Preliminary geologic map emphasizing bedrock formations in Alameda County, California: A digital database

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Geologic Explanation

Introduction

This map database represents the integration of previously published and unpublished maps by several workers (see Sources of Data) and thousands of man-hours of new geologic mapping and field checking by the authors. The data are released in a preliminary digital form to provide an opportunity for regional planners, local, state, and federal agencies, teachers, consultants, and others interested in geologic data to have the new data long before a traditional paper map is published. The authors currently plan to produce a second version of the geologic map of Alameda County that would include subdivided Quaternary units and enhanced stratigraphic description and nomenclature, both as a digital product and as a traditional paper map. The timing of release of these products, and indeed whether they will be produced at all, depends on a variety of factors, including funding, outside author control.

Stratigraphy

Lithologic associations in Alameda County are divided into nine assemblages; I, II, and V - XI (Assemblages III and IV occur only in Contra Costa County). As defined in Graymer, Jones, and Brabb (1994), assemblages are large, fault - bounded blocks that contain a unique stratigraphic sequence. The stratigraphic sequence differs from that of neighboring assemblages by containing different rock units (e.g. the freshwater limestone (Tlp) in Assemblage VIII is missing from the other Assemblages), or by different stratigraphic relationship among similar rock units (e.g. the Orinda Formation (Tor) overlies the Claremont Chert (Tcc) in Assemblage I, whereas in Assemblage VI three other formations (To, Tt, and Tbr) totaling more than 500 meters thick lie between the Orinda and Claremont). These stratigraphic differences represent changes in depositional conditions in one or more large depositional basins. The current adjacent location of the different assemblages reflects the juxtaposition of different basins or parts of basins by large offsets along the faults that bound the assemblages.

In general, in Alameda County the Tertiary strata rest with angular unconformity on two complexly deformed Mesozoic rock complexes. One of these Mesozoic complexes is made up of: the Coast Range ophiolite, which includes serpentinite, gabbro, diabase, and basalt; keratophyre; and overlying Great Valley sequence. Within this complex in the Berkeley and Hayward areas the Great Valley sequence rests unconformably on ophiolite and volcanic rocks in several places. This complex represents the accreted and deformed remnants of Jurassic oceanic crust, and overlying arc volcanic rocks and a thick sequence of turbidites.

The second Mesozoic complex is the Franciscan complex, which is composed of weakly to strongly metamorphosed graywacke, argillite, limestone, basalt, serpentinite, chert, and other rocks. The rocks of the Franciscan complex in Alameda County were probably Jurassic oceanic crust and pelagic deposits, overlain by Late Jurassic to Late Cretaceous turbidites. Although Franciscan rocks are dominantly little metamorphosed, high-pressure, low-temperature metamorphic minerals are common in the Franciscan complex (Bailey, Irwin, and Jones, 1964), and the presence of high grade metamorphic blocks in sheared but relatively unmetamorphosed argillite matrix (Blake and Jones, 1974) reflects the complicated history of the Franciscan. The complex was subducted beneath the Coast Range ophiolite during Cretaceous time. Because the Novato Quarry terrane (Kfn) forms the lowest in the stacked sequence of terranes in the Bay Area (Wakabayashi, 1992) subduction took place, at least in part, after the Late Cretaceous (Campanian) deposition of the sandstone of the Novato Quarry terrane. Because of the subduction relationship, the contact between the two Mesozoic complexes is everywhere faulted (Bailey, Irwin, and Jones, 1964), and the Franciscan complex presumably underlies the entire county.

Tertiary rocks rest with angular unconformity on both Mesozoic complexes. In Assemblages IX and X, Tertiary rocks are on the Franciscan complex. The more usual situation is observed in all other assemblages, where Tertiary rocks overlie strata of the Great Valley sequence, although in most assemblages the contact is now faulted.

Three types of intrusive rocks have been mapped in Alameda County. One is a small stock of coarse-grained, crystalline granular, quartz diorite that intrudes the Coast Range ophiolite in the Cedar Mtn. quadrangle (KJqd). Another type occurs as small rhyolite plugs intruding Cretaceous and Tertiary strata in the Sunol area (Tsv). The third type forms a large body of fine grained quartz diorite in the Oakland area (Kfgm). These rocks are not included in any assemblage because of their intrusive nature.

Paleontology

Hundreds of fossil collections from Contra Costa County have been described in the literature during the past century, and thousands more have been collected by geologists working for petroleum companies. A partial list of references is provided by Freeberg (1990). Preparation of a digital database of this information is under way by scientists at the U.S. Geological Survey and the University of California, Berkeley.

Radiometric Ages

A compilation of the radiometric ages of rocks in Contra Costa and other counties south of latitude 38 degrees is provided by Lindquist and Morganthaler (1991). Additional data are provided by Wright (1974), Sarna-Wojcicki (1976, and written communication, 1990), Sarna-Wojcicki and others (1979), and Curtis (1989).

