Preface to Washoe Valley area Open File Report

We wrote the chapters included here for a text to be printed as part of the Washoe City Environmental Folio. Many of the maps of this folio and in particular these referred to in this report have been printed and are available from the Nevada Bureau of Mines and Geology, Reno, Nevada. References in the text to Geologic Map, Hazard Map etc. refer to the published maps and naturally this text is most useful when used in conjunction with the maps.

Public release of this text as an open file report was precipitated by interest in the May 30, 1983 catastrophic wet debris flow on Slide Mountain. Slide Mountain has been the site of many wet and dry debris flows in the recent and geologic past, and we direct the reader who is particulary interested in debris flows to sections in the text describing and analyzing the hazards in the Slide Mountain area. See in particular the description of debris flows in the Text to Accompany the Geological Map, the discussion of rockfall avalanches and wet debris flows in the Geologic Hazards chapter and the chapter on Flood Hazards and Fluvial Debris Hazards along Principal Streams.

We are indebted to Mary Milan, Catherine Rieser, and Margo Maquire for the resourceful typing and word processing and to Kate McMasters and Bruce Rodgers for the marathon drafting and photography that made this open file promptly available.

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GEOLOGY, GEOPHYSICS, GEOLOGIC HAZARDS AND ENGINEERING AND GEOLOGIC CHARACTER OF EARTH MATERIALS IN THE WASHOE LAKE AREA: TEXT TO ACCOMPANY MAPS OF THE ENVIRONMENTAL SERIES, WASHOE CITY QUADRANGLE, NEVADA.

by

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TEXT TO ACCOMPANY GEOLOGICAL MAP

by

R. W. Tabor and S. Ellen

INTRODUCTION

The geologic map is the main source of data used in compiling the Washoe City folio. As such, the geologic map has many applications to the practical world of land-use planning, resource evaluation, engineering, and the minimizing of geologic hazards, and it serves to illuminate the geologic history of the Washoe Lake area. This historical value is closely related to its practical use, for a comprehension of the geologic history leads to a greater understanding of the processes forming the earth materials that we live on and use.

We have separated this chapter of the folio into two sections. The first section summarizes the geologic history of the area in terms understandable to the layman; the second describes the map units in somewhat technical terms that will be best understood by readers with some geologic training.

We identify and describe two fundamental types of material on the geologic map: bedrock and unconsolidate deposits. Bedrock is mostly hard and, within the area shown, relatively continuous beneath both a soil cover (not shown on the geologic map) and the unconsolidated deposits. The unconsolidated deposits are mostly silt, sand, and gravel eroded from bedrock highlands and redeposited in basins and valleys on top of the bedrock.

The geologic units discussed here are grouped according to the processes that formed them. Most unconsolidated deposits are classified according to the major depositional agent--wind, water, gravity, or glacial ice--that was primarily responsible for their formation. We classify a few unconsolidated deposits as having formed from malefic processes because these processes threaten man and his works, and we can expect similar processes to take place in the near future in Washoe Valley. Some rocks and deposits classified under other headings--for example volcanic rocks, glacial moraines, and sandstone--are also derived from processes threatening to man but pose no immediate hazard.

ACKNOWLEDGMENTS

Many coworkers have helped us in the field, in the laboratory, and in administration of the project. We have been assisted in the field work during 1973-74 by Earl Brooks, Rubin Avelar, Paul C. Russell, and John C. Tinsley III. We especially wish to thank Ed Bingler and John Bell of the Nevada Bureau of Mines and Geology for their administrative and editorial efforts. Many of our colleagues have contributed valuable discussion, including George Thompson, Ed Bingler, Harold Bonham, Jr., Ken Luza, Patrick A. Glancy and Terry Katzer. Malcolm M. Clark gave considerable time and advice on mapping the glacial deposits. Carl Wentworth and Brian Atwater helpfully reviewed the manuscript. We were accorded considerable Washoe Valley hospitality by C. Bruce McDonald of the Davis Creek County Park Rangers and by Mrs. James Griel of the Bar J. Ranch.

GEOLOGIC HISTORY

Three main chapters of geologic history embrace all the rocks and deposits of Washoe Valley. The first chapter is represented by the oldest, hardest, and most extensive rocks of the area: baked and recrystallized (metamorphosed) sedimentary and volcanic rocks and igneous granodiorite that invaded these rocks as an upwelling melt (fig. 1). Probably the melt reached the surface to form volcanoes, but today we see only the part that crystallized deep in the crust as an enomous mass of rock called a batholith. These rocks owe their hardness to the heat and pressure that formed them deep in the Earth's crust. Many tens of millions of years later, after these rocks were uplifted and exposed by erosion, molten rock welled up again and spilled out onto the Earth's surface. During this second period in the geologic story, volcanoes erupted to fill valleys and basins with lava and volcanic rubble. The third period of history was very short compared to the earlier two and encompassed the deposition of sediments in the basins and valleys that we see today.

Thus, the first two chapters of history encompass the formation of most of the bedrock, and the third the formation of the unconsolidated deposits along with minor volcanic rocks. We will examine these events and processes in more detail, beginning with oldest rocks, those called metamorphic rocks on the geologic map.

About 200 million years (m.y.) ago, sediment and volcanic debris were deposited on an ocean floor (fig. 1A). This material compacted to become sandstone, shale, conglomerate, and volcanic breccia as it became deeply buried under younger deposits. Squeezed between crustal blocks, the rocks were folded and highly compressed; the shale developed finely spaced, parallel cracks known as slaty cleavage. About 120 m.y. after these rocks were originally deposited, when they were still many kilometers below the Earth's surface, the rocks were intruded by granitic melt (fig. 1B) that heated the older rocks. New minerals formed as the older rocks were recrystallized (metamorphosed) over broad areas.

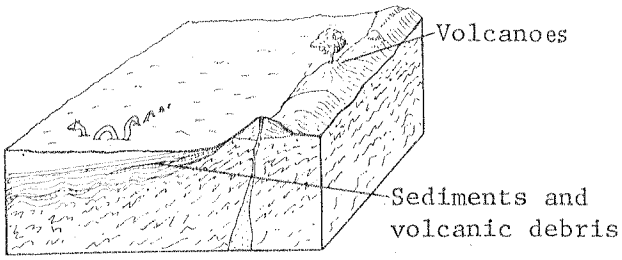
The granitic rock, called granodiorite, is a small part of the Sierra Nevada batholith, a mass of rock more than 560 kilometers (km) long and about 130 km wide. The batholith took a long time to form; parts of it crystallized about 200 m.y. ago, but the granodiorite of the Washoe area cooled about 80 m.y. ago.

As the stresses in the Earth's crust changed, eventually the granodiorite and the surrounding metamorphic rocks rose and were cut into by eroding streams. Molten rock continued to form deep in the earth, and much came to the surface as volcanic rock in much of Nevada and adjoining states. Eruptions in the Washoe Lake area began about 22 m.y. ago and continued until about 1 m.y. ago, but most of the lava and volcanic rubble that have not been stripped away by erosion accumulated about 12 m.y. ago. The earliest eruptions were flows of hot volcanic ash that spread over vast areas with a rapidity suggesting a land of low topographic relief (fig. 1C).

A few million years after the volcanic ash-flow eruptions, much of Nevada and parts of the surrounding states broke into numerous large north-trending blocks that shifted up and down along faults to form a basin-and-range

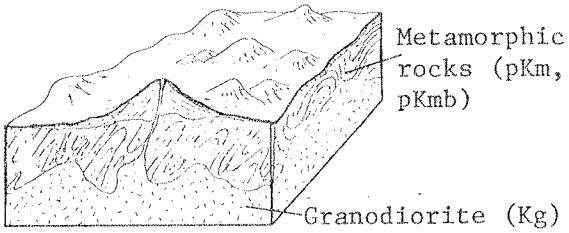
FORMATION OF THE BEDROCK

200 million years ago



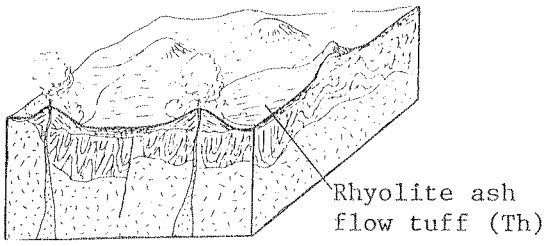
Sediments and volcanic debris deposited on ocean floor.

80 million years ago



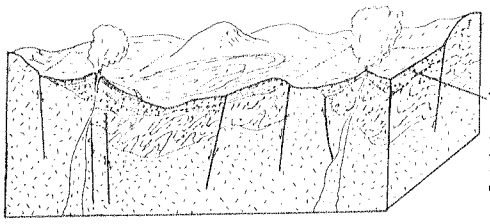
Folded, faulted, and eroded(?) sedimentary rocks are intruded and metamorphosed by granodiorite of the Sierra Nevada batholith. Probable volcanos derived from erupted batholith melt are no longer in evidence.

22 million years ago



After uplift and erosion, voluminous ash flow tuffs erupt and spread over much of the land.

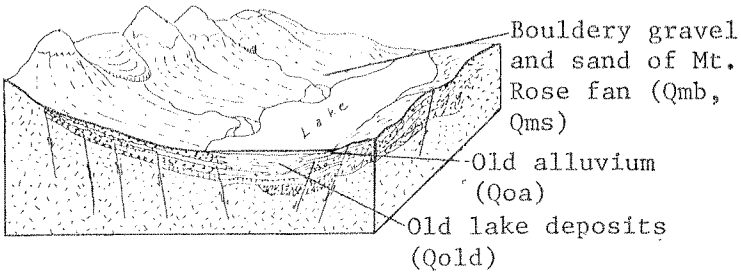
12 million years ago



Fault block mountain ranges and basins develop. Continued erosion. Renewed volcanic activity with deposition of breccias and flows.

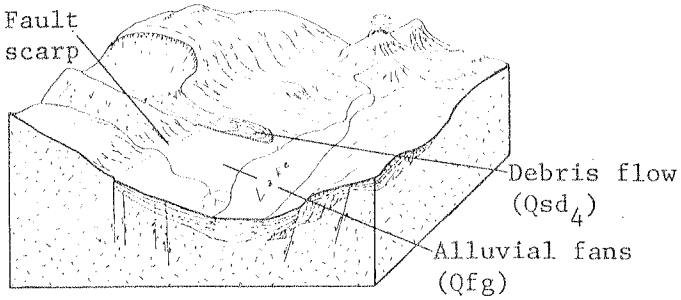
FORMATION OF THE UNCONSOLIDATED DEPOSITS

1 million years ago



The Sierra Nevada has risen along faults; Washoe valley and other basins have formed. Older rocks are partially buried by sand, gravel, and fine-grained lake deposits. Rhyolite dome erupts. Glacial melt streams deposit fans of gravel along Sierra front.

1000 years ago



Depositional processes continue as lake deposits mingle with sand fans at basin edge. Movement along range-front faults continue. Debris flow decends from Slide Mountain. The scene is much like that of today.

Figure 1.--Geologic history of Washoe Valley area, illustrated by diagrammatic views. Geologic units are shown in parentheses.

topography similar to that we see today. Elevated blocks were eroded by running water and wind, and subsided blocks became covered with debris washed down from the adjoining highlands. Andesitic volcani rocks (Kate Peak Formation) erupted on the flanks of the mountain blocks and flowed into the down-faulted valleys (fig. 1D). The youngest basalt and rhyolite erupted only a few million years ago onto a land surface not greatly different from that of today. The third chapter of geologic history began as streams filled the newly formed fault-bounded basins with sediment, mostly silt, sand, and gravel. The age of the oldest unconsolidated materials, deposited at the bottom of the basin of Washoe Valley (See Cross-Section Sheet, I-I' through K-K' is unknown, but the exposed unconsolidated deposits range from those close to a 500,000 years old to sand blown by today's Washoe zephyrs

The oldest unconsolidated deposits were formed in a number of ways. Sand and gravel washed into the basin by streams, along with mixtures of mud and rock carried in by debris flows, are interbedded with finely layered sand and silt typical of lake deposits. Near Washoe City, old lake deposits contain thin beds of diatomite, a white chalky material made up of microscopic siliceous skeletons of freshwater diatoms, a type of alga. Most basins probably contained lakes on and off throughout their history.

The fine-grained stream and lake sediments were partly covered by bouldery gravel of the Mount Rose fan (fig. 1E; cross-sections D-D' and E-E', which spread eastward from the northern Carson Range. It is likely that this wedge of gravel was deposited by glacial streams overloaded with materials eroded by early Pleistocene glaciers. Eroded moraines that were deposited by the early glaciers (glacial moraine 1) are prominent in the upper drainage of Brown's Creek.

The Steamboat Hill rhyolite dome erupted about one million years ago; its ejecta seem not to have traveled far from the dome. About 0.5 m.y. ago, on the other hand, volcanic eruptions as far away as Mount Lassen in northern California were spewing ash across California and Nevada. The ash washed down into the basins to become a thin layer between lower gravel beds of the Mount Rose fan.

The uplift of the Sierra Nevada block not only created an impressive escarpment between the top of Slide Mountain and Washoe Valley but also broke and crushed the rocks along the east-facing mountain front. Much of the movement took place along discrete faults, but considerable rock on either side of the faults is crushed also. The weakened rock standing high in a steep face broke loose periodically--perhaps during earthquakes generated by movement on the faults--and crashed down steep slopes as rockfall avalanches. The huge, rapidly moving masses of rock fragments, buoyed by entrapped air, rushed down the valley of Ophir Creek and adjoining creeks and came to rest in steep-fronted, bulbous piles on the flat floor of the valley. The earliest exposed debris flow from Slide Mountain may have come down during or shortly after the early Pleistocene glaciation (Cross-Section Sheet I-I'), but at least seven more flows came down many thousands of years later; the latest four crashed down since about 1100 years ago (fig. 1F).

When the early Pleistocene glaciers receded, streams building the Mount Rose fan ceased depositing outwash and began cutting canyons into the fan. Deposition in Washoe Valley probably continued, and, as today, material was

deposited by streams and wind; much was deposited in lakes (see cross-sections I-I' and K-K'). Streams from late Pleistocene glaciers added more gravel to the Mount Rose fan. Glacial outwash 2 (50,000-150,000 years old) spread out from glaciers in Galena Creek and spilled down Brown's creek. Smaller glaciers on Slide Mountain dumped coarse bouldery gravel into the major creeks which deposited the gravel in deep fan on the floor of Washoe Valley. Younger ice advances about 10,000 years ago left moraines (glacial moraine 4), but the outwash was less extensive than that from earlier advances.

Faulting continued during this time as the Carson and Virginia Ranges rose higher relative to the valleys. A few blocks of older alluvial deposits were caught up between faults, mostly along the margins of the valleys, and thus were exposed to erosion.

The most recent unconsolidated deposits reflect the desert climate prevailing today to the east. Deposits on the east side of Washoe Valley and locally on the west side and on Steamboat Hills are rich in windblown sand. Rain is scarce, and only an occasional storm flushes debris down the creeks to mix with the sand. On the west side of the valley, numerous streams continually carry sand and gravel down from the Carson Range and spread them out in Washoe and Pleasant Valleys, where the windblown sand is lost in the rapidly accumulating stream deposits.

Much of what has happened in the Washoe Valley area in at least the third period of its geologic history may happen again during man's occupation of the valley. In the descriptions that follow, we have emphasized the malefic processes by grouping their deposits under one heading. The geologic story still goes on in Washoe Valley.

DESCRIPTION OF BEDROCK

Metamorphic rocks

Metamorphosed sandstone, shale, conglomerate, volcanic tuff and breccia, and minor impure limestone crop out in steeply dipping north-trending beds in the northeast quarter of the quadrangle. Most of these rocks are thermally metamophosed, and near the contact with granodiorite they are completely recrystallized to black hornfels or mica phyllites. Slatey clevage runs parallel to the intrusive contact northeast of New Washoe City. The occurrence of slate and hornfels east of Pleasant Valley suggests that the intrusion lies not far below, an inference supported by some water-well data (see Cross-Sections Sheet, cross-sections C-C' and D-D'). Metamorphism is less intense north of Pleasant Valley, although the granodiorite is exposed just north of the quadrangle (Thompson and White, 1964, p. 1)

Detailed descriptions and chemical analyses of the metamorphic rocks are given by Thompson and White (1964, p. A4-A10), who suggested that the rocks may be of Triassic age or older on the basis of their similarity to fossiliferous rocks of nearby areas. The metasedimentary rocks are tightly folded, but a few observations of graded beds suggest that the sequence tops mostly to the west. Fairly continuous major rock units are probably present, as indicated by broad bands on color aerial photographs, but we were unable to find differences in the rock on the ground except for one narrow, discontinuous bed of volcanic breccia and conglomerate.

Rocks formed from melts

Hornblende-biotite-granodiorite

The granodiorite of the Sierra Nevada batholith in the Carson and Virginia Ranges is remarkably uniform. Except for a shattered chalky zone along the east side of the Carson Range, for local areas of faint lineation formed by alined hornblende or aggregates of hornblende and biotite, and for concentrations of pegmatite or aplite dikes, the granodiorite differs little from one place to another. Thompson and White (1964, p. A5, A10-A11) described the granodiorite and gave chemical data on it. Modal data for representative samples are given in figure 2.

Prominent joint sets break the granodiorite into rectilinear blocks. The most common trend of joints in the Carson Range is north-northeast, with steep inclination. Joints are not so obvious in the Virginia Range, although the rounded boulders left scattered on the surface by disintegrative weathering of the granodiorite were once bounded by joints.

Disintegration by weathering of the granodiorite to angular coarse sand is a striking feature of the granitic terrane, especially on the east side of Little Valley and in the Virginia Range. The granodiorite may be disintegrated to depths of 15 m or more, but most cuts in disintegrated rock reveal scattered hard blocks within the weathered rock and a very irregular contact between fresh and disintegrated materials.

K-Ar ages on biotite indicate that the batholith cooled during the Late Cretaceous. A biotite age for fresh-appearing fine-grained hornfels collected within 200 m of the granodiorite contact is 83.6 ± 1 m.y., and a biotite age for somewhat altered granodiorite from a drill core collected about 170 m below the surface of a quarry northeast of New Washoe city is 74.7 ± 1 m.y. (table 1); alteration of the granodiorite may account for the younger age. Evernden and Kistler (1970, pl. 1) reported similar Late Cretaceous ages for granitic rocks of the Carson range south of the quadrangle.

Table 1--Radiometric Ages of biotite from granodiorite

Sample	K_2O [1/] (wt percent)	$^{40}Ar_{rad}$ (mole/g)	$^{40}Ar_{rad}/^{40}Ar_{total}$	Age (m.y.)
RWT 129-73	9.12 9.08 9.06	1.148×10^{-9}	.856	83.6 ± 1
WL-1-560	8.92 8.94	1.021×10^{-9}	.921	74.7 ± 1

[1/] Flame photometric analyses by L. Schlocker.

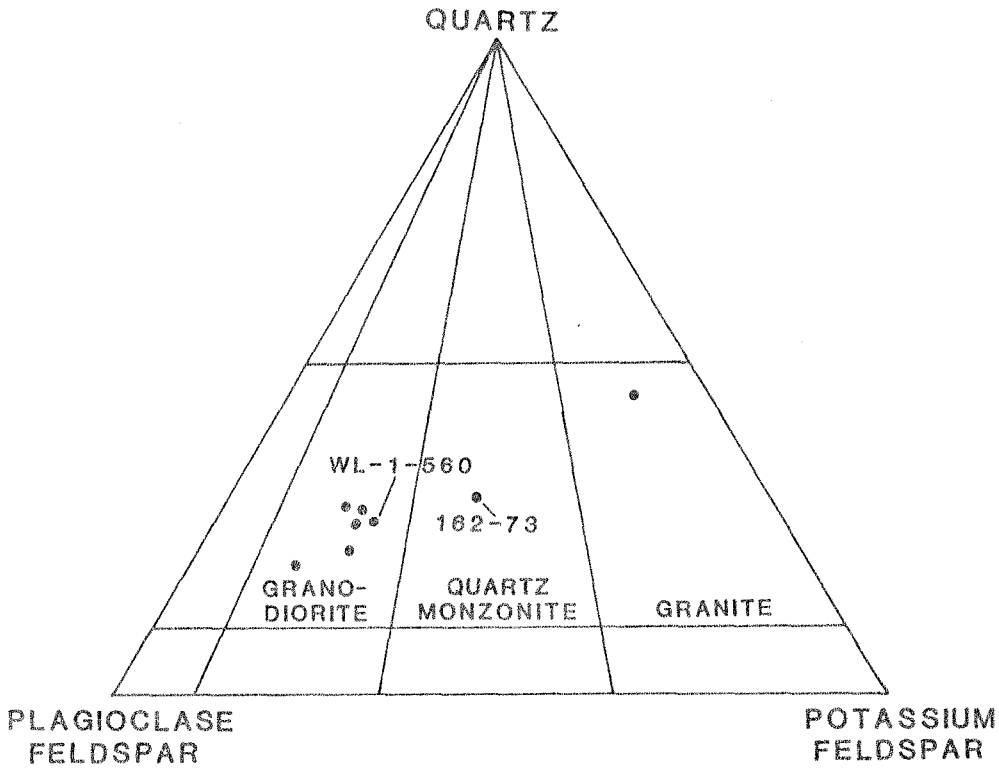


Figure 2.--Modal composition of hornblende-biotite granodiorite from Carson and Virginia Ranges. 162-73 is an atypical phase (about 2% biotite) exposed in lower Franktown Creek. Sample WL1-560, dated as 74.7 m.y., is from drillcore obtained north of New Washoe City.

Shallow seismic refraction profiles and water-well data indicate that granodiorite underlies the Mount Rose fan and parts of Pleasant Valley (cross-sections C-C',D-D', and E-E'. Granodiorite probably floors the basin of Washoe Valley (cross-section H-H' through K-K', although relatively thin layers of andesitic volcanic rocks possibly overlie the granodiorite buried by alluvium. A magnetic high found by a regional aeromagnetic study (Dempsey and Vargo, 1965) suggests that the contact between the granodiorite and metasedimentary rocks that is exposed north of New Washoe City swings north on the west side of Little Washoe Lake (fine dotted contact on Geologic Map).

Hornblende dacite porphyry dikes

Gray to black dacite dikes 2 to 6 m thick cut the granodiorite with sharp contacts. They are difficult to distinguish in the field from andesite dikes of the Kate Peak Formation. The dacite dikes contain phenocrysts of plagioclase, hornblende, and quartz (generally strongly resorbed) in a fine-grained holocrystalline groundmass of quartz, plagioclase, potassium feldspar and opaque and alteration minerals. The dike on Steamboat Hills contains groundmass clinopyroxene.

Rhyolite tuff shown as the Hartford Hill Formation on the geologic map

A small area of distinctive purple rhyolite float on the east edge of the quadrangle indicates an underlying rhyolite ash-flow tuff, which is extensively exposed less than 2 km to the east in the Virginia City quadrangle. The rhyolite was described as the Hartford Hill Rhyolite Tuff by Thompson (1956, p. 50) and Bonham and Papke (1969, p. 23-25). Recently, this name has been abandoned in favor of a refined subdivision (Bingler, 1978), but we do not know where the rhyolite in Washoe Valley falls in the general rhyolite section. The rhyolite is of early Miocene Age on the basis of stratigraphic relations and radiometric dates (Bonham and Papke, 1969, p. 25; Bingler, 1978, p. D1-D5).

Alta Formation

Volcanic rocks assigned to the Alta Formation crop out in only a few small areas of the Washoe City quadrangle, but much of the Alta is exposed nearby in the Virginia Range to the east, where it overlies the rhyolite tuff. The Alta Formation has been described in detail by Calkins (1944, p. 12-15), Thompson (1956, p. 51-52), Thompson and White (1964, p. A12), and Bonham and Papke (1969, p. 25-28). Its age is early or middle Miocene on the basis of stratigraphy and radiometric dates (Bonham and Papke, 1969, p. 27-28; Whitebread, 1976, p. 6).

In the Washoe City quadrangle, outcrops of flows, tuffs, and breccia of the Alta Formation are dark purple, green, gray black, and brown. Flows are generally highly and irregularly fractured, but some flows have well-developed columnar joints. The rocks are mostly hornblende andesite, but include some dacite and some black, somewhat glassy soda trachyte (Thompson and White, 1964, p. A12) that crops out on the north side of Steamboat Hills. The volcanic rocks are commonly highly altered to sericite, calcite, chlorite, and clay minerals, in contrast to the unaltered overlying Kate Peak Formation. However, on the north side of Steamboat Hills some rocks mapped with the Alta are relatively fresh and very similar to the Kate Peak Formation. A highly

altered white dike in Galena Creek is similar to the Alta in all respeects except for a high potassium feldspar content in the groundmass.

Kate Peak Formation

The Kate Peak Formation is mostly black, brown, and red hornblende-pyroxene andesite in flows and bedded breccias. The formation characteristically contains phenocysts of plagioclase and clinopyroxene in a fine-grained holocrystalline to partly glassy groundmass rich in plagioclase, pyroxene, and opaque ore minerals. Many flows contain phenocrysts of hornblende or pseudomorphs of magnetite after hornblende, and a few contain hypersthene and, more rarely, olivine.

The Kate Peak and its regional relations have been thoroughly described by Thompson and White (1964, p. A12-A15), White, Thompson, and Sandberg (1964, p. B23-B25), and Bonham (1969, p. 31-37). On the basis of K-Ar ages for hornblene and biotite from flows and intrusive rocks of the Kate Peak, the formation is middle Miocene (Bonham and Papke, 1969, p. 132; Whitebread, 1976, p. 6).

In the Steamboat Hills area, crudely bedded to well-bedded breccias of the Kate Peak unconformably overlie older rocks, predominantly pre-Cretaceous metasedimentary rocks (cross-section C-C'). The breccias are overlain by as much as 120 m of andesitic flows. In most other areas of the quadrangle, the exposed Kate Peak is either mostly breccia or interbedded breccias and flows, although exposures in the interbedded terrane are so poor that the existence of flows is inferred from concentrations of a single variety of andesite in the slope rubble.

A bold outcrop of strongly flow banded, glassy pyroxene andesite on the east boundary of the area may be part of an extrusive dome. The conspicuous flow banding dips east, whereas breccias exposed just to the north of the mass dip west. Thompson and White (1964, pl. 1) indicated that the body is intrusive, but the absence of flow banding parallel to contacts and the glassy texture suggest that it is a dome, partly eroded, buried by breccias, and now partly exhumed.

Andesitic dikes of the Kate Peak are generally gray to black, with large phenocrysts of plagioclase and (or) small prisms of shiny hornblende. The dikes are partly glassy or entirely crystalline.

Basalt

A small area of red to black olivine basalt erupted on the northeast side of Steamboat Hills. This rock was included in the Lousetown Formation by Thompson and White (1964, p. A17) and White, Thompson, and Sandberg (1964, p. B35), although the basalt was considered Pleistocene, significantly younger than Lousetown at its type locality about 9.5 km north of Virginia City. The rock ranges from dense to highly scoriaceous; some flow tops are ropy. Whole-rock K-Ar ages of about 2.5 m.y. (Silberman and White, 1975, p. 1272-1273) obtained on a sample collected just north of the Washoe City quadrangle place the flows in the Pliocene.

Steamboat Hills rhyolite and associated deposits

The rhyolite dome on the southwest side of Steamboat Hills is at the southwest end of a line of domes extending across Truckee Meadows (north of the quadrangle). The Steamboat Hot Springs bubble up northeast of the dome on the same line, a feature suggesting that the linear source of the rhyolitic magma is still hot (White and others, 1964, p. B37-B38); the rest of the dome is mantled with coarse pumice fragments as large as a third of a meter across. Sanidine from the dome yields a K-Ar date of 1.2 ± 0.1 m.y. (M. L. Silberman, written commun., 1973; Silberman and White, 1975, p. 1272-1273), indicating a Pleistocene age.

Around the base of the dome is a partially indurated deposit of angular granule- to pebble-size fragments of pumice and metamorphic basement rock. The abundance of metamorphic rock fragments, best seen in exposures on the north side of Steamboat Hills, suggests explosive excavation of a large mass.

