from the adjacent Mt. Baldwin Marble and granodiorite contact zone. The total area of potential mineralization is low and the more readily available tungsten minerals elsewhere in the eastern Sierra and United States as well as the decreased demand for this element as a war material suggest that little economic incentive could be expected for further exploration or development of this prospect. Most of the Mammoth area sheelite prospects were claimed in the early 1950's, and few have been worked since. Mineralization along the marble/granodiorite contact is typically garnet and pyroxene with small amounts of quartz, calcite, and sheelite. Blacklight examination by the author suggests values of less than 1% WO_3 for the sheelite ores with very small reserves of but a few tons of potential ore.

Additional mineral values that should be considered for an Impact Statement are those of gravel and hydrothermal energy. A gravel pit is located along the northern margin of the impact study site and more gravel exists in similar moraine-margine sites where partly sorted glacial outwash provides gravel reserves. Precisely similar deposits exist to the north along both the old and new Mammoth roads and adequate gravel is not difficult to find within the Mammoth region such that non-development of gravel reserves in the study site would not have a local or regional impact except upon potential owners of those gravel reserves. Hydrothermal exploration is ongoing in the Mammoth area in both geologically logical and completely illogical sites, with much environmental degradation resulting from the exploration. There is very little chance of significant hydrothermal resources within the study site. There are no known volcanic vents or deep intrusives or extrusives of young enough geologic age to provide high heat flow differentials. However, judging by the selection of sites for ongoing hydrothermal exploration, there is apparently a great deal of geological naivete expressed in this newly developing field and I could not predict that exploration might not some day be carried out along the lower flanks of the range-front escarpment within the study area. The area is one of high groundwater saturation below the surficial glacial deposits and any stored heat of the volcanic eruptions of the last 1 million years would certainly have been largely carried away. Water issuing from fissures in the latite near the back of the Mammoth Consolidated mine is warmer than might be expected (about 58° F) but is by no means indicative of high enough heat flows to be used for power generation where temperatures at depths of 250° to 350° F are needed.

HYDROLOGY

There are no streams within the study area. An ephemeral channel which fills with water during the spring and early summer is noted in Section 10 along the NW margin of the study plot in an area of high local groundwater table at the base of the eastern escarpment about 0.5 mile south of the townsite of Old Mammoth. This ephemeral channel, and a nearby more-or-less permanent pond constitute the only surface water in the study site. The reason for the lack of surface water in this region of high snowfall accumulation is that the well-jointed granodiorite bedrock that makes up the bulk of the study area effectively absorbs surface melt and precipitation to channel it either into the joint systems or through the bouldery surface deposits. Audible running water beneath the lower rock glacier deposits of Blocky Canyon and Solitude Canyon and aspen and willow thickets below Blocky Canyon and The Niche attests to the flow of water via these avenues. The surfaces of both the granodiorite and the latite on Solitude Plateau and Gold Mountain are unrilled and ungullied and do not carry surface runoff. Snowmelt at all times but when the ground is frozen will sink directly into the deep mantle of decomposed granite, pumice, and joint blocks. When the ground is frozen, the water will pond or flow only a short distance before being absorbed or stored. Storage of water along the plateau summit is evident from the pockets of trees on Gold Mountain (occupying areas where Tertiary stream gravels mantle the latite surface) and the krumholtz on the granitic rocks of the higher portions of Solitude Plateau. Waters draining into the mines of Gold Mountain are probably largely of meteoric origin absorbed on the mountain summits. All the mines are wet, and the Old Mammoth Mine is used as a drinking water supply for some people living in the Mill City area.

Areas of maximum snow accumulation are along the leeward (north and east facing) summit slopes of the main escarpment. Snow remains in nivation hollows at the heads of Blocky Canyon and The Niche throughout most years and such has been the case throughout much if not all of the Quaternary juding by development of some of the largest nivation hollows in the Sierra Nevada in these sites here (see Surficial Geology). This water feeds a shallow subsurface drainage system to ultimately reach the base of the escarpment to water the well sub-irrigated meadows south of Old Mammoth. These meadows within the study area are located on glacial outwash and stagnant-ice debris left there as the glaciers last receded from the lower Mammoth Creek Valley, probably about 12,000 to 16,000 years ago. These sediments are relatively poorly sorted and composed of much fine-grained material and are thus not readily permeable so tend to pond water during spring periods of maximum snow melt. Closed depressions formed by collapse of the ground following melting of glacial ice blocks within the sediments fill with water seasonally, and upon occasion remain full throughout the year.

Any topographic or hydrographic actions that tended to modify the runoff characteristics of the snow-melt from the escarpment face within the study area would change the hydrographic regime of the Old Mammoth meadows, both within and outside the study area. Increased rapidity of runoff, as through road building or slope compaction, or through removal of timber or brush would increase peak flows to the meadows and cause surface drainage of an area that is drained in a subsurface fashion most of the time. This would tend to increase erosion and gullying in the meadows, while decreasing the late season sub-irrigation of the meadows. Hillslope erosion could be serious with slope soil compaction on any of the metamorphic rocks within the study plot, as well as upon the morainal landforms. The blocky talus and rock glacier deposits derived from the granodiorite would not erode by fluvial action readily and could tolerate much manipulation but removal of the vegetation from the granitic slopes would have two major potential effects. First, it would increase the peak flow due to snowmelt runoff, causing potential hydrographic upset in the meadows below; and second, it would render revegetation difficult since these timber stands largely owe their survival in this blocky soil-free substrate to the stored water and mineral nutrient matter found within the void spaces of the granodiorite blocks. On the coarse blocky slopes where surface erosion would not be a hazard, subsurface "erosion" of these mineral fines by increased rates of melting of snowpack exposed to more intense sun and rain, and by increased rainfall intensities, could deplete the limited foundation for the biotope. More xeric microsites in autumn following vegetation clearing could render revegetation more difficult. On the surface of Gold Hill, and possibly on the granodioritic terrane of Solitude plateau, the timber stands are essentially topoedaphic relicts. If removed over multi-acre areas, they would not recover in today's climate due to loss of favorable late summer and autumn soil moisture conditions by draining of the subsoil joint fissure moisture storage sites.

