



## **Geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California**

By M.C. Blake, Jr.<sup>1</sup>, R.W. Graymer<sup>2</sup>, and D.L. Jones<sup>2</sup>

Digital database by

Adam Soule<sup>2</sup> and R.W. Graymer<sup>2</sup>

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<sup>1</sup>1911 Wilson Ave, Bellingham, WA 98225

<sup>2</sup>345 Middlefield Rd., M/S 975, Menlo Park, CA 94025

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# Geologic Explanation and Acknowledgements

## Introduction

This map and map database represent the integration of previously published and unpublished maps by several workers (see Sources of Data index map and the corresponding table or the Arc-Info coverage ma-so and the textfile maso.txt) and new geologic mapping and field checking by the authors and others. The new data also include a new depiction of structural and stratigraphic relationships of rock packages (terranes). These new data are released in digital form to provide an opportunity for regional planners, local, state, and federal agencies, teachers, consultants, and others interested in geologic information to obtain the new data long before a traditional printed map could be published.

## Stratigraphy

### Mesozoic Complexes

In general, the Tertiary strata in the map area rest with angular unconformity on three highly deformed Mesozoic rock complexes: the Great Valley complex, the Franciscan complex, and the Salinian complex. The Great Valley complex is made up of the Jurassic Coast Range ophiolite, which in the map area consists mostly of serpentinite with associated smaller amounts of gabbro, diabase, and basalt, and the Great Valley sequence, made up of sandstone and shale of Jurassic and Cretaceous age. Although the sedimentary rocks and ophiolite have been tectonically separated everywhere in the map area, the Great Valley sequence was originally deposited on the ophiolite. The depositional relationship is known from contacts exposed in Sonoma, Solano, and Alameda Counties in the San Francisco Bay region, as well as elsewhere in California. This complex represents the accreted and deformed remnants of Jurassic oceanic crust and a thick sequence of turbidites.

The Franciscan complex is composed of weakly to strongly metamorphosed graywacke, argillite, basalt, serpentinite, chert, limestone, and other rocks. The rocks of the Franciscan complex in the map area were probably Jurassic oceanic crust and Jurassic to Cretaceous pelagic deposits overlain by Upper Jurassic to Upper Cretaceous turbidites. Although Franciscan complex rocks are dominantly little metamorphosed, high-pressure, low-temperature metamorphic minerals are common in 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 Zone.

The Salinian complex is composed of granitic plutonic rocks, and inferred gabbroic plutonic rocks at depth, overlain in places by strata as old as Cretaceous. In the map area, it is separated from the combined Franciscan and Great Valley complexes on the east by the San Andreas Fault Zone. In places outside the map area, small outcrops of pre-plutonic (Paleozoic?) rocks, such as marble, hornfels, schist, and metavolcanic rocks, are preserved (Brabb and others, 1998). The plutonic rocks are part of a batholith that has been displaced northward by offset on the San Andreas Fault system. Recent isotopic studies plus paleogeographic reconstructions (James and others, 1993; Wentworth and others, 1998b) suggest that these rocks were displaced northward from an original position some 310 km to the south, adjacent to the Mojave Desert. Earlier paleomagnetic data, suggesting displacements on the order of 2,500 km, are now being questioned. The Salinian complex rocks are for the most part not included in this study because they have recently been remapped by Clark and Brabb (1997).

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 separated 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 Sheet 2 and below).

### Description of Terranes

#### Great Valley complex

Healdsburg terrane  
KJgv, Kgvn, KJgvs

Near Black Point (Petaluma Point quadrangle), and in several places near Burdell Mountain (Petaluma River quadrangle, see Sheet 2 for quadrangle locations, Sheet 1

for distribution of rock units), Lower Cretaceous sedimentary rocks crop out that have similar lithology, structural state, and fossil content to strata found to the east along the west side of the Great Valley. Identical rocks are found to the north near Healdsburg where as much as 3,000 m of conglomerate is underlain by basalt, gabbro, and peridotite of the Coast Range ophiolite. Igneous rocks on the map are restricted to a single outcrop of basalt along Atherton Avenue (east of Novato, Novato quadrangle) that underlies several meters of friable mudstone containing scattered pebbles and fossils (*Buchia* sp.) of Early Cretaceous age (Berkland, 1969). Overlying the mudstone are hundreds of meters of pebble to cobble conglomerate, with scattered lenses of sandstone defining the bedding.

The greatest difference between the Healdsburg terrane and coeval Great Valley sequence rocks to the east is the composition of the conglomerate, which in the Healdsburg terrane is dominated by pebbles of light-colored (often pink) rhyolite porphyry and rhyolitic welded ash-flow tuff plus minor quartz sandstone (Blake and others, 1984). Biotite from two cobbles near Black Point yielded a K-Ar age of about 145 Ma (Berkland, 1969). The source area for this Late Jurassic rhyolite remains unknown but appears to be somewhere south of the present Sierra Nevada magmatic arc, based on sedimentologic and petrologic analyses (Jayko and Blake, 1993).

All outcrops of Great Valley sequence rocks in the map area are assigned to the Healdsburg terrane.

#### Coast Range ophiolite sp, sc

The Coast Range ophiolite underlies the late Jurassic and Cretaceous strata of the Great Valley sequence in all the terranes of the Great Valley complex. Therefore the ophiolite is not truly a separate terrane. Nevertheless, the outcrops of ophiolite in the area are shown separately on the terrane map (Sheet 2 or ArcInfo coverage ma-terr) because they are spatially and structurally distinct from sedimentary rocks known to be part of the Healdsburg terrane.

Although outcrops of the Coast Range ophiolite in other parts of the San Francisco Bay region include all the rock types that make up the ophiolite suite (pillow basalt, sheeted diabase, static gabbro, cumulate gabbro, peridotite), the only lithology present in the map area is serpentinite. However, serpentinite that is structurally interleaved with Franciscan mélange 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. Large, coherent bodies are shown as Coast Range ophiolite on the terrane map, whereas smaller bodies within the mélange are not differentiated, even though they are derived from the same ophiolite.

All serpentinite in the Coast Ranges was originally considered to be part of the Franciscan complex (for example, Page, 1966). Later workers noted that in many places the serpentinite was associated with other ophiolitic rocks and structurally over the Franciscan rocks. The fault boundary was called the Coast Range thrust and was thought to represent the subduction-derived contact between the overlying Great Valley complex rocks and underplated Franciscan complex rocks (for example, Irwin, 1973). Still later workers noted that many serpentinite outcrops contain high-grade metamorphic blocks and high-temperature serpentine (antigorite). These workers subdivided the serpentinite into high-grade Franciscan and low-grade Coast Range Ophiolite bodies (for example, Coleman, 1996). The idea of two different serpentinites was supported by the observation that in many places the serpentinite was not structurally over the Franciscan complex rocks, but interleaved within them. However, some outcrops of high-grade serpentinite are structurally on top of Franciscan complex rocks and are clearly associated with other rock types of the ophiolite suite and even overlying Great Valley sequence strata (for example, Evarts, 1977). In addition, many of the interleaved serpentinites are low grade (for example, those at Mount Tamalpais, San Rafael quadrangle).

We therefore consider all serpentinites to be derived from the same ophiolite. High-grade bodies represent the base of the ophiolite of the overlying plate that was deep in the subduction zone, whereas low-grade bodies represent higher levels of the overlying plate that were never subjected to high temperature conditions. Interleaving of serpentinite into the Franciscan complex, as well as entraining of high-grade blocks into the high-temperature serpentinite, occurred during accretion and subsequent deformation of the Franciscan complex terranes.

