CALIFORNIA DIVISION OF MINES AND GEOLOGY
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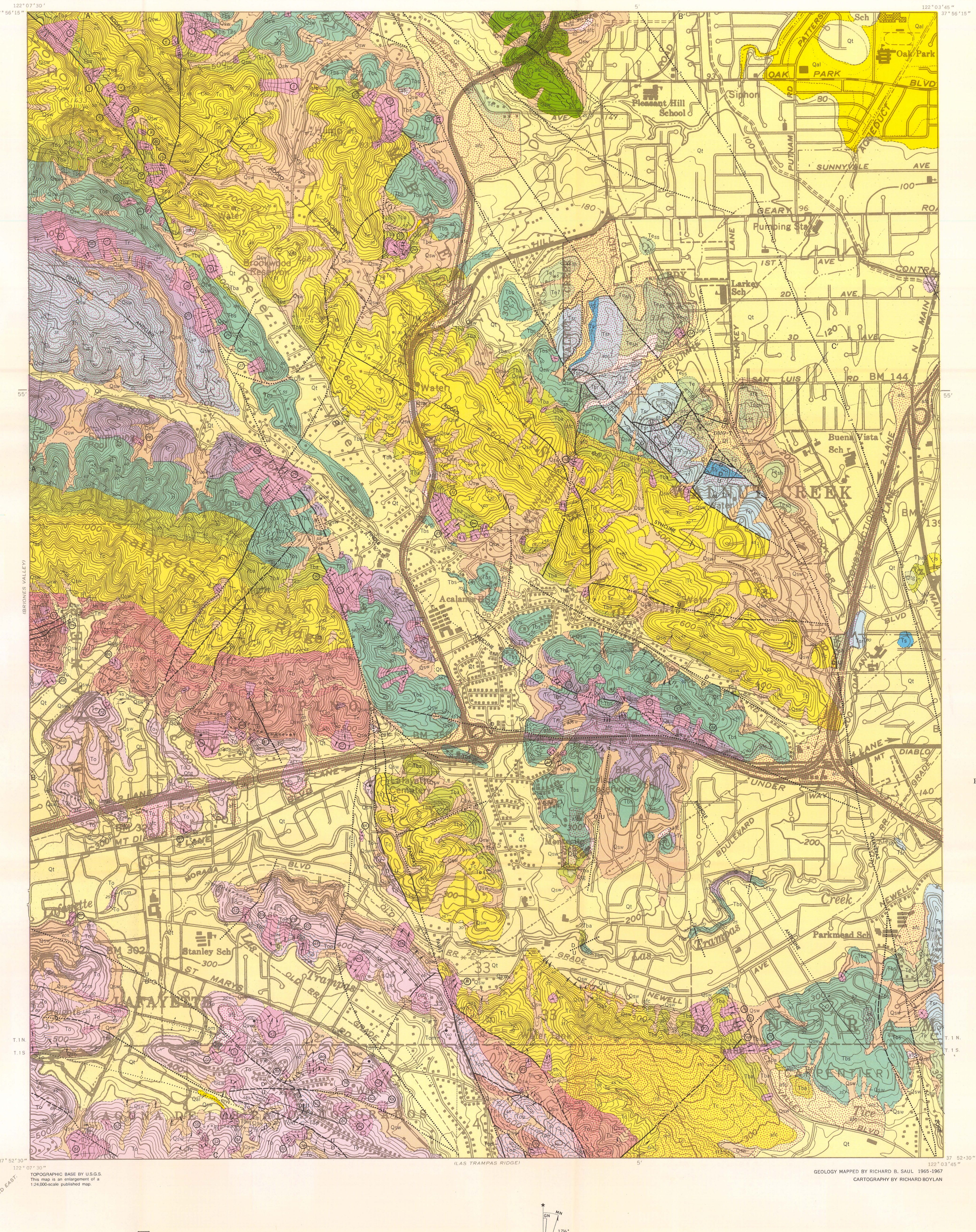
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF CONSERVATION

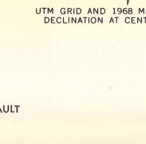
SW 1/4 WALNUT CREEK QUADRANGLE
MAP SHEET 16



TOPOGRAPHIC BASE BY U.S.G.S.
This map is an enlargement of a 1:24,000-scale published map.

GEOLOGY MAPPED BY RICHARD B. SAUL 1965-1967
CARTOGRAPHY BY RICHARD BOYLAN

QUADRANGLE LOCATION



UTM GRID AND 1968 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

EXPLANATION

QUATERNARY — Holocene

afc — Artificial fill or cut

Qsw — Slopewash
Soil and rubble

Qal — Alluvium

QUATERNARY — Pleistocene

Qtg / Qt — Terrace deposits
Gravel, sand, silt and clay. Locally capped by gravel (Qtg).

TERTIARY — Pliocene

To / Top / Tom — Orinda Formation
Generally soft sandstone, siltstone, and claystone, some hard sandstone and conglomerate units.
Top = Pinole member
Tuff, tuff breccia and tuffaceous sediments.
Tom = Moraga Basalt member
Vesicular and dense nonvesicular basalt.

TERTIARY — Upper Miocene

sh / Tn — Neroly Formation
Sandstone and shale grading upward to increasing proportion of shale and some conglomerate. sh denotes two main shale units.

Tc — Cierbo Sandstone
Massive to well bedded, fine to coarse grained, abundantly fossiliferous sandstone.

Tba / Tbs — Briones Formation
Tba = Shale member
Clay shale and shaly siltstone. Fossiliferous sandstone unit not everywhere mapped.
Tbs = Sandstone member
Mostly fine- to coarse-grained sandstone interbedded with shaly siltstone and mudstone.

TERTIARY — Middle Miocene

Tr — Rodeo Formation
Shale: porcelaneous fissile and friable mudstone, argillaceous siltstone and shaly fine-grained mudstone, sandstone.

Th — Hambre Sandstone
Interbedded fine-grained sandstone and shale.

Ts — Sobrante Formation(?)
Hard pebbly sandstone and coarse-grained sandstone overlain by massive siltstone.

TERTIARY — Oligocene

Tsr — San Ramon Formation
Hard, gray to blue gray fine-grained sandstone.

TERTIARY — Upper Eocene

ss / Te sh — Upper Eocene, Undifferentiated
Interbedded clay shale, siltstone, and mainly fine-grained sandstone; ss denotes sandstone unit; sh, shale.

MESOZOIC — CRETACEOUS — Upper Cretaceous

ss / K sh — Del Valle Formation(?)
Interbedded and chaotically intermixed shale, siltstone, sandstone and conglomerate. ss denotes sandstone unit; sh, shale. Not everywhere separated.

CENOZOIC

SYMBOLS

Contact
(dashed where approximately located)

Fault
(dashed where approximately located; dotted where concealed; queried where uncertain; U - upthrown side, D - downthrown side: Arrows show apparent relative movement)

Possible zone of shearing and adjustment between units of unlike competence.