SURFICIAL GEOLOGY

The surficial geology of the study site is illustrated on Plate 3. This plate is from Curry (1971, p. 23) and one should refer to that volume and its references for the most detailed description of the regional surficial deposits. Specific mention will be made here of the major deposits of the Impact Study area site.

Tertiary surfaces: The low relief upland areas outlined on Plate 3 are portions of what I have termed the Solitude Surface (Curry, 1968a). Within the study area, this surface is developed upon both the granodiorite and the mineralized latite. As exposed in the cirque headwalls of Sherwin Canyon, one can see that the surface is made up of an intensely frost-rived and chemically decomposed mixture of granitic debris, volcanic blocks, pumice, and joint blocks, totalling 20 or more feet thick. On the latite, the thickness is less, generally less than five feet, but in the forested pockets an admixture of Tertiary alluvial gravels, Pliocene basalt, and Pliocene scoriaceous waterlaid ash creates a thicker mantle of frost-rived material.

Upon these surfaces one also finds considerable volcano-clastic debris, including, along the western margin of the study site, blocks of quartz latite derived from Mammoth Mountain or vicinity that weigh up to 200 lbs. These air-fall explosion ejecta are of virtually all lithologies found in and around the Long Valley Caldera, from andesitic scoria and lapilli through quartz latite and rhyolite to pumice and obsidian. These materials have rained down upon the surface throughout the many millions of years of its subareal exposure and, during periods of intense Pleistocene frost action, have been incorporated into the frost-rubble mantle of the Surface.

Locally, in leeward sites along the north border of the Tertiary Surface and in windrows behind tree-islands, pumice deposits up to 10's of feet thick are found. Most ~~of~~ these are admixed with locally derived frost-rived material, and some are observed to have been frozen at times of repeated autumn visits, suggesting permafrost conditions near the bases of nivation hollows at the head of The Niche and Blocky Canyon. If permanently frozen ground is found beneath this pumice insulation, it can be expected to behave similarly to that of Mammoth Mountain (see section on Hazard Geology).

Within these Tertiary surfaces, are eroded a series of cirque-like shallow basins near the top of the main Sierran escarpment. These basins are floored with similar deposits to those found on the erosion surface, suggesting similar antiquity of several million years. I have illustrated these deposits on Plate 3 by areas of open triangles. I believe these are most probably areas of past and present snow accumulation, nearly continuously throughout all the glacial periods of the Pleistocene and late Pliocene, and that nivation has been responsible for their formation. This means that these are constantly areas of wetness due to snowmelt through much or all of each summer, and that frequently this wetness remains until the following winter to freeze and result in cryoturbidation, or frost riving and mixing of the surficial materials. Today these cirque head deposits are areas of late-lying or near permanent snow banks and similarly are areas of saturated ground throughout the year, although the ground may be frozen near the more snow-free upland surfaces in winter.

PLATE 3 Surficial geology

LEGEND

QUATERNARY — HOLOCENE — PLEISTOCENE — TERT.

Qm — Rock Glaciers of Matthes age (Qm+ includes advances of ≈ 1100 B.P.)

Qr — Till and Rock Glaciers of Recess Peak age (Qr+ includes advances of ≈ 1100 B.P.)

Qeh — Till of the Hilgard glaciation (Qehrg = Hilgard Rock Glaciers)

Qdt — Till of D-group advances (patterned where over 25,000 years old) (Qdrg = D-group Rock Glaciers)

Qct — Till of C-group advances not noted in this map area

Erratics of B-group advances

Erratics of A-group advances (open triangles indicate areas of possible A-group cirques)

Qv — Volcanic rocks between 192,000 and about 1,000,000 years old. Pyroclastic where patterned with crosses.

Tv — Volcanic rocks between 3,000,000 and 3,060,000 years old

Remnant of the Solitude Erosion Surface. Tertiary alluvium where stippled. Arrow = transport direction

