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Late quaternary history of the San Gregorio Fault near Pescadero, California

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**LATE QUATERNARY HISTORY OF THE SAN GREGORIO FAULT
NEAR PESCADERO, CALIFORNIA**

A thesis presented to the Faculty of the Department of Geology

San José State University

In partial fulfillment of the requirements for the degree

Master of Science

by

Anna Sojourner

August 2000

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ABSTRACT

LATE QUATERNARY HISTORY OF THE SAN GREGORIO FAULT NEAR PESCADERO, CALIFORNIA

By Anna Sojourner

The Coastways fault is one of the only on-land sections of the San Gregorio fault zone. This study focuses on the fluvial geomorphology and late Quaternary history of the area between San Gregorio and Pescadero, California. Particular emphasis is placed on evidence for recent fault activity.

Fluvial terraces of lower San Gregorio Creek, Pomponio Creek, and Bradley Creek were correlated. Three to four correlative terrace levels in lower San Gregorio Creek, Pomponio Creek, and Bradley Creeks bear no evidence of Holocene offset.

A paleoseismic trench at Bradley Creek exposed late Holocene sediments. No evidence of faulting is present, indicating that the Coastways segment of the San Gregorio fault may not have ruptured in the last 4000 years. Up to 1.4 meters of sediments, deposited since about 1930, were present in the paleoseismic trench.

ACKNOWLEDGEMENTS

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Walter Barnhardt of the USGS conducted Ground Penetrating Radar surveys of the trench site. Rufus Catchings and Mark Goldman of the USGS, and Samantha Hansen performed a shallow seismic reflection survey across the trench site.

Thanks to many volunteers who helped with hard work, especially Anne Rosinski, who fought poison oak and brambles without complaining, and Mike Smith and Forrest McFarland, who set shores and pounded fence posts all day long. Robert Langridge and Mike Rymer of the USGS provided support. Karen Holmes, Jim Walker, Carolyn Domrose, Jennifer Thornburg, John Hamilton, and Gernot Laganda all came out to help scrape and log. Joni Mehlers' generosity will not soon be forgotten. Matthew Hoover, Editorius Maximus, deserves gratitude, as do my Mom and Dad, whom I couldn't do without.

TABLE OF CONTENTS

INTRODUCTION.....	1
Location and Setting.....	4
Methods.....	6
GEOLOGIC SETTING.....	10
Crystalline Bedrock.....	11
Cretaceous and Tertiary Rocks Southwest of the SGfz.....	11
Cretaceous Pigeon Point Formation.....	11
Oligocene Vaqueros Formation.....	12
Oligocene to Miocene Monterey Formation.....	12
Tertiary Rocks Northeast of the SGfz.....	12
Quaternary Units.....	15
Marine Terrace Deposits.....	15
Pleistocene Alluvium.....	16
Holocene Alluvium.....	16
Land Use History.....	16
Previous Work.....	19
FLUVIAL TERRACES AND ALLUVIAL SEDIMENTS OF SAN GREGORIO CREEK, POMPONIO CREEK, AND BRADLEY CREEK.....	22
Introduction.....	22
Overview of Stream Terraces.....	25
San Gregorio Creek Terraces.....	27

Qt1: 3 to 7 meters	27
Qt2: 9 to 25 meters	29
Qt3: 18 to 75 meters	32
Qt4: 215 to 260 meters	33
Pomponio Creek Terraces	35
Qt1: 0 to 3 meters	35
Qt2: 3 to 25 meters	37
Qt3: 35 to 55 meters	38
Qt4: 135 to 200 meters	38
Bradley Creek Terraces	39
Qt1: 1 to 5 meters	40
Qt2: 18 to 40 meters	40
Qt3: 70 to 120 meters	43
Terrace Ages and Correlations	44
San Gregorio Creek Terraces	44
Pomponio Creek Terraces	44
Bradley Creek Terraces	45
Summary of Terrace Unit Ages	46
Evidence For Tectonism	49
San Gregorio Creek	49
Pomponio Creek	49
Bradley Creek	50
Summary	50

Qt1.....	50
Qt2.....	51
Qt3.....	51
Qt4.....	52
PALEOSEISMIC TRENCH AT BRADLEY CREEK.....	53
Introduction.....	53
Site Characterization.....	55
Bucket Auger Samples.....	56
Ground Penetrating Radar.....	57
Seismic Reflection.....	59
Paleoseismic Trench.....	61
Sediments.....	63
Qa1.....	63
Qa2.....	63
Qa3.....	65
Age of Units.....	66
Radiocarbon Dates.....	66
Historical Artifacts.....	67
Evidence of Faulting.....	69
IMPLICATIONS FOR ACTIVITY ON THE COASTWAYS FAULT.....	71
CONCLUSIONS.....	73
REFERENCES CITED.....	74

LIST OF ILLUSTRATIONS

Figure

1.	Index Map of Coastal California Faults.....	2
2.	Geologic Map of southern San Mateo County.....	3
3.	Map of San Mateo County Coast.....	5
4.	Panoramic View of Terraces at Bradley Creek.....	26
5.	San Gregorio Creek Terrace Profile.....	28
6.	Floodplain Sediments at San Gregorio Creek.....	30
7.	Gravel at Location 2	31
8.	Pomponio Creek Terrace Profile.....	34
9.	Typical Terrace of Pomponio Creek.....	36
10.	Bradley Creek Terrace Profile.....	41
11.	Weathering Profile of Bradley Creek Terrace.....	42
12.	Map of Bradley Creek Area.....	54
13.	Stacked and Migrated Seismic Data.....	60
14.	Velocity Model.....	62
15.	Close-up of Meters 0 – 6 of Trench.....	64
16.	Picture of Bottle found in Trench.....	68

Plate

1. Map Showing Fluvial Terrace Surfaces of Lower San Gregorio Creek, Pomponio Creek, and Bradley Creek, with Faults, Trench Location, and Creek Profile Lines.....in pocket
2. Terrace Profiles for Lower San Gregorio, Pomponio, and Bradley Creeks.....in pocket
3. Log of Paleoseismic Trench at Bradley Creek.....in pocket

Table

1. Summary Table of Terrace Elevations and Approximate Ages.....48
2. Radiocarbon Data.....58

INTRODUCTION

The San Gregorio fault zone (SGfz) is the northernmost in the system of faults west of the San Andreas fault (Fig. 1). It extends northward from Monterey Bay and joins the San Andreas fault at Bolinas Bay (Fig. 1). Many workers consider the SGfz continuous with the Hosgri fault to the south (Simpson et al., 1997). Because much of the SGfz lies offshore, it is unclear exactly which strands are active or how they relate to less active strands (Ross et al., 1999b). Relatively little is known about the history of offset, slip rate, and slip sense of the SGfz (Simpson et al., 1997).