#### Franciscan complex

##### Marin Headlands terrane Kfgwy, KJfch, Jfgs

The rocks at the Marin Headlands consist of pillow basalt overlain by radiolarian chert, which in turn is overlain by sandstone (graywacke) and shale. These rocks were part of the type locality of the Franciscan Formation (Lawson, 1914), and they have the further distinction of being one of the first terranes to be recognized in the North American Cordillera (Blake and others, 1974).

Detailed mapping (Schlocker, 1974; Wahrhaftig, 1984) plus topical studies, including radiolarian biostratigraphy (Murchey, 1984), chert sedimentology and geochemistry (Karl, 1984; Murray and others, 1990), and geochemistry of the basalt (Shervais, 1989), suggest that the basalt formed during the Early Jurassic (about 190 Ma) at a mid-ocean ridge, was covered by a blanket of radiolarian chert during its long (nearly 100 m.y.) trip across the ocean, and eventually reached a trench where the

chert was covered by Cretaceous turbidites derived from a volcanic arc. The volcanic arc was probably related to ocean-continent subduction, because the sandstones contain a small amount of potassium feldspar and other minerals indicative of continental sources. Therefore, turbidite deposition may mark the approach of the Marin Headlands terrane to North America, followed by partial subduction and accretion.

Where all of this took place is not well documented, but both the radiolarian biostratigraphy and paleomagnetic studies (Hagstrum and Murchey, 1993) suggest that the basalt and basal chert formed near the equator and then were carried eastward or northeastward toward North America. These studies suggest that the terrane entered a trench far to the south of its present position (somewhere around southern Mexico) and then was carried northward as much as 4,000 km by dextral strike-slip faulting. An earlier paleomagnetic study (Curry and others, 1984) suggested that the clastic sedimentary rocks, presumably deposited in the trench, formed at much higher latitudes (<1,000 km south of their present position), but this interpretation is problematical because all the rocks are remagnetized (Hagstrum and Murchey, 1993).

Regardless of these details, the history of the Marin Headlands terrane represents an attractive model for other Franciscan complex terranes, even though many of these lack parts of the stratigraphic sequence or are too metamorphosed to permit dating of the radiolarians (Murchey and Blake, 1993).

#### Yolla Bolly terrane KJfm, Jfmch, Jfmg

The Yolla Bolly terrane is one of the most widespread and distinctive Franciscan complex terranes in the map area. It 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, 1998a).

Most of the areas identified as Yolla Bolly terrane (Sheet 2) consist of metagraywacke and subordinate interbedded slaty mudstone plus scattered lenses of metachert. These cherts were originally thought to be interbedded with the graywacke but it is now clear that

they underlie it and have been repeated by knife-sharp thrust faults and isoclinal folds. In a few places, thin lenses of bluish or greenish metabasalt (bluestone or greenstone) is preserved beneath the metachert, but most of this basal oceanic material has been removed by faulting. However, some fairly large bodies of metagreenstone are present.

Unlike Yolla Bolly rocks in the high northern Coast Ranges and in the Diablo Range to the southeast of the map area, the metagraywackes in Marin County are not resistant but underlie areas of low relief and are prone to landslides. Much of this is probably related to the presence of secondary swelling clays (vermiculite) formed during weathering of the metagraywacke (Berkland, 1964). The reason for the difference in weathering between metagraywacke here and elsewhere is not well understood.

#### Alcatraz terrane Kfs, Kfss, Kfsh

On Alcatraz and Yerba Buena Islands, north and east of San Francisco in San Francisco Bay, and in eastern San Francisco (Sheet 2), 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 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 ellioti* 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 Middle Cretaceous (Cenomanian) age (oral comm., W.P. Elder, 1997).

Although the Middle 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.

#### Novato Quarry terrane Kfs, Kfch

The Novato Quarry terrane forms a relatively narrow, discontinuous northwest-trending belt between the San Andreas and Hayward faults (Sheet 2 and Graymer and others, 1996). 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* sp. of Late Cretaceous (Campanian) age have been found in this terrane. Sandstone composition also differs from the Alcatraz terrane. Sandstone is arkosic with abundant K-spar, indicating derivation from a granitic or rhyolitic source area.

Excellent exposures can be seen in several quarries in Marin County including the type locality near Ignacio (northwest of Hamilton Air Force Base, Novato quadrangle) and the San Rafael Rock Quarry at Point San Pedro (San Quentin quadrangle). These rocks are also well exposed at Point Richmond and Point San Pablo (San Quentin quadrangle). The age of these rocks constrains Franciscan complex deposition to have continued at least into Campanian time, with subsequent subduction and accretion.

Earlier detailed mapping (Berkland, 1969) showed several narrow lenses of radiolarian chert, in fault contact with the arkosic sandstone, along the western slopes of Big Rock Ridge (Novato quadrangle). Although these chert lenses were mapped as being in fault contact with the sandstone, it now appears possible that they represent pieces of the basal oceanic crust of the Novato Quarry terrane. Because no information regarding radiolarians from these cherts is available, they should be collected and studied.

#### San Bruno Mountain terrane Kfs

Another graywacke terrane of unknown age crops out in San Francisco, and along Bolinas Ridge in western Marin County (mostly in Bolinas and Inverness quadrangles). It is characterized by relatively well-bedded turbidites containing abundant detrital K-spar plus widespread veins of hydrothermal quartz and adularia that are spatially related to rhyolite dikes and other intrusive bodies. Adularia from San Bruno Mountain, just south of the map area, and Bolinas Ridge have been dated at about 12-13 Ma (McLaughlin and others, 1996).

Numerous attempts to find fossils in these rocks have been unsuccessful. Hemipelagic shales were collected for foraminifers and dinoflagellates, but none were preserved. The problem appears to be the widespread hydrothermal alteration.

It has recently been suggested (Wakabayashi, 1992) that the San Bruno Mountain terrane is the same as the Novato Quarry terrane. However, based on point counts of the sandstones (Jayko and Blake, 1984) and unpublished chemical analyses we believe that these terranes are distinct.

#### Nicasio Reservoir terrane Jfg, KJfch, Kfgwy

An elongate belt of pillow basalt, gabbro, and minor radiolarian chert can be followed from Mt. Tamalpais (San Rafael quadrangle) north to Black Mountain (Inverness quadrangle) in western Marin County (Sheet 1). These rocks have been mapped in considerable detail (Gluskoter, 1962; Wright, 1984), and the basalts have received considerable attention including detailed study of their geochemistry, petrology (Swanson and Schiffman, 1979), and paleomagnetic character (Gromme, 1984). In addition, some of the chert has been dated (Murchev and Jones, 1984), and the overlying graywackes were the subject of a petrographic and geochemical study by Wright (1984).

These topical studies suggest that the Nicasio Reservoir terrane represents a fragment of a Late Jurassic-Early Cretaceous ocean island (similar to Hawaii) that formed about 20 degrees south of its present position and was accreted to the continental margin after Early Cretaceous (Valanginian-Hauterivian) time. Its position in the map area outboard of the Novato Quarry terrane suggests that it was moved into its final relative structural position in Late Cretaceous (Campanian) or later time.

#### Permanente terrane Kfl, Kfg, Kfdb

Several blocks of gray limestone with replacement chert crop out along the San Andreas Fault Zone, north of Bolinas (Bolinas quadrangle). These are identical, lithologically and paleontologically, to the Calera Limestone of the San Francisco Peninsula (Sliter, 1984), and were assigned to the Permanente terrane by Blake and others (1984). The Permanente terrane consists of accreted sea-mounts that formed near the equator (Tarduno and others, 1985).

In addition to the scraps of limestone along the San Andreas Fault Zone, another outcrop of Middle Cretaceous limestone is exposed along the north shore of San Francisco Bay near Point Bonita. This limestone is interbedded with alkalic pillow basalt and was referred to as "the Point Bonita block" (Clark and others, 1991). The limestone, basalt, and associated diabase are probably a piece of the Permanente terrane that structurally underlies the Marin Headlands terrane.