Qal — Alluvium and Outwash

Qls — Landslides

Qt — Talus, Scree, Mudflow debris and Slopewash

Paleozoic and Mesozoic Bedrock with greater than 50% exposure

Contact: dashed where approx., queried where assumed

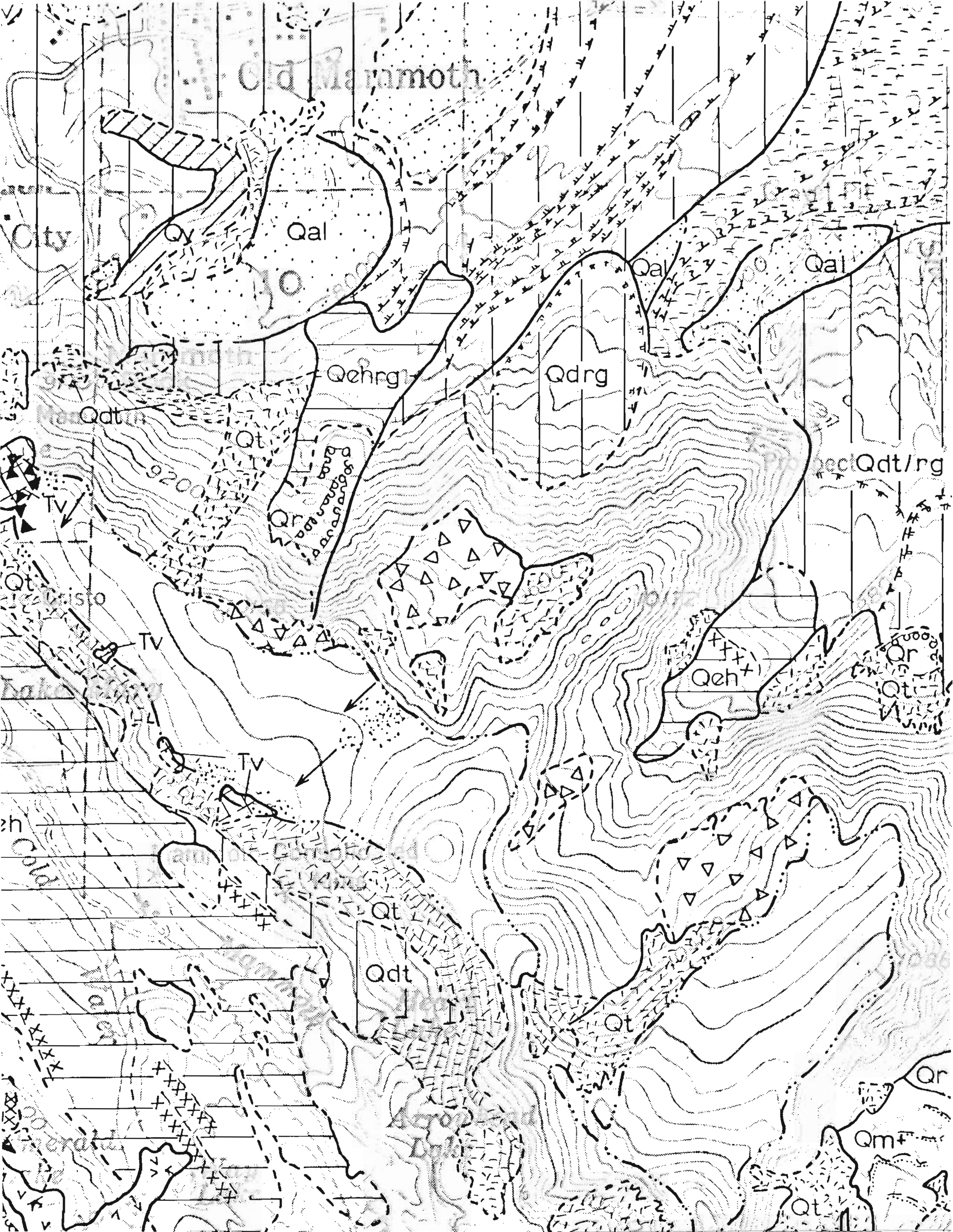
Moraine crest

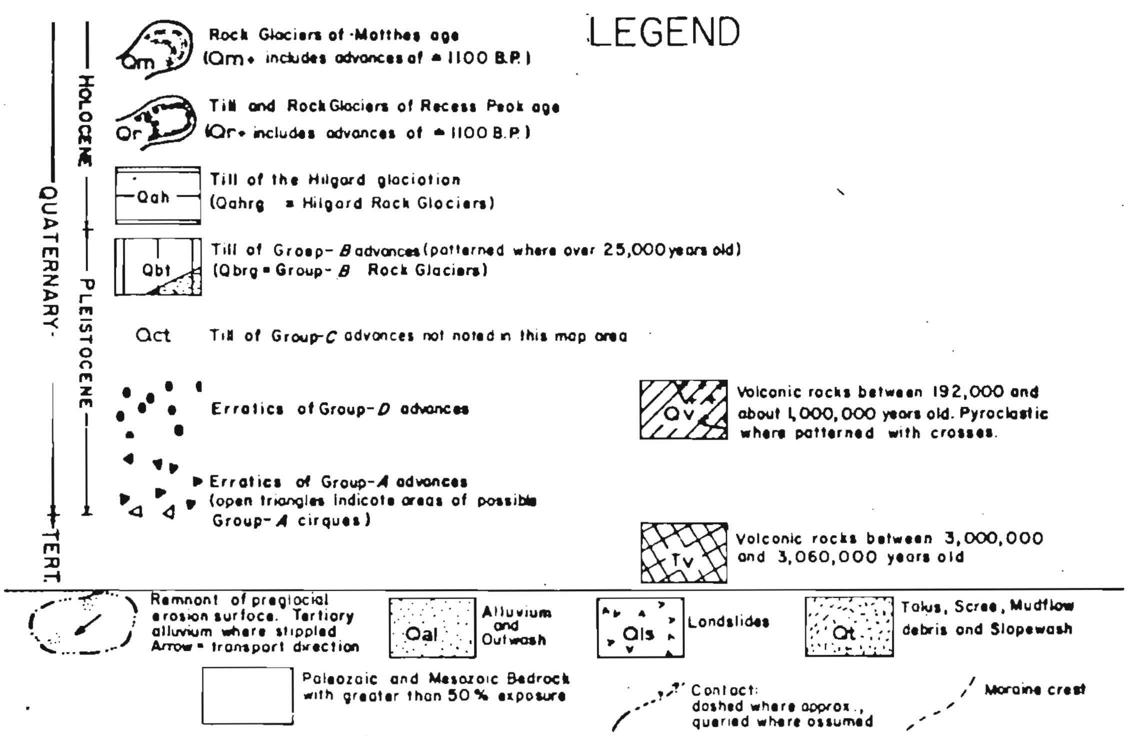
Scale 1:31000

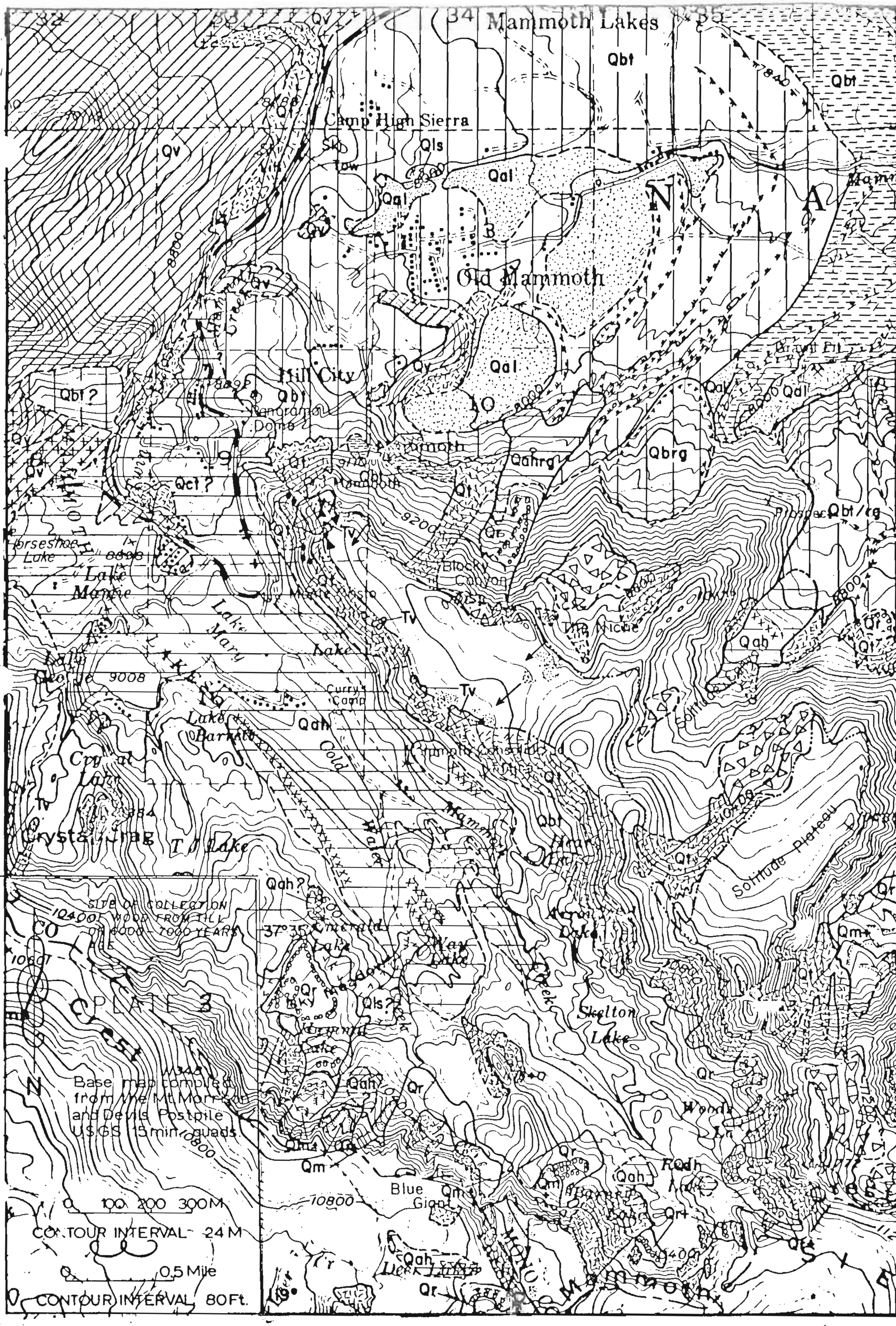
0 .5 1.0 km

0 .5 1.0 mile

facing p. 12


Old Mammoth
City
Qy
Qal
Qal
Qal
Qehrg
Qdrg
Qdt/m
Qt
Qr
Tv
Tv
Tv
Qt
Qdt/rg
Qeh
Qr
Qt
Qt
Qdt
Qt
Qr
Qm
Qt


LEGEND
QUATERNARY
HOLOCENE
PLEISTOCENE
TERT.
Qm
Rock Glaciers of Matthes age
(Qm + includes advances of ≈ 1100 B.P.)
Qr
Till and Rock Glaciers of Recess Peak age
(Qr + includes advances of ≈ 1100 B.P.)
Qah
Till of the Hilgard glaciation
(Qahrg = Hilgard Rock Glaciers)
Qbt
Till of Group-B advances (patterned where over 25,000 years old)
(Qbrg = Group-B Rock Glaciers)
Qct
Till of Group-C advances not noted in this map area
Erratics of Group-D advances
Erratics of Group-A advances
(open triangles indicate areas of possible Group-A cirques)
Qv
Volcanic rocks between 192,000 and about 1,000,000 years old. Pyroclastic where patterned with crosses.
Tv
Volcanic rocks between 3,000,000 and 3,060,000 years old
Remnant of preglacial erosion surface. Tertiary alluvium where stippled
Arrow = transport direction
Qal
Alluvium and Outwash
Qls
Landslides
Qt
Talus, Scree, Mudflow debris and Slopewash
Paleozoic and Mesozoic Bedrock with greater than 50 % exposure
Contact: dashed where approx., queried where assumed
Moraine crest


Mammoth Lakes
Qbt
Camp High Sierra
Qv
Qls
Qal
Old Mammoth
Hill City
Qbt?
Panorama Dome