Structure

The faults of Alameda County are characterized by both strike-slip and dip-slip components of displacement. There are four major fault systems that display large right-lateral offsets, the Hayward, the Stonybrook-Palomares-Miller Creek-Moraga, the Calaveras, and the Greenville. These fault systems trend roughly N30W. Most of these fault systems include many fault strands in a broad (as much as 10 km wide) zone. Offset is distributed on the various faults in the zones, and the locus of fault movement associated with a fault zone has changed through geologic time (see Graymer, Jones, and Brabb, 1995, for a description of the Hayward fault zone, Montgomery and Jones, 1992, for a description of part of the Calaveras fault zone). All of the fault systems have strands which have been active during Quaternary time and some, such as the Hayward, Calaveras, and Greenville, have generated historic earthquakes or display active creep (Lienkaemper, 1992, Radbruch-Hall, 1974, Herd, 1977a, 1977b and 1978, Cockerham and others, 1980). As much as 170 km of right slip has been taken up by the Hayward, Stonybrook-Palomares-Miller Creek-Moraga, and Calaveras fault systems since 8 Ma (McLaughlin and others, 1996). Of this, about 43 km was probably taken up by the Hayward fault system (Fox and others, 1985). These fault systems also form most of the boundaries of the assemblages. The juxtaposition of rocks with different stratigraphic histories across these faults lends support to the idea of large offsets. Note, however, that the Hayward fault system does not form an assemblage boundary.

In addition to strike-slip faults, faults in Alameda County can be divided into three categories based on the fault-normal component of displacement and orientation. The first of these categories comprises transpressional faults within the major strike-slip fault zones. These faults trend roughly parallel to the strike-slip faults discussed above, but display a large component of thrust or reverse displacement. Examples of this type of fault are the Mission, Warm Springs, and Arroyo Aguague faults in the Hayward fault zone. The compressional component of deformation on these faults is caused by the small but important component of plate motion at right angles to the trend of the strike-slip fault zones (Jones and others, 1995), as well as fault-normal compression related to changes in trend of the strike-slip fault zone (Andrews and others, 1993). The transpressional faults also have a component of strike-slip offset, although the amount of offset is for the most part undetermined.

The second category of fault consists of thrust and reverse faults that trend at high angle to the strike-slip fault zones (N60E-N60W). Examples of this type include the Verona and Williams faults. These faults reflect compression directed parallel to plate motion.

The third category of fault with a fault-normal component of offset in Alameda County comprises transtensional faults, or faults with oblique normal offset. These faults occur within the major strike-slip fault zones (trending about N30W). The best example of this type is the Chabot fault. The transtensional faults reflect deformation during a period (late Pliocene to early Pleistocene, see Graymer, Jones, and Brabb, 1995) when regional stress contained a small but significant fault-normal extensional component.

Both types of faults with compressional deformation underwent late Quaternary deformation (Graymer, Jones, and Brabb, 1995, Andrews and others, 1993, Herd and Brabb, 1980), but the amount of seismic hazard that they represent remains to be determined. The transtensional faults, on the other hand, appear to have ceased moving for the most part by late Pleistocene time.

Folds in Alameda county can be divided into three categories based on axial trend and style of deformation. The first category includes tight folds and overturned folds with inclined axial planes whose axes trend obliquely to the major strike-slip fault zones (about N60W). These folds were probably caused by the same component of regional stress that formed the strike-slip faults and the thrust and reverse faults of the second category discussed above. These folds occur in the north-central part of the county, in the region between the Calaveras and Moraga-Miller Creek-Palomares faults.

The second category of fold contains tight, upright folds whose axes strike roughly parallel to the major strike-slip faults (about N30W). These folds must have been formed by a component of regional compression perpendicular to the strike-slip faults (Jones and others, 1995). For the most part, only synclines of this category are preserved, anticlines having been disrupted by faulting of the first category discussed above. Folding of this type is present in the western part of the county between the Hayward and Moraga-Miller Creek-Palomares-Stonybrook faults and on either side of the Calaveras fault in the south part of the county.

The third category of fold in Alameda County includes the broad anticline and related smaller folds of the Altamont anticline in the northeastern part of the county, east of the Greenville fault. This fold trends roughly paralell to the major strike-slip faults, and therefore must be caused by regional compression perpendicular to the strike-slip faults, in a manner similar to that of the second category of folds.

Preserved folds in Alameda County for the most part formed in late Miocene or later time, as late Miocene strata are involved in the folds. Pre-late Miocene folding undoubtably occurred, associated with subduction of the Franciscan complex beneath the Coast Range ophiolite and subsequent deformation associated with the unconformity at the base of the Tertiary sequence. These folds have been totally disrupted, being best preserved as homoclinal sequences of Cretaceous strata. The youngest folding must postdate the Pliocene and Pleistocene deposition of the Livermore gravels (QTl), as those strata are folded in at least one area. Late Pleistocene strata have not been observed to be folded, but are tilted and uplifted in several places in the west part of the county.

