U.S. Department of the Interior
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In cooperation with the California Department of Conservation, Division of Mines and Geology

Geology of the Cordelia and the northern part of the Benicia 7.5 minute quadrangles, California: A Digital Map Database

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Geologic Explanation

Introduction

This map database represents the integration of previously published and unpublished maps by several workers (see Sources of Data index map and the corresponding table or the coverage cdbe_so and the textfile cdbeso.txt) and new geologic mapping and field checking by the authors. 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 data to have the new data long before a traditional paper map is published. The data include a revised depiction of Quaternary units in the area emphasizing depositional environment, important new observations of lithology, paleontology, and structure, and a new interpretation of structural and stratigraphic relationships of rock packages (assemblages).

Stratigraphy

Lithologic associations in the area are divided into three assemblages (see index map on the map sheet or the coverage cdbe_as). As defined in Graymer, Jones, and Brabb (1994), assemblages are large, fault - bounded blocks that contain a unique stratigraphic sequence. The stratigraphic sequence differs from that of neighboring assemblages by containing different rock units, or by different stratigraphic relationship among similar rock units. These stratigraphic differences represent changes in depositional conditions in one or more large depositional basins. The current adjacent location of the different assemblages reflects the juxtaposition of different basins or parts of basins by large offsets along the faults that bound the assemblages.

In general, the Tertiary strata in the map area rest with angular unconformity on a complexly deformed Mesozoic rock complex, made up of the Coast Range ophiolite, which includes serpentinite, gabbro, diabase, and basalt; keratophyre which is closely associated with the ophiolite; and overlying Great Valley sequence of Jurassic and Cretaceous age. This complex represents the accreted and deformed remnants of Jurassic oceanic crust, overlying arc volcanic rocks, and a thick sequence of turbidites. An angular unconformity at the base of the Tertiary strata has been preserved in all of the assemblages. This unconformity is not exposed in the North Mt. Diablo assemblage in the map area, but is exposed in the area north of Mt. Diablo to the south and east of the map area..

Also present in the map area is a small body of rock from a second Mesozoic complex, the Franciscan Complex. The Franciscan in the mapped area is limited to a fault bounded lens of melange present in the west part of American

Canyon. Because the Franciscan Complex probably tectonically underlies the Coast Range Ophiolite/Great Valley complex throughout the San Francisco Bay area (Bailey and others, 1964), the fault sliver present in the mapped area is probably a fragment dragged up from below the base of the Coast Range Ophiolite by the uplift associated with the Lake Herman fault (see below). Because the Franciscan in the mapped area is only found in this fault sliver, it is not considered to be part of any assemblage.

In addition, there is a tiny fault sliver of algal limestone exposed about 1.5 kilometers south of Jameson Canyon. The limestone there is associated with silica-carbonate rock (altered serpentinite), which suggests that it too may have been dragged from below by fault movement, either from the Franciscan Complex or the Coast Range Ophiolite. However, the age of the rock is unknown, and there is not clear correlative rock in any nearby exposure of Franciscan or ophiolitic rock.

Whereas the assemblages in the mapped area all contain similar Mesozoic basement rocks, they are differentiated by Tertiary stratigraphy. In the westernmost assemblage in the map area, the Martinez assemblage, the Mesozoic rocks are overlain by Paleocene strata of the Vine Hill Sandstone. Although not exposed at the surface, the Paleocene and early Eocene Las Juntas Shale is thought to also be present in the subsurface beneath Benicia based on outcrops just to the south across the Carquinez Strait in Contra Costa County. In contrast, the base of the Tertiary sequence in the central assemblage in the area, the American Canyon assemblage, is the Eocene Domingene Sandstone. In addition, the lithology of strata of the same age in the different assemblages is different. For example, the clean quartz sandstone of the Eocene Domingene Formation is different from the arkosic sandstone of the Eocene Muir Sandstone.

The easternmost assemblage, the Northern Mt. Diablo assemblage, is mostly not exposed in this area, but the rocks east of the Green Valley fault zone are in structural continuity with well exposed rocks to the southeast in Contra Costa County (Graymer, Jones, and Brabb, 1994). The main difference between rocks there and rocks in the map area is the lack of thick beds of Sonoma Volcanics beneath the Tulare Formation in the south. The Lawlor Tuff, which crops out beneath the Tulare Formation in the southern area, is correlative with part of the Sonoma volcanics immediately southeast of the mapped area (Sarna-Wojcicki, 1976). The difference in thickness of volcanics reflects the proximity to the eruptive center of the Sonoma volcanic field. It should be noted that Sonoma Volcanics of similar age (Fox and others, 1985) crop out in both the American Canyon assemblage and the North Mt. Diablo assemblage, suggesting that juxtaposition along the Concord - Green Valley fault was in part accomplished prior to the development of the Sonoma volcanic field in this area (about 5.4 to 3.4 Ma, see description of Tsv below), or that the depositional settings of the two assemblages were separated originally by as little as 15 kilometers (see below).