DESCRIPTION OF UNCONSOLIDATED UNITS

Material mostly deposited by streams

Old alluvium

Old alluvium no doubt underlies younger units in much of Pleasant Valley and Washoe Valley. Where exposed, its orange silt, sand, and gravel generally contrast strongly with the gray and white younger sediments. Most clasts in the old alluvium are weathered and clay coated; granitic clasts are completely rotten. Bedding is well developed at only a few exposures. Although Thompson and White (1964, p. A24) stressed the advanced development of soil on old alluvium, which they called pre-Lake Lahontan (pre-Tahoe Glaciation), we found well-developed soils in only two places. The main criteria that we used to separate older from younger alluvium are: weathering, mostly expressed by disintegration of granitic rock types; degree of erosion; and tectonic deformation, mostly faulting. Up-faulted old alluvium just west of Washoe Lake at the south boundary of the area does have well-developed soil (prismatic dark A horizon at least 0.5 m thick over a B horizon thicker than 1 m, with caliche). Dark soil with a calcareous B horizon is less well developed locally on patches of old alluvium near the southeast corner of the quadrangle. These patches appear to be upfaulted slivers of slope wash and of bedded gravel and sand that were deposited by streams on the basin flats. On the other hand, old alluvium with little soil appears to be faulted against granodiorite in NW1/4 sec. 15, T. 16 N., R. 19 E.

Hummocky topography west and southeast of Little Washoe Lake and a few exposures of bedded gray-green to orange clay-coated sand and gravel suggest terrane underlain by old alluvium, although a thin cover of mostly windblown sand makes the exact origin of these deposits uncertain.

Well-rounded cobbles and pebbles of granodiorite and volcanic and metamorphic rocks on two hills in and near New Washoe City appear to be remnants of old alluvium. Thompson and White (1964, p. A44) proposed that this gravel was related to an old pediment surface, although the gravel could also be derived from Jumbo Creek, deposited when the creek was eroding at a higher level than today.

A scattering of rounded granite cobbles in a broad divide east of Little Washoe Lake indicates another patch of old alluvium. The main valley drainage may have crossed this divide before formation of the gorge now occupied by Steamboat Creek to the west.

The old alluvium deposits probably have a great age range. Those with well-developed soils are probably pre-Lake Lahontan or pre-Tahoe, as suggested by Thompson and White (1964, p. A24), who compared these soils with those described to the east by Morrison (1964). The other old alluvium may be considerably younger.

Unbedded pebbly sand

Well-rounded pebbles and cobbles in a loose, coarse-sand matrix form a bar-like ridge southeast of Little Washoe Lake. Absence of pronounced weathering suggests that this material may be younger than most other old alluvium, but the material is unique and its origin is unknown.

Basin alluvium and slope deposits

Small basins, mostly in the Carson Range, are filled with coarse granodioritic sand and gravel. Processes of deposition here may be similar to those now building fans on the west side of the main valley.

Well-bedded gray sand exposed at 2080 m in an artificial creek in Little Valley overlies red oxidized sand (old alluvium?). Both the gray and red sands contain carbonized wood fragments. A sample of carbonized wood collected from gray sand just above the red sand gave a ^{14}C age of 2060 ± 175 years before present (B.P.) (table 2).

Table 2--Radiometric ages of carbonized wood fragments

Age determinations by James Buckley of Teledyne Isotopes, Inc.

Sample	^{14}C (per mil)	Age (years)
RWT 98-73	-226 ± 17	2060 ± 175
RWT 132-73	- 44 ± 9	360 ± 80

Deltaic deposits

Streams entering Washoe Lake are building deltas of well-bedded very fine to coarse sand. We mapped the extent of these deposits by their dark colors on aerial photographs, features that probably indicate water close to the surface.

Materials mostly deposited by wind

Old windblown sand

East of New Washoe City, brown to well-sorted medium to coarse sand and scattered wind-faceted pebbles as large as 10 cm in diameter are exposed in the banks of an unnamed, mostly dry creek reaching the flats near Pershing Drive. The sand is predominantly composed of very well rounded, frosted grains of quartz and feldspar with coarser granules of volcanic and metamorphic rocks. Broad tongue-shaped swells paralleling the creek suggest the extent of the deposit, although the deposit is mostly overlain by more recent windblown material (see section entitled "sand, undifferentiated"). Although the role of wind in forming this deposit is primary, the coarser clasts may represent material contributed by the creek that at present cuts into the deposits.

Old sand dunes(?)

Small, irregular vegetated mounds along the east side of Washoe Lake north of the boat ramp are composed of dark-brown fine to coarse sand. Sand from a mound just north of the ramp contains as much as 40 percent gray rounded grains of volcanic rock completely altered to clay; the slight height of the mounds above the surrounding terrain suggests a sand dune origin.

Sand, undifferentiated

Large areas east of Washoe Lake are overlain by rather nondescript deposits of light- to dark-brown loose, fine to very coarse sand with rare pebbles or cobbles. Much of this material is windblown, as indicated by the sorting and rounding of the grains; wind-faceted pebbles are common. Although this sand mantles almost all the desert terrain, it is mapped only where it forms the dominant surficial material, probably thicker than 1 m thick and more or less continuous.

Carbonized wood fragments from a small patch of undifferentiated sand east of Washoe City yielded a ^{14}C age of 360 $\pm$ 80 years B.P. (table 2).

Windblown sand and dunes

Gray to white, loose, relatively well sorted fine to coarse quartz-feldspar sand fills shallow swales in the Virginia Range, commonly in the lee of the ridges of rises blocking southwesterly or westerly winds. Depth of this material probably ranges from less than 1 to about 4 m. Because we identified windblown sand on the basis of color in aerial photographs, the sand may be more extensive than shown; it grades into other mantling materials, mostly undifferentiated sand.

Dunes along the east side of Washoe Lake are composed of angular, generally fine-to coarse-grained quartz and feldspar in poorly developed to well-developed beds, dipping northeast, that are mostly bare of vegetation. We have no data to indicate that the dunes are moving or growing eastward, but we may assume that they are.

Lake deposits

Old lake deposits

Thin beds of fine sand and silt, locally diatomaceous, are best exposed in a ditch northwest of Washoe City. Thompson and White (1964, p. A25) included some old lake deposits in their pre-Lake Lahontan unit and reported diatom identifications consistent with an early Pleistocene age assignment. The lake deposits interfinger westward with the sand facies of the Mount Rose fan, which has been shown to be about 0.5 m.y. old. West of Little Washoe Lake (W1/2NW1/4 sec. 24), an elongate patch of old lake deposits is mislabled "deltaic deposits" on the geologic map.

East of Washoe Lake, old strand lines and water-well data indicate a considerable area underlain by unexposed lake deposits, shown on the map as thin undifferentiated sand. The old lake deposits likely extend to the north under thicker undifferentiated sand as well (cross-section I-I'. The old strand lines generally parallel the present lakeshore, a relation indicating that they formed when the lake stood higher than today.

Lake deposits

The youngest lake deposits of mud and sand are exposed around themargin of the lake. This material may overlie a variety of other deposits, and some areas mapped as lake deposits include wave-cut benches in other materials.

Glacial deposits

Large amounts of silt, sand, gravel, and boulders were deposited along the east side of the Carson Range by Pleistocene glaciers and their melt streams. The most extensive glacial-moraine and outwash deposits are in Browns and Galena Creeks. Thomposon and White (1964, p. A20-21) described the major glacial deposits, and their description of oldest glacial deposits and of Tahoe and Tioga Tills applies well to units mapped here as glacial moraines 1, 2, and 4, respectively (see descriptions of units, Geological Map). The main criteria that we used to distinguish moraine ages are nested relations and degree of erosion, although we also used overall degree of weathering where this was consistent with the other criteria.

Glacial moraines

The oldest moraine (glacial moraine 1) is highly weathered and eroded to inconspicious mounds; the granitic rocks are entirely rotten and rarely seen on the surface. Younger moraines have distinct ridge forms, and the granitic rocks are much fresher and harder. In glacial moraine 2 (probable Tahoe age), the granitic rocks are rotten to partly rotten beneath the surface. The surface granitic rocks, though weathered and rounded are generally hard. We identified glacial moraine 3, localized above upper Price Lake (fig. 3) and along upper Galena Creek, as separate ridges only; the deposits are indistinguishable from those of glacial moraine 2. Small moraines of glacial moraine 4 (probable Tioga age) are generally sharp creasted and covered with many fresh angular granitic boulders; buried boulders are mostly angular and mostly fresh. Moraines mapped as undifferentiated are not nested and (or) are ambiguously weathered and eroded.

The nested relations, overall distribution, erosion, and weathering of the moraines indicate that glacial moraines 2 and 4 probably correspond to the Tahoe (about 126,000-62,000 years B. P.) and Tioga (about 62,000-9800 years B. P.) Glaciations, as suggested by Thompson and White (1964, p. A20-A21; absolute ages are from Burke and Birkeland, 1979, p 21-51). The probability that the coarse bouldery facies of the Mount Rose fan is outwash associated with glacial moraine 1 and consists of deposits associated with one or more pre-Tahoe Glaciations is discussed below. Unvegetated neoglacial moraines occur upvalley from glacial moraine 4 (probable Tioga age) west of Hidden Lake.

Glacial outwash deposits

Glacial outwash deposits 2 and 4 are associated with and downstream from moraines of the same age. Glacial outwash 4 cannot be easily distinguished on the surface in Galena Creek, and granitic boulders in glacial outwash 4, which overlies deposits of glacial outwash 2, may extend farther out onto the Mount Rose fan and may be present in Browns Creek.

Deposits of the Mount Rose fan

Between Reno and Washoe Valley, a broad bouldery surface slopes eastward from the Carson Range; the even slope of the surface is best appreciated from Mount Rose Highway (Nevada State Highway 27), which climbs the fan near the north boundary of the quadrangle. We have called this feature the Mount Rose fan, a term here used descriptively, because the overall origin of the surface is probably much more complex than simple alluvial-fan in accumulation (see Thompson and White, 1964, p. A43). A large part of the fan in the Washoe City quadrangle is covered by glacial outwash 2 or the Tahoe(?) Glaciation.

Coarse bouldery debris with minor silt and sand makes up the Mount Rose fan northwest of Little Washoe Lake. The boulders are mostly granodiorite and volcanic rock with minor metamorphic rock. Boulders in Bowns Creek are as large as 2 m across. The granitic boulders are thoroughly rotten and rarely found on the surface of the fan, although the fan is littered with granitic sand from disintegrated boulders. Locally, clasts are predominantly of volcanic rock resembling Kate Peak lavas, and the matrix is tuffaceous.

In a ditch northwest of Washoe City, coarse rubble of the fan intertongues with beds of fine to coarse sand that in turn interfingers eastward with lakebeds of laminated silt and sand rich in diatoms. A thick section of thin-bedded silt and sand, somewhat indurated, is exposed north of lower Browns Creek. In this section are interbedded white glassy tuffs essentially identical in trace-element composition to a pumiceous tuff erupted near Mount Lassen, California (Sarna-Wojcicki and others, 1977). A fission-track age on zircons from the tuff in Washoe Valley is 860,000 $\pm$ 240,000 years but paleomagnetic data and new age data on the correlated pumice tuff of the Lassen region place the age at about 450,000 years B.P. (Meyer and others, 1980). We cannot explain the age discrepancy but accept the chemical correlation and the more thoroughly investigated younger age.

Sketchy data from water wells in the area of Callahan Ranch Road suggest that the fine-grained facies of the fan largely underlies the bouldery materials (cross-sections D-D' and E-E'). White, Thompson, and Sandberg

(1964, p. B39-B40) also reported sand and pebbly gravel from the lower horizon of the fan in drill holes near Steamboat Hot Springs. The fine-grained facies may have been deposited in or near lakes that occupied a basin west of Steamboat Hills.

Bingler (1975, p. 3) proposed that the Mount Rose fan was glacial outwash formed during the Donner Lake Glaciation (Illinoian). Thompson and White (1964, p. A24) considered the bouldery deposits to be older, that is, pre-lake Lahontan (pre-Tahoe) or Sherwin (early Pleistocene) on the basis of weathering and soil deelopment. However, studies south of Washoe Valley along the east side of the Sierra Nevada (Clark, 1967, p. 49-57; Sharp, 1968, p. 361-362) and to the north in the Truckee River drainage (Birkeland, 196, p. 812-817) suggest that several early Pleistocene glaciations occurred, any one of which could correlate with glacial moraine 1 and (or) outwash from the Mount Rose fan. The revised age of 450,000 years for the tuff in the base of the fan makes one of the latter correlations more likely.

Glacial outwash, undifferentiated

A large, strongly convex fan on Winters Creek at the foot of the Carson Range, deeply incised by the creek, is made up of sand and granitic boulders as large as 3 m across. Surface boulders of granitic rock are highly weathered and some are rotten throughout. Coarse bouldery sand exposed in the creek at about 2100 m is crudely bedded, and the boulders are thoroughly rotten. Both of these deposits appear to be outwash and may well be correlative with the widespread glacial outwash 2 elsewhere.

Glacial outwash and (or) landslide deposits

Deposits in the creek south of Winters Creek may be outwash, but they occur in long ridges that could also be the remains of a debris flow. A cnvex fan in a small creek north of Jones Creek is sprinkled with granodiorite boulders, although only a little granodiorite is exposed at the extreme upper end of the drainage, which shows very little evidence of glaciation. This material may be glacial outwash 2 from small glaciers high on the mountain, but it could also be of landslide origin. Unsorted granitic rubble west of Lower Price Lake is surrounded by debris-flow deposits to which it is similar, but it could be part of glacial moraine 2 (unlabeled) at the extreme edge of the quadrangle (see section entitled "Slide Mountain debris flows" and fig. 3).

Deposits formed by malefic processes

Some deposits in the Washoe Valley area have been created by processes that can be harmful to both people and structures. Landslides, rockfall avalanches, debris flows, and floods have created such deposits and will do so again. Some malefic processes are catastrophic: they happen very rapidly even by man's standards.

Landslides, as the term is used in this report, are more or less coherent masses of rock or soil that have moved downslope at rates that range from barely perceptible to as much as several meters per day. A debris flow is a more rapid downvalley flow of loose rock and soil. Rockfall avalanches, also called sturzstroms (Hsu, 1975), are a type of debris flow generated by the fall of enormous masses of rock from steep mountainsides, the fallen material

flowing downcanyon at velocities commonly exceeding 100 km/h (Hsu, 1975, p. 130). Wet debris flows occur where a mixture of debris and water forms a thick, concrete-like slurry that flows downslope or downcanyon at velocities generally as high 20 km/hr (Hsu 1975, p. 130). Wet debris flows grade into flows of waterborne debris, which in turn grade into floods as the amount of water increases in proportion to the weight of debris.

We have mapped deposits of debris flows and Holocene floods separately, but most of the material of alluvial fans--excepting the windborne fraction--is deposited by both debris flows and floods, so that fans are included here with the deposits of malefic processes.

Alluvial fans

Fans built into Washoe Valley from the west are composed of partly bedded, angular, fine to coarse granodioritic sand, deried from disintegration of the granodiorite bedrock of the Carson Range, that has been carried onto the valley floor and spread in broadly convex fans by periodic floods and debris flows issuing from the canyons of year-round streams. The fan and interbedded lake deposits range from less than 1 to more than 600 m thick on the basis of gravity studies of the valley (see Cross-section Sheet), and interfinger eastward with fine sand and silt of the deltaic and lake deposits.

The broad fan deposits of Pleasant Valley are mostly bouldery gravel and sand. The sand fraction is generally finer grained on the east side of the valley. The fan of Galena Creek is at least 6 m higher than that of Steamboat Creek; the two fans are separated by a steep, eroded escarpment. Well-sorted, well-bedded volcanic ash and fine quartz sand lenses are exposed in the escarpment out into the Galena Creek fan. Very fine to coarse-grained deposits forming fans east of Washoe Lake are predominantly granodioritic sand, much of which is windblown.

Pebbly to bouldery sand in mostly steep sided fans is deposited at the mouths of several gullies or canyons that generally have little or no running water. Addition of coarse materials to these fans is probably sporadic and catastrophic. The Jumbo Creek fan is mostly composed of fine to coarse sand with scattered pebbles and gravel lenses. We mapped the extent of the fan by its greater content of coarse pebbles in comparison with surrounding deposits. Some water is always present in Jumbo Creek canyon to the east, but much of the Jumbo Creek fan has been built by the sporadic storms that feed the creek

Old landslide deposits

We recognized deposits of some old landslides by their morphology of flats and escarpments, similar to a giant stair; of others, by their hummocky topography with or without a concave scar at the head. Much of the old landslide debris in the Carson Range is unsorted rubble, partly to highly weathered. The old landslide on the northeast side of Slide Mountain has very subdued, hummocky topography, but the concavity of the scar is quite visible on aerial photography.

The large old landslide on the north side of Pleasant Valley is hummocky, outlined at the upper end by a prominent scarp; individual blocks in the slide

are very large, though shattered. The ages of the old landslides probably cover a wide span of Pleistocene and Holocene time.

Young landslide deposits

Fresh scarps are associated with only a few small landslides, excluding the rockfall avalanches of Slide Mountain. These slides consist mostly of unsorted angular debris. The age of sliding is unknown, but features are much fresher than those of the old landslides. A possible incipient slide constitutes the hillside west of Pleasant Valley; irregular bumps and ledges suggest some creep or movement, despite the general continuity of the bedrock structure, This slide is not shown on the geologic map. We recognized it and a few smaller slides after publication of the geoloic map and show them on the geologic hazards map only.

Debris flows

The debris-flow deposits of Slide Mountain are largely the remains of a series of rockfall avalanches derived from the prominent scar in closely fractured chalky granodiorite on the southeast face of Slide Mountain (fig. 3). The deposits commonly consist of an unsorted mixture of blocks of granitic rock in a matrix of silty sand with minor clay, but some deposits consist of granitic blocks as large as 3 m across without matrix.

The rockfall avalanche deposits are characterized by pronounced longitudinal rides as high as 10 m near their margins, and by bulbous frontal lobes that, in some flows, are more than 30 m high. The sequence of flow units shown on the geologic map is based on identification of individual flows or groups of flows and on the manner in which they overlap of crosscut one another. We have identified individual flows by their lobate fronts with concentric ridges, by parallel ridges along the margins, and by contacts where exposed in cross section in the gorge of Ophir Creek.

Both rockfall avalanches and wet debris flows have been responsible for transporting debris downcanyon. Debris flows 1 through 8 are best explained as due to rockfall avalanches because in places the flows display uphill trajectories that could only be caused by high velocities. This interpretation is supported by the association of these deposits with the scar on Slide Mountain and with the partly buried group of slide blocks, outline by fine short dashes on the geologic map and shown in figure 3.

Within debris flows 4 and 5 (geologic map), and perhaps in other flows, are veins of the zeolite stilbite; some veins run parallel to flow contacts, others crosscut the contacts. Blocks of granodiorite are altered to soft material within 1 m of the veins. Similar veins cut shattered granodiorite of the slide blocks in upper Ophir Creek

Much of the stillbite alteration is exposed in the gorge of Ophir Creek on a linear projection of the faults cutting the earlier debris flows along the mountain front. Bowers Hot Spring presumably ascends along a fault system south of Ophir Creek, and hot springs of the same system may have caused the alteration of the debris-flow material. Oxygen isotopic ratios in the stilbite and in water of Bowers Hot Spring are similar (Ivan Barnes, written Commun., 1974). Zeolite alteration of granitic rocks by hot-spring waters along faults has been reported in Colorado (Sharp, 1970, p. B14-B20).

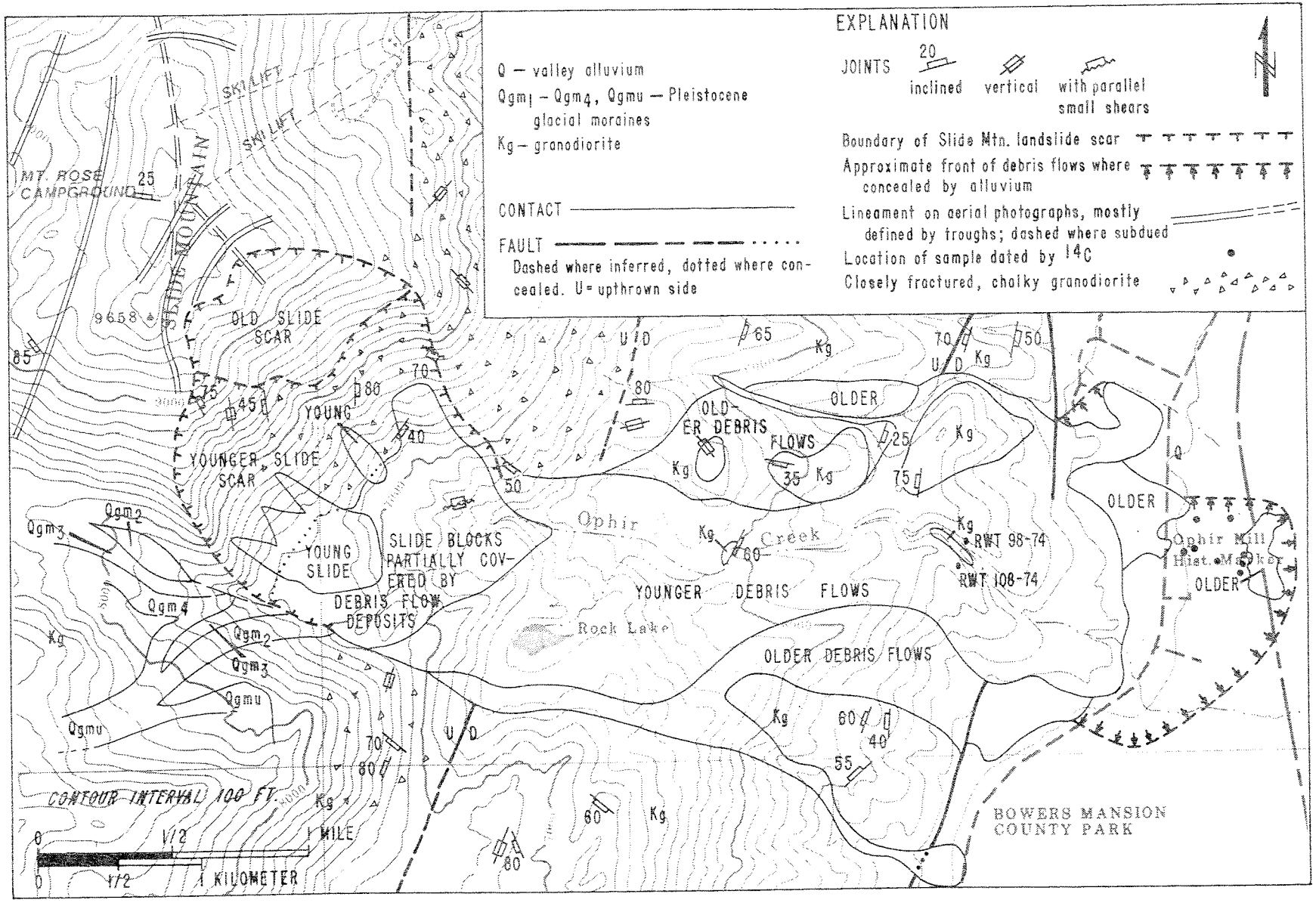


Figure 3.--Generalized map of the Slide Mountain debris flows and related features.

Many rockfall avalanches may have been triggered by earthquakes, which could have loosened and shaken free the weak, fractured granitic rock; the resulting rockfall would become a rapid and devastating flow. Wet debris flows may also be triggered by earthquakes, but these flows require water saturation of loose debris prior to the earthquakes.

Of the eight debris-flow deposits originating as rockfall avalanches, debris flow 1 is considerably older than the succeeding flows; the flow is distinctly more weathered and partly buried in the alluvium of Washoe Valley. Thompson and White (1964, p. A23) estimated debris flow 1 to be hundreds of thousands of years old or older on the basis of similarity in weathering to that of other old deposits, such as those of the Mount Rose fan which we now know to be about 0.5 m.y. old.

A series of nested glacial moraines in upper Ophir Creek (fig. 3) suggest that some slides postdate the Tahoe Glaciation (125,000-62,000 years B. P.). A pronounced ridge of glacial moraine 2 (probable Tahoe age) extends down to the south side of Upper Price Lake. No matching ridge occurs on the north side, although a piece of the matching moraine forms a prominent ridge farther upvalley. The lower end of this ridge may have been torn away by debris flows.

Of the younger flows, debris flows 5 through 8 rushed downvalley within the last 1100 $\pm$ 200 years[1], as determined by a ^{14}C age for carbonized wood debris (sample RWT 108-74; (W3239)) in sediment buried by debris flow 5. Two separate samples of charcoal from deposits at the base of an older flow (debris flow 4) give what appear to be anomalously young ages: 630 $\pm$ 200 (sample RWT 98-A-74; (W3020)) and 550 $\pm$ 200 years (sample RWT 98-B-74; (W3228)). We cannot explain these ages if the samples came from beneath debris flow 4, as we originally thought. The exposed layer of charcoal debris may be part of a younger canyon filling plastered on the steep exposures of the older debris flow. The 1100-year age is more reliable because it is on a sample collected from a nearly vertical exposure where the revealed stratigraphy of the debris flows is certain.

A rockfall or rockfall avalanche from Slide Mountain was reported to accompany an earthquake in 1852 (Slemmons and other, 1965). Thus, all evidence suggests that rockfall avalanches have occurred repeatedly over a long period extending into the recent past. Elongate, curving swales near the crest of the mountain and parallel to the slide scar (fig. 3) suggests cracks bounding incipient slide blocks; very large masses of rock may have been loosened and now stand ready to fall when shaken by future earthquakes.

The youngest debris-flow deposits (debris flow 9), which appear to have been formed by wet debris flows, are smaller than the older flows, are mostly confined to canyon bottoms, and show no evidence of the high velocities associated with rockfall avalanches. This distinction is confirmed by the relation between volume and travel distance in documented flows reported by Hsu (1975), shown in figure 2 of the chapter entitled "Geologic hazards." Volume and travel distances for representative examples of debris flows 1 through 8 lie within the range considered reasonable for rockfall

[1] Age determinations by Meyer Rubin, Branch of Isotope Geology, U. S. Geological Survey, Reston, Va. Sample location in Fig. 3.

avalanches. Deposits of the youngest flows (debris flow 9) are too small in volume to be due to rockfall avalanches and hence must have moved as wet debris flows.

Most of the wet debris flows moved down the valley north of Ophir Creek. Their frontal lobes are well preserved, and the large trees growing on them suggest a minimum age of at least 100 to 200 years. A remnant of flow ridge, shown as debris flow 9 on lower Ophir Creek, may be somewhat older.

The total volume of rockfall avalanche deposits was conservatively estimated by Thompson and White (1964) to be about 0.1 km^3. We estimate that a volume of the deposits must at be least this large.

Talus

Angular blocks of rock, commonly ranging from a few centimeters to 0.5 m in size, form steep slopes below bedrock cliffs. Extensive deposits of this rubble occur mostly at the foot of the slide scar on Slide Mountain, but small patches, commonly included in the landslide deposits on the map, are common elsewhere. The talus may be composed of fresh blocks indicating constant addition of material from above, or of highly weathered lichen-covered and (or) of partly soil- and plant-covered blocks suggesting that deposition ceased a long time ago.

Flood deposits

Deposits of silt, sand, gravel, and boulders with little vegetation, left by relatively recent floods, occur west of Washoe Lake. The deposits are distinctively white on aerial photographs and we mapped them on this basis. The flood deposits are probably more extensive than we have shown because they have been obscured by land reclamation, especially in farm areas. Material east of the canyon mouths is mostly sand; thickness of the flood deposits probably ranges from 1 to 3 m. The deposits in Pleasant Valley are very coarse bouldery gravel.

Miscellaneous deposits

Siliceous sinter and travertine

Siliceous sinter and travertine make up small white patches on Steamboat Hills. White, Thompson, and Sandberg (1964, p. B42) described opaline sinter (SiO_2) similar to the small patch near the northeast corner of the quadrangle. Travertine ($CaCO_3$) mantles the areas shown on the old landslide above Pleasant Valley; the occurrence of similar deposits at Steamboat Springs indicates that these areas were once the sites of hot springs. The age of the springs is unknown; some altered rocks associated with Steamboat Hot Springs are as old as 1 m.y. (Silberman and White, 1975, p. 1273).

TEXT TO ACCOMPANY GEOLOGIC CROSS SECTIONS; GRAVITY AND SHALLOW SEISMIC PROFILES

By

R. W. Tabor and S. Ellen

Introduction

Interpretation of what lies unseen beneath the earth's surface from exposures of rock on it and limited subsurface data requires imagination. Furthermore, all geologic cross sections rely heavily on fundamental geologic concepts of how rocks form. Geophysical data can greatly improve the geologist's confidence in the validity of his interpretation, but the geophysical models are also built on assumptions (see below) that allow great variation in interpretation. The geologic cross sections of the Washoe City quadrangle are based on conventional geologic reasoning and interpretations of surface geology, supplemented by a few shallow seismic profiles and a gravity study. In addition, some drill hole data have been used, most of it from water well logs filed by drill operators with the Nevada State Department of Water Resources. Our interpretation of what the driller reported is at best an educated guess strongly influenced by what we thought should be there.

We gratefully acknowledge the following people for help with the geophysical studies: Floyd Gray and Jose Rivera helped with the seismic traverses; John Coyle helped collect gravity data; Janell Edman collected considerable gravity data and reduced them; Howard Oliver advised and encouraged us through the gravity data reduction process and helped with the modeling; and Bob Sikora and Sharon Allshouse did most of the gravity data reduction.

Geologic Cross Sections

For discussion of the interpretation of the cross sections and the geologic history, we refer the reader to the Washoe City quadrangle geologic map.

Gravity Study

In some situations the nature of rock underlying the surface can be determined by measuring the gravitational attraction of the rock. The measurement of this gravitational force must be done very carfully to detect the small differences in local rock density compared to the huge attractive force of the earth itself. In addition, measurements must be corrected for elevation differences between points (a measurement at a higher elevation is further from the Earth's core, hence records a weaker force) as well as the positive attractive force of hills and "negative" attractive force of valleys surrounding the measurement point. When all these corrections are made to the individual gravity measurements, the result, called the complete Bouguer gravity anomaly, reflects the density of the rock that underlies the measurement point.

Gravity studies in Washoe Valley area were begun in 1952 by Thompson and Sandberg (1958, p. 1269-1281). Additional stations were established by John Erwin, University of Nevada (Erwin, 1973 and written commun., 1975). For this project stations were established largely by Janell Edman in 1974, and supplementary stations by Stephen Ellen in 1975. The Edman and Ellen stations were

measured with La Coste and Romberg gravimeters G102 and G130, respectively, with reading accuracy of .01 milligals.

The gravity surveys by Edman and Ellen are tied to Chapman's (1966) base stations at Stanford University (no. 176) and Carson City (no. 351), respectively, and their data are on the same datum as gravity maps covering adjacent parts of California (Oliver and Robbins, 1974; Oliver and others, 1974). From data obtained by reoccupying a number of stations originally established by Thompson and Sandberg and by Erwin, we determined that datum corrections of plus 4.0 mgal and plus 0.8 mgal, respectively, should be made to the older data. After datum corrections, the four surveys are generally consistent to within 0.1 mgal.

Complete Bouguer anomalies were compiled by methods outlined by Plouff (1966), Oliver (1973), and Robbins, Oliver, and Plouff (1973) using an assumed density of 2.67 g/cm^3 for topography above the minimum station elevation.

The terrain corrections employ a digital model utilizing 1'x1' and 3'x3' averaged elevations and were carried out to a distance of 166.7 km from each station.

Gravity cotours shown on the Washoe City quadrangle were drawn by hand from the stations shown on the map and supplemented by data from surrounding areas. The minimum Bouguer anomaly determined (-205.3 mgal) is located west of Washoe Lake on the boundary of secs. 10 and 11, T.16N.,R.19E.

A two-dimensional model of the subsurface basin structure constructed from the gravity data is shown in figure 4 and section J-J. Modeling was done on a computer following the method of Talwani, Worzel, and Landisman (1959) as modified by Oliver and Plouff (written commun., 1975), assuming a density difference of 0.6 g/cm^3 between the sediments in Washoe basin and granitic country rock.

The assumed 0.6 g/cm^3 density contrast is derived from estimates of the density of probable granitic bedrock of 2.7 g/cm^3 and average sedimentary fill of 2.1 g/cm^3 . The fill consists of at least two facies: aluvial gravel and sand, and lacustrine sand, silt, and clay. Studies in the Mono basin about 150 km to the south (Christensen and others, 1969, p. 5229) indicate that alluvial sediments there probably have an overall density of about 2.3 g/cm^3 and the lake sediments 1.8 g/cm^3 . The mono basin sediments contain much low-density volcanic debris and diatomite. There is evidence of diatomite in the older lake sediments of Washoe Lake and there may be some volcanic ash, but because the drainage basin is smaller than Mono basin, there is likely to be more granitic sand washed in from the peripheral mountains and the 1.8 g/cm^3 figure would be a bit low. If, in fact, the fill of Washoe basin is light because of a high content of diatomite or volcanic ash, the actual basin fill could be shallower than portrayed by as much as 30 percent.

The model further assumes that Washoe Valley is an infinitely long trough, in which case maximum thickness of the sediments in the basin would be about 580 m (1,900 ft). In reality, Washoe Valley is at best an elongage bowl, and the thickness determined in the model is too small by a few percent

The magnitude of the local gravity anomaly associated with Washoe Valley (fig. 4) depends, in part, on what is assumed for the regional gravity

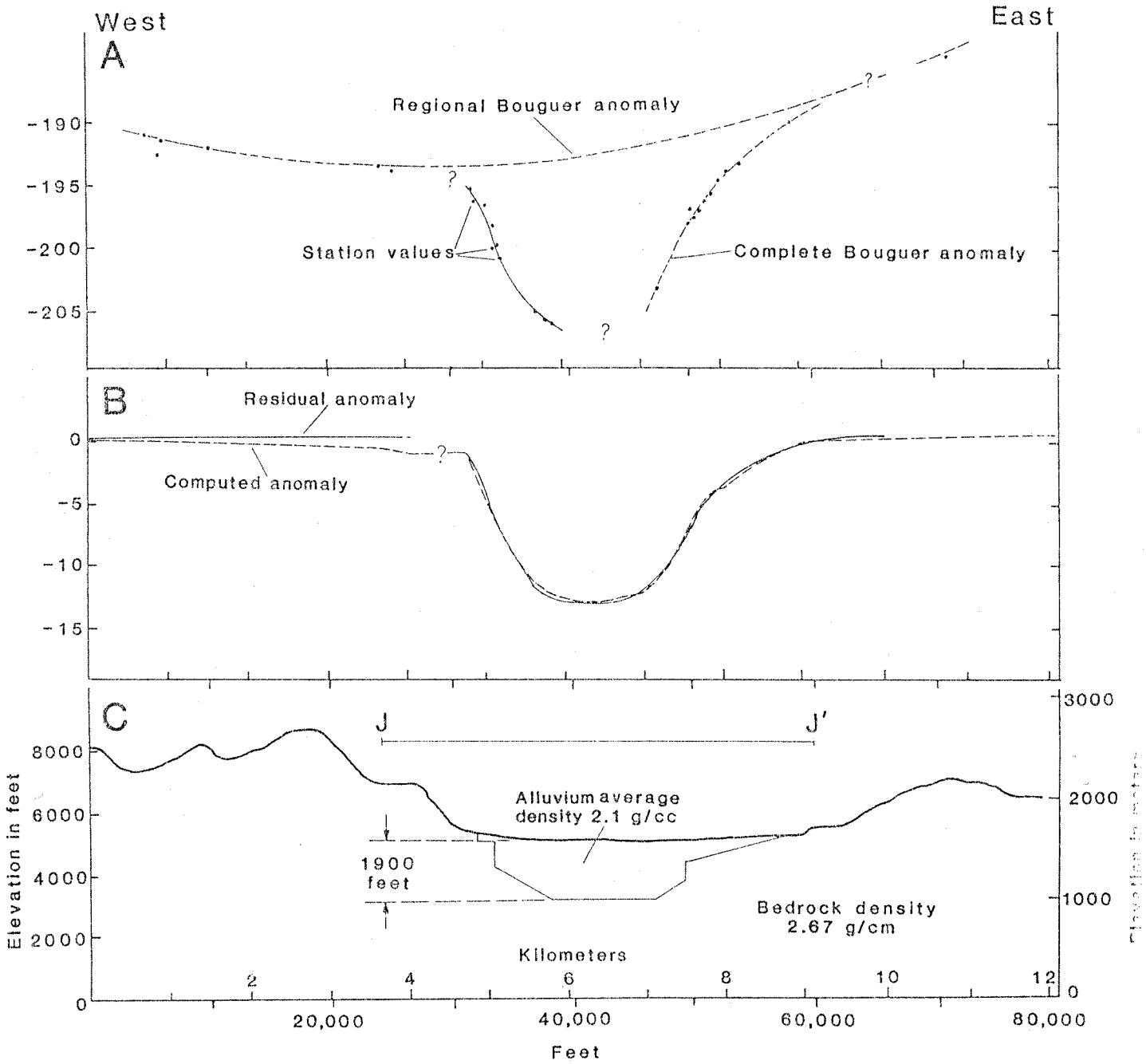


Figure 4.--Gravity profiles and modeled geologic cross section, Washoe Valley. In A, lower curve is complete Bouguer anomaly drawn through values at stations (dots) no more than one mile from cross section and projected into it. Upper curve is regional anomaly projected across Washoe Valley from bedrock stations on either side. In B, residual anomaly derived by subtracting complete Bouguer anomaly from regional anomaly is compared with complete residual anomaly calculated from relationships in model depicted in C, which shows topography and shape of alluvial basin.

gradient. The regional gradient was constructed from gravity stations on bedrock at least 1.6 km (1 mile) from deep alluvial fill, although the gradual downward slope of the computed curve (fig. 4B) on the west towards Washoe Valley suggests the gravitational effects of the alluvial basin are measurable on bedrock farther than 1.6 km from the basin. We then modified the regional profile (fig. 4A) to bring the thickness of the sedimentary wedge on the east side of the valley closer to thicknesses indicated by well and seismic profile data (section J-J). Even without this modification and allowing for a more far-reaching effect of the basin, there is a broad sage in the total Bouguer profile suggesting that some bedrock less dense than 2.7 g/cm^3 lies under the valley at much greater depths than analyzed in this study.

The computed complete Bouguer profile is not everywhere a perfect fit with the observed profile but is fairly close where the control is best. Faults suggested by the configuration of the two-dimensional model are shown in section J-J'. The steep gravity gradient that is interpreted as a buried fault on the east side of J-J' could be explained as a rapid facies change from lake deposits to alluvial gravels, as has been suggested for steep gradients well out in Mono basin (Christensen and others, 1968, p. 5230).

We drew the adjoining cross sections through the valley by analogy with the computed model. Considering the unknowns and assumptions in the model, they are probably about as good as the modeled cross section.

Shallow Seismic Refraction Profiles

We made several shallow seismic refraction profiles in the Washoe Valley area to determine depth to bedrock. The best profiles were used to construct cross sections D-D', E-E' and J-J'. The surveys were made in 1974 with a Bison signal enchancement seismograph. Energy was delivered to the ground by a 182-kg metal ball dropped from various heights up to about 3 m.

Figure 5 summarizes the configuration of subsurface materials interpreted from the time-distance plots. Reverse profiles were not run. In profiles 1, 2, and 3, which run parallel to structures and to the probable depositional slopes, we assumed that the contacts between units are relatively flat-lying and that errors in velocites are small. Profile 4 was run across structure and down the expected dip of contacts; there may be small errors in depth, and assuming a 5° slope of the contact (the slope predicted by the gravity model) up to a 15 percent error in velocities. The profiles are at best approximate. Interpreted stratigraphy for the profiles is compatible with water well data in the same areas.

(revised 1956), which rates the local effects of an earthquake on a scale of twelve designated by Roman numerals. For instance:

Intensity II: felt by persons at rest, or on upper floors, or otherwise favorably placed.

Intensity V: felt outdoors, awakens sleepers, disturbs liquids and spills some, and displaces or upsets some unstable objects.

Intensity XIII: disturbs steering of motor cars, damages masonry of ordinary quality as well as masonry of good quality (not designed to resist lateral forces), moves frame houses on foundations if not bolted down, throws out loose panel walls.

Intensity XII: damage is nearly total. Displaces large rock masses, distorts lines of sight and level, and throws objects into the air.

The intensity of an earthquake depends on the amount of energy released, the distance from the associated fault, the type of underlying deposits or bedrock, and the depth to the groundwater table, which in turn depends on the general climatic conditons and possibly the season of the year.

Estimates of relative severity of shaking in the various deposits of the Washoe Lake area are based on well-documented studies elsewhere that indicate that ground shaking is generally greater in partly consolidated sand and gravel and particularly in unconsolidated fine-grained sand and mud than in adjacent or underlying bedrock (Gibbs and Borcherdt, 1974, p. 40; Medvedev, 1965, p. 51; Borcherdt and others, 1975). The intensity also tends to be greater where the unconsolidated materials are saturated and the water table is close to the surface. Medvedev (1965, p. 49) indicates that the intensity increases from ground where the water table is about 10 meters below the surface to ground where the water is within 1 meter of the surface. Below 10 meters, changes in the depth to the water table have little effect on intensity.

The shaking zones on the map (A through F) are not intended to indicate unit differences in intensity. Present data suggest that there could be a difference of as much as 3 units in intensity experienced on bedrock from that on saturated lake sediments with the water table near the surface (Medvedev, 1965; Gibbs and Borcherdt, 1974, p. 40). This means that if an intensity of V is experienced on the granitic bedrock (zone E) near Washoe Lake, an intensity of VIII may be experienced on saturated fine-grained lake sediments (zone A). Because the severity of shaking increases nearer to the fault, the depicted zones of shaking may be modified if an earthquake occurs in or near the quadrangle. The zones are probably appropriate for an earthquake far from the quadrangle. All zones will be strongly shaken within a few miles of the focus of a strong earthquake.

No ground motion studies have been made in Washoe Valley, and surface mapping alone does not directly indicate the nature of the deposits at depth. For these reasons the severity zones of this map are in part based on geologic inference. For instance, the inferred distribution of lake sediments at depth on the east side of the lake is based on ancient shore lines exposed

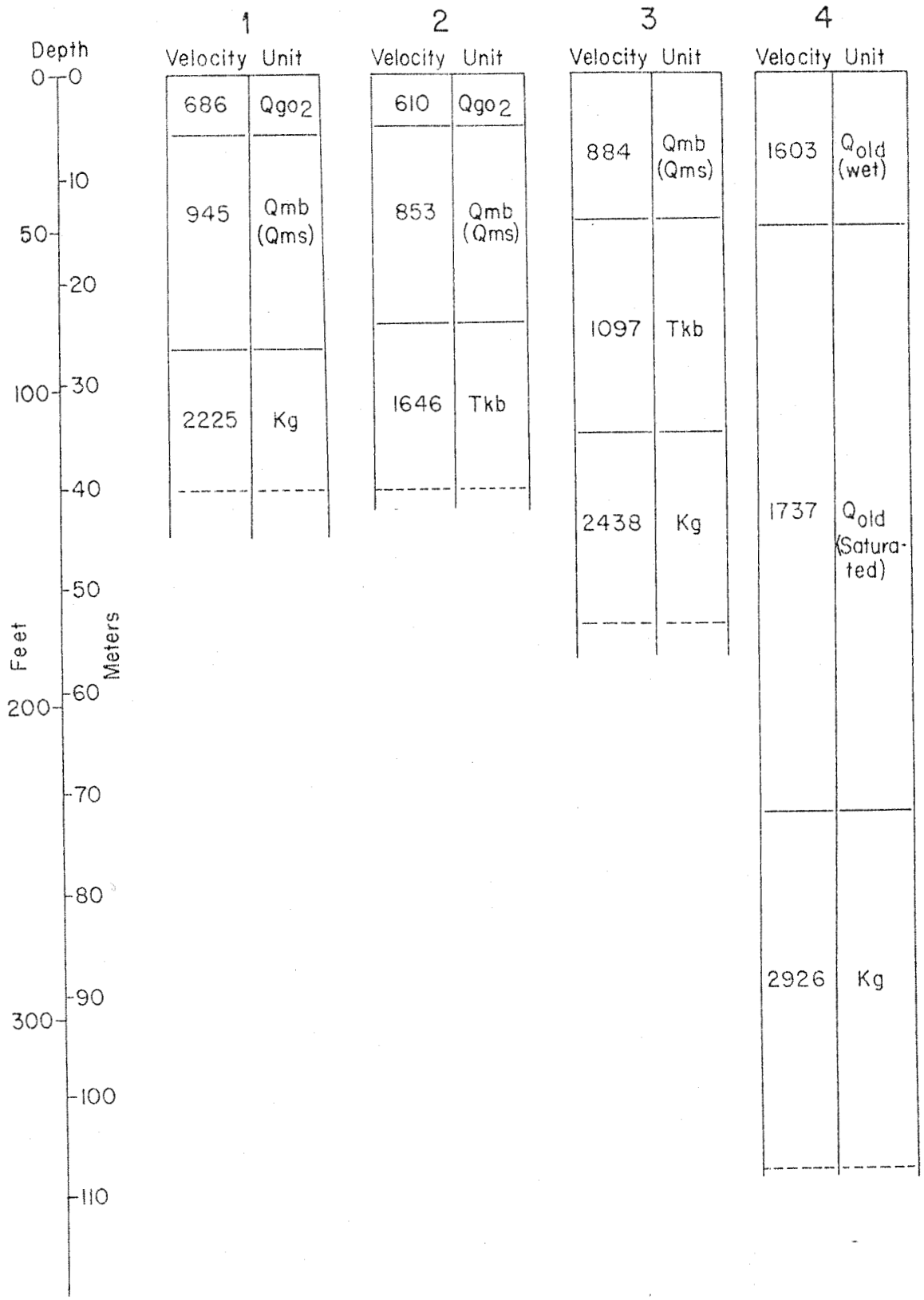


Figure 5.--Summary of Bison Seismograph refraction profiles. Depths and primary wa velocities (in meters/sec) are approximate. Symbols refer to rock units on map.

TEXT TO ACCOMPANY GEOLOGIC HAZARDS MAP

By R. W. Tabor, S. Ellen, and M. M. Clark

The geologic hazards map was compiled from geologic mapping and depicts potential hazards to the lives, works, and activities of people. This map alone does not provide sufficient information for selecting or designing for specific building sites. Individual sites should receive special geologic studies, particularly where hazardous conditions are suggested by this map.

We thank Roger Borcherdt and K. R. Lajoie for considerable help and discussion of earthquake hazards. Frank Jerauld of the U.S. Forest Service, Carson City, Nev., supplied data on known snowslide hazards.

Earthquake Hazard

Earthquakes in the Washoe Lake area are frequent compared to the United States as a whole. Between 1854 and 1960 at least six earthquakes between magnitudes 5 and 6 and many smaller ones have occurred within 20 miles of Washoe Lake (Slemmons, and others 1965a). In 1852, a large earthquake, uncertainly located but with an estimated magnitude greater than 7, reportedly triggered a large landslide from Slide Mountain (Slemmons and others 1965b).

In the Washoe Lake area the hazards from earthquakes fall into three categories: (1) ground shaking, (2) ground rupture along faults, and (3) other ground failure induced by shaking, which includes differential ground settlement and liquefaction failure. Landslides and rockfall avalanches are types of ground failure that may accompany earthquakes but may occur independently as well; we discuss them here separately.

Most earthquakes are produced when strains that have accumulated in the Earth's crust are suddenly released, producing shaking and offsets along fractures in the crust called faults. The severity of shaking at the ground surface depends on the amount of energy released by the movement (proportional to the earthquake's magnitude), the distance from the ruptured part of the fault, and how the intervening rocks and sediments transmit and modify the initial shaking. Magnitude is estimated for each earthquake from seismograph records in surrounding regions. Any earthquake greater than magnitude 5 may cause damage; undoubtedly there will be future earthquakes of magnitude 5 and greater in the Washoe Valley area.

Ground on opposite sides of an active fault will be displaced from the pre-earthquake position by amounts commonly ranging from a few millimeters to several meters. Generally, the greater the magnitude of the earthquake, the larger the displacement. An earthquake may trigger landslides, cause local compaction of sediments with consequent settling of the surface, and through liquefaction make water-saturated sand layers below the surface lose their strength. Each of these hazards is discussed below.

Ground shaking

Severity of shaking can be approximately described by intensity, which measures the effects or damage done at any one place by an earthquake. Intensity commonly is measured by the modified Mercalli Intensity Scale of 1931

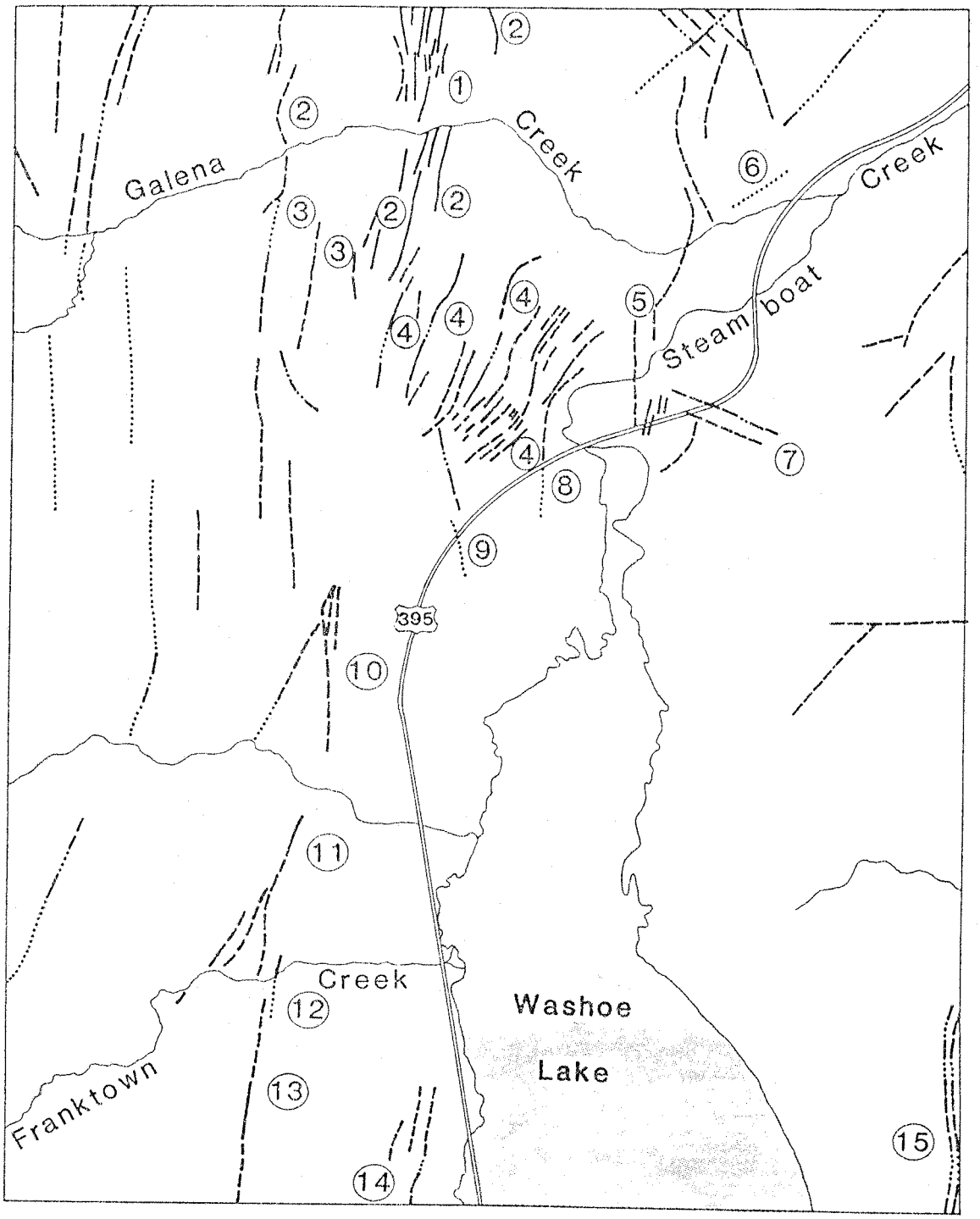


Figure 6.--Location of faults on Geologic Hazards map described by numbered notes in text.

at the surface in the southeast part of the quadrangle and on incomplete water-well data in the New Washoe City area. The lake sediments are overlain locally by less than 15 m of alluvial sand and gravel, which is assumed not to influence the seismic response of the underlying lake sediments. Lake sediments interfinger with the coarser sediments at the basin margins (see cross section sheet, and intensity probably would decrease gradually away from the lake, rather than sharply as indicated by the zone boundaries on the map. Subsurface studies at particular sites would help improve the definition of these boundaries.

West of Little Washoe Lake, old lake sediments are interbedded with alluvial sand and gravel, and sparse and incomplete water-well data west of the main lake suggest that some lake sediments lie more than 40 m beneath the fan sediments. Assuming that sand and gravel from the Carson Range have accumulated rapidly on the west side of the lake over a long period of geologic time, as they appear to be doing today, fine-grained lake sediments probably are less abundant in the alluvial pile on the west than on the east side (see cross section sheet). The effects of such interbeds of fine-grained sediment on the overall intensity are complicated and little understood, but in general the intensity of shaking will be characteristic of the uppermost thick layers, (15 m) in this case sandy alluvium.

Ground Rupture Along Faults

Active faults can be particularly dangerous to structures that have been built directly across them. Few buildings can be designed economically to withstand even a few centimeters of offset without major structural damage. Roads, pipelines and other structures can be severely damaged by ground rupture and offset along faults.

The greatest future hazard, both from surface faulting and accompanying shaking, is likely to come from faults that show the greatest rate of displacement in late Quaternary time. Far more detailed studies than those done so far will be required to determine rate and character of displacement on the faults shown on this map. Until such studies are completed, it would be prudent to assume that faults showing the most recent movement are also those with the greatest rate of displacement, and hence most likely to move again (see Wallace, 1968; Brown, 1970; Clark, Grantz, and Rubin, 1972).

The following notes, referenced by number on figure 6, indicate the evidence for the time of most recent movement along the faults shown.

Notes on Faults

1. Two faults of this group cut terraces in Jones Creek that are as young or younger than the Tioga glaciation (which ended about 10,000 years ago). Most of these faults have scarps 1-3 meters high.
2. Faults are similar to #1 in topographic expression but show no apparent offset of deposits younger than probable Tahoe outwash (50,000 to 150,000 years old).
3. Faults offset late Miocene volcanic rocks (about 12 million years old) and early Pleistocene deposits (about 860,000 years old). Tahoe outwash was probably deposited against the fault scarps or against topographic highs of upraised blocks, but the evidence is not clear.

4. Faults offset early Pleistocene deposits but have topographic expression similar to #1. Some faults appear to be buried by Tahoe outwash. The fault shown extending across Browns Creek apparently brought up bedrock on its east side.

5. Two faults offset probable Tahoe outwash. The eastern fault is expressed by a topographic ridge.
6. A ridge of old alluvium that may be as old as or older than Tahoe outwash (50,000-150,000) has probably been uplifted by a fault now buried by more recent alluvium.
7. Linear features are defined by very slight topographic changes and vegetation. Fault cuts early Pleistocene deposits (of about 860,000 years). Southern fault could be much older.
8. Buried fault is inferred to have uplifted old lake and alluvium deposits on the east. There is no photographic lineament or topographic expression of this fault.
9. Very subtle lineament on aerial photographs suggests a buried fault, which could be in bedrock or buried old alluvium. Fault may control groundwater movement and thus influence vegetation on younger deposits.
10. Westernmost fault of group cutting old alluvium forms faceted spurs on range front and appears to cut third unit of Slide Mountain debris flows (see geologic map). This fault does not cut probable glacial outwash of Tahoe age.
11. Fault is expressed as faceted spurs and lneament on aerial photographs in old alluvium. It offsets oldest unit of Slide Mountain debris flows. Bowers hot spring apparently rises along the fault.
12. Small escarpment at edge of old alluvium may indicate relatively recent movement, but there is no evidence of faulting in young fan deposits or stream deposits on south.
13. Fault is exposed in gravel pit on road to Little Valley (NW 1/4 NW 1/4 sec. 15) and separates bedrock from old alluvium. Lineament on aerial photographs shows extension north and south.
14. Faults cut old alluvium. Two westernmost faults ae expressed as lineaments on aerial photographs only. Eastern fault has pronounced escarpment with probable young deltaic material deposited along base. Old alluvium has thick soil and caliche profile, suggesting that faulting is older than Tahoe glaciation (50,000-150,000 years ago; see text of geologic map). Gravity contours suggest faults extend to bedrock (see geologic cross section).
15. Subtle lineament on aerial photographs and subdued terrace reveal faults. They appear to bound a wedge of old valley alluvium and are locally overlain by younger steep fan deposits. Well-developed soil on old upraised alluvium suggests faulting is older than Tahoe glaciation (50,00-150,000 years ago). Several springs are alined on the faults.

Most unnumbered faults cut Kate Peak volcanic rocks, which are as young as 12 million years old. Faults cutting granodiorite on the east escarpment of the Carson Range may have been active during uplift of the Sierra Nevada and formation of the basins, which began about 20 million years ago. Because these faults cut only old rocks, recent activity is difficult to detect. We found no evidence of recent activity based on geomorphic criteria such as scarps or offset drainage.

Ground failure

In addition to being shaken during an earthquake, parts of the flat and gently sloping floors of Washoe and Pleasant Valley may shift and be distorted. Such ground failure results from liquefaction of water-saturated layers of sand and from local compaction and settling.

Areas subject to liquefaction and settling during shaking are not shown on the hazards map because we do not know details of what lies beneath the surface. In general, ground failure is most likely in shaking zones A and B, which are most likely to experience intense shaking and have some conditons favorable for liquefaction. Ground failure is less likely in zone F and is least likely in zone D. Ground failure due to shaking in zone E, bedrock, occurs as rockfall avalanches, debris flows, and landslides. Areas subject to these potential hazards are shown on the map.

Rockfall Avalanche and Landslide Hazards

Downslope movement of soil and rock debris has occurred and will undoubtedly recur in a variety of styles, involving fast or slow movement of wet or dry material. We distinguish four basic kinds of movement that present potential hazards in the Washoe Valley area. Abundant debris carried by flooding streams, here called water-borne debris flows, constitute one hazard and are shown on the Flood and Related Debris Flow Hazards Map. Water-borne debris flows grade into less fluid, slower moving slurries here called wet debris flows. Rockfall avalanches are catastrophic falls of large masses of broken rock from steep slopes that become debris flows that move very rapidly down canyons with little or no included water. Finally, some ground has failed by landslides that have moved relatively slowly in large, fairly coherent masses.

Rockfall Avalanches and Wet Debris Flows

Ophir Creek canyon and adjacent areas have been repeatedly inundated by rockfall avalanches and wet debris flows over the recent geologic past (see discussions of catastrophic deposits and debris flows of Slide Mountain in geologic map text). By these processes enormous volumes of granitic debris, including abundant blocks of rock up to 3 meter across, have flowed rapidly down-canyon. Rockfall avalanches commonly move faster than 100 km/hr and wet debris flows at less than 20km/hr (Hsu, 1975, p. 130); both kinds of flows are sudden and rapid enough to be devastating to life and structures in their path. Many rockfall avalanches are probably triggered by earthquakes. Some wet debris flows may be triggered by earthquakes but some occur simply from saturation of loose debris.

The hazards map shows two levels of potential hazard from future rockfall avalanches and wet debris flows: (1) area of most probable inundation and (2) area of maximum expectable inundation. The area of probable inundation includes terrain subject to both rockfall avalanche and wet debris flows. The area of probable inundation by rockfall avalanche has already been inundated by a series of rockfall avalanches (debris flows 2-8 on the geologic map). The hazard within this area is greatest in the upper part of Ophir Creek canyon since many of the younger rockfall avalanches have flowed only part way down the canyon. Probable inundatin by wet debris flows is shown in canyons where such flows have occurred already (debris flow 9) and in canyons

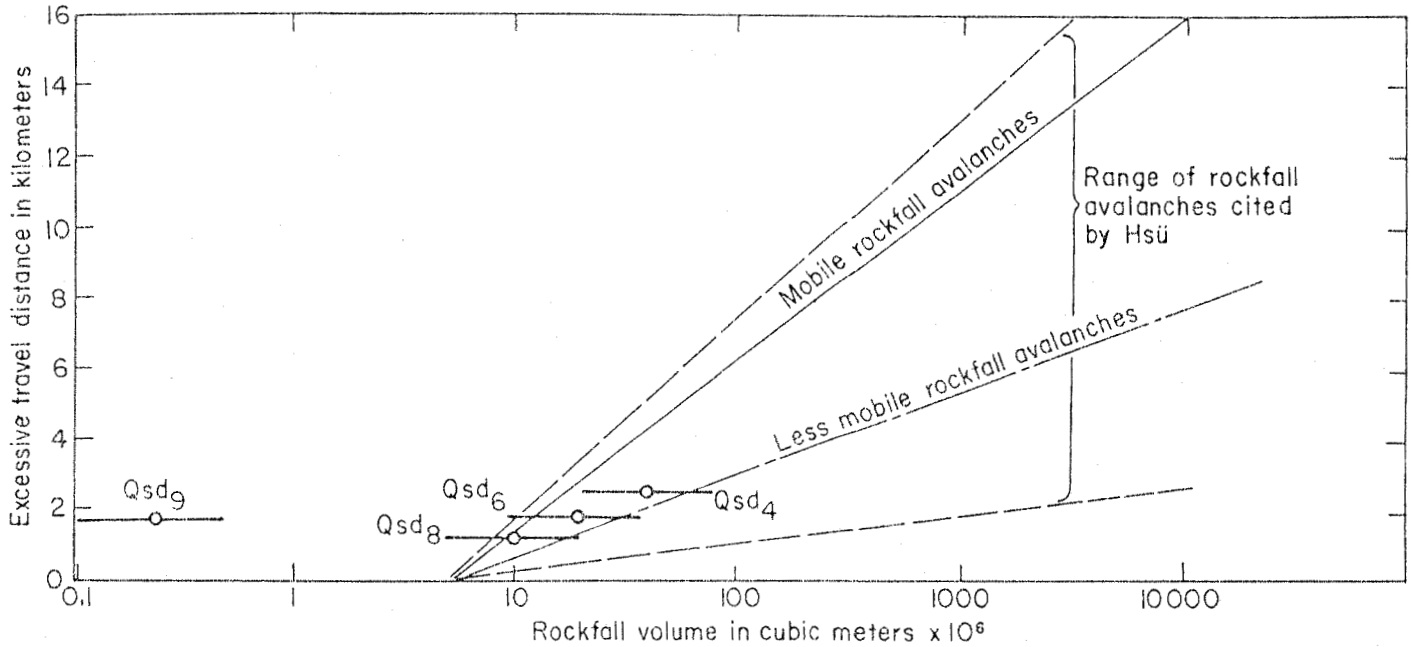


Figure 7.--Diagram showing relation of volume to excessive travel distance of reported rockfall avalanches (after Hsü, 1975, fig. 8). Volumes shown for Slide Mountain events are estimated from cores sections of deposits constructed from the geologic map, assuming continuity of deposits from foot of scar. Probable range of error in the volumes shown by arrows. Volumes shown represent volumes of deposits including pore space, not volumes of in-place rock before fall.

immediately to the north where conditions of available debris and gradient of channel are similar.

A carbon-14 age of 1,100±200 years on wood buried by flow 5 suggests that large rockfall avalanches can be expected on the average of once every 250 to 400 years. A rock avalanche is reported to have accompanied a large earthquake in 1852 (Slemmons and others 1965b). We do not know the recurrence interval for wet debris flows. Trees that appear to be 100-200 years old based on their size are growing on the youngest wet debris flows deposits.

The area of maximum expectable inundation by rockfall avalanche is bounded in the Ophir Creek area by the outer limits of the oldest deposit (debris flow 1), which probably came down hundreds of thousands of years ago. North of Ophir Creek canyon maximum expectable inundation is indicated for potential rock avalanches falling from the steep east-facing slopes of Slide Mountain. Although there is no evidence of past rockfall avalanches here, the long steep face underlain by closely fractured chalky granodiorite similar to that in the scar above Ophir Creek may fail in an earthquake and give rise to rockfall avalanches. To predict the extent of inundation following a failure of this face, we determined the mobility of the Ophir Creek rockfall avalanches by estimating volumes of individual flows and their "excessive travel distance" as defined by Hsu (1975). Roughly defined, excessive travel distance is the distance traversed by the flow away from the steep scarp where the rock broke loose. These values are plotted on figure 7. The upper solid line in this figure represents the more mobile types of rockfall avalanche as reported from other areas and is used here to approximate the behavior of rockfall avalanches in the Ophir Creek area. By inference, future rockfall avalanches of similar materials will have similar mobility. Assuming failure of a roughly 100-meter-thick slab from the upper half of the steep faces underlain by chalky granodiorite, we estimated maximum expectable volumes of potential rockfall avalanches, and, by reference to figure 7, derived the expectable excessive travel distance, which defines the area of maximum expectable inundation on the map.

The likelihood of maximum inundation is very remote and is considered possibly only under unusually severe earthquake shaking. The areas outlined have not been affected during the hundreds of thousands of years that Ophir Creek canyon has been repeatedly inundated by debris flows, and there is no evidence that during this time the stability of the slope has decreased significantly.

Landslides

Landslide deposits other than the rockfall avalanches and debris flows are scarce in most of the quadrangle. One area of abnormal landslide abundance is in Steamboat Hills above Pleasant Valley, where several coherent landslide masses have moved, apparently slowly, downslope. Another is at the foot of the steep slope on Slide Mountain where landslide deposits consist largely of debris from the closely fractured granodiorite upslope.

Probably few or none of the mapped landslides in the area are active now, but many could be reactivated either by earthquake shaking or by earthwork or changes in water conditions accompanying development.

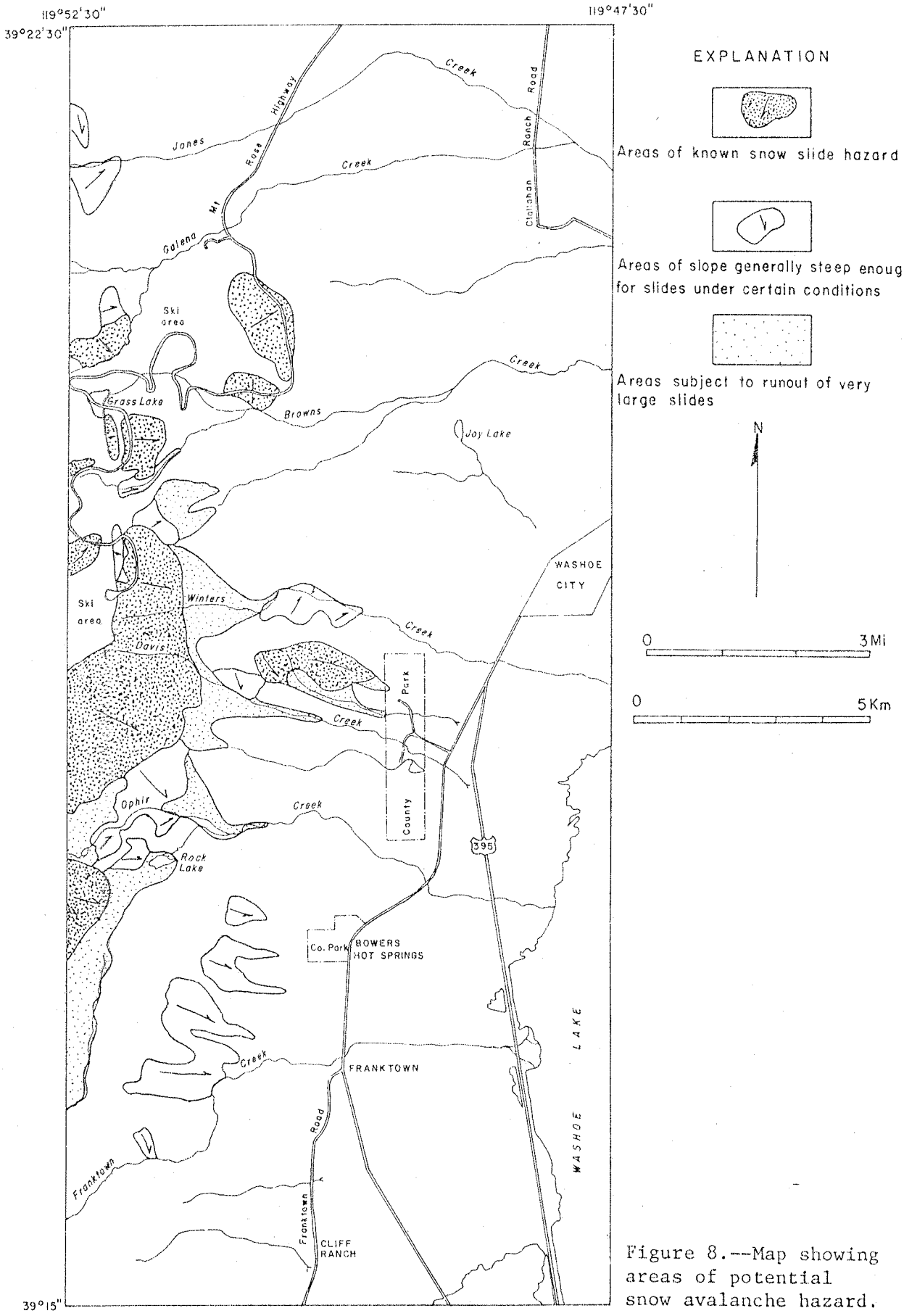


Figure 8.--Map showing areas of potential snow avalanche hazard.

Landslides too small to show on the map are common immediately along drainages that are incised into deposits accumulated at the base of slopes.

Snowslide Hazard

Snow avalanches can occur on any slopes over 15° (27 percent) but are more frequent on slopes between 30° and 45° (60-100 percent). Conditions under which avalanches occur vary considerably and are not easily predicted. The most favorable time for avalanche formation is just after heavy snowfall, especially if there has been much wind. The history of temperature and humidity change before and during the storm is important (LaChapelle, 1968, p. 423-425).

We prepared figure 8, a map of snowslide hazards, by interpretation of terrain information from the topographic map, the slope map of this folio, vegetation information from aerial photographs, and data supplied by Frank Jerauld of the U.S. Forest Service. Areas shown in the "known slide hazard" category (1) have had one to ten slides in years of average snowfall and weather conditions. Exceptionally large avalanches that may occur in these areas will have considerable runouts.

Areas "generally steep enough for slides" (2) have many slopes steeper than 26° (50 percent) and locally steeper than 35° (70 percent). Small surficial snow slides may occur on these slopes in most years, but large slides are rare, especially below 2000 m (6,600 ft), where dense forest is common. The terrain in category (2) could be hazardous to the cross-country skier or winter hiker.

TEXT TO ACCOMPANY FLOOD HAZARDS AND FLUVIAL DEBRIS HAZARDS ALONG PRINCIPAL STREAMS,

BY

P. A. Glancy, T. L. Katzer

Flood Hazards

Flood frequency for principal streams was determined by using basing characteristics, streamflow measurements, channel geometry (Moore, 1968). and available gaging station records.

Except for Galena Creek, where flood frequency was determined by the log Pearson method, more weight was given to the channel geometry results and rounding was always to a higher number to provide an added safety factor. The flood-flow estimates shown in this illustration are accurate to about one significant figure, but are reported to as many as two significant figures for relative comparison.

Frequency estimates are presented in terms of average conditions for long periods of time, and no prediction is made for regularity of recurrence. For example, a flow having a 100-year recurrence interval may occur several times within a 100-year period, or it may not occur at all. However, it does theoretically, have a 1-percent chance of occurring every year.

Flood magnitudes of the given frequencies were determined by relating long-term mean discharge to floods of known frequency at long-term gaging stations. The 100-year flood flows presented here gave slightly higher results when compared with the 100-year flood flows obtained using Hardison's method (Hardison, 1973). Part of this difference is probably due to rounding upward as an added safety factor. Flooding of a magnitude greater than the 100-year flood may occur in any area in any given year.

Detailed site studies are required to determine water depths and degree of damage resulting from the above floods. The water depths and damage will increase from the 10-year to the 100-year flood in the canyons. However, this is not necessarily true for the valley margins and floor, where water may leave the channel and spread out to a shallow depth over a large area.

Stream-channel cross sections were surveyed, roughness coefficients were selected, and channel slopes were determined so the Manning flow equation could be solved in terms of discharge to develope depth-discharge relations. The depths of the 100 year floods were obtained from these relations, and the flood plains were defined on the basis of these depths.

The 100-year flood plains of Franktown, Ophir, and Winters Creeks were difficult to define because the channel capacities are insufficient to carry the flood flows, and therefore large valley areas would be inundated by shallow sheet flow. Ponding west of the freeway (U.S. 395) will occur in some areas as a result of the high lake stage.

Except for Browns, Galena, and Jones Creeks, the flood mapping downstream from Little Washoe Lake was done by the U. S. Army Corps of Engineers (1972).

If the total area tributary to Washoe Lake was subjected to a 100-year flood, the resultant runoff into the lake would raise the lake level about 4 feet above the spillway (assuming the lake was nearly full at the onset of flooding). The volume of inflow, about 24,000 acre-feet, was estimated by correlating the 100-year flood peak of nearby gaging stations with the resultant runoff. These data were then extrapolated to ungaged areas to obtain the total quantity.

Quantitative data were generally unavailable to categorize known past floods in terms of magnitude and probable frequency of recurrences. A summary of general data for selected historical floods is as follows:

Creek	Date	Type of storm	Remarks
Franktown	a Feb. 2, 1881	Rain on Snow	Dam failed in Little Valley; most of Franktown destroyed.
	b Dec. 23, 1955	Rain on snow	Hobart Dam failed, extensive damage to mill and houses
Ophir	a July 6, 1890	Unknown	Ophir Reservoir dam failed; extensive damage to mill and houses.
Browns	c June 11, 1927	Thunderstorm	Grass Lake Reservoir dam failed; farmland damage in Pleasant Valley.
Galena	c July 13-18, 1911	Thunderstorm	Mt. Rose Highway bridge washed out.
	c July 29, 1952	Thunderstorm	Extensive damage to Galena Creek campground, fish hatchery, and and ranchlands. One related death.
	c July 20, 1956	Thunderstorm	Extensive damage, four deaths.
	c Jan. 30-Feb 1, 1963	Rainstorm	Farmland damage
	c Aug. 15. 1965	Thunderstorm	Farmland damage
Steamboat	c Jan. 16-24, 1886	Rain on snow	one death.

a. Ratay, 1972, p. 177, 289.
b. U. S. Geological Survey, 1963, p. 286.
c. V. O. Goodwin, U. S. Forest Service, written commun., 1971.

Fluvial Debris Hazards

Water-borne debris hazards exist within the Washoe City quadrangle. The most likely hazardous areas are along principal drainage courses, as shown on the Flood and Fluvial debris hazards map. Intense flooding in western Nevada is known to be capable of quickly mobilizing large quantities of debris

ranging from clay-size material to large boulders. The debris generally causes damage mainly (1) through impact during transit, (2) by abrasion of fragile objects that are incorporated into the moving debris and damaged during transport, (3) by burying objects and areas where the debris comes to rest, and (4) by erosion along the path of debris transit. The degree of hazard posed by the moving debris depends on several factors, including quantity of debris in transit, its particle-size distribution, kinetic energy of the water-sediment mixture, the specific land use in areas subject to erosion or deposition and the effectiveness of warning prior to arrival of the debris.

In western Nevada, historic damage to man and his properties by fluvial debris has normally been the result of flooding caused by intense rainfall or snowmelt runoff. However, debris damage also has resulted from a rapid release of stored water following the failure of dams. The dam failures have not always been associated with storm runoff or abnormally intensive snowmelt runoff.

The potential for debris movement within any drainage area depends on: (1) An available supply of debris, (2) particle-size distribution of the debris, (3) the degree of landscape and channel slope, which contributes to the initial movement of the debris and also controls its continued motion or deposition, (4) the degree of exposure of available debris to the force of moving water, and (5) the availability of water necessary to mobilize and maintain motion of the debris. These were the principal factors used to delineate the debri-hazard zones shown on the map. Almost no quantitative data were available regarding past debris movement in the Washoe City quadrangle; as a result, the extents of the mapped hazard areas were estimated on the basis of field evidence of past debris movement, landscape and vegetative cover at the time of mapping, and experience of the investi-gators in observing, measuring, and interpreting characterisitics of debris movement elsewhere in the region. Therefore, the location of mapped hazardous zones is subject to change with the further accumulation of information regarding local hydrology, and improved knowledge concerning characteristics of debris movement. The areal extent of the zones might also require modification in the future because of changes in local landscape and land-use characteristics, including alteration of vegetative cover.

Although the Flood and Fluvial Debris Hazards Map shows only those estimated hazardous areas associated with principal drainage channels, additional areas are undoubtedly subject to potential fluvial-debris hazards. These additional areas, including those associated with smaller drainage units, could also be the sites of intensive debris movement and deposition under special sets of circumstances. Proper combinations of land-surface slope, available debris, and adequate hydraulic energy can and do occasionally mobilize destructive debris loads in very small drainages (commonly less than 1 square mile). Therefore, successful planning to avoid the destructive effects of water-borne debris depends on careful consideration of many controlling parameters and a wide range of natural and man-caused effects that can trigger such hazards.

Large differences in landscape characteristics and climate throughout the Washoe City quadrangle contribute to similarly large ranges in debris-hazard potential. Drainage along the west side of the area originates mainly in the

Sierra Nevada, which is subject to considerably heavier snowpack and greater precipitation than is the Virginia Range along the east side of the quadrangle. However, vegetation also is generally much heavier throughout most of the western highlands than it is to the east. As a consequence, the western areas are generally better protected against debris movement on hillside slopes.

The entire area is subject to intense precipitation from thundershowers, which occasionally causes heavy runoff from even moderately vegetated slopes. Also, heavy rains on snowpact can cause intensive runoff accompanied by severe stream-channel erosion that mobilizes large amounts of debris. Poorly vegetated areas are naturally most subject to intense runoff over both hillslopes and in main drainage channels, and are therefore generally the most hazardous areas.

Along stream channels that are deeply incised, flood flows and their entrained debris loads generally remain confined to normal flood-plain zones. However, channels that are weakly incised or essentially nonincised can readily be abandoned during flooding, particularly when debris blocks the chnnels and radically diverts the flood flow. Normal flood-plain mapping and zoning criteria generally do not consider channel abandonment and drainage diversion caused by entrained debris. Thus, off-channel areas that might appear safe according to normal criteria can be subjected to serious flooding and debris hazards caused by the diverted flow. Likewise, on-channel areas downstream from the point of diversion, which transitionally would be accepted as hazardous, may excape damage. Specific areas probably prone to this channel-abandonment process include (1) most of the depositional areas on alluvial fans, (2) middle reaches of Galena Creek downstream from Highway 27 and upstream from the canyon just west of Pleasant Valley, and (3) the lower reaches of numerous unnamed ephemeral drainages. As a result of the uncertainties posed by this unpredictable process, the map should be viewed as only a general guide to probable hazardous areas, rather than being accepted for planning purposes as indicating well-defined, reliable may units. Detailed planning for specific areas may require detailed on-site mapping with great attention to the combined effects of flood flows and their accompanying debris loads.

ENGINEERING AND GEOLOGIC CHARACTER OF EARTH MATERIALS

by

S. E. Ellen and R. W. Tabor

Introduction

Engineering character of earth materials varies from place to place in the Washoe Lake area, and these variations may strongly affect the ease or success of land development. Engineering character of materials determines the ease and permanence of grading for roads and buildings, the ease of providing stable foundations, and the success of septic-tank absorption systems.

In this report we describe the engineering character, composition, and physical properties of the rock and soil materials of the Washoe City quadrangle. We describe engineering character in terms of specific engineering characteristics, such as bearing capacity, excavatability or cut-slope stability, each of which describes the response of earth materials to particular engineering demands of development.

We have evaluated the engineering character of earth materials in the Washoe Lake area using a reconnaissance method developed by C. M. Wentworth and others in a study of the engineering character of hillside materials in the San Francisco Bay region, California (unpub. data, 1971-78). Using this method, we have systematically inferred engineering characteristics of materials in this area from field observations of their composition and physical properties. Field studies in the Washoe Lake area have been supplemented by free-swell testing for expansivity of materials by M. B. Norman and R. J. Greenwood, X-ray diffraction analysis of clay materials by M. B. Norman, data from selected water-well logs on file with the Nevada State Engineer, and engineering test data for one site south of the Washoe City quadrangle (Nevada Highway Department, 1972). Information was also obtained from Thompson and White (1964), Rush (1967), discussion with Carl Cahill of the Washoe County Health Department (1973), discussion with Robert A. Matthews (1979), and others maps of this folio, especially the Hydrologic Map. We include descriptions of composition and physical properties because they are the basic data from which we have inferred engineering character, and because they provide basic information from which other aspects of engineering behavior may be inferred in the future.

The descriptions apply to the units delineated on the Geologic Map and Cross Sections. Because most of these units are heterogeneous, the unit descriptions include information about all the materials present in a unit rather than the particular materials present at a given site. The user can estimate the engineering characteristics at a site from the unit descriptions if the particular materials within the unit can be recognized. However, information presented here cannot replace the detailed site study necessary for design of structures. The information here is best suited for recognizing problem areas prior to development. For example, problems may be anticipated in units described as containing expansive materials, even though expansive materials do not occur everywhere in these units.

Table 3.--Expectable severity of problems to residential development resulting from engineering characteristics of material within 8m (25 ft) of the ground surface: P, substantial problem; m, minor or possible problem, --, little or no problem; H, potential hazard (see hazard maps). Underlined symbol indicates that problem occurs in most of the unit; no underline indicates that problem occurs in one tenth to one half of the unit.

Geologic Map unit, grouped as in unit descriptions	Permeability	Bearing Capacity	Expansivity	Excavatability	Fill Character	Cut-slope Stability	Other
Qa	--	--	--	--	--	--	m
Qf	--	m	--	m	m	--	H
Qdd	--	m	--	--	--	--	P
Qyl	--	m	--	--	--	P	H
Qld	P	m	P	--	m	--	P
Qws, Qwd	--	m	--	--	--	--	P
Qsu	--	m	m	--	--	--	P
Qfg	m	m	--	--	--	--	P
Qfs	m	m	--	--	--	--	--
Qfsb	--	m	--	--	m	--	P
Qfb	P	--	m	m	m	--	--
Qt	--	m	--	P	m	P	P
Qba	m	P	m	--	--	m	--
Qs	P	m	m	--	--	P	P
Qsd_{1-9}, Qsdu	m	--	--	m	m	--	H
Qsdc	--	--	--	P	P	--	H
Qsdb	--	--	m	m	m	--	H
Qgm_{1-4}, Qgmu	P	--	--	m	m	--	--
$Qgo_{2,4}$, Qgou	m	--	--	m	m	--	--
Qows	--	--	--	--	--	--	--
Qod	--	m	--	--	--	--	P
Qst	--	--	--	m	m	--	--
Qol	P	m	m	--	m	P	H
Qgl	m	--	--	m	m	--	--
Qogb	--	--	--	--	--	--	P
Qoa - sand	P	m	P	--	m	--	--
Qoa - gravel and sand	m	--	m	m	m	--	--
Qold - E.side of Washoe Lake	P	m	m	--	m	--	P
Qold - W.side of Washoe Lake	P	m	P	--	m	m	--
Qmb	P	m	m	m	m	m	--
Qms	P	m	m	--	m	m	--
Qsh	P	m	m	m, P	m	--	--
Qsg	m	m	m	--	--	--	--
Tb	P	m	P	m, P	m	--	--
Tfk	P	--	--	m, P	m	--	--
Tkb	P	m	m	m, P	m	--	--
Tkd, Tki	P	--	--	m, P	m	--	--
Tku	P	m	m	m, P	m	--	--
Ta	P	m	m	m, P	m	--	--
Tad	P	m	m	m, P	m	P	m
Kg	P	--	--	P	m	--	--
Kg, highly fractured	P	--	m	m, P	m	--	--
pKm, pKmb	P	m	m	m	m	m	m
Bleached pKm	P	m	m	m, P	m	m	m

Summary of Engineering Character of Geologic Units

Table 3 summarizes the engineering character of each geologic unit in terms of the impact of the materials of that unit on residential development. The development is assumed to involve light loads of structures and pavements, septic tank systems for waste disposal, and, on slopes, the creation of level sites by cut and fill. Success of water wells is not evaluated. Only the effects of materials within about 8 m (25 ft) of the ground surface are considered in table 3; the effects of fresh bedrock are excluded (see Effects of Weathering).

The summaries in table 3 are intended to serve as a rough, initial appraisal of problems related to engineering character of earth materials. Problems are noted in those materials that require additional work to be used effectively, as where excavation is difficult, or in those materials that may not serve intended purposes, as where permeability values are too low for septic tank absorption systems. Table 3 lists the severity of problems that occur in each unit, but does not describe the problems or the particular materials in which they occur. More complete and specific description of engineering character is included under Unit Descriptions and in the discussion below.

Effects of Weathering

Bedrock and unconsolidated deposits shown on the Geologic Map and Cross Sections are physically and chemically modified near the ground surface by weathering, as sketched in figure 9. Effects of weathering are most pronounced in bedrock materials. In the areas shown as bedrock on the Geologic Map, bare rock generally does not appear at the ground surface, but is covered by a surficial mantle of soil and rock debris (fig. 9B, C). The surficial mantle is commonly soft or loose granular material that includes blocks of rock. Thickness of the surficial mantle is variable and often difficult to estimate, but generally follows the pattern shown in figure 10.

Bedrock near the ground surface shows effects of weathering (fig. 9B, C). The most significant effects are the opening of existing fractures, development of new fractures, softening of the rock through breakdown of mineral grains, and release and movement of clay and oxides. Bedrock modified in these ways is termed weathered bedrock in contrast to the deeper, unmodified, fresh bedrock. The depth of bedrock weathering is highly variable even within small areas. Where rock does not crop out, weathering is generally significant to depths of 3 to 10 m (10 to 30 ft).

In the Washoe City area soil has formed within 1 m (3 ft) or so of the ground surface. Soil is generally best developed on gently sloping or flat ground where downslope movement has not interrupted the slow chemical weathering processes that leach the surficial soil and concentrate clay and other materials in the subsoil (fig. 9C, D). In unconsolidated deposits and surficial mantle, soil formation is accompanied by downward movement of clay and oxides that coat grains to depths of at least 5 m (15 ft). Soil development is stronger and coatings of clay and oxides more abundant in the older unconsolidated deposits that have been weathered longer.

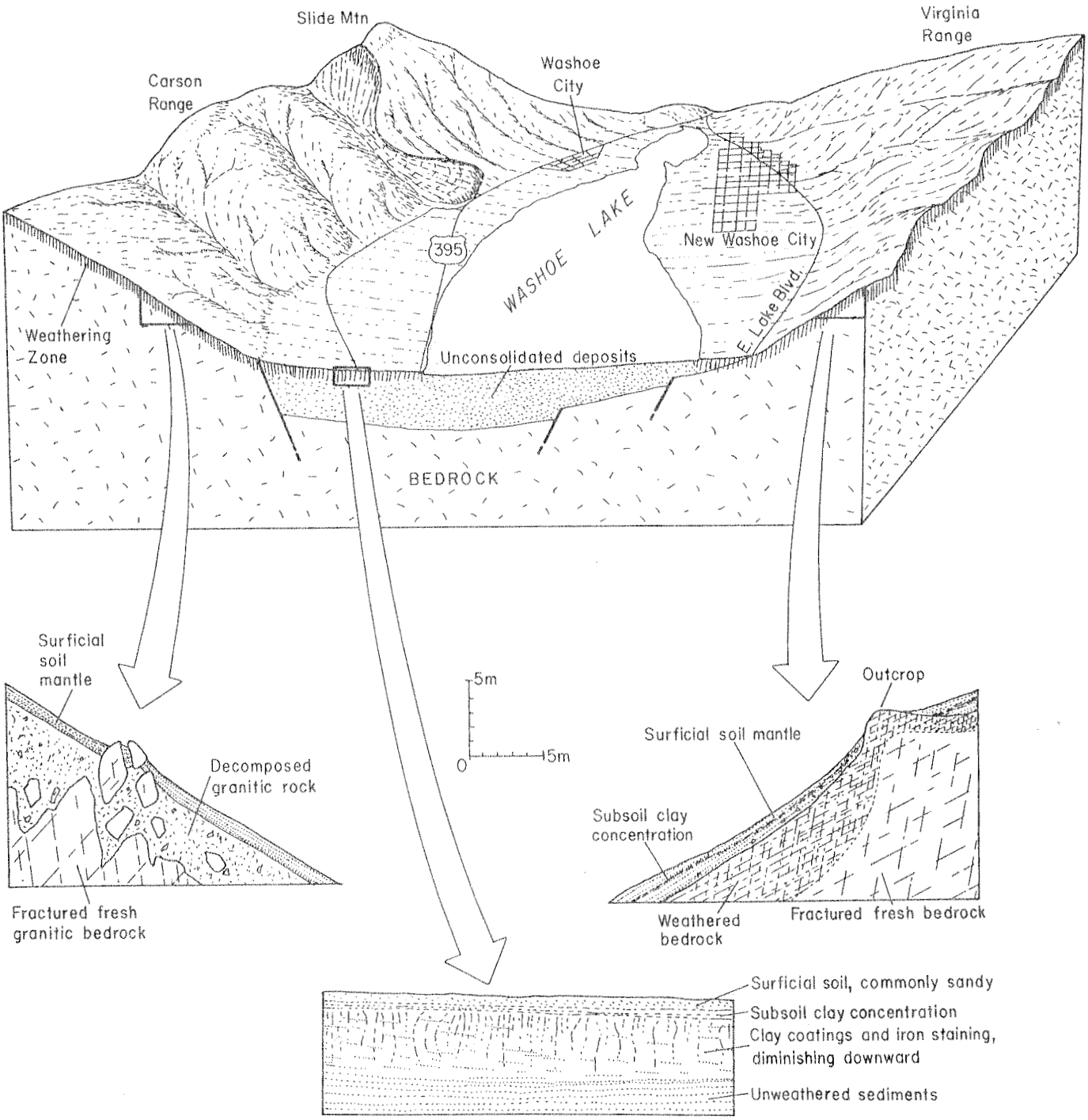


Figure 9.--Weathering effects on earth materials in the Washoe Lake area. (A) Schematic block diagram of Washoe Lake area. (B) Schematic cross section of weathering phases on granitic bedrock. (C) Schematic cross section of weathering phases in nongranitic bedrock, showing development of new fractures in weathered zone. (D) Schematic cross section of weathering effects on unconsolidated deposits.

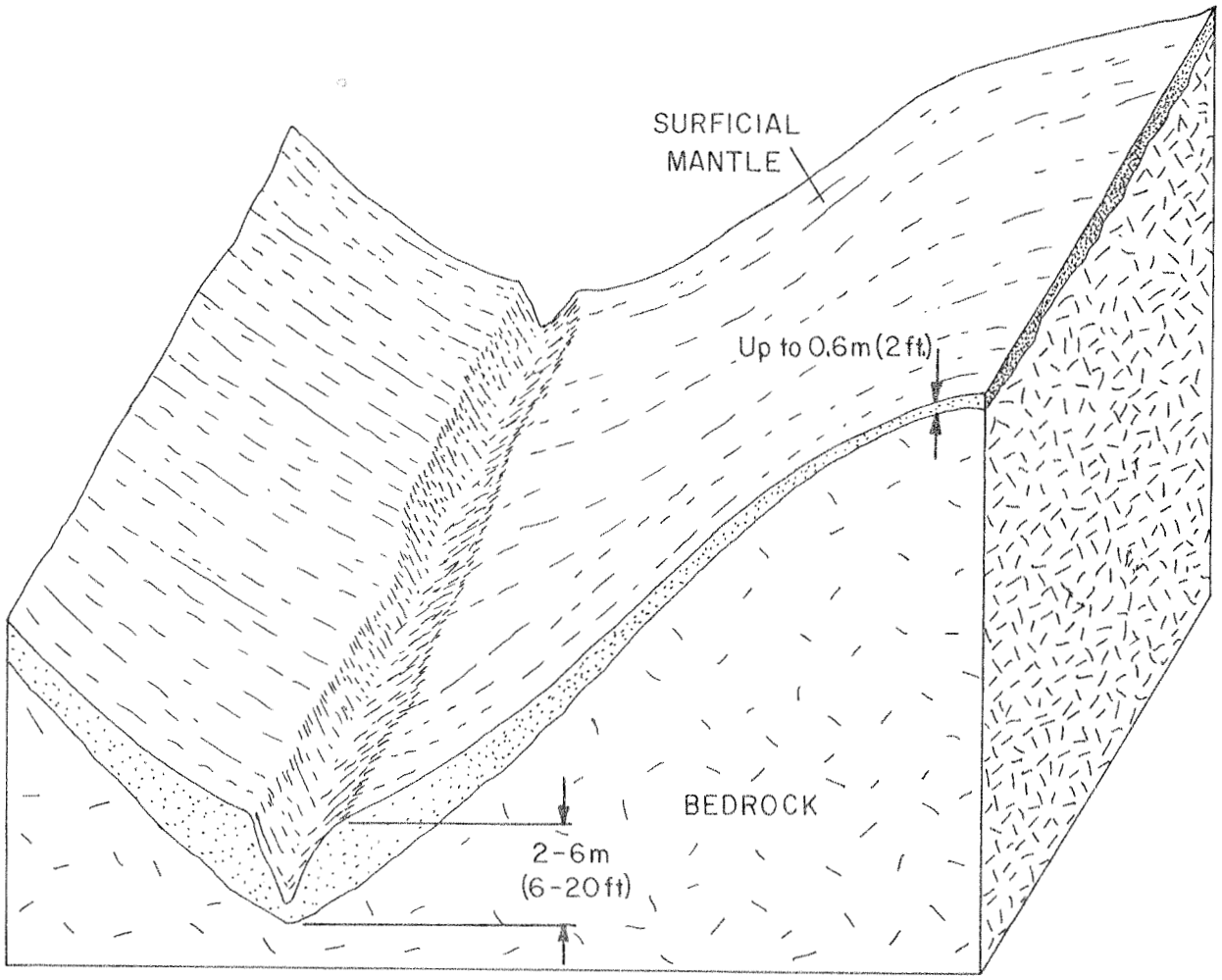


Figure 10.--Schematic block diagram of hillside and canyon showing typical variation in thickness of surficial mantle.

Explanation and Use of Unit Descriptions

The terms used in each entry of the unit descriptions are discussed below, along with information necessary for use and interpretation of the data in each entry.

Composition

We describe the composition of the unweathered materials that occur in the unit and the approximate proportion of the areal extent of the unit underlain by each type of material. For unconsolidated deposits the principal distinguishing factor is size of grains and rock fragments (tables 4 and 6). A material is called clay, and behaves basically as clay, where more than one-fourth to one-third of a sample consists of clay-size particles, a proportion sufficient to completely fill pores between larger grains. Clays are described as sandy or silty where sand or silt constitutes much of the material. Materials are called sand or silt if they behave basically as granular materials. Sands or silts are called clayey if they contain clay sufficient to provide some cohesion but in amounts less than one-fourth to one-third of the material. Materials are called gravels where they consist largely of pebbles or larger clasts (table 4). Sorting describes the distribution of grain sizes in a material; well-sorted materials have nearly uniform grain size, whereas poorly sorted materials have a broad range of grain sizes. Granular materials are called clean where finer clay-silt matrix is absent. Information compiled from water-well logs is clearly designated because the reliability of these logs is uncertain, and because the well logs describe vertical rather than areal abundance of materials. The discussion of the geologic map contains additional information on composition of some units.

Weathering and Soil

For bedrock units we generally describe the typical composition of surficial mantle, the composition and thickness of soil developed in the mantle, and significant weathering effects on bedrock other than those described above for typical weathered bedrock. For unconsolidated deposits we generally describe the thickness and composition of soil developed on the unit, in particular the presence of clayey subsoil, and weathering effects that extend deeper into the material.

Table 4. Grain-Size Scale

Size Class	Intermediate diameter of particle	
	Millimeters	Inches
Boulders	256	10
Cobbles	64-256	2.5-10
Pebbles	2-64	0.08-2.5
Sand		0.002-0.08
very coarse	1-2	
coarse	0.5-1	
medium	0.25-0.5	
fine	0.125-0.25	
very fine	0.062-0.125	
Silt	0.004-0.062	
Clay	<.004	

We describe soil as poorly (or weakly) developed where it exhibits little concentration of clay in the subsoil and hence is only a slight modification of the parent material. Well-developed soils are those that show prominent differentiation of materials in the soil profile, particularly concentration of clay in the subsoil. Materials in which original pore spaces are filled by secondary clay are described as clay-clogged. Soil thickness is commonly measured to the base of clay concentration in the subsoil.

Thickness

We report thickness in approximate terms for those units whose thickness is known within useful limits. All units vary in thickness over their area of exposure. Unconsolidated deposits, in particular, commonly thin near their margins. The thickness of many units at specific points can be estimated from the Geologic Cross Sections. However, the thickness of some unconsolidated deposits near Washoe Lake has been exaggerated in the Cross Sections.

Physical Properties

Hardness of materials is crudely measured with the geologic hammer according to the hardness scale in table 5. Fracture spacing and parallel parting both describe the spacing of cracks or planes of weakness in the material. Fractures break across bedding or foliation; parallel parting breaks along bedding or foliation. Fracture and parallel parting together define the spacing of planes of weakness and hence the size of naturally occurring pieces of the material. Soft materials generally lack mechanically significant fracture and parting. Bedding describes the thickness of beds and their distinctness. Beds are called distinct where they contrast in composition and contacts between beds are sharp; indistinct beds lack contrast, or contacts are vague or gradational. Measures of fracture spacing, bedding thickness, spacing of parallel parting and size of fragments are defined in table 6. Where a specific property, such as bedding, is absent, no entry is given in the unit descriptions.

Physical properties of weathered and fresh materials are described separately wherever differences between them are significant to engineering character. Physical properties of soil and surficial mantle are not described for each unit because these materials are commonly loose to firm approaching soft with variably abundant rock fragments.

Engineering characteristics

Engineering characteristics are reported only where they require special attention in development.

Table 5. Hardness Scale
For geologic hammer hitting intact pieces of material with moderate force:

Hard - Hammer head bounces with solid sound
Very firm - Intermediate between firm and hard
Firm - Hammer head dents with thud, pick point dents or slightly penetrates
Firm approaching soft - Intermediate between firm and soft
Soft - Pick point penetrates
Loose - Material lacks cohesion, little resistance to hammer

Table 6. Scale of fracture spacing, bedding thickness and fragment size.

Metric	Bedding thickness	Fracture spacing	Fragment size	Customary U.S.
0-1 cm	Very thin	Very close	Very small	0 - 0.5 in.
1-5 cm	Thin	Close	Small	0.5 - 2 in
5 cm - 0.33 m	Medium	Moderate	Medium	2 - 12 in.
0.33 - 1 m	Thick	Wide	Large	12 - 36 in.
1 m	Very thick	Very wide	Very large	36 in.

Maximum dimension generally specified where greater than 1 m (36 in.)

Permeability

Permeability describes the ease with which water can move through the ground. We report estimates of permeability in four classes, each covering a range of at least two orders of magnitude of the coefficient of permeability (fig. 11). We undertook no laboratory or field testing of permeability but estimated it from physical properties (through the relations shown in table 7) on the basis of the few control data shown in figure 11. This procedure has yielded only approximate quantitative predictions of permeability. Where more accurate information is needed, laboratory or field tests are necessary.

Water moves in the ground through interconnected pores that consist of spaces between grains (intergranular pores) and along open fractures. The permeability of material is controlled by the abundance, openness, and interconnectedness of these two kinds of pore spaces. The permeability of unconsolidated deposits, surficial mantle, and soil results largely from intergranular pores; permeability of bedrock may result from intergranular pores, fractures pores, or both.

For each bedrock unit we estimate permeability of fresh bedrock at depth, shallow weathered bedrock, and surficial mantle. Estimates for fresh bedrock at depth (at least 100 m (300 ft) beneath the ground surface) report the largely intergranular permeability of materials below the level at which unloading and weathering have opened fractures. Estimates reported for shallow bedrock refer to weathered bedrock within about 10 m (30 ft) of the ground surface, and assume some opening of fractures and distinct bedding planes, and the release of clay in certain rock types. Permeabilities at depths between the deep and shallow cases are generally intermediate in value.

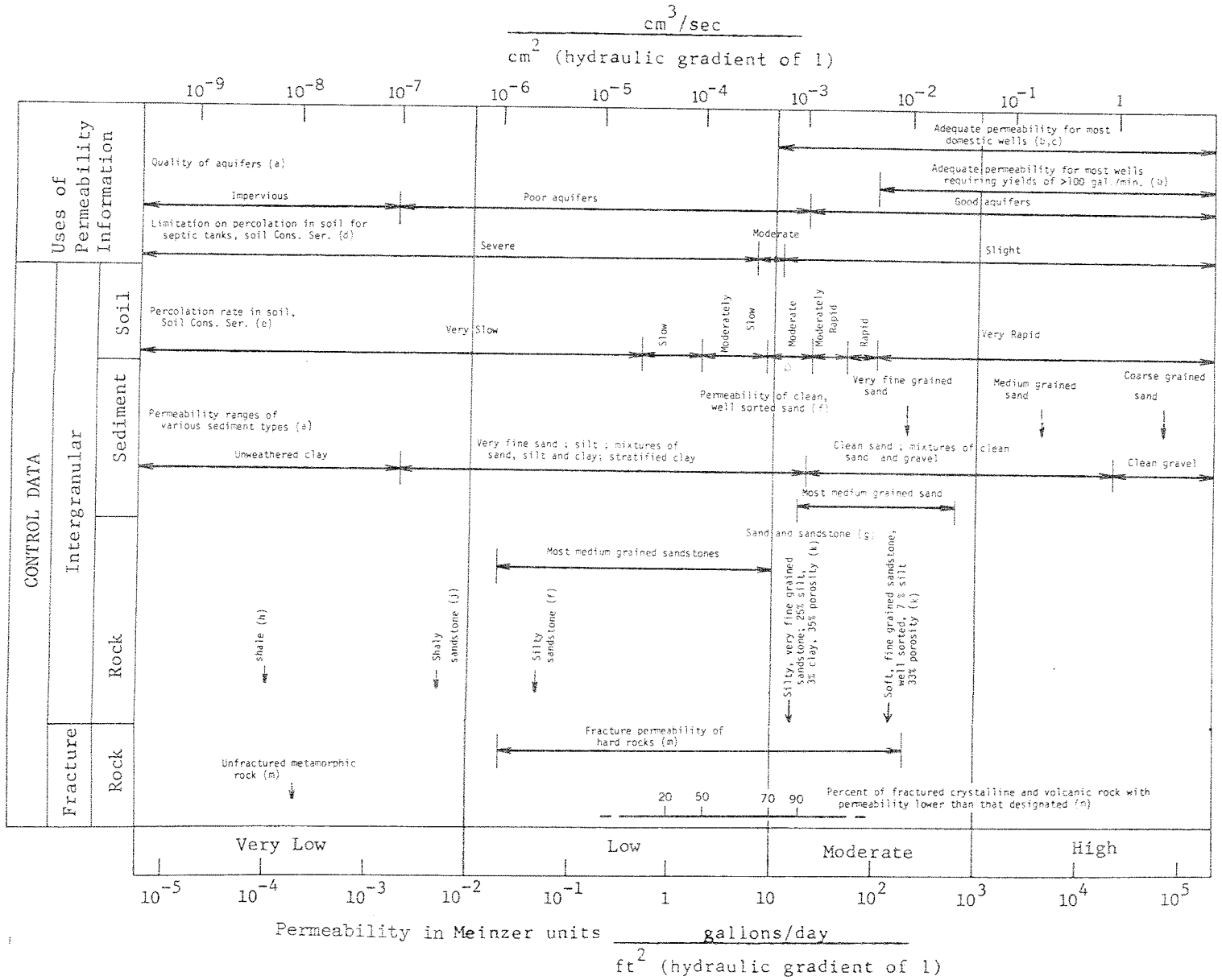


Figure 11.-- Permeability scale, showing control data and ratings for some uses. Small letters in parentheses refer to sources of data: (a) Todd, 1959, p.53; (b) Wenzel, 1942, p.11-12; (c) Johnson, 1964; (d) U.S. Soil Conservation Service, 1968, p.a25; (e) Wagner and Nelson, 1961, p.93; (f) Davis and DeWiest, 1966, p.164; (g) Davis and DeWiest, 1966, p.351; (h) Davis and DeWiest, 1966, p.349; (j) Davis and DeWiest, 1966, p.348; (k) Stearns, 1927, p.168; (m) Davis and DeWiest, 1966, p.319-320; (n) Dutcher, L.C., written communication, 1972.

Table 7. Permeability related to material character

Intergranular permeability	
Very low	In clayey rock and hard rock, saturated severely expansive clayey surficial mantle, and probably in saturated significantly expansive clayey mantle
Low	In firm sandstone lacking abundant clay matrix or crystalline cement but without visible porosity[1/], and in unexpansive clayey surficial mantle
Moderate	In granular material, including sandy surficial mantle, with visible porosity[1/] estimated to be equivalent to that of loose, very fine grained sand
Fracture permeability	
Very low	In most rock more than 100 m (300 ft) below ground surface, and in saturated, expansive, soft to firm clayey rock
Low	In most fractured rock less than 10 m (30 ft) below ground surface (wide or closer fracture spacing)
Moderate	Possible in very closely to moderately fractured rock less than 10 m (30 ft) below ground surface, except wher abundant free clay (soft to firm clayey rock)
High	Possible where fractures have been opened in landslides and in hard rock near faults

[1/]Visible porosity - intergranular pores evident under 10x hand lens
Obvious porosity - intergranular pores clearly evident to naked eye

For unconsolidated units we generally estimate permeabilities for contrasting compositions within the deposit and for the soil. Permeability estimates for all unconsolidated deposits, surficial mantle, and soil assume that material is saturated.

Application to Water Wells and Septic-tank Systems

Permeability information is useful for predicting the success of water wells and septic-tank systems, as shown at the top of figure 11. Successful wells commonly require moderate or high permeability in materials beneath surficial mantle. Further information on water-yielding capability of wells can be found in the Hydrologic Map of this folio.

Limitations on percolation rates for septic tank absorption systems can be evaluated using the permeabilities reported for near-surface materials in each unit. For many areas where bedrock units are shown on the map, absorption systems will intersect both surficial mantle and weathered bedrock, so that the permeabilities of both materials will determine the success of a system. In unconsolidated deposits the permeabilities of materials from 0.6 m (2 ft) to 2 m (6 ft) depth will be involved, including soil and subsoil.

Percolation rates should be adequate where the materials involved have moderate or high permeability; low or very low permeability results in severe limitations (figure 11). Some high permeability materials in the area, such as much of the surficial mantle over bedrock, permit such rapid movement of septic-tank effluent that contamination of water supplies can result. Additional information on percolation rates, especially for shallow absorption systems in the flat valley-floor areas, may be obtained via the Soils Map of this folio.

Success of septic-tank systems requires, in addition to adequate permeability, sufficient depth to high seasonal ground water and sufficiently gentle slope. High seasonal ground water (as well as impermeable materials) must generally be at least 1.2 m (4 ft) below the absorption system (Nevada State Board of Health, 1972, p. 19). Since absorption systems must be at least 0.6 m (2 ft) deep (Nevada State Board of Health, 1972, p. 18), depth to ground water of less than 1.5 m (5 ft), as shown on the Hydrologic Map, probably prohibits use of septic-tank systems, and depths to ground water of less than 3 m (10 ft) may affect their design. Limitations imposed by steepness of slope are less clearly defined, but proposed sytems on slopes steeper than 20% (see Slope Map) generally come under close scrutiny by the regulatory agency. Such slopes require absorption systems deeper than 1.5 m (5 ft), so that bedrock as well as surficial mantle will probably be encountered, possibly leading to contamination of well water.

The information in this folio on permeability, depth to ground water, and steepness of slope can be used only as an approximate guide to those areas where the ground can successfully accommodate septic-tank systems. Success of systems at specific sites can be predicted only by the on-site inspection and percolation tests required for approval of proposed systems.

Bearing Capacity

Bearing capacity is the capacity of materials to support structures. Poor bearing capacity results from weak or compressible materials that permit excessive settlement or distortion of structures. Distortion resulting from shrink and swell of expansive foundation materials is treated separately below; distortion from failure related to earthquake-induced liquefaction is treated in the discussion of the Geologic Hazards Map. We evaluate bearing capacity of each unit only for light loads such as frame houses, which we assume to exert foundation pressures of less than 1000 lb/ft Heavy structures may cause bearing-capacity problems in many materials that would exhibit no problems under light loads, notably in the soft to loose materials of surficial mantle and many unconsolidated deposits, especially those containing substantial amounts of mica.

Because no engineering test data are available for the Washoe City quadrangle, we have estimated bearing capacity largely on the basis of the compositions of materials in each unit. This information is supplemented by the probability that the unit is saturated (inferred from the Hydrologic Map) and by crude estimates of standard penetration resistance based on data for one site immediately south of the quadrangle (Nevada Highway Department, 1972). The bearing capacity of each material is catagorized as posing problems, possible problems, or no problems. Problem materials include organic clay, peat, and loose organic sand, silt or mud, materials for which the Uniform Building Code (1976, table 29-B) requires foundation

investigation. Clays, silts, saturated uniform fine sand, loose sand, and sand-silt mixtures are materials catagorized as possible problems; these satisfy Uniform Building Code (1976) standards, but show presumptive bearing capacities of less than 1000 lb/ft (Hough, 1957, figures 10-12 and 10-13; Uniform Building Code 1970).

All estimates assume that the highly organic surface layer of soil is removed or penetrated by foundations, because organic materials, being compressible, will commonly fail where used to support structures. Loose granular materials reported as having no problems may settle when subjected to shaking or vibration, especially sustained vibration as produced by nearby operation of heavy machinery.

Expansivity

Expansivity is the capability of some clayey materials to swell when wetted and shrink upon drying. We call materials expansive if they are capable of swelling sufficiently and with enough force to damage light structures such as frame houses, roads, slabs, or septic-tank systems. We do not evaluate potential for swell under heavier loads. In the Washoe Lake area a substantial proportion of soils, particularly subsoils, are expansive.

Shrink or swell of expansive materials results from change in water content. Significant changes in water content of shallow materials can be brought about during development by such seemingly inconsequential actions as removing or planting trees or constructing slabs on grade, measures that change the evaporation and evapotranspiration regimes. Similarly, adding water to the ground through septic-tank systems and irrigation, or removing water from the ground by wells, can promote significant expansion or contraction. The severity of movement depends, in part, upon the change in water content and the thickness of expansive material involved. These factors can be determined only by detailed site studies, so we evaluate simply the inherent capability of materials to swell.

For purposes of foundation design, engineers measure expansivity with loaded-swell tests, whereby the material is subjected to changes in moisture under a confining load. Because such tests are expensive and time consuming, we have used the free-swell test (Krynine and Judd, 1957, p. 144). This is a simple laboratory test that measures the capacity of dry, finely broken material to take on water and expand without a load. The relation between free swell and swell under light loads is shown in figure 12 for a suite of samples selected to span a broad range of free-swell values (based on work in the San Francisco Bay region by Wentworth and others). Using this relation we have estimated expansivity under light loads from free-swell values of samples selected from each unit.

Free-swell values of samples from the Washoe Lake area are plotted in figure 13; locations of samples are shown in figure 14. Most samples show two values: the small dots show the free-swell value obtained by the standard test; the large symbols show the value resulting after systematic additional tap-down of the sample. The tap-down serves to eliminate the component of apparent swell that results from loose packing of sand and silt, and thereby helps identify swell caused by expansive clay. The expansivities we report in the descriptions are based on the tapped-down free-swell values where these are available; otherwise they are based on the values obtained by the standard

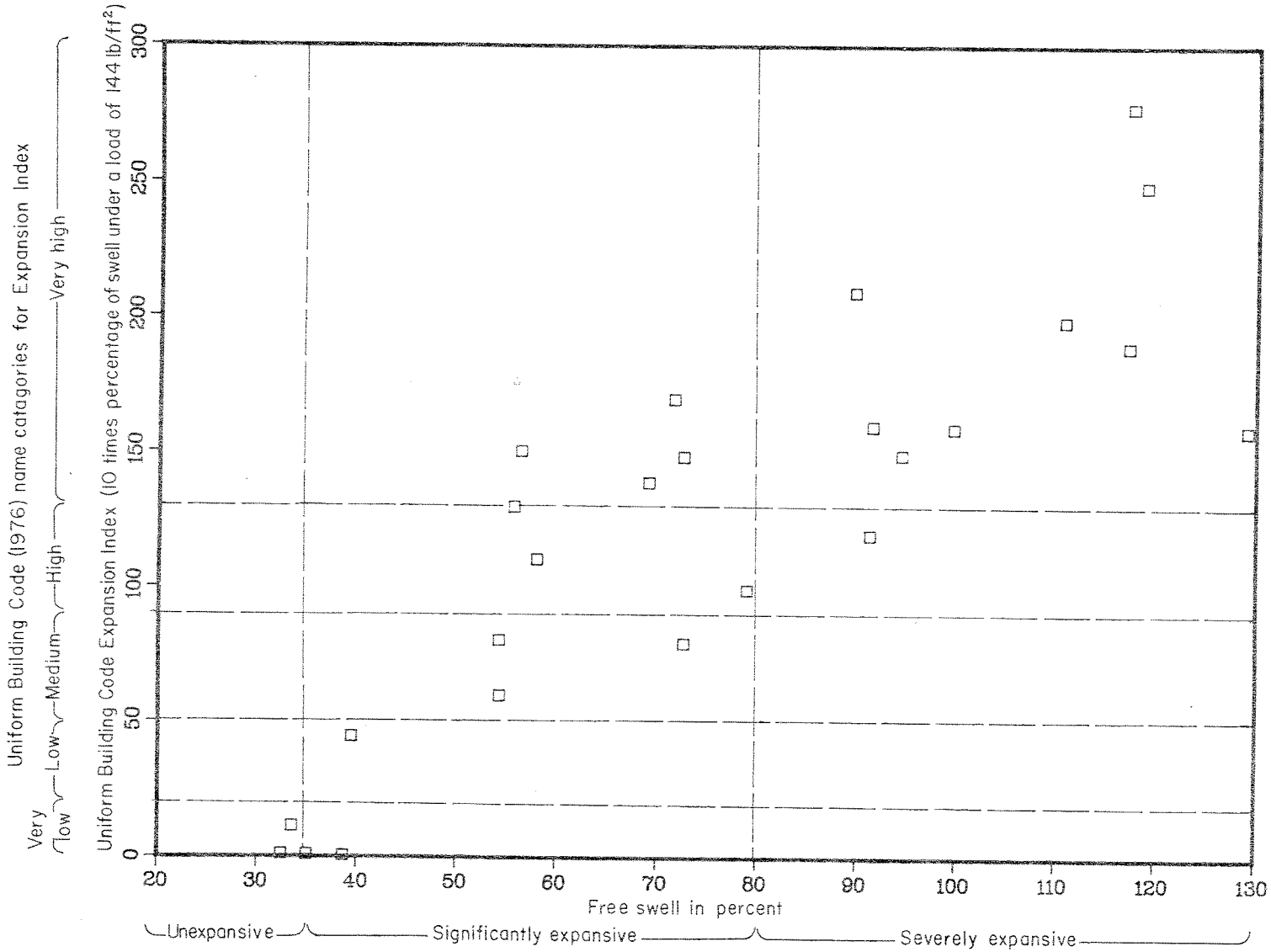


Figure 12.--Control data for reconnaissance estimates of expansivity. The Expansion Index of the Uniform Building Code (1976), measuring swell under confining load of 144 lb/ft, is plotted against standard, untapped free-swell values for a suite of samples collected in the San Francisco Bay region that cover a broad range of free-swell values. On the basis of these data, the range of free-swell values is divided into unexpansive corresponding to very low expansion index; significantly expansive, corresponding to variably low to very high expansion index; and severely expansive, corresponding to high to very high expansion index. The Uniform Building Code (1976) requires that structural designs include consideration of expansivity for all materials with an expansion index of 20 and above.

method. Note that our estimates of expansivity are based on comparison of the tapped-down values of this study with the untapped control samples shown in figure 12. Thus if our estimates are in error, they probably underestimate the expansivity of materials. Estimates of abundance of each sampled material have been combined with the free-swell values shown in figure 13 in describing expansivity for each unit.

X-ray diffraction analysis of eight samples, representing a broad range of parent material (figure 14), shows the clay portion of most samples to consist largely of mixed-layer montmorillonite. The layers intermixed with montmorillonite are largely illite, though chlorite and unidentified minerals are also interlayered. Minor to significant amounts of kaolinite and lesser amount of chlorite(?) and sepiolite(?) are present in most samples, and kaolinite is dominant in one.

Birkeland (1969) concluded that montmorillonite should be the dominant clay mineral in soils of this area. Although many of the samples that we examined were not soil, and despite the fact that we obtained low free-swell values for some highly clayey materials (particularly from the lake deposits), the total results suggest that most clay minerals are montmorillonitic and thus are expansive. Clayey materials in the Washoe Lake area should be considered expansive until proven otherwise, especially those that show popcorn texture or shrinkage cracking, or those that slough rapidly from cut slopes. The Soils Map and text provide additional sources of information on the distribution of expansive soils.

Excavatability

Materials in the Washoe Lake area vary in their ease of excavation from those that can be dug with a shovel to those that require blasting. We evaluate excavatability in terms of the effectiveness of three common methods of excavation--trenching, ripping, and heavy ripping or blasting, as defined in figure 15. Evaluations in terms of these excavation methods and machines can be applied directly or used as standards of comparison for other machines or objectives.

Trenching is a common excavation objective for which the Case 580, a medium-duty backhoe, is commonly used. Only soft material is here termed easy to trench, but hard material can be trenched with difficulty wherever relatively loose pieces smaller than the 0.6 m (2 ft) trench width are available to be plucked out. Trenching of material that cannot be dug with a backhoe alone requires heavier equipment or prior loosening with special techniques, such as ripping, mechanical splitting, or blasting.

Ripping is a common method of breaking material to permit trenching or larger excavations, and the Caterpillar D8 (or equivalent) crawler tractor is a routinely used, heavy-duty machine. The effectiveness of ripping firm to hard rock on an open, accessible surface depends primarily on the ability of the ripper tooth to penetrate the rock along fractures or bedding planes. Hard rock can resist ripping where the spacing of fractures or bedding planes exceeds about 1 m (3 ft). Some very widely fractured, tough but not especially hard rock, such as much of the breccia of the Kate Peak Formation, may be grooved by the ripper tooth without being broken.

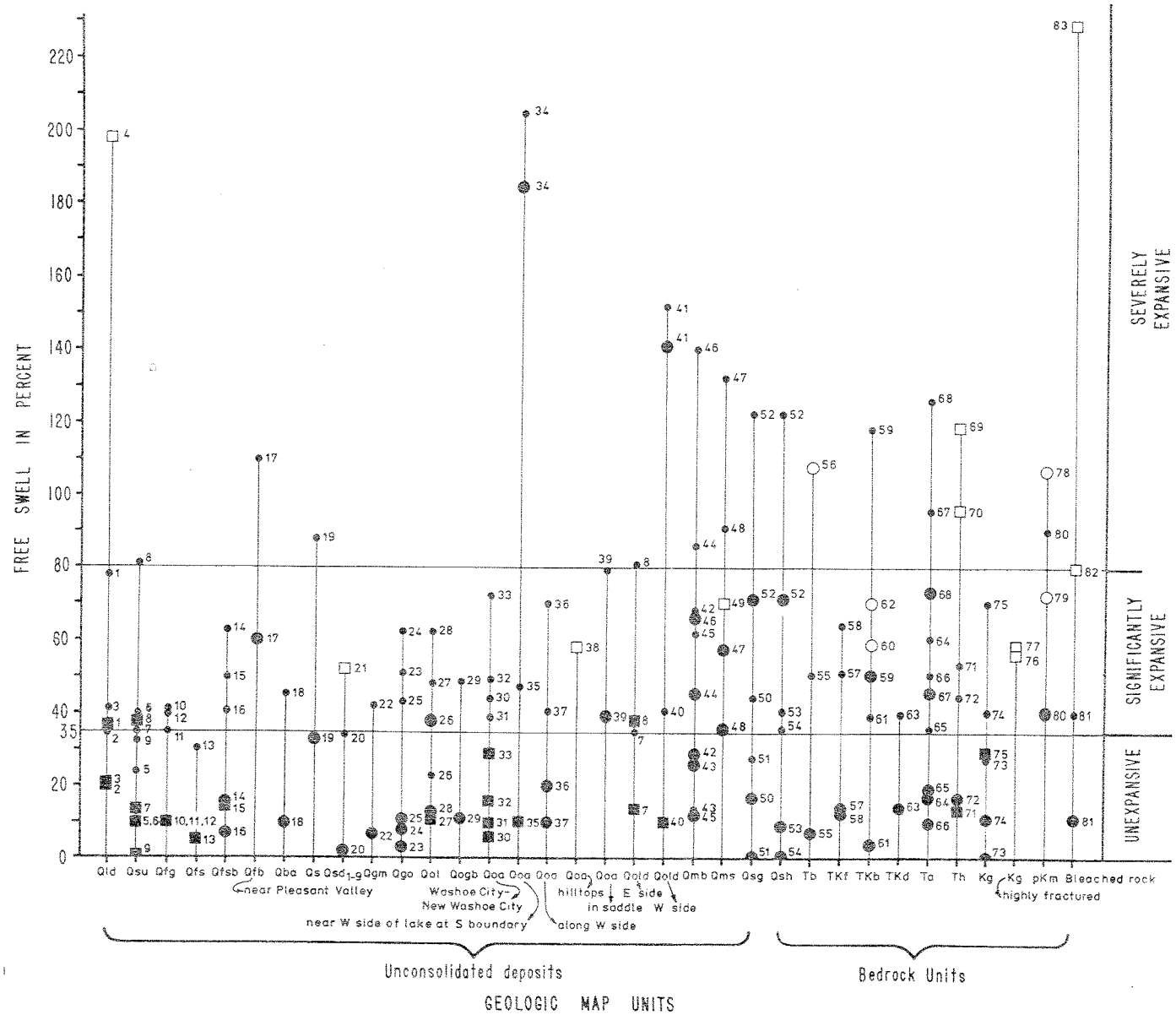


Figure 13.--Free-swell values of samples arranged by geologic unit. Sample numbers refer to localities shown on figure 14. Two values are given for most samples: a value for the standard free-swell test, shown by small dot, and the value obtained after extra tap-down of the material, shown by large solid symbols. Samples having only the standard test value are shown by large open symbols. Large round symbol identifies sample as soil or surficial mantle; square symbol identifies sample as bedrock or unconsolidated deposit.

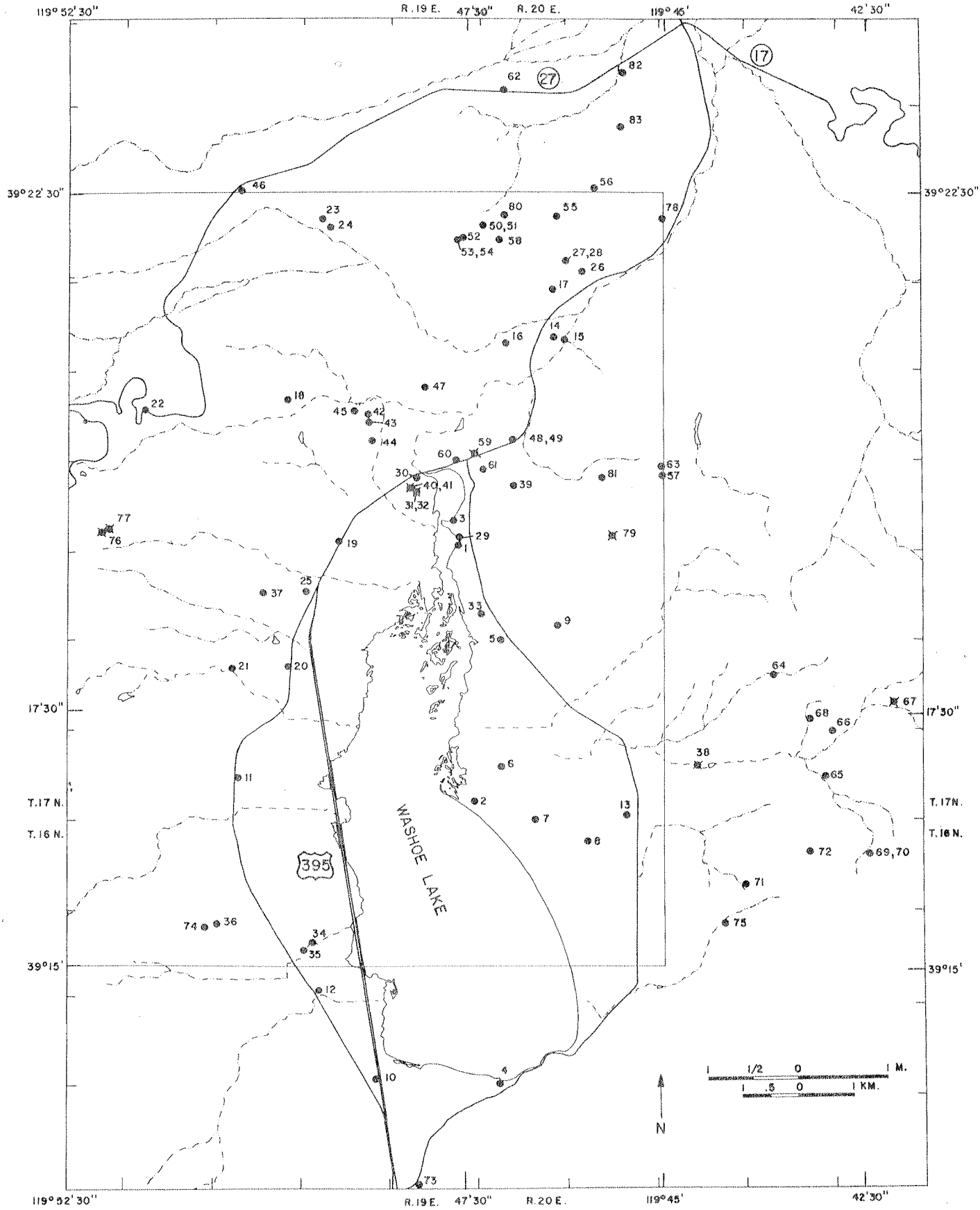


Figure 14.--Locations of free-swell samples and X-ray samples (designated by X superimposed on sample location dot). Boundary of Washoe City quadrangle is shown within figure.

Most materials that cannot be ripped with a D8 or equivalent tractor can be ripped with heavier or tandem equipment. If the material cannot be ripped in this fashion, techniques such as blasting must be employed. In the past, blasting has been required in much rock in the area, but ripping techniques continue to improve; hence heavy ripping and blasting are combined in this evaluation. Blasting, as used here, includes the use of hydraulic hammers and other mechanical splitters.

Our estimates of excavatability are based on the relations shown in figure 15 between excavation methods and physical properties of materials. The relations were determined in the study by Wentworth and others (unpub. data, 1971-78) in the San Francisco Bay region through limited field observations and discussions with engineering geologists, engineers, and equipment operators familiar with excavation work there.

Fill character

We report the presence of materials that might create problems if used to build compacted fills for support of light loads such as roads or houses. Compacted fill is in common use wherever level sites are required in sloping terrain, as sketched in figure 16. We have not evaluated suitability of materials for use in other types of fill, such as to impound water, buttress other earth, or support heavy loads. Most materials in the Washoe build compacted fills, but some materials cause more problems than others. The major detrimental components of compacted fills, once vegetation and the loose organic soil have been removed, are abundant clay, particularly plastic clay, and oversize rock fragments. Abundant clay makes it difficult to obtain the moisture content needed for proper compaction. Rigid pieces of rock larger than about 15 cm (6 in) across cannot be routinely incorporated in compacted fills because they are larger than the thickness of each compacted layer added to the fill. Where such pieces amount to more than about 5 percent of the volume of fill, they commonly require segregation and special handling. The difficulties related to the presence of clay and oversize fragments result in added cost for proper compaction, or, if proper compaction is not achieved, in subsequent settlement of the fill. We have inferred the presence of clayey fill, highly plastic clayey fill, and oversize fragments from composition and physical properties of each unit using the relations in table 8. The descriptions refer to the material after excavation, handling, and compaction by heavy equipment. These estimates are not sufficient for design of fills, which require detailed site study.

Excavation methods

Can be trenched	Can excavate a trench 0.6 m (2 ft) wide using Case 580 or equivalent backhoe
With ease	Digging can be accomplished largely by drawing bucket of the backhoe through material
With difficulty	Digging requires extensive loosening of pieces of rock by plucking and working with teeth of the backhoe bucket
Requires ripping	Can break up material on an open surface by drawing one ripper tooth through it with a Caterpillar D8 or equivalent crawler tractor
Requires heavy ripping or blasting	Ripping may be effective where either heavier equipment or tandem tractors are used, or blasting or equivalent methods may be necessary to break up the rock

Although these methods are applicable to different types of excavations, they form a sequence of increasing difficulty of excavation; material that requires ripping cannot be trenched, and material that requires heavy ripping or blasting cannot be ripped.

Excavatability related to physical properties

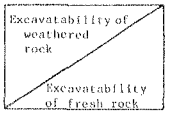
In the tables below, Trench means can be trenched as defined above, with ease and with difficulty being designated by w/ease and w/diff. Likewise Rip means Requires ripping, and HR or B means Requires heavy ripping or blasting.

Surficial mantle

Sandy and clayey surficial mantle - Trench w/ease	Rocky surfical mantle - Trenching difficult where abundant medium and larger hard blocks

Bedrock and unconsolidated deposits

Excavatability of bedrock is evaluated in the tables below according to spacing of planes of weakness and hardness. The diagonal line dividing most boxes, as illustrated below, separates the evaluation for weathered rock, in which fractures and parting are slightly open, from the evaluation for fresh rock, in which fractures are tight. Where only one evaluation is given in a box, that evaluation applies to both fresh and weathered rock. Excavatability of unconsolidated deposits is evaluated from hardness of the material modified by size of included blocks of rock. Because fracture and parting are largely insignificant in unconsolidated deposits, appropriate ratings are those listed for homogeneous or indistinctly bedded material with very wide fracture spacing.



Homogeneous or indistinctly bedded material

Hardness

Spacing of Fractures	0	Soft and loose	Firm approaching Soft	Firm	Very Firm	Hard
Very close 1 cm (.5 in.)		Trench w/ease	Trench w/ease / Trench	Trench / Trench w/diff or rip	Trench / Rip	Trench / HR or B
Close 5 cm (2 in.)		Trench w/ease	Trench w/ease / Trench	Trench w/diff / Trench w/diff or rip	Trench w/diff / Rip	Trench w/diff / HR or B
Moderate 0.3 m (12 in.)		Trench w/ease	Trench	Trench w/diff / Trench w/diff or rip	Trench w/diff / HR or B	Trench w/diff / HR or B
Wide 1 m (36 in.)		Trench w/ease	Trench	Rip / Rip or HR or B	Rip / HR or B	Rip / HR or B
Very wide		Trench w/ease	Trench	HR or B	HR or B	HR or B

Distinctly bedded material

Hardness of interbedded materials

Thickness of harder beds	0	Soft with firm or harder	Firm approaching soft with very firm or harder	Firm with hard
Very thin 1 cm (0.5 in.)		Trench w/ease	Trench w/ease	Trench w/ease / Trench w/diff or rip
Thin 5 cm (2 in.)		Trench	Trench	Trench / Trench w/diff
Medium 0.3 m (12 in.)		Trench w/diff	Trench w/diff	Trench w/diff
Thick 1 m (36 in.)		Good ripping	Good ripping	Rip

Figure 15.--Excavatability inferred from physical properties.

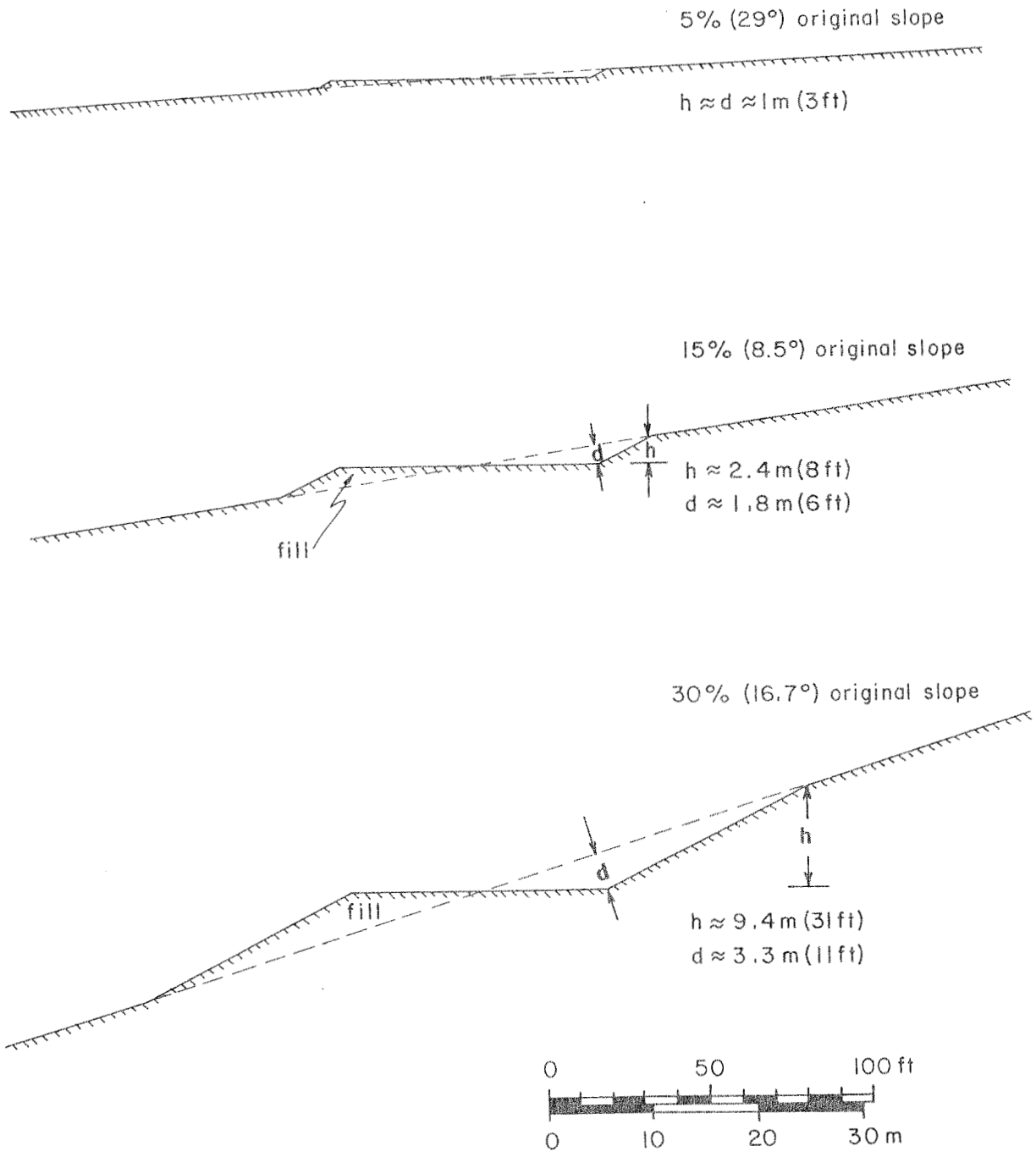


Figure 16.--Cross section showing effect of differences in original slope on height and depth of cut required to create level cut-and-fill pads of identical width using 2:1 (50%) cut-and-fill slopes. Pad width is 24m (80 ft), sufficient for one residential housepad.

Table 8. Fill character inferred from physical properties

Fill character describes the existence of clayey fill and highly plastic clayey fill, and the presence fo more than 5% oversize fragments (larger than 15 cm (6 in.) diameter) remaining after handling and compaction by heavy equipment.

Clayey fill (more than about one-third clay) is derived from clayey surficial mantle and from clayey rock that is soft to firm approaching soft.

Highly plastic clayey fill (more than about one-third highly plastic clay) is derived from severely expansive surficial mantle and from severely expansive clayey rock that is soft to firm approaching soft.

Oversize fragments are reported where 10% or more of a material consists of hard to very firm pieces of medium size (see table 4), or 5% consist of very firm to hard pieces of large or very large size.

Cut-slope Stability

Cut-slope stability describes the likelihood that materials will stand for a long time in cut slopes excavated to create level sites for roads or buildings. Most materials in the Washoe Lake area are stable in the relatively gentle (2:1, 50%) standard cut slopes for which stability is evaluated here, but stability of some units is less certain. Many materials are unstable where steeper cuts are required.

Effect of Ground Slope on Cut Slopes

The height of cut slopes depends upon the original slope of the ground surface. Figure 16 illustrates the depths of 2:1 (50%) cut slopes needed to create cut-and-fill pads of a given width on original slopes of 5%, 15%, and 30%, values that separate slope categories shown on the Slope Map of this folio. On slopes up to 15%, which make up the valley floors and most of the Mount Rose fan, cut slopes will generally be less than 2 m (6 ft) deep and should pose few problems even if the materials are unstable. In contrast, on slopes of 50% and more, which are present in the Carson Range and in parts of Steamboat Hills, the standard 2:1 (50%) cut slope cannot create level space, and steeper cuts must be used. Much of the granular surfical mantle of these steep hillside areas, although stable in the standard 50% cut slope considered in this evaluation, becomes unstable in cut slopes of about 60% or steeper. Where the ground slope approaches 60% the entire surficial mantle approaches critical equilibrium, and any failures initiated by cuts are likely to extend well upslope.

Evaluation of Cut-slope Stability

We evaluate the long-term (50-year) stability for a model cut slope of specified height and inclination, as illustrated in figure 17. The 2:1 (50%) inclination chosen for the model cut slope is the inclination adopted as standard by the Uniform Building Code (1976). We assume that bedrock exposed in the model cut slope is weathered.

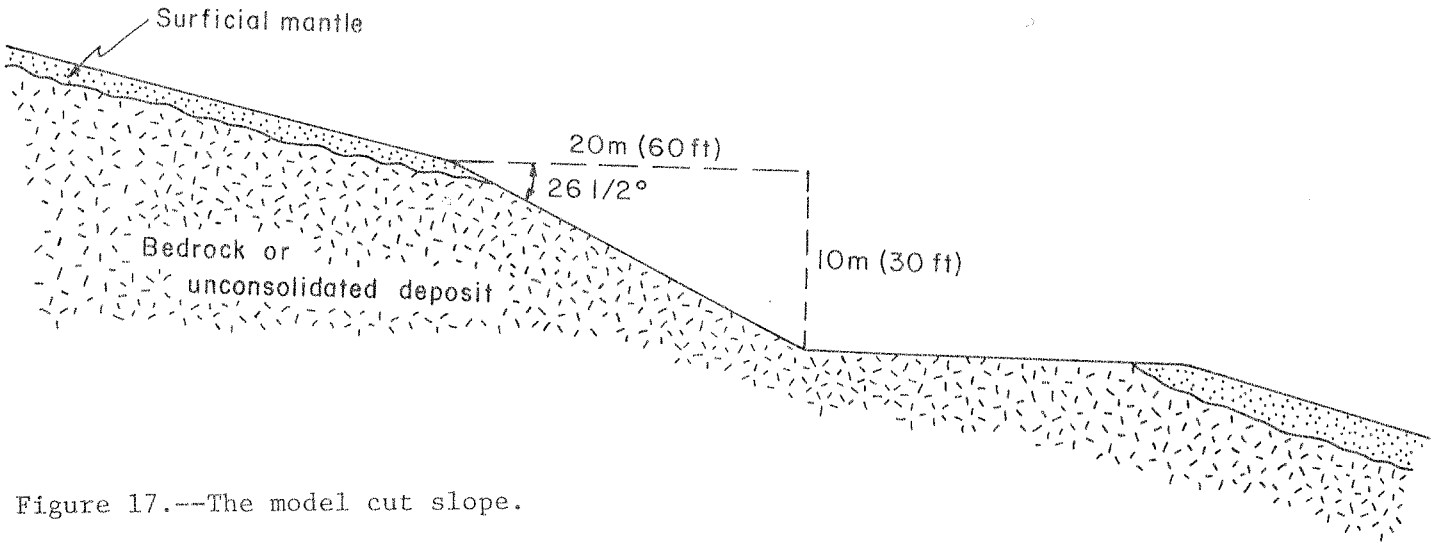


Figure 17.--The model cut slope.

In our estimates of stability we assume that materials in the model cut slope undergo conditions of saturation and earthquake shaking appropriate for their areas of occurrence. Data on depth to ground water (Hydrologic Map) suggest that long-term saturation of materials is likely only in the flat, low-lying areas where cut slopes are generally unnecessary. Precipitation data (Rush, 1967, p. 12 and figs. 5 , 6) suggest that temporary seasonal saturation of materials to depths approaching that of the model cut slope is likely only in the Carson Range, where precipitation exceeds 5 cm (2 in.) per month (to as much as 15 cm (6 in.) per month). Elsewhere the cut slope is probably saturated only occasionally during its lifetime. Moderate shaking by earthquakes can be expected during the lifetime of a cut slope, but we consider simultaneous saturation and shaking to be unlikely, so we do not consider liquefaction failure of cut slopes (see Geologic Hazards). Because the orientations of cuts relative to planes of weakness in materials vary from place to place, the stability of materials having significant planes of weakness is evaluated for two geometric situations. In adverse structural orientation, planes of weakness are left unsupported by the cut; in favorable structural orientation, the cut does not remove support from planes of weakness (fig. 18).

We have inferred the stability of materials in the model cut slope from physical properties of each unit by the relations described in figure 19. We report stability in terms of the expectable abundance of major failures in the model cut slope, major failure here meaning failure of two-thirds or more of the cut height, not including rockfall or minor sloughing. We have not estimated stabilities for geologic units that exclusively underlie slopes of less than 15%, or for soils, which are commonly too thin to offer significant stability problems. Surficial mantle (other than soil) is commonly granular material of high stability in the model cut slope, but exceptions are noted.

The stabilities reported for the model cut slope can be used to estimate the likely performance of the materials in higher or lower cut slopes of the same inclination, using the following rule of thumb. Most materials that are highly stable in the model cut slope, including most materials in the area, will remain highly stable in higher cuts; the few materials that are of moderate or poorer stability in the model cut will be much less stable in higher cuts and more stable in lower cuts.

Although our predictions of cut slope behavior may be used to anticipate the problems to be encountered in a given area, the stability of a given cut at a particular place can be estimated only crudely using this information. The stability of individual cut slopes depends on local factors that can be determined only through detailed site study and analysis.

Other problems

Problems distinct from the engineering characteristics evaluated but related to engineering use of earth materials include high water table, strongly acidic ground water produced by materials of unusual composition, uncommonly rapid disintegration by weathering, and present-day accumulation or movement of deposits.

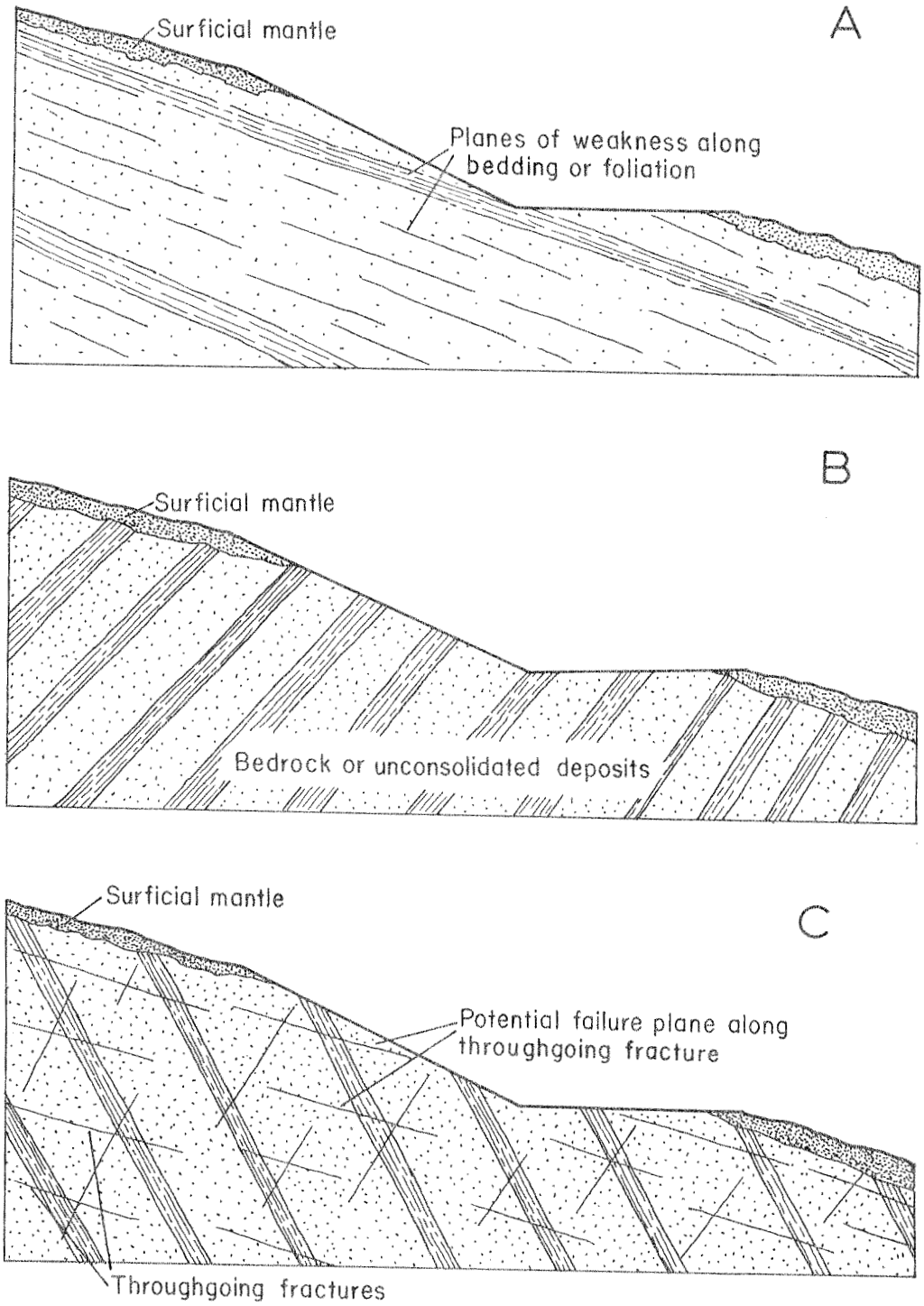


Figure 18.--Conditions of structural orientation in cut slopes. (A) Adverse orientation of bedding or foliation, in which planes of weakness are inclined out of the cut slope at an angle less than the cut slope. (B) Favorable orientation of bedding or foliation, in which planes of weakness are inclined into the cut slope. (C) Favorable orientation of bedding or foliation but adverse orientation of one set of throughgoing fractures, the other form (along with A) of adverse structural orientation.

Stability ratings related to estimated percentage of major failure

Estimated percentage of major failure	Stability rating
100	
	Very low
75	
	Low
30	
	Moderate
10	
	High
0	

Stability with favorable structural orientation

Composition of material	Soft	Firm, approaching soft	Firm	Very firm to hard
Sand	High	High	High	High
Clay	Low	Moderate	High	High
Expansive clay	Very low	Low	Moderate	High

Stability with adverse structural orientation

Spacing of parallel parting or throughgoing fracture. Spacing of parting reported in unit descriptions; spacing of throughgoing fracture assumed to be 3-10 m (10-30 ft) for all units.	Abundance and expansivity of free clay				
	No clay	Scarce clay	Scarce expansive clay	Abundant clay	Abundant expansive clay
0-0.3 in (0-1 ft)	High	Moderate to low	Very low	Very low	Very low
0.3-1 in (1-3 ft)	High	Moderate	Low	Low to very low	Very low
1-1.5 m (3-5 ft)	High	High	Moderate	Low	Low to very low
1.5-3 m (5-10 ft)	High	High	Moderate	Moderate to low	Low
3-10 m (10-30 ft)	High, stands well in steeper cuts	High	High	High to moderate	Moderate

Figure 19.--Cut-slope stability of weathered bedrock and unconsolidated deposits inferred from physical properties. The ratings describe the estimated long-term stability of the cut slope (fig. 17) in terms of anticipated percentage of major failures.

Unit Descriptions of Composition, Physical Properties, and Engineering Characteristics of Earth Materials

Abbreviations used: WS = weathering and soil; H = hardness; F = fracture; B = bedding; PP = parallel parting; P = permeability; BC = bearing capacity; Exp = expansivity; Exc = excavatability; FC = fill character; CSS = cut slope stability.

Qa - Artificial fill

Composition: Excavated and recompacted material. In Steamboat Hills composed of unit pKm, including disseminated sulfides; near Little Washoe Lake probably composed largely of unit Tkb; along west side of Washoe Lake probably composed of granitic sand and rock. WS: None.
Physical properties: H: Variable. B: Indistinct horizontal layering, largely medium in thickness, from construction of fill.
Engineering characteristics: P: Variable. Exc: Can be trenched. FC: In Steamboat Hills sulfides may cause rapid breakdown of rock fragments in fill.
Other problems: Acid groundwater likely in Steamboat Hills.

Qf - Flood deposits

Composition: Sand with variably abundant gravel, boulders and silt. In canyons contains many boulders, some as large as 5 m; below mouths of canyons less bouldery, in places only sand. In Pleasant Valley abundant gravel and boulders. WS: None.
Thickness: Probably 1-3 m.

Physical properties: H: Sand soft to loose, cobbles and boulders largely hard. B: Sand medium to thick in places, largely unbedded where large boulders.
Engineering characteristic: problems in loose sand. Exc: Sand can be trenched with ease, blocks may cause difficulty, boulders may require ripping or overexcavation. FC: Oversize fragments common in much of unit.
Other problems: May be subject to flooding.

Qdd - Deltaic deposits

Composition: Sand, very fine to very coarse grained, some silty. WS: 0.2 m poorly developed soil.
Physical properties: H: Soft to loose. B: Distinct, probably thin to thick, nearly horizontal.
Engineering characteristics: P: Moderate to high. BC: Possible problems. Exc: Can be trenched with ease.
Other problems: High water table. Qyl - Young landslide deposits. Geologic Hazards Map (this folio) shows some landslide deposits not shown on Geologic Map.
Composition: Unsorted debris derived from underlying or upslope materials. Character varies. WS: Little soil.
Physical properties: Variable.
Engineering characteristics: P: Variable, low to high intergranular and fracture permeability. BC: Possible problems in loose or cracked material. Exc: Variable. FC: Variable. CSS: Generally very low.
Other problems: Poor slope stability.

Qld - Lake deposits

Composition: Interbedded clayey and sandy sediment, much of each. Clayey sediment is silty and fine sandy clay to clayey silt, includes buried soils. Sandy sediment ranges from silt to very coarse sand and minor gravel, most moderately well sorted and fairly clean. Well logs show largely sand and clay (2/3 sand to 2/3 clay), minor gravel. WS: Little.

Thickness: Up to about 10 m; largely underlain by old lake deposits consisting of similar materials in similar proportions.

Physical properties: H: Sandy sediment largely soft to loose, some approaches firm; clayey sediment soft when wet, firm when dry. F: Clays cracked when dry. B: Distinct, thin to thick, nearly horizontal.

Engineering characteristics: P: Clayey sediments low to very low, sandy sediments moderate to high. BC: Possible problems in most of unit. Exp: Sandy sediment unexpansive; much clayey sediment unexpansive, much significantly expansive, some severly expansive. Exc: Can be trenched, sticky clay and high water table may cause difficulty. FC: Much clayey fill, highly plastic clayey fill in places.

Other problems: High water table.

Qws - Windblown sand; Qwd - Dunes.

Composition: Clean sand, well to moderately sorted, fine- to coarse-grained. WS: No soil.

Thickness: Qws from less than 1 m to about 6 m; Qwd to about 10 m.

Physical properties: H: Loose. B: Largely indistinct.

Engineering characteristics: P: Largely high. BC: Possible problems. Exc: Can be trenched with ease. CSS: High.

Other problems: High water table in much of Qwd. Dunes may shift.

Qsu - Sand, undifferentiated.

Composition: Largely sand, fine- to very coarse-grained, ranges poorly to well sorted, much moderately to well sorted; much clean, much silty, most has scattered pebbles and cobbles as large as 20 cm. Clayey, silty sand in New Washoe City along Lakeside Drive between Clark and Douglas Drives and south of New Washoe City over unit Qold. Well logs show largely sand with some clay, gravelsand boulders. WS: Some organic enrichment in upper 0.5 m.

Thickness: Mostly 1-3 m, up to 10 m; 0.2-1 m, more or less continuous, where shown as pattern over other units on Geologic Map.

Physical properties: H: Loose to soft. B: Largely indistinct.

Engineering characteristics: P: Much sand moderate, much high, possibly low in clayey sand near New Washoe City; clay reported in wells probably low to very low. BC: Possible problems in loose sand. Exp: Largely unexpansive, some clayey sand significantly expansive. Exc: Can be trenched with ease. FC: Generally no clayey fill or oversize fragments.

Other problems: High water table in some places.

Qfg - Alluvial fans of granodioritic sand.

Composition: Largely granodioritic sand, medium- to very coarse-grained, micaceous, moderately to well sorted, most somewhat silty, some clean, some clayey. Includes gravel with boulders toward margin of basin, finer sediments (to sandy silts) toward center of basin. Local clayey buried soil. Well logs show mostly sand with 10% or more clay

layers, some boulders and gravel. WS: Much of upper 2 m rich in organic material, beneath which much material iron-stained and clay-coated to nearly clogged.
Thickness: Probably up to 10 m.
Physical properties: H: Largely soft, some clayey sand firm when dry. B: Mostly indistinct, some distinct, most nearly horizontal. Well logs show clayey layers up to 3 m thick, sand layers up to 25 m thick.
Engineering characteristics: P: Largely moderate to high, some low, local very low. BC: Possible problems in organic-rich sand and in saturated fine sand near Washoe Lake. Exp: Largely unexpansive, local clay layers may be expansive. Exc: Can be trenched with ease. FC: Minor local clayey fill, oversize fragments locally near basin margin.
Other problems: High water table in most of unit.

Qfs - Alluvial fans of very fine- to coarse-grained sand
Composition: Quartz-rich silty sand, largely medium-grained, ranging very fine- to very coarse-grained; numerous pebbles up to 0.5 cm across, cobbles locally as large as 10 cm, increasing in size and abundance upslope. Sand largely moderately sorted, ranging poorly to well sorted; contains many partially rounded windblown grains. WS: Soil largely absent, locally some clay coating in upper 0.5 m.
Thickness: Probably up to 10 m.
Physical properties: H: Loose to soft. B: Largely indistinct, nearly horizontal.
Engineering characteristics: P: Most moderate to high, near surface some low due to clay coatings. BC: Possible problems in loose sand. Exc: Can be trenched with ease. Qfsb - Alluvial fans in Pleasant Valley

Qfsb - Alluvial fans in Pleasant Valley
Composition: Largely gravel, with some sand that increases in proportion toward east side of valley, and 5-10% lenses of well sorted, distinctly bedded sand, tuffaceous sand, and ash. Gravel largely closely packed, well-rounded pebbles, cobbles, and some boulders, in matrix of well to moderately sorted fine- to very coarse-grained sand. Sand fine- to coarse-grained, poorly to well sorted, much pebbly or cobbly. Lenses of clean, well-sorted fine- to very coarse-grained sand and fine- to very fine-grained tuffaceous sand and ash are closely associated with thin clay layers. Well logs show about equally abundant sand, clay, and gravel including boulders; some clay within 3 m of surface. WS: Clay coatings in upper 3 m. Largely variably rocky, silty sand soil; some clayey, silty sand soil, to 1 m or more thick; some well-developed with caliche, some poorly developed. Local buried soils.
Thickness: To greater than 40 m.
Physical properties: H: Sand matrix in gravels largely soft, some firm from clay and iron cementation; clasts hard. B: Absent to indistinct in much gravel. Well-sorted sand and fine ash form distinct lenticular medium to thick beds; associated clay layers thin to very thin, distinct. Well logs show clayey intervals commonly to 3 m thick; sand and gravel intervals very thick (to 10 m).
Engineering characteristics: P: Largely moderate, much high; soil largely moderate, some high. BC: Possible problems in loose sand, saturated fine sand, and clay. Exc: Can be trenched, much with difficulty due to cobbles and boulders. FC: Common oversize fragments, possibly clayey fill.

Other problems: High water table in much of unit. Alluvial fans with boulders.

Qfb - Alluvial fans with boulders

Composition: Variably abundant angular to rounded pebbles to boulders in dominant matrix of sand, some clayey. Boulders minor near Jumbo Creek, more abundant and large to very large (to 3-5 m) near Pleasant Valley and Washoe City; clasts both scattered in matrix and packed in gravel lenses. Matrix is fine- to coarse-grained sand, poorly to well sorted, with some silt and clay. Unit may include clay or sandy clay; near Jumbo Creek well logs suggest sand and clay within 3 m of surface, overlying gravel, sand and clay. WS: Near Jumbo Creek some matrix clay-coated, rarely clogged; near Pleasant Valley and Washoe City much clay-coated, some clogged; clay coatings decrease below about 3 m. Near Jumbo Creek little soil development; near Pleasant Valley and Washoe City much silty sand soil, much sandy clay, all variably rocky.

Thickness: To more than 80 m in Pleasant Valley; to more than 20 m near Washoe city.

Physical properties: H: Matrix largely soft, some firm, clasts hard to firm. B: Largely lenticular and indistinct, some distinct, thin to very thick (to more than 2 m).

Engineering characteristics: P: Near Jumbo Creek most of unit moderate to high, some low; near Pleasant Valley and Washoe City most of unit moderate, some high, some low to very low. Exp: Fan material largely unexpansive, may be significantly expansive in places; much soil near Pleasant Valley significantly expansive. Exc: Can be trenched, some with difficulty where boulders common; some very large boulders may require blasting or special handling. FC: Oversize fragments and clayey fill in some places, especially near Pleasant Valley and Washoe City.

Qt - Talus

Composition: Angular pieces of local bedrock ranging from sand-size to very large blocks; largely medium to large blocks in Steamboat Hills, small to very large blocks in abundant silty granodioritic sand on Slide Mountain. WS: None.

Physical properties: H: Loose deposit of generally hard pieces. B: Probably crude, parallel to ground surface.

Engineering characteristics: P: High. BC: Possible problems. Exc: Can be trenched, or ripped where large blocks, but excavation dangerous because of steep slopes and instability of deposits. FC: Oversize fragments in much. CSS: High in standard cut slope, but very low in steep slopes existing on these deposits.

Other problems: Accumulation by rockfall from steep slopes above; much creeps downslope. Any excavation can cause rapid failure up and down slope.

Qba - Basin alluvium

Composition: Interbedded sand, silt, and gravel, local clayey interbeds. Small deposits over unit Kg in Carson Range largely coarse-grained granodioritic sand. Basins on or downslope of Kate Peak Formation probably contain much clay and silt. Basins on and downslope of glacial moraines or debris flow deposits probably contain abundant silt. Large deposit in Little Valley consists of surficial layer about 3 m thick of fine to coarse sand interbedded with silt and pebble to

cobble gravel, overlying red-orange sand and interbedded gravel; clayey lake deposits possible locally. WS: Most soils poorly developed, sandy.

Thickness: Mapped where more than about 3 m. Reaches 15 m in Little Valley.

Physical properties: H: Largely soft, pebbles and cobbles hard, red-orange deposits in Little Valley may approach firm. B: Generally distinct, very thin to thick, some indistinct beds very thick; nearly horizontal.

Engineering characteristics: P: Largely moderate to high with low interbeds in places, much low and possibly very low over Kate Peak Formation; soil similar. BC: Loose organic sand may cause problems. Exp: Largely unexpansive, possibly expansive in deposits over Kate Peak Formation Exc: Can be trenched with ease. FC: Local clayey fill and oversize fragments. CSS: Largely high, possibly moderate in deposits over Kate Peak Formation.

Qs - Slope deposits

Composition: Angular rock rubble, sand, silt and clay, generally poorly sorted, blocks up to large, some possibly very large. In places includes talus as described for unit Qt. WS: Generally poorly developed, variably rocky, sandy soil: on gentle slopes, as near Washoe City, sandy clay soil more than 1 m thick.

Thickness: Probably up to 10 m.

Physical properties: H: Largely soft with hard blocks. B: Generally absent, some indistinct beds up to very thick.

Engineering characteristics: P: Probably largely moderate to high; soil near Washoe City largely low. BC: Possible problems in soil near Washoe City. Exp: Largely unexpansive; in places, as near Washoe City, soil may be significantly expansive. Exc: Most can be trenched, blocks may cause difficulty. FC: Local oversize fragments and clayey fill. CSS: High in standard cut slope, but steepness of deposits commonly requires cuts steeper than 2:1, which are probably of low stability.

Other problems: Rockfall from above in places.

Qsd_{1-9}, -Qsdu - Debris flow deposits of Slide Mountain.

Composition: Poorly sorted mixture of variably abundant granodiorite blocks up to large, some up to 4 m, suspended in poorly sorted, angular, silty sand, generally with minor clay. Blocks commonly constitute 10-50% of material (locally to 75%). In Ophir Canyon, zeolite (stilbite) veins cut the deposits, and blocks are locally altered to and coated with zeolites; alteration softens some blocks. WS: Qsd largely coated with clay and iron oxide to deeper than 3 m; most blocks on surface rounded, most blocks beneath surface softened to deeper than 7 m. Qsd_{2-9} generally lack staining and clay coating, though present in places to at least 2 m deep; many blocks on surface angular, many to most beneath surface hard. In general younger deposits show more angular and harder blocks. Soil variably rocky, somewhat coherent silty sand, less than 0.3 m thick on Qsd_{2-9} and Qsdu to 0.7 m thick on Qsd_1.

Thickness: Up to at least 60 m.

Physical properties: H: Largely soft, some approaching firm, blocks hard to firm. B: Crude, indistinct thick to very thick (to at least 25 m) layers of blocky and less blocky debris.

Engineering characteristics: P: Generally moderate, some low in silty and clayey material. Exp: Largely unexpansive, local clayey silty sand

may be significantly expansive. Exc: Much can be trenched with ease, hard blocks may cause difficulty; very large blocks may require blasting or special handling. FC: Common oversize fragments.

Qsdc- Coarse deposits of Slide Mountain debris flows
Composition: Angular blocks of granodiorite up to 6 m across, no matrix. WS: None.
Thickness: 3 m to probably 15 m or more.
Physical properties: H: Loose deposit of hard blocks.
Engineering characteristics: P: High, to moderate if matrix present at depth. Exc: Requires blasting where blocks too large to move whole. FC: Entirely oversize fragments.

Qsdb - Shattered granodiorite in slide block at foot of Slide Mountain scar.
Composition: Granodiorite similar to highly fractured Kg but somewhat more closely fractured and fractures more open (due to jostling of mass in slide movement). WS: Little soil.
Thickness: Up to greater than 130 m.
Physical properties: H: Firm to hard. F: Largely close to moderate, some wide.
Engineering characteristics: P: Moderate to high fracture permeability to base of deposit. Exp: Largely unexpansive, but clay gouge and crushed material along fractures may be signficantly expansive in places. Exc: Much can be trenched with difficulty, almost all can be ripped. FC: Common oversize fragments.

$Qgm_{,1-4}$, Qgmu - Glacial moraine
Composition: Angular to rounded blocks, generally medium to 1.3 m but some up to larger than 4 m, suspended in generally poorly sorted, prominently silty sand matrix, commonly with clay sufficient to make it nearly firm when dry. In places matrix includes much clean, poorly sorted, fine- to coarse-grained sand. Blocks scattered to closely packed. WS: In Qgm_1 most buried granitic boulders soft to firm, surface granitic boulders few and rounded. In Qgm_{2-4} most buried granitic boulders hard, surface boulders relatively plentiful and hard. Much of Qgm_1 iron stained and clay coated to deeper than 6 m; some soil development to 2 m. Qgm_{2-4} show little staining; some soil development to 1 m on Qgm_2, only slight development on Qgm_{3-4}. Soils variably rocky, poorly sorted silty sand with minor clay.
Thickness: Up to 25 m or more.
Physical properties: H: Matrix soft, approaching firm where dry, blocks hard to soft. B: Largely absent, clean sand irregularly distributed.
Engineering characteristics: P: Qgm_1 generally low, some moderate to high in cleaner sands; Qgm_{2-4} largely low to moderate, some high. Surficial mantle probably largely moderate. Exc: Much can be trenched with ease, especially Qgm_1, much with difficulty, especially Qgm_{2-4}; very large blocks may require blasting or special handling. FC: Common oversize fragments, especially in Qgm_{2-4}.

Qgo_{2-4}, Qgou - Glacial outwash.
Composition: Largely gravel of rounded to angular granitic blocks, most blocks medium to 1.3 m but some as large as 4 m in Qgo_2 and Qgou, in matrix of poorly to well sorted, fine- to very coarse-grained sand, largely clean, some silty. Blocks closely packed to suspended in

matrix. Some beds of sand without blocks. WS: Most blocks on ground surface hard, but some to almost all granitic blocks beneath ground surface firm to soft. Some Qgou iron stained and clay coated. Soils up to 1 m thick; variably rocky, silty to slightly clayey sand, some clayey subsoil.
Thickness: Qgo_2 about 5-7 m; Qgo_4 and Qgou up to 15 m or more.
Physical properties: H: Matrix largely soft, much approaching loose, some Qgou approaching firm; blocks commonly hard near ground surface, soft to hard beneath. B: Most indistinct, medium to very thick.
Engineering characteristics: P: Moderate to high, probably mostly high; surficial mantle largely moderate, some subsoil low. Exc: Some can be trenched with ease, much with difficulty. Common large hard blocks may require blasting or special handling. FC: Common oversize fragments.

Qows - Old windblown sand
Composition: Clean sand, medium- to coarse-grained, moderately well to well sorted, with films of iron oxide and clay. Includes scattered pebbles and cobbles as large as 10 cm. WS: Slight enrichment of silt and organics in upper 2 m.
Thickness: Up to 10 m or more.
Physical properties: H: Soft, nearly loose.
Engineering characteristics: P: High. Exc: Can be trenched with ease.

Qod - Old sand dunes(?)
Composition: Dark, fine- to coarse-grained sand, fairly well sorted, locally with up to 40% of grains completely altered to clay. WS: Organic-rich sandy soil at least 10 cm thick.
Thickness: Occurs as hummocks 1 m to about 5 m high.
Physical properties: H: Soft. B: Some indistinct thin to medium beds.
Engineering characteristics: P: Moderate to high. BC: Possible problems. Exc: Can be trenched with ease. FC: Local clayey fill.
Other problems: High water table. Qst - Siliceous sinter and travertine
Composition: Chalcedonic and opaline sinter (SiO_2) and travertine ($CaCO_3$), as crusts or replacement masses in other materials. WS: None.
Thickness: Up to 1 m.
Physical properties: H: Hard. F: Commonly moderate to wide, ranging close to very wide. B: Most layered thin to medium. PP: Close to moderate along layering in sinter.
Engineering characteristics: P: Low to very low fracture permeability. Exc: Most can be trenched with difficulty, some may require ripping. FC: Common oversize fragments.

Qol - Old landslide deposits.
Composition: Near Pleasant Valley, brecciated, sheared and weathered slate and phyllite (pKm) with much sandy and silty clay. In Carson Range, largely granitic rubble. WS: Near Pleasant Valley, up to at least 6 m of clayey weathered material with blocks of hard rock, overlain by 0.3 to 0.7 m variably rocky brown clayey to silty soil.
Thickness: Up to at least 40 m.
Physical properties: Variable. In Carson Range, commonly blocks of hard rock in soft or firm matrix.

Engineering characteristics: P: In Carson Range, generally high to moderate intergranular permeability; near Pleasant Valley, probably largely moderate fracture permeability to base of deposit, much low to very low permeability in soil and clayey weathered material. BC: Possible problems in soil and clayey weathered material near Pleasant Valley. Exp: Near Pleasant Valley, largely unexpansive, some soil and clayey weathered material may be significantly expansive; in Carson Range, unexpansive. Exc: Most can be trenched, some may require ripping, large blocks in Carson Range may require blasting or special handling. FC: Near Pleasant Valley much clayey fill; in Carson Range common oversize fragments. CSS: Probably low near Pleasant Valley; high in Carson Range.
Other problems: Possible poor slope stability.

Qgl - Glacial outwash and/or landslide deposits
Composition: Largely poorly sorted, variably silty sand, with abundant medium to large blocks. In upper Davis Creek, orange granitic sand with mostly decomposed granitic boulders; north of Jones Creek forms fan with scattered boulders; in upper Ophir Creek, unsorted granitic rubble. Similar to Qsd and Qgm. WS: Soil largely variably rocky, silty sand, up to about 1.3 m thick in upper Davis Creek; probably poorly developed elsewhere.
Thickness: Up to at least 15 m.
Physical properties: H: Matrix soft, some approaching firm, blocks hard to firm. B: Some indistinct very thick beds.
Engineering characteristics: P: Probably largely moderate, much high, some low. Exp: Largely unexpansive, may be expansive locally north of Jones Creek. Exc: Most can be trenched, large hard blocks may require blasting or special handling. FC: Common oversize fragments. Qogb - Unbedded pebbly sand in bar-like ridge.
Composition: Well-rounded and polished pebbles and lesser cobbles to as large as 12 cm in matrix of mostly coarse- to very coarse-grained sand, clean to fine sandy and silty. WS: Rocky, silty sand soil to 0.7 m thick includes 0.2 m organic surficial soil, partially clay-clogged subsoil.
Thickness: Probably 3 m or more.
Physical properties: H: Soft to loose with hard clasts, clayey subsoil approaches firm.
Engineering characteristics: P: Mostly high, moderate in subsoil. Exc: Can be trenched with ease.
Other problems: High water table in much of unit.

Qoa - Old alluvium, dominantly sand: (1) between Washoe City and New Washoe City, (2) west of Washoe City, (3) at Davis Creek County Park, (4) near west side of Washoe Lake at south edge of quadrangle, (5) along faults in southeast corner of quadrangle.
Composition: Sand, medium to very coarse grained, clean and well sorted to silty and poorly sorted, minor pebble gravel and pebbly sand, local cobbles. At (1) well logs show largely sand, some silty sand, some gravel with cobbles, minor clay layers; bedrock or hard boulders within 3 m of surface in parts cof New Washoe City area. At (4) well logs show sandy clay to 30 m, largely sand with thinner clay layers from 30 to 60 m, clay abundant from 60 to 160 m. WS: At (1), (2) and (3), clay coatings and iron staining variable, strongest from base of soil to 3 m, diminish below 5 m, some pores clogged, most largely open; soil

sandy, 0.3 to 1 m thick, some clayey near base. At (4), clay coating and staining to 3 m, some nearly clogged; soil well developed, 0.3 to 1.3 m thick, much dark sandy clay, some caliche. At (5), iron stained but little clay coating; soil dark sandy clay to clayey sand, 0.5 m to more than 2 m thick, some caliche, subsoil nearly clay-clogged.
Physical properties: H: Soft, firm where clay coated. B: Very thin to very thick beds and lenses.
Engineering characteristics: P: Largely moderate to high, some low in upper 3 m. Soil largely moderate at (1), (2), and (3); much low, some very low, at (4); low to very low at (5). BC: Possible problems in clayey soil at (4) and (5). Exp: Largely unexpansive; some severely expansive soil, particularly subsoil, at (4); some soil probably significantly expansive at (5). Exc: Can be trenched, largely with ease. FC: Some highly plastic clayey fill from soil at (4); some clayey fill from soil at (5).

Qoa - Old alluvium, gravel and sand: (1) on Franktown Road near south edge of quadrangle; (2) near Franktown ; (3) in Ophir Canyon; (4) in Pleasant Valley; (5) on hilltops near New Washoe City; (6) in saddle east of Little Washoe Lake; (7) east of Pleasant Valley.
Composition: Sand with variably abundant gravel. At (1), (2), and (3) sand and gravel matrix are largely medium- to very coarse-grained granitic sand, some silty, poorly to well sorted. At (6) and (7), sand and gravel matrix are largely clean and moderately to well sorted, largely medium grained. Gravel clasts largely rounded; most are decomposed granitic rock except at (4) through (7). Some gravel in parts of (1), up to boulders; in (6) and (7) some gravel, up to cobbles; it (4) much to most is gravel, cobbles up to 20 cm; at (5) much to most is gravel, up to boulders; at (2) most is gravel, up to cobbles; and at (3) almost all is gravel of closely packed granitic cobbles and boulders, most large, some up to 2 m across. WS: Variably clay coated and iron stained, to more than 5 m deep in places, greatest from base of soil to 3 m; some nearly clay-clogged at (1), other areas only partially clogged. Soil sandy, variably rocky, variably developed, 0.3 to 1 m thick at (1), (2), (4), and (5); absent at (3); variably rocky sandy clay to clayey sand with clayey subsoil at (6) and probably at (7).
Physical properties: H: Sand and gravel matrix soft, firm where clay coated; clasts largely firm to soft at (1), (2) and (3), largely hard at (4) through (7). B: Up to very thick, some lenticular.
Engineering characteristics: P: Largely moderate to high, some low at (1) in upper 3 m; soil largely moderate, much subsoil low at (6) and probably (7), some low at (1). Exp: Largely unexpansive; most subsoil significantly expansive at (6) and probably at (7), some possibly at (1). Exc: Can be trenched, most with ease, blocks may cause difficulty at (2), (4) and (5). FC: Oversize fragments likely at (5), possible at (4).

Qold - Old lake deposits, east side of Washoe Lake. Well logs show interbedded sand and clay, roughly equally abundant, with minor gravel. WS: Surficial mantle largely unit Qsu, including much clayey and silty sand.
Thickness: To more than 300 m.
Physical properties: H: Soft to firm, hard clasts. F: Probably absent. B: Intervals of contrasting composition thick to 15 m, roughly horizontal.

Engineering characteristics: P: Moderate to high in sand, low to very low in clay; surficial mantle largely moderate to high, some possibly low. BC: Possible problems in loose or saturated sand. Exp: Some surficial mantle significantly expansive; up to half of deposits may be expansive. Exc: Can be trenched. FC: Much clayey fill, may be highly plastic.
Other problems: High water table in much of unit.

Qold - Old lake deposits, west side of Little Washoe Lake.
Composition: Two types of material interbedded, much of each: (1) White to light gray diatomaceous and ashy sediments, including fine- to very fine-grained silty sandstone, siltstone, some claystone. (2) Well to moderately sorted clean sand, largely medium- to very coarse-grained, and gravel of pebbles and cobbles; some silty and clayey fine- to very fine-grained sand. Well logs show about equally abundant clay and sand, some gravel. WS: Clean sand and gravel iron-stained but little clay coating. Soil on unit is dark brown, variably rocky, 0.3 m to greater than 1 m thick; probably largely sandy, some sandy clay subsoil.
Physical properties: (1) and (2) interbedded in thick to 15 m, roughly horizontal intervals.
Composition 1: H: Largely firm, ranges very firm to soft, much has low density. F: Very close to moderate. B: Distinct, very thin to more than 1.3 m. PP: Close to very close in most beds thicker than medium.
Composition 2: H: Soft to loose, clasts hard to firm. B: Distinct, largely thin to thick.
Engineering characteristics: P: Diatomaceous and ashy sediments largely low, some moderate; clean sand and gravel moderate to high. Soil largely low to moderate, sandy clay subsoil very low to low. BC: Possible problems in sandy clay subsoil. Exp: Probably largely unexpansive, sandy clay subsoil severely expansive. Exc: Can be trenched, some with difficulty. FC: Some highly plastic clayey fill (from subsoil). CSS: Moderate where adverse bedding (probably common), high where favorable bedding.

Qmb - Deposits of Mt. Rose fan, bouldery facies
Composition: Consists of two types of material, interbedded: (1) Variably abundant (5 to 70%) pebbles, cobbles and boulders suspended in poorly sorted silty and clayey sand matrix. Clasts to cobble-size in much of unit; boulders generally large, some up to 4 m. Matrix locally tuffaceous. Makes up half to most of the unit. (2) Well-sorted, closely packed gravel of pebbles to boulders in silty sand matrix; minor lenses of moderately to well-sorted sand. Makes up some to half of the unit. WS: Well-sorted materials iron stained and clay coated to 2-3 m deep. Soil 0.3 to 1 m thick, variably rocky, largely sandy, some to half with clayey subsoil.
Thickness: Roughly 20 to 35 m.
Physical properties: (1) and (2) occur in very thick (to greater than 3 m) bodies of irregular shape and distribution.
Composition 1: H: Soft to firm, blocks hard (volcanic) to soft (granitic). B: Indistinct, very thick (to more than 3 m).
Composition 2: H: Soft, clasts soft to hard. B: Very thin to very thick, some lenticular.
Engineering characteristics: P: (1) low to locally moderate; (2) largely moderate, some high. May increase somewhat below upper 3 m.

Soil largely moderate, some to half low to very low (clayey subsoil). BC: Possible problems in clayey subsoil. Exp: Deposits unexpansive; most soil unexpansive, but much subsoil significantly expansive. Exc: Most can be trenched, with difficulty where hard blocks; very large blocks may require blasting or special handling. FC: Oersize fragments in much, clayey fill in much. CSS: Moderate to high.

Qms - Deposits of Mt. Rose Fan, sand and silt facies

Composition: Consists of four types of material, interbedded in roughly equal proportions: (1) White to light gray, tuffaceous and some diatomaceous sediments, including fine-grained tuff; high-matrix tuffaceous and diatomaceous sand, largely fine- to medium-grained; and tuffaceous mudstone and shale. (2) Clean sand and gravel, most well to moderately well sorted, including fine- to very coarse-grained sand, pea gravel, and local lenses of rounded cobbles. (3) Poorly sorted clayey and somewhat tuffaceous sand, largely fine- to medium-grained; most clay-clogged, ranges from clay coated to sandy clay. (4) Variably abundant pebbles to boulders (up to 1.3 m across) suspended in poorly sorted silty and clayey sand matrix. Well logs suggest roughly equally abundant sand and clay, some gravel; intervals of contrasting compositions thick to 8 m. WS: Clean materials iron stained and clay coated to clogged to 2-3 m deep. Soil variably rocky, 0.3 to 1 m thick, well developed; and 50% clayey, and 50% sandy.

Thickness: Up to 15 m (from well logs).

Physical properties: (1), (2), (3), and (4) typically interbedded in very thick (more than 2 m), intervals.

Composition 1: H: Largely firm, ranging soft to very firm, some has low density. F: Original fracture largely close to moderate; much has superimposed close to very close weathering fracture. B: Distinct, very thin to very thick. PP: Close to very close in much.

Composition 2: H: Soft, clasts hard to soft. B: Thin to very thick, some lenticular.

Composition 3: H: Soft to firm, some very firm. F: Close to moderate in some. B: Medium to very thick. PP: On some bedding planes.

Composition 4: H: Soft to firm, blocks hard (volcanic) to soft (granitic). B: Indistinct very thick (to greater than 3 m).

Engineering characteristics: P: Largely low, much moderate and high in very thick zones or beds. Unit is main aquifer in Mt. Rose Fan area. (1) largely low, ranging very low to moderate; (2) moderate to high; (3) and (4) low. Below upper 2-3 m, (3) and (4) have some moderate, (2) more high. About half of soil moderate to high, half low to very low. BC: Possible problems in clayey soil. Exp: Largely unexpansive, some clayey sand significantly expansive. Soil largely unexpansive, up to 30% significantly expansive. Exc: All can be trenched, difficult in places. FC: Much clayey fill from soil, local oversize fragments. CSS: Moderate where bedding is adverse (probably common); high where bedding favorable.

Qsh - Steamboat Hills Rhyolite

Composition: Largely low-density, pumiceous rhyolitic glass, containing sparse phenocrysts. Pumice devitrified to chalky white material along many flow bands, but most of unit is fairly fresh gray glass. Some perlite, minor obsidian. On lower slopes of cone, bedrock overlain by breccia of pumice blocks cemented by clay, up to more than 2 m thick.

WS: Surficial mantle on cone is sand with abundant blocks of pumice, little or no clay. On lower flanks (50% or less of unit) surficial mantle is clayey, silty sand with some clay soil and subsoil.
Thickness: Up to more than 60 m.
Physical properties: H: Very firm, breccia on lower slopes firm with very firm pieces. F: Close to very wide (1.3 m), much moderate to wide. B: Very close to close flow banding in much of unit.
Engineering characteristics: P: Fracture permeability at depth largely very low to low, in shallow rock largely low; breccia on lower slopes has high intergranular permeability. Surficial mantle largely moderate to high, some low to very low in subsoil on lower flanks. BC: Possible problems in clay soil and subsoil. Exp: Bedrock unexpansive; surficial mantle largely unexpansive, some significantly expansive clay soil and subsoil on lower slopes. Exc: Where weathered, most bedrock requires ripping, some requires heavy ripping or blasting; where fresh, most requires heavy ripping or blasting. Most surficial mantle can be trenched, some with difficulty. FC: Abundant oversize fragments, some clayey fill from soil. CSS: High, can stand well in steeper cuts.

Qsg - Granule conglomerate of rhyolite pumice and metamorphic rock.
Composition: Interbedded sediments, largely clean and well to moderately well sorted, consisting of granule to pebble conglomerate of pumice and metamorphic clasts; coarse- to very coarse-grained sandstone; and fine- to medium-grained sandstone, some approaching siltstone. Roughly 50% conglomerate, 25% coarse sandstone and 25% fine sandstone. Minor hard blocks as large as medium suspended in sediment. WS: Up to 50% of material, especially near surface, partially clay-clogged and cemented. Most soil pebbly, slightly clayey, silty sand; minor cracked clay soil, possibly more abundant as subsoil.
Thickness: 1 m to probably more than 10 m.
Physical properties: H: Largely soft approaching loose, but much, especially near surface, is firm because of clay cement; clasts hard to firm. B: Distinct, thin to very thick (at least 1.3 m), most thin to medium.
Engineering characteristics: P: Largely high, some low to moderate especially near surface; soil largely moderate, some low to very low. BC: Possible problems in clay soil. Exp: Sediments unexpansive; soil largely unexpansive, some significantly expansive soil or subsoil. Exc: Can be trenched, some possibly with difficulty. FC: Some clayey fill from soil.

Tb - Basalt
Composition: Basaltic flow rock with sparse phenocrysts, much vesicular, interlayered with much red scoriaceous flow rock and some cinder breccia. Cinder breccia consists of pyroclastic fragments from sand-size to medium and some large blocks, much crudely to moderately well sorted, much unsorted. WS: Much flow rock crops out, much has rocky, clayey silt and sand surfical mantle. Cinder breccia, where exposed just beyond quadrangle boundary, is weathered orange with clay coatings to 3 m deep; soil well developed, clayey, about 1 m thick, clay subsoil.
Thickness: Up to greater than 10 m.
Physical properties: H: Flow rock hard; scoria firm; cinder breccia soft with firm, some hard, blocks. F: Flow rock generally moderate to

wide, some very wide (up to 2 or 3 m); absent in cinder breccia. B: Distinct very thick flows separated by scoriaceous rock and probably by cinder breccia; absent within flows except for flow banding of elongate vesicles and alined phenocrysts; indistinct in cinder breccia.
Engineering characteristics: P: Flow rock has largely low-fracture permeability at depth, largely low to moderate in shallow rock, except scoriaceous zones and cinder breccia have high intergranular permeability to depth. Surficial mantle largely moderate to high, low to very low over cinder breccia (minor). BC: Possible problems in soil over cinder breccia (minor). Exp: Bedrock unexpansive; surfical mantle largely unexpansive, subsoil over cinder breccia (minor) severely expansive. Exc: Most weathered rock requires ripping and some may require heavy ripping or blasting; most fresh rock requires heavy ripping or blasting. Most surficial mantle can be trenched, some with difficulty. FC: Abundant oversize fragments, possibly local clayey fill from soil. CSS: High, flow rock can stand well in steeper cuts.

Tkf - Kate Peak Formation, flow rocks
Composition: Non-vesicular porphyritic andesite flow rocks, consisting of phenocrysts in holocrystalline to partly glassy matrix. Some flow breccia and interflow rubble of tightly packed blocks, minor tuff-breccia as described for unit Tkb. WS: Surficial mantle largely sand to clayey sand with abundant hard blocks, some sandy clay. Much outcrop or blocks of rock on surface. Sheds blocky and sandy debris downslope.
Physical properties: H: Largely hard, firm where weathered along fractures and very close parting within several meters of ground surface. F: Most moderate to 1.3 m, much wide to 1.3 m, some with crude columnar form; some very wide (to 8 m) with internal incipient fracture. B: Flows and breccia zones very thick (to more than 50 m); within flows, crude very thick layers of massive rock (to more than 10 m) and rock with parallel parting; flow banding in roughly half at very thin to thick. PP: Prominent in about half, ranges very close to wide, commonly close to moderate.
Engineering characteristics: P: Largely very low to low fracture permeability at depth, low to possibly moderate in shallow rock; flow breccia and interflow rubble have high intergranular permeability to depth. Surficial mantle largely moderate to high, some low. Exc: Where weathered, much parted rock can be trenched with difficulty, but most of unit requires ripping and some requires heavy ripping or blasting; most fresh rock requires heavy ripping or blasting. Most surficial mantle can be trenched, but blocks cause difficulty. FC: Abundant oversize fragments. CSS: High in bedrock, possibly moderate in surficial mantle.

Tkb - Kate Peak Formation, breccia
Composition: Largely breccia of variably abundant blocks of andesitic rock suspended in matrix. Blocks range up to more than 2 m across, generally medium to large. Matrix generally coarse sand- to silt-size lithic grains and ash with few to locally plentiful pumiceous fragments. Most matrix poorly sorted, some moderately well sorted lithic sand, in places with indistinct lenses of pea gravel. Includes some tuff (without blocks), some flow rock (as described for unit Tkf), minor intrusive rock (similar to unit Tki). WS: Weathering commonly colors top 0.7 m of bedrock brown. Surficial mantle is clayey sand to

clayey, silty sand with blocks, some silty clay subsoil. In places in Carson Range firm slopewash of clay-coated silty sand to greater than 7 m. Abundant clay in many materials derived from this unit. Sheds blocky debris downslope.

Physical properties: H: Blocks hard, matrix largely firm, some hard, some soft; tuff firm to soft; flow rock and intrusive rock hard; little affected by weathering. F: Breaks around blocks, hence hard pieces generally medium to large, some up to 2 m; major fractures commonly wide to moderate, some up to 2 m, between which much rock has irregular close to moderate weathering fracture to depths of 3 m or more; in some tuff close to moderate. B: Largely indistinct, some distinct, thin to very thick (to more than 7 m); poorly sorted beds commonly thick to very thick, well-sorted beds commonly thin to medium. PP: Largely absent, close in some tuff within 1 m of surface.

Engineering characteristics: P: Largely low, some moderate and local high intergranular permeability persists to depth. Surficial mantle largely moderate to low, some high, some low to very low in subsoil. BC: Possible problems in clay subsoil. Exp: Bedrock unexpansive. Surficial mantle largely unexpansive, some significantly expansive clay subsoil. Exc: Most weathered rock requires ripping, some may require heavy ripping or blasting; some fresh rock can be ripped, most probably requires heavy ripping or blasting. Most surficial mantle can be trenched, block cause difficulty. FC: Common oversize fragments, some clayey fill from subsoil. CSS: High in bedrock, moderate in surficial mantle.

Tkd, Tki - Kate Peak Formation, dome and intrusive masses.

Composition: Porphyritic, somewhat vesicular, glassy to holocrystalline pyroxene andesite. WS: Surficial mantle silty fine sand with abundant hard blocks; some clay films.

Physical properties: H: Hard. F: Largely wide to 1.3 m in unit Tkd, moderate to wide in unit Tki. B: Prominent flow banding in Tkd and in some Tki. PP: Moderate to 1.3 m along flow banding; together with fracture produces large to very large rectangular blocks in Tkd.

Engineering characteristics: P: Largely very low to low fracture permeability at depth, low to possibly moderate in shallow rock. Surficial mantle largely moderate to high. Exc: Most weathered rock can be ripped; some weathered rock and all fresh rock require heavy ripping or blasting. Large blocks in surficial mantle may require ripping or special handling. FC: Abundant oversize fragments.

Tku - Kate Peak Formation, undivided.

Composition: Much of both flow rock (Tkf) and breccia (Tkb), some local intrusive rocks (Tki). WS: Surficial mantle sand to clayey sand, some clayey subsoil, with abundant hard blocks. Sheds debris downslope.

Physical properties: As described for units Tkf and Tkb. Flows and breccias distinctly interbedded in very thick (3 m to greater than 30 m) intervals, irregular in form and thickness.

Engineering characteristics: As described for units Tkf and Tkb.

Ta - Alta Formation

Composition: Porphyritic volcanic flow rock and tuff-breccia, mostly hornblende andesite, ranging to dacite and soda trachyte. Commonly altered to purple and green colors, but some, including soda trachyte on

north side of Steamboat Hills, is unaltered. Tuff-breccia of very small to large, some very large, angular to rounded blocks in dense, fine-grained matrix. Unit includes much of both flow rock and tuff breccia: area above New Washoe City largely breccia; area on east side of Steamboat Hills flow rock; area on north side of Steamboat Hills much of both. WS: Much develops weathering fracture to 3 m or deeper; some outcrops fresh. Surficial mantle largely clayey silty sand with hard blocks; much sandy clay subsoil over breccia.

Physical properties: H: Flow rock largely hard fresh, firm to hard weathered; breccia matrix firm to hard, blocks largely hard, some firm, fresh and weathered. F: Flow rock largely close to moderate, some to wide, some with superimposed very close to moderate weathering fracture; breccia generally lacks continuous fractures, breaks along irregular very close to moderate fractures; most breccia breaks across blocks, some breaks around blocks. B: Largely absent in breccia; flow banding and foliation in much flow rock. PP: Prominent in much flow rock largely at close to moderate; irregular very close to moderate parting in some breccia.

Engineering characteristics: P: Flow rock largely very low at depth, low to moderate fracture permeability in shallow rock; breccia largely very low at depth, low fracture permeability in shallow rock. Surficial mantle largely moderate, much approaching low, some high; much low to very low in subsoil over breccia. BC: Possible problems in clayey subsoil over breccia. Exp: Bedrock largely unexpansive; surficial mantle largely unexpansive, much subsoil over breccia significantly expansive. Exc: Most weathered flow rock can be trenched with difficulty, almost all can be ripped; fresh flow rock requires heavy ripping or blasting. Most breccia requires ripping or heavy ripping or blasting. Surficial mantle can be trenched, blocks may cause difficulty. FC: Common oversize fragments, some clayey fill from subsoil. Rock fragments may degrade rapidly. CSS: High in bedrock, moderate in surficial mantle.

Tad - Alta Formation, dike

Composition: Hornblende andesite, much bleached and softened, much hard, unbleached. Probably contains disseminated sulfide minerals. Adjacent unit pKm is brecciated and weakened. WS: Surficial mantle over unbleached rock is silty sand with hard blocks; over bleached rock includes clayey material.

Thickness: Up to greater than 40 m.

Physical properties: H: Hard to firm. F: Probably moderate to wide.

Engineering characteristics: P: Fracture permeability largely very low to low at depth, low to moderate with possibly some high in shallow rock; surficial mantle high to low, some very low. BC: Possible problems in clayey material. Exp: Largely unexpansive, some surficial mantle and weathered rock probably expansive. Exc: Most can be ripped; some may require heavy ripping or blasting. Surficial mantle can be trenched, blocks may cause difficulty. FC: Common oversize fragments, probably some clayey fill. May include sulfide minerals with potential for rapid breakdown of rock fragments in fill. CSS: Probably largely high, low in brecciated adjacent pKm.

Other problems: Possible acid groundwater.

Kg - Hornblende-biotite granodiorite

Composition: Granitic rock, largely hornblende-biotite granodiorite, some quartz monzonite. In places crudely foliated by alinement of mafic minerals (shown by short dashes on Geologic Map). Scattered aplite and pegmatite dikes and quartz veins locally constitute up to 40% of rock mass; minor dark inclusions rich in mafic minerals. Locally contains bleached, soft clayey material. WS: Much near-surface granitic rock decomposed to coarse- to very coarse-grained sandy material. Decomposed material irregularly distributed, in many places more than 8 m thick, in some places more than 16 m thick, commonly surrounding blocks or knobs of hardrock as sketched in figure 1(b). Areas in which decomposed material commonly abundant and thick shown as prime sources of "dg" on Energy and Mineral Resources Map (this folio); areas that contain shallow decomposed material shown as secondary sources of "dg". Surficial mantle largely medium- to very coarse-grained granitic sand, much with minor silt, some with clay coatings, variably abundant hard blocks; generally 0.7 to 2 m thick, some slope wash to at least 4 m.
Physical properties: H: Fresh granitic rock, aplite, pegmatite, and mafic inclusions hard; decomposed rock firm to soft with hard blocks. F: Granitic rock commonly wide to very wide (2 m), ranging from close to moderate near faults to 3 m; incipient close to very close fractures affect spalling and decomposition; aplite very close to wide. B: Absent except local weak foliation, thin to very thick (at least 2 m) aplite and pegmatite dikes, and mafic inclusions generally to medium, locally to thick. PP: Largely absent, present in some of unit within 3 m of surface as incipient very close to close spalling, particularly near fractures.
Engineering characteristics: P: Fracture permeability largely very low at depth, generally low but locally moderate in shallow rock. Decomposed rock low to possibly moderate; surficial mantle high to moderate. Exp: Largely unexpansive; local clay-rich decomposed rock may be significantly expansive. Exc: Most hard rock requires heavy ripping or blasting; most decomposed rock can be trenched and all can be ripped except very large included blocks. Surficial mantle can be trenched, blocks may cause difficulty. FC: Oversize fragments common except in much decomposed rock. CSS: High. Hard rock can stand well in steeper cuts. At higher elevations in Carson Range, decomposed material and surficial mantle erode rapidly in cut slopes, vegetative protection difficult to get established (Robert A. Matthews, oral commun., 1979).

Kg with triangular pattern - Highly-fractured granodiorite
Composition: Granitic rock similar in composition to unit Kg but includes much rock with closer fracture spacing, irregular fracture orientation, and greater abundance of spalling fractures and crushed clay- to sand-sized material along fractures. Disordered rock mass of variably sized bodies of hard, widely to very widely fractured rock between some to as much as 70% soft to firm rock decomposed because of closer fracture spacing and related development of spalling fractures. WS: Much weathers rapidly to loose sand because abundant spalling fractures are loosened by extreme temperatures and freeze-thaw in Carson Range. Surficial mantle is silty very fine- to very coarse-grained sand with blocks of rock.
Physical properties: H: Variable, hard to soft. F: Variable, very close to 3 m; generally moderate to very wide in coherent portions, very

close to moderate in fracture zones and decomposed rock. PP: Very close to close parallel spalling fractures in much weathered rock.
Engineering characteristics: P: Variable, largely low to moderate with some high fracture permeability to depth; surficial mantle moderate to high. Exp: Largely unexpansive; significantly expansive clay gouge and crushed material along some fractures. Exc: Variable, much can be ripped, much requires heavy ripping or blasting. Surficial mantle can be trenched, blocks may cause difficulty. FC: Oversize fragments in much. CSS: High; rapidly decomposes to sand. Decomposed material and surficial mantle erode rapidly in cut slopes, vegetative protection difficult to get established (Robert A. Matthews, oral commun., 1979).

pKm and pKmb - Metamorphic rocks

Composition: Metagraywacke, slate, phyllite, metaconglomerate, metavolcanic tuff and breccia, and rare marble; metavolcanic breccia separately mapped (pKmb). Variably foliated, most with subtle foliation, some to 30% of unit strongly foliated. Within 20 m of contact with Kg, unit is thermally metamorphosed to hornfels, schist, and granofels, with aplite and pegmatite dikes and quartz veins. May contain sulfide minerals, especially in places shown as metallic mineral occurrences on Energy and Mineral Resources Map. WS: Little effect on rock that crops out; softens strongly foliated rock to more to 6 m deep in places, releasing much clay. Surficial mantle largely clayey, silty sand with hard blocks, some sandy clay subsoil.
Physical properties: H: Fresh and most weathered rock hard; some to 30% weathered firm to soft to more than 6 m deep in places, commonly in swales. F: Generally close to moderate, some wide, rarely to 1.3 m. B: Generally indistinct, some distinct, thin to very thick; tightly folded. PP: Very close in up to 30% of unit; largely absent in outcrop.
Engineering characteristics: P: Fracture permeability largely very low at depth, low to possibly moderate in shallow rock; surficial mantle largely moderate to low, some high, some very low in subsoil. BC: Possible problems in clayey subsoil. Exp: Largely unexpansive; some clayey subsoil expansive. Exc: Most weathered rock can be trenched with difficulty, some with ease, all can be ripped; most fresh rock requires heavy ripping or blasting. Surficial mantle can be trenched, blocks may cause difficulty. FC: Oversize fragments in much, some clayey fill from subsoil. Sulfides may cause rapid breakdown of rock fragments in fill, especially in areas of metallic mineral occurrences shown on Energy and Mineral Resources Map. CSS: Largely high, some moderate where adverse foliation; moderate in surficial mantle.
Other problems: Acid ground water in areas of sulfide mineralization.

pKm with dotted pattern - Bleached metamorphic rocks.

Composition: Variably bleached and altered metamorphic rock, ranging from unaltered rock to thoroughly bleached, soft, low-density mass of residual silica and clay minerals, in places with hard silicified masses. Within quadrangle occurs northeast of New Washoe City, shown by black dotted pattern on Geologic Map. Bleaching also prominent in unit Tad. WS: Bleaching is a special type of weathering (Thompson and White, 1964, p. A26, A27), resulting from sulfuric acid formed where atmospheric oxygen reacts with disseminated sulfides or rising hydrogen sulphide. Hence bleaching largely confined to zone of weathering,

generally to depths of 6 to 10 m. Oxidation of sulfides still active, evidenced by acidity of soils (pH as low as 3.5) and of runoff from bleached areas (pH as low as 2.4). Surficial mantle largely rocky clayey sand to sandy clay; distinct light color.

Thickness: Commonly to 10 m.

Physical properties: H: Variable, irregular mixture of soft to firm with hard. F: Variable, largely close to moderate remaining from unbleached pKm, some irregular close to very close, some wide or very wide (to 3 m or more) in hard silicified masses.

Engineering characteristics: P: Largely very low at depth, low to moderate with some high in shallow rock; surficial mantle moderate to low, some very low. BC: Possible problems in clayey materials. Exp: Largely unexpansive, some expansive materials in both soil and weathered rock. Exc: Most can be trenched, some may require ripping, silicified masses may require heavy ripping or blasting. Surficial mantle can be trenched. FC: Some oversize fragments, some clayey fill. Sulfides may cause rapid breakdown of rock fragments in fill. CSS: Largely high, possibly to low in places.

Other problems: Acid groundwater.

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