Qahrg
Qbrg
Qbt/rg
Qct?
Blocky Canyon
Horseshoe Lake
Lake Mamie
Lake Mary
Tv
The Niche
Qab
Curry's Camp
Lake Barrett
Qah
Cold Water
Crystal Lake
Crystal Crag
T J Lake
Solitude Plateau
Qah?
SITE OF COLLECTION OF WOOD FROM TILL OF 6000 - 7000 YEARS
Emerald Lake
Way Lake
Qr
Qls?
Skelton Lake
PLATE 3
Crest
Base map compiled from the Mt Morrison and Devils Postpile USGS 15 min. quads.
Qm
Blue Giant
Qrt
Woods
Deer Lakes
0 100 200 300M
CONTOUR INTERVAL 24 M
0 0.5 Mile
CONTOUR INTERVAL 80 Ft.
Mammoth
8800
9200
10800

Stream gravels are found at the head of The Niche and also near the northwesternmost extremety of the study area on the Tertiary Surfaces. These are gravels derived from highland areas that one time existed east and north of the present escarpment but have since downfaulted and eroded away. These gravels are of rock types found in the Mt. Morrison roof pendant, not all of which are exposed in the Mammoth Rock outlier. They are graded from northeast to southwest indicating that direction of fluvial transportation. The 3.06 million-year-old Mammoth Mine basalt fills these stream channels, and above the Old Mammoth Mine apparently dammed the local stream to form a small accumulation of volcanic lake sediments beneath the basalt. The significance of this series of gravels is that it reveals the direction of warping of the Tertiary surface toward Mammoth Mountain after the formation and abandonment of the stream channels, and it gives one an indication of some of the rock types that may lie buried several thousand feet beneath Lower Mammoth Creek valley floor in the vicinity of the townsite of Old Mammoth.