From Point Año Nuevo north to San Gregorio Beach (Points A and B, Fig. 2), a complex system of short fault segments and subparallel strands, both onshore and offshore, make up the Frijoles and Coastways segments of the San Gregorio fault zone. This study concentrates on the Coastways fault, the easternmost strand (Plate 1). Although some workers consider the SGfz capable of producing a $\sim M 7$ to $M 7 \frac{1}{2}$ earthquake (Simpson et al., 1997), the California Department of Mines and Geology (CDMG) removed the Coastways strand in the San Gregorio and La Honda quadrangles from the list of active fault zones (Smith, 1981). The CDMG interpreted aerial photographs to indicate very little evidence of Holocene activity on the Coastways segment.

Because of its proximity to highly developed areas and its seismogenic potential, more information about the SGfz is needed. The Coastways segment is one of

Figure 1 Index map of study area and major faults in west-central California. Modified from Graham and Dickinson (1978).

Figure 2 Geologic map of coastal San Mateo County showing major bedrock units. Point Año Nuevo lies at location A and San Gregorio State Beach lies at location B. Tunitas, Lobitos, San Gregorio, Pomponio, and Tahana Members are subdivisions of the Pliocene Purisima Formation. Quaternary marine terraces are denoted by the abbreviation QMt. From Brabb et al., 1998.

the only parts of the fault on land. Characterizing the Coastways segment will illuminate the history and seismogenic potential of the San Gregorio fault zone and clarify the relation of the Coastways segment to the Seal Cove and Frijoles strands. This thesis focuses on the fluvial geomorphology and late Quaternary history of the area between San Gregorio and Pescadero (Figure 3), with particular emphasis on evidence for recent activity on the Coastways segment.

Location And Setting

The study area lies in the coastal lowlands between San Gregorio State Beach and the town of Pescadero (Fig. 3), and includes all or portions of the drainage basins of San Gregorio Creek, Pomponio Creek, and Bradley Creek (Plate 1). The study area lies within the San Gregorio and La Honda 7.5-minute USGS topographic quadrangles (USGS, 1953). San Gregorio Creek, the largest of the three creeks, has a drainage area of 130 km² (50.9 mi²) above a gaging station located about 1.5 kilometers upstream from the mouth of the river (USGS, 2000). Pomponio Creek and Bradley Creek are smaller drainage basins and have areas of 17.9 km² (7 mi²) and 12.3 km² (4.8 mi²), respectively. The area is characterized by a moderate coastal climate. Northern coastal scrub vegetation dominates the areas just inland from the coastal strand areas, and uplands are covered with second-growth forest (Munz, 1965). Beginning in the late 1800's, native redwood trees were logged throughout the mountains along the California coast

Figure 3 Location map of the Pacific coast of the greater San Francisco Bay Area, including study area.

(Thornburg and Weber, 1998). Rainfall is moderate, averaging 669.5 mm per year, and falls chiefly in December, January, and February (National Climatic Data Center, 1999). Little rain falls in the summer months, but winter storms cause flooding in local creeks almost annually. Thick historical flood sediments blanket many low-lying parts of the study area. Most of southern San Mateo County is agricultural and used for grazing cattle.

West-flowing streams drain through the study area into the Pacific Ocean from steep hills east of the study area. Ridge crests reach about 300 meters (1,000 feet) and are incised up to about 180 meters (600 feet) by the larger streams, San Gregorio and Pomponio Creeks. Quaternary marine terraces line the coast. Near Davenport, about 40 kilometers south of the study area, as many as five levels of marine terraces have been mapped and correlated (Weber et al., 1995). Shoreline angles are not exposed in the terraces near San Gregorio Creek (Weber et al., 1995), so any marine terraces in the study area cannot be definitively correlated to terraces elsewhere.

Methods

The study area comprises lower San Gregorio Creek, Pomponio Creek, and Bradley Creek. I compiled fault traces mapped by Weber (1995) and Brabb (1980) on the San Gregorio and La Honda USGS 7.5-minute topographic quadrangles. Weber et al. (1995) also mapped Quaternary marine terraces,

landslides, and Quaternary alluvial deposits, which are not shown on my maps, but which I used in my mapping.

I mapped the watershed boundaries of lower San Gregorio Creek, Pomponio Creek, and Bradley Creek using available topographic maps. In each watershed, I delineated flat or gently-sloping surfaces evident on the 40-foot contour maps, then checked them against air photos (USGS, 1987, USGS 1988). I correlated sets of terraces based on their elevations relative to the thalweg. To assess the relative elevations of terraces along the creeks, I plotted the height of the terraces on the stream profiles. To eliminate the sinuosity of the channel, I drew a straight line that bisected the channels (Plate 1). Thus, the terraces do not fall at great distance upstream when they actually lie close to the mouth of the stream, as would happen if the channel distance of the actual creek were used on the x-axis. To obtain terrace elevations, I drew a line on a topographic map through the terrace and parallel to the line along the creek. Distortion of the terrace forms is unavoidable using this method. If the terrace slopes towards the center line of the creek, it appears flat in cross-section rather than tilted downstream. If the line through the terrace is not parallel to the true midline of the terrace, the steepness of the terrace slope is exaggerated.

I made preliminary correlations of sets of terraces plotted on the stream profile based on their elevation relative to the stream gradient. To test these preliminary correlations, I field-checked terrace surfaces for:

- the presence or absence of alluvium;
- the minimum thickness of alluvium, where possible to determine;

- the sedimentology of alluvium, including weathering of sediments and clasts not stratigraphically confined; and
- charcoal or organic material to carbon date.

This method of correlation, in which terraces are correlated primarily upon their elevations relative to the stream, is commonly used. However, as Merritts (1994) point out, correlations that fail to demonstrate continuity between terraces may not reveal the complex interplay of river gradient, tectonics, and sea level changes. To avoid error, continuous, detailed surveys of terraces should be made in the field (Merritts et al., 1994). Nonetheless, a preliminary correlation is a useful first step to making detailed maps of terraces.

I mapped terraces in the study area and grouped them by elevation (Plate 1). I compiled longitudinal profiles for each stream from the USGS 7.5-minute topographic quadrangles (Plate 2). I then compiled the data with Adobe Illustrator on USGS 7.5-minute topographic quadrangles available as .tif files from the USGS at <http://bard.wr.usgs.gov>. Each terrace unit is designated with a number for its position in the watershed (e.g., Qt1 is the lowest and youngest of the terraces, Qt2 lies above it).