Description of Units

Surficial deposits (Quaternary). Overlying all assemblages:

Qar	Artificial deposits (Holocene). Clay, silt, sand, gravel, cobbles, and boulders used to construct dams.
Qu	Surficial deposits, undivided (Holocene and Pleistocene).
Qls	Landslide deposits (Holocene and Pleistocene). Landslides are intentionally omitted from most of this map because they are so numerous they would conceal much of the information on bedrock geology. Only a few of the large landslide areas are shown. For more comprehensive reports of landslides in the area, see Nilsen and others (1979)
Qt	Terrace deposits (Holocene(?) and Pleistocene). Clay, silt, sand, gravel, and cobbles forming geomorphically distinct terraces. This unit is only differentiated in a few places.
Qoa	Older alluvium (Pleistocene). Alluvial clay, silt, sand, gravel, and cobbles. This unit is only differentiated in a few places.

Tertiary Intrusive Rocks

Tsv	Silicic volcanic rocks (Miocene or younger). Rhyolite and dacite plugs, dikes, and sills. The mapped outcrop of these rocks is limited to a small area north and south of Sunol.

Mesozoic Intrusive Rocks

KJqd	Quartz diorite (Jurassic or younger). Coarse-grained, crystalline-granular quartz diorite. Feldspars are more or less altered. Outcrop is limited to one small stock (several hundred meters in diameter) near Cedar Mountain in the Diablo Range.

Rocks that presumably underlie the entire area

KJf	Undivided Franciscan complex (Jurassic and Cretaceous). More or less sheared and metamorphosed graywacke, shale, mafic volcanic rock, chert, ultramafic rock, limestone, and conglomerate. Highly sheared sandstone and shale forms the matrix of a melange containing blocks of many rock types, including sandstone, chert, greenstone, blueschist, serpentinite, eclogite, and limestone. Locally divided into:

Kfn	Novato Quarry terrane of Blake and others (1984) (late Cretaceous). Distinctly bedded to massive, fine- to coarse-grained, mica bearing, lithic wacke. Where distinctly bedded, sandstone beds are about one meter thick, and siltstone interbeds are a few centimeters thick. Sedimentary structures are well preserved. At the type area in Marin County, fossils of Campanian age have been discovered, but none have yet been collected in Alameda County. In north Oakland, the sandstone is associated with a one kilometer diameter body of fine-grained quartz diorite (Kfgm). Although the margins of the intrusive body are pervasively sheared, the diorite was probably originally intruded into the sandstone, judging from the extensive hydrothermal alteration in many parts of the sandstone outcrop area.
KJfs	Franciscan sandstone, undivided (Late Jurassic to Late Cretaceous). Undivided graywacke and meta-graywacke.
KJfm	Franciscan melange (Late Jurassic and/or Early Cretaceous). Sheared black argillite, graywacke sandstone, and minor green tuff, containing blocks and lenses of meta-graywacke (fs), chert (fc), shale, metachert, serpentinite (sp), greenstone (fg), amphibolite, tuff, eclogite, quartz schist, greenschist, basalt, marble (fl), conglomerate, and glaucophane schist. Blocks range in size from pebbles to several hundred meters in length. Only some of the largest blocks are shown on the map.
KJfe	Eylar Mountain terrane of Crawford (1976) (Late Jurassic and/or Early Cretaceous). More or less sheared and metamorphosed mudstone, siltstone, graywacke, conglomerate, chert, and minor pillow basalt. Mudstone is almost everywhere metamorphosed to slate or chlorite phyllite. Sedimentary structures are well preserved locally. Graywacke ranges from massive, coarse-grained and conglomeratic sandstone to distinctly bedded, medium- and coarse-grained sandstone. Although most Eylar Mountain terrane graywacke in Alameda County is little foliated, locally it displays foliation as pronounced as textural zone 2A. The depositional contact of clastic sedimentary rocks on chert is preserved in several locations. Chert is mostly thin-bedded, red and green, more or less recrystallized,

containing a few well preserved radiolarians locally. In some places chert has been altered to white meta-chert. Widely dispersed, small outcrops of basalt are distinctly pillowed, amygduloidal, and lacking phenocrysts. In many locations the basalt is converted to bright green meta-basalt.

KJfg	Franciscan greenstone (Late Jurassic and/or Early Cretaceous). More or less metamorphosed basalt, generally pervasively altered. Pillow structure is well preserved locally. In places the basalt is amygduloidal.