Fault plane in section
(A = away; T = toward)

Shear zone

Axis of anticline
(arrow showing direction of plunge; dotted where concealed)

Axis of syncline
(arrow showing direction of plunge; dotted where concealed)

Axis of overturned syncline

Strike and dip of beds
(queried where uncertain)

Strike and dip of rotated beds

Strike and dip in excavation

General strike and dip of contorted beds

Strike of vertical beds

Horizontal beds
(queried where uncertain)

Strike and dip of overturned beds
(queried where uncertain)

Strike and dip of beds in ancient marine slide

Overturned beds in ancient marine slide

Bedrock outcrop

Spring or seep

Clay rich unit
(not everywhere shown)

Pebbles in soil
(probably from conglomerate)

Mappable conglomerate unit

Mappable shale unit

Fossil locality,
Division of Mines and Geology

LANDSLIDES

Surficial movement

Eroded slopewash

Slopewash slide

Bedrock slide
(stippled scarp; dashed where approximately located; numbered if listed in text)

Eroded older slide

Probable upslope continuation or renewal of slide movement

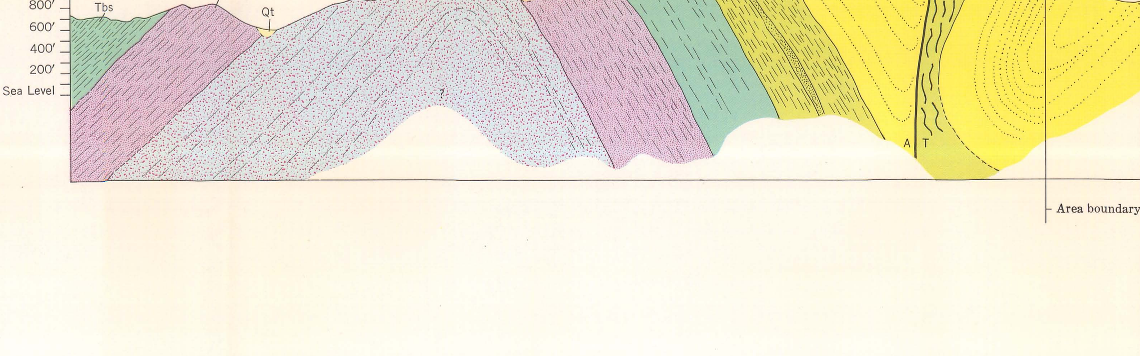
GEOLOGY AND SLOPE STABILITY OF THE SOUTHWEST QUARTER OF THE WALNUT CREEK 7½-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

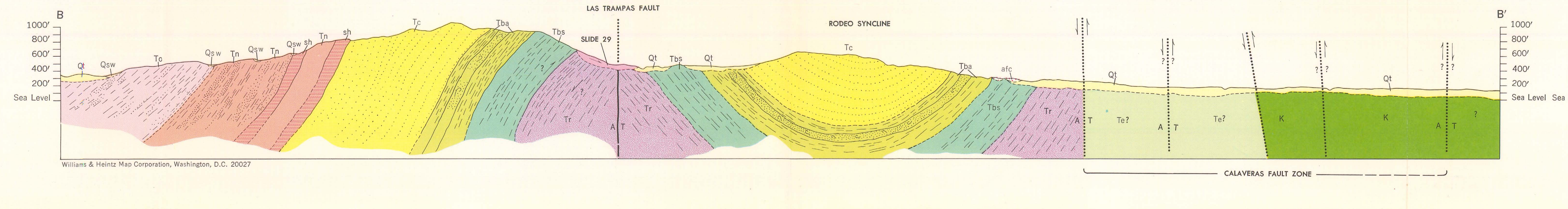
by Richard B. Saul

SCALE 1:12000

1 MILE — 0 — ½ — 1
1000 — 0 — 1000 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET
1 KILOMETER — .5 — 0 — 1

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 5 FOOT CONTOURS
DATUM IS MEAN SEA LEVEL





Williams & Heintz Map Corporation, Washington, D.C. 20027

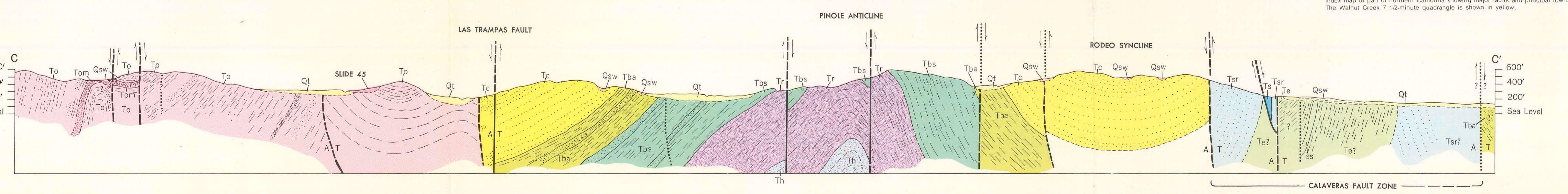


Table 1 Stratigraphic and Physical Data of the Rocks in the Southwest Quarter of the Walnut Creek 7½-Minute Quadrangle

