AREAL AND ENGINEERING GEOLOGY OF THE OAKLAND EAST QUADRANGLE, CALIFORNIA

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Table 1.—*Generalized description of engineering properties of map units*

[Underline indicates geologic conditions that may be critical to planning, design, and construction of engineering works]

Map unit [1]	General lithologic description	Topographic form
Artificial fill (Qaf)	Composition varies from place to place. Consists largely of Merritt Sand dredged from bay along shore of Alameda. Most highway fills composed of mixtures of rock and soil derived from nearby cuts or borrow areas. Some fills contain concrete, bricks, and other miscellaneous refuse. Only large fill areas shown on map; innumerable fills too small to show on map have been made for highways, streets, and building pads	Flat, level areas a few feet above sea level along the edge of the bay, or flat fills in valley bottoms; also terraces and ramps for highways
Bay mud (Qbm)	Silt, clayey, sandy, with small lenses of sand; contains shells and organic material which in some places forms thin peaty layers. Olive-gray, massive, structureless. Soft and fluid at top, increasingly consolidated with depth. Plastic. Swells when wetted, shrinks and cracks upon drying. Maximum known thickness in this area 25 feet. Two consolidation tests of mud exposed near Derby Street, which may be older bay mud now above sea level, showed compression of 14 and 17 percent	Slopes gently from landward edge toward center of bay; forms tidal flats; much now covered by artificial fill
Alluvium and colluvium (Qac)	Composition varies from place to place. In small, swift-flowing streams, recent alluvium—largely sand, pebbles, and boulders; alluvium in flat valleys and colluvium on hillsides generally finer material, usually dark in color. Alluvium and colluvium underlain by rocks of Contra Costa Group commonly contain much swelling clay. Colluvium as much as 60 feet in thickness on west side of Moraga Valley; alluvium a few inches to more than 75 feet in thickness	Recent alluvium fills stream valleys and forms flat valley bottoms; alluvium fills and obscures many old hillside ravines too small or indistinct to show on map; colluvium mantles sides of hills
Undivided Quaternary deposits (Qu)	Composition and physical properties vary. Consists predominantly of Temescal Formation. Probably includes covered or unrecognized San Antonio Formation and gravel, sand, and clay (Qg), as well as Recent alluvium and colluvium, and artificial fill. Symbols for Qtc, Qts, and Qtb shown in parentheses where these units can be positively identified (see Temescal Formation)	Primarily in valleys and on gentle slopes between San Francisco Bay and the Berkeley Hills
Temescal Formation (Qtc, Qts, Qtb)	As used by Lawson (1914) comprises several presumably contemporaneous alluvial units of different origin, lithology, and physical properties. Qtc, dark alluvium filling stream channels in the eroded San Antonio Formation; consists of irregularly bedded clay, silt, sand, and gravel with organic material and some Claremont chert; dark-yellowish-brown to olive-gray. Poorly consolidated; one consolidation test on Peralta Creek showed compression of 16 percent; 3–18 feet thick. Qts, material apparently derived from erosion of the San Antonio Formation; consists of lenses of clay, silt, sand, and gravel with Claremont chert; yellowish brown; in places lithologically indistinguishable from San Antonio Formation; origin assumed from topographic form and lower compressive strength as indicated by one consolidation test on Sausal Creek (compression 12 percent). Qtb, alluvium derived from the Berkeley Hills, probably deposited simultaneously with Qts, consists of well-consolidated gravel-sand-silt-clay mixtures with firm pebbles and little or no Claremont chert; moderate yellowish brown; well exposed on Arroyo Viejo where a consolidation test showed a compression of 6 percent, and on 73rd Street, where it has been tilted to an angle of 72°	In flat valley bottoms and gentle slopes between San Francisco Bay and the Berkeley Hills. Qtc fills meandering channels cut in underlying material

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density[2] moisture content and Unified Soil Classification[3]	Remarks (Includes use and earthquake stability)
None in most places	Depends on composition; varies from place to place	Depend on composition. Properly engineered fill placed over bay mud generally suitable for light structures. **Fill over bay mud may settle differentially as bay mud compacts under load**	Vary with composition. 106 (hydraulic sand fill); 23 percent (14: 92–119; 18–37 percent)	Properly engineered fill generally suitable for use as foundation for light structures; **fill overlying bay mud is susceptible to movement under earthquake stress**
None in most places	Can be moved with hand tools; **trucks and other heavy equipment may become mired in mud** if excavation with such equipment is attempted	Must be supported in most cuts. **May settle differentially under load.** Sensitivity generally low, but **use of very heavy equipment to place fill may cause remolding and loss of strength. When used as fill upper part may swell when wet and shrink when dry**	81; 51 percent (22: 46–106; 20–125 percent) Pt; CL–CH	Can be used as fill if properly compacted but may be difficult to place because of high moisture content. **Earthquake stability poor** (Duke, 1958; Gilbert in Gilbert and others, 1907; Lawson, 1908; Louderback, 1942)
Thickness of soil varies from a few inches to several feet. In flat valleys soil as much as 3 feet in thickness has developed on alluvium. **In places soil clayey, shrinks and swells**	Can be moved with hand tools. Where material is clayey, **may be very heavy and sticky when wet, sticking to tools and miring heavy equipment**	Depend on composition. **Alluvium and colluvium derived from rocks of Contra Costa Group generally contain expansive clay. May cause heaving and cracking of structures in flat areas; susceptible to sliding on hillsides.** Alluvium in old ravines may slide in cuts	100; 23 percent; (66: 86–122; 8–34 percent) GW–OH	Dry density, moisture content, and Unified Soil Classification determined on sandy and silty clay derived from Moraga Formation and Contra Costa Group
Soil may be as much as 3 feet thick. **In places soil clayey, shrinks and swells; may cause damage to buildings**	Can be moved with hand or power tools	Depend on composition; generally good. **Slides have formed where colluvium apparently derived from gabbro**	Varies	Mapped with Temescal Formation in Oakland West quadrangle (Radbruch, 1957)
In places a soil as much as 3 feet in thickness has formed on the Temescal Formation; **soil clayey, shrinks and swells with seasonal moisture changes**	May be moved with hand tools. Clay beds may be sticky when wet	Slope stability and foundation conditions fair to poor. Some minor slumping in steep cuts. Qtc generally softer than underlying and adjacent material; **buildings founded partly on Temescal channel material and partly on older material may be damaged by differential settlement**	86 (Qtc); 42 percent; (3: 73–104; 25–71 percent); 100 (Qts); 23 percent 110 (Qtb); 14 percent; (39: 92–133; 3–22 percent); Qtc, GC–OH; Qts, GC–CH; Qtb, GM–CH	