Assemblage I

Tbp	Bald Peak Basalt (late Miocene). Massive basalt flows. Ar/Ar ages of 8.37+0.2 and 8.46+0.2 Ma have been obtained from rocks of this unit (Curtis, 1989).
Tst	Siesta Formation (late Miocene). Non-marine siltstone, claystone, sandstone, and minor limestone.
Tmb	Moraga Formation (late Miocene). Basalt and andesite flows, minor rhyolite tuff. Ar/Ar ages obtained from rocks of this unit range from 9.0+0.3 to 10.2+0.5 Ma (Curtis, 1989). Interflow sedimentary rocks (Tmbs) are mapped locally.
Tor	Orinda Formation (late Miocene). Distinctly to indistinctly bedded, non-marine, pebble to boulder conglomerate, conglomeratic sandstone, coarse- to medium-grained lithic sandstone, and green and red siltstone and mudstone. Conglomerate clasts are sub-angular to well rounded, and contain a high percentage of detritus derived from the Franciscan complex.
Tcc	Claremont Chert (middle to late Miocene). Laminated and bedded chert, minor brown shale and white sandstone. Chert occurs as distinct, massive to laminated, gray or brown beds as much as 10 cm thick with thin shale partings. Distinctive black, laminated chert occurs locally in the Berkeley Hills. Interbedded sandstone (Tccs) mapped locally.
Tush	Unnamed gray mudstone (early Miocene).

Tsm Unnamed glauconitic mudstone (Oligocene(?) and Miocene). Brown mudstone is interbedded with sandy mudstone containing prominent glauconite grains. Both rock types locally contain phosphate nodules up to one centimeter in diameter. Brown siltstone and fine-grained sandstone (Tsms) are locally interbedded. The unit is bounded below and above by faults. It was mapped as Sobrante(?) Formation by Radbruch (1969).

Tes Unnamed mudstone (Eocene). Green and maroon, foraminifer rich mudstone, locally interbedded with hard, distinctly bedded, mica bearing, quartz sandstone. This unit is bounded above and below by faults.

Ta Unnamed glauconitic sandstone (Paleocene). Coarse-grained, green, glauconite rich, lithic sandstone with well preserved coral fossils. Locally interbedded with gray mudstone and hard, fine-grained, mica bearing quartz sandstone. Outcrop of this unit is restricted to a small, fault - bounded area in the Oakland hills.

Assemblage II -

QTl Livermore gravels (Pliocene and Pleistocene). Poorly to moderately consolidated, indistinctly bedded, cobble conglomerate, gray conglomeratic sandstone, and gray coarse-grained sandstone. Also includes some siltstone and claystone. Clasts contain mostly graywacke, chert, and metamorphic rocks probably derived from the Franciscan complex.

Mullholland Formation of Ham (1952) (late Miocene and Pliocene). Divided into upper and lower members, outcrop of the upper member is restricted to Contra Costa County.

Tmll Lower member; sandstone and mudstone. Includes sandstone marker beds (Tmls), mapped locally.

Tus Unnamed sedimentary and volcanic rocks (late Miocene). Includes conglomerate, sandstone, siltstone, and limestone (Tusl) mapped locally.

Tn	Neroly Sandstone (late Miocene). Blue, gray, and brown, volcanic - rich, shallow marine sandstone, with minor shale, siltstone, tuff, and andesitic conglomerate.
Tbr	Briones Formation (middle and late Miocene). Sandstone, siltstone, conglomerate and shell breccia. The Briones Formation in this assemblage contains a tuffaceous layer with a K/Ar age of 14.5+0.4 Ma (Lindquist and Morganthaler, 1991).
	Divided locally into:
Tbi	I member of Wagner (1978). Massive feldspathic sandstone.
Tbg	G member of Wagner (1978). Massive sandstone, pebble conglomerate, and shell breccia. Locally subdivided into:
Tbgc	Conglomerate.
Tbgl	Limestone.
Tbf	F member of Wagner (1978). Fine -grained feldspathic sandstone and locally prominent brown shale.
Tbe	E member of Wagner (1978). Medium - grained sandstone with abundant shell breccia beds; lithologically similar to unit Tbg.
Tbd	D member of Wagner (1978). Massive, medium - grained sandstone with local conglomerate layers.
Tro	Rodeo Shale, Hambre Sandstone, Tice Shale, and Oursan Sandstone, undivided (middle Miocene)
Tr	Rodeo Shale (middle Miocene). Brown siliceous shale with yellow carbonate concretions.
Th	Hambre Sandstone (middle Miocene). Massive, medium - grained sandstone, weathers brown.
Tt	Tice Shale (middle Miocene). Brown siliceous shale
To	Oursan Sandstone (middle Miocene). Greenish gray, medium - grained sandstone with calcareous concretions.
Tcs	Claremont Shale (middle Miocene). Brown siliceous shale with yellow carbonate concretions and minor interbedded chert. Also includes interbeds of light gray and white quartz sandstone and siltstone (Tccs) mapped locally.

Ts	Sobrante Sandstone (middle Miocene). Massive white, medium - grained calcareous sandstone.
	Great Valley sequence (Cretaceous)
Ku	Unnamed sedimentary rocks (Late Cretaceous, Cenomanian and Turonian). Massive to distinctly bedded, biotite bearing, brown weathering, coarse- to fine-grained graywacke and lithic wacke, siltstone, and mudstone. Also contains lenses of pebble to boulder conglomerate (Kc), mapped locally.

