Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco Counties, California

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Geologic Explanation and Acknowledgements

Introduction

This report contains a new geologic map at 1:50,000 scale, derived from a set of geologic map databases containing information at a resolution associated with 1:24,000 scale, and a new description of geologic map units and structural relationships in the mapped area. The map database represents the integration of previously published reports and new geologic mapping and field checking by the author (see Sources of Data index map on the map sheet or the Arc-Info coverage pi-so and the textfile pi-so.txt). The descriptive text (below) contains new ideas about the Hayward fault and other faults in the East Bay fault system, as well as new ideas about the geologic units and their relations.

These new data are released in digital form in conjunction with the Federal Emergency Management Agency Project Impact in Oakland. The goal of Project Impact is to use geologic information in land-use and emergency services planning to reduce the losses occurring during earthquakes, landslides, and other hazardous geologic events. The USGS, California Division of Mines and Geology, FEMA, California Office of Emergency Services, and City of Oakland participated in the cooperative project.

The geologic data in this report were provided in pre-release form to other Project Impact scientists, and served as one of the basic data layers for the analysis of hazard related to earthquake shaking, liquifaction, earthquake induced landsliding, and rainfall induced landsliding.

The publication of these data provides an opportunity for regional planners, local, state, and federal agencies, teachers, consultants, and others outside Project Impact who are interested in geologic data to have the new data long before a traditional paper map could be published. Because the database contains information about both the bedrock and surficial deposits, it has practical applications in the study of groundwater and engineering of hillside materials, as well as the study of geologic hazards and the academic research on the geologic history and development of the region.

Stratigraphy

Mesozoic Complexes

In general, the Tertiary strata in the map area rest with angular unconformity on two highly deformed Mesozoic rock complexes. One of these, the Great Valley complex, is made up of the Coast Range ophiolite, which in the map area consists mostly of serpentinite, gabbro, diabase, basalt, and keratophyre (altered silicic volcanic rocks); and Great Valley sequence, composed of sandstone, conglomerate, and shale of Jurassic and Cretaceous age. Although the sedimentary rocks and ophiolite have been tectonically separated almost everywhere in the map area, the Great Valley sequence was originally deposited on the ophiolite. The depositional relationship is known from two contacts exposed in the map area (Berkeley Hills, Jones and Curtis, 1991, and Hayward Hills, Graymer and others, 1996), contacts exposed in Sonoma and Solano Counties in the San Francisco Bay region, and contacts elsewhere in California. This complex represents the accreted and deformed remnants of arc-related Jurassic oceanic crust and a thick sequence of turbidites.

The second Mesozoic complex is the Franciscan complex, which is composed of weakly to strongly metamorphosed graywacke, argillite, basalt, serpentinite, chert, limestone, and other rocks. The rocks of the Franciscan complex in the area were probably Jurassic oceanic crust and Jurassic to Cretaceous pelagic deposits overlain by Late Jurassic to Late Cretaceous turbidites. Although Franciscan complex rocks are dominantly little metamorphosed, high-pressure, low-temperature metamorphic minerals are common in rocks that crop out as mélange blocks within the complex (Bailey and others, 1964). High-grade metamorphic blocks in sheared but relatively unmetamorphosed argillite matrix (Blake and Jones, 1974) reflect the complicated history of the Franciscan complex. The complex was subducted beneath the Coast Range ophiolite, at least in part, during Late Cretaceous time, after the deposition of the Franciscan complex sandstone containing Campanian (Late Cretaceous) fossils that crops out in the map area (Novato Quarry terrane). Because the Franciscan complex was accreted under the Great Valley complex containing the Coast Range Ophiolite, the contact between the two Mesozoic complexes is everywhere faulted (Bailey and others, 1964), and the Franciscan complex presumably underlies the entire San Francisco Bay area east of the San Andreas fault.

Both the Franciscan and the Great Valley complexes have been further divided into a number of fault-bounded tectonostratigraphic terranes (Blake and others, 1982, 1984). When the terranes were first established, the prevailing philosophy was to identify separate terranes if any doubt existed about stratigraphic linkage between structurally seperated entities. As a result of further research, much additional data, in particular new fossil localities, are known and the distribution and nature of the original terranes have been greatly modified in this report (see below).

Description of Terranes

Great Valley complex

Del Puerto Terrane

The main body of Great Valley complex rocks that have been assigned to the Del Puerto Terrane (Blake and others, 1984) lies east of the Diablo Range, some 50 km east of the study area. There the basal part of the sequence is composed of dismembered ophiolite and a thick accumulation of silicic volcanic rocks (keratophyre and quartz keratophyre), overlain by silicic tuff and tuffaceous sandstone of the Late Jurassic Lotta Creek Formation and Late Jurassic to Early Cretaceous turbidites. These rocks are overlain by Late Cretaceous and Paleocene strata that overlap eastward onto Sierran basement.

Although the Jurassic and Early Cretaceous Great Valley complex rocks in the study area are for the most part dismembered and highly deformed, they are herein assigned to the Del Puerto Terrane based on the following criteria: 1) the presence of large bodies of keratophyre within the ophiolitic rocks, 2) the presence of a sliver of silicic tuff similar to that of the Lotta Creek Formation, and 3) the absence of much silicic volcanic detritus in the Late Jurassic and Early Cretaceous strata (which would be suggestive of Healdsburg rather than Del Puerto terrane). Although the Late Jurassic and Early Cretaceous strata in the map area are similar to those of the Elder Creek terrane, including the presence of ophiolite-clast breccia at the base of the sequence in one outcrop in the Hayward quadrangle, Elder Creek terrane is characterized by its lack of keratophyre within the basal ophiolite. Therefore all Great Valley complex rocks in the map area are assigned to the Del Puerto Terrane.

The basal ophiolitic rocks in the map area include most of the rock-types that make up the ophiolite suite, including serpentinite, pyroxenite, gabbro, diabase, and massive and pillowed basalt. However, serpentinite that is structurally interleaved with Franciscan complex mélange or that contains high-grade metamorphic blocks, has previously been mapped as part of the Franciscan complex, so it is important to point out that all serpentinite in the map area is herein considered to be part of or derived from the Coast Range ophiolite (see Blake and others, 2000, for a more complete discussion of the serpentinite).

Franciscan complex

Yolla Bolly terrane

Among the many other Franciscan complex terranes in the San Francisco Bay region, one of the most widespread and distinctive units consists of metagraywacke, metachert, and metabasalt, all containing abundant blueschist-facies minerals such as lawsonite, jadeitic pyroxene, and metamorphic aragonite. In addition, the metagraywackes are characterized by a weak to pronounced foliation (TZ-2 of Blake and others, 1967). These rocks have been correlated with the type Yolla Bolly terrane of northern California (Blake and others, 1984) based on similarities in lithology, sandstone composition, age, and metamorphic state.

No fossils are known from the Yolla Bolly rocks of the study area, but similar metacherts from the nearby Diablo Range (Sliter and others, 1993) have yielded ages that range from Early (?) to Late Jurassic, and the overlying metagraywacke is latest Jurassic (Tithonian, Crawford, 1976) presumably marking the time when the oceanic rocks entered the trench (Wentworth and others, 1998).

The outcrops of Yolla Bolly terrane rocks in the mapped area comprise a north-northwest trending thrust block of jadite-bearing metagraywacke with a pronounced foliation (TZ-2B) in the Richmond quadrangle.

Alcatraz terrane

On Alcatraz and Yerba Buena Islands, north and east of San Francisco in San Francisco Bay, and in eastern San Francisco, another graywacke-rich terrane (broken formation) crops out that lacks the metamorphic minerals and foliation seen in the Yolla Bolly terrane and instead contains metamorphic prehnite and pumpellyite. These rocks have also been observed by the authors in drill cores extracted along the San Francisco Bay Bridge Crossing east of San Francisco.

Fossils found in these rocks have been the subject of considerable controversy. In fact, the first fossil ever found in what was then called the Franciscan Formation, was in a boatload of rock from Alcatraz Island. This consisted of an *Inoceramus elliot*i of Cretaceous age (see Bailey and others, 1964, for a discussion, including the fact that the fossil was destroyed in the 1906 San Francisco earthquake). A subsequent fossil discovery on Alcatraz (Armstrong and Gallagher, 1977) was identified as *Buchia sp.* of Early Cretaceous age. More recently, additional fossils were found by personnel of the National Park Service and include an *Inoceramus sp.* of undoubted early Late Cretaceous (Cenomanian) age (oral commun., W. P. Elder, 1997).

Although the early Late Cretaceous age for the Alcatraz rocks is similar to that of the nearby Marin

Headlands terrane graywacke, pronounced differences in sandstone composition (Jayko and Blake, 1984) suggest that it is a separate terrane.

In the map area, the outcrops of Alcatraz terrane form two narrow thrust belts of unfoliated graywacke in the Richmond quadrangle.

Novato Quarry terrane

This terrane forms a relatively narrow, discontinuous, northwest- trending belt between the San Andreas and Hayward faults. It consists largely of thin-bedded turbidites with local channel deposits of massive sandstone (see Blake and others, 1984, for discussion of depositional environments as well as photographs of typical outcrops). Although the strata are in many places folded and locally disrupted (broken formation), they are nearly everywhere well bedded.

Like the Alcatraz terrane, the sandstone contains metamorphic prehnite and pumpellyite. However, the Novato Quarry terrane is younger than the Alcatraz terrane; several specimens of *Inoceramus schmidti* of Late Cretaceous (Campanian) age have been found in this terrane (Bailey and others, 1964). In addition, Alcatraz terrane sandstone lacks K-feldspar, but Novato Quarry terrane sandstone composition is arkosic with abundant K-feldspar, indicating derivation from a granitic or rhyolitic source area.

Outcrops in the map area form a 1-km-broad, fault-bounded belt of well-bedded graywacke in the Richmond and Oakland East quadrangles. South of the California College of Arts and Crafts in the Oakland East quadrangle, the graywacke is intruded by a small 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. The age of the diorite is unknown, but the extent of deformation within the intrusive body, similar to that of the surrounding sandstone, suggests that it was formed before accretion of the Novato Quarry terrane.

The age of the Novato Quarry terrane rocks constrains Franciscan complex deposition to have continued at least into Campanian time, with subsequent subduction and accretion.

Central "terrane" (Mélange)

All of the previously-described Franciscan complex terranes in the map area are tectonically enclosed in an argillite matrix mélange that has been called the Central terrane (Blake and others, 1982, 1984). Most of the matrix consists of sheared mudstone (argillite) and lithic sandstone, within which are mixed numerous blocks and slabs of greenstone, chert, metamorphic rocks, serpentinite, and other rocks. Although treated as a single terrane, the mélange is actually the result of the tectonic and/or sedimentary mixing of rocks derived from several terranes: the rocks that would form the sheared matrix from one terrane, the chert, greenstone and metamorphic rocks from other Franciscan complex terranes, and the serpentinite from the Coast Range ophiolite. In particular, most of the chert blocks that crop out in the mélange can be assigned with confidence to the Marin Headlands terrane based on similarity of radiolarian faunas (Murchey and Jones, 1984).

In a few places, such as the abandoned quarry at Greenbrae in Marin County northwest of the study area (Blake and others, 2000), it is possible to see preserved slabs of interbedded graywacke, mudstone, chert, and tuffaceous greenstone that could represent the original sedimentary accumulation that has been subsequently sheared to form the mélange matrix. Such rocks have yielded both megafossils and microfossils (radiolaria and dinoflagellates) of Late Jurassic and Early Cretaceous age (Blake and Jones, 1974; Murchey and Jones, 1984).

Despite their similar ages, the radiolarian fauna found in the Marin Headlands chert blocks in the mélange is different from that found in chert interbedded in the matrix. This difference in chert faunas has led to the concept that the mélange matrix is derived from some kind of deep-water, continental margin deposit into which the other terranes were introduced by tectonic or sedimentary processes. Deformation during accretion resulted in the interleaving of the rocks that would become mélange and the accreted terranes. Deformation during subsequent uplift has led to both the almost complete disruption of the original sedimentary character of the matrix and the inmixing of exotic blocks derived from the accreted terranes, such as the chert blocks from Marin Headlands terrane (Blake and Wentworth, 1999). Only in a few locations, like Greenbrae, are the mélange matrix strata preserved.