A valley at Bradley Creek was identified as a paleoseismic site. To constrain the location of the fault within this valley, a variety of techniques were employed. I took bucket auger samples to characterize the sediments, and I used a carbon sample taken from the bucket auger samples confirmed that the sediments are prehistoric. Walter Barnhardt of the U.S. Geological survey made Ground Penetrating Radar (GPR) transects across the fault zone to image shallow (<2 m) subsurface anomalies. Rufus Catchings of the U.S. Geological Survey put a

seismic reflection line across the valley, which imaged the upper 300 meters of the subsurface and was processed to highlight the uppermost few meters.

To study the history of the Coastways fault, I excavated a paleoseismic trench two to three meters deep and 50 meters long at Bradley Creek. The trench crossed a topographic break that lies along the strike of geomorphic features that clearly mark the fault to the north and south. The trench was long enough to cover all likely projections of the fault as mapped by Brabb (1980) and Weber (1995). After scraping the walls to remove backhoe toolmarks, I logged the trench at a scale of 1:20. I sent carbon samples collected in the trench to Lawrence Livermore National Laboratories (LLNL) Center for Accelerator Mass Spectrometry. Dates from LLNL were calibrated to calendar dates using the relation of Stuiver and Reimer (1993).

GEOLOGIC SETTING

The San Gregorio fault zone (SGfz), considered a major right-lateral strike-slip fault, is the westernmost part of the San Andreas fault system (Weber et al., 1999b). Despite its location and seismogenic potential, comparatively little is known about its history of offset or slip rate, primarily because about 85 percent of the SGfz lies offshore. Parts of the SGfz lie onshore between Año Nuevo and Point Montara (Fig. 3), where it consists of two major strands: the Frijoles fault and the Coastways fault. The Coastways fault, the subject of this work, lies subparallel to and east of the Frijoles strand (Fig. 2). The onshore Coastways fault is 27 km long between Año Nuevo and San Gregorio beach, and passes through the study area (Fig. 2; Plate 1), intersecting San Gregorio and Pomponio Creeks, and paralleling Bradley Creek.

Southwest of the SGfz, basement rocks are overlain by at least 2600 m of Cretaceous clastic sediments. Northeast of the SGfz, Cretaceous sediments are absent, and the Salinian basement is overlain by more than 10,000 m of Paleocene to Pleistocene marine clastic sedimentary and volcanic rocks (Clark and Brabb, 1978). The following stratigraphic and unit descriptions were taken from Clark and Brabb (1978).

Crystalline Bedrock

West of the San Andreas fault, Cretaceous and Tertiary sediments overlie Mesozoic granodiorite, the basement rock of the Salinian block. The Salinian block has been displaced northwestward from its origin near today's southern Sierra Nevada. Salinian granitoids form the basement in the area between Año Nuevo and San Gregorio Beach, but are not exposed in the study area.

Cretaceous and Tertiary Rocks Southwest of the SGfz

Cretaceous Pigeon Point Formation

Southwest of the SGfz, the Late Cretaceous Pigeon Point Formation overlies crystalline basement. The Pigeon Point Formation is exposed at Pescadero Beach, 2 km west of the southern edge of the study area (Fig. 2). The Pigeon Point Formation is about 2700 m thick, but its base is not exposed. It is made up of interbedded sandstone, mudstone, and conglomerate. In the southern part of the San Gregorio quadrangle, it is unconformably overlain by the Vaqueros Formation, while inland from Pescadero beach and to the south, it is overlain unconformably by the Purisima Formation.

Oligocene Vaqueros Formation

The Vaqueros Formation unconformably overlies the Pigeon Point Formation at Pescadero Beach and also crops out at Point Año Nuevo, about 8 km south of the study area. It consists of about 230 m of shallow marine sedimentary rocks, chiefly siltstone and sandstone.

Oligocene to Miocene Monterey Formation

The Monterey Formation is exposed at Point Año Nuevo, where it lies in gradational contact above the Vaqueros Formation. It is an approximately 215 m-thick unit of principally thin-bedded and laminated siliceous mudstone. It is unconformably overlain by the Pliocene Purisima Formation.

Tertiary Rocks Northeast of the SGfz

Clark and Brabb (1978) divide the Tertiary section northeast of the San Gregorio fault into four sequences – the Paleocene, the Eocene to lower Miocene, the Middle Miocene, and the Upper Miocene to Pliocene. Paleocene Sequence rocks are not exposed in the study area, but consist of 270 to 600 m of erosional

remnants of sandstone and siltstone that crop out near Ben Lomond Mountain, about 35 km south of the study area.

Eocene to Lower Miocene strata include the Butano Sandstone, San Lorenzo Formation, Zayante Sandstone, Vaqueros Sandstone, Mindego Basalt, and Lamberti Shale, with a cumulative thickness of over 4500 m. Only the Butano Sandstone, a submarine fan deposit, crops out near the study area, along Pescadero Creek south of the Bradley Creek watershed.

Middle Miocene strata include the Lompico Sandstone and the Monterey Formation. The Lompico Sandstone lies nonconformably on crystalline basement, and unconformably on Eocene to lower Miocene sequences. The Monterey Formation lies conformably on the Lompico Sandstone.

The upper Miocene to Pliocene Santa Cruz Mudstone is exposed in the southern portion of the La Honda quadrangle southeast of the study area (Fig. 2). The Santa Cruz Mudstone is composed of up to 2700 m of siliceous medium- to thick-bedded mudstone. The Santa Cruz Mudstone overlies the 130-meter-thick late Miocene Santa Margarita Sandstone, a very thick-bedded arkosic sandstone.

The Pliocene Purisima Formation, the youngest part of the Tertiary section northeast of the San Gregorio fault, is widely exposed in the study area (Fig. 2). Mudstone and sandstone of the Purisima Formation are exposed in the hills of the eastern part of the study area and were described in detail by Touring (1959). The Purisima Formation is divided into five members, listed here from oldest to youngest: Tahana sandstone member, Pomponio mudstone member, San

Gregorio sandstone member, Lobitos mudstone member, and Tunitas sandstone member. Of these, the Tahana sandstone, the Pomponio mudstone, and the San Gregorio sandstone are exposed in stream cuts or are present as clasts in fluvial terraces at several localities along San Gregorio, Pomponio, and Bradley Creeks. The following descriptions of Purisima bedrock encountered in the study area are based on Touring (1959) and Brabb (1980).