The structural history of the Permanente terrane blocks in Marin County is not clear. They could be all that remains of a once more extensive terrane, or they could be blocks that were carried northward in the San Andreas Fault Zone. However, because the San Andreas Fault Zone now passes several kilometers west of Point Bonita, the latter possibility would require that the fault bounding the Point Bonita rocks on the east be a part (now probably inactive) of the San Andreas Fault Zone.

Central “terrane” (Mélange)

fsr (with blocks and lenses of Kfs, Kfss, Kfgwy, KJfch, KJfm, KJfgc, Jfg, Jfgs, Jfmgs, Jfmch, Jfmgc, Jfmj, Jspm, sp, sc)

All of the previously-described Franciscan and Great Valley 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). However, these rocks do not comprise a terrane in the strict tectonostratigraphic sense, in that they are the result of combining rocks from several terranes.

Most of the mélange 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 mixing of rocks derived from several terranes: the rocks that would form the sheared matrix from an unnamed and almost completely disrupted terrane, the chert, greenstone, graywacke, and metamorphic blocks from accreted Franciscan complex terranes, and the serpentinite from the Coast Range ophiolite.

In a few places, such as the abandoned quarry along Hwy 101 at Greenbrae (San Rafael quadrangle), it is possible to see preserved slabs of interbedded graywacke, mudstone, chert, and tuffaceous greenstone that probably 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 chert blocks in the mélange is different from that found in chert in the matrix. 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.

This difference in chert fauna 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 accreted or dispersed. Deformation during accretion resulted in the interleaving of the rocks that would become mélange matrix 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 incorporation of exotic blocks derived from the accreted terranes, such as the chert blocks from the Marin Headlands terrane (Blake and Wentworth, 1999). Only in a few locations, like Greenbrae, are the mélange matrix strata preserved.

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 Coast Range ophiolite above).

## Tertiary Overlap Sequence

The Mesozoic rocks in the study area are unconformably overlain by Miocene and younger strata. These strata lie on both the Franciscan and Great Valley complexes, and for the most part postdate (overlie) the faults bounding the complexes and terranes. They are therefore termed an overlap sequence. Juxtaposition of Franciscan and Great Valley complex terranes must predate deposition of these Miocene and younger strata.

Strong evidence suggests, however, that the overlap rocks and underlying Mesozoic rocks have been offset a large distance from their Miocene location. The overlap sequence includes the Miocene marine strata that crop out on and near Burdell Mountain (Ts, Petaluma River quadrangle), which lie unconformably on rocks of the Great Valley complex and Franciscan mélange. These Miocene rocks probably correlate with the middle Miocene strata of the Lone Tree unit of Osuch (1970), which is deposited on both Great Valley and Franciscan complex rocks near Hollister, about 190 km southeast of the mapped area (Osuch, 1970; Drinkwater and others, 1992; Wentworth and others, 1998a). This correlation is based on lithology, age, number and general type of fossils, and position below coeval and correlated volcanic rocks. The 190-km separation between the two outcrop areas is due to Miocene and younger offset along faults of the East Bay fault system (see Structure below for more on these faults and their offset).

## Sonoma Volcanics

Tsv, Tsr, Tsri, Tsa, Tst

The Sonoma Volcanics require special attention because of the wide range of rock types and ages included in this unit. In the map area, the rocks can be divided into three distinct volcanic packages: the andesite of Burdell Mountain, the mafic volcanics of the Tolay Creek area, and the remaining Sonoma Volcanics composed of mainly andesite and rhyolite (fig. 1).

The Burdell Mountain area volcanics differ from the other Sonoma Volcanics in their age,  $11.8 \pm 0.8$  Ma (K/Ar, Mankinen, 1972) to  $12.47 \pm 0.74$  (K/Ar, Fox and others, 1985b), and lithology, predominantly massive plagioclase and quartz-plagioclase porphyry andesite and dacite with a black or dark-gray groundmass. We correlate these rocks with andesite in the Quien Sabe Volcanics of Taliaferro (1948) and Leith (1949) that crops out about 190 km southeast of Burdell Mountain. The correlation is based on similar lithology and age (Drinkwater and others, 1992) and the presence of underlying fossiliferous Miocene marine strata. The Burdell Mountain andesite has been offset from the Quien Sabe Volcanics along faults of the East Bay fault system in the same way as the underlying Miocene strata mentioned above.

The mafic volcanic rocks of the Tolay Creek area (including the Donall Ranch volcanics of Youngman, 1986) differ from the Burdell Mountain volcanics in their

younger age,  $8.52 \pm 0.18$  to  $10.64 \pm 0.27$  Ma (K/Ar and fission track, Fox and others, 1985b), and more mafic composition. These rocks have been correlated by Fox and others (1985a) and Youngman (1986) with similar volcanics in the Berkeley Hills, about 45 km southeast of the study area, based on similar lithology and age. The volcanics of the Tolay Creek area are also possibly correlative with mafic volcanics known to predate and underlay the Petaluma Formation in oil test wells (Morse and Bailey, 1935), although Jones and Curtis (1991) suggested that the test well rocks are better correlated with the Quien Sabe/Burdell Mountain volcanics. Better age constraints, new data regarding the strata underlying the test well rocks, or careful geochemical comparison would resolve the question.

It is important to note that the Tolay Volcanics of Morse and Bailey (1935) included both the volcanics of the Burdell Mountain area and the Tolay Creek area, which are considered distinct herein. Previous correlations of Miocene volcanics (Fox and others, 1985a; Jones and Curtis, 1991; McLaughlin and others, 1996) treated the two volcanic bodies as a single unit, but distinguishing these two volcanic units is important for our discussion of Miocene and younger fault offset.

The remaining Sonoma Volcanics for the most part postdate and overlie the Petaluma Formation, although the base of the volcanics in places interfingers with the upper part of the Petaluma Formation. The volcanic rocks have yielded K/Ar and fission track ages of  $1.4 \pm 0.8$  to  $7.96 \pm 0.14$  Ma (Fox and others, 1985b; Sarna-Wojcicki, 1976). These rocks are also more silicic than the other two volcanic units, being made up mostly of andesite, dacite, and rhyolite.

These younger Sonoma Volcanics form a thick volcanic field in the area east of the Rodgers Creek fault zone. West of the fault zone they become distinctly thinner, and are only found as relatively thin tuff beds within the Wilson Grove Formation in the western part of the map area.

## Paleontology

Two sets of fossils proved especially productive in distinguishing the age of the units in the mapped area. The first set is made up of radiolaria, silicic plankton, that are preserved in chert in the Franciscan complex. The second set is composed of members of the genus *Inoceramus*, which proved to be invaluable in determining the age of the various Franciscan complex sandstones.

A good overview of fossils from the map area is provided by Wright (1974). More recent work on radiolaria from the map area has been done by Murchey and Jones (1984) and Murchey (1984).

## Radiometric Ages

Many radiometric ages have been published from rocks collected within and near the map area. Several K/Ar and Ar/Ar ages have been obtained from samples of Sonoma Volcanics. These ages have been published by Sarna-

Wojcicki (1976), Fox and others (1985b), and Youngman (1986). An overview of radiometric ages in the northern San Francisco peninsula and Marin Headlands area is provided by Lindquist and Morganthaler (1991).

## Structure

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, and Neogene oblique reverse faulting that continues at the present time.

The earliest structural relations in the map area are those that juxtapose the multiple terranes of the Franciscan complex and the Great Valley complex. Structural relations 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 structurally highest and innermost. 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 more coherent, less metamorphosed terranes.