Map Unit and Thickness	Age and Correlation	General Description	Weathering and Soil Development	Slope Stability	Workability	Remarks
Artificial fill or cut	(Quaternary) Holocene.	Appears generally to be mixture of locally obtained rocks; most street and other small cut-and-fill areas not shown.	None.	Fill ranges from good to poor depending on compaction and site preparation. Cuts in weak rocks commonly cause slope failures.	Depends on composition and amount of coarse rubble or riprap.	Fill composed largely of soil, or placed on soil-covered slopes, is apt to fail.
Slopewash (soil and weathered rock)	Quaternary.	Fragments of the more resistant bedrock units mixed with various amounts of soil through a range that includes deposits comprised wholly of soil and organic debris; swale deposits accumulations with more admixed organic material, generally more plastic and expansive; locally thickened by landslide debris.		Poor when wet.	Works easily; adobe forms troublesome mud when wet.	Adobe soils expansive; troublesome to slab structures; should be removed from foundation sites.
Gravel terrace capping 0–50± Feet Terrace deposits 0–100± Feet	Quaternary. Yielded Pleistocene fossils (Savage, 1951).	Interbedded clay, silt, sand, and gravel of irregular thickness; contains channel and fill structures; commonly capped by gravel; may include slide debris locally.	Yields loamy soil with compact, clay-rich B horizon grading downward into sand, clay, clay-rich loam.	Poor in cuts and along stream banks; gravelly, sandy layers near surface more stable, probably due to clay, iron oxide cement.	Works easily.	Permeability probably uneven due to irregularly distributed clay-rich lentils; gravel too sparse (too little land available) to be source of aggregate.
Orinda Formation* 5,000± Feet	Pliocene. Includes Mulholland Formation (Ham, 1952) and probably equivalent to Contra Costa Group (Savage, 1951); appears conformable on Neroly Formation on Lafayette Ridge; faulted, possibley buttressed against older rocks along Las Trampas fault. Unconformable on lower units of Neroly east of Las Trampas fault.	Primarily soft, poorly consolidated, gray, gray-green, tan, and reddish-brown clay shale, siltstone, sandstone, and sandy conglomerate and a few thin units of tuff; an undetermined but small proportion of widely spaced, moderately hard sandstone and conglomerate units as much as 100 feet thick; limy, concretionary beds in what appears to be upper part of this faulted and folded section.	Generally yields deep, clay-rich, coherent, expansive, adobe-type soil.	Poor except on favorably situated firm sandstone and conglomerate units.	Generally works easily; some sandstone and conglomerate units might be difficult for light earth-moving equipment. Selected material might make good compacted fill blend.	Rocks lying above, between and below Moraga basalt member and Pinole member included in this formation because of qualitative similarity; contained gravel and gravel yield to stream deposits too small to be of commercial value; permeability generally poor except in sandier, coarse-grained units.
Moraga Basalt Member of the Orinda Formation* 30–100–(?) Feet	Pliocene. Lithologically similar to the rocks exposed to the west in the Berkeley Hills, named by A. C. Lawson (1914); said by Taliaferro (1951, p. 143) to ". . . interdigitate with the Orinda . . ."	Basalt, dense to fractured and weathered; locally vesicular and amygdaloidal; softer, more porous material more common in upper part of flow or sequence of flows but no consistent layering.	Weathers to stony, clay-rich, loamy soil.	Good; stands well in cuts; overlain and underlain by silt and clay shale which pose undercutting, drainage, differential settling and sliding hazards.	Fairly easy to work due to weathering and fractures but material deeper than five or six feet likely to be too hard for light earth-moving equipment.	Good foundation stability but foundations should not overlap subjacent or superjacent rocks; generally fractured enough to afford fair permeability; good riprap and road base.
Pinole Tuff Member of the Orinda Formation* 400(?) Feet	Pliocene. Age date 5.2 million years, KA (Evernden, et al., 1964); appears continuous with rocks so designated by Ham (1952).	Principally white, vitric tuff or tuffaceous breccia with interlayered andesite, tuffaceous shale, and sandstone; east of Las Trampas fault includes gray, tuffaceous breccia containing glass blebs and cherty, silicified tuff.	Yields heavy-textured, adobe soil, which is apt to be thin or broken by bedrock exposures on slopes.	Excellent to poor depending on local composition, weathering, and structure.	Most exposures appear easily worked; vitric tuff in bed of Las Trampas Creek north of Topper Court might require blasting; silicified material on ridge east of Glenside Road might be difficult to work but appears to be in thin beds.	Foundation stability range good to bad, as with slope stability; generally permeable through a wide and uneven range; some material quarried, probably for road base.
Neroly Formation 1,400± Feet	Upper Miocene and Pliocene (?). Conformable on Cierbo Sandstone: base drawn at bottom of lowest mappable shale unit; identified from descriptions of Hall (1958), Ham (1952), Pease (1954).	Lower half comprises basal buff-to-gray, weathering, shaly, fine-grained sandstone, siltstone, and mudstone, with local concentrations of carbonaceous debris, overlain by 300 feet of gray to purplish, coarse-grained and buff-weathering shale; upper half tan-weathering shaly sandstone units ranging from 10 to 130 feet thick interbedded with massive-to-well-bedded, gray-to-buff sandstone becoming conglomeratic in the upper 100 feet; above this, a distinctive lavender-to-light-gray shale grading upward into about 50 feet of soft tan sandstone and shaly sandstone capped by 10± of conglomerate.	Weathers to heavy, clay-rich soil deeper over shale and thin to absent over sandstone and conglomerate.	Good on sandstone; fair on shaly sandstone; poor on shale units, upper part of section subject to slumping; bedding plane failure (block gliding) likely if undercut.	Works easily except lower massive sandstone unit, which might rip with difficulty where free of joints and shears; aqueduct tunnel was driven as much as 100 feet a day through these rocks in fault block west of Las Trampas fault.	Poor permeability in shale units, moderate to good in sandstone if sheared, fractured or jointed; probably poor in thick sandstone units and well-cemented conglomerate, has been used for freeway fill; small quantities of "coal" reported taken from near base of lowest shale, water now issuing from caved adit. (Mr. Brown, Rolling Hills Ranch, 1965).
Cierbo Sandstone 1,500 Feet	Upper Miocene. Conformable on Briones Formation; identified from descriptions of Hall (1958), Ham (1952), Pease (1954).	Massive and well bedded, fine- to coarse-grained, gray, abundantly fossiliferous sandstone and pebbly sandstone; pebbles in thin beds inches to several feet thick, most abundant in upper 200 to 300 feet; fossils generally concentrated in hard, concretionary beds several inches to several feet thick—rarely, several tens of feet thick.	Weathers to heavy loam; forms rounded ridges with abundant rock outcrops, especially fossiliferous beds.	Good; stands well in steep cuts.	Difficult to excavate; strongly cemented, fossil-rich beds may require blasting where thick or abundant.	Permeability good where weathered and fractured; fresh rock poor; fossiliferous, concretionary beds impermeable; very little crushing and fracturing near faults; a source of crushed rock (Davis and Goldman, 1958).
Briones Formation (shale member) 500± Feet	Upper Miocene. Conformable on sandstone member. Identified from Hall (1958), Ham (1952), Pease (1954).	Clay shale interbedded with subordinate proportions of shaly siltstone. Upper half of member includes sandstone unit about 100 feet thick containing resistant, concretionary fossil beds in some outcrops. Sandstone not everywhere mapped.	Yields a heavy adobe-type soil.	Poor, especially in and near fault zones; tends to slake and slump in cuts forming small angular fragments.	Easily worked, generally highly fractured.	Low permeability. Sandstone unit more stable but might be subject to slump or block gliding on subjacent shale. Should compact well in fill.
Briones Formation (sandstone member) 800± Feet	Upper Miocene. Conformable on Rodeo Shale.	Predominantly fine-grained to coarse-grained, gray, buff- to brown-weathering sandstone in units 25 feet to 200 feet thick, interbedded with shaly siltstone and mudstone units ranging from ten to as much as 60 feet thick; sandstone commonly fossiliferous.	Weathers to clay-rich loam.	Generally good; shale units gully, slump to moderate extent, more in fault zones; block gliding potential hazard.	Easily worked, highly jointed and fractured; some sand units might resist light earthmoving equipment.	Permeability high to low, depending on texture of individual unit, degree of shearing, jointing, fracturing; alternation of rock types might cause differential settling of foundations; appears to be good mixture for fill.
Rodeo Shale 800± Feet	Middle Miocene. Intergrades conformably with subjacent Hambre Sandstone, identified from descriptions of Doumani (1957), Ham (1952), Pease (1954); probably equivalent to all or part of Hall's (1958) lower Briones member.	Interbedded siltstone and thin, fine-grained sandstone units near contact with Hambre; grades upward into faintly lavender siliceous shale, yellowish-brown- to dark brown-weathering brownish-black shale, fissile siltstone and argillaceous siltstone.	Weathers to heavy adobe-type soil; slakes and swells in cuts forming small angular fragments.	Poor, but siliceous shale in lower and middle parts is fair where not faulted, dipping down slope, or undercut.	Works easily, highly fractured.	Permeability low to moderate depending on clay content, fracturing, weathering.
Hambre Sandstone 1,000± Feet	Middle Miocene. Identified from descriptions of Hall (1958), Ham (1952), Pease (1954); probably includes part of Hall's "middle Monterey undifferentiated". Base not exposed.	Interbedded, gray, buff-weathering fine-grained, sparsely fossiliferous sandstone, shaly siltstone and shale; sandstone predominant in upper half of exposed section, shale in lower half.	Yields clay-rich loam, sandstone forms rounded ridges with sparse bedrock outcrops.	Not observed in large variety of circumstances; probably similar to Briones Formation; sandstone in recent road cut southeast of Lawson Hill, Briones Valley quadrangle, shows no tendency to slump, is breaking down to fine sand and silt; shale units probably present.	Appears easy to work; few hard, fossiliferous, concretions do not appear to form extensive layers; shale near axis of Pinole anticline highly fractured.	Permeability moderately high to low, depending on texture of unit, degree of shearing, fracturing. Appears to be good fill material, especially with all unit types blended.
Sobrante Formation 0–600± Feet	Middle Miocene. Lithologically similar to Sobrante of Lutz (1951), Ham (1952), and Hall (1958); base not well exposed; reported disconformable on San Ramon (Ham, 1952, p. 8).	Hard, pebbly sandstone and coarse-grained sandstone overlain by massive siltstone.	Conglomeratic sandstone forms ridges; siltstone yields clay-rich loamy soil.	Good to fair.	Siltstone works easily; sandstone and conglomerate might resist light earthmoving equipment.	Permeability low; volume too small and too urbanized to be commercial source of rock.
San Ramon Formation Thickness undetermined	Oligocene. Unconformable on Upper Eocene; lithology and stratigraphic position same as described by Clark (1918), Ham (1952), Pease (1954); outcrop on Las Trampas Creek just west of freeway appears to be that described by Clark (1918, p. 78-79).	Hard, predominantly fine-grained, tan- to gray-weathering, gray to blue-gray tuffaceous sandstone; in Calaveras fault zone outcrops generally crossed by iron-stained fractures.	Weathers to loamy, clay-rich soil, outcrops common.	Good.	Resistant to excavation but probably fairly easy to rip.	Permeability low except where strongly fractured; good fill and riprap.
Upper Eocene undifferentiated Thickness undetermined	Upper Eocene. Tejon fauna collected few tens of feet below contact with San Ramon (DMG 7).	Gray, brown-weathering, clay shale and siltstone interbedded with generally fine-grained, brown- to light-buff-weathering, fossiliferous sandstone (ranging from several feet to more than 100 feet) Shale contains scattered richly fossiliferous concretions.	Weathers to clay-rich loam and adobe soil; sandstone units form rounded ridges.	Slope stability good to fair in sandstone; some silty sandstone spalls and quickly decomposes to sandy silt on exposure. Shale unstable.	Easy to work.	Permeability moderate to poor in sandstone depending on grain size; low in shale; blended sandstone and shale good for compacted fill.
Del Valle Formation(?) Thickness undetermined	Upper Cretaceous. *Inoceramus* fragments, some indistinct ammonite-like shell fragments; lithologic similarity to Del Valle Formation as described by Hall (1958); might include rocks of Paleocene or Eocene age.	Interbedded and chaotically intermixed gray, brown-weathering shale, light to dark gray, coarse-pebbly, sparsely-concretionary sandstone and rust-brown-weathering, sparsely-concretionary and fossiliferous conglomerate.	Yields loamy, stony, clay-rich and adobe-type soils; sandstone and conglomerate at or near surface on ridge and steep slopes.	Good to poor; structural complexity requires local investigation because of drastic differences in physical properties of bedrock within a few tens of feet.	Easily worked except for a few thin, strongly cemented conglomerate and sandstone beds.	Wide range of permeability due to complex structure; as a mixture should make good compacted fill.