However, the mechanism by which the mélange blocks were originally incorporated into the matrix rock is an issue of some debate. The sedimentary model suggests that blocks (olistoliths) were transported into the depositional environment of the matrix material by gravity driven debris slides. The trench associated with the subduction zone provides an area of suitably steep slopes and the converging plates bring the displaced terranes into proximity of the continental margin mélange matrix. The resulting olistostrome then undergoes the deformation described above, disrupting the original depositional character of the matrix/block relationships. In contrast, the tectonic model suggests that blocks in mélange have been incorporated only by tectonic processes. During and after accretion, lenses of rock derived from incoming exotic terranes are interleaved by faulting with continental margin deposits. Subsequent deformation during uplift further broke up the lenses of exotic rocks, forming the mélange blocks observed today.

I prefer the tectonic model for the Franciscan mélange for the following reasons:

1. No original depositional relationship between block and matrix has been observed, although areas (like Greenbrae) of relatively undisrupted matrix are known.
2. Radiolarians in the matrix are of similar age to those in blocks. If the blocks were deposited as olistoliths, they would have to be lithified prior to redeposition. This implies they should be appreciably older than the matrix.
3. The Marin Headlands terrane and other terranes are characterized by an upper stratigraphic section composed of graywacke thought to have been derived from volcanic arc sources as the terrane approached a subduction zone. This suggests that exotic terranes were receiving sediments, not eroding to produce large blocks, as they entered the subduction zone. The sedimentary model requires that the nature of deposition changed as the terrane entered the trench, and that the entire thickness of graywacke be removed in places to allow generation of chert blocks (and the entire thickness of chert to allow generation of greenstone blocks) or that they received sediment at one subduction zone and then eroded into another subduction zone.
4. High-grade metamorphic blocks are incorporated into low-grade mélange matrix. The tectonic model provides the mechanism (fault offset) to transport material from the deeper part of the subduction zone back into the upper part, intermixing it with lower grade rock. The sedimentary model requires that blueschist metamorphism was complete before formation of olistoliths, suggesting a tectonic history of deep subduction, uplift to the surface, erosion and deposition, shallow subduction and accretion, and a second period of uplift to the surface.
5. Blueschist metamorphic blocks were metamorphosed during Late Jurassic and Early Cretaceous time (Nelson, 1991; McDowell and others, 1984), the same time that mélange matrix sediments were being deposited at the surface. If metamorphic mélange blocks were emplaced into matrix sediments by sedimentary processes, the metamorphic age of the blocks should be appreciably older to account for the time required to unroof the metamorphic rocks.

The presence of serpentinite blocks in the mélange also suggests that blocks of the Coast Range ophiolite may have been incorporated into the mélange during uplift and disruption, although the correlation of the serpentinite blocks with the Coast Range ophiolite is unproven (see Blake and others, 2000).

Tertiary Stratigraphy

The Mesozoic rocks in the study area are overlain by Paleocene and younger strata. These Tertiary rocks probably originally were deposited unconformably over the amalgamated terranes of both the Mesozoic complexes in the area, as evidenced by preserved unconformities mapped throughout the San Francisco Bay region (for example, Graymer and others, 1994, 1996; Blake and others, 2000; Wentworth and others, 1998). However, the depositional contact at the base of the Tertiary sequence is only preserved in the northeast corner of the Briones Valley quadrangle in the mapped area. Everywhere else in the map area the original contact has been disrupted by faulting.

The stratigraphic relationships in the mapped area have been used to subdivide the area into stratigraphic Assemblages. As defined in Graymer and others (1994, the concept of Assemblages was originally proposed in Jones and Curtis, 1991), an Assemblage is a fault-bounded rock body, which has a stratigraphic sequence that is significantly different from surrounding rock bodies. The map area has been divided into six Assemblages (see the Index Map of Assemblages on the map sheet, or Arc/Info coverage pi-as/). Examples of significant differences in stratigraphy between Assemblages in the area are as follows: the late Miocene section in Assemblage I contains a thick pile of volcanic rocks, but the neighboring Assemblages contain little or no late Miocene volcanics; the basal unit in Assemblage VII is middle Miocene (unconformable on Mesozoic rocks south of the map area), whereas neighboring Assemblages have Paleocene basal strata; Assemblage III contains a unique suite of rocks, including diatomite, not found in neighboring Assemblages. The differences between Assemblages is summarized in the Correlation of Map Units table (see map sheet or Arc/Info coverage pi-corr/).

The juxtaposition of these fault-bounded rock bodies with significantly different stratigraphies suggests that they originally formed in separate depositional basins or widely separated parts of a large basin and have since been juxtaposed by large offsets on the bounding faults. The East San Francisco Bay region is thought to have experienced about 180 km of Miocene or younger right-lateral offset related to the San Andreas fault system (McLaughlin and others, 1996). The juxtaposition of different Assemblages suggests that most of that offset has taken place on Assemblage-bounding faults.

Paleontology

Many different kinds of fossils have proved invaluable in understanding the geology of the map area: *Buchia* in the Franciscan and lower Great Valley complex rocks, Ammonites and *Inoceramus* in the Franciscan and upper Great Valley, radiolarians in the latest Cretaceous, Paleocene corals, Miocene mollusks, nonmarine vertebrates, and diatoms. Perhaps the most widespread and useful fossils, however, are the foraminifers. In the map area they are found in the upper Great Valley complex rocks and throughout the Tertiary rocks.

A partial list of references to paleontological reports in the map area and surrounding areas is given by White (1990) and by Freeburg (1990). Preparation of a digital database of fossil localities and associated paleontologic information is being prepared by workers at the USGS and University of California, Berkeley.

Radiometric Ages

Three different types of rock bodies in the study area have yielded radiometric ages. The volcanic rocks in the Berkeley Hills (Tmb, Tst, Tbp) have been carefully studied, the most recent report of ages is Grimsich and others (1996). Several silicic tuffs outcrop in the map area, and studies of these rocks have been published by Sarna-Wojcicki (1976) and Sarna-Wojcicki and others (1979). Finally, analysis of the keratophyre (Jsv) has been published by Curtis (1989). An overview of radiometric ages in the northern San Francisco Bay region, including the map area, is provided by Lindquist and Morganthaler (1991).

Structure

The structures in the map area can be roughly divided into four provinces, each with a distinct structural trend and style. The first is the San Francisco Bay block, west of the Hayward fault zone, which roughly corresponds with Assemblage XII. In this area there is little evidence of throughgoing Tertiary deformation, mainly because of the almost complete lack of Tertiary strata in the area. Quaternary strata sit unconformably on Franciscan complex rocks, and there is no known evidence for fault offset or folding of the Quaternary strata. However, small faulted outcrops of Miocene rocks in Marin County do suggest that this block has undergone some Miocene or younger deformation (Blake and others, 2000).

The second structural province is the Hayward fault zone as defined by Graymer and others (1995), the area between the San Francisco Bay plain and the Moraga-Miller Creek-Palomares fault. In this area, the structures are dominated by closely spaced, east-dipping, north-15°-west-trending faults. Most fold axes in this area have been disrupted by faults, but two large synclines are preserved with axial trends of about north 30° west. Structures within this zone deform and truncate the late Miocene volcanics of the Berkeley Hills and include the actively creeping strands of the Hayward fault (see below). Geodetic studies also indicate as much as 1 mm/yr of active uplift in this area (Gilmore, 1992). Therefore much of the deformation in this region is late Miocene or younger and continues at this time.

The rocks east of the Moraga-Miller Creek-Palomares fault but west of the Calaveras fault make up the third structural province. This area is characterized by broad folds and widely spaced reverse faults that trend about north 45° west. Late Miocene to early Pliocene strata are fully involved in this deformation, suggesting that most of the folding and faulting occurred in late Miocene or younger time. Unruh and Lettis (1998) suggested that much of the deformation in this area is related to geometric accomodation of right-lateral regional stress, but Jones and others (1994) suggest that there is a significant component of compression perpendicular to the observed strike-slip offset on major faults like the Hayward and Calaveras. The deformation in this area is probably due to a combination of these two stresses. Paleoseismic studies have found evidence for Quaternary offset on both the Franklin Canyon fault (Geomatrix, 1998) and the Miller Creek fault (Wakabayashi and Sawyer, 1998).

The fourth structural province is that east of the Calaveras fault. This area, only a small fraction of which lies in the map area (Las Trampas Ridge quadrangle), is dominated by the southwest-vergent overturned folds and thrust faults related to the Diablo thrust. These structures deform the Pliocene strata in the area, and studies of Pleistocene terraces suggest that uplift and deformation is still very active here.

The complex structures found in the study area result from a complicated structural history that includes late Mesozoic to early Cenozoic subduction and accretion, subsequent uplift and detachment faulting, followed by oblique strike-slip and reverse faulting that continues at the present time.

The earliest structural relationships in the map area are those that juxtapose the multiple terranes of the Franciscan complex and the Great Valley complex. Structural relationships in this area, as well as in the Diablo Range (Blake and Wentworth, 1999) and the northern Coast Ranges (Wentworth and others, 1984), suggest that the Yolla Bolly terrane is the structurally highest and innermost of Franciscan complex terranes in the area. Additionally, the age of the graywacke of the Yolla Bolly terrane, which probably reflects its approach to North America, is older than other Franciscan complex graywackes in the area. Therefore the Yolla Bolly accreted first, followed by the younger, more coherent, less metamorphosed terranes. The order of accretion of structurally lower terranes is more problematical (see Blake and others, 1999, for a discussion of the accretion of these and related terranes), but the Campanian age of graywackes in the Novato Quarry terrane requires that accretion of Franciscan complex terranes continued into Campanian or younger time.

Presumably the rocks that would become the matrix for the mélange terrane were formed between the subduction zone and North America, allowing the incoming terranes to be subducted into them. At the same time or later the terrane/mélange package was wedged under the Coast Range ophiolite (Wentworth and others, 1984).

The period of accretion and crustal thickening was followed by one or more periods of unroofing and attenuation. The previously stacked terranes were significantly thinned, and previously buried ophiolite and Franciscan complex rocks were brought to the surface. This thinning resulted in the almost complete attenuation of the Coast Range ophiolite in the map area, leaving only the dismembered fragments of the ophiolite present. Attenuation also took place between the Franciscan complex terranes, as evidenced by the "pinching out" of some terranes in the region (for example, the Novato Quarry terrane is found structurally below the Alcatraz terrane in the map area, but not in Marin County). Krueger and Jones (1989) and Harms and others (1992) showed that the first period of regional attenuation probably initiated 60-70 Ma. They suggested that extension was complete by late Oligocene time based on the age of strata that overlapped extensional faults (Page, 1970), but in some parts of the San Francisco Bay area, unroofing may have persisted into the middle Miocene, as suggested by the unconformable contact of middle Miocene strata on Franciscan complex rocks in the Diablo Range (Osuch, 1970; Graymer and others, 1996) and on Great Valley complex strata in Marin (Blake and others, 1999). Before attenuation was completed, regional uplift of buried layers to the surface had been accomplished by the early Eocene, as indicated by the presence of ophiolite and Franciscan complex detritus in sedimentary strata of that period both south and east of the mapped area (for example, the Domingene Sandstone in the Cordelia area contains detritus derived from the Coast Range ophiolite, Graymer and others, 1999). The attenuation of this period probably completely obliterated most of the original thrust faults in the mapped rocks. For example, the original subduction related thrust fault between the Franciscan complex and Coast Range ophiolite was reactivated as a detachment fault throughout most of its extent (Krueger and Jones, 1989), and many of the other rock units in the map area are also bounded by normal faults. However, the timing of offset on most of the faults is poorly constrained, so there may be some faults that remain from the initial stage of accretion and thrusting. The tectonic model of incorporation of blocks into the Franciscan complex mélange suggests that the tectonic mixing associated with mélange was accomplished during attenuation, and disruption of coherent parts of the mélange matrix in Marin County by normal faulting supports this idea (Blake and others, 1999).