Table 1.—*Generalized description of engineering properties of map units*—Continued

Map unit [1]	General lithologic description	Topographic form
Merritt Sand (Qm)	Sand, fine-grained, silty, clayey, with lenses of sandy clay and clay. Well-sorted. Contains small amount of organic material. Yellowish-brown to dark-yellowish-orange. No bedding observed. Slightly coherent, in most places consolidation increases at depth. Maximum known thickness 65 feet	Forms low mound on which city of Alameda is built
San Antonio Formation Upper member (Qsu)	Clay, silt, sand, and gravel. Some pebbles soft; most firm. Most beds contain flakes and pebbles of white Claremont chert, some gravel almost entirely chert. Contains montmorillonite clay. Pale-yellowish-brown to grayish-orange. Consolidation varies, some layers loose, unconsolidated. Three consolidation tests on clay layers showed compression of 4 to 6 percent. Maximum thickness unknown. May include some Temescal Formation and lower member where exposures too poor to differentiate units	Primarily in rather steep dissected hilly areas between San Francisco Bay and steep front of Berkeley Hills
Lower member (Qsl)	Gravel, weathered, dense, with silty clay matrix. Some pebbles firm, most soft; breaks across pebbles when struck with pick. Unit very uniform in lithology, contains a few slightly silty, pebbly clay lenses. Contains little or no Claremont chert. Contains montmorillonite clay. Light-brown to grayish-orange. Two consolidation tests showed compression of 5 and 7 percent. Maximum thickness unknown	In steep to moderately sloping hilly areas between San Francisco Bay and the steep front of the Berkeley Hills
Gravel, sand, and clay (Qg)	Gravel, sand, silt, and clay; olive-gray, dark-yellowish-orange, light-brown. Contains swelling clay; expands when wet, shrinks and cracks when dry. Overlies Leona Rhyolite, contains pebbles of rhyolite. Beds poorly defined; average thickness of beds about 30 feet. Tilted and contorted. Contains molluscs of probable early Pleistocene (Irvingtonian) age. Southwest of Oak Knob Naval Hospital overlies deeply weathered Leona rhyolite	Small ridge within Hayward fault zone and minor rounded hills nearby
Leona Rhyolite (Tl)	Rhyolite. Fresh rock light-gray to greenish- or light-bluish-gray, weathers to white or dark-yellowish-orange, may be iron-stained reddish-orange. Fresh rock contains abundant pyrite in many places. Contains a small amount of glass. Sheared and fractured. May include small amounts of Franciscan and Knoxville sandstone and shale too small to show on the map. Much of rhyolite apparently intrusive (Case, 1963); in places intruded overlying Knoxville shale, now baked and contorted at contact	Forms steep knobby dissected hills

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density [2] moisture content and Unified Soil Classification [3]	Remarks (Includes use and earthquake stability)
Very little weathering discernible; top few inches may contain small amount of organic material	Can be moved with hand or power tools	Must be supported in cuts; most will slump to natural angle of repose of loose sand when dry. Good foundation material	107; 14 percent (14: 100–115; 4–21 percent) SP–SC	Merritt Sand dredged from the bay is one of the main sources of artificial fill
Soil as much as 3 feet thick in places. Soil swells and shrinks with seasonal moisture changes and may cause damage to buildings; may creep on slopes	Can be moved with hand tools	Large slides have formed in this unit. Factors contributing to slide probably include presence of montmorillonite clay and alternating poorly consolidated sand and clay; steep slopes; and ground water. Generally suitable foundation material for light structures where slopes are not steep	105; 18 percent (77: 91–123; 8–30 percent) GM–CH	
Most pebbles soft, probably weathered in place. Soil as much as 3 feet thick in places. Depth of weathering unknown. Soil clayey, shrinks and swells	Can be moved with hand or power tools	Generally stable in 1:1 cuts; some slumping on steep slopes	114; 16 percent (25: 106–123; 10–21 percent) GC	
Unit appears to be weathered to depth of maximum exposure—50 feet. Weathered rock soft, clayey, joints iron-stained. Soil clayey, 1–3 feet thick	Can be moved with hand tools or power equipment	Slope stability poor, slides abundant. Slides have formed in clayey layers of of this unit on slopes as gentle as 2:1. Foundation conditions unknown, probably fair. Swelling of expansive clay could cause damage to structures	103 (sandy and silty clay with some gravel); 21 percent (65: 75–125; 11–44 percent) GC–CH	Earthquakes may trigger landslides in this unit
Weathering as much as 30 feet deep; highly weathered rock consists of loose fragments in clay matrix. Soil generally lacking or less than 18 inches thick; in ravines may be more than 12 feet thick	Can generally be moved with power equipment; in some places requires blasting	Slope stability and foundation conditions good. Rare debris slides observed where rock excessively fractured and weathered	162 (s); 0.1 percent; 99 (weathered); 20 percent (3: 98–102; 9–27 percent)	Crushed Leona Rhyolite is a major source of fill and base rock; pyrite formerly mined for sulfur; **runoff from rhyolite hills very acid and corrodes concrete sewer pipe. Some slopes so steep that development may be difficult**