* Savage, Ogle, and Creely (1951) proposed the name Contra Costa group, to include rocks of the Orinda Formation, Pinole Tuff, and Moraga Formation in this area. In adjoining areas the Contra Costa Group includes additional formations (Radbruch and Case, 1967). In this report the Orinda Formation is used instead of the Contra Costa Group of Savage and Ogle because, in the field, no distinction could be made between the Orinda Formation and the very similar, overlying Mulholland Formation. Furthermore, the Orinda and Mulholland Formations share characteristics which engineering geologists commonly attribute to the "Orinda" in this broad sense.

It is evident that the Pinole Tuff and Moraga Formations are products of volcanic events (centered outside the area) during the continuous deposition of Orinda-type sediments. The work of Ham (1952) and Hall (1958) indicates eastward and southward feathering out of the volcanic rocks of the Pinole Tuff and Moraga Formation. The problem of units of formation rank lying within another formation has been negated in the area of this report by reducing the rank of the Pinole Tuff to Pinole Tuff Member of the Orinda Formation and the rank of the Moraga Formation (Volcanics of some authors) to the Moraga Basalt Member of the Orinda Formation.

Table 2. Landslides in the Southwest Quarter of the Walnut Creek 7½-Minute Quadrangle

Map Number	Type	Principal Geologic Unit(s) Involved	Relative Age*	Probable Cause(s) for Sliding	Principal Evidence for Sliding	Remarks
1	Slump.	Shale member of Briones Formation.	Older renewed failure along east and southeast flanks.	Oversteepening by erosion along a fault zone.	Hummocky surface; headward basin-like depression; recent renewed failure in weak material.	The slump is adjacent to a zone of intense folding and shearing.
2	Slump with shallow sliding on scarp.	Cierbo Sandstone, and shale member of Briones Formation.	Older.	Oversteepening by erosion in material weakened by crushing along a fault.	Hummocky surface on fault zone, one of the most intensely disturbed zones along the Las Trampas fault.	The boundaries of this slump are drawn arbitrarily along bounding drainage courses because this material probably is modified by erosion.
3	Slump: possibly some renewed shallow sliding in headward area.	Shale member of Briones Formation and Cierbo Sandstone.	Older with at least one recent, small slump on south margin.	Oversteepening by erosion on and near a fault.	Hummocky surface concave amphitheater-like headward scarp.	Water from a spring on the fault in the scarp area could be a contributing factor. The slide mass appears once to have been tapped by a well. (Geology conducive to failure, toe eroded.)
4	Slopewash slump.	Shale member of Briones Formation.	Younger.	Oversteepening by erosion on deformed and sheared shale.	Complexly wrinkled, rilled and slumped surface.	This feature is barely distinguishable from bedrock slide. Considerable quantity of bedrock material probably is involved.
5	Slump.	Shale member of Briones Formation; some Cierbo Sandstone.	Older.	Erosional oversteepening of disturbed rocks in and near Las Trampas fault.	Hummocky surface; headward, basin-like depression. Downslope features are large enough to be evident on the base map.	This slide underlies a heavily wooded slope and is eroded—factors which obscure identifying features.
6	Slumps.	Cierbo Sandstone and some of the shale member of the Briones Formation.	Younger.	Failure in crushed and weathered sandstone and shale in and near fault zone.	Concave scarp area, lobate toe, and irregular surface.	The two adjacent slides are of apparently similar origin.
7	Slump and earth flow.	Shale member of Briones Formation.	Older.	Failure of slope underlain by weathered shale, base of slope possibly undercut by water course; erosion in toe.	Concave scarp area; lobate toe and irregular surface.	Outcrop evidence suggests that, in this area, this shale unit is contorted and possibly sheared.
8	Slump.	Shale member of Briones Formation.	Older.	Erosional oversteepening of sheared shale near fault.	Concave scarp area and convex toe best seen in profile, but not distinct.	Identification of this slide is doubtful; it is probably old enough to be partly removed by headward erosion in the ravine to the southeast. The toe appears to have overridden divide at head of ravine.
9	Slump.	Shale member of Briones Formation.	Younger.	Oversteepening by erosion slope on disturbed shale near fault.	Well-defined scarp; depressed scarp area; disrupted service road; lobate toe.	Renewed movement is likely (1965).
10	Slump.	Shale member of Briones Formation.	Older.	Oversteepening by erosion in disturbed shale in and near fault.	Irregular slope profile heading in amphitheater-like scarp area.	Identification is reasonably certain although much of the slide is wooded. Topographic features are definite enough to show clearly on a topographic base.
11	Slump.	Shale member of Briones Formation.	Older.	Oversteepening by erosion in disturbed shale in and near fault.	Hummocky surface.	
12	Slump.	Shale member of Briones Formation; Cierbo Sandstone.	Older.	Oversteepening by erosion in disturbed rocks at junction of Las Trampas fault and minor fault.	Large amphitheater-like scarp basin, hummocky surface.	This feature has been subject to remedial measures connected with road maintenance.
13	Slump?	Sandstone member of Briones Formation.	Older.	Erosional undercutting of dip slope.	Reversed dip in sandstone at base of slope.	Because this rock unit contains abundant interbedded shale, it is possible that block gliding on bedding planes might have been involved.
14	Slump.	Shale and sandstone members of Briones Formation.	Older.	Oversteepening by erosion in disturbed rocks near fault.	Hummocky surface in chute-like ravine which heads in amphitheater-like scarp.	This is probably a combination of slide and earth flow drawing primarily from shale beneath the headward area. The surface is probably subject to accelerated creep during rainy seasons.
15	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope.	Nearly level, semicircular bench low on slope around which drainage is deflected; broad, concave scarp area.	Lobate toe area is well outlined on topographic base map.
16	Slump.	Rodeo Shale.	Younger.	Oversteepening by erosion caused in part by drainage from older slide (15).	Scarps and hummocky ground confined to steep-walled swale.	West half of this slide comprises renewed movement of old slide material.
17	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope.	Scarp-like up slope area; irregular ground at foot of slope.	This slide indistinct and eroded.
18	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope.	Large mass of structureless material underlying area of low relief at base of slope.	Probability of sliding at this site is enhanced by nearness to fault.
19	Slump.	Shale member of Briones Formation.	Older.	Erosional oversteepening of slope.	Concave upper slope; hummocky area along base of slope.	Bedrock probably dips 70° to 80° northeast. The slide probably is shallow but shale might be weakened by nearness to fault.
20	Slump.	Shale member of Briones Formation.	Older.	Erosional oversteepening of slope.	Scarps and hummocky surface.	The shale is more prone to failure because of involvement in movement on fault (see also under 21).
21	Slump; complex.	Shale member of Briones Formation; subordinate volume of Cierbo Sandstone.	Older with minor recent movement in toe area; recent in scarp area.	Erosional oversteepening of slope.	Concave upper slopes and recent scarps; massive, structureless shale debris exposed in cut in toe area; generally convex down slope area.	The bedrock underlying this slope has been involved in movement on faults.
22	Slump.	Sandstone member of Briones Formation.	Older.	Erosional oversteepening of slope.	Fairly distinct scarp; hummocky slope.	A generally stable formation with favorable dip failed here because of fracturing and weathering in and near fault zone.
23	Slump; complex.	Shale member of Briones Formation.	Older; younger failures in toe mass.	Erosional oversteepening of slope.	High, prominent scarp; lobate toe mass forms bench on lower slope; hummocky surface; deflected stream course.	The shale probably has been strongly sheared and milled near the fault in the scarp area; there may be some water seepage from the fault.
24	Slump.	Shale member of Briones Formation.	Older with renewed movement.	Undercutting of stream deflected by slide (23) on opposite bank.	Glutted stream channel, cracked and failing slope.	Scarp area is being used as dumping site; continued movement is likely (1965).
25	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope.	Hummocky slope surface below anomalous concave area.	This appears to have once forced drainage to undercut slopewash on the opposite slope, causing slopewash slump.
26	Slump.	Sandstone member of Briones Formation.	Older.	Failure of water-saturated shaly sandstone and overlying soil at spring site.	Hummocky, swampy ground heading in indistinct scarp area.	This could be slopewash slump.
27	Slump.	Sandstone member of Briones Formation.	Older.	Failure in fractured and weathered shaly sandstone; structural weakness probably due to crushing near fault and related minor faults.	Shallow, concave scarp area; hummocky, depressed, lower slope and convex toe; rotated bedding in crown area.	Paved road crossing slide shows evidence of instability (1965).
28	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope underlain by rocks weakened by proximity to fault.	Distinct, concave scarp area; hummocky lower slope.	The toe probably is undercut by erosion along water course.
29	Slump; complex.	Rodeo Shale; sandstone member of Briones Formation.	Older.	Erosional oversteepening on slope underlain by rocks weakened by proximity to fault and related minor faults.	Steep scarp areas showing displaced bedrock; hummocky surface and extensive convex toe area. Spring Hill Road unstable in toe area.	Toe masses probably extend to and are truncated by the stream course. Block gliding of up slope sandstone masses on underlying shale may have taken place. (1965)
30	Slump.	Shale member of Briones Formation; Rodeo Shale.	Older.	Erosional oversteepening of slope underlain by incompetent rocks further weakened by proximity to fault.	Scarp; hummocky surface.	
31	Slump; complex.	Rodeo Shale; sandstone member of Briones Formation; Cierbo Sandstone.	Older.	Erosional oversteepening of slope largely underlain by incompetent rocks further weakened by proximity to fault.	Extensive, concave, hummocky slope showing multiple slumps and seepage; lobate toe.	The scarp area is complex and least determinable on Cierbo Sandstone; a prominent bench about half way down slope is underlain by fractured Briones Sandstone. The ridge on the north flank of the slide is capped by disordered Briones Sandstone which might be a remnant of an older slide.
32	Slump; complex.	Shale member of Briones Formation.	Older with renewed recent movement on northwest flank.	Ancient: erosional oversteepening of slope. Recent: undercutting by road cut.	Scarps, hummocky slope; lobate toe.	
33	Slump.	Cierbo Sandstone.	Older.	Erosional oversteepening on slope underlain by rocks weakened near junction of fault and contact with weak, underlying shale.	Amphitheater-like scarp area; lobate toe.	This might be shallow enough to classify as slopewash slump.
34	Slump.	Upper(?) Eocene shale.	Younger.	Erosional oversteepening of slope.	Scarp; hummocky surface; lobate toe mass.	This is probably shallow and might be classified as slopewash slump.
35	Slump; complex.	Rodeo Shale; sandstone member of Briones Formation.	Older to younger.	Erosional oversteepening of slope.	Scarps, hummocks, glutted water course.	
36	Slump.	Rodeo Shale; sandstone member of Briones Formation.	Older.	Erosional oversteepening of slope.	Concave scarp area; irregular slope and toe area.	
37	Slump.	Rodeo Shale; sandstone member of Briones Formation.	Older.	Erosional oversteepening of slope.	Indistinct scarp; hummocks; convex toe area.	