The order of accretion of structurally lower terranes is more problematical. If structural position is related to order of accretion, the terranes in the map area probably accreted in the following order: Alcatraz, Novato Quarry, Nicasio Reservoir, Marin Headlands, San Bruno Mountain, and Permanente. Note that the arrival of the Novato Quarry terrane must postdate the deposition of the Late Cretaceous (Campanian) sandstones within it, and therefore in this model all the Franciscan complex terranes in the area except the Yolla Bolly and Alcatraz Island must have accreted in Campanian or later time. On the other hand, if the age of graywacke in a terrane marks its approach to the continental margin and accretion, the terranes probably accreted in the following order: Nicasio Reservoir, Alcatraz Island, Marin Headlands, Permanente, and Novato Quarry. The age of the San Bruno Mountain graywackes is unknown, so its order of accretion cannot be determined using this model. The latter model requires that the present structural position of the terranes is related primarily to large amounts of post-accretionary fault offset.

Presumably the rocks that would become the matrix for the mélangé 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/mélangé 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 serpentinized peridotite of the basal ophiolite present. Attenuation also took place between the Franciscan complex terranes, as evidenced by the structural pinching out of some terranes in the area. 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 (Ts) on Franciscan complex rocks in the Diablo Range (Osuch, 1970; Graymer and others, 1996) and on Great Valley complex strata in Marin County. 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 detritus in sedimentary strata of that period both south and east of the mapped area (for example, the Domingene Sandstone in the Cordelia area, 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, also see fig. 2), 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. Jones (1987) also suggested that the tectonic mixing associated with mélangé was accomplished during attenuation, and disruption of coherent parts of the mélangé matrix in the map area by normal faulting supports the idea.

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 the faulted middle Miocene strata (Ts) at Burdell Mountain (Petaluma River quadrangle). Jones and others (1994) described a significant component of compression normal to the San Andreas Fault system, and we suggest that the imbricate structure of the terranes in the map area (fig. 2 and the terrane map on Sheet 2) is the result, at least in part, of this compression. However, because the Pliocene Wilson Grove Formation seems to lap across the terrane-bounding faults, most of the reactivated offset on terrane-bounding faults probably was completed by Pliocene time. Pliocene and younger transpressional faulting was probably focused on faults east or west of the Wilson Grove Formation, such as the San Andreas, Tolay, or Rodgers Creek Faults, although the Wilson Grove Formation is pervasively folded.

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 and underlying marine strata at Burdell Mountain with similar rocks at Quien Sabe (fig. 1) requires about 190 kilometers of right-lateral offset on faults that run east of Burdell Mountain. The correlation of the volcanic rocks near Tolay Creek with similar rocks in the Berkeley Hills (fig. 1) has been used to constrain offset on the Hayward-Rodgers Creek Fault system to about 45 kilometers (Fox and others, 1985a). However, there is another outcrop of mafic volcanic rocks with underlying strata like that of the Berkeley Hills that crops out in the hills east of Union City, south of the map area (fig. 1). Offset of the southernmost volcanics near Tolay Creek to these rocks would permit as much as 80 kilometers of offset on the Hayward-Rodgers Creek Fault system. Nevertheless, that leaves 110 to 145 kilometers of offset unaccounted for.

McLaughlin and others (1996) correlated the volcanics of Burdell Mountain, the volcanics near Tolay Creek, and the volcanics of the Berkeley Hills with the Quien Sabe Volcanics, which would imply very small offset between the Burdell Mountain volcanics and those near Tolay Creek (less than 15 kilometers), and partition the remaining 95 to 130 kilometers of offset to faults east of the Hayward-Rodgers Creek Fault system. However, that correlation, based on overlapping ages of the various northerly volcanics with the Quien Sabe Volcanics, is problematical. Not only are the ages of the Burdell Mountain volcanics distinct from those of the other two areas ( $11.8 \pm 0.8$  to  $12.47 \pm 0.74$  Ma for Burdell Mountain,  $8.52 \pm 0.18$  to  $10.64 \pm 0.27$  Ma for Tolay Creek, see above,  $9.2 \pm 0.03$  to  $9.99 \pm 0.02$  Ma for Berkeley Hills, Grimsich and others, 1996), but the thick sequence of Tertiary strata underlying the volcanics of the Berkeley Hills (and presumably those near Tolay Creek, although they have never been observed) is completely different from the thin layer of Miocene strata underlying the Quien Sabe and Burdell Mountain Volcanics. In fact, the rocks directly under the volcanics of the Berkeley Hills are fluvial, whereas those under both the Burdell Mountain and Quien Sabe Volcanics are marine. The difference in age and underlying rocks suggests that the volcanics of the Berkeley Hills (and presumably the correlative volcanics near Tolay Creek) formed in a different depositional area at some distance from those at Quien Sabe and Burdell Mountain.

Given the idea of northward younging of volcanic centers related to the migration of the Mendocino triple junction proposed by Fox and others (1985a), it may be possible to estimate the approximate location of the younger Berkeley Hills/Tolay Creek volcanic center relative to the Quien Sabe volcanic center. The distance between the 12 Ma Quien Sabe volcanic field and the southeasternmost Sonoma Volcanics (3-5 Ma) is about 180 km, so northward migration of the volcanic centers should average about 20-25 km per Ma. Note that the

actual amount may be slightly larger, because the Quien Sabe Volcanics may have been moved north after eruption by offset on the Ortigalita Fault Zone east of them. Given the volcanism of the Berkeley Hills started about 9.9 Ma, that suggests the volcanic center was about 40-50 km north of the Quien Sabe center.

If this admittedly speculative location is approximately correct, it allows us to partition fault offset of the various volcanic bodies. The volcanics of the Berkeley Hills now lie about 140 km north of the Quien Sabe volcanics, or about 95 km north of the estimated position of their original volcanic center. Alternatively, the volcanics east of Union City (as above) could be considered the southern extent of the volcanics of the Berkeley Hills, which are about 105 km north of the Quien Sabe volcanics, or about 60 km north of the estimated position of their original volcanic center. In either case, the right-lateral offset to move the volcanics to their current location must have taken place on faults east of the volcanic outcrops. This partitions 60 - 95 km of offset onto the Calaveras-Green Valley, Palomares-Miller Creek-Moraga, Franklin Canyon, and related faults. As discussed earlier, the Hayward-Rodgers Creek Fault system is thought to have offset the volcanics 45 - 80 km. Note that these estimates are linked by which outcrop (Berkeley Hills or Union City) is used to estimate offset for the Berkeley Hills volcanics, therefore total offset on the Hayward-Rodgers Creek Fault and the faults to the east must be about 140 km. The remaining 50 km of total offset must have taken place on faults between the volcanics at Burdell Mountain and those near Tolay Creek, including the Tolay Fault. This 50 km offset explains the juxtaposition of older Quien Sabe derived volcanics now at Burdell Mountain with (and slightly north of) younger Berkeley Hills derived volcanics now near Tolay Creek.

Given the estimates of fault offset for the Chabot and Mission Faults in Alameda County (fig. 1), southeast of the mapped area (Graymer, 1999), the southern outcrop of possible Berkeley Hills Volcanics is probably not a good indicator of the southern extent of the Berkeley Hills volcanic body, because the outcrop has been moved many kilometers north relative to the Berkeley Hills outcrop. It is more likely that the southern outcrop is a fault sliver left behind by initial offset of the volcanic body, and moved into its current position by later offset on the

faults east of it. Therefore the preferred partitioning of total fault offset is: Hayward-Rodgers Creek Fault, 45 km; Hayward-Tolay Fault, 50 km; and faults east of the Berkeley Hills, 95 km. Note that because both the Tolay and the Rodgers Creek Faults root into the Hayward Fault Zone, the total Neogene offset for it is about 95 km.