Quaternary Deposits: Late Tertiary glacial deposits correlative with the 2.7 million year old Deadman Pass glacial tills exist on the west and southwest flank of Gold Mountain but do not enter the study area. Except for the nivation cirques of composite age, all the glacial and related deposits of the study area are of Quaternary age, approximately less than 2.4 million years old.

The main glacial deposits of the study area are those at the base of the escarpment comprising the northern one-fourth of the site. These deposits are a series of right-lateral moraines and outwash deposits of at least two and possibly three periods of Wisconsin advance during the last 100,000 years.

The Wisconsin deposits, correlated with the Tioga and Tahoe glacial advances of the Sierra Nevada, are sharp-crested, little dissected moraines up to 300 feet high. These are made up of granitic and mostly metavolcanic rocks of upper Mammoth Creek, carried down to these sites of deposition. The gravel pit just west of Sherwin Creek is in Tahoe age outwash, probably 60,000 to 75,000 years old against the large Tahoe moraine rising over 200 feet directly west of it. Within these morainal materials are some blocks of epidote-rich greenstone that contain trace amounts of uranium, but not of economic value. Detailed descriptions of these Mammoth Creek glacial deposits are found in Curry (1968b, p. 34x-43x). Along Sherwin Creek, the glacial till exposed where Solitude Canyon meets the Sherwin Creek trail is a composite of true till and rock glacier debris. This Sherwin Canyon glacial sequence was heavily debris loaded due the prevalence of well jointed granodiorite in its headwaters and the active frost-riving along its cirque headwalls. The Sherwin Creek Pleistocene deposits are virtually unique in the Sierra Nevada, acting as the impetus of Kesseli's studies (1941a, 1941b). Within the study plot over 500 vertical feet of Wisconsin till and rock glacier material is stacked in the mouth of the Canyon. Most of the actual ground surface is a Tioga rock glacier that was defeated against the Tahoe and earlier moraines of that canyon. There is no other place in the United States, outside of Alaska, where such extensive rock glacier deposits are found of so many geologic ages. Sherwin Lakes occur at the contact between till and rock glacier blocks, although this is gradational reflecting a change in balance between snow load and rock debris load on the canyon glaciers.

Rock glaciers also exist in Blocky Canyon, The Niche, and Solitude Canyon. That rock glacier in Blocky Canyon overrides the Tioga moraine of Mammoth Creek, thus indicating that this rock glacier is younger or was at least active later than the Tioga ice-marginal moraines. This is the only place this relationship has been recognized in the Sierra Nevada. The rock glaciers of these escarpment canyons represent a nested series of deposits of late glacial and neoglacial age. None are demonstrably active today, although they were no doubt active in the last 1500 years and may contain residual ice today in the higher cirque-head areas. If this was the case, they could be remobilized by changing the loading of the rock glacier surface through undercutting the toes or loading the heads, or they could be reactivated by increasing retained snowpack upon their surfaces through snowfences or other modifications of snow accumulation. These rock glaciers are sites of Balch ventilation--that is, they accept cold air draining into them from above and tend to become refrigerated just as do ice caves and the "Earthquake Fault" along the Minaret Summit road. Water draining into them can freeze when ambient air temperatures are well above freezing above the rock glacier surface. The rock glaciers in all the canyons have thorough water drainage beneath them today except that of Recess Peak age in upper Blocky Canyon, which thus may still retain some interstitial ice.

Talus also mantles many of the slopes of the main escarpment. Major talus slopes are mapped on Plate 3 (Qt). Many of the talus slopes are active today, but those west of Blocky Canyon are largely partly vegetated and only added-to today by the frequent snow avalanches found in that entire area between Mammoth Rock and Blocky Canyon. Much of the vegetated area within and around the cirque below The Niche is talus covered although not directly mapped as such since this talus is now stabilized and not being added-to today. The talus mapped elsewhere in the study plot is all active today. On the slopes of Gold Mountain, where the talus is made up of small blocks and plates of the mineralized latite, rates of talus movement vary from 0 to 6 cm per annum as determined from comparative photographs taken over an 8 year period. Disturbance of any kind speeds talus transport to feet per year. In undisturbed sites on the talus slopes of Sherwin Canyon with granodioritic materials, mean velocities of surficial talus materials have not yet been determined but are evidently slower than on the latites judging from sililar comparative photographs that show too few blocks moving to assess average values. Despite the 'active' appearance of these slopes, no detectable motion of particles is observed in 8-10 years of detailed photos at several representative study sites away from disturbance by humans. Most of these talus slopes are of both Quaternary and Recent geologic age, but were most active last during the periods of neoglacial advances in this area from 1300 to 1850 AD, around 0 AD, around 600 B.C., and also around 8000 to 12,000 years ago.

Soils: True biogeochemical soil is not abundant in the study area. Even the oldest Tertiary surfaces possess but a heterogeneous mixture of physical and chemical weathering products with no zonation. Partly weathered decomposed graniticminerals and volcanic ash extents to a great depth, over 100 feet along joint faces, and can afford substrate to plant species able to tolerate such pedologically immature substrates.

The only readily definable soils in the area occur on the glacial tills in the northern part of the plot. Even on the oldest Tahoe age units, these soils are azonal A/C weathering profiles consisting of a weak accumulation of organic material up to 4 inches deep overlying a gradational contact to a zone of oxidation with 7.5 to 10YR colors. Zones of clay accumulation, if present, are not readily detectable in the field and probably constitute a less than 4% admixture of illuviated clay minerals. On the younger moraines of Tioga age, the soils are essentially identical except that depth of oxidation is somewhat less on sites of a given exposure. In the lowland meadow areas a deeper organic layer is found, up to 9 inches deep, overlying unaltered silts. In the swales between moraine crests, colluvial soils with organic-rich accumulations admixed with pumice occur to observed depths up to 2 feet. On the hillslopes of the range escarpment, soils are restricted to pockets and benches of alluvial and colluvial accumulations of organic-rich slope materials. No zonal soils are found and no illuviated horizons or debris can be detected. Most hillslopes were recently either talus, bedrock, or scree. These are either today active or were active in the recent neoglacial paleoclimatic events of greater snowfall and frost action, and have not developed soils in the last 2000 years. The marked summer drougth is probably responsible for the lack of significant soil formation on the morainal materials of many tens of thousands years of age.