38	Slump.	Rodeo Shale.	Older.	Erosional oversteepening of slope.	Slide plane well exposed in road cut low on its eastern flank.	Most features are concealed or removed by erosion.
39	Slump.	Neroly Formation; Orinda Formation.	Older.	Erosional oversteepening of slope.	Lobate toe area; bedrock, exposed near southeast flank, appears to have been deflected southeastward; rocks exposed in building-site excavation, near west flank, appear to be rotated approximately 105° to dip into the slope rather than down the slope.	The scarp is modified by erosion; most of the slide is in an incompetent unit at the base of the Orinda Formation.
40	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Scarp; hummocky surface; lobate toe.	
41	Slump.	Orinda Formation.	Older to younger.	Ancient: Erosional oversteepening of slope. Recent: Road cut failure.	Irregular surface; unstable road cut; glutted water course.	The slide is shallow but includes a high proportion of bedrock material.
42	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Convex lower slope below scarp-like, concave area.	This identification is doubtful; the slide is old enough to be obscured by erosion.
43	Slump; complex.	Orinda Formation.	Older to younger.	Oversteepening due to headward erosion along fault. Movement recurrent due to truncation of toe by Las Trampas Creek.	Narrow ravine glutted with disordered, hummocky debris.	
44	Slump; possibly some block gliding.	Pinole Tuff Member of Orinda Formation.	Younger(?)	Undercutting by Las Trampas Creek.	High scarp, irregular bench-like area; disordered bedding in creek bank.	This slide is subject to early renewal of movement (1965).
45	Slump.	Orinda Formation.	Older.	Undercutting by Las Trampas Creek.	Depressed hummocky area; deflection of Las Trampas Creek; disordered debris in creek bank.	The low gradient of slide suggests renewed movement in preexisting slide structure.
46	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Hummocky slope; convex area resembling toe at base of slope.	This could be shallow and composed largely of slopewash.
47	Slump; complex.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Broad, deeply gullied, hummocky ravine.	Features are obscured by erosion.
48	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Amphitheater-like, nearly continuous scarp, hummocky slope.	
49	Slump.	Orinda Formation.	Younger(?)	Erosional oversteepening of slope.	Scarp; lobate toe.	
50	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope.	Scarp; lobate toe.	
51	Slump; complex.	Orinda Formation.	Older.	Erosional oversteepening of slope underlain by incompetent rocks probably further weakened by proximity to fault.	At least two distinct scarps; hummocky slope; lobate toe.	
52	Slump?	Orinda Formation.	Older.	Erosional oversteepening of slope.	Pebbly, side-hill bench.	This might be an erosional remnant of ancient slide or only a remnant of a terrace.
53	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Nearly level clearing down slope from amphitheater-like feature; irregular surface in toe area; toe deeply eroded exposing soft, structure-less bedrock material.	
54	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Nearly level area below amphitheater-like feature; hummocky surface; toe eroded exposing structure-less bedrock material.	There is some evidence of repeated failure on the north flank but all features are subdued by erosion.
55	Slumps.	Orinda Formation.	Younger.	Erosional oversteepening of slope; bedrock might be weakened by fault.	Scarps, hummocky surfaces, lobate toes.	This is a group of similar slumps probably involving more soil than bedrock.
56	Slumps.	Orinda Formation.	Younger.	Erosional oversteepening of slope probably by deflection of drainage around toe of older slide (53).	Scarps; hummocky surfaces.	These are two similar features of essentially the same age.
57	Slump.	Orinda Formation?; Pleistocene Terrace.	Younger.	Failure of soil and alluvium in undercut bank of Lafayette Creek.	Sharp scarp with continuing movement cracking pavement along Dewing Ave., (1965); hummocky; failure reported to have destroyed partly completed apartment structure, footings of which now are disarrayed.	Movement has caused trouble with the utilities underlying the adjoining streets; this might be in debris of an older slide from the slope to the south.
58	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope in or near a fault zone.	Scarp, hummocky surface, lobate toe which appears to have diverted drainage. Opposite slope currently site of considerable creep.	The scarp might have been altered by excavation, but no access surface is obvious. In 1965 it was receiving channeled drainage from residential site above. Recurrent movement is likely.
59	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope, possibly by undercutting of drainage around ancient slide.	Scarp, side-hill scar, debris at foot of slope.	This is a shallow slide.
60	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope.	Scarp, depressed hummocky surface.	This might be on or near a fault. Seepage in water course at the base might indicate chronic local saturation of slopewash and weathered rock.
61	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Slope erosion exposes deep, structureless bedrock debris. Slope depressed.	Though a debatable slide, it might be larger than shown, including the low ridge along its north flank.
62	Slump.	Orinda Formation.	Older.	Erosional oversteepening of slope.	Depressed, faintly scarplike upper slope. Large, low, toe-like mound at base of slope.	Perhaps this is not a slide. Drainage appears to have been forced northward along the foot of this slope but might be from differing areas of slope-wash contributing slopes.
63	Slumps, possibly some block gliding.	Pinole Tuff Member of Orinda Formation; Orinda Formation.	Older.	Undercutting of dip slope by Las Trampas Creek.	Fairly distinct scarp; eroded west flank of slide exposed in stream bank near Topper Court; rotated beds in scarp area; hummocky surface.	Erosion of the toe by Las Trampas Creek has made renewed movement possible. Such failure could dam the creek and cause flooding of local residential areas (1965).
64	Slump; possibly some block gliding.	Pinole Tuff Member of Orinda Formation; Orinda Formation.	Older.	Undercutting of dip slope by Las Trampas Creek.	Subdued but fairly discernible scarp; depressed upper slope; hummocky surface, rotated beds in scarp area.	The toe is eroded by Las Trampas Creek; renewed movement, at least in the toe area is likely (1965).
65	Slump; possibly some block gliding.	Pinole Tuff Member of Orinda Formation.	Older; some minor surficial movement in scarp area.	Undercutting of dip slope by Las Trampas Creek.	Scarp; side-hill scar; hummocky toe area.	The toe is undercut by Las Trampas Creek; renewed movement in the toe mass is likely (1965).
66	Slump.	Quaternary terrace (alluvium).	Younger.	Undercutting of Las Trampas Creek bank.	Scarp, which heads along lower edge of building foundation; hummocky toe mass and disrupted soil and vegetation.	Undercut stream bank might have been further weakened by runoff from roofs of buildings.
67	Slump.	Neroly Formation.	Younger.	Erosional oversteepening of slope.	Scarp, side-hill depression, hummocky surface.	This is probably shallow and mostly soil; it might involve rubble from road grading
68	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope.	Scarp, hummocky surface.	Continued creep is likely; threatens to choke water course (1965).
69	Slump.	Neroly Formation.	Younger.	Erosional oversteepening of slope or oversteepening due to addition of rubble from road cut.	Scarp, hummocky slope, toe mass.	This shallow slide is probably partly due to failure in road grading rubble.
70	Slump.	Orinda Formation.	Younger.	Undercutting by road cut.	Scarp; hummocky; displaced soil and rock material.	
71	Slump; complex.	Orinda Formation.	Older to younger.	Erosional oversteepening of slope, grading, probable disruption of both bedrock and ground water flow by faulting.	Multiple, headward progressing scarps, hummocky surface, continued movement manifest by recent scarps and marginal creep.	Toe area altered by grading, appeared stable in Feb. 1966. Streets to north and upper slope show incipient failure; tarred cracks along downhill side.
72	Slump.	Orinda Formation.	Younger.	Erosional oversteepening of slope.	Scarp fairly distinct; depressed, hummocky slope, fairly distinct toe mass.	This might reflect some of same bedrock conditions as 71.
73	Slump, probably complex.	Shale member of Briones Formation.	Older.	Erosional oversteepening of slope.	Large, amphitheater-like scarp area; hummocky surface.	The toe is eroded.
74	Slump.	Shale member of Briones Formation.	Older.	Erosional oversteepening of slope.	Indistinct scarp, depressed slope, subdued but irregular surface and toe.	
75	Slump.	Shale member of Briones Formation.	Older with some younger soil movement and gullying.	Erosional oversteepening of slope.	Subdued but distinct scarp; hummocky surface.	The lower slope is convex but its natural state is obscured somewhat by cultivation and erosion.
76	Slump.	Shale member of Briones Formation.	Older with some younger shallow movement of soil and grading rubble in scarp area.	Erosional oversteepening of slope.	Scarp, depressed, hummocky upper slope, lobate toe.	Failure might have been promoted by shearing due to faulting.
77	Slump.	Sandstone and shale members of Briones Formation.	Older.	Erosional oversteepening of slope.	Scarp, hummocky surface, lobate toe.	This is a somewhat debatable slide involving a large proportion of slope-wash and is perhaps classifiable as a slopewash feature.
78	Slump.	Neroly Formation.	Younger.	Erosional oversteepening of slope.	Scarp, hummocky surface, lobate toe.	This is a shallow slide.
79	Slump.	Rodeo Shale.	Younger.	Erosional oversteepening of slope.	Scarp, hummocky surface, lobate toe.	
80	Slump; complex.	Orinda Formation.	Older and younger.	Erosional oversteepening of slope.	Ancient: fairly well defined scarp; convex a few tens of feet down-slope suggestive of backward rotation at top of toe mass. Recent: fresh (fall of 1965), vertical, 20-foot, semi-circular scarp. Toe modified by grading.	This probably has been the site of repeated failures. The face of the fresh scarp shows soil-filled tension cracks dipping into the slope all the way to its base. Nearby slope surfaces and parts of the street show creep and tensional cracking.
81	Slump.	Orinda Formation(?)	Younger.	Erosional oversteepening of slope along fault zone.	Subdued scarp; convex lower slope; glutted water course.	There is some doubt, but the existence of this slide is highly probable; it is possible that weak material in the slope west of and within the fault zone has slumped down over more stable rocks east of the fault.
82	Slumps.	Sandstone member of Briones Formation.	Younger.	Erosional oversteepening of slope.	Scarps, hummocky surface, lobate toes.	
83	Slump.	Shale member of Briones Formation.	Older.	Erosional oversteepening of slope.	Fairly distinct though eroded scarp; lobate toe; surface somewhat irregular.	The scarp is overridden by a downward moving lobe of slopewash.
84	Slumps.	Shale member of Briones Formation.	Older, the renewed movement in toe mass of easternmost slide most younger.	Erosional oversteepening of slope.	Faint to distinct scarps, lobate toes.	This is a group of similar, probably shallow slumps.
85	Slump.	Neroly Formation.	Younger.	Erosional oversteepening of slope.	Scarp, hummocky surface, lobate toe.	This is a shallow slide involving a small proportion of bedrock; there is possibly a secondary effect of faulting or shearing in bedrock.
86	Slump.	Neroly Formation.	Younger?	Erosional oversteepening of slope.	Scarp, hummocky surface.	It is probably shallow.
87	Slump.	Orinda Formation.	Younger.	Oversteepening of slope by erosion and/or artificial cuts.	Scarp, hummocky surface.	Air photos suggest that the highway cut is the principal cause of failure; continued movement is to be expected most likely toward the most recent cut in the west flank (1966).
88	Slump.	Rodeo Shale.	Younger.	Erosional oversteepening of slope.	Scarp, hummocky surface, lobate toe.	This is shallow and largely slopewash.