By late Miocene time, the regional tectonic stress again changed to transpression associated with the development of the San Andreas fault system. Many of the terrane bounding faults were reactivated as reverse faults at this time, as evidenced by uplift associated with the Hayward fault zone (Graymer and others, 1995). Jones and others (1994) described a significant component of compression normal to the San Andreas fault system, and I suggest that the pervasive tight folding and imbricate faulting of the strata in the map area is due to this compression. It is important to note that late Miocene to early Pliocene rocks are fully involved in the compressional deformation, so the deformation must have occurred for the most part in late Miocene or younger time.

In addition to compressive deformation, there is strong evidence of large amounts of right-lateral offset in late Miocene and later time. The correlation of the volcanic rocks in the region suggest that the Hayward fault zone has undergone about 95 km of Miocene and younger right-lateral offset, and faults east of the Berkeley Hills, including the Moraga-Miller Creek-Palomares fault zone and the Calaveras fault zone, have undergone an additional 95 km (Graymer, 1999; Blake and others, 2000; see the index map of faults on the map sheet or the Arc/Info coverage pi-flt for fault names).

Active faulting in the map area is thought to be focused on the Hayward and Calaveras fault zones (Hart and Bryant, 1997). The Hayward fault zone in the map area experienced up to 2 meters of right-lateral surface fault rupture during the 1868 earthquake (Lawson, 1908), and one or more strands of the fault zone are known to be actively creeping along much of the length of the fault zone (Lienkaemper, 1992). The Calaveras fault probably generated an earthquake with a magnitude around 5.6 that was centered in San Ramon Valley (Las Trampas Ridge quadrangle) in 1861 (Ellsworth, 1990). However, evidence for Holocene offset on the Calaveras fault is not known from the northern part of the San Ramon Valley or northward, which has suggested to many workers (Working Group on California Earthquake Probabilities, 1999) that the throughgoing seismogenic deformation associated with the Calaveras fault in the southern part of the San Ramon Valley and southward diverges from the Calaveras fault in or near the mapped area. The nature of the divergence is very poorly understood, but the deformation may become distributed on other northwest-trending structures that run through the map area between the Calaveras and Moraga-Miller Creek-Palomares faults (Las Trampas Ridge and Briones Valley quadrangles).

Description of Map Units

Surficial Deposits

af **Artificial fill (Historic)**—Man-made deposit of various materials and ages. Some are compacted and quite firm, but fills made before 1965 are nearly everywhere not compacted and consist simply of dumped materials

alf **Artificial levee fill (Historic)**—Man-made deposit of various materials and ages, forming artificial levees as much as 20 feet (6.5 meters) high. Some are compacted and quite firm, but fills made before 1965 are almost everywhere not compacted and consist simply of dumped materials. The distribution of levee fill conforms to levees shown on the most recent U.S. Geological Survey 7.5 minute quadrangles

Qhasc **Artificial stream channels (Historic)**--Modified stream channels, usually where streams have been straightened and realigned, but also including those channels that are confined within artificial dikes and levees

Qhaf1 **Younger alluvial fan deposits (Holocene)**--Brown, poorly-sorted, dense, sandy or gravelly clay. Small fans at mountain fronts have a probable debris flow origin. Larger Qhaf1 fans away from mountain fronts may represent the modern loci of deposition for Qhaf

Qhaf **Alluvial fan and fluvial deposits (Holocene)**--Alluvial fan deposits are brown or tan, medium dense to dense, gravely sand or sandy gravel that generally grades upward to sandy or silty clay. Near the distal fan edges, the fluvial deposits are typically brown, never reddish, medium dense sand that fines upward to sandy or silty clay. The best developed Holocene alluvial fans are on the San Francisco Bay plain. All other alluvial fans and fluvial deposits are confined to narrow valley floors

Qhb **Basin deposits (Holocene)**--Very fine silty clay to clay deposits occupying flat-floored basins at the distal edge of alluvial fans adjacent to the bay mud (Qhbm)

Qhbs **Basin deposits, salt-affected (Holocene)**--Clay to very fine silty-clay deposits similar to the Qhb deposits except that they contain carbonate nodules and iron-stained mottles (U.S. Soil Conservation Service, 1958). These deposits may have been formed by the interaction of bicarbonate-rich upland water and saline water of the San Francisco Bay estuary. With minor exceptions, salt-affected basin deposits are in contact with bay mud deposits, Qhbm

Qhbm **Bay mud (Holocene)**--Water saturated estuarine mud, predominantly gray, green, and blue clay and silty clay underlying marshlands and tidal mud flats of San Francisco Bay. The upper surface is covered with cordgrass (*Spartina sp.*) and pickleweed (*Salicornia sp.*). The mud also contains a few lenses of well-sorted, fine sand and silt, a few shelly layers (oysters), and peat. The mud interfingers with and grades into fine-grained deposits at the distal edge of Holocene fans and was deposited during the post-Wisconsin rise in sea-level, about 12 ka to present (Imbrie and others, 1984). Estimated thickness: 0-40 m. In places it rests unconformably on bedrock

Qhbr **Beach ridge deposits (Holocene)**--Long narrow ridge of probably well-sorted sand inferred from 1939 imagery. Observed between Emeryville and Berkeley, these deposits are now beneath the Interstate 80 roadbed

Qhfp **Floodplain deposits (Holocene)**--Medium to dark gray, dense, sandy to silty clay. Lenses of coarser material (silt, sand, and pebbles) may be locally present. Floodplain deposits usually occur between levee deposits (Qhl) and basin deposits (Qhb)

Qhl **Natural levee deposits (Holocene)**--Loose, moderately-sorted to well-sorted sandy or clayey silt grading to sandy or silty clay. These deposits are porous and permeable and provide conduits for transport of ground water. Levee deposits border stream channels, usually both banks, and slope away to flatter floodplains and basins. Levee deposits are best developed along San Pablo and Wildcat Creeks on the bay plain in Richmond. Abandoned levee systems have also been mapped

Qhsc **Stream channel deposits (Holocene)**—Poorly-sorted to well-sorted sand, silt, silty sand, or sandy gravel with minor cobbles. Cobbles are more common in the mountainous valleys. Many stream channels are presently lined with concrete or riprap. Engineering works such as diversion dams, drop structures, energy dissipaters, and percolation ponds also modify the original channel. Many stream channels have been straightened, and these are labeled Qhasc. This straightening is especially prevalent in the lower reaches of streams entering the estuary. The mapped distribution of stream channel deposits is controlled by the depiction of major creeks on the most recent U.S. Geological Survey 7.5 minute quadrangles. Only those deposits related to major creeks are mapped. In some places these deposits are under shallow water for some or all of the year, as a result of reservoir release and annual variation in rainfall

Qds **Dune sand (Holocene and Pleistocene)**--Fine-grained, very well sorted, well-drained, eolian deposits. They occur mainly in large sheets, as well as many small hills, most displaying Barchan morphology. Dunes display as much as 30 m of erosional relief and are presently being buried by basin deposits (Qhb) and bay mud (Qhbm). They probably began accumulating after the last interglacial high stand of sea level began to recede about 71 ka, continued to form when sea level dropped to its Wisconsin minimum about 18 ka, and probably ceased to accumulate after sea level reached its present elevation (about 6 ka). Atwater (1982) recognized buried paleosols in the dunes, indicating periods of nondeposition

Qms **Merritt sand (Holocene and Pleistocene)**--Fine-grained, very well sorted, well-drained eolian deposits of western Alameda County. The Merritt sand outcrops in three large areas in Oakland and Alameda. Previously thought to be only of Pleistocene age, the Merrit sand is probably time-correlative with unit Qds, based on similar interfingering with Holocene bay mud (Qhbm) and presumably similar depositional environments associated with long-term sea-level fluctuations. The Merrit sand displays different morphology from unit Qds, however, forming large sheets up to 15 meters high with yardang morphology

Qls **Landslide deposits (Holocene and/or Pleistocene)**--Poorly sorted clay, silt, sand, and gravel. Only a few very large landslides have been mapped. For a more complete map of landslide deposits, see Nilsen and others (1979)

Qpaf **Alluvial fan and fluvial deposits (Pleistocene)**—Brown, dense, gravely and clayey sand or clayey gravel that fines upward to sandy clay. These deposits display various sorting and are located along most stream channels in the county. All Qpaf deposits can be related to modern stream courses. They are distinguished from younger alluvial fans and fluvial deposits by higher topographic position, greater degree of dissection, and stronger soil profile development. They are less permeable than Holocene deposits and locally contain fresh water mollusks and extinct late Pleistocene vertebrate fossils. They are overlain by Holocene deposits on lower parts of the alluvial plain and incised by channels that are partly filled with Holocene alluvium on higher parts of the alluvial plain. Maximum thickness is unknown but at least 50 m

Qpaf1 **Alluvial terrace deposits (Pleistocene)**--Deposits consist of crudely bedded, clast-supported gravels, cobbles, and boulders with a sandy matrix. Clasts as much as 35 cm intermediate diameter are present. Coarse sand lenses may be locally present. Pleistocene terrace deposits are cut into Qpaf alluvial fan deposits a few meters and lie up to several meters above Holocene deposits

Qmt **Marine terrace deposits (Pleistocene)**--Three small outcrops of marine terraces are located about 5 m above present mean sea level. Similar terraces are located north of the map area on the south shore of San Pablo Bay in the extreme northwest Contra Costa County at Lone Tree Point, Wilson Point, and an unnamed outcrop in between (Helley and Graymer, 1997b). The oyster beds at the base of those outcrops unconformably overlie the Cierbo Sandstone of Miocene Age and are in turn overlain by about 5 m of greenish-gray silty mudstone. The oysters have been dated by the Uranium-Thorium method (Helley and others, 1993) and are of last interglacial age, approximately 125 ka

Qpoaf **Older alluvial fan deposits (Pleistocene)**--Brown dense gravely and clayey sand or clayey gravel that fines upward to sandy clay. These deposits display various sorting qualities. All Qpoaf deposits can be related to modern stream courses. They are distinguished from younger alluvial fans and fluvial deposits by higher topographic position, greater degree of dissection, and stronger profile development. They are less permeable than younger deposits, and locally contain freshwater mollusks and extinct Pleistocene vertebrate fossils

QTi **Irvington Gravels of Savage (1951) (Pleistocene and Pliocene?)**--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. In the map area, these gravels are limited to several very small outcrops in the San Leandro quadrangle, thought to be offset from the main exposures of this unit in Fremont, south of the map area, by movement on the Hayward fault zone (Graymer, 1999). A large suite of early Pleistocene vertebrate fossils from this unit in quarries in Fremont was described by Savage (1951)

QTu **Undifferentiated continental gravels (Pleistocene and/or Pliocene)**--Semi-consolidated to unconsolidated poorly sorted gravel, sand, silt, and clay distributed in isolated patches throughout the map area. These deposits are unrelated to modern drainages and are most abundant in the Walnut Creek-Concord Valley (Briones Valley quadrangle) and in patches that appear to represent an ancestral drainage emanating from the north face of Mt. Diablo flowing northwesterly down the Clayton-Concord valley northeast of the map area. Their main distinction is not being related to modern drainage or Pleistocene drainage. Thickness varies but most outcrop areas exceed 50 m. No soil profile development is preserved at most localities due to erosion. These deposits probably reflect the late Cenozoic uplift of the Coast Ranges (Jones and others, 1994)

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)**--Nonmarine 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). Includes, mapped locally:

