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Bedrock geology of the San Francisco Bay Area: A local sediment source for bay and coastal systems

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ABSTRACT

Local watersheds may contribute over half of the sediment load coming into San Francisco Bay today. The bedrock underlying these watersheds is the ultimate source for most of this sediment. This paper outlines the geologic history of this bedrock, which records the complex tectonic history of the San Francisco Bay Area over the last 200 Ma. The Jurassic to Eocene Franciscan Complex in the Bay Area is the most widespread bedrock. The local Franciscan can be broken into nine tectonic terranes that represent pieces of seafloor that were accreted to the North American margin in over a 100 Myr period of subduction. Each terrane has a unique age range, sequence of seafloor rocks, and metamorphic history. The Franciscan rocks were thrust eastward under the Great Valley Complex. The Great Valley Complex reflects a forearc basin comprised of Jurassic ocean crust—the Coast Range ophiolite—and overlying Jurassic and Cretaceous turbidite-dominated sedimentary rocks of the Great Valley Group. By the beginning of the Cenozoic Era, shallowing of the angle of subduction along the continental margin led to uplift and infilling of the forearc basin to shelf depth. Recorded at this time are sedimentary sequences governed by eustatic sealevel changes and evidence of the first unroofing of Franciscan rocks. Marine sedimentary rocks dominate the region through the Miocene and unconformities within the Early Tertiary sedimentary record reflect periods of tectonic activity and uplift. Middle to late Miocene sedimentary rocks are extensively deposited throughout the Bay Area. In the late Miocene, the Mendocino triple junction passed northward through the area and transform tectonism commenced. A slab window developed behind the triple junction resulted in volcanic activity that produced the Sonoma Volcanics in the North Bay and volcanics of the East Bay Hills. By Pliocene time, terrestrial sedimentary rocks were being deposited in many parts of the Bay Area. Faulting associated with the San Andreas system led to the development of small basins, the displacement of local bedrock blocks, and the transport of the Salinian Complex from the southern Sierra to the western margin of the Bay Area. The modern topography of the region started emerging by about 6 Ma to 4 Ma, when compression across the San Andreas system increased and uplift of the Coast Ranges began. The first estuarine influence in San Francisco Bay is recorded in ~600 ka rocks, about the same time as the modern Sacramento River system started flowing through the San Francisco estuary/valley.

Today's local San Francisco Bay watershed is comprised of numerous small stream systems around the Bay with headwaters in the surrounding hills and mountains. Active tectonism produces relief in these watersheds of typically 500 m or more, with the ridgelines typically supported by more resistant bedrock units. Steep topography leads to rapid bedrock erosion, particularly of the finer-grained sedimentary rocks. Landslides provide a significant portion of the sediment carried by the streams and several of the bedrock units are more prone to landslides, particularly the Central and Novato Quarry terranes of the Franciscan Complex, and finer-grained units of both the Great Valley Group and Tertiary rocks. Many of the larger streams have dammed reservoirs that trap much of their sediment load before it can reach the bay.

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1. Introduction

There are two primary sources for modern sediments in San Francisco Bay and the coastline near the bay's mouth: 1) the Sacramento/San Joaquin River system and 2) the many relatively small local watersheds surrounding the bay. The Sacramento/San Joaquin River system watershed spans from the Sierra Nevada Mountains' crest westward to the Coast Range Mountains' crest on the east side of California's Central Valley. The watershed covers 37% of California's area and accounts for 95% of the area that drains into San Francisco Bay (McKee et al., 2003) (Fig. 1 inset). Porterfield (1980) calculated that the Sacramento/San Joaquin River system accounted for about 86% of an average 6.6 million m^3/yr total sediment load that reached San Francisco Bay from 1909 to 1966. These river sediments are mostly derived from granitic rocks exposed in the Sierra