HAZARD GEOLOGY

Faults and Earthquakes: The range-front fault zone at the base of the eastern escarpment is an active fault in that it has been the locus of more or less continuous offset throughout Quaternary time. This fault takes the form of several discontinuous fault traces each showing evidence of basin-side (north) block downward movement. The faults are most readily apparent one mile west of the townsite of Old Mammoth where a fault scarp can be seen trending N 75 W and extends from the Old Mammoth Lakes road to the New Mammoth Lakes road. This fault cannot be traced into the study area but may curve eastward to connect with the east-west trending fault that crosses Sherwin Creek at that creek's junction with the site boundary, passing just north of the gravel pit and extending as a discontinuous series of small escarpments transecting Tioga morainal material to the Old Mammoth Meadows. This fault trace is much more readily apparent to the east where it cuts the several moraines exposed at the mouth of Sherwin and Laural canyons.

Since hillslope processes are active in the region today and have been even more so in the Recent geologic past, it is probable that other faults may be obscurred beneath the talus and rock glacier rubble elsewhere along the eastern base of the escarpment. About 300 meters north of Mammoth Rock fluvial erosion on the quartz latite west of the Old Mammoth meadow and south of Panorama Dome seems confined to a fault zone but late Wisconsin movement cannot be demonstrated. Despite the vague surface expression, the fault shown crossing Sherwin Creek on the Geologic Map has had a rate of offset of 1 foot per 1000 years for the last several hundred thousand years. The youngest control point is 15,000 to 20,000 years old. This fault movement may occur only once every 20,000 years, or, more probably, it may occur in increments discontinuously along the length of the fault trace such that some portion moves every few hundred to few thousand years.

The changes in the activity of hot springs of Hot Creek and Casa Diablo during recent earthquakes attests to the activity of local faults today near the study site. Elsewhere along the range-front fault, in Owens Valley near Lone Pine, and in Bridgeport Valley near Fales Hot Springs, offsets of over four feet have been demonstrated in early historic or just pre-historic times. Design offsets of 10 feet during a given large magnitude earthquake would probably be adequate for impact study criteria. The expectable magnitude of earthquakes in the Mammoth region would be similar to those elsewhere along the range-front fault--at the theoretical limit of earthquake intensities--Richter magnitude 8.75. Such very large earthquakes have occurred in the eastern Sierra, 100 years ago at Lone Pine, and can occur again at any time. Inadequate base seismological record is available to determine the recurrance interval of such an earthquake here at present but the area is one of high seismic activity. Local ground accellerations to be expected in an earthquake at Mammoth within a mile of the fault would be in excess of 0.5 g. California public building codes would not protect against such ground accellerations.

Soil Stability and Erosion: Road construction and compaction of surface materials present the greatest threat of surface erosion in the study plot. The hazard is greatest on the finer-grained heterogeneous engineering soil types on hillslopes of any steepness. These soils are found in the scree slopes and vegetated slopes on metamorphic colluvial materials around the Mammoth Rock outlier (ie., the areas mapped as metamorphic rocks and the slopes below them) and upon the glacial tills and finer fractions of sloping outwash. In all these areas erosion hazard is high. In comparison, the equallly high erosion hazard on the slopes of Mammoth Mountain is there due to slope compaction and seasonal ground freezing, thus decreasing rates of infiltration of snowmelt waters, and increasing the effectiveness of surface runoff. Pumic accumulations on the slopes of the Sherwin Creek site are less deep than on Mammoth Mountain but in the local leeward sites at the crest of the escarpment, conditions precisely analogous to those of Mammoth Mountain apply.

Locations of waterbars and frequency of waterbars on roads and compacted hillslopes affect the erosive potential of the substrates. Adequate waterbar density on the "high" erosive potential soils varys as a function of steepness of slope. On slopes of 5-15%, waterbars would be needed every 100 horizontal feet; on slopes of 15% to 30% every 50 feet; on slopes of 30% to 45% every 25 feet; and on slopes above 45% waterbars are of dubious value in erosion control on these substrates or any others. Special care should be taken in leading the surface flow localized by waterbars to adequately porous drainbed for each bar.

Substrate materials on the Solitude Plateau Tertiary surface are of moderate erodability where compacted or artificially rilled. These areas do not today possess integrated surface drainage networks, having virtually full subsurface drainage. The accidental construction of such drainage networks, either directly through road or trench construction, or indirectly through concentration of surface waters by compaction or construction of impermeable objects on the surface. Waterbar construction guidelines are one every 200 horizontal feet on 5-15% slopes; one every 100 feet on 15-30% slopes, and one every 50 feet on 30-45% slopes.

Hillslopes of the canyons and eastern escarpment in granodioritic terrane have low potential erodability hazard. The well jointed nature of the bedrock and blocky nature of the slope materials suggest that construction activities would not greatly alter present runoff regimes. An exception occurs on the combined rock glacier/till deposits of lower Sherwin Creek east of the Pappas Prospect road. This material is evidently mostly heterogeneous till, supporting permanent lakes and streams. Such material is of moderate to high erodability depending upon the percentages of the void spaces between larger boulders that are filled with fine materials. If filled, the sites have high erodability.

The alluvium mapped on Plate 3(Qal) also has high potential erodability indices but is generally flat lying and, unless undercut or trenched, will not greatly contribute to surface water turbidities or sediment yields from the units.

In comparison to Mammoth Mountain, the entire Sherwin Creek study site is not as fragile from a soils-engineering standpoint. Individual areas of glacial moraines and metamorphic debris slopes are as erodable or more erodable than the compacted latite and pumice slopes of Mammoth Mountain but the unique post-Wisconsin blocky rock-glacier deposits of the Sherwin area are nearly immune to fluvial erosion. They are, however, subject to landslide or rock fall because they are very unstable. These rock glacier deposits are formed by ice transport and left precariously balanced after that ice melts away. Where ice remains, as it may on the upper Blocks Canyon deposit, roads exposing such ice would cause thermal erosion and instability of the mass.