Table 1.—*Generalized description of engineering properties of map units*—Continued

Map unit [1]	General lithologic description	Topographic form
Contra Costa Group		
Bald Peak Basalt (Tbp)	Basalt with minor amounts of sedimentary rocks. Large plagioclase phenocrysts abundant. Fresh basalt dark gray, weathers yellowish gray. Typically cut by many intersecting fractures, along which alteration has taken place, so that in any exposure rock commonly consists of dark, hard subangular blocks 1 inch to 1 foot across, in a matrix of soft, light-colored material, predominantly clay with some silt-sized mineral grains. Maximum thickness unknown; comformably overlies Siesta Formation	Forms moderately steep hillsides and caps small ridges. Outcrop area very small, at north end of Siesta Valley
Siesta Formation (Ts)	Claystone, silty, and sandstone, very fine grained to medium-grained; greenish-gray to pale-brown. Claystone generally massive, may be very finely laminated. Minor pebbly conglomerate, cherty limestone, impure tuff, and basalt. Cut by faults. Beds 1 inch to 12 feet thick; most 1–5 feet thick. Maximum thickness unknown. Conformably overlies Moraga Formation	Flat or gently rolling topography of bottom and sides of Siesta Valley
Moraga Formation (Tmb, Tmc)	Basalt and andesite flows, Tmb, dark-gray; moderate-red in oxidized tops of flows, locally amygdaloidal. Interbedded clastic rocks, Tmc, include conglomerate, sandstone, siltstone, agglomerate, tuff, and mixture of volcanic and nonvolcanic debris; minor limestone and lignite. Thickness of beds a few inches to 200 feet. Yellowish-gray rhyolite tuff within clastic sequence forms marker bed, variable in thickness, near middle of formation. Poorly sorted volcanic debris on hill south of Moraga substation may be volcanic mudflow. Some bodies of clastic rock too small to show on map are included in Tmb; additional unrecognized clastic rocks probably included in Tmb where exposures are poor. Entire formation sheared and fractured. Maximum estimated thickness 1,300 feet. Conformably overlies and probably interfingers with Orinda Formation	Forms prominent, steep-sided ridges. Slopes generally more than 30°
Orinda Formation Tor	Conglomerate, sandstone, siltstone, and claystone; contains swelling clay. Bluish-gray, greenish-gray, and grayish-red. Beds 1 inch to 100 feet thick. Sheared and fractured, numerous joints. Beds lenticular. Contains minor diabase dikes. Maximum estimated thickness approximately 2,300 feet. Overlies Tice Shale and Claremont Shale with apparent erosional and possibly slight angular unconformity	Primarily forms valleys, but harder rocks of formation in places form steep ridges
Contra Costa Group, undivided Tcu	Conglomerate, sandstone, and siltstone, with minor amounts of limestone and tuff, interbedded and lenticular. Greenish-gray, reddish-brown. Contains unnamed rocks younger than formations of the Contra Costa Group (Bald Peak, Siesta, Moraga, and Orinda) recognized west of Moraga fault. Rocks poorly consolidated, contain montmorillonite clay. Fractured, cut bv faults; prominent and widespread jointing; joint surfaces iron-stained. Beds less than 1 inch to 80 feet thick. Maximum thickness of unit unknown	Underlies rolling to moderately steep-sided hills and intervening northwest-trending valleys in northeast corner of quadrangle