Paleontology

Two sets of fossils proved especially productive in distinguishing the age of the units in the mapped area. The first set, made up of members of the genus *Buchia*, a Late Jurassic to Early Cretaceous mollusk, provides the ability to differentiate between the Knoxville Formation (KJk) and the lithologically similar parts of the younger parts of the Great Valley Sequence (Ku). *Buchia* from the map area have been identified by D.L. Jones (this study), and have been reported by T.W. Dibblee, Jr. (U.S. Geological Survey, unpublished mapping), and S.P. Bezore and D.L. Wagner (Calif. Div. Mines and Geology, oral comm., 1998).

The second set is nannoplankton, which proved to be invaluable in distinguishing between the younger shale of the Markley Formation (Tmk, Tmkj) and the older Nortonville Shale (Tnv). Eight Eocene nannoplankton samples are described by Bukry and others (1998), with ages ranging from middle Eocene, zone CP12b, to late middle Eocene, zone CP14a.

In addition, collections of foraminifers from the map area helped provide the general stratigraphic framework, though they were for the most part insufficient for the specific stratigraphic determinations possible with *Buchia* or nannoplankton. Seven samples of Cretaceous foraminifers collected by Howard Sonneman (Exxon Corporation) were reexamined by the late William Sliter (U.S. Geological Survey) in 1997. Sliter believed that four of the samples are probably Coniacian, G-2 zone of Goudkoff (1945), two are Albian, based on the planktic foraminifer *Ticinell primula*, and one is Cenomanian to Albian, based on the presence of *Osangularia californica*. In contrast, thirteen Cretaceous foraminfer samples were collected during this study and examined by Michael Mickey (Micropaleo Consultants, Inc.). He believes that all of the samples are Campanian, probably E zone of Goudkoff (1945).

Two collections of Eocene mollusks from the Domingene Sandstone were examined by Charles Powell II (U.S. Geological Survey), who indicated that the fossils are long-ranging, with a possible age from early to late Eocene.

Four samples of radiolarians from the Markley Formation were examined in 1998 by Joyce Blueford (Math/Science Nucleus). Most of the specimens were poorly preserved, but one had a moderately preserved and diverse assemblage. Blueford compares three of the samples with radiolarians found in the Jameson Shale of Weaver (1949), which is equivalent to the Jameson Mudstone member of the Markley Formation described in this report, and one with those in the Sidney Flat Shale member of the Markley Formation of Clark and Campbell (1942).

Radiometric Ages

No radiometric ages have been published from rocks collected within the map area. However, several K/Ar and Ar/Ar ages have been obtained from samples of Sonoma Volcanics collected nearby, both to the north and to the southeast. These ages have been published by Sarna-Wojcicki (1976) and Fox and others (1985). An overview of radiometric ages in the northern San Francisco Bay area is provided by Lindquist and Morganthaler (1991).

Structure

Faults and fault names are shown in the index map (or in the coverages cd_sp-flt and be_sp-flt). Two new fault names are used herein, the Lake Herman fault and the Sky Valley fault. The Sky Valley fault has previously not been mapped as a continuous feature. The Lake Herman fault is mostly equivalent to the West Sulphur Springs Valley thrust fault of Weaver (1949), but we have renamed it because for the most part it does not run in Sulphur Springs Valley (now called Sky Valley), to disassociate it from the erroneously named East Sulphur Springs Valley thrust fault (actually a normal fault), and because the name Sulphur Springs Valley no longer appears on U.S. Geological Survey quadrangles.

Active faulting in the mapped area seems to be confined to the Green Valley fault zone and associated faults in the area north of Cordelia. However, uplift of older alluvial deposits (Qpoaf) into preserved alluvial terraces in Sky Valley, the area southeast of Lake Herman, and the area around Blue Rock Springs Park, suggests that Quaternary compressional deformation and uplift have affected most of the area. This uplift may have been accomplished by oblique reverse offset on the Green Valley fault system, a hypothesis supported by the observation that older alluvial terraces have been uplifted more compared to surrounding younger deposits in the areas closer to the Green Valley fault zone. The mapped area can be divided into four main structural regimes, based on the trend and magnitude of deformation found there.