The Tahana member is up to 650 m thick. It is composed of medium- to very fine-grained tuffaceous siltstone and sandstone. Near the base are pebbly conglomerate beds described by Touring (1959) and Brabb (1980). The Pomponio mudstone is a sequence of up to 110 m of light gray, bedded, silicified mudstone, and gray laminated silty mudstone. Concretions are common. Along the length of Pomponio Creek, Pomponio mudstone is exposed in stream cuts and in fluvial terraces. The San Gregorio member is a massive sandstone between 45 and 110 m thick. The sandstone is greenish-gray and fine-grained, and weathers to light brown or tan color. In the study area, it contains small pebbles of chert and volcanic rock fragments.

The SGfz bounds two bedrock sequences that contrast markedly in thickness and lithology. This demonstrates that there has been significant offset along this part of the SGfz at least since the Cretaceous.

Quaternary Units

Marine Terrace Deposits

At the western edge of the study area, marine terraces form prominent benches along the coast. Brabb (1980) described the marine terrace sediments in the San Gregorio and La Honda quadrangles as poorly consolidated and indurated sand and gravel less than 30 m thick. Marine terraces south of the study area have been studied extensively (Bradley and Griggs, 1976, Weber et al., 1994, 1995). North of Pescadero Creek, marine terraces are discontinuous. Weber et al. (1995) reported that marine terraces at the mouth of San Gregorio Creek cannot be definitely assigned to one of the groups of terraces mapped to the south of the study area. Their elevations are about 45 to 120 m (150 feet to 400 feet) above sea level, indicating that they may be 200,000 to as much as 400,000 years old, based on the elevation of shoreline angles of marine terraces to the south (Weber et al., 1999b)

Pleistocene Alluvium

Fluvial terraces of probable Pleistocene age are found in the higher reaches of the creeks in the study area. Many lack alluvial sediments and are stripped

surfaces cut into bedrock. A few older alluvial surfaces are marked by cobbles scattered on the terrace surface and within the top meter of soil. These are discussed in greater detail in later sections of this thesis.

Holocene Alluvium

Historic-aged and late Holocene alluvium blankets the floodplains of San Gregorio and Bradley Creeks. Poorly sorted sand and gravel channel deposits and finer overbank deposits underlie the lowest terrace surfaces. Pomponio Creek lies within a narrow bedrock canyon, and the youngest terraces are not as well developed as in lower San Gregorio and Bradley Creeks. In San Gregorio Creek, terraces of Holocene age are cut on sand and gravel deposits. In Bradley Creek, a much smaller watershed than San Gregorio Creek, the late Holocene alluvium that underlies the historical deposits is much finer-grained than the historical sediments.

Land Use History

Thornburg and Weber (1998) reported an accumulation of 4 to 5 m of historical sediment in San Gregorio Creek between 1862 and 1906. They logged a 4 to 5 meter-high, 115 meter-long cut bank in San Gregorio Creek near the mapped

trace of the Coastways fault. The sediments exposed in the cut bank are very young channel and overbank deposits containing historical artifacts, such as nailed boards. The historical artifacts were found about one meter above the present stream level, and show that the sediments of the lowest terraces of San Gregorio Creek are unequivocally historic in age. A clastic dike, probably associated with liquefaction produced by the 1906 earthquake, is present in the sediments.

My work reveals that in Bradley Creek, historical sediments are at least 1.4 m thick. The significant aggradation that occurred in Bradley Creek in the 20th century was probably caused by land use practices as well as by significant storms (Engstrom, 1996).

Before the arrival of Spanish missionaries in the late 1700's, southern San Mateo County was occupied by the Ohlone Indians. About 10 small tribes of 100 to 250 people each lived in San Mateo County, including groups living at the present sites of the towns of San Gregorio and Pescadero (Postel, 1988). The town of Pescadero, established in 1853, was home to both Portuguese whalers and Spanish cattle ranchers. Cattle roamed freely among unfenced hills. By 1883, Pescadero was also home to at least one large dairy farm (Alley, 1883). Farming of vegetables and flowers became prevalent in the coastal lowlands in the 20th century, but this area has been grazed heavily since the first arrivals of Europeans, and heavy grazing continues today.

The redwood groves surrounding Pescadero and San Gregorio were logged extensively in the mid-1800's. By the late 1870's, active sawmills lined Pescadero Creek a few km east of the town of Pescadero, as well as San Gregorio Creek and its tributaries (Stanger, 1967). Bradley Creek is not large enough to support a sawmill, and no mention was made by Stanger (1967) of logging around Bradley Creek. Stanger (1967) also makes no mention of sawmills in Pomponio Creek.

Logging and cattle grazing denude and destabilize hillslopes and add large amounts of sediment to rivers (Wood, 1971). Thornburg and Weber (1998) inferred that the accumulation of thick historical sediments in San Gregorio Creek occurred as a result of logging near La Honda and the storms of 1862, which remain the largest on record for California (Engstrom, 1996).

Land use practices of the 19th and 20th centuries altered the geomorphology of coastal San Mateo County, but each watershed has its own native vegetation and history of land use, and sediment loads that vary in volume and rate of deposition. Nonetheless, it is clear that the modern sedimentation rate throughout coastal San Mateo County is significantly higher than the prehistoric rate, as a direct result of human works

Previous Work

The area between San Gregorio and Año Nuevo Point was mapped by Touring (1959), who defined the Coastways strand of the fault based on bedrock juxtaposition. Lajoie et al. (1974) mapped the unconsolidated and moderately consolidated deposits of San Mateo County. Clark and Brabb (1978) described the bedrock sections on both sides of the fault. Brabb (1980). Weber et al. (1995) mapped Quaternary deposits and faults within the San Gregorio fault zone from Davenport, about 40 km south of the study area, to San Gregorio Beach. Brabb et al. (1998) published a digital geologic map of the Palo Alto 30 x 60 quadrangle.

Thornburg and Weber (1998) excavated four trenches along the Frijoles fault, the westernmost segment of the San Gregorio fault zone, near Año Nuevo Point (Fig. 2). They documented four ground-surface ruptures in the last six to eight thousand years. At Año Nuevo the Coastways segment lacks the conspicuous offsets of Quaternary materials exposed in seacliffs that are present on the Frijoles trace (Weber et al., 1999b). Paleoseismic work on the Coastways segment at Año Nuevo failed to demonstrate activity more recent than Pleistocene (Weber et al., 1999b), suggesting that the Frijoles trace is more active than the Coastways trace. However, about 2 km north of Point Año Nuevo, at Cascade Ranch, some slip may be transferred from the Frijoles trace to the Coastways via a zone of complex faulting (Weber et al., 1999b).