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density [2] moisture content and Unified Soil Classification [3]	Remarks (Includes use and earthquake stability)
Alteration with much softening along fractures in rock observed wherever exposed; soil sparse, generally only 2 or 3 inches thick	Can generally be moved with power equipment because of intensive fracturing and alteration	Slope stability and foundation conditions good. Small blocks of unaltered material fall out of weathered matrix and accumulate at base of cuts	Not determined	
Weathering irregular, depth varies from a few inches to as much as 15 feet. Weathered rock soft, structureless, clayey. Soil lacking or as much as 3 feet thick, more in ravines	Can be moved with hand tools or power equipment	**Many slides form on both natural and cut slopes in this unit,** although some highway cuts appear to be stable at 1:1 slopes. Foundation conditions fair to poor. **Expansion of clayey soil may cause damage to structures**	150 (s) (siltstone); 1.2 percent; 116 (weathered siltstone); 17 percent	**Part of floor of Siesta Valley north of Highway 24 consists of old slide material** of the Siesta Formation
Tops of individual flows oxidized red; soil sparse, where developed is generally clayey. Colluvium may be as much as 60 feet thick	Clastic rocks or intensely fractured volcanic rocks can be moved with power equipment; basalt and andesite generally require blasting	Basalt and andesite generally stable, and foundation conditions good. **Many small slides form in clastic rocks, and in places very large slides have moved on clayey clastic units or formed in overlying clayey colluvium**	168 (s) (basalt); 0.5 percent	Crushed volcanic rock from the Moraga Formation is a major source of fill and base rock in this area; some large, firm blocks of unweathered volcanic rock also used as riprap. **Slopes so steep that development may be difficult**
Depth of weathering irregular; varies from 3 to 20 feet; weathered rock soft, clayey. Soil sparse; may be lacking or as much as 3 feet thick, more in hillside ravines	Can generally be moved with power equipment, but some dense, hard sandstone or conglomerate lenses may require blasting	**Slope stability poor; many slides in both rock and soil on both natural and cut slopes.** Slides occur on many natural slopes as flat as 20°, although some cuts appear stable at 1: 1. **Swelling of expansive clay in rock and overlying soil could cause damage to structures**	143 (s) (ss); 1.3 percent; 140 (ss, sh, and cgl.); 7 percent; (7: 134–150; 5–14 percent)	**Sandstone or conglomerate beds that require blasting for removal may disintegrate in cuts after exposure to air. May squeeze in tunnels**
Weathering irregular, from a few inches to several feet deep. Weathered rock soft, clayey. Soil generally lacking, but as much as 10 feet thick in ravines; generally clayey	Can be moved with power equipment	**Slope stability poor. Abundant slides in both soil and rock, on natural and cut slopes.** Slides most abundant on north-facing slopes; slides in rock may move on joint surfaces (Radbruch and Weiler, 1963) **Expansion of clayey soil derived from this unit may cause heaving of structures**	131 (s) (ss); 2.1 percent; 143 (s) (siltstone), 4.6 percent; 108 (cgl., ss, siltstone, weathered?); 15 percent; (7: 96–123; 7–23 percent)	Properly compacted material from formation suitable for artificial fill. Earthquakes may trigger soilslips and landslides in this unit, particularly if rocks and soil are saturated. **Abundant landslides may increase cost of development**

Table 1.—*Generalized description of engineering properties of map units*—Continued

Map unit	General lithologic description	Topographic form
Monterey Group: Tice Shale (Tt)	Shale, siliceous, and fine-grained sandstone. Yellowish-gray, light-gray, and light-brown. Contains sandstone dikes. Shale is finely laminated, generally in beds 1 inch or less in thickness. Total thickness unknown. Stratigraphic relationship with underlying Claremont Shale unknown; may be slightly unconformable	Underlies steep hillside
Monterey Group: Claremont Shale (Tc)	Chert, finely laminated, and shale, rhythmically bedded; also contains dark clay shale, siliceous shale, porcellanite, and sandstone. Bituminous in places. Cut by sandstone and diabase dikes. Weathered chert white to yellowish gray; when fresh, medium-light-gray to medium-dark-gray. Chert beds commonly 1–4 inches in thickness, interbedded shale less than 1 inch thick. Fractured and intensely contorted; chert brittle, breaks easily into small pieces. Sandstone member near base generally firm, fractured in places. May be more than 1,000 feet thick; comformably overlies Sobrante(?) Sandstone	Forms very steep-sided ridges in Berkeley Hills. Forms main prominent ridge in hills
Monterey Group: Sobrante(?) Sandstone (Tso)	Siltstone and shale with some fine-grained sandstone, glauconitic in places. Dark-olive-gray or olive-gray when fresh, weathers light brown or distinctive pale red. Contains gypsum in places, fracture surfaces commonly coated with pale yellowish-orange or grayish-yellow jarosite (Briggs, 1951). Bedding obscure. Jointed, fractured; breaks into pieces approximately an inch across. Foraminifera from this unit have been dated as Saucesian and (or) Relizian in age. Thickness not determined owing to deformation and poor exposures; stratigraphic relationship with underlying Eocene sandstone and shale unknown	Underlies moderately steep slopes
Sandstone and shale (Tss)	Massive, fine-grained sandstone; glauconitic sandstone, soft silty sandstone with organic material, siltstone, dark-colored clay shale. Fresh sandstone medium gray, weathers yellowish brown. Some rocks closely resemble underlying Cretaceous rocks, some are almost indistinguishable from overlying rocks. Some fine-grained rocks in places coated with yellow jarosite (Briggs, 1951). Sheared and fractured. Contains sparse molluscan fauna. Thickness unknown, probably 500–1,000 feet; in fault contact with underlying rocks	Forms moderately steep sided ridges and valleys in Berkeley Hills
Pinehurst Shale* (Tp)	Shale, siliceous, light-gray to medium-gray, and sandstone, hard, fine-grained, yellowish-gray. Beds 10 feet to less than 1 inch thick, most 3 inches to 3 feet. Contorted, cut by numerous faults. Contains Paleocene foraminifera. Maximum exposed thickness 500–700 feet; appears conformable with underlying red and gray shale at top of Redwood Canyon Formation	Underlies steep ridges and hillsides