Tms **Interflow sedimentary rocks**

Tor **Orinda Formation (late Miocene)**--Distinctly to indistinctly bedded, nonmarine, pebble to boulder conglomerate, conglomeratic sandstone, coarse- to medium-grained lithic sandstone, and green and red siltstone and mudstone. Conglomerate clasts are subangular to well rounded, and contain a high percentage of detritus derived from the Franciscan complex

Tcc **Claremont chert (late to middle Miocene)**--Laminated and bedded chert, minor brown shale, and white sandstone. Chert crops out as distinct, massive to laminated, gray or brown beds as much as 10 cm thick with thin shale partings. Distinctive black, laminated chert crops out locally in the Berkeley Hills. Lawson (1914) named rocks of this unit and coeval rocks elsewhere in and around the map area Claremont Shale, but within the area of Assemblage I, including Claremont Canyon, this unit is made up of much more chert than shale. Therefore, in this report I use the informal name Claremont chert for the rocks in Assemblage I and the formally accepted name Claremont Shale (Tcs) for coeval rocks in other assemblages where shale is the dominant lithology. The Claremont chert also includes, mapped locally:

Tccs **Interbedded sandstone**

Tss **Unnamed sandstone (Miocene(?))**

Tush **Unnamed gray mudstone (early Miocene)**

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

Tsms **Interbedded sandstone**--Brown siltstone and fine-grained sandstone are locally interbedded

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

Great Valley Complex

Kss **Unnamed lithic sandstone (Cretaceous)**

Assemblage II

Mullholland Formation of Ham (1952) (Pliocene and late Miocene)--Divided into upper and lower members:

Tmlu **Upper member**--Conglomerate, sandstone, and mudstone

Tmll **Lower member**--Sandstone and mudstone. Includes:

Tmls **Sandstone marker beds**--Mapped locally

Tus **Unnamed sedimentary and volcanic rocks (late Miocene)**--Includes conglomerate, sandstone, siltstone. Also includes, mapped locally:

Tub **Interbedded basalt**

Tul **Interbedded limestone**

Tlt **Lafayette Tuff (late Miocene)**--K/Ar age of 8.2 ± 2.0 Ma (Sarna-Wojcicki, 1976)

Tn **Neroly Sandstone (late Miocene)**--Blue, gray, and brown, volcanic-rich, shallow marine sandstone, with minor shale, siltstone, tuff, and andesitic conglomerate

Tc **Cierbo Sandstone (late Miocene)**

Tbr **Briones Sandstone (late and middle Miocene)**--Sandstone, siltstone, conglomerate and shell breccia. The Briones Sandstone in this assemblage contains a tuffaceous layer with a K/Ar age of 14.5+0.4 Ma (Lindquist and Morganthaler, 1991)

In the southern part of the assemblage, locally divided 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.

In the northern part of the assemblage, locally divided into:

Tbu **Upper sandstone and shale member**

Tbh **Hercules Shale Membe--**Gray shale and siltstone

Tbl **Lower sandstone and siltstone member**

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:

Tccs **Sandstone interbeds**--Interbeds of light gray and white quartz sandstone and siltstone, mapped locally

Ts **Sobrante Sandstone (middle Miocene)**--Massive white, medium-grained calcareous sandstone

Tts **Tuffaceous sandstone (Miocene and/or Oligocene)**--Light-gray tuffaceous sandstone and tuff, with minor conglomerate and siltstone, marine. Clark (1918) correlated this unit with the Kirker Tuff, which crops out north of Mount Diablo, east of the map area, based on similar lithology and the presence in both units of 11 fossil species, including *Acila shumardi*. Durham (1944) indicated that *A. shumardi* is indicative of a late Oligocene age, the accepted age for the Kirker Tuff, but the underlying San Ramon Sandstone is considered to be early Miocene. This apparent contradiction has caused me to use the less restricted age indicated

Tsr **San Ramon Sandstone (Miocene and/or Oligocene)**--Massive, medium- to coarse-grained, fossiliferous, marine sandstone. The accepted age for this unit is early Miocene, based on Addicott (1970) who noted that Weaver and others (1944) had reclassified the molluscan zone of the San Ramon Sandstone fauna (*Echinophoria apta*) from late Oligocene to early Miocene. However, Kleinpell (1938) reported early Zemorrian foraminifera from this unit. Weaver and others (1944) classified the Zemorrian as early Miocene (probably based on the relationships in this unit), but more recent work on foraminiferal zonation by McDougall (1983) has shown the Zemorrian zone to be entirely Oligocene. In addition, the San Ramon Sandstone underlies tuffaceous sandstone and tuff correlated with the Kirker Tuff, which is considered to be Oligocene. The contradiction in accepted ages of the two units and the contradiction of foraminiferal and molluscan zonation has caused me to use the less restricted age indicated

Tshc **Shale and claystone (Eocene)**--Also contains minor sandstone

Great Valley Complex

Ku **Unnamed sedimentary rocks (Late Cretaceous, Turonian and Cenomanian)**--Massive to distinctly bedded, biotite-bearing, brown-weathering, coarse- to fine-grained graywacke and lithic wacke, siltstone, and mudstone. Also contains:

Kc **Conglomerate**--Lenses of pebble to boulder conglomerate, mapped locally

Assemblage III

Tcgl **Conglomerate, sandstone, siltstone (Pliocene and Miocene)**--Contains abundant clasts of Claremont chert. Includes:

Tcglt **Rhyolite tuff and tuff breccia**--Correlated with the 5.7 to 6.1 Ma Roblar tuff of Sarna-Wojcicki (1992) in Sonoma County (Sarna-Wojcicki, written commun.,1990)

Tdi **Diatomite (Miocene)**—Light-gray to white with minor brown shale

Tsa **Sandstone (Miocene)**--Massive, light-gray, fine- to medium-grained

Tmu **Mudstone, shale, and siltstone (Miocene)**

Assemblage IV

Most of the stratigraphic section of this assemblage does not crop out in the map area; see Graymer and others (1994) for a complete description of the units in this assemblage.

Tchs **Unnamed shale (Miocene)**--Light-brown mudstone and siltstone, interbedded with fine-grained brown sandstone. This unit crops out only on Castle Hill west of Alamo in the northeast part of the Las Trampas Ridge quadrangle

Tuc **Unnamed conglomerate (Miocene)**--Brown pebbly sandstone and siltstone. This unit crops out only on Castle Hill west of Alamo in the northeast part of the Las Trampas Ridge quadrangle

Ts **Sobrante Sandstone (Miocene)**--Gray to brown, fine- to medium-grained sandstone and minor conglomerate

Tsr **San Ramon Sandstone (Miocene and/or Oligocene)**--Bluish-gray to brown, medium-grained sandstone with conglomerate locally present in basal part. The accepted age for this unit is early Miocene, based on Addicott (1970) who noted that Weaver and others (1944) had reclassified the molluscan zone of the San Ramon Sandstone fauna (*Echinophoria apta*) from late Oligocene to early Miocene. However, Kleinpell (1938) reported early Zemorrian foraminifera from the San Ramon Sandstone. Weaver and others (1944) classified the Zemorrian as early Miocene (probably based on the relationships in this unit), but more recent work on foraminiferal zonation by McDougall (1983) has shown the Zemorrian zone to be entirely Oligocene. In addition, the San Ramon Sandstone in Assemblage II underlies tuffaceous sandstone and tuff correlated with the Kirker Tuff, which is considered to be Oligocene. The contradiction in accepted ages of the two units and the contradiction of foraminiferal and molluscan zonation has caused me to use the less restricted age indicated

Tes **Escobar Sandstone of Weaver (1953) (Eocene)**—Massive, medium- to coarse-grained, brown sandstone with shale in the basal part

Muir Sandstone of Weaver (1953), upper member (Eocene)--Massive, yellow-weathering arkosic sandstone. Divided into:

Tmru **Upper member**—Sandstone

Tmrl **Lower member**—Claystone with thin sandstone in the basal part

Tvh **Vine Hill Sandstone of Weaver (1953) (Paleocene)**--Glauconitic sandstone. Locally, divided into:

Tvhu **Upper member**--Sandstone and shale

Tvhl **Lower member**--Glauconitic sandstone

Great Valley Complex

Ku **Undivided Great Valley complex rocks (Cretaceous)**--Sandstone, siltstone, shale, and minor conglomerate. Locally, divided into:

Kcs **Gray, massive quartz arenite**

Ksh **Siltstone and shale**

Kus **Sandstone, siltstone, and shale**

Assemblage V

Most of the stratigraphic section of this assemblage does not crop out in the map area; see Graymer and others (1994) for a complete description of the units in this assemblage.

Tgvt **Green Valley and Tassajara Formations of Conduit (1938), undivided (Pliocene and Miocene)**--Nonmarine sandstone, siltstone, and conglomerate. South of the map area, includes a 5-meter-thick tuff marker bed. A tuff in this unit has a K/Ar age of 4.0±1.0 Ma, while tuff layers lower in the unit have been correlated with the Roblar tuff of Sarna-Wojcicki (1992) in Sonoma County, which has K/Ar ages of 5.7±0.5 Ma and 6.1±0.1 Ma, and the Pinole Tuff of Assemblage II, which has a K/Ar age of 5.2±0.1 Ma (Sarna-Wojcicki, 1976)

Tn **Neroly Sandstone (Miocene)**--Brown, massive, marine sandstone with abundant volcanic clasts

Assemblage VII

The Tertiary strata of this assemblage do not crop out in the map area; see Graymer and others (1996) for a description of the complete stratigraphic sequence in this assemblage.

Great Valley complex

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. Locally, conglomerate (Kc) and siltstone (Kslt) members of this formation have been mapped

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 Conglomerate (Late Cretaceous, Turonian and/or Cenomanian)**--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. In areas of little conglomerate, this unit is distinguished from other Great Valley complex sandstones by its stratigraphic position, the presence of minor conglomerate, and its massive character. Includes, mapped locally:

Kcg **Conglomerate**

Kslt **Siltstone**

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

KJk **Knoxville Formation (Early Cretaceous and Late Jurassic)**--Mainly dark, greenish-gray silt or clay shale with thin sandstone interbeds. The depositional contact of Knoxville Formation on ophiolite and silicic volcanic rocks can be observed at several locations in the region, including outcrops in the Hayward quadrangle.

The Knoxville Formation is distinguished from the structurally overlying Joaquin Miller Formation by the greenish color, more poorly developed bedding, the presence of *Ammonite* and *Buchia* fossils. Locally includes:

KJkc **Conglomerate--**Thick pebble to cobble conglomerate beds in the lower part of the Knoxville Formation

KJkv **Volcanoclastic breccia--**Locally at the base, the formation contains beds of angular, volcanoclastic breccia derived from underlying ophiolite and silicic volcanic rocks

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, 1980b,d; 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:

sc **Silica carbonate rock**

spm **Serpentinite matrix mélange**--Sheared serpentinite with large blocks (up to 10 meters or more in diameter) of high-grade metamorphic rocks such as amphibolite and actinolite schist

Assemblage XII

This assemblage is characterized by having no Tertiary or Great Valley complex rocks in the map area and only a thin section of these rocks elsewhere in the region. For the most part, including everywhere in the map area, Quaternary deposits are in angular unconformity directly on Franciscan complex rocks.

Franciscan complex

Franciscan complex rocks presumably underlie the entire area (see above for further discussion of the Franciscan complex and the terranes that it comprises).