Simpson et al. (1997) used paleoseismic and archeological data to interpret the history of the Seal Cove fault near Moss Beach (Fig. 3), about 30 km north of the

study area. Five Holocene-active fault strands define a broad zone of faulting at least 22 m wide. Simpson et al. (1997) interpreted the most recent event to have occurred after the deposition of an Indian midden between 1270 AD and 1400 AD and before the arrival of Spanish missionaries circa 1775 AD. The penultimate event occurred between 620 AD and 1400 AD. Its timing was constrained by carbon dating of bulk samples from an organic-rich soil horizon.

The slip rate of the SGfz has long been the subject of debate. Graham and Dickinson (1978) suggested that Cretaceous and Tertiary bedrock have been offset up to 115 km, yielding an average late Cenozoic slip rate of 7 to 9 mm per year. Clark et al. (1984) correlated bedrock units in the Santa Cruz Mountains with units in Point Reyes, and estimated an average late Cenozoic slip rate of 13 to 16 mm per year. Near Año Nuevo, measurement of offset marine terrace risers led to an estimate of 4 to 10 mm per year since the late Pleistocene (Weber and Lajoie, 1980; Weber, 1994). Sedlock and Hamilton (1991) reviewed the findings of other workers and presented an estimate of Neogene slip of 1 to 3 mm per year. Simpson and Lettis (1999) argue that the onshore Seal Cove fault has a late Pleistocene slip rate of at least 4 to 6 mm per year, and that the offshore strand may have a similar slip rate.

Since the arrival of Spanish Missionaries in the area in around 1775, no large surface-faulting event has been recorded on the San Gregorio fault. However, Topozada et al. (1981) reported two historical earthquakes that might be associated with the San Gregorio fault zone: an 1856 M 5 to M 5 $\frac{1}{2}$ earthquake near Pillar Point (30 km north of the study area), and an 1884 M 5 $\frac{3}{4}$ to M 6

earthquake southeast of Año Nuevo Point. Weber et al. (1999a) reported truncation of faults by the plowed horizon and offset of the modern soil in trenches at Año Nuevo Point, indicating late Holocene faulting on the Frijoles fault.

FLUVIAL TERRACES AND ALLUVIAL SEDIMENTS OF SAN GREGORIO CREEK, POMPONIO CREEK, AND BRADLEY CREEK

Introduction

A graded river is a system in equilibrium. J. Hoover Mackin applied Le Chatelier's rule to rivers in 1948, and Merritts et al. (1994) summarized his concept of graded rivers:

A graded stream is one with a "...slope that will provide the velocity required for transportation of all the load supplied to it from above...[it] is a slope of transportation;....influenced directly neither by the corrosive power of the stream nor bedrock resistance to corrosion".

Where rivers flow into the sea, the potential energy of falling water reaches zero and no further work (conversion of potential energy to kinetic energy) can be done by the stream. The base level of a stream is the altitude at which the erosive capacity of a river is lowest. A stream may respond to temporary base levels (e.g., dams) or local base levels (e.g., nickpoints), but ultimately a coastal river is controlled by sea level. The base level of a stream can change as a result of either eustatic sea level fluctuations or tectonic uplift or subsidence.

Repeated glaciation during Quaternary time had major impacts on the base level of California streams. Sea level was at least 100 meters lower during Quaternary glaciation, lowering base levels of most modern rivers (Bloom, 1998). The lower reaches of rivers that enter the ocean are dominated by the effects of changing sea level (Merritts et al., 1994). During glacial advances, sea level drops and

rivers incise their valleys. With glacial retreat, sea level rises and rivers aggrade. Two of the rivers in the study area, San Gregorio Creek and Pomponio Creek, flow directly into the ocean and have lagoons at their mouths, a result of Holocene sea level rise.

Tectonic uplift or crustal warping can control the local base level of a stream, resulting in changes to stream gradient. When the equilibrium between the channel gradient and the hydraulic properties of the stream is perturbed, the concave-upwards profile of a stream may be locally steepened or flattened. Longitudinal profiles are often convex upward across an axis of uplift (Hitchcock et al., 1994).

The gradient of a river responds relatively rapidly to changes in base level. The morphology of a river system may reflect changes in gradient by deflection around uplifted zones, aggradation or degradation of tilted reaches, changes in channel pattern, or changes in bedload grain size (Holbrook and Schumm, 1999). At the same time, stream gradients may be affected by climate fluctuations, which influence the density and type of vegetation, sediment influx, and runoff within a watershed.

Rivers with resistant bedrock channels respond more slowly and less sensitively to shifts in base level than do rivers with alluvial channels (Merritts et al., 1994). In the study area, Bradley Creek and the lower reaches of San Gregorio Creek are alluvial channels. Pomponio Creek is a bedrock channel east of Stage Road (Plate 1), but is an alluvial channel west of the nickpoint at Stage Road.

When a river downcuts its valley, parts of the former valley floor are preserved as fluvial terraces. A river downcutting into bedrock may leave cut (strath) terraces with a thin alluvial veneer as remnants of its former position. If alluviation of the valley floor precedes downcutting, then a fill terrace is created (Bloom, 1998).

Terraces can provide a record of the tectonic history of an area. Terraces may preserve the gradient of a stream when it formed them if they are not subsequently deformed. Terrace sediments can be relatively dated using soils and weathering, or dated absolutely using radiometric methods. The spatial relations and ages of terrace remnants can be used to constrain the timing and possible causes of downcutting and gradient changes, including tectonics, base level change, climate change, and human works (Bloom 1998).

Longitudinal profiles of terraces can help in deciphering the history of a stream. Gradients reconstructed from terraces may be steeper or flatter than the modern gradient, as a result of either tectonism or changes in stream competence. Terraces may converge at a modern or ancient base level, or diverge from one. Converging profiles indicate that gradients have decreased over time, which could result from decreasing competence or headwater uplift. Divergence in gradients indicates base level rise, which progressively flattens the gradient (Bloom, 1998).

In practice, the effects of base level changes and tectonics on the geologic record are difficult to separate. Even adjacent rivers do not simultaneously adjust to the same modification in base level, because basin shape and hydrology may differ

(Merritts et al., 1994). Correlating terraces between rivers can also be difficult, because gradients in each basin are unique.