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density[2] moisture content and Unified Soil Classification[3]	Remarks (Includes use and earthquake stability)
Weathering irregular. In some places rock appears fresh, in others weathered and softened along joints to maximum depth observed, about 6 feet. Soil thin; maximum depth 2 feet	Can be moved with power equipment	Slope stability good. Stands in slopes of approximately ½:1 with minor sloughing of small fragments. Behavior as foundation unknown; probably good	Not determined	
Weathering extends to depths of more than 20 feet; characterized by lightening of color, widening of fractures; little softening of chert. Fresh rock rarely seen at surface. Soil 2 inches to 3 feet thick	Chert and shale can generally be moved with power equipment, but may need blasting; sandstone beds, especially near base of unit, usually require blasting	Stands in ½:1 cuts, but in places subject to slump and creep. **Diabase dikes generally hydrothermally altered to soft, clayey material; may carry water and cave in tunnels** (Page, 1950)	152 (chert); 2.5 percent; (3: 150–153; 1–5 percent)	**Slopes so steep that development may be difficult in places. Gas may be encountered when tunneling through this formation** (Page, 1950)
Weathering extensive, especially along joints; some weathered rock firm, most soft, iron-stained, clayey. Depth of weathering unknown, more than 10 feet where observed. Soil varies from a few inches to 3 feet in thickness, thicker in ravines	Can be moved with power equipment	Generally stands in 1:1 cuts with minor sloughing	137 (s) (sh); 3.6 percent; 143 (s) (fine ss); 1.1 percent	
Maximum depth of weathering unknown. Fresh rock rare at surface. Weathered rock soft. Soil 1–3 feet thick; may be as much as 15 feet thick in ravines	Can generally be moved with power equipment; some beds of massive sandstone may require blasting	Slope stability and foundation conditions vary with material, but generally good unless sheared and wet. In many places stands in 1:1 cuts, but may slide if wet and sheared	108 (weathered siltstone); 17 percent; 143 (weathered ss); 2.4 percent	
Depth of weathering more than 20 feet; weathered rock hard; unweathered material rare on surface. Soil sparse, largely rock fragments with minor organic material	Can be moved with power equipment	Slope stability generally good: stands in 1:1 slopes with minor sloughing. Foundation conditions unknown	156 (s) (shale); 1.9 percent	

Table 1.—*Generalized description of engineering properties of map units*—Continued

Map unit [1]	General lithologic description	Topographic form
Redwood Canyon Formation* (Kr)	Sandstone, fine- to medium-grained, yellowish-brown, in beds 6 inches to 12 feet thick; contains round dark concretions as much as 2 feet in diameter ("cannon balls"). Interbedded with clayey siltstone and very fine grained sandstone, medium-gray to dusky-yellow, in beds less than 1 inch to 1 foot thick. Rocks contain abundant flakes of organic material, display crenulated bedding. Some dark shale beds. Distinctive light-olive-gray and grayish-red Late Cretaceous foraminiferal shale at top of unit described separately by Case (1968), has been included with Redwood Canyon Formation in this report. Rocks deformed, faulted, fractured. Thickness unknown, probably between 1,700 to 2,000 feet; grades into underlying Shephard Creek Formation	Forms steep-sided ridges and canyons
Shephard Creek Formation* (Ks)	Shale, massive, olive-gray; also interbedded shale and fine sandstone. Massive shale in beds 20 feet or more in thickness. Faulted and fractured. No fossils found. Thickness unknown, may be as much as 1,500 feet. Grades into underlying Oakland Conglomerate	Forms valleys in most places because soft shales of formation are easily eroded
Oakland Conglomerate (Ko)	Conglomerate, with sandstone matrix, and sandstone, coarse- to medium-grained; minor amounts of shale. Pebbles and cobbles in conglomerate commonly 1—8 inches in diameter. Many clasts fractured. In places, sandstone contains shale fragments. Yellowish-brown, weathered; fresh rock not seen on surface. Sandstone and conglomerate in lenticular beds mostly 3-10 feet thick. Sheared and fractured. Appears nearly barren of fossils. Maximum thickness about 1,000 feet; gradational with underlying Joaquin Miller Formation	Generally caps a ridge
Joaquin Miller Formation* (Kjm)	Sandstone, fine- to medium-grained; shale; minor conglomerate. In places contains fragments of organic material. Yellowish-brown in outcrop, medium- to dark-gray on fresh surfaces. Massive to thin-bedded. Beds one-quarter of an inch to 10 feet thick. Sandstone beds increase in frequency and thickness toward top of unit. Shale near base distinguished by massive character from fissile Knoxville shale, from which it is separated by East Chabot fault. In places contorted, sheared, fractured; most joints iron-stained. Fossils rare. A crude approximation of the thickness of this deformed unit is 2,500 feet	Forms steep-sided ridges and canyons
Upper Cretaceous rocks, undivided (Ku)	Sandstone, fine- to coarse-grained, and shale. Light-gray when fresh, weathers yellowish-brown; fresh rock rarely seen on surface. Some massive sandstone beds, but predominantly alternating beds of sandstone and shale, without any visible distinguishing characteristics of other Cretaceous units. Sheared, fractured, and contorted. May include any of the Upper Cretaceous units and possibly unrecognized Eocene rocks. Fossils rare; part of a spirally-coiled ammonite of probable late Late Cretaceous age found in the south bore of the rapid transit tunnel. Thickness and stratigraphic relations unknown	Forms moderately steep-sided ridges and canyons
Serpentine (sp)	Serpentine, pale-greenish-yellow, green, bluish-gray, black, and pale-blue; generally soft and intensely sheared. May include small amounts of Leona Rhyolite and Franciscan Formation too small to show on the map.	Underlies moderately steep dissected hills and valleys