Assemblage V -

QTl	Livermore gravels (Pliocene and Pleistocene). Poorly to moderately consolidated, indistinctly bedded, cobble conglomerate, gray conglomeratic sandstone, and gray coarse-grained sandstone. Also includes some siltstone and claystone. Clasts contain mostly graywacke, chert, and metamorphic rocks probably derived from the Franciscan complex.
Tgvt	Green Valley and Tassajara Formations of Conduit (1938), undivided (Pliocene and Miocene). Non - marine sandstone, siltstone, and conglomerate. A 5 meter thick tuff marker bed (Tgvtt) is mapped locally. This tuff is correlated with the Pinole Tuff of Assemblage II, which has a K/Ar age of 5.2+0.1 Ma. Another tuff in this unit has a K/Ar age of 4.0+1.0 Ma, while a tuff layer lower in the unit has been correlated with the Roblar tuff in Sonoma County which has K/Ar ages of 5.7+0.5 Ma and 6.1+0.1 Ma (Sarna-Wojcicki, 1976).
Tn	Neroly Sandstone (late Miocene). Brown, massive, marine sandstone with abundant clasts of volcanic rocks.
Tc	Cierbo Sandstone (late Miocene). Light - gray, massive sandstone with marine fossils. Contains sandstone and conglomerate near the base.
Kss	Unnamed sandstone (Late Cretaceous, Campanian and Maastrichtian). Massive to distinctly bedded, coarse- to fine-grained, biotite- and quartz-bearing lithic wacke and siltstone. Also includes lenses of pebble to cobble conglomerate and minor amounts of mudstone.

Kslt	Unnamed siltstone (Late Cretaceous, Campanian). Siltstone interbedded with minor shale, claystone, and sandstone.
Ku	Unnamed mudstone (Late Cretaceous, Cenomanian and Turonian). Massive to distinctly bedded, gray mudstone and fine siltstone. Also includes minor amounts of biotite- and quartz-bearing lithic wacke.
	Coast Range ophiolite (Jurassic). Consists of:
Jb	Massive basalt and diabase
Jgb	Gabbro and diabase
sp	Serpentinite

Assemblage VI

Tol	Oro Loma Formation of Briggs (1953) (Pliocene). Poorly consolidated reddish silt, sand, and gravel.
Tn	Neroly Sandstone (late Miocene). Blue sandstone, minor siltstone, shale, tuff, and andesite-pebble conglomerate.
Tc	Cierbo Sandstone (late Miocene). Distinctly thick-bedded, fine- to coarse-grained, moderately consolidated, light gray to white quartz sandstone with minor lithic and biotite grains. Locally the unit contains beds of highly fossiliferous, coarse-grained sandstone. The fossils are predominantly of the genus *Ostrea*. The unit also contains minor pebble conglomerate locally.
	Great Valley sequence (Cretaceous). In Alameda County, the sequence in this Assemblage consists of:
Kel	Unit E, lower member (Late Cretaceous). Light gray to gray-brown, foraminifer bearing siltstone and mudstone. Reddish-brown weathering and iron concretions are conspicuous.
Kd	Unit D - Sandstone (Late Cretaceous). Medium to coarse grained, light gray, clean sandstone. Grains include quartz,

feldspar, and biotite. Spherical weathering is common. In places the clean sandstone is interbedded with fine to medium grained, biotite and muscovite bearing wacke with mudstone rip-up clasts. Sandstone beds form packages up to 10 meters thick with 1 to 2 meters of interbedded siltstone and mudstone. The unit also locally includes:

Kds Shale member. Brown to gray, micaceous mudstone and brown micaceous siltstone. One layer is dark gray-brown to dark gray, massive, foraminifer rich, siliceous mudstone.

Unit C - Sandstone and shale (Late Cretaceous). Consists of:

Kcu Upper member, shale and siltstone. Also includes sandstone interbeds (Kcus) mapped locally.

Kcm Middle member. Medium grained, brown to gray, biotite rich wacke with some mudstone rip-up clasts. Contains interbeds of siltstone, shale, and conglomerate.

Kcl Lower member, shale and siltstone with minor sandstone. Also includes sandstone interbeds (Kcls) mapped locally.

Kbsh Unit B, shale member (Late Cretaceous). Olive-gray mudstone and micaceous siltstone. Forms reddish soil. Contains sandstone interbeds.

Assemblage VII

QTi Irvington Gravels of Savage (1951) (Pliocene(?) and Pleistocene). Poorly to well consolidated, distinctly bedded pebbles and cobbles, gray pebbly sand, and gray, coarse-grained, cross-bedded sand. Cobbles and pebbles are well- to sub-rounded, and as much as 25 cm in diameter, and consist of about 60 percent micaceous sandstone, 35 percent metamorphic and volcanic rocks and chert probably derived from the Franciscan complex, and 5 percent black laminated chert and cherty shale derived from the Claremont Formation. A large suite of early Pleistocene vertebrate fossils from this unit was described by Savage (1951).