Overview of Stream Terraces

I delimited three to four terrace units in each creek in the study area. The modern terraces, unit Qt1, lie at 3 to 9 meters above the stream channel. Terraces of Qt2 lie 3 to 40 meters above the stream channel. Terraces of Qt3 lie 18 to 75 meters above the stream channel. In Bradley Creek, Qt4 is not present, but in San Gregorio and Pomponio Creeks, it lies 135 to 260 meters above the stream channels.

The low-lying terraces of Qt1 flank their streams closely. They are the best preserved of all terrace units and are often in use as cultivated fields in San Gregorio Creek.

In San Gregorio Creek, many terraces of Qt2 are also in use as cultivated fields and grazing land. The terraces lie close to the modern streams but at a higher elevation than those of Qt1. In Pomponio Creek, the terraces of Qt2 are deeply incised. A panoramic view of Qt2 terraces west of Bradley Creek (Fig. 4) shows broad, nearly flat surfaces that grade to a former level of Bradley Creek.

Older terrace remnants of Qt3 and Qt4 are considerably more dissected than the younger terraces. They consist primarily of small discontinuous remnants. In Bradley Creek, the terraces of Qt3 are found a considerable distance away from

Figure 4 View to the north and upstream north along Bradley Creek. Bradley Creek is covered with trees. Prominent terraces can be seen west of the creek.

the modern creek and may have formed along tributaries to Bradley Creek. The well-developed terraces of Qt4 occupy the divide between the watersheds of San Gregorio and Pomponio Creek. The surfaces are stripped surfaces, without alluvial deposits.

San Gregorio Creek Terraces

San Gregorio Creek is the largest of the three creeks in the study area (Plate 1), measuring 130 km² (50.9 mi²) above the stream gauge about 1.5 kilometers upstream of its mouth (USGS, 2000). San Gregorio Creek flows westward to the ocean, and it is fed by numerous tributaries from the north and very few to the south. The Coastways fault crosses the creek near its mouth (Fig. 2). I mapped terraces only along the westernmost 10 kilometers (6 miles) of the creek.

Terraces along San Gregorio Creek can be broadly grouped into four levels, based on their elevations above the modern channel (Fig. 5; Plate 2). They are discussed from lowest to highest in the following paragraphs.

Qt1: 3 to 7 meters

The lowest terraces of San Gregorio Creek (Qt1) make up the modern and historical floodplain. They lie at about 3 to 7 meters (10 to 25 feet) above the present stream channel and grade to sea level. They can be correlated along the

EAST

WEST

Vertical Exaggeration: 10x

- LEGEND
- ◆ Modern Channel
 - ◆ Qt1
 - ◆ Qt2
 - Qt3
 - Qt4
 - ? Correlation Uncertain

Figure 5 Terrace profile of lower San Gregorio Creek. Faults mapped by Brabb (1980) and Weber et al. (1995) intersect the profile line A-B. The profile line is shown on Plate 1. Points A, B, and C are inflection points in the profile line.

length of the profiled stream, without apparent discontinuity across the fault zone.

Fine silty and sandy sediments generally underlie the terrace surfaces (Location 1, Plate 1; Fig. 6). The alluvium is up to 5 meters thick. Historical artifacts found in these terraces indicate that Qt1 is probably entirely historic in age (Thornburg and Weber, 1998). Most of the modern floodplain surfaces are currently in use as cultivated fields.

Qt2: 9 to 25 meters

Terraces of Qt2 occupy the area close to the channel, but are slightly higher than the modern terraces Qt1. The terraces of Qt2 lie about 9 to 25 meters (30 to 80 feet) above the modern stream channel and grade to a level about 12 meters (40 feet) above the present-day sea level (Plate 2). Qt2 surfaces are also relatively continuous along the length of the stream, and Qt2 surfaces show no apparent discontinuity across the fault zone (Fig 6.; Plate 2).

Terrace surfaces of Qt2 are generally underlain by sandy alluvium with large, rounded cobbles of sandstone and volcanic rock interspersed in the top meter. Soil is not well developed on the Qt2 surfaces.

At the mouth of San Gregorio Creek, the stream has exposed the terrace at location 2, and the younger modern floodplain terraces are clearly set into it. A charcoal sample collected from the deposits at location 2 (Fig. 7) was dated at

Figure 6 Massive sandy and silty sediments underlying the modern floodplain (Qt1) of San Gregorio Creek at location 1 (Plate 1). Shovel is approximately 50 cm long.

Figure 7 Gravel underlying Qt2 terrace at location 2 (Plate 1), at the mouth of San Gregorio Creek. A carbon sample from this gravel was dated at 10,150 to 10,390 years before present (Table 2). Shovel is approximately 1.5 meters long.

10,150 to 10,390 years before present (Table 2). The charcoal could be much older than the host sediment if it was reworked from another deposit, but the sample was collected from within deposits under the terrace. Therefore, the terrace surface must be younger than the charcoal sample, and the terrace is Holocene. The terraces of Qt2 grade to an elevation of about 12 meters above sea level at the present coastline.

Qt3: 18 to 75 meters

A third group of terraces (Qt3) includes remnants that lie between 18 and 75 meters (60 to 250 feet) above the modern stream channel. The lowest of these grade to about 25 meters (80 feet) above sea level at the coast. I subdivide Qt3 into two levels, 3a and 3b. Qt3 contains terraces that lie within a broad range of elevations. These terrace surfaces cannot be correlated based on sediments or weathering but only upon elevation: no materials for absolute dating were found.

Possible discontinuity of the Qt3 surfaces near the location of the fault suggests that Qt3 may be disrupted by faulting (Fig. 5; Plate 2). However, the terraces included with Qt3 may actually belong to two terrace units that should be correlated separately. Thus, the question of tectonic disruption cannot be answered definitively.

Qt4: 215 to 260 meters

Most of the terraces within Qt4 lie on the drainage divide between San Gregorio and Pomponio Creeks (Plate 1), between 215 and 260 meters (700 to 850 feet) above modern San Gregorio Creek. These terraces are also included in the Pomponio Creek profile (Fig. 8) and described further in the following section. Where observed in the field, these terraces are stripped bedrock surfaces, lacking soil or cobbles. Terraces of Qt4 grade to 110 to 120 meters (360 to 400 feet) above sea level at the coast.

Terraces of Qt4 profiled within cross-section line A-B (Plate 1) are sedimentologically distinct from those along the line B-C. The terraces along B-C are stripped bedrock surfaces, while terraces along A-B generally have a thin scattering of rounded cobbles on top of soil and soft sediments. Therefore, it is not certain that Qt4 terraces along A-B were formed by the same stream as Qt4 terraces along B-C, although they correlate well based on altitude. Although terraces of Qt3 might appear to be offset near the fault zone, similar offset in the terraces of Qt4 is not readily apparent. This could be because terraces assigned to Qt4 along lines A-B and B-C were formed separately, and they do not constitute a single group of terraces. Alternatively, this could invalidate the interpretation of possible offset on Qt3.