KJf **Undivided Franciscan complex rocks (Cretaceous and Jurassic)**--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 mélange containing blocks of many rock types, including sandstone, chert, greenstone, blueschist, serpentinite, eclogite, and limestone. Locally divided into:

Kfn **Sandstone of the 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 1 m 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 1-km-diameter body of:

Kfgm **Fine-grained quartz diorite (Late Cretaceous?)**--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

Kfa **Sandstone of the Alcatraz terrane of Blake and others (1984) (Cretaceous)**--Coarse-grained, biotite- and shale-chip-bearing lithic wacke. Large biotite grains and shale chips up to 2 mm diameter are prominent in hand sample. In the map area the sandstone is massive, with some thin shale partings. Dark greenish-gray where fresh, weathers to yellowish-brown

KJfy **Metasandstone of the Yolla Bolly terrane of Blake and others (1982) (Cretaceous(?) and Late Jurassic)**--Strongly foliated, coarse-grained, shale-chip-bearing lithic wacke. Jadeite is visible under the hand lens, and prominent in thin-section

KJfs **Franciscan complex sandstone, undivided (Late Cretaceous to Late Jurassic)**--Graywacke and meta-graywacke not assigned to any terrane

KJfm **Franciscan complex mélange (Cretaceous and/or Late Jurassic)**--Sheared black argillite, graywacke, and minor green tuff, containing blocks and lenses of graywacke and meta-graywacke (fs), chert (fc), shale, metachert, serpentinite (sp), greenstone (fg), amphibolite, tuff, eclogite, quartz schist, greenschist, basalt, marble, conglomerate, and glaucophane schist (fm). Blocks range in size from pebbles to several hundred meters in length. Only some of the largest blocks are shown on the map

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Digital Publication and Database Description

Introduction

This publication includes, in addition to cartographic and text products, geospatial (GIS) databases and other digital files. These files are published on the Internet through the USGS Publications Group web sites. The database files are particularly useful because they can be combined with any type of other geospatial data for purposes of display and analysis. The other files include digital files that support the databases and digital plot files that can be used to display and print the cartographic and text products included in this publication.

Following is the digital publication and database description. It contains information about the content and format of the digital geospatial databases used to create this digital geologic map publication. **This information is not necessary to use or understand the geologic information in the map sheet, and preceding geologic description.** The digital map and database description contains information primarily useful for those who intend to use the geospatial databases. However, it also contains information about how to get digital plot files of the map sheet and geologic pamphlet via the Internet or on magnetic tape, as well as information about how the map sheets and pamphlets were created, and information about getting copies of the map sheets and text from the U.S. Geological Survey.

In addition, the USGS has adopted new policies regarding revision of publications, introducing the concept of version numbers similar to those used in the computer industry. The following pamphlet contains information about the version system and about how to access a revision list explaining changes from version 1.0, if any have been made.

The digital map database, compiled from previously published and unpublished data and new mapping by the author, represents the general distribution of bedrock and surficial deposits in the mapped area. Together with the accompanying pamphlet file (available as oakmf.ps, oakmf.pdf, or oakmf.txt), it provides current information on the geologic structure and stratigraphy of the area covered. The database delineates map units that are identified by general age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source maps limits the spatial resolution (scale) of the database to 1:24,000 or smaller. The content and character of the digital publication, as well as methods of obtaining the digital files, are described below.

For those who don't use digital geologic map databases

For those interested in the geology of the mapped area who do not use an ARC/INFO compatible Geographic Information System (GIS), we have provided two sets of plotfiles containing images of much of the information in the database. Each set contains an image of a geologic map sheet and an explanatory pamphlet. There is a set of images in PostScript format and another in Adobe Acrobat PDF format (see the sections “PostScript plot files” and “PDF plot files” below).

Those interested who have computer capability can access the plot file packages in either of the two ways described below (see the section “Obtaining the digital database and plotfile packages”). However, it should be noted the plot file packages do require gzip and tar utilities to access the plot files. Therefore additional software, available free on the Internet, may be required to use the plot files (see section “Tar files”). In addition, the map sheet is large and requires a large-format color plotter to produce a plot of the entire image, although smaller plotters can be used to plot portions of the images using the PDF plot files (see the sections “PostScript plot files” and “PDF plot files” below).

Those without computer capability can obtain plots of the map files through USGS Map-On-Demand service for digital geologic maps (see section “Obtaining plots from USGS Information Services”) or from an outside vendor (see section “Obtaining plots from an outside vendor”).

Also, USGS has adopted version numbers for publications, similar to that used in the computer industry. See the section “Revisions and version numbers” for details on this new policy.

MF2342 Digital Contents

This publication includes three digital packages. The first is the PostScript Plotfile Package, which consists of PostScript plot files of a geologic map, explanation sheet, and geologic and digital description pamphlet. The second is the PDF Plotfile Package, and contains the same plotfiles as the first package, but in Portable Document Format (PDF). The third is the Digital Database Package, and contains the geologic map database itself, and the supporting data, including base maps, map explanation, digital and geologic description, and references

Postscript plotfile package

This package contains the images described here in PostScript format (see below for more information on PostScript plot files):

oakmap.ps A PostScript plottable file containing an image of the geologic map and base maps at a scale of 1:50,000, along with a map key, including terrane map, index maps, cross sections, and correlation chart.

oakmf.ps A PostScript plot file of the pamphlet containing detailed unit descriptions and geological information, plus references cited, and describing the digital content of the publication (this pamphlet).

PDF plotfile package

This package contains the images described here in PDF format (see below for more information on PDF plot files):

oakmap.pdf A PDF file containing an image of the geologic map and base maps at a scale of 1:50,000, along with a map key, including terrane map, index maps, cross sections, and correlation chart.

oakmf.pdf A PDF plot file of the pamphlet containing detailed unit descriptions and geological information, plus references cited, and describing the digital content of the publication (this pamphlet).

Digital database package

The database package includes geologic map database files for each quadrangle in the map area. The digital maps, or coverages, along with their associated INFO directory have been converted to uncompressed ARC/INFO export files. ARC export files promote ease of data handling and are usable by some Geographic Information Systems in addition to ARC/INFO (see below for a discussion of working with export files). The ARC export files and the associated ARC/INFO coverages and directories, as well as the additional digital material included in the database, are described below:

ARC/INFO export file	Resultant Coverage	Description of Coverage
ri-geol.e00	ri-geol/	Faults, depositional contacts, and rock units in the Richmond quadrangle. This coverage includes arcs, polygons, and annotation.
ri-strc.e00	ri-strc/	Strike and dip information and fold axes in the Richmond quadrangle. This coverage includes arcs, points, and annotation. **Note:** The structure coverage may include additional point data that is not plotted in the map sheet (plotfiles oakmap.ps or oakmap.pdf) because of space constraints at map scale.
bv-geol.e00	bv-geol/	Faults, depositional contacts, and rock units in the Briones Valley quadrangle. This coverage includes arcs, polygons, and annotation.
bv-strc.e00	bv-strc/	Strike and dip information and fold axes in the Briones Valley quadrangle. This coverage includes arcs, points, and annotation. **Note:** The structure coverage may include additional point data that is not plotted in the map sheet (plotfiles oakmap.ps or oakmap.pdf) because of space constraints at map scale.

ow-geol.e00	ow-geol/	Faults, depositional contacts, and rock units in the Oakland West quadrangle. This coverage includes arcs, polygons, and annotation.
oe-geol.e00	oe-geol/	Faults, depositional contacts, and rock units in the Oakland East quadrangle. This coverage includes arcs, polygons, and annotation.
oe-strc.e00	oe-strc/	Strike and dip information and fold axes in the Oakland East quadrangle. This coverage includes arcs, points, and annotation. **Note:** The structure coverage may include additional point data that is not plotted in the map sheet (plotfiles oakmap.ps or oakmap.pdf) because of space constraints at map scale.
sl-geol.e00	sl-geol/	Faults, depositional contacts, and rock units in the San Leandro quadrangle. This coverage includes arcs, polygons, and annotation.
lt-geol.e00	lt-geol/	Faults, depositional contacts, and rock units in the Las Trampas Ridge quadrangle. This coverage includes arcs, polygons, and annotation.
lt-strc.e00	lt-strc/	Strike and dip information and fold axes in the Las Trampas Ridge quadrangle. This coverage includes arcs, points, and annotation. **Note:** The structure coverage may include additional point data that is not plotted in the map sheet (plotfiles oakmap.ps or oakmap.pdf) because of space constraints at map scale.
ha-geol.e00	ha-geol/	Faults, depositional contacts, and rock units in the Hayward quadrangle. This coverage includes arcs, polygons, and annotation.
ha-strc.e00	ha-strc/	Strike and dip information and fold axes in the Hayward quadrangle. This coverage includes arcs, points, and annotation. **Note:** The structure coverage may include additional point data that is not plotted in the map sheet (plotfiles oakmap.ps or oakmap.pdf) because of space constraints at map scale.

The database package also includes the following ARC coverages, and files:

ARC Coverages, which have been converted to uncompressed ARC/INFO export files:

ARC/INFO export file	Resultant Coverage	Description of Coverage
oak-quad.e00	oak-quad/	Polygon, line, and annotation coverage showing index map of quadrangles in the map area.
oak-corr.e00	oak-corr/	Polygon, line, and annotation coverage of the correlation table for the units in this map database. This database is not geospatial.
oak-so.e00	oak-so/	Polygon, line, and annotation coverage showing sources of data index map for this map database (see oakso.txt for sources of data list).
oak-as.e00	oak-as/	Polygon and line coverage of the index map of stratigraphic assemblages in the map area. (Assemblages are described in the publication pamphlet oakmf.ps, oakmf.pdf, or oakmf.txt)
oak-terr.e00	oak-terr/	Polygon, line, and annotation coverage of the index map of terranes in and around the study area. (Terranes are described in the publication pamphlet oakmf.ps, oakmf.pdf, or oakmf.txt)
oak-flt.e00	oak-flt/	Line and annotation coverage of the index map of faults and fault names for this map database.

oak-xsa.e00	oak-xsa/	Polygon, line, and annotation coverage of cross-section A-A'-A". This database is not geospatial.
oak-xsb.e00	oak-xsb/	Polygon, line, and annotation coverage of cross-section B-B'-B". This database is not geospatial.

ASCII text files, including explanatory text, ARC/INFO key files, PostScript plot files, and an ARC Macro Language file for conversion of ARC export files into ARC coverages:

oakmf.ps	A PostScript plot file of the pamphlet containing detailed unit descriptions and geological information, plus references cited, and describing the digital content of the publication (this pamphlet).
oakmf.pdf	A PDF version of oakmf.ps.
oakmf.txt	A text-only file containing an unformatted version of oakmf.ps.
oakso.txt	A text-only file containing a list of sources of data keyed to areas recorded in the coverage oak-so.
import.aml	ASCII text file in ARC Macro Language to convert ARC export files to ARC coverages in ARC/INFO.
mf2342d.rev	A text-only file containing the revisions list for this report.
mf2342e.met	A parsable text-only file of publication level FGDC metadata for this report.

The following supporting directory is not included in the database package, but is produced in the process of reconverting the export files into ARC coverages:

info/	INFO directory containing files supporting the databases.

Tar files

The three data packages described above are stored in tar (UNIX tape archive) files. A tar utility is required to extract the database from the tar file. This utility is included in most UNIX systems and can be obtained free of charge over the Internet from Internet Literacy's Common Internet File Formats Webpage (http://www.matisse.net/files/formats.html). The tar files have been compressed and may be uncompressed with **gzip**, which is available free of charge over the Internet via links from the USGS Public Domain Software page (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/public.html). When the tar file is uncompressed and the data is extracted from the tar file, a directory is produced that contains the data in the package as described above. The specifics of the tar files are listed below:

Name of compressed tar file	Size of compressed tar file (uncompressed)	Directory produced when extracted from tar file	Data package contained
mf2342a.tgz	6.3 MB (29 MB)	oakps	PostScript Plotfile Package
mf2342b.tgz	6.8 MB (6.8 MB)	oakpdf	PDF Plotfile Package
mf2342c.tgz	4.9 MB (15.5 MB)	oakdb	Digital Database Package

PostScript plotfiles

For those interested in the geology of the map area who don't use an ARC/INFO compatible GIS system we have included a separate data package with two PostScript plot files. One contains a color plot of the digital geologic map at 1:50,000 scale (oakmap.ps), along with an assemblage map, terrane map, cross sections, correlation chart, and map key. In addition, a second PostScript file, containing the geologic description and discussion and an appendix including a description of the digital content of the publication, is provided (oakmf.ps).