QTl Livermore Gravels (Pliocene and Pleistocene). Poorly to moderately consolidated, indistinctly bedded pebbles and cobbles, gray pebble and cobble bearing sand, and gray, coarse-grained sand. This unit is similar to the Irvington

	Gravels, but lacks clasts derived from the Claremont Formation.
Tv	Unnamed volcanic rocks (late Miocene and/or Pliocene). White to gray rhyolite, dacite, and andesite tuff, breccia, and volcanoclastic conglomerate, and massive, black and red, plagioclase, pyroxene, and olivine porphyry basalt.
Tor	Orinda Formation (late Miocene). Distinctly to indistinctly bedded pebble to boulder conglomerate, conglomeratic sandstone, and coarse- to medium-grained lithic sandstone. Conglomerate clasts include red, green, and black chert, quartzite, greenstone, diorite, lithic sandstone, and minor andesite. The formation contains interlayered plagioclase porphyry dacite (Torv), mapped locally.
Tbr	Briones Formation (late Miocene). Distinctly to indistinctly bedded, gray and white, fine- to coarse-grained, quartz-lithic sandstone and shell breccia. Pebble and cobble conglomerate lenses are present in a few places. Conglomerate clasts include black and red chert, quartzite, andesite, argillite, siltstone, basalt, felsic tuff, and quartz. The formation also includes distinct, thin interbeds of hard white to light gray sandstone and gray siltstone near its base.
Tt	Tice Shale (middle or late Miocene). Distinctly bedded, dark brown, gray, and tan siltstone, mudstone, and siliceous shale. The shale contains numerous fish scales and poorly preserved foraminifers in places. Bright orange weathering lenses of tan dolomite are present in the shale locally.
To	Oursan Sandstone (middle or late Miocene). Distinctly bedded black mudstone, and foraminifer bearing, brown to tan siltstone and fine-grained sandstone. The unit also contains large (as much as 2 meters long) lenses of bright orange weathering, tan dolomite, similar to those found in the overlying Tice Shale. The Oursan Sandstone in Assemblage VII occupies the same stratigraphic position as the type Oursan in Contra Costa County, but differs from the type in color, presence of dolomite lenses, and absence of invertebrate fossils.

	Claremont Formation (middle and/or late Miocene). Divided informally into:
Tcs	Chert and siliceous shale member. Distinctly bedded, massive, gray and black, laminated chert, and dark brown to gray, finely laminated siliceous shale. Some of the shale contains poorly preserved fish scales and foraminifers. Bright orange weathering lenses of tan dolomite occur locally. This unit is distinguished from the overlying Tice Shale by the presence of chert beds and lack of non-siliceous mudstone.
Tccs	Sandstone and siltstone member. Light brown, gray, and white, fine-grained quartz sandstone and siltstone.
Ts	Sobrante Sandstone (middle Miocene). White, fine- to medium-grained quartz sandstone.
Tsh	Unnamed shale, sandstone, chert and dolomite (early Miocene). Massive, orange weathering, medium-grained quartz sandstone, interbedded laminated gray chert and dolomite, dark gray, concretionary siltstone and mudstone, and conglomerate. Conglomerate contains pebbles of varicolored chert, andesite, and quartzite in a dolomite matrix.
	Tolman Formation of Hall (1958) (Eocene?). Divided into:
Ttls	Gray, algal limestone, interbedded with white, calcium carbonate matrix pebble conglomerate, and clean, medium- to coarse-grained sandstone with calcite cement. Sandstone grains include quartz, feldspar, and lithic fragments, and in places include a large percentage of algal debris. Sandstone weathers orange.
Tts	Dark gray to dark greenish-gray, indistinctly bedded, glauconite bearing, medium- to coarse-grained lithic sandstone. Locally interbedded with minor amounts of fine-grained sandstone and siltstone.
	The Tolman Formation is bounded above by a fault. It overlies Redwood Creek Formation sandstone and Pinehurst shale along an obscured contact.

Tps	Unnamed siltstone and sandstone (Paleocene). Dark gray, indistinctly to distinctly bedded siltstone, claystone, and shale, in places containing abundant, poorly preserved foraminifers. Grades downward into indistinctly bedded, dark brown to green, coarse-grained, glauconite bearing lithic sandstone.
	Great Valley sequence (Late Jurassic to Late Cretaceous). In Assemblage VII, the sequence consists of:
Kp	Pinehurst Shale (Late Cretaceous, Campanian). Siliceous shale with interbedded sandstone and siltstone. This unit also includes maroon, concretionary shale at base. This formation was originally considered to be Paleocene, but it contains foraminifers and radiolarians of Campanian age in its type area and throughout its outcrop extent.
Kr	Redwood Canyon Formation (Late Cretaceous, Campanian). Distinctly bedded, cross-bedded to massive, thick beds of fine- to coarse grained, biotite and quartz-rich wacke and thin interbeds of mica rich siltstone. This formation is conformably overlain by the Pinehurst Shale.
Ksc	Shephard Creek Formation (Late Cretaceous, Campanian). Distinctly bedded mudstone and shale, mica rich siltstone, and thin beds of fine-grained, mica-rich wacke. This formation is conformably overlain by the Redwood Canyon Formation.
Kcv	Unnamed sandstone, conglomerate, and shale of the Castro Valley area (Late Cretaceous, Turonian and younger(?)). The lower part of the unit is composed of distinctly bedded, mica bearing siltstone, fine-grained mica bearing wacke, shale, and, locally, one thin pebble conglomerate layer. The middle part of the unit is composed of distinct, thick beds of medium- to coarse-grained, mica-rich wacke and pebble to cobble conglomerate. The middle part grades upward into the upper part, which is composed of distinctly to indistinctly bedded, medium- to fine-grained, mica-rich wacke and siltstone. This unit is bounded above and below by faults.