The southwest part of the area, southwest of the fault herein called the Lake Herman fault, is a broad synformal structure broken at the core by the Southampton fault. The Southampton fault is probably a steep, west dipping reverse fault that places west dipping Cretaceous strata up over and against east dipping Tertiary strata in the Benicia area. The structural trend in this part of the map area is roughly between N30W and N60W, although the Southampton fault trends NS in the area east of Vallejo, truncating the Tertiary strata in the footwall.

The central part of the map area, between the Lake Herman fault and the Green Valley fault, but mostly south of American Canyon, is characterized by tight, overturned folds, and imbricate faults, as shown in cross-section A-A'. The mapped relationships suggest a three-stage development of the structures in the area. The first stage was one of latest Cretaceous or Paleocene compression or oblique compression, which was manifested by at least four stacked sequences of Coast Range Ophiolite and Great Valley sequence rocks. This compression was followed by a time of extension or oblique extension in the Eocene related to the attenuation of the thickened crust, leading to the detachment faults in the map area that place higher parts of the sequence on lower (Great Valley sequence rocks over serpentinite, for example). The extension was accompanied by basin formation, as shown by the presence of a basal conglomerate in the Domingene Formation containing cobbles and boulders derived from the Coast Range Ophiolite. The period of extension was followed by another period of compression or more probably oblique compression. This period resulted in the juxtaposition of the Martinez and American Canyon assemblages along the Lake Herman fault, the tight, east-vergent folding of the Tertiary strata, and the east vergent oblique reverse fault herein called the Sky Valley fault. The Sky Valley fault is part of this later compressional period because it truncates the attenuation faults in the Mesozoic rocks, because splay faults from it form minor cross-faults in the folded Tertiary rocks, and because Sky Valley fault itself cuts the Tertiary strata northeast of Page Flat. The Lake Herman fault is probably a reactivated part of the earlier imbricate reverse structures, but it also is part of the later deformation because it forms the boundary between two assemblages with different Tertiary stratigraphy. Because the structures of the younger period are mostly east vergent, the west vergent Lake Herman fault must have formed as a back thrust in an east vergent system, probably taking advantage of the pre-existing crustal weakness. The structures in this part of the map area trend generally N30W to NS, although they bend to N60W near the west edge of the map in the westernmost part of American Canyon. Many of the structures are truncated on the north by the N60E trending normal faults in the east part of American Canyon and the EW trending fault about 3 km south of Jameson Canyon and east of Napa Junction. The latest period of deformation in this area must postdate Eocene deposition, but precede the Quaternary because Pleistocene surficial deposits lack geomorphic expression of fault deformation.

The northern part of the area is characterized by broadly folded, gently dipping Tertiary strata, predominantly Markley Formation, as shown in cross-section B-B'. The gently dipping strata are cut by two reverse faults that juxtapose older parts of the Tertiary section over younger rocks. Although the strata are generally equivalent to those found in the central part of the map area (the one exception is that Nortonville Shale was not found by us between the Domingene and Markley Sandstones), the lack of strong deformation suggests that this structural block was detached from the rocks to the south, and has deformed independently from those rocks. Structures in the northern part have no well defined trend, ranging from EW to NS. The one outcrop that suggests that more deformation may be present in this area than reflected by the gently dipping beds is the fault lens of silica-carbonate rock and associated algal limestone south of Jameson Canyon. The presence of ophiolitic rock at the surface suggests large amounts of uplift. The mechanism that brought this fault lens to the surface is at present not understood. The gently folded strata in this area are capped by relatively undeformed Pliocene Sonoma Volcanics, indicating that most of the structures formed after Eocene deposition but before Pliocene volcanism.

The eastern part of the map area is dominated by reverse-oblique right-lateral faults related to the Green Valley fault zone. The Green Valley fault zone is presently active, as shown by evidence of creep in three places in the map area (CDMG, 1993), and microseismicity (Olson and Showalter, 1991). Offset of the Sonoma volcanics from the map area to the area west of Grizzly Bay, to the southeast of the map area, suggests that the zone may have as little as 15 km of post-volcanic (about 4 Ma) offset. The Green Valley fault zone trends between N20W and NS. The similarity in trend between the Green Valley fault zone and the structures in the central part of the map area, including the Sky Valley and Lake Herman faults, raises the interesting possibility that those faults were the foci of right oblique deformation in Miocene or Pliocene time that has now transferred to the Green Valley fault zone.