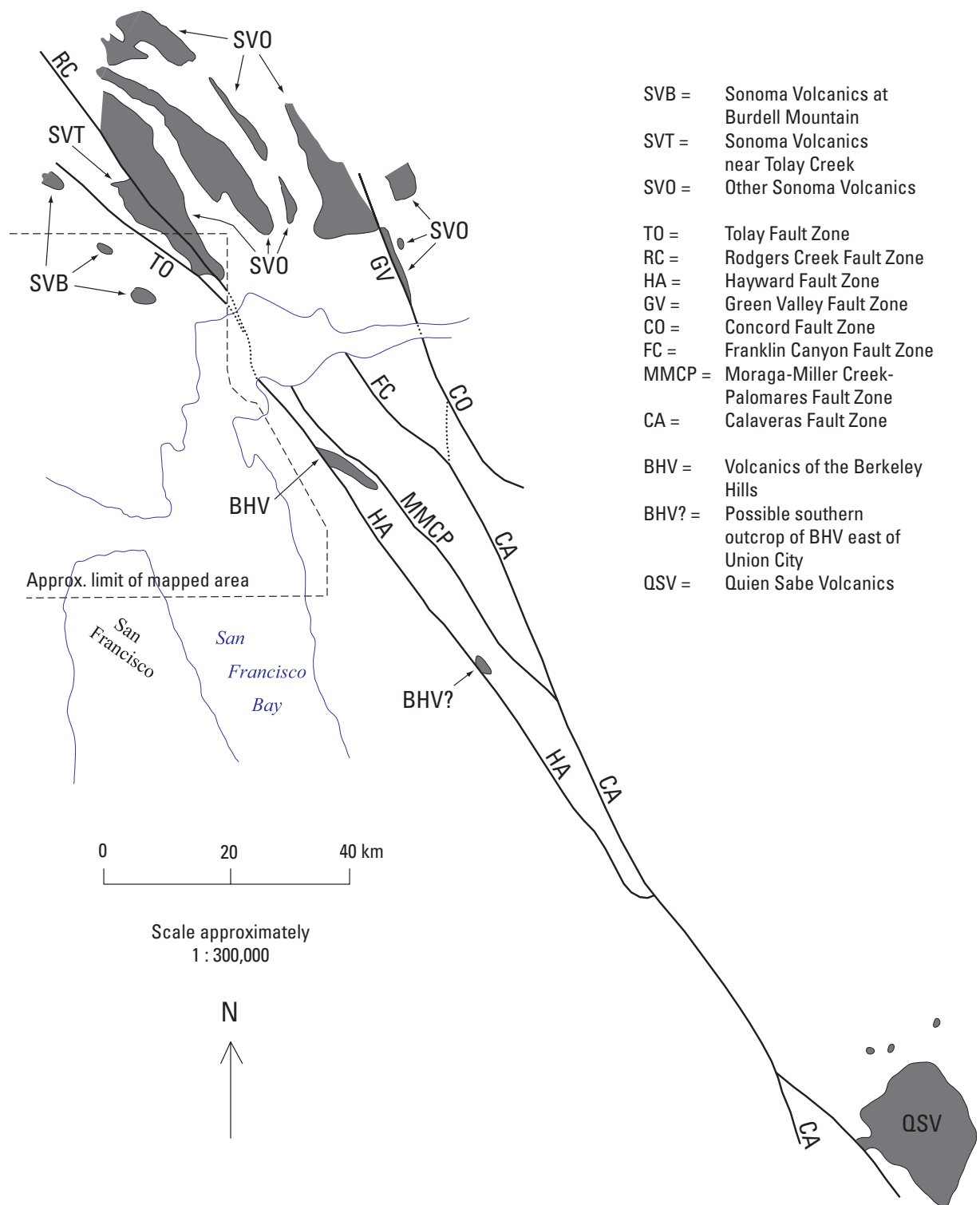
Active faulting in the map area is thought to be focused on the San Andreas and Rodgers Creek Fault Zones (Hart and Bryant, 1997). The San Andreas Fault in the map area experienced 4.5 to 5 meters of right-lateral surface fault rupture in the map area during the 1906 earthquake (Galloway, 1966; Lawson and others, 1908). The Rodgers Creek Fault is thought to be the northern extension of the Hayward Fault, which generated the large earthquake of 1868, although no fault rupture occurred in the map area during that quake. The 1969 Santa Rosa earthquakes (M 5.6 and M 5.7) were also generated by the Rodgers Creek Fault (Budding and others, 1991).

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**Figure 1.** Sketch map of the San Francisco Bay region showing distribution of various units within the Sonoma Volcanics, fault zones that may have offset parts of the Sonoma Volcanics from their original volcanic centers, and other volcanic rocks correlated with units in the Sonoma Volcanics. Note that lines on the map represent multiple fault strands in fault zones up to one kilometer or more wide.



# Description of Map Units

## SURFICIAL DEPOSITS

- Qaf **Artificial fill (Quaternary)**—Of varying character, consisting of clay, silt, sand, rock fragments, organic material, and (or) man made debris. Distinguished on map only in southern Marin and San Francisco Counties; but present elsewhere, especially within unit Qmf.
- Qmf **Artificial fill over marine and marsh deposits (Quaternary)**—Mud similar to unit Qm overlain by artificial fill, the limits of which are not mapped. Landward boundary is historic margin of bay marshlands from Nichols and Wright (1971)
- Qs **Beach sand (Quaternary)**—Well to moderately sorted; loose to soft
- Qd **Dune sand (Quaternary)**—Well sorted; loose to soft
- Qm **Marine and marsh deposits (Quaternary)**—Mud, including much organic material, silty mud, silt, and sand; very soft to soft where wet. Only exposed east of Tomales Bay
- Qls **Landslide deposits (Quaternary)**—Largely bedrock debris
- Qal **Alluvium (Quaternary)**—Sand, gravel, silt, and clay; loose to soft and friable
- Qsr **Slope debris and ravine fill (Quaternary)**—Angular rock fragments in sand, silt, and clay matrix; generally light yellow to reddish-brown. Only mapped in San Francisco
- Qu **Undifferentiated surficial deposits (Quaternary)**—Includes beach sand, marine deposits, artificial fill, alluvium, landslides, and, in South San Francisco quadrangle, some Colma Formation
- Qr **Volcanic gravel (Quaternary)**—Contains large angular blocks of rhyolite derived from unit Tsri; present only in northeast corner of Petaluma River quadrangle
- Qob **Older beach deposits (Quaternary)**—Predominantly well-sorted, medium- to coarse-grained, gray sand
- Qoal **Older alluvium (Quaternary)**—Poorly sorted sandstone and conglomerate; poorly indurated; lens-shaped bedding irregularly present, crossbedding common; locally contains small wood fragments along San Andreas fault zone; includes thinly laminated siltstone or claystone with interbedded gravels
- Qt **Marine and stream terrace deposits (Quaternary)**—Variably sorted and bedded sand, silt, and gravel; soft to poorly indurated. In the mapped area, this unit only crops out northwest of Stinson Beach
- Qmi **Millerton Formation (Quaternary)**—Deeply weathered, poorly indurated, marine and freshwater clay, silt, gravel, and conglomerate; maximum thickness about 20 m; exposed along Tomales Bay
- Qc **Colma Formation (Quaternary)**—Fine- to medium-grained sand with minor amounts of sandy silt, clay, and gravel as interbeds. Sand is well sorted, soft, and friable; occurs on Angel and Yerba Buena Islands and in San Francisco