Figure 8 Pomponio Creek terrace profile. The fault intersects the profile at the western nickpoint, located at Stage Road (Plate 1). A dam and spillway create another nickpoint in the upstream reaches of the creek. The projection line is shown on Plate 1. Points D, E, and F are inflection points in the projection line, and are also shown on Plate 1.

Pomponio Creek Terraces

Pomponio Creek runs roughly parallel to and south of San Gregorio Creek for about 10 kilometers (6 miles; Plate 1). The Pomponio Creek watershed is about 17.9 km² (7 mi²). At Stage Road, a nickpoint in the creek profile (Fig. 8; Plate 2) is formed by an outcrop of the Pomponio Mudstone Member of the Purisima Formation, bounded by the San Gregorio fault (Brabb, 1980). Pomponio Creek is fed in its eastern end by numerous ephemeral tributaries of less than 1 kilometer (0.6 miles) length. At the easternmost end of Pomponio Creek, a dam and a spillway create another nickpoint in the creek profile (Fig. 8; Plate 2).

Pomponio Creek is a bedrock canyon east of Stage Road (Plate 1), and where observed in the field, all Qt3 and Qt4 surfaces are bedrock surfaces. Those terraces of Pomponio Creek that are not stripped surfaces are underlain by coarse, angular gravel (Fig. 9). Terrace sediments incorporate more fine material and more rounded cobbles downstream, but gravel exposed in stream terraces near the mouth of the river is still coarse to very coarse, and subangular to angular.

Qt1: 0 to 3 meters

The modern floodplain of the creek (Qt1) comprises fewer than 10 low-lying

Figure 9 Sediments underlying a typical Qt2 terrace surface of Pomponio Creek, underlain by angular gravels and mud, and deeply incised.

terrace surfaces spread along the length of the stream. Pomponio Creek has incised deeply into the older Qt2 terraces without significant lateral channel erosion, so there is little room available in the channel for a modern floodplain. Terraces of Qt1 lie no more than 3 meters (10 feet) higher than the stream channel. At those locations, sediments underlying the Qt1 surfaces are predominantly sand and mud, with sparse cobbles.

Qt2: 3 to 25 meters

The extensive terraces along Pomponio Creek are mostly terraces of unit Qt2. Sediments under Qt2 are typically angular, clast-supported gravel interbedded with sand and mud (Fig. 9). Terraces of Qt2 lie between 3 to 25 meters (10 to 80 feet) above the modern stream channel and grade to about 12 meters (40 feet) above modern sea level, similar to the Qt2 terraces of San Gregorio Creek. These terraces are deeply incised by Pomponio Creek's channel. For example, at location 3 (Plate 1), the modern channel lies as much as 12 meters (40 feet) below the surface of the terrace adjacent to it. Based on the elevation to which Qt2 grades, I assign Qt2 a Holocene age in Pomponio Creek.

Qt3: 35 to 55 meters

Bedrock surfaces about 35 to 55 meters (120 to 180 feet) above modern Pomponio Creek make up a third level of terraces (Qt3). The accessible surfaces of Qt3 are stripped surfaces lacking alluvium or soil that could be used for assessing ages. Unit Qt3 grades to about 50 meters (160 feet) above modern sea level. In contrast, Qt3 grades to only 25 meters (80 feet) above sea level in San Gregorio Creek. However, Pomponio Creek is a narrower bedrock channel, with a smaller drainage area than San Gregorio Creek. Even adjacent rivers may not respond to climate or tectonic changes identically (Merritts et al., 1994).

Qt4: 135 to 200 meters

Prominent surfaces assigned to unit Qt4 mark the northern watershed boundary of Pomponio Creek (Plate 1), and were also included as San Gregorio Creek terraces. They lie between 135 and 200 meters (440 to 650 feet) above the stream channel. These flat to gently-sloping surfaces are easily discernible on maps and air photos, and their consistent gradients indicate that they are stream terraces. These surfaces lack cobbles or other alluvial sediments and are covered with a soil interspersed with blocky Pomponio mudstone fragments two to three centimeters across. Terrace unit Qt4 grades to about 170 meters (560 feet) above sea level at the coast at Pomponio Creek.

It is not clear whether Qt4 surfaces are associated with Pomponio Creek or San Gregorio Creek, although several terraces that lie entirely within the lower

Pomponio Creek watershed correlate well with this set of terraces. Within the Pomponio Creek watershed, this group of terraces does not extend west across the fault, so offset of this group of terraces cannot be assessed.

The profile of Pomponio Creek terraces lacks a prominent displacement coincident with the fault and bedrock nickpoint in the river. The nickpoint is caused by the juxtaposition of bedrock and alluvial sediments that have differing resistance to erosion.

Bradley Creek Terraces

Bradley Creek, at 12.3 km² (4.8 mi²), is the smallest of the three creeks in the study area. It flows to the south for about five kilometers (three miles) from its drainage divide with Pomponio Creek near Stage Road to its termination in Pescadero Creek, near Pescadero Road (Plate 1). In its uppermost two kilometers, the creek parallels the San Gregorio fault, in contrast to San Gregorio and Pomponio Creeks, which cross the fault nearly perpendicular to its strike. The watershed bulges to the east to include Chandler Gulch and Shaw Gulch, the two largest tributaries of Bradley Creek. Bradley Creek is nestled in the westernmost part of its basin, and terrace remnants are relatively less common on the western side of the basin (Plate 1). The stream profile is steep in its uppermost 0.6 kilometer (2000 feet), and flattens towards the creek mouth; the terrace profiles mimic the concave-upwards shape (Fig. 10).

Figure 10 Bradley Creek terrace profile. Paired terraces 5 and 10 and 11 and 12 are discussed in text. Letters G and H are inflection points on the profile line and are shown on Plate 1.

Qt1: 1 to 5 meters

Bradley Creek has an extensive modern floodplain between 1 and 5 meters (3 to 15 feet) above the thalweg. Clay, silt, and fine sand dominate the sediments underlying the terraces of Qt1. Rare sandy gravel contains clasts generally less than 5 centimeters diameter. The sediments of location 4 are described more completely in the Paleoseismic Trench section.