Ko	Oakland Sandstone (Late Cretaceous, Cenomanian and/or Turonian). Massive, medium- to coarse-grained, biotite and quartz-rich wacke and prominent interbedded lenses of pebble to cobble conglomerate. Conglomerate clasts are distinguished by a large amount of silicic volcanic detritus, including quartz porphyry rhyolite. Conglomerate composes as much as fifty percent of the unit in the Oakland hills, but it becomes a progressively smaller portion of the unit to the south.
Kjm	Joaquin Miller Formation (Late Cretaceous, Cenomanian). Thinly bedded shale with minor sandstone. The shale grades into thinly bedded, fine-grained sandstone near the top of the formation. The contact with the overlying Oakland Sandstone is gradational.
Ksh	Unnamed shale (Early Cretaceous)
Ks	Unnamed sandstone and shale (Cretaceous). Distinctly bedded, gray to white, hard, in places cross-bedded, mica bearing, coarse- to fine grained sandstone, siltstone, and shale. Sandstone is granitic (quartz, feldspar, and biotite grains) or lithic, and forms discontinuous outcrops on ridges and uplands. Siltstone and shale outcrop only in canyons.
KJk	Knoxville Formation (Late Jurassic and Early Cretaceous). Mainly dark, greenish-gray silt or clay shale with thin sandstone interbeds. Locally includes thick pebble to cobble conglomerate beds in its lower part (KJkc). Locally at the base the formation contains beds of angular, volcanoclastic breccia (KJkv) derived from underlying ophiolite and silicic volcanic rocks. The depositional contact of Knoxville Formation on ophiolite and silicic volcanic rocks can be observed at several locations in Alameda County.

Volcanic Rocks overlying Coast Range ophiolite

Jsv	Keratophyre and quartz keratophyre (Late Jurassic). Highly altered intermediate and silicic volcanic and hypabyssal rocks. Feldspars are almost all replaced by albite. In some places, closely associated with (intruded

into?) basalt. This unit includes rocks previously mapped as Leona and Northbrae rhyolite, erroneously considered to be Tertiary (Dibblee, 1980, 1981, Radbruch and Case, 1967, Robinson, 1956). Recent biostratigraphic and isotopic analyses have revealed the Jurassic age of these rocks (Jones and Curtis, 1991). These rocks are probably the altered remnants of a volcanic arc deposited on ophiolite during the Jurassic Period.

Coast Range ophiolite (Jurassic). Consists of:

Jpb	Pillow basalt, basalt breccia, and minor diabase.
Jb	Massive basalt and diabase.
Jgb	Gabbro
sp	Serpentinite. Mainly sheared serpentinite, but also includes massive serpentinized harzburgite. In places, pervasively altered to silica carbonate rock.

Assemblage VIII

QTl	Livermore Gravels (Pliocene and Pleistocene). Poorly to moderately consolidated, indistinctly bedded cobbles and pebbles, gray pebble and cobble bearing sand, and gray, coarse-grained sand.
Tlp	Unnamed freshwater limestone (Pliocene(?))
Tss	Unnamed sandstone (late Miocene and/or Pliocene). Distinctly to indistinctly bedded, poorly consolidated, white, fine-grained sandstone and siltstone, interbedded with diatomite, gray diatomaceous chert, and tan, freshwater limestone.
Tbr	Briones Formation (late Miocene). Distinctly to indistinctly bedded, gray and white, fine- to coarse-grained, quartz-lithic sandstone and shell breccia. Pebble and cobble conglomerate lenses are present in a few places. Conglomerate clasts include black and red chert, quartzite, andesite, argillite, siltstone, basalt, felsic tuff, and quartz. Shell breccia beds form erosion resistant ridges and peaks.
Tt	Tice Shale (late Miocene). Thin, distinct beds of dark brown shale and claystone. Weathers reddish brown.

To	Oursan Sandstone (late Miocene). Indistinctly bedded, fine- to medium-grained, olive sandstone, siltstone and claystone.
Ks	Unnamed sandstone and shale (Cretaceous).