In general, rock glaciers formed of jointed granitic blocks are not stable enough for any but very careful negotiation by a walking man for 2000 years or more. Those formed in Recess Peak time are occasionally unstable with 10% to 20% precariously balanced surface boulders. The younger Matthes deposits, not found in the study plot, have up to 50% unstable surface boulders that will move with a man's weight. The rock glaciers attributed to the Hilgard period of advance immediately following the retreat of Tioga ice in Plate 3 generally have but 1% to 3% of their surface boulders in a presently unstable state. Construction on such rock glaciers or removal of their toes can, of course, cause the whole mass to readjust to an angle-of-repose talus slope and would be expected to do so during undercutting or an ensuing earthquake.

Scree slopes and vegetated talus slopes along the non-rock glacier covered areas of the escarpment and sides of Sherwin Canyon are largely dominated today by slope creep soil processes. The colluvial mantle varies from inches to 10's of feet thick and rests at an angle of repose. Any oversteepening of such slopes, as through road construction, will ultimately cause instability and readjustment of the entire slopes to the apex of the colluvial deposit. The mass wasting erosion hazard of such slopes is thus high. Mass wasting hazard is not great for any other substrate slope combinations in the study plot except the steeper (greater than 20%) moraine slopes where rotational slumping could be expected if the materials were saturated and either loaded at the tops or undercut at the bases of the slopes.

Volcanic hazards: Volcanic activity is only temporarily quiescent in the Mammoth Lakes area. This is among the most active such areas in California, surpassed only by Mt. Lassen in magnitude of recent eruptions. Within the last 1000 years, cinder cones and steam explosion craters have occurred within 20 miles of the study site. Within the last 100,000 years, the entire north half of Mammoth Mountain was blown away in one or more explosions, depositing debris throughout the study site and burying the site of the present town of Mammoth Lakes in at least 20 feet of 1-6 feet quartz latite blocks. Pumice eruptions from within and around the Long Valley caldera have deposited pumice blankets at least inches thick over the study site on several occasions within the last 2000 years. More such eruptions can reasonably be expected in the near geologic future (100-1000 years).

The most serious hazard to the study site would be the eruption of Mammoth Mountain, especially an explosive eruption. Ash, pumice and blocks of rock up to feet in diameter could be expected to fall in the study site, possibly without warning. The chances of such an eruption are remote but finite within the next 100 years--about 1 chance in 1000 based upon dates of past eruptions of that mountain, about once every 100,000 years, the last time 150,000 years ago. Another volcanic hazard is of a passive lava flow in the Mammoth Creek valley. Such an event has about the same chance as a Mammoth Mountain eruption, but would not constitute a serious human threat since it would occur slowly over days to weeks.

Avalanche hazard: All of the cirque headwalls of The Niche, Blocky Canyon and Solitude Canyon, as well as the full north-slope of the main Sierran Escarpment are subject to avalanche hazard. The area from Blocky Canyon to Mammoth Rock is subject to avalanching every winter with severe avalanching taking out mature conifers of 50 or more years age occurring about once every 20 years in any given avalanche track. These avalanche frequencies are determined from increment boring of trees in and adjacent to these avalanche tracks. Even where slopes are timbered with mature conifers locally west of Blocky Canyon, slab and dry-snow avalanches have occurred judging from evident avalanche damage and I would estimate that at least small avalanches occur over most of this slope at least once a winter. The slopes of the canyon walls of Solitude Canyon likewise run every year in normal snow accumulation conditions. Only the lower slopes of The Niche and Blocky Canyon are without frequent large avalanche hazard along the eastern escarpment. Due to lack of accumulation and low slope gradients, the Solitude surface is without avalanche hazard, while such hazard is minimal in the lower morainal topography due to short slope segments. In comparison to Mammoth Mountain, the avalanche hazard of the area west of Blocky Canyon is comparable only to that of the main headwall below the summit cornice on Mammoth Mountain.