## ROCKS WEST OF AND WITHIN THE SAN ANDREAS FAULT ZONE

- QTm **Merced Formation (early Quaternary and late Pliocene)**—Soft, buff-weathering, blue-gray siltstone with fine-grained silty sandstone in upper part; siltstone contains friable, fine-grained, clayey sandstone, some beds of shale pebble conglomerate, scattered calcareous concretions commonly containing fossils, and carbonized wood; sandstone is crossbedded and contains scattered layers of rounded pebbles and of shell fragments. Occurrence restricted to San Andreas Fault Zone
- Tsc **Santa Cruz Mudstone (late Miocene)**—Thin- to thick-bedded and faintly laminated olive-gray to pale-yellowish-brown marine siliceous mudstone with thin elongate carbonate concretions
- Tm **Monterey Shale (late and middle Miocene)**—Siliceous shale and minor chert; shale weathers white to gray or pinkish brown and is commonly laminated to thin bedded, variously micaceous, silty, porcelaneous, or cherty and locally contains calcareous concretions or sandstone or siltstone interbeds; chert is dark gray-brown and laminated, with thin shale and sandstone interbeds; fish scales, carbonaceous material, and molds of foraminifers, diatoms, and fish remains are variably present

## ROCKS EAST OF AND WITHIN THE SAN ANDREAS FAULT ZONE

### Tertiary overlap sequence

- Twg **Wilson Grove Formation (Pliocene)**—Structureless to poorly bedded, firm sandstone, light gray where fresh, weathering grayish or pale yellowish orange; mostly fine-grained to very fine grained with moderate

to good sorting; local thin pebble lenses near base, and, in western part of area, about 7 to 10 m of thick-bedded, coarse-grained to very coarse grained, locally pebbly sandstone that forms resistant outcrops

### **Petaluma Formation (Pliocene)**

- Tps Siltstone and claystone member**—Unbedded claystone, siltstone, and mudstone containing thick lenses of friable, cross-bedded, well-sorted sandstone and pebble conglomerate; pebbles consist of Franciscan lithologies, laminated siliceous shale and chert, and volcanic rock; unit includes a structureless vitric tuff bed about 3 to 8 m thick that consists largely of pumice lapilli and glass shards; brackish and fresh water molluscs occur locally, and vertebrate fossils of Hemphillian (early Pliocene and late Miocene) and Blancan (early Quaternary and late Pliocene) age have been found outside the map area
- Tpc Gray claystone member**—Gray claystone, unbedded to locally laminated with common thin interbeds of micritic ostracodal, or pisolitic limestone, and rare interbeds of tuffaceous mudstone. Ostracoda are abundant in some beds, fish remains are common, and thin-shelled mollusks are found locally
- Tsv Sonoma Volcanics (Pliocene and Miocene)**—Undifferentiated, includes rock near Burdell Mountain with a K-Ar age of 11.8 Ma (Mankinen, 1972). Locally subdivided into:
- Tsr Rhyolite lava flows**—Locally contains intercalated rhyolite tuff
- Tsri Rhyolite plugs and dikes**—May in part be extrusive
- Tsa Andesite and basalt lava flows**
- Tst Pumiceous ash flow tuff**—Locally partly welded, with intercalated bedded tuff
- Ts Sandstone (Miocene)**—On Burdell Mountain: calcareous, fine-grained tuffaceous sandstone, locally containing fossiliferous medium- to coarse-grained pebbly sandstone at base. Near San Antonio Creek: calcareous, medium- and fine-grained sandstone and siltstone with locally abundant barnacle plates and molluscan fragments, and fossiliferous, very coarse-grained, pebbly sandstone

### **Franciscan Complex**

- Kfs Sandstone and shale (Cretaceous)**—Sandstone and interbedded shale, with minor conglomerate; crops out in alternating sequence of largely medium-thick to very thick sandstone beds with generally minor interbedded shale and predominantly shale with interbedded thin to medium-thick sandstone beds; rock is locally severely sheared or brecciated but lacks tectonic inclusions of other rock types such as greenstone and chert which are common in unit fsr; thicker sandstone beds are medium- to coarse-grained arkosic wacke containing 2 to 25 percent detrital potassium feldspar, but commonly 2 to 5 percent, whereas thinner sandstone beds are fine grained, quartz rich wacke, and contain 0 to 2 percent detrital potassium feldspar; sandstone is light gray where fresh, weathering to buff colors, and shale is commonly dark gray; laumontite veins, calcite veins, and microscopic secondary prehnite and (or) pumpellyite are common in sandstone. Rocks of this unit typically form resistant topography. Excellent exposures occur in the quarry at Point San Pedro. In San Francisco, this unit is locally subdivided into:
- Kfss Massive sandstone (Cretaceous)**—Thick-bedded and massive graywacke sandstone interbedded with thin layers of fissile shale and fine-grained sandstone; some thick conglomerate lenses
- Kfsh Thin-bedded sandstone and shale (Cretaceous)**—Predominantly interbedded and laminated shale and fine-grained sandstone; beds generally 5 to 13 cm thick
- Kfl Limestone and chert (Cretaceous)**—Interbedded, thin-bedded gray limestone and black, red, green, and gray radiolarian chert. Beds are mostly less than 0.5 m thick. Restricted in study area to two small masses in the San Andreas Fault Zone between Olema and Bolinas. Foraminifera from this unit south of the study area indicate that the limestone formed near the equator during the Early (Barremian) and Late (Turonian) Cretaceous epochs (Wentworth and others, 1998a)
- Kfg Greenstone (Cretaceous)**—Consists of pillow lava and less abundant tuff, breccia, and intrusive basalt, interlayered with pelagic limestone (Kfl) and diabase dikes (Kfdb)
- Kfch Chert (Cretaceous)**—Red chert with shale interbeds. Locally altered and recrystallized, with manganese mineralization present in many outcrops. This unit crops out only in three lenses southwest of Hamilton Air Force Base
- Kfgwy Graywacke (Cretaceous)**—Graywacke, shale, and some metagraywacke; sandstone contains 0 to rarely as much as 5 percent detrital potassium feldspar. Coherent graywacke masses are as large as several miles long, but distribution largely unknown, and only locally distinguished on map. In southern Marin County and parts of San Francisco, graywacke and shale are well-bedded, up to 300 m thick, and overlie chert and greenstone. Shown to scale where possible, smaller masses shown by a triangle with a 'w' next to it
- Kfdb Diabase (Cretaceous)**—Finely crystalline mafic dike rock, thought to be a fragment of a sheeted dike complex (Wahrhaftig, 1984). This unit crops out only near Point Bonita