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density[2] moisture content and Unified Soil Classification[3]	Remarks (Includes use and earthquake stability)
Weathered to depth of more than 20 feet. Weathered rock generally firm, iron-stained; some soft, crumbly. Soil sparse, generally less than 1 foot thick	Can generally be moved with power equipment; may require blasting in places	Slope stability of sandstone generally good; stands in ½:1 cuts; foundation conditions good. **Slides common in dark shale beds and in red and green shale at top of unit**	140 (s) (ss); 2.4 percent (2: 137–143; 1.2–3.5 percent)	**Slopes in places so steep that development may be difficult**
Weathered along joints to maximum observed depth of 20 feet. Weathered shale soft, crumbly, clayey. Soil and colluvium generally 5 feet or more in thickness	Can generally be moved with power equipment	Slope stability and foundation conditions appear to be good for most of unit, but **slides common on steep slopes in southeast part of outcrop area** (see map)	156 (s) (shale); 2.3 percent	
Thoroughly weathered to maximum observed depth of 20 feet. Weathered sandstone firm to soft, slightly clayey; conglomerate pebbles hard. Soil generally sparse or lacking	Can generally be moved with power equipment	Slope stability and foundation conditions good	125 (s) (weathered ss); 2.3 percent	
Maximum depth of weathering unknown; may be as much as 50 feet in places; weathered rock firm to soft. Soil commonly a few inches to 3 feet thick, more in ravines	Can be moved with power equipment	Slope stability and foundation conditions generally good to fair; minor sloughing in cuts	150 (s) (ss); 1.5 percent; 115 (weathered ss); 12 percent (7: 105–122; 9–17 percent)	Age based on ammonite reported by Case (1963)
Depth of weathering may be 60 feet or more; some weathered rock firm; most soft, crumbly. Soil and colluvium may be as much as 25 feet thick in ravines	Can be moved with power equipment	Slope stability and foundation conditions good to poor. In places stands in 1:1 cuts, but **subject to both minor sloughing and major sliding. One of the largest slides in the Berkeley Hills—the Drury Road slide—involves rocks of this unit**	See individual Cretaceous units	**May squeeze in tunnels** where sheared
Serpentine intensely sheared, surface weathering difficult to detect. Soil sparse or absent, seldom as much as 1 foot thick	Can be moved with power equipment in most places; blasting seldom required	Slope stability and foundation conditions fair to poor; **intensely sheared serpentine may slide in slopes as low as 2:1**	159 (s); 0.1 percent; 104 (decomposed); 18 percent (19: 87–121; 8–30 percent)	**May squeeze in tunnels**

Map unit[1]	General lithologic description	Topographic form
Gabbro (gb)	Gabbro, medium-grained, greenish-gray; generally altered to mottled, pale-greenish-yellow, soft material	Outcrop area small; generally on moderately steep hillsides
Franciscan Formation Sandstone and shale (KJfs)	Sandstone (graywacke), fine- to coarse-grained, greenish-gray where fresh, yellowish-brown to yellowish-orange where weathered; and shale, olive-gray. Sandstone contains fragments of other rocks, particularly shale. Beds a few inches to 30 feet in thickness. Some sandstone massive, some in thin beds interbedded with shale. Sheared and fractured. Age of Franciscan rocks ranges from Late Jurassic to Late Cretaceous (Bailey, Irwin, and Jones, 1964); age in this area unknown. Thickness and stratigraphic relations unknown	Underlies moderately steep but generally rounded hills; sharply dissected by steep-walled valleys
Franciscan Formation (Continued) Chert and shale (KJfc)	Chert and shale, rhythmically bedded; generally grayish-red, yellowish-brown where weathered, some grayish-green. Cut by numerous quartz veins. Brittle, fractured, breaks into small pieces. Some chert beds as much as 5 feet thick, but more commonly one-half inch to 3 inches thick, separated by shale partings less than 1 inch in thickness. Thickness and stratigraphic relations obscure	Forms knobs and ridges
Greenstone (KJfg)	Fine-grained igneous rock, predominantly basalt; dense, hard, tough; amygdaloidal in places. Fresh rock dark greenish gray; yellowish brown, moderate brown, grayish brown where weathered. Cut by numerous fractures; commonly altered to soft chloritic material and highly weathered	Underlies moderately steep hills
Metamorphic rock (KJfm)	Includes silica-carbonate rock (see explanation), low-grade schists, and semischists. Quartzo-feldspathic schist derived from sandstone is common near Hayward fault. Abundant glaucophane schist apparently derived from and grades into siltstone, sandstone, and greenstone. Sheared, fractured, altered; many quartz veins; glaucophane coats many fracture surfaces. Color yellowish-brown, gray, light-brown; glaucophane-rich rocks grayish-blue. Unit includes small amounts of unmetamorphosed sandstone, greenstone, serpentine	Generally underlies steep hillsides: silica-carbonate rock forms prominent craggy knobs
Knoxville Formation (Jk)	Shale, olive-gray, fissile; sandstone, fine- to medium-grained, olive-gray; also includes pebble conglomerate in dark shale or sandstone matrix, minor concretionary limestone, and lignite. Some shale massive, some interbedded with sandstone. Shale contains abundant *Buchia piochii*. Includes younger *Buchia*-bearing marine sedimentary rocks described by Case (1968). Thickness and stratigraphic relations unknown	Generally forms valleys, because soft shales of formation are easily eroded