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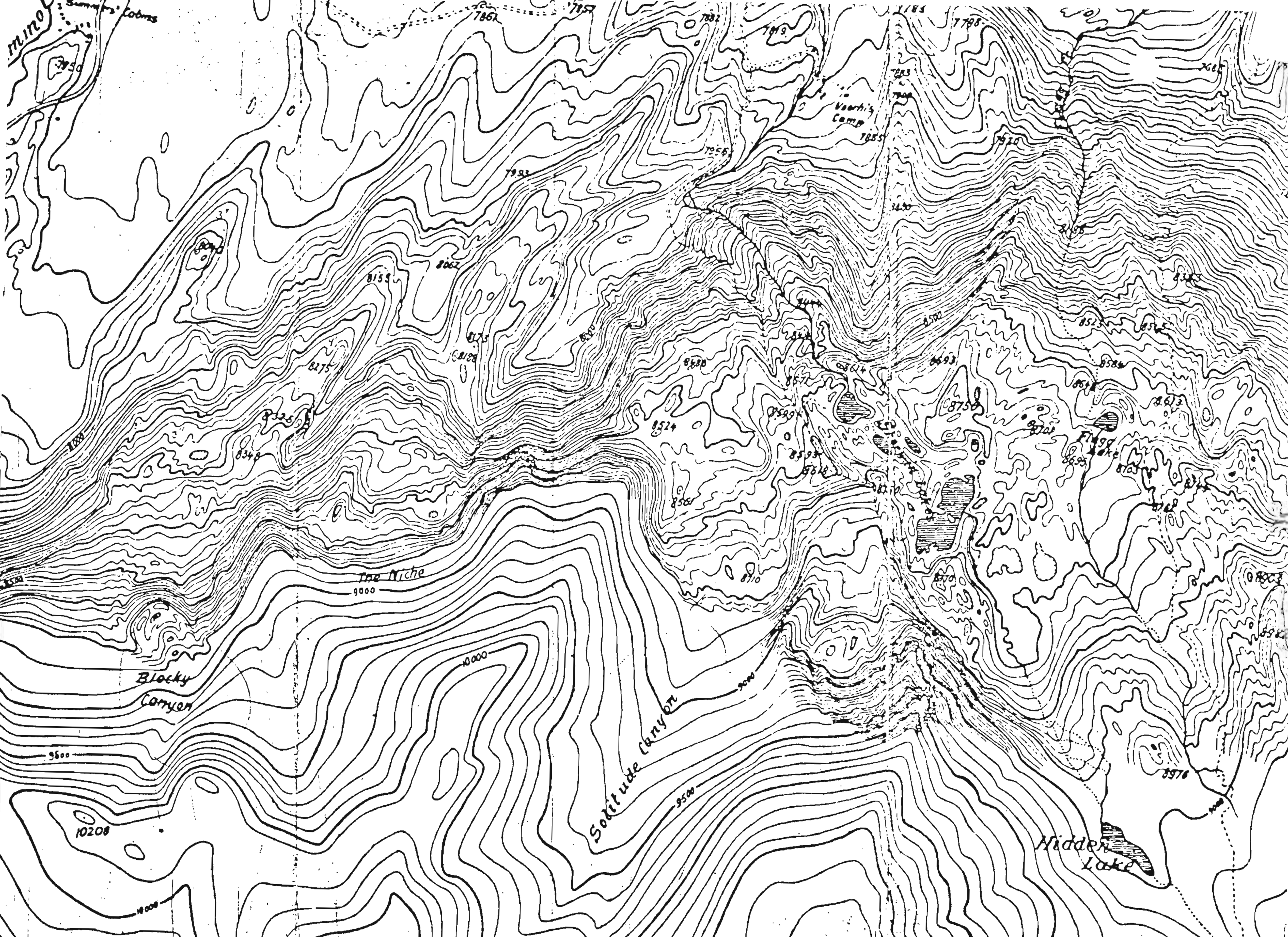
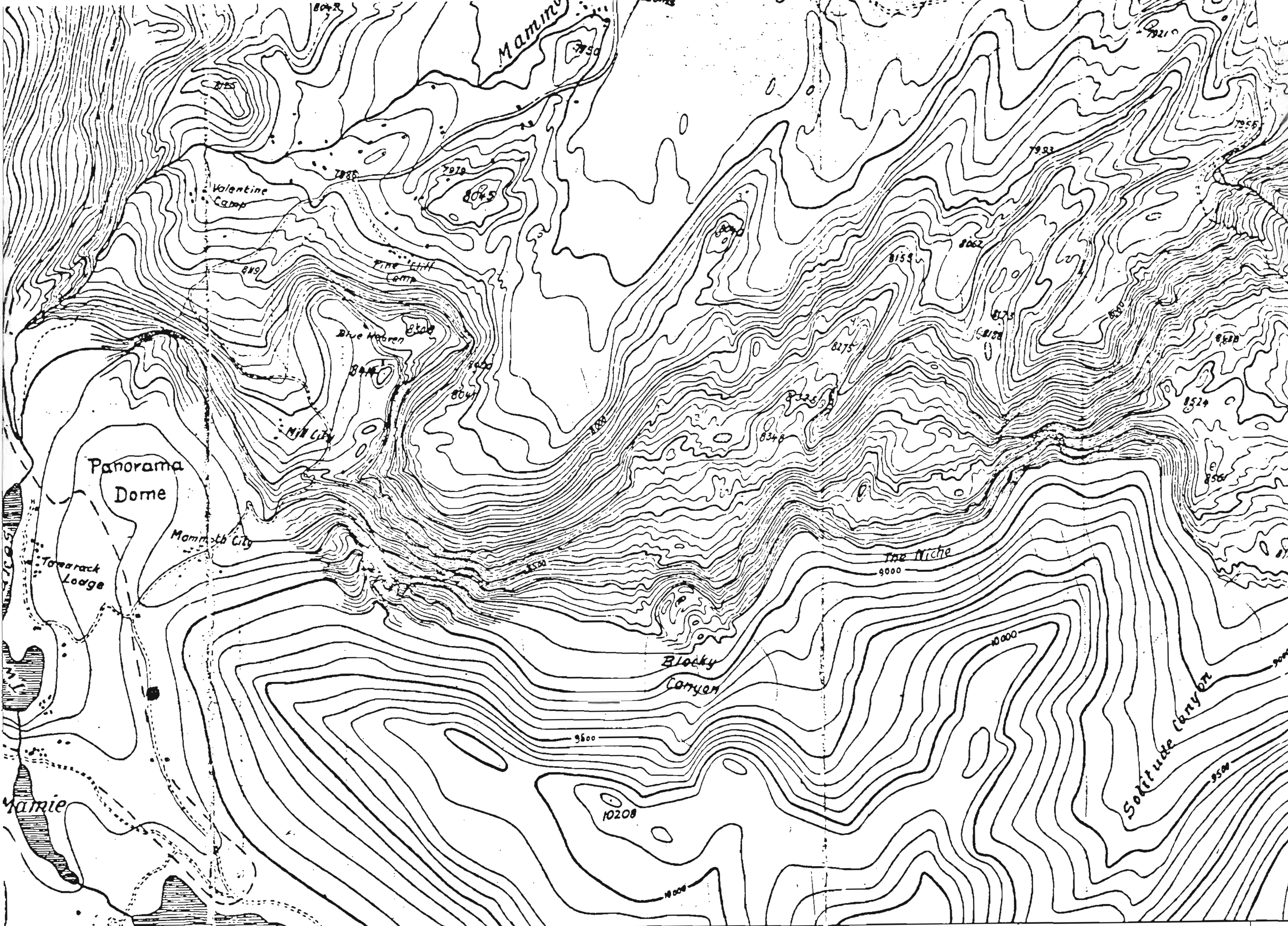


C	Contour intervals 20 and 100 feet	KESSELI	E	1941



B KESSELI 1941 C Contour intervals 20 and 100 feet