The PostScript images of the geologic maps and map explanation are 52 inches high by 34.5 inches wide, so a large plotter is required to produce paper copies at the intended scale. In addition, some plotters, such as those with continual paper feed from a roll, are oriented with the long axis in the horizontal direction, so the PostScript image will have to be rotated 90 degrees to fit entirely onto the page. Some plotters and plotter drivers, as well as many graphics software packages, can perform this rotation. The geologic description is on 8.5- by 11-inch pages.

The PostScript plotfiles for maps were produced by the 'postscript' command with compression set to zero in ARC/INFO version 7.1.1. The PostScript plotfiles for pamphlets were produced in Microsoft Word 6.0 using the Destination PostScript File option from the Print command.

PDF plotfiles

We have also included a second digital package containing PDF versions of the PostScript map sheet and pamphlet described above. Adobe Acrobat PDF (Portable Document Format) files are similar to PostScript plot files in that they contain all the information needed to produce a paper copy of a map or pamphlet and they are platform independent. Their principal advantage is that they require less memory to store and are therefore quicker to download from the Internet. In addition, PDF files allow for printing of portions of a map image on a printer smaller than that required to print the entire map without the purchase of expensive additional software. All PDF files in this report have been created from PostScript plot files using Adobe Acrobat Distiller. In test plots we have found that paper maps created with PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that those users with the capability to print the large PostScript plot files use them in preference to the PDF files.

To use PDF files, the user must get and install a copy of Adobe Acrobat Reader. This software is available **free** from the Adobe website (http://www.adobe.com). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an on-line manual and tutorial.

There are two ways to use Acrobat Reader in conjunction with the Internet. One is to use the PDF reader plug-in with your Internet browser. This allows for interactive viewing of PDF file images within your browser. This is a very handy way to quickly look at PDF files without downloading them to your hard disk. The second way is to download the PDF file to your local hard disk, and then view the file with Acrobat Reader. **We strongly recommend that large map images be handled by downloading to your hard disk**, because viewing them within an Internet browser tends to be very slow.

To print a smaller portion of a PDF map image using Acrobat Reader, it is necessary to cut out the portion desired using Acrobat Reader and the standard cut and paste tools for your platform, and then to paste the portion of the image into a file generated by another software program that can handle images. Most word processors (such as Microsoft Word) will suffice. The new file can then be printed. Image conversion in the cut and paste process, as well as changes in the scale of the map image, may result in loss of image quality. However, test plots have proven adequate. Many software packages designed to handle images (such as Adobe Illustrator or Photoshop) will open and work with PDF files and will produce plots of part or all of the large images without loss of image quality.

Obtaining the Digital Database and Plotfile Packages

The digital data can be obtained in any of two ways:

a. From the USGS Western Region Publications Web Page.
b. Sending a tape with request

To obtain tar files of database or plotfile packages from the USGS web pages:

The U.S. Geological Survey now supports a set of graphical pages on the World Wide Web. Digital publications (including this one) can be accessed via these pages. The location of the main Web page for the entire USGS is

http://www.usgs.gov

The Web server for digital publications from the Western Region is

http://geopubs.wr.usgs.gov

Go to

http://geopubs.wr.usgs.gov/map-mf/mf2342 to access this publication. Besides providing easy access to the entire digital database, the Western Region Web page also affords easy access to the PostScript plot files for those who do not use digital databases (see below).

To obtain tar files of database or plotfile packages on tape:

The digital database package, including database files, PostScript plotfiles, and related files can be obtained by sending a tape with request and return address to:

Oakland Metropolitan Area Geologic Database
c/o Database Coordinator
U.S. Geological Survey
345 Middlefield Road, M/S 975
Menlo Park, CA 94025

Do not omit any part of this address!

Copies of either the PostScript or PDF plot-file packages can also be obtained by sending a tape with request and return address to:

Oakland Metropolitan Area Geologic Map Plotfiles
c/o Database Coordinator
U.S. Geological Survey
345 Middlefield Road, M/S 975
Menlo Park, CA 94025

Do not omit any part of this address!

NOTE: Be sure to include with your request the exact names, as listed above, of the tar files you require. A report number is not sufficient.

The compressed tar file will be returned on the tape. The acceptable tape types are:

2.3 or 5.0 GB, 8 mm Exabyte tape.

Obtaining plots from a commercial vendor

Those interested in the geologic map, but who use neither a computer nor the Internet, can still obtain the information. We will provide the PostScript or PDF plot files on digital tape for use by commercial vendors who can make large-format plots. Make sure your vendor is capable of reading Exabyte tape types and PostScript or PDF plot files. Many vendors can also download the plotfiles via the Internet. Important information regarding file formats is included in the sections "Tar files," "PostScript plot files," and "PDF plot files" above, so be certain to provide a copy of this document to your vendor.

Obtaining plots from USGS

U.S. Geological Survey provides a map-on-demand service for certain map plotfiles, such as those described in this report. In order to obtain plots of the map sheet and accompanying pamphlet, contact:

USGS Information Services
Box 25286
Denver Federal Center
Denver, CO 80225-0046

(303) 202-4200

FAX: (303) 202-4695

e-mail: infoservices@usgs.gov

Revisions and version numbers

From time to time, new information and mapping, or other improvements, will be integrated into this publication. Rather than releasing an entirely new publication, the USGS has adopted a policy of using version numbers similar to that used in the computer industry. The original version of all publications will be labeled Version 1.0. Subsequent small revisions will be denoted by the increase of the numeral after the decimal, while large changes will be denoted by increasing the numeral before the decimal. Pamphlets and map products will be clearly marked with the appropriate version number. Information about the changes, if any, that have been made since the release of Version 1.0 will be listed in the publication revision file. This file will be available at the publication web site (see above) and will also be included in the digital database package. A simplified version of the revision list will be included in the publication metadata.

Digital database format

The databases in this report were compiled in ARC/INFO, a commercial Geographic Information System (Environmental Systems Research Institute, Redlands, California), with version 3.0 of the menu interface ALACARTE (Fitzgibbon and Wentworth, 1991, Fitzgibbon, 1991, Wentworth and Fitzgibbon, 1991). The files are in either GRID (ARC/INFO raster data) format or COVERAGE (ARC/INFO vector data) format. Coverages are stored in uncompressed ARC export format (ARC/INFO version 7.x). ARC/INFO export files (files with the .e00 extension) can be converted into ARC/INFO coverages in ARC/INFO (see below) and can be read by some other Geographic Information Systems, such as MapInfo via ArcLink and ESRI's ArcView (version 1.0 for Windows 3.1 to 3.11 is available for free from ESRI's web site: http://www.esri.com). The digital compilation was done in version 7.2.1 of ARC/INFO with version 3.0 of the menu interface ALACARTE (Fitzgibbon and

Wentworth, 1991, Fitzgibbon, 1991, Wentworth and Fitzgibbon, 1991).

Converting ARC export files

ARC export files are converted to ARC coverages using the ARC command IMPORT with the option COVER. To ease conversion and maintain naming conventions, we have included an ASCII text file in ARC Macro Language that will convert all of the export files in the database into coverages and create the associated INFO directory. From the ARC command line type:

Arc: &run import.aml

ARC export files can also be read by some other Geographic Information Systems. Please consult your GIS documentation to see if you can use ARC export files and the procedure to import them.

Digital compilation

The geologic map information was digitized from stable originals of the geologic maps at 1:24,000 scale. The author manuscripts (pen on mylar) were scanned using an Altek monochrome scanner with a resolution of 800 dots per inch. The scanned images were vectorized and transformed from scanner coordinates to projection coordinates with digital tics placed by hand at quadrangle corners. The scanned lines were edited interactively by hand using ALACARTE, color boundaries were tagged as appropriate, and scanning artifacts visible at 1:24,000 were removed.

Base maps

Base Map layers were derived from published digital raster graphics (DRGs) obtained from the U.S. Geological Survey Mapping Division Website for the San Francisco Bay area (http://bard.wr.usgs.gov). Please see the website for more detailed information about the original databases. Because the base map digital files are already available at the website mentioned above, they are not included in the digital database package.

Faults and landslides

This map is intended to be of general use to engineers and land-use planners. However, its small scale does not provide sufficient detail for site development purposes. In addition, this map does not take the place of fault-rupture hazard zones designated by the California State Geologist (Hart and Bryant, 1997). Similarly, because only some of the landslides in the mapped area are shown, the database cannot be used to completely identify or delineate landslides in the region. For a more complete depiction of landslide distribution, see Nilsen and others (1979), Ellen and others (1988, 1997), Pike (1997), and Wentworth and others (1997).

Spatial resolution

Uses of this digital geologic map should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. The fact that this database was edited at a scale of 1:24,000 means that higher resolution information is not present in the dataset. Plotting at scales larger than 1:24,000 will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Database specifics

What follows is a brief and simple description of the databases included in this report and the data in them. For a comprehensive look at the database structure and content, please see the FGDC Metadata file, mf2342d.met, included in the database package and available separately at the publication web page.

The map databases consist of ARC coverages and supporting INFO files, which are stored in a Stateplane projection (Table 1). Digital tics define a 2.5 minute grid of latitude and longitude in the geologic coverages corresponding with quadrangle corners and internal tics.

Table 1. Map Projection File

The maps are stored in Stateplane projection. The following is an annotated projection file of the type used in Arc/Info.

```
PROJECTION STATEPLANE
UNITS METERS
ZONE 3326                    -Arc/Info code corresponding to California Coordinate System, Zone 3
SPHEROID CLARKE1866
PARAMETERS
END
```

The content of the geologic database can be described in terms of the lines, points, and areas that compose the map. Each line, point, or area in a map layer or index map database (coverage) is associated with a database entry stored in a feature attribute table. Each database entry contains both a number of items generated by Arc/Info to describe the geometry of the line, point, or area, and one or more items defined by the authors to describe the geologic information associated with that entry. Each item is defined as to the amount and type of information that can be recorded. Descriptions of the database items use the terms explained in Table 2.

Table 2. Field Definition Terms

ITEM NAME	name of the database field (item)
WIDTH	maximum number of digits or characters stored
OUTPUT	output width
TYPE	B-binary integer, F-binary floating point number, I-ASCII integer, C-ASCII character string
N. DEC.	number of decimal places maintained for floating point numbers

Because the database structure for each of the seven quadrangles included in this publication is the same, in the description of the feature attribute tables below the notation <quad> has been used to denote that the description applies to any of the quadrangle coverages. For example, <quad>-geol means that the description applies to the geologic coverage for any quadrangle. The specific notation for a single coverage can be made by replacing <quad> with the two letter code for each quadrangle (ri – Richmond, bv – Briones Valley, ow – Oakland West, oe – Oakland East, lt – Las Trampas Ridge, sl – San Leandro, ha – Hayward). For example, ri-geol denotes the geologic coverage for the Richmond quadrangle. Similarly, some descriptions apply to all coverages in the publication. In that case, the notation <coverage> has been used. For example, <coverage>-ID means that the description is the same for every coverage. The specific notation for a single coverage can be derived by replacing <coverage> with the coverage name (ie. RI-GEOL-ID for the coverage ri-geol).

Lines

The lines (arcs) are recorded as strings of vectors and are described in the arc attribute table (the format of the arc attribute table is shown in Table 3). They define the boundaries of the map units, the boundaries of open bodies of water, and the map boundaries. These distinctions, including the geologic identities of the unit boundaries, are recorded in the LTYPE field according to the line types listed in Table 4.