- KJfm Metamorphic rocks (Cretaceous and Jurassic)**—Variably sheared, containing blueschist minerals; chiefly metagraywacke with slight to moderated metamorphic fabric (textural zone 2 of Blake and others, 1967), but includes much metagreenstone (types II and III, metabasalt of Coleman and Lee (1963) largely distinguished as unit Jmgs), metachert, and minor amounts of metaconglomerate. Metagraywacke and minor slaty interbeds are similar to sandstone and shale of Kfs, Kfgwy, and fsr in color and bedding character, although bedding is commonly obscure. Rock is fractured and variably sheared, locally severely; tectonic inclusions, particularly of coarse-grained metamorphics and serpentinite, are common where unit is severely sheared. Severely sheared rock and metagraywacke that yields vermiculite on weathering form relatively subdued topography, whereas metagreenstone generally forms rugged mountains. Good exposures of these rocks occur in roadcuts along northeast side of Stafford Lake (west of Novato in the northeast corner of the San Geronimo quadrangle)
- KJfch Chert (Cretaceous and Jurassic)**—Chert with shale interbeds. Chert is thin bedded, closely fractured, and parts along bedding planes; contains tests of radiolaria that range in age from early Jurassic (Tithonian) to Middle Cretaceous (Cenomanian) age (Murchey, 1984); crops out as irregularly shaped bodies as long as 4.5 km. In southern Marin County and parts of San Francisco, chert up to 100 m thick overlies pillow lava and is overlain conformably by a few feet of fine-grained, black shale that grades into overlying graywacke and shale. Shown to scale where possible, smaller masses shown by a triangle with a 'c' next to it
- KJfgc Greenstone and chert (Cretaceous and Jurassic)**—Undivided Jfgs and KJfch, too tightly interlayered to show as separate units at map scale
- Jfg Greenstone (Jurassic)**—Consists of pillow lava and less abundant tuff, breccia, and intrusive basalt, diabase, and rare gabbro. Local lenses of thin-bedded radiolarian chert are as thick as 30 m. Fresh rock is hard, relatively unshaped, and ranges from essentially structureless to strongly pillowed; deeply weathered in places; crops out in elongate masses as long as 14 km, which, with one exception, are aligned in a northwest-trending band 5 kilometers east of the San Andreas Fault Zone
- Jfmgs Metagreenstone (Jurassic)**—Ranges from greenstone with patchy occurrence of blue amphiboles to schistose rock containing well developed glaucophane and lawsonite (type II to type III metabasalt of Coleman and Lee, 1963); occurs in unit KJfm largely as the former, and in unit fsr largely as the latter in discrete masses as long as 1 mile. Shown to scale where possible, smaller masses shown by a diamond with a 'u' next to it
- Jfmch Metachert (Jurassic)**—Fine-grained banded chert with bands or layers defined by bluish colors indicating the presence of blue amphibole; occurs as small discrete masses in fsr and as small unmapped lenses in KJfm and Jmgs. Shown to scale where possible, smaller masses shown by a diamond with an 'r' next to it
- Jfmgc Metagreenstone and metachert (Jurassic)**—Undivided Jfmgs and Jfmch, too tightly interlayered to show as separate units at the map scale
- Jfgs Greenstone (Jurassic)**—Similar to unit Jfg, except crops out as small, discrete masses as long as 1.5 km. In southern Marin County and parts of San Francisco, crops out as well-bedded pillow lavas and minor intrusive diabase that forms lowest exposed portion of section; overlain by chert and graywacke and repeated several times by faulting (Wahrhaftig, 1984); smaller masses are hard and relatively unfractured, but larger masses typically are closely fractured or sheared, are softened by weathering, and bear distinctive red soil. Shown to scale where possible, smaller masses shown by a triangle with a 'g' next to it
- Jfmg Metamorphic rocks (Jurassic)**—Chiefly gneissic, including glaucophane-garnet schist, eclogite, and garnet amphibolite (type IV metabasalt of Coleman and Lee, 1963). Shown to scale where possible, blocks too small to be shown to scale are shown by a diamond with a 'h' next to it
- Jspm Massive serpentinite (Jurassic)**—Hard, massive serpentine. Includes some partly serpentinized peridotite. This unit is mapped only in San Francisco
- sp Serpentinite (Jurassic)**—Including relatively fresh ultramafic rock; crops out as lenses and irregularly shaped masses, largely within and along boundaries of fsr; most serpentinite displays a prominent shear fabric. Shown to scale where possible, smaller masses shown by a triangle with an 's' next to it
- sc Silica-carbonate rock (Jurassic)**—Hard, tough rock that crops out mostly along margins of serpentinite bodies and as small discrete masses in severely sheared mélange locally contains minor cinnabar. Some parts of the rock may be Tertiary in age. Shown to scale where possible, smaller masses shown by a triangle with a 'n' next to it
- fsr Mélange**—A tectonic mixture of variably sheared shale and sandstone containing (1) hard tectonic inclusions largely of greenstone, chert, graywacke, and their metamorphosed equivalents, plus exotic high-grade metamorphic rocks and serpentinite and (2) variably resistant masses of graywacke, greenstone, and serpentinite up to several miles in longest dimension, and including minor discrete masses of limestone too small to be shown. Blocks and resistant masses have survived the extensive shearing evident in the mélange's matrix, and range in abundance from less than 1 to 50 percent or more of the rock mass. The

degree of shearing in the unit ranges from gouge to unsheared rock, with resistant masses relatively unsheared and matrix sheared. Severely sheared shale is abundant in areas where blocks are abundant. Fresh, relatively unsheared rock is hard, the larger resistant masses are pervasively fractured, and blocks are commonly tough and relatively unfractured. Sandstone is graywacke, grayish green where fresh, weathering to brown, commonly medium to coarse grained, containing abundant angular lithic grains and no detrital potassium feldspar, except rarely as much as 5 percent. Graywacke is locally veined with quartz and carbonate, and usually contains microscopic secondary pumpellyite. Topography of coherent masses resembles that of unit Kfs, whereas highly sheared matrix typically yields subdued, gently-rounded topography. Good exposures of both sheared matrix and relatively unsheared graywacke and shale occur at the crushed rock quarry just east of the intersection of State Highway 17 and U.S. Highway 101, in Greenbrae (Novato quadrangle)

## Great Valley Complex

- KJgv **Undivided Great Valley complex shale, sandstone, and conglomerate (Cretaceous and (or) Jurassic)**—Interbedded shale, sandstone, and pebble conglomerate; crops out on Burdell Mountain and along San Antonio Road north of Burdell Mountain. Sandstone associated with *Buchias* and other fossils at these two localities contains more than 10 percent detrital potassium feldspar
- Kgvn **Novato Conglomerate (Cretaceous)**—Pebble to boulder conglomerate with abundant rhyolite clasts and less abundant dark chert and granitic clasts. Minor coarse sandstone lenses and interbeds contain more than 10 percent detrital potassium feldspar. The unit contains thin, vesicular basalt in outcrop east of Novato along Atherton Avenue, which joins State Highway 37 about 2.5 miles east of Highway 101 (Novato quadrangle). Sandstone with *Buchias* along Atherton Avenue contains 0 percent detrital potassium feldspar
- KJgvs **Sandstone and claystone (Cretaceous and (or) Jurassic)**—Sandstone and interbedded gray claystone, with rare thin sandstone beds and calcareous nodules, and dark gray, laminated, platy siltstone. Crops out on the southeast margin of unit Kgvn in the Novato quadrangle.
- sp **Serpentinite (Jurassic)**—Greenish-gray to bluish-green sheared serpentinite, enclosing variably abundant blocks of unsheared rock. Blocks are commonly less than 3 m in diameter, but range in size from several centimeters to several meters; they consist of greenish-black serpentinite, schist, rodingite, ultramafic rock, and silica-carbonate rock, nearly all of which are too small to be shown on the map
- sc **Silica-carbonate rock (Jurassic)**—Hard, tough rock that crops out mostly along margins of serpentinite bodies. Locally contains minor cinnabar. Some parts of the rock may be Tertiary in age



# 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, explanation 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, explanation 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. Therefore, the description is included here.

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 chapter 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 authors, represents the general distribution of bedrock and surficial deposits in the

mapped area. Together with the accompanying text file (mageo.txt, mageo.pdf, or mageo.ps), 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 1:62,500 or smaller. The content and character of the database, as well as three methods of obtaining the database, 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 explanation, 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 any of the three 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").

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

## MF2337 Digital Contents

This report consists of three digital packages. The first is the PostScript Plotfile Package, which consists of PostScript plot files of a geologic map, explanation sheet, and geologic description. 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, 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):

mamap.ps	A PostScript plotfile containing an image of the geologic map and base maps at a scale of 1:62,500, along with a map key including terrane map, index maps, and correlation chart.
mamf.ps	A PostScript plotfile that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.

## PDF plotfile package

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

mamap.pdf	A PDF file containing an image of the geologic map and base maps at a scale of 1:62,500, along with a map key including terrane map, index maps, and correlation chart.
mageo.pdf	A PDF file that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.