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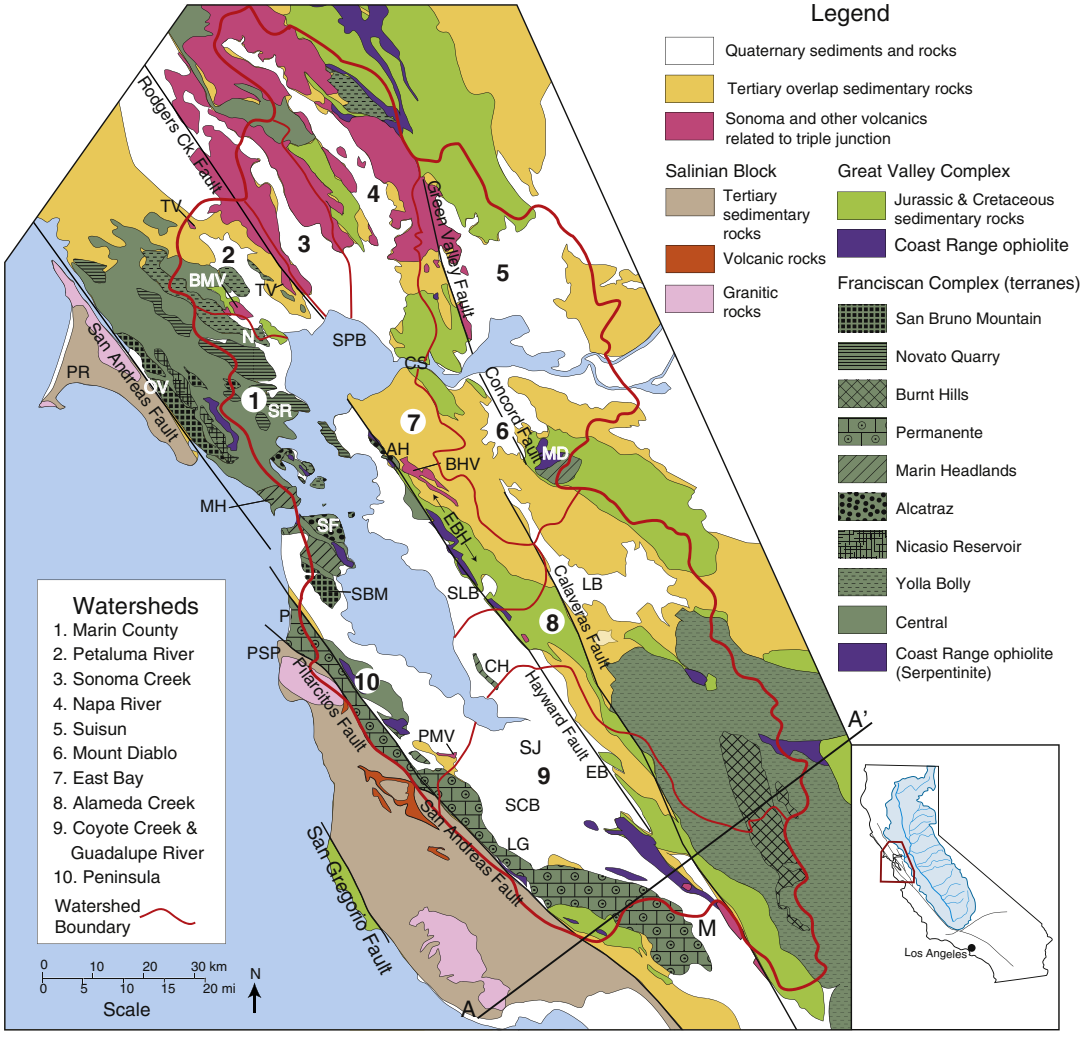

Fig. 1. Generalized geologic map of San Francisco Bay Area showing local watershed areas of Porterfield (1980) discussed in this paper. Geology based on Graymer et al. (2006) with refinements from Bartow (1985), Brabb et al. (1998), Wentworth et al. (1998), Blake et al. (2000), Dawson (2000), Graymer (2000), Graymer et al. (2007), and Wagner and Gutierrez (2010). Locations mentioned in the text are denoted as follows: AH = Albany Hills, CH = Coyote Hills, CS = Carquinez Straits, EBH = East Bay Hills, LG = Las Gatos, M = Morgan Hill, MD = Mount Diablo, MH = Marin Headlands, N = Novato, OV = Olema Valley, P = Pacifica, PSP = Point San Pedro, PR = Point Reyes, SBM = San Bruno Mountain, SF = San Francisco, SJ = San Jose, SR = San Rafael. Miocene basins mentioned in text are denoted as follows: EB = Evergreen basin, LB = Livermore basin, SCB = Santa Clara basin, SLB = San Leandro basin, SPB = San Pablo basin. Volcanic rocks mentioned in text are denoted as follows: BHV = volcanics of Berkeley Hills, BMV = Burdell Mountain volcanics, PMV = Page Mill volcanics, TV = Tolay volcanics. Inset map shows location of San Francisco Bay Area geology and watershed map in California with major faults (black) and Sacramento/San Joaquin rivers watershed and major tributaries shown in blue.

Range and metamorphic and volcanic rocks exposed along the western front of these mountains. Other sources for these river sediments include volcanic rocks of the Cascade Range to the northeast and diverse rock types of the Klamath and Franciscan terranes of the Coast Range to the north and west of the Central Valley, as well as the Mesozoic sedimentary rocks of the Great Valley Group and overlying Cenozoic rocks in the Central Valley.

The remaining sediments coming into San Francisco Bay are derived from the local San Francisco Bay watersheds (Fig. 1). In recent years, sediments from these local watersheds have become increasingly important as sediment input from former hydraulic mining in the Sierra Nevada foothills has waned, and dam construction, bank hardening and channelization in the Sacramento and San Joaquin valleys and delta have reduced sediment supply from the Sacramento/San Joaquin River system (Schoellhamer, 2011; Barnard et al., 2013–this volume). Bay Area urbanization and other disturbances also have resulted in an increase of locally derived sediment loads, although this trend may have subsided in recent years (see Barnard et al., 2013–this volume). Lewicki and McKee (2010) calculated that contributions from local watersheds may now account for approximately 56% of the total suspended load entering San Francisco Bay. The formation and distribution of these local basement and overlying rocks are the focus of this paper, which provides the geologic framework for the sources of an increasing important component of modern bay sediments.

The local watershed sediment sources include Jurassic and Cretaceous igneous and sedimentary basement rocks (and their metamorphic equivalents) and overlying Cenozoic sedimentary and volcanic rocks. This paper is divided into three sections. The first section discusses the geologic evolution and processes responsible for San Francisco Bay Area rocks and geomorphology. The second section discusses the local rocks in more detail, dividing them into the following groups for discussion: Franciscan Complex (~30% of total watershed area), Great Valley Complex (~15%), Tertiary overlap sequence (~15%), and Sonoma Volcanics (~10%). Plutonic and sedimentary rocks of the Salinian block west of the San Andreas fault also are briefly discussed as they provide some sediment to the open coast north and south of the Golden Gate. Although Quaternary sediments cover ~30% of the local watershed area, they are