* Difference in relative age determined somewhat arbitrarily, based on recognition of slide features; younger slides are recognized by their sharp morphologic features or by recognizably younger movement; all slides in slope wash were considered younger; older slides have subdued morphologic features or were classified by evidence described under remarks column.

GEOLOGY AND SLOPE STABILITY OF THE SOUTHWEST QUARTER OF THE WALNUT CREEK 7½-MINUTE QUADRANGLE, CONTRA COSTA COUNTY, CALIFORNIA

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S.W. ¼ WALNUT CREEK QUADRANGLE
CALIFORNIA DIVISION OF MINES & GEOLOGY
MAP SHEET 16
1973

ABSTRACT

The southwest quarter of the Walnut Creek 7½-minute quadrangle is in a hilly terrain of complex faulting and landsliding. Most of the rocks are marine in origin, ranging in age from Upper Cretaceous (?) to Quaternary with subordinate basaltic flows and pyroclastic material. Most of the sedimentary rocks are Miocene and comprise the Hambre Sandstone, Rodeo Shale, Briones Formation, Cierbo Sandstone, and part of the marine-nonmarine transitional rocks of the Neroly Formation; about one-quarter of the mapped area is underlain by the nonmarine Orinda Formation of Pliocene age. The steeply dipping, northwest-trending Calaveras and Las Trampas faults are the most important structural features of the mapped area and are the most probable sites of future seismicity. Most of the landslides in the mapped area are the slump type and are concentrated along fault lines, outcrops of weaker rock types, and oversteepened stream banks.