Description Of Map Units

af **Artificial fill (Historic)**--Loose to very well consolidated gravel, sand, silt, clay, rock fragments, organic matter, and man-made debris in various combinations. Thickness is variable and may exceed 30 m in places. Some is compacted and quite firm, but fill made before 1965 is nearly everywhere not compacted and consists simply of dumped materials alf **Artificial levee fill (Historic)**--Man-made deposit of various materials and ages, forming artificial levees as much as 6.5 m high. Some are compacted and quite firm, but fills made before 1965 are almost everywhere not compacted and consist simply of dumped materials. The distribution of levee fill conforms to levees shown on the most recent U.S. Geological Survey 7.5-minute quadrangle maps

Qhasc **Artificial stream channels (Historic)**--Modified stream channels, in most places where streams have been straightened and realigned

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

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

Qhaf **Alluvial fan and fluvial deposits (Holocene)**--Alluvial fan deposits are brown or tan, medium dense to dense, gravely sand or sandy gravel that generally grades upward to sandy or silty clay. Near the distal fan edges, the fluvial deposits are typically brown, never reddish, medium dense sand that fines upward to sandy or silty clay

Qcl **Colluvium (Holocene)**--Loose to firm, friable, unsorted sand, silt, clay, gravel, rock debris, and organic material in varying proportions

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

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

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

Tsv **Sonoma Volcanics, undivided (Pliocene and Miocene?)** -- Silicic, intermediate, and minor mafic volcanic rocks, including white rhyolite tuff and vesicular plagioclase porphyry andesite. Tuffaceous rocks on strike immediately southeast of the mapped area have been correlated with the 3.96 $\pm$ 0.16 (K/Ar age) Ma Lawlor Tuff (Sarna-Wojcicki, 1976) and nearby andesite has yielded a K/Ar age of 3.37 ± 0.23 Ma (Fox and others, 1985). In addition, andesite just north of the mapped area north of Cordelia has yielded a K/Ar age of 4.2 ± 0.41 Ma (Fox and others, 1985), and farther north of the mapped area rocks in the Sonoma volcanic field have yielded K/Ar ages of 5.36 ± 0.16 Ma (Sarna-Wojcicki, 1976). Rocks as old as 8 Ma (Fox and others, 1985) or 12 Ma (Blake and others, 1974) have been included in the Sonoma Volcanics, but because those rocks are separated from the mapped area by strike-slip faults with possible large offset, the relationship of the older volcanics to the Sonoma Volcanics in the mapped area is unknown. In the mapped area, formation includes, mapped locally:

Tss **Volcanic mudstone, sandstone, and conglomerate**--Poorly to well consolidated tuffaceous mudstone (lahar), and volcanoclastic sandstone and conglomerate. Sandstone is cross-bedded in places. Conglomerate clasts are well-rounded to angular, and made up of vesicular and massive andesite and basalt. Sims and others (1973) mapped this unit as Tehama Formation, which is coeval with the upper part of the Sonoma Volcanics (Sarna-Wojcicki, 1976). However, the unit in the mapped area is overlain by basaltic flow rock, which is not present in the Tehama Formation elsewhere (see Graymer and others, 1994, for a recent description of the Tehama Formation in Contra Costa County). This suggests that the unit is better considered a sedimentary part of the Sonoma Volcanics. Sims and others (1973) mapped a similar sedimentary unit within the Sonoma Volcanics in the area east of Napa. The volcanic nature of the detritus in this unit, as well as the presence of volcanic mudstone, precludes the possibility that this unit predates the Sonoma Volcanics. Because the contact between the sedimentary rocks and overlying basalt was not observed, it is possible that the contact is a fault, which would be permissive of these rocks being Tehama Formation. The generally conformable bedding in the two outcrops suggests a depositional tie, however.

Tc **Cierbo Sandstone (Miocene)** -- Orange-weathering, white, clean, quartz-biotite and quartz-lithic sandstone. Locally contains pebble conglomerate with clasts of vari-colored chert, andesite, rhyolite, and quartz. Also contains locally shell hash in clean, hard, white quartz-lithic sandstone.

Tv **Unnamed volcanics (Miocene?)** -- Black basalt. Outcrops only in one hill north of Napa Junction, in the westernmost part of the Cordelia quadrangle. Possible Miocene age is based on similarity of rock to other Miocene volcanics in the San Francisco Bay area and on association with the Cierbo sandstone.