Table 3. Content of the Arc Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	ITEM DESCRIPTION
FNODE#	4	5	B		starting node of arc (from node)
TNODE#	4	5	B		ending node of arc (to node)
LPOLY#	4	5	B		polygon to the left of the arc
RPOLY#	4	5	B		polygon to the right of the arc
LENGTH	4	12	F	3	length of arc in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
LTYPE	35	35	C		line type (see Table 4)
FAULTNAME	35	35	C		name of fault (oak-flt only)

Table 4. Line Types Recorded in the LTYPE Field

<quad>-geol, oak-terr, oak-as, oak-flt (no contacts)	<quad>-strc	oak-corr, oak-so and oak-quad
contact, approx. located	f.a., anticline, approx. located	map boundary
contact, certain	f.a., anticline, inferred	box
contact, inferred	f.a., overturned anticline, approx.	bracket
contact, inferred, queried	f.a., overturned syncline, approx.	scratch boundary
fault, approx. located	f.a., syncline, approx. located	quad
fault, certain	f.a., syncline, certain	contact, certain
fault, concealed	f.a., syncline, inferred	leader
fault, concealed, queried		
fault, inferred		
fault, inferred, queried		
leader		
map boundary		
normal fault, approx. located		
normal fault, certain		
normal fault, concealed		
reverse fault, approx. located		
reverse fault, certain		
reverse fault, concealed		
s.s. fault, r.l., approx. located		
s.s. fault, r.l., approx. located@		
s.s. fault, r.l., certain		
s.s. fault, r.l., certain@		
s.s. fault, r.l., concealed		
scratch boundary		
thrust fault, approx. located		
thrust fault, certain		
thrust fault, concealed		
thrust fault, inferred		
water boundary		

Note, not every line type listed is present in every coverage. For example, oak-terr only has some of the fault types listed.

The geologic and structural line types are ALACARTE line types that correlate with the geologic line symbols in the ALACARTE line set GEOL61.LIN according to the ALACARTE lines lookup table (GEOL61.LUT). For more information on ALACARTE and its linesets, see Wentworth and Fitzgibbon (1991).

Areas

Map units (polygons) are described in the polygon attribute table (the format of the polygon attribute table is shown in Table 5). In the geologic coverages (<quad>-geol) and the correlation coverage (oak-corr), the identities of the map units from compilation sources are recorded in the PTYPE field by map label (Table 6). Map units are described more fully in the accompanying text file. In other coverages, various areal information is recorded in the PTYPE field (data source region number, assemblage number, terrane label, quadrangle name). Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with polygon information will have a polygon attribute table, and these coverages will not have a point attribute table.

Table 5. Content of the Polygon Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	ITEM DESCRIPTION
AREA	4	12	F	3	area of polygon in square meters
PERIMETER	4	12	F	3	length of perimeter in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTYPE	35	35	C		unit label or other area label

Table 6. Unit labels (See oakmf.ps, oakmf.pdf, or oakmf.txt for descriptions of units)

H2O	Qhfp	Tmru
Jb	Qhl	Tms
Jgb	Qhsc	Tmu
Jpb	Qls	Tn
Jpb?	Qms	Tn?
Jsv	Qmt	To
KJf	Qpaf	To?
KJfm	Qpaf1	Tor
KJfs	Qpoaf	Tr
KJfy	Ta	Tr?
KJk	Tbd	Tro
KJkc	Tbe	Ts
KJkv	Tbf	Ts?
Kc	Tbg	Tsa
Kcg	Tbgc	Tshc
Kcs	Tbgl	Tsm
Kcv	Tbh	Tsms
Kfa	Tbi	Tsr
Kfgm	Tbl	Tss
Kfn	Tbp	Tst
Kjm	Tbr	Tt
Ko	Tbu	Tt?
Kp	Tc	Tts
Kr	Tcc	Tub
Ksc	Tccs	Tuc
Ksh	Tccs?	Tul
Kslt	Tcgl	Tus
Kss	Tcglt	Tush
Ku	Tchs	Tvh
Kus	Tcs	Tvhl
QTi	Tdi	Tvhu
QTi?	Tes	af
QTu	Tes?	alf
Qds	Tgvt	fc
Qhaf	Th	fg
Qhaf1	Th?	fm
Qhasc	Tlt	fs
Qhb	Tmb	sc
Qhbm	Tmll	sp
Qhbr	Tmls	sp?
Qhbs	Tmlu	spm

Note, not every unit label listed is present in every coverage. For example, queried units are not present in the correlation table coverage.

Points

Data gathered at a single locality (points) are described in the point attribute table (the format of the point attribute table is shown in Table 7) The identities of the points from compilation sources are recorded in the PTTYPE field by map label (Table 8). Additional information about the points is stored in additional attribute fields as described below and in Table 9. Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with point information will have a point attribute table, and these coverages will not have a polygon attribute table.

Table 7. Content of the Point Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	ITEM DESCRIPTION
AREA	4	12	F	3	area of polygon in square meters
PERIMETER	4	12	F	3	length of perimeter in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTTYPE	35	35	C		unit label
DIP	3	3	I		dip of bedding or foliation
STRIKE	3	3	I		strike of bedding or foliation

Table 8. Point Types Recorded in the PTTYPE Field

<quad>-strc
----

approx bedding
bedding
bedding w/tops
crumpled bedding
flat bedding
foliation
joint
ot bedding
ot bedding w/ tops
vert bedding
vert bedding w/ tops
vert foliation and bedding

The geologic point types in the structure coverage are ALACARTE point types that correlate with the geologic point symbols in the ALACARTE point set ALCGEOL.MRK according to the ALACARTE point lookup table. For more information on ALACARTE and its pointsets, see Wentworth and Fitzgibbon (1991).

References Cited

Aarons, B.L., 1958, Geology of a portion of the Las Trampas Ridge and Hayward quadrangles, California: Berkeley, University of California, M.A. thesis.

Addicott, W.O., 1970, Miocene gastropods and biostratigraphy of the Kern River area, California: U.S. Geological Survey Professional Paper 642, 174 p.

Armstrong, C. F., and Gallagher, Kathy, 1977, Fossils from the Franciscan assemblage, Alcatraz Island: California Geology, v. 30, p. 134.

Atwater, B.F., 1982, Geologic maps of the Sacramento-San Joaquin delta, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1401, 15 p., 21 sheets, scale 1:24,000.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Division of Mines and Geology, Bull. 183, 177 p.

Blake, M. C., Jr., Bartow, J. A., Frizzell, V. A., Jr., Schlocker, Julius, Sorg, Dennis, Wentworth, C. M., and Wright, R. H., 1974, Preliminary geologic map of Marin and San Francisco Counties and parts of Alameda, Contra Costa, and Sonoma Counties, California: U. S. Geological Survey Map MF-574.

Blake, M.C., Jr., Graymer, R.W., and Jones, D.L., 2000, Digital geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California (Digital database by Soule, A., and Graymer, R.W.): U.S. Geological Survey Miscellaneous Field Studies Report 2337, 29 p., 2 sheets, 1:62,500 scale, 8 Arc/Info coverages and associated files.

Blake, M. C., Jr., Howell, D. G., and Jayko, A. S., 1984, Tectonostratigraphic terranes of the San Francisco Bay Region, *in* Blake, M. C., ed., 1984, Franciscan Geology of Northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 43, p. 5-22.

Blake, M. C., Jr., Howell, D. G., and Jones, D. L., 1982, Preliminary tectonostratigraphic terrane map of California: U. S. Geological Survey Open-File Report 82-593, 9 p., 3 maps, scale 1: 750, 000.

Blake, M. C., Jr., Irwin, W. P., and Coleman, R. G., 1967, Upside-down metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon: U. S. Geological Survey Professional Paper 575C, p. 1-9.

Blake, M. C., Jr., and Jones, D. L., 1974, Origin of Franciscan melanges in northern California: Society of Economic Paleontologists and Mineralogists, Special Paper No. 19, p. 255-263.

Blake, M.C., Jr., and Wentworth, C.M., 1999, Structure and metamorphism of the Franciscan Complex, Mt. Hamilton area, Northern California: International Geology Review, v. 41, p. 417-424.

Clark, B.L., 1918, The San Lorenzo series of middle California: University of California Publications in Geological Sciences, v. 11, p. 45-234.

Conduit, C., 1938, The San Pablo flora of west central California: Carnegie Institute of Washington Publications Contributions to Paleontology, v. 476, p. 217-268.

Crawford, K.E., 1976, Reconnaissance geologic map of the Eylar Mountain quadrangle, Santa Clara and Alameda Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-764, scale 1:24,000.

Curtis, G.H., 1989, Late Cenozoic volcanic rocks of the central Coast Range, *in* Wahrhaftig, C., and Sloan, D., Geology of San Francisco and vicinity, Field trip guidebook T 105: Washington, D.C., American Geophysical Union, p. 33-35.

Dibblee, T.W., Jr., 1980a, Preliminary geologic map of the Briones Valley quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-539, scale 1:24,000.

___1980b, Preliminary geologic map of the Hayward quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-540, scale 1:24,000.

___1980c, Preliminary geologic map of the Las Trampas Ridge quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-545, scale 1:24,000.

___1980d, Preliminary geologic map of the Richmond quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey Open-File Report 80-1100, scale 1:24,000.

Doumani, G.I., 1957, Stratigraphy of the San Pablo Group, Contra Costa County, California: Berkeley, University of California, M.A. thesis, 72 p.

Durham, J.W., 1944, Megafaunal zones of the Oligocene of northwestern Washington: University of California Publications in Geological Sciences, v. 27, no. 5, p. 101-240.

Ellen, S.D., Cannon, S.H., and Reneau, S.L., 1988, Distribution of debris flows in Marin County *in* Ellen, S.D., and Wieczorek, G.F., eds., Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 1434, plate 6, scale 1:62,500.

Ellen, S.D., Mark, R.K., Wieczorek, G.F., Wentworth, C.M., Ramsey, C.W., and May, T.E., 1997, Principal debris-flow source areas in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 97-745E, scale 1:275,000 and 1:125,000.

Ellsworth, W.L., 1990, Earthquake history, 1769-1989, *in* Wallace, R.E., ed., The San Andreas fault system, California: U.S. Geological Survey Professional Paper 1515, p. 153-187.

Fitzgibbon, T.T., 1991, ALACARTE installation and system manual (version 1.0): U.S. Geological Survey Open-File Report 91-587B.

Fitzgibbon, T.T., and Wentworth, C.M., 1991, ALACARTE user interface-AML code and demonstration maps (version 1.0): U.S. Geological Survey Open-File Report 91-587A.

Freeberg, J., 1990, Selected references to the geologic environment of Alameda County: U.S. Geological Survey Library Circular, 28 p.

Geomatrix Consultants, 1998, Final Report, Walnut Creek Water Treatment Plant Expansion Seismic Study-Phase II: prepared for the East Bay Municipal Utilities District, Oakland, California, 57 p. plus Appendices.

Gilmore, T.D., 1992, Historical uplift measured across the eastern San Francisco Bay region, *in* Borchardt, G., Hirschfeld, S.E., Lienkaemper, J.J., McClellen, P., Williams, P.L., and Wong, I.G., eds., Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 55-62.

Graymer, R.W., 1999, Offset history of the Hayward fault zone, San Francisco Bay region, California [abs.]: Geological Society of America Abstracts with Programs, v. 31, no. 6, p. A59

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1994, Preliminary geologic map emphasizing bedrock formations in Contra Costa County, California: A digital database: U.S. Geological Survey Open-File Report 94-622, includes plotfiles for 2 sheets, scale 1:75,000, database description pamphlet, 10 pp, geologic description and interpretation pamphlet, 20 pp.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1995, Geologic map of the Hayward fault zone, Contra Costa, Alameda, and Santa Clara Counties, California: A digital database: U.S. Geological Survey Open-File Report 95-597.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1996, Preliminary geologic map emphasizing bedrock formations in Alameda County, California: A digital database: U.S. Geological Survey Open-File Report 96-252, includes plotfiles for 2 sheets, scale 1:75,000, database description pamphlet, 14 p., geologic description and interpretation pamphlet, 33 p.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1999, Geology of the Cordelia and the northern part of the Benicia 7.5 minute quadrangles, California: A Digital Map Database: U.S. Geological Survey Open-File Report 99-162, includes plotfiles for one sheet, scale 1:24,000, database description pamphlet, 11 p., geologic description and interpretation pamphlet, 8 p.