Table 1.—*Generalized description of engineering properties of map units*—Continued

Weathering and soil development	Workability	Slope stability and foundation conditions	Dry density[2] moisture content and Unified Soil Classification[3]	Remarks (Includes use and earthquake stability)
Much gabbro highly altered to very soft clayey material; thick black clayey expansive soil commonly developed on gabbro	Can be moved with power equipment in most places	Slope stability and foundation conditions poor in many places. Altered gabbro and overlying clayey soil subject to creep and sliding. Slides on knoll southeast of Mills College are in dark soil probably derived from weathered gabbro	174 (s); 0.4 percent; 156 (s) (weathered); 1.1 percent	
Weathered rock firm to soft. As much as 20 feet sand and sandy soil may be developed on this unit, especially on the soft, massive weathered sandstone in the Piedmont area	In places can be moved with power equipment; dense, massive sandstone may require blasting	Slope stability and foundation conditions in fresh rock good; subject to sliding where intensely sheared	162 (s) (ss); 0.5 percent; 119 (weathered ss); 12 percent; (6: 115–124; 8–15)	Sandstone has been quarried to provide crushed rock for fill and base course in this area
Weathering slight; weathered rock remains hard; maximum depth of weathering observed 12 feet; soil sparse, generally a few inches thick	Can be moved with power equipment where fractured; may require blasting in places	Slope stability and foundation conditions good; stands in 1:1 to ½:1 slopes with minor sloughing of small fragments	162 (s) (chert); 0.8 percent	In places has been used for fill
Unweathered greenstone seldom exposed on surface; highly weathered rock consists of crumbly rock fragments in clayey matrix. Soil less than 1 foot thick	Can be moved with power equipment	Slope stability fair. Stands in 1½:1 to 1:1 cuts. Foundation conditions good	171 (s); 1.0 percent (2: 162 – 181; 0.7–1.3 percent)	In places greenstone has been used for fill
Surface weathering of silica-carbonate rock slight; weathering of other metamorphic rocks varies; some very soft. Much silica-carbonate rock bare of soil; in places soil may be several feet thick	Generally can be moved with power equipment, although some silica-carbonate rock may require blasting	Slope stability and foundation conditions fair; generally stands in 1:1 cuts	181 (s) (glaucophane schist) 0.2 percent	
Depth of weathering irregular; may be 20 feet or more in places. Some weathered rock firm, most soft, clayey. Soil commonly 1–3 feet thick	Can be moved with power equipment	Slope stability and foundation conditions generally fair; minor sloughing in cuts	160 (s) (ss); 1.4 percent; 116 (weathered sh); 15 percent (3: 113–120; 13–19 percent)	May squeeze in tunnels where sheared

*For origin of names and detailed discussion of stratigraphy of these formations see Case (1963; 1968).

[1]All map units shown in the explanation are described in the text with the exception of the undivided Pinehurst Shale and Redwood Canyon Formation (TKpr) and landslide deposits (Qls), which generally consist of disturbed soil and (or) other earth material similar to that of the map unit shown surrounding the landslide on the map.

[2] Dry density (underlined) expressed in pounds per cu ft; based on one sample of fresh rock unless otherwise noted. Number of samples and range of dry density and moisture content given in parentheses; (12: 106–109; 17–20 percent). (s) indicates sample collected at the surface. Moisture content (percent) generally higher for subsurface samples of rocks than for those collected at the surface.

[3] Unified Soil Classification (letter symbol) given where applicable (U.S. Army, Corps of Engineers, 1953, "The Unified Soil Classification System": U.S. Army, Corps of Engineers, Tech. Memo. 3–357, v. 1–3).

Faulting:

The rocks of most of the above units have been compressed into northwest-trending folds and **cut by numerous faults.** These faults range in size from very small breaks a few inches in length with a displacement of less than an inch to faults of the Hayward fault zone, which extends from the northwest corner to the southeast corner of the quadrangle and for many miles farther in either direction. The Hayward fault zone is here considered as the zone within which surface breakage associated with earthquakes has been recorded during historic time and other movement has taken place recently enough in the geologic past that geologic and geomorphic features indicating recent movement are still clearly visible. The fault zone lies in a broad band of acute deformation, described by Lawson in the San Francisco folio (1914). A major fault, the Chabot fault (named by Robinson, 1956), which is older than the currently active Hayward fault zone and apparently inactive, lies east of the Hayward fault zone and subparallel to it, separating the Upper Cretaceous rocks to the northeast from the older rocks and the Leona Rhyolite[4] to the southwest. The Chabot fault and a number of other northwest-trending faults east of the Hayward fault zone are cut by north-trending predominantly right-lateral faults and lesser northeast-trending predominantly left-lateral faults, recognized by Case (1963).

The fractured rocks along any of the faults mentioned above may form passages for ground water, and cuts made across them may require draining; the soft sheared rocks are also subject to landsliding.

Surface outcrops, as well as exposures in the Bay Area Rapid Transit Berkeley Hills tunnel, show that a low-angle, eastward-dipping fault, thought to be an extension of the Chabot fault, separates Upper Cretaceous rocks from serpentine, rhyolite, and Knoxville shale north of Lake Temescal. A fault bounding the rhyolite on the east has been recognized in this area by Lawson (1914), Clark (1917) and Case (1963). It is presumed to be a reverse fault, with the Upper Cretaceous rocks thrust to the southwest over the younger Leona Rhyolite and the older rocks it has intruded.