Assemblage IX

Tbr	Briones Formation (late Miocene). Distinctly to indistinctly bedded, gray and white, fine- to coarse-grained, quartz-lithic sandstone and shell breccia. Pebble and cobble conglomerate lenses are present in a few places. Conglomerate clasts include black and red chert, quartzite, andesite, argillite, siltstone, basalt, felsic tuff, and quartz. Shell breccia beds form erosion resistant ridges and peaks.
Tt	Tice Shale (late Miocene). Thin, distinct beds of dark brown shale and claystone. Weathers reddish brown.
To	Oursan Sandstone (late Miocene). Indistinctly bedded, fine- to medium-grained, olive sandstone, siltstone and claystone. Pebble and shell fragment conglomerate is present near the base.
Tcc	Claremont Formation (middle and/or late Miocene). Distinctly bedded, massive, gray and black, laminated chert, and dark brown, black, or gray, finely laminated siliceous shale. Some of the shale contains poorly preserved fish scales and foraminifers. The unit also contains locally interbedded, light colored, calcareous sandstone, and 0.3 to 2 meter thick beds of limestone.
Ttem	Temblor Sandstone (middle Miocene). Thickly and indistinctly bedded, olive, fine- to coarse-grained sandstone and pebble conglomerate. Vertebrate and invertebrate fossils are common in many parts of this unit. The Temblor Sandstone unconformably lies on the Franciscan melange in this Assemblage.

Assemblage X

Tn	Neroly Sandstone (late Miocene). Medium-grained, blue, quartz, feldspar, and mica-bearing sandstone. This unit also

contains green, glauconite bearing, pebble conglomerate layers, mapped locally (Tnc).

Tbr Briones Formation (late Miocene). Distinctly to indistinctly bedded, gray and white, fine- to coarse-grained, quartz-lithic sandstone and shell breccia. Pebble and cobble conglomerate lenses are present in a few places. Conglomerate clasts include black and red chert, quartzite, andesite, argillite, siltstone, basalt, felsic tuff, and quartz. Shell breccia beds form erosion resistant ridges and peaks. This unit unconformably overlies Franciscan greenstone (KJfg) and melange (KJfm) in the east part of this Assemblage.

Assemblage XI

Tol Oro Loma Formation of Briggs (1953) (Pliocene). Poorly consolidated reddish silt, sand, and gravel.

Tn Neroly Sandstone (late Miocene). Blue sandstone, minor siltstone, shale, tuff, and andesite rich pebble and boulder conglomerate.

Tc Cierbo Sandstone (late Miocene). Distinctly thick-bedded, fine- to coarse-grained, moderately consolidated, light gray to white quartz sandstone with minor lithic and biotite grains. Locally the unit contains beds of highly fossiliferous, coarse-grained sandstone. The fossils are predominantly of the genus *Ostrea*. The unit also contains minor pebble conglomerate locally.

Tte Tesla Formation (Eocene). White and buff sandstone, siltstone, anauxitic claystone, and carbonaceous shale, with minor coal.

Great Valley sequence (Cretaceous).

Ksuh Unnamed shale (Late Cretaceous).

Ksus Unnamed sandstone (Late Cretaceous).

Ksu Unnamed sandstone and shale (Late Cretaceous).

Kkh Horsetown Formation of Huey (1948) (Early Cretaceous). Dark shale and thin beds of sandstone.

Sources of Data

1. New mapping by the authors, 1992-1995 using maps and information in the following reports as a foundation: Blake and others (1974), Dresen (1979), Whiteley (1978), Lienkaemper (1992), Turnbull (1976), Herd (1978), Hall (1958), Robinson (1956), Radbruch (1969), Case (1968), Radbruch (1957), California Division of Mines and Geology (1972-1989), Dibblee (1972, 1973, 1980b, d-h, l, 1981a-b), Estes and others (1983), Liniecki (1983), Graham and others (1983), Hill (1983), Bauder (1975), Bauder and Liou (1978), Cotton (1972), Crawford (1976), Gokce (1978), Perkins (1974), and Aarons (1958).

2. Wagner (1978), Haltenhoff (1978), Dibblee (1980e-f, h), California Division of Mines and Geology (1982c), and some new mapping by the authors (1992-95).

3. Dibblee (1980i), Herd (1977a), California Division of Mines and Geology (1982d), and some new mapping by the authors (1995).

4. Dibblee (1980m)

5. Sonneman and Switzer (unpublished maps, EXXON, 1961-62), Sweeney and Springer (1981), Carpenter and others (1980), Carpenter and others (1984), Dibblee (1980a), California Division of Mines and Geology (1982a), and some new mapping by the authors (1995). See also Huey (1948), Herd (1977a), and Oakshott (1980).

6. Sonneman and Switzer (unpublished maps, EXXON, 1961-62), Huey (1948), California Division of Mines and Geology (1982b), and some new mapping by the authors (1995). See also Dibblee (1980c, j), Throckmorton (1988), and Brabb and others (1971).

7. Atchley and Dobbs (1960). See also Snetsinger (1976).

8. Graymer and others (1994). See also Dibblee (1980k), Hall (1958), California Division of Mines and Geology (1980), and Herd (1977b).

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