Grimsich, J.L., Scott, G.R., Swisher, C.C., III, and Curtis, G.H., 1996, Paleomagnetism and $^{40}Ar/^{39}Ar$ dating of the Miocene Contra Costa Group, Berkeley Hills, California [abs.]: EOS, Transactions, American Geophysical Union, v. 77, no. 46, p. 165.

Ham, C.K., 1952, Geology of Las Trampas Ridge, Berkeley Hills, California: California Division of Mines and Geology Special Report 22, p. 1-26.

Harms, T.A., Jayko, A.S., and Blake, M.C., Jr., 1992, Kinematic evidence for extensional unroofing of the Franciscan complex along the Coast Range fault, northern Diablo Range, California: Tectonics, v. 11, p. 228-241.

Hart, E.W., and Bryant, W.A., 1997, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, revised 1997, 38 p.

Helley, E.J., Fitzpatrick, J.A. and Bischoff, J.F., 1993, Uranium series dates on oyster shells from elevated marine terraces of San Pablo Bay, California: U.S. Geological Survey, Open-File Report 93-286.

Helley, E.J., and Graymer, R.W., 1997a, Quaternary geology of Alameda County and surrounding parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, California: A digital database: U.S. Geological Survey Open-File Report 97-97, includes plotfiles for 2 sheets, scale 1:100,000, database description pamphlet, 13 pp, geologic description and interpretation pamphlet, 8 pp.

Helley, E.J., and Graymer, R.W., 1997b, Quaternary geology of Contra Costa County and surrounding parts of Alameda, Marin, Sonoma, Sacramento, and San Joaquin Counties, California: A digital database: U.S. Geological Survey Open-File Report 97-98, includes plotfiles for 2 sheets, scale 1:100,000, database description pamphlet, 13 pp, geologic description and interpretation pamphlet, 9 pp.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984, The orbital theory of Pleistocene climate: Support from a revised chronology of the marine d18O record *in* Berger, A.L., and others, eds., Milankovitch and climate, Part 1: D. Reidel Publishing Company, p. 269-305.

Jayko, A. S., and Blake, M. C., Jr., 1984, Sedimentary petrology of graywacke of the Franciscan Complex in the northern San Francisco Bay Area, California, in Blake, M. C., Jr., ed., Franciscan Geology of Northern California: Pacific Section S.E.P.M., Vol. 43, p. 121-134.

Jones, D.L., 1987, Extensional faults in collisional settings; comparison of California and Japan [abs.]: Geological Society of America Abstracts with Programs, v. 19, no. 7, p. 720.

Jones, D.L., and Curtis, G.H., 1991, Guide to the geology of the Berkeley Hills, central Coast Ranges, California, *in* Sloan, D., and Wagner, D.L., eds., Geologic Excursions in Northern California: San Francisco to the Sierra Nevada, California Division of Mines and Geology Special Publication 109, p. 63-74.

Jones, D. L., Graymer, R. W., Wang, C., McEvilly, T. V., and Lomax, A, 1994, Neogene transpressive evolution of the California Coast Ranges: Tectonics, v. 13, p. 561-574.

Kleinpell, R.M., 1938, Miocene stratigraphy of California, IX: Tulsa, OK, American Association of Petroleum Geologists, 450 p.

Krueger, S.W., and Jones, D.L., 1989, Extensional fault uplift of regional Franciscan blueschists due to subduction shallowing during the Laramide Orogeny: Geology, v. 17, p. 1,157-1,159.

Lawson, A.C., 1914, Description of the San Francisco District; Tamalpais, San Francisco, Concord, San Mateo, and Hayward quadrangles: U. S. Geological Survey Geological Atlas Folio 193, 24 p., scale 1:65,500.

Lawson, A.C., chairman, 1908, The California earthquake of April 18, 1906--Report of the State Earthquake Investigation Commission: Carnegie Institution of Washington, Publication 87, 2 v.

Lienkaemper, J.J., 1992, Map of recently active traces of the Hayward fault, Alameda and Contra Costa Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2196, 13 p., 1 sheet, scale 1:24,000.

Lindquist, T.A., and Morganthaler, J.D., 1991, Radiometric ages of rocks in the San Francisco-San Jose quadrangles, California: California Division of Mines and Geology Map No. 5, scale 1:250,000.

McDougall, Kristin, 1983, Upper Eocene to lower Miocene benthic foraminifers from the Santa Cruz Mountains area, California, *in* Brabb, E.E., ed., Studies in Tertiary stratigraphy of the California Coast Ranges: U.S. Geological Survey Professional Paper 1213, p. 61-82.

McDowell, F.W., Lehman, D.H., Gucwa, P.R., Fritz, D., Maxwell, J.C., 1984, Glaucophane schists and ophiolites of the Northern California Coast Ranges; isotopic ages and their tectonic implications: Geological Society of America Bulletin, v. 95, no. 11, p. 1,373-1,382.

McLaughlin, R. J., Sliter, W. V., Sorg, D. H., Russell, P. C., and Sarna- Wojcicki, A. M., 1996, Large-scale right-slip displacement on the East San Francisco Bay Region fault system: Implications for location of late Miocene to Pliocene Pacific plate boundary: Tectonics, v. 15, p. 1-18.

Murchey, B. M., and Jones, D. L., 1984, Age and significance of chert in the Franciscan Complex in the San Francisco Bay Region, *in* Blake, M. C., Jr., ed., Franciscan Geology of Northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 43, p. 23-30.

Nelson, B.K., 1991, Sediment-derived fluids in subduction zones; isotopic evidence from veins in blueschist and eclogite of the Franciscan Complex, California: Geology, v. 19, no. 10, p. 1,033-1,036.

Nilsen, T.H., Wright, R.H., Vlasic, T.C., and Spangle, W.E., 1979, Relative slope stability and lands-use planning in the San Francisco Bay Region, California: U.S. Geological Survey Professional Paper 944, 96 p.

Osuch, L.T., 1970, Geology of the Three Sisters quadrangle, California: Berkeley, University of California, M.S. thesis, 55 p.

Page, B.M., 1970, Time of completion of underthrusting of Franciscan beneath Great Valley rocks west of Salinian block, California: Geological Society of America Bulletin, v. 81, no. 9, p. 2,825-2,833.

Pease, M.H. Jr., 1954, Geology of the Sobrante Anticline and vicinity, Briones Valley quadrangle, Contra Costa County, California: Berkeley, University of California, M.A. thesis, 92 p.

Pike, R.J., 1997, Index to detailed maps of landslides in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 97-745D.

Radbruch, D.H., 1957, Areal and engineering geology of the Oakland West quadrangle, California: U.S. Geological Survey Miscellaneous Investigation Series Map I-239, scale 1:24,000.

Radbruch, 1969, Areal and engineering geology of the Oakland East Quadrangle, California: U.S. Geological Survey Map GQ-769, 1:24,000 scale.

Radbruch, D.H., and Case, J.E., 1967, Preliminary geologic map and engineering geologic information, Oakland and vicinity, California: U.S. Geological Survey Open-File Report 67-183, 1:24,000 scale.

Robinson, G.D., 1956, Geology of the Hayward quadrangle, California: U.S. Geological Survey Miscellaneous Geologic Quadrangle Map GQ-88, 1 sheet, scale 1:24,000.

Sarna-Wojcicki, A.M., 1976, Correlation of Late Cenozoic tuffs in the central Coast Ranges of California by means of trace- and minor-element chemistry: U.S. Geological Survey Professional Paper 972, 30 p.

Sarna-Wojcicki, A.M., 1992, Long-term displacement rates on the San Andreas fault system in northern California from the 6-Ma Roblar tuff, *in* Borchardt, Glenn, and others, eds., Earthquake hazards in the eastern San Francisco Bay Area, Proceedings of the 2nd Conference on Earthquake Hazards in the eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 29-30.

Sarna-Wojcicki, A.M., Bowman, H.W., and Russell, P.C., 1979, Chemical correlation of some late Cenozoic tuffs of northern and central California by neutron activation analyses of glass and comparison with X-ray fluorescence analysis: U.S. Geological Survey Professional Paper 1147, 15 p.

Savage, D.E., 1951, Late Cenozoic vertebrates of the San Francisco Bay region: University of California Publications Bulletin of the Department of Geological Sciences, v. 28, p. 215-314.

Sheehan, J.R., 1956, Structure and stratigraphy of N.W. Contra Costa County, California: Berkeley, University of California, M.A. thesis.

Sliter, W. V., McDougall, Kristin, Murchey, B. M., and Kohnen, E. V., 1993, Mesozoic and Cenozoic microfossils from geologic units within the San Jose 1:100,000 quadrangle, California: U. S. Geological Survey Open-File report 93-344, map scale 1: 100, 000.

Unruh, J.R. and Lettis, W.R., 1998, Kinematics of transpressional deformation in the eastern San Francisco Bay region, California: Geology, v. 26, p. 19-22.

U.S. Soil Conservation Service, 1958, Soil survey of the Santa Clara area: U.S. Soil Conservation Service Series 1941, no. 17, 202 p.

Wagner, J.R., 1978, Late Cenozoic history of the Coast Ranges east of San Francisco Bay: Berkeley, University of California, Ph.D. thesis, 160 p., 12 plates.

Wakabayashi, John, 1992, Nappes, tectonics of oblique plate convergence, and metamorphic evolution related to 140 million years of continuous subduction, Franciscan Complex, California: Journal of Geology, v. 100, p. 19-40.

Wakabayashi, J. and Sawyer, T.L., 1998, Paleoseismic investigation of the Miller Creek fault, eastern San Francisco Bay area, California: Final Technical Report submitted to U.S. Geological Survey, National Earthquake Hazards Reduction Program, Award No. 1434-HQ-97-GR-03141, 17 p., 7 figures, plate.

Weaver, C.E., 1953, Eocene and Paleocene deposits at Martinez, California: Washington University Publications in Geological Science, v. 7, p. viii, 1-102.

Weaver, C.E., Beck, R.S., Bramlette, M.N., Carlson, S.A., Forrest, L.C., Kelley, F.R., Kleinpell, R.M., Putnam, W.C., Taliaferro, N.L., Thorup, R.R., VerWieke, W.A., Watson, E.A., 1944, Correlation of the marine Cenozoic formations of western North America [chart no. 11]: Geological Society of America Bulletin, v. 55, no. 5, p. 569-598.

Wentworth, C.M., Blake, M.C., Jr., Jones, D.L., Walter, A.W., and Zoback, M.D., 1984, Tectonic wedging associated with emplacement of the Franciscan Assemblage, California Coast Ranges, *in*, Blake, M.C., Jr., ed., Franciscan geology of Northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Book 43, p. 163-174.

Wentworth, C.M., Blake, M.C., Jr., McLaughlin, R.J., and Graymer, R.W., 1998, Preliminary geologic map of the San Jose 30 X 60 minute quadrangle, California: A digital map image: U.S. Geological Survey Open-File Report 98-795, includes plotfiles for 2 sheets, scale 1:100,000, database description pamphlet, 6 pp, geologic description and interpretation pamphlet, 47 p.

Wentworth, C.M., and Fitzgibbon, T.T., 1991, ALACARTE user manual (version 1.0): U.S. Geological Survey Open-File Report 91-587C.

Wentworth, C.M., Graham, S.E., Pike, R.J., Beukelman, G.S., Ramsey, D.W., and Barron, A.D., 1997, Summary distribution of slides and earth flows in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 97-745C.

White, E.R., 1990, Contra Costa County, California; selected earth sciences references: U.S. Geological Survey Open-File Report 90-629, 19 p.

Working Group on California Earthquake Probabilities, 1999, Earthquake probabilities in the San Francisco Bay Region: 2000 to 2030 – A summary of findings: U.S. Geological Survey Open-File Report 99-517

Wright, R.H., 1974, Map showing the distribution of potassium feldspar and fossils in Mesozoic rocks of Marin and San Francisco Counties, and parts of Alameda, Contra Costa, and Sonoma Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-573, 1 sheet, scale 1:125,000.