Several thrust faults have been mapped north and east of the quadrangle; most of them dip to the southwest but some dip to the northeast (Ham, 1952; Lawson, 1914). Ham (1952) tentatively correlated the Moraga fault (Clark, 1933) with the Cull Creek thrust fault in the Las Trampas Ridge quadrangle; correlation of the Moraga fault with part of Ham's Miller Creek thrust fault was proposed later by Case (1963). Compression late in the Tertiary, and possibly in the very early Pleistocene, may have produced the northwest-trending folds and faults (with the exception of the Hayward fault) and two subordinate sets of wrench faults.

It has been suggested (Bailey, Irwin, and Jones, 1964) that the Knoxville and younger rocks have been thrust over the underlying Franciscan Formation in many parts of California. However, no evidence to either confirm or deny this hypothesis was found in the Oakland East quadrangle, as the volume of Franciscan and Knoxville rocks exposed is relatively small and the rocks are badly contorted; the age of the Franciscan Formation in this area is unknown; and the structure of the Franciscan and Knoxville is here further complicated by the intrusion of the Leona Rhyolite and recent movement along the Hayward fault zone.

The Hayward fault zone is the only one in the quadrangle along which movement is known to have taken place in historic time. It apparently represents the most recent episode of deformation in this area, and appears to cut the older Chabot fault; it is not itself cut by any north- or northwest-trending cross faults. **Severe earthquakes were caused by movement along faults within the Hayward fault zone in 1836 and 1868.** Surface ruptures along the fault zone were reported from San Pablo (to the northwest) to Mission San Jose (to the southeast) in 1836, and from Berkeley to Warm Springs (34 miles to the southeast) in 1868. Therefore, **the entire length of the Hayward fault zone in this quadrangle can be assumed to be active.** The exact lines of ground rupture in 1836 and 1868 within the quadrangle are unknown, except for reported breakage extending across the west side of the California School for the Deaf and Blind and northwestward between Prospect and Warring Streets, at the northwest corner of the quadrangle, and near Foothill Boulevard about a block southeast of 98th Street, near the southeast corner of the quadrangle (Radbruch, 1967). Recent right-lateral offset along faults within the zone is indicated by bends in Arroyo Viejo and Strawberry Creek. Movement along the faults has apparently been both vertical and horizontal, with the most recent movement right lateral; that is, if one looks across a fault, rocks on the far side of the fault appear to have moved to the right— with respect to those on the near side. In the Hayward fault zone, rocks on the northeast side of a fault appear to have moved southeast with respect to those on the southwest side.

The exact width of the Hayward fault zone is difficult to determine, but it is estimated to range from about 500 feet south of Lake Temescal to more than three-fourths of a mile near the southeast corner of the quadrangle. Fault traces shown along the zone are based on evidence that includes lines of springs, topographic sags or trenches, fault scarps, offset streams, fault contacts between rocks of different age and lithology; borings showing unusual depth to rock (interpreted as indicating erosion and alluvial deposition along a crushed zone); and extensive shearing of exposed rock. In many places the trace locations can only be inferred. The traces shown on the map should not be construed as indicating the only lines within the zone where movement has taken place in the past, nor are they necessarily lines where movement will take place in the future. Future movement within the Hayward fault zone may or may not follow the specific traces of faulting shown on the map.

Slow tectonic movement, or creep, is at present taking place at several locations along the Hayward fault zone, with resultant damage to manmade structures which cross the line of creep. Both the Claremont water tunnel and the drainage culvert under the University of California stadium have been damaged by this slow movement along a fault plane or band of shearing within the Hayward fault zone. It is not known whether creep is occurring along the fault zone elsewhere in this quadrangle, although discrepancies recently noted in rechecks of survey lines crossing the zone at 98th Avenue and at Lincoln Avenue may indicate right-lateral movement within the fault zone of approximately 0.1 to 0.15 foot in 10 years (Earl Buckingham, supervising Civil Engineer, City of Oakland, oral commun., 1966). Tectonic creep within the Hayward fault zone has been observed southeast of this area, in Fremont (Radbruch, Bonilla, and others, 1966). Cracking and offset of curbs seen to the northwest, in Richmond, and cracking, right-lateral offsets, and distortion of curbs, streets, and buildings observed to the southeast, in Hayward, are also the result of creep along the Hayward fault zone. **Structures which lie within or cross the Hayward fault zone may not only be damaged by sudden movement, offset, and rupture along a fault at the time of an earthquake originating in the fault zone, but may also be subject to constant strain and damage due to the opposite sides of faults within the zone continuously moving very slowly in opposite directions.**

[4] The age of the Leona Rhyolite was considered early or middle Pleistocene by Robinson (1953, 1956) on the basis of work in the Hayward quadrangle. He believed it to be post-Pliocene because it was little deformed in the area studied. Previous workers (Lawson, 1914; Clark, 1917) reported that the rhyolite had been much affected by faulting, and recent work by the author and others (Case, 1963) in the Oakland East quadrangle indicates much faulting and deformation of the rhyolite. Lawson tentatively dated the Leona Rhyolite as late Tertiary, probably Pliocene; Clark thought it was probably Pliocene or older. Deeply weathered Leona Rhyolite is overlain by deformed alluvial deposits of probable Irvingtonian (early Pleistocene) age. Its age is therefore considered to be Pliocene(?) in this report.

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