Tmk **Markley Formation (Eocene)** -- Mainly buff weathering, white to light-gray, quartz-mica sandstone. Characterized in many places by small to large plates of white mica (up to several mm). In places, the sandstone also includes carbonized plant debris and other carbonaceous material. This unit also includes white or brown weathering, brown or dark-gray, foraminifer- and diatom-bearing, brown mudstone and sandy mudstone. In some outcrops the mudstone is laminated and siliceous and has a slabby parting. The mudstone has been previously mapped in places as Nortonville Shale (for example Sims and others, 1973), but it is distinguished by younger fossils and by being more siliceous. In the mapped area this formation also includes, mapped locally:

Tmkj **Jameson Mudstone member** -- Laminated and siliceous, foraminifer-, diatom-, and radiolarian-bearing brown mudstone with slabby parting. This unit is similar to the Nortonville Shale, but contains younger fossils and is more siliceous.

Tnv **Nortonville Shale (Eocene)** -- Gray-weathering, brown shale. Also contains thin beds of fine-grained, dark-gray, quartz-lithic-glauconitic sandstone. This unit pinches out in the area north of American Canyon.

Td **Domingene Sandstone (Eocene)** -- Gray-weathering, white, clean, quartz, quartz-lithic, and quartz-biotite sandstone, locally cross-bedded. In one outcrop north of American Canyon, the sandstone contains abundant invertebrate fossils (shells). Also in the area north of American Canyon, this unit contains near the base a prominent ridge-forming boulder to pebble conglomerate containing clasts of serpentinite, gabbro, pyroxenite, crinoidal limestone, black argillite, and diorite.

Tmr **Muir Sandstone of Weaver (1953) (Eocene)** -- Massive, yellow-weathering, arkosic sandstone. Also includes claystone and thin sandstone in the lower part.

Tlj **Las Juntas Shale of Weaver (1953) (Paleocene and Eocene)** -- Gray shale with minor siltstone. This unit does not crop out in the mapped area, but does crop out between the Muir

Sandstone and Vine Hill Sandstone across the Carquinez Strait in Martinez, and is presumed to be present but covered in the same stratigraphic position in Benicia.

Tvh **Vine Hill Sandstone of Weaver (1953) (Paleocene)** -- Glauconitic sandstone and shale.

Great Valley Sequence:

Ku **Undivided sandstone and shale (Early and Late Cretaceous)** -- Interbedded carbonaceous-biotite wacke, white-mica-carbonaceous sandstone, greenish-gray mudstone and shale, laminated fine-grained sandstone and gray shale, carbonaceous siltstone, black shale, and fine-grained mica wacke. Locally includes hard laminated clean white quartz-lithic-biotite sandstone and fossil-hash gritstone. This unit contains foraminifers of both Albian and Campanian age in the mapped area.

KJk **Knoxville Formation (Late Jurassic and Early Cretaceous)** -- Gray shale with concretions. Locally contains pebbly gritstone with green shale chips and probable glauconite. This unit is differentiated from Ku by the presence of fossil *Buchia*, including both *Buchia piochii* and *Buchia pacifica*, and by the absence of thick beds of sandstone.

Jsv **Silicic volcanic rocks (Late Jurassic)** -- Orange-weathering, white, altered silicic (quartz keratophyre) and intermediate (keratophyre) volcanic rocks. Locally contains red jasper, rhyolite, and rhyolite tuff.

Coast Range Ophiolite (Jurassic):

Jb **Basalt** -- Black basalt and pillow basalt, locally amygduloidal.

Jgb **Gabbro** -- Locally also contains plagioclase-porphyry diabase, pyroxenite, and serpentinite.

sp **Serpentinite** -- Locally also contains pyroxenite and silica-carbonate rock.

Franciscan Complex (Cretaceous and Jurassic)--In the mapped area composed of:

KJfm **Franciscan melange**--Sheared gray argillite matrix containing very large (more than 10 meters across) to very small (less than one meter across) blocks of hard, gray meta-graywacke, altered basalt (greenstone), metachert, and red, ribbon chert. In one block, the depositional contact between ribbon chert and greenstone has been preserved.

ls **Algal limestone (age unknown)**--In the mapped area, this unit only crops out as a small fault-bounded sliver associated with silica-carbonate rock (altered serpentinite) about 1.5 kilometers south of Jameson Canyon.

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