Qt2: 18 to 40 meters

At locations 5, 6, and 7, (Plate 1), a series of terrace surfaces (Qt2) lies about 18 to 40 meters (60 to 130 feet) above the modern stream and grades to about 24 meters (80 feet) above sea level (Fig. 4). The terraces are underlain by fluvially reworked sand derived from the Purisima Formation. About 60 centimeters of soil has formed on the deposits (Fig. 11). Scattered small (~1 cm diameter) weathered and oxidized pebbles in the soil indicate fluvial deposition. Although its continuity and gradient strongly suggest a former level of Bradley Creek, the terrace at location 5 is back-tilted to the west. The tilting suggests that Bradley Creek did probably not deposit these surfaces, particularly because they lie quite

Figure 11 Weathering profile of a Qtz terrace west of Bradley Creek, at location 7 (Plate 1). Weathered sandy loam underlies the surface of terrace, and preserves very small weathered pebbles.

close to its headwaters and have little catchment area upstream. Rather, they were most likely deposited by gullies flowing eastward into Bradley Creek, and they grade to a former base level of Bradley Creek. Backtilting also suggests that they may be the toes of old landslides, also graded to a level of Bradley Creek. However, Weber et al. (1995) did not map them as landslides.

Qt3: 70 to 120 meters

A third terrace level lies 70 to 120 meters (220 to 400 feet) above Bradley Creek and grades to about 85 meters (280 feet) above sea level. Most of the Qt3 terraces are stripped surfaces cut in bedrock. East of Bradley Creek, some Qt3 terraces have the flat to gently sloping shape of fluvial surfaces, with sediments that include very coarse gravel and highly rubified soil (Locations 8 and 9, Plate 1). Clasts in the gravel are weathered, well-rounded and up to 20 centimeters in diameter. The surfaces grade to Bradley Creek. However, the sediments underlying the surfaces are not conformable to the surfaces, are too coarse to have been deposited by Bradley Creek, and are capped by sandstone. The sediments underlie stripped surfaces of the Purisima Formation and I interpret them to be part of the pebble conglomerate in the Tahana Member of the Purisima Formation described by Clark and Brabb (1978). Alternatively, they may be part of the Purisima Formation that was not previously described. The Purisima Formation includes very coarse nearshore gravel deposits (L. White,

San Francisco State University, personal communication, 1999) exposed near Moss Beach, about 20 kilometers north of the study area.

Terrace Ages And Correlations

San Gregorio Creek Terraces

San Gregorio Creek has at least four terrace units. The lowest are historic in age (Thornburg and Weber, 1998). The next level, Qt2, is Holocene in age, based on carbon dating of charcoal found at location 2 (Plate 1) and the elevation to which Qt2 grades. Units Qt3 and Qt4 are probably mid- to late- Pleistocene and mid- Pleistocene, respectively. It is not clear whether high stripped surfaces in Qt4 originated with San Gregorio Creek or with Pomponio Creek.

Marine terraces near the mouth of San Gregorio Creek are discontinuous, and have not been definitively correlated to marine terraces to the south (Weber et al., 1995).

Pomponio Creek Terraces

The lowest level of terraces, Qt1, is not extensively developed in Pomponio Creek and is quite low to the channel. Pomponio Creek is a narrower channel

than San Gregorio Creek, and there is less space to develop young terraces in. The stream channel of Pomponio Creek is quite narrow, and little space is available for modern deposits. These surfaces grade to modern sea level and are late Holocene or historic-aged terraces, based on their elevation above the stream.

The best developed terraces of Pomponio Creek, Qt2, are deeply incised by the creek. They grade to about 12 meters (40 feet) above modern sea level, similar to Qt2 in San Gregorio Creek. Qt2 terraces of Pomponio Creek contain no datable materials, but grade to an elevation similar to the Holocene Qt2 terraces of San Gregorio Creek. Terrace levels Qt3 and Qt4 are mostly stripped surfaces that lack soils and dateable materials, but may be correlative to the Qt3 and Qt4 levels in San Gregorio Creek.

Bradley Creek Terraces

Bradley Creek has three levels of terrace remnants. Terraces of Qt1, the modern floodplain, are underlain by predominantly fine sediments and correlate well to one another based on spatial relations and sedimentology. The terraces above Bradley Creek follow the concave-upwards profile of the river.

Qt1 is unequivocally historical, based on a number of artifacts found just below the surface of Qt1 at location 4. Qt2 grades to about 24 meters above sea level and is Holocene in age if it correlates to Qt2 in San Gregorio and Pomponio

Creeks. Qt3 grades to about 85 meters above sea level and may be late Pleistocene in age.

Summary of Terrace Unit Ages

Terrace unit Qt1 is of historical or late Holocene age, based upon the presence of historical artifacts in San Gregorio and Bradley Creek. Based on the age of a charcoal sample from a Qt2 terrace in San Gregorio Creek, I assign terrace unit Qt2 a maximum age of 10,390 years, or Holocene.

Marine terraces in the area between Pescadero Beach and San Gregorio Beach cannot be definitely correlated to other well-defined marine terraces to the south (Weber, et al., 1995). I assign ages to terrace levels Qt3 and Qt4 based solely upon the elevation that they grade to above modern sea level and the elevations of marine terrace shoreline angles further south defined by Weber et al. (1999b).

Because Bradley Creek is a tributary to Pescadero Creek and does not drain directly into the ocean, only the elevations of terraces on San Gregorio and Pomponio Creeks were used to find the average elevation above sea level for Qt3 – about 45 meters. This lies between the 24 meter shoreline angle of the 103 ka Pigeon Point terrace, and the 61 meter shoreline angle of the 213 ka Bolsa terrace (Weber et al., 1999b).

Unit Qt4 is not present at Bradley Creek, but is present in San Gregorio Creek and Pomponio Creek. It grades to 215 to 260 meters above modern sea level in San Gregorio Creek and to 135 to 200 meters above modern sea level in

Pomponio Creek. Most terraces of Qt4 are stripped surfaces in bedrock along the drainage divide between San Gregorio and Pomponio Creek. The Pomponio Creek terraces grade to a lower elevation because there are downstream terraces included in the unit Qt4 in Pomponio Creek that lie at a lower elevation than any Qt4 terraces in San Gregorio Creek. In both San Gregorio and Pomponio Creeks, few Qt4 terraces are present west of the fault so drawing a single terrace correlation line to the shore is difficult. It is difficult to assign Qt4 to one marine terrace based on its elevation, but it may correlate to the Gazos terrace, estimated to be 320 ka (Weber et al., 1999b).

The marine terraces in the study area lie on a different structural block than the terraces to the south. The uplift rate of marine terraces in the study area is not known. Thus, these correlations are tenuous.

Table 1 **