## Digital database package

The database package includes geologic map database files for 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 -----
ma-geol.e00	ma-geol/	Polygon and line coverage showing faults, depositional contacts, and rock units in the map area.
ma-strc.e00	ma-strc/	Point and line coverage showing strike and dip information and fold axes.
ma-blks.e00	ma-blks/	Point coverage showing location of high-grade blocks in Franciscan rock units.
ma-altr.e00	ma-altr/	Polygon coverage showing areas of hydrothermal alteration.

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 -----
ma-quad.e00	ma-quad/	Line coverage showing index map of quadrangles in the map area. Lines and annotation only.
ma-corr.e00	ma-corr/	Polygon and line coverage of the correlation table for the units in this map database. This database is not geospatial.

ma-so.e00	ma-so/	Polygon and line coverage showing sources of data index map for this map database.
ma-terr.e00	ma-terr/	Polygon and line coverage of the index map of tectonostratigraphic terranes in the map area. (Terranes are described in mageo.txt or mageo.ps)

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

mamf.ps	A PostScript plotfile that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.
mamf.pdf	A PDF version of mamf.ps.
mamf.txt	A text-only file containing an unformatted version of mamf.ps without figures.
mafig1.tif	A TIFF file of Figure 1 from mamf.ps
mafig2.tif	A TIFF file of Figure 2 from mamf.ps
maso.txt	ASCII text-only file containing sources of data related to coverage ma-so.
import.aml	ASCII text file in ARC Macro Language to convert ARC export files to ARC coverages in ARC/INFO.
mf2337d.met	A parsable text-only file of publication level FGDC metadata for this report.
mf2337e.rev	A text-only file describing revisions, if any, to this publication.

The following supporting directory is not included in the database package, but is produced in the process of reconvertng 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>). Both 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
mf2337a.tgz	5.6 MB (27 MB)	maps	PostScript Plotfile Package
mf2337b.tgz	5.4 MB (5.4 MB)	mapdf	PDF Plotfile Package
mf2337c.tgz	3.4 MB (12 MB)	mageo	Digital Database Package

## PostScript plot files

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 geologic map database at 1:62,500 scale (mamap.ps). A second plot file contains a color plot of the explanation sheet, including a terrane map, correlation chart, and map key. Because this release is primarily a digital database, the plot files (and plots derived therefrom) have not been edited to conform to U.S. Geological Survey standards. Small units have not been labeled with leaders and in some instances map features or annotation overlap. Sample plots by the authors have proven to be quite legible and useful, however. In addition, a third PostScript file containing the geologic description and discussion is provided (mageo.ps).

The PostScript images of the geologic maps and map explanation are 36 inches high by 43 inches wide, so it requires a large plotter 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 plot files

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.

## Obtaining the Digital Database and Plotfile Packages

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

- a. From the Western Region Geologic Publication Web Page.
- b. Anonymous ftp over the Internet
- c. 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/mf2337>

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 and PDF plot files for those who do not use digital databases (see below).

#### **To obtain tar files of database or plotfile packages by ftp:**

The files in these reports are stored on the U.S. Geological Survey Western Region FTP server. The Internet ftp address of this server is:

<ftp://geopubs.wr.usgs.gov>

The user should log in with the user name 'anonymous' and then input their e-mail address as the password. This will give the user access to all the publications available via ftp from this server.

The files in this report are stored in the subdirectory:

[pub/map-mf/mf2337](ftp://pub/map-mf/mf2337)

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

Database files, PostScript plotfiles, and related files can be obtained by sending a tape with request and return address to:

Marin and San Francisco 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:

Marin and San Francisco 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. An MF Report number is not sufficient, unless you are requesting both the database package and plotfile package for the report.

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 Map On Demand Services**

U.S. Geological Survey is planning to provide a plot-on-demand service for map files, such as those described in this report, through Map On Demand Services. In order to obtain plots, contact Map On Demand Services at:

U.S. Geological Survey  
Information Services  
Box 25286  
Federal Center  
Denver, CO 80225-0046

(303) 202-4200  
1-800-ASK-USGS

FAX: (303) 202-4695

e-mail: [infoservices@usgs.gov](mailto:infoservices@usgs.gov)

Be sure to include with your request the MF Report number **and** the exact names, as listed in the Database Contents section above, of the plotfiles you require. A MF Report number and its letter alone may not be sufficient, unless you are requesting plots of all the plotfiles for that report.

## 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 7.1.1 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 1:62,500 scale. The author manuscripts (pen on mylar) were scanned using a 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 maps (Aitken, 1997) obtained from the U.S. Geological Survey Geologic Division Website for the Western Region (<http://wrgis.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 1:62,500 means that higher resolution information is not present in the dataset. Plotting at scales larger than 1:62,500 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, m2337d.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 Lambert projection. The following is an annotated projection file of the type used in Arc/Info.

```
PROJECTION LAMBERT
UNITS METERS                      -on the ground
SPHEROID CLARKE1866
PARAMETERS
37 3 60.000                      -1st standard parallel
38 25 60.000                     -2nd standard parallel
-120 30 0.00                     -central meridian
36 30 0.000                     -latitude of projection's origin
0.00000                          -false easting (meters)
0.00000                          -false northing (meters)
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 some of the database structure for is similar for all coverages, some descriptions apply to all coverages in the publication. In that case, the notation <coverage> has been used to indicate the description is valid for any included coverage. The precise description for a particular coverage can be made by substituting the name of the coverage for <coverage>. 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. MA-GEOL-ID for the coverage ma-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	
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)

**Table 4.** Line Types Recorded in the LTYPE Field

ma-geol and ma-terr	ma-strc	ma-so and ma-quad
-----	-----	-----
contact, certain	f.a., anticline, certain	county, boundary
contact, approx. located	f.a., anticline, concealed	map boundary
fault, certain	f.a., anticline, approx. located	quad
fault, concealed	f.a., syncline, certain	source boundary
fault, concealed, queried	f.a., syncline, concealed	water boundary
fault, approx. located	f.a., syncline, approx. located	leader
fault, inferred		
reverse fault, certain		
reverse fault, concealed		
scratch boundary		
water boundary		
map boundary		

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

The geologic linetypes 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	
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



**Table 6.** Unit labels (see the Geologic Description section for a description of map units)

Jfg	Kfsh	Qt
Jfgs	Kfss	Qu
Jfmch	Kgvn	Tm
Jfmg	QTm	Tpc
Jfmgc	Qaf	Tps
Jfmgs	Qal	Ts
Jspm	Qc	Tsa
KJfch	Qd	Tsa?
KJfgc	Qls	Tsr
KJfm	Qm	Tsri
KJgv	Qmf	Tst
KJgvs	Qmi	Tsv
Kfch	Qoal	Twg
Kfdb	Qoal?	fs?
Kfg	Qob	fsr
Kfgwy	Qr	sc
Kfl	Qs	sp
Kfs	Qsr	water

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	
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 (structure coverage only)
STRIKE	3	3	I		strike of bedding or foliation (structure coverage only)
BKTYPE	2	2	C		type of melange block (ma-blks only)

**Table 8.** Point Types Recorded in the PTTYPER Field

ma-strc	ma-blks
-----	-----
approx bedding	blk.h (high grade)
bedding	blk.l (low grade)
bedding w/tops	
foliation	
ot bedding	
ot bedding w/tops	
vert 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). The point types in the block coverage (ma-blks) indicate whether the metamorphic block is high-grade or low-grade. The type of metamorphic block is recorded in the BKTYPE field, as shown in Table 9 (equivalent PTYPEs are shown in parentheses).

**Table 9.** Block Types Recorded in the BKTYPE Field

ma-blks
-----
c (KJfch)
g (Jfgs)
h (Jfmg)
n (sc)
r (Jfmch)
s (sp)
u (Jfmgs)
w (Kfgwy)

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