INTRODUCTION

Suburban growth in the San Francisco Bay region has led to an increased recognition of problems of slope stability. Wise land use decisions in this seismic and geologically complex region require a detailed understanding of the geology.

Walnut Creek and the adjoining communities of Lafayette and Pleasant Hill are areas of moderately rapid urban growth. These communities lie in a region of widespread landsliding and athwart, or in close proximity to, the active Calaveras fault zone. These geologic features pose major problems to orderly land development in this area.

Geologic Setting

The San Francisco Bay Area is crossed by an active, north-northwest-trending fault system comprising, from west to east, the zones of the San Andreas, Hayward, and Calaveras faults (index map). The area of this report lies adjacent to and west of the trace of the Calaveras fault on the eastern edge of the Berkeley Hills. These hills comprise a belt of faulted anticlinal and synclinal folds that roughly parallel the trace of the Hayward and Calaveras faults (Jennings and Burnett, 1961; Taliaferro, 1951, op. p. 128; Page, 1966, p. 265). Folds and faults in the mapped area reflect adjustment to strain resulting from differential, right-lateral movement between the large block underlying the Berkeley Hills west of the Calaveras fault zone and a block, including the Mount Diablo region, east of the Calaveras fault zone.

Rocks in the mapped area range in age from Upper Cretaceous (?) to Quaternary. Marine and transitional marine-nonmarine sedimentary rocks are dominant. The latter group of strata is Mio-Pliocene in age and includes minor proportions of volcanic rocks. The strata exposed in the area are not homogeneous; they comprise interlayered units which range from firm, ridge-forming sandstone to claystone barely stronger than the soil that forms upon it. Variations in slope stability reflect these diverse factors.

FAULTS

In the vicinity of Walnut Creek, the northwest-trending Calaveras fault is the most important structural feature and the most likely site of both seismic and nonseismic earth movements. Another major fault, the Las Trampas fault, parallels the Calaveras fault about 2 miles west.

Calaveras Fault

The Calaveras fault is a plane of separation and right-lateral movement between two major structural blocks. Lawson (1914), who originally called it the Franklin fault, described the Calaveras fault as a thrust, with the northeast block upthrown. West over east thrusting in the Pleasanton area, some 20 miles south of Walnut Creek, has been suggested by Gibson and Wollenberg (1968). Vertical or nearly vertical shearing or fault planes related to the trace of the Calaveras fault are exposed at several places near Walnut Creek.

Much of the true nature of the Calaveras fault zone in the Walnut Creek-Pleasant Hill area is obscured by alluvium, streets, and buildings. It is evident, however, that the zone is a complex zone of many faults. Existence of the fault trace beneath the alluvium is indicated by topographic features northwest of Pleasant Hill School. The alignment of ridges, truncated spurs, valleys, swales, ravines, and landslides extends this trace northwest into the Briones Valley quadrangle.

At Walnut Creek the apparent relationship of the Sobrante Formation (middle Miocene) and the Briones Formation (upper Miocene) suggests that the following strata are missing: the Claremont Shale (middle Miocene), the Oursan Sandstone (middle Miocene), and the Tice Shale (middle Miocene). These strata are not exposed in the mapped area but are present in the Las Trampas Ridge quadrangle (Ham, 1952) and the Pleasanton area (Hall, 1958) to the south, and in the Orinda area to the west (Pease, 1952). Also missing are the Hambre Sandstone (middle Miocene) and the Rodeo Shale (middle Miocene).

Byerly (1951, p. 159) and Richter (1958, p. 476) consider the Calaveras fault zone to be active. Page (1966, p. 274) suggests that the Calaveras fault zone ". . . might be considered to be only dormant." Richter attributes a 5.4-magnitude shock of October 24, 1955, (epicenter between Walnut Creek and Concord) to this fault; but no such event in recent times appears to have produced any surface rupture significant enough to be readily recognized in the immediate vicinity of the city of Walnut Creek.

Las Trampas Fault

As mapped in this work, the Las Trampas fault has been traced through a more northerly course than that portrayed by Lawson (1914). The Las Trampas fault is roughly parallel to the Calaveras fault zone; the plane of the fault is essentially vertical.

Early in September of 1967, a smooth-walled, 12-foot diameter aqueduct tunnel was bored through the Las Trampas fault about 200 feet below the surface in the southeast end of Lafayette Ridge southwest of Acalanes High School. About a week later, a right-lateral offset of approximately 1 inch was noted on a slip-plane of the fault. This movement probably was a local rebound of stressed fault zone material although it may be evidence of creep movement on the Las Trampas fault. No surface evidence of such movement was observed but it is significant that the Las Trampas fault is under stress.

Although there is a consistent component of separation in the right lateral sense (plate 1), the apparent horizontal separation of corresponding geologic features on either side of the Las Trampas fault is not consistent. The inconsistency may be assumed to have been introduced by unevenly distributed, and difficult to estimate, amounts of vertical movement and folding. The cause of the stress probably is related to the nearby Calaveras fault zone. In the area lying between the Las Trampas fault and the Calaveras fault zone, the manner in which the Pinole anticline and Rodeo syncline have been distorted and faulted strongly suggests such stress. The Las Trampas fault may be analogous to the Pleasanton fault 2 miles east of the Calaveras fault zone.

FOLDS

The parts of the Pinole anticline and Rodeo syncline included in the area of this report lie entirely west of, and are truncated by, the Calaveras fault zone. The tuncation of these folds and their subsequent segmentation by the Las Trampas fault caused additional smaller scale folding and faulting. These effects are most obvious along the west side of the Las Trampas fault in the Lafayette area where a syncline and probably an adjoining anticline have formed in a narrow, fault-bounded area underlain by the Orinda Formation (cross section C-C'). In the southwest corner of the mapped area, the Orinda Formation appears in folds and faults that parallel the Pinole anticline.

East of the Calaveras fault zone the strata dip, with few exceptions, steeply east-northeast toward the axis of the overturned Walnut Creek syncline lying to the east of the mapped area. This fold was described and named by Lawson (1914).

The axis of a syncline in Orinda-like sediments is exposed about 200 feet south of Contra Costa Canal just west of North Main Street in the city of Walnut Creek. This fold was caused by compressional forces acting normal to the Calaveras fault zone, but its extent was not determined.

ROCK STRENGTH AND STABILITY

Folding and faulting has resulted in the local elevation, erosion, and mechanical weakening of rocks in the mapped area. In general, clay- and silt-rich strata like those of the Orinda Formation are less stable than coarser grained units such as the Cierbo Sandstone. The stability of mixed sequences, such as the Briones Formation and the Hambre Sandstone, depends upon the intensity of fracturing, relief, and the dip of the bedding in relation to the outcrop at any given site. The lower and middle parts of the Rodeo Shale are siliceous and consequently more stable. The effect of bedding as a control of direction of failure is commonly secondary to fracturing in the fine-grained sedimentary rocks. This is due in part to the milling of such rocks between more competent units during folding and faulting. In the more resistant siliceous shale of the Rodeo and the lavender shale of the upper part of the Neroly Formation, bedding planes are the principal structural weakness except where the shale is milled by faulting.

The massive, generally well-indurated Cierbo Sandstone is the most stable of all sedimentary units in the mapped area. The abundance of hard, fossiliferous beds locally increase its strength. Other rock units are individually as competent or more competent than the Cierbo Sandstone but are, without exception, thinner and more intimately associated with weak strata such as shale, siltstone, or mudstone. Erosion or failure of the weaker strata can deprive the stronger rocks of support. Examples of such competent units are the fossiliferous sandstone units of the Briones Formation, the tuffaceous sandstone of the San Ramon Formation and conglomerate beds of the Del Valle Formation (?).

Pebbly sandstone and conglomerate units in the Orinda Formation are of local importance because they are the most stable sedimentary rocks in this formation. A few of these units are shown on the map, one of which is well exposed in the old railroad cut northeast of Stanley School in Lafayette. These units are poorly exposed and were mapped only locally where they could be traced for a few tens of feet.

The "Moraga Formation (volcanics)" and the "Pinole Tuff", two units that are much thicker and more prominently exposed in neighboring regions, are reduced in rank to members of the Orinda Formation in this report (table 1, footnote). The Moraga Basalt Member is stable, but the underlying and overlying rocks are generally unstable. The Pinole Tuff Member comprises volcanic debris that has a wide range of texture, firmness, and alteration. Some exposures have yielded landslides (Slides 44, 63, 64, and 65) although others appear to be stable.

SLOPE STABILITY

Some geologically recent event has caused the stream channels of the mapped area to become deeply entrenched to their uppermost reaches. Bedrock slopes formerly buttressed by stream deposits, slope wash accumulation, and landslide debris are losing support as the banks cut back through these deposits into the slope bases. The concentration of landslides in weak rocks and near faults is evident on the map along active stream channels. Howard (1951, p. 96) suggests that a fresh marine terrace around the shores of San Pablo Bay indicates a recent regional emergence. Conversely, Emery (1960, p. 20) suggests that a world-wide eustatic lowering of sea level took place about 3000 years ago.

The Cierbo Sandstone and Briones Formation are natural water reservoirs in the trough of the Rodeo syncline and on the flanks of the Pinole anticline. These structures are breached by faults, erosion, and the works of man. Locally, ground water escapes through springs and seeps which create slope stability problems.

Runoff is controlled to some extent by rock type. Sandy rocks, such as the Cierbo Sandstone and parts of the Briones Formation and the loamy soils which form upon them, tend to absorb water and inhibit runoff. In contrast, clay-rich rocks and the heavy soils which form upon them contribute to high runoff. These effects are both augmented and moderated by vegetation.

Slopes underlain by fine-grained sedimentary rocks rich in clay are generally grassy. While Rodeo Shale is exposed on both flanks of the Pinole anticline west of the Las Trampas fault, south-facing slopes on the north flank are grass covered. The upper, less stable part of the shale is landslid. On the north-facing slope of the south flank of the anticline, the porcelaneous part of the Rodeo Shale is covered by scrub oak, bay, buckeye, and poison oak thicket. The upper part is covered by interspersed grass and oaks. Only one slide (number 88) was identified in this exposure.

On north-facing slopes, in the southwest quarter of the mapped area, heavily wooded to interspersed oaks and grass cover the Orinda Formation. Slopes with other exposures are predominantly grass covered. Here again the less-wooded and grassy slopes are the least stable. It is possible that some ancient slides are masked by vegetation and that the distribution of grass and trees might not always have been the same. Areas of grass used for grazing are less stable than adjacent, natural slopes.

Vegetative cover is not a controlling factor in deep, bedrock slope failures, but weathered rock and soil are more stable if they are host to a well-developed root mass.

Landslides

Some slopes in the mapped area have had a long history of landslide movement. The remnants of very ancient slides should be anticipated in these areas. A description of each landslide is presented in table 2; most of the slides are slump-type slope failures.

A slump is "the downward slipping of a mass of rock or unconsolidated material of any size, moving as a unit or as several subsidiary units, usually with backward rotation on a more or less horizontal axis parallel to the cliff or slope from which it descends" (Sharp, 1960, p. 65). Slumps may involve either soil or bedrock or both. Slumps involving only soil are denoted differently from bedrock failures on the map.

Slumps involving intensely disturbed rocks, such as those along the trace of the Las Trampas fault in the northwest corner of the mapped area, may be relatively deeper than those in rocks that have not been strongly broken. Some slumps in weathered shale are shallow, as indicated by their scarp heights and by the depth and dip of their surface of rupture.

In addition to slumping, block gliding is a type of movement that is apt to occur on slopes that are parallel, or nearly parallel, to bedding, layering, or shear planes.

Block gliding is the movement of a mass or block of competent, cohesive rock along a subjacent bedding plane, zone of shearing, or soft, incompetent rock unit. Although this type of landslide does not appear to be a common feature in the mapped area, it is of potential importance where competent and incompetent rocks are interlayered. Slide 13, in the northwest corner of the mapped area, is a possible example. Here the sandstone member of the Briones Formation appears to have been undercut sufficiently to glide. Other slides on the Pinole anticline probably resulted from block gliding on dip slopes.

Features portrayed on the map by sinuous arrow symbols, singly, in swarms, or within boundaries, represent sites of rapid soil creep, incipient failure, and soil slumps and earth-flows.

Earth-flows dramatize the triggering capacity of water which adds weight and reduces the cohesiveness of clay-rich materials. Earth-flows are very fluid masses of soil and rock debris which commonly develop from either soil slumps or deeper slumps when the toe masses have become highly disordered and intermixed with soil. Being more fluid than slumps, earth-flows more quickly lose their identifying features. They are most common in geologic units which yield slumps but can develop in any elevated soil mass subject to soaking. Soil and rock debris mapped as slope wash is a likely source for earth-flows.

Other Surficial Units

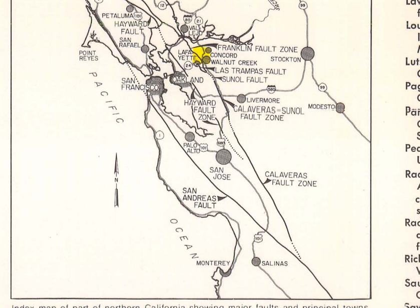
The unit mapped as slope wash is composed of angular fragments of the more resistant bedrock units. These fragments are mixed with various amounts of soil including many deposits comprised wholly of soil and organic debris. This material lies on slopes and on the floors of ravines and, in some areas, chokes narrow valleys. The uphill contact of slope wash was arbitrarily drawn where the thickness is approximately 3 feet. The lower contact is drawn where slope wash appears to merge with, or wedge out over, older soil-covered terrace surfaces.

During wet weather, slope wash is unstable and plastic. Its rate of movement ranges from extremely slow creep to the rapid flow of slumps and mudflows. Slope wash is affected by many of the factors of exposure and vegetation described in the section on slope stability. Slope wash derived from sandy rocks tends to be better drained, becomes less plastic when wet, and supports heavier vegetation. The converse is true of slope wash on more clay-rich subjacent rocks.

In level areas, one of the most troublesome stability problems is expansive soil. Strongly expansive soil loses volume when it dries; this is manifest in deep cracks which form during the dry season and a corresponding expansion when wet. Such soils commonly are called "adobe." Adobe soils are present in the Walnut Creek area. Carpenter and Cosby (1939) use this term, and their map and report can be used as a rough guide to delineate expansive soils. However, the development of any soil-covered area should be preceded by soil tests unless these deposits are to be removed. Statements concerning soils in the Walnut Creek area are included on table 1.

Except for the area below 80 feet in elevation in the northeast part of the Walnut Creek area, Quaternary alluvium is mapped at only a few sites where there is rapid transport or deposition of sediments and in areas large enough to depict on the map. Most of the major drainage channels are floored by alluvium composed of clay, silt, sand, and gravel; but these deposits are not extensive enough to show on the geologic map. Bedrock exposed in the channels, however, is shown by slight exaggeration, to portray as much structural continuity in the bedrock as is reasonably possible.

Quaternary alluvial deposits are not extensive enough to offer exploitable volumes of sand and gravel. Indeed, flood control projects where presently planned (1966) probably will hide most major natural channels. In the northeast part of the mapped area, 80 foot contour lines were used as a boundary between Quaternary terrace deposits and Quaternary alluvium. This appears to be the elevation of the first major break in slope above the surface as it merges northward with the flood plane of the Sacramento River. There probably are a number of discrete terrace levels within the area mapped as Quaternary terrace that have been concealed and altered by human activity.



Index map of part of northern California showing major faults and principal towns. The Walnut Creek 7 1/2-minute quadrangle is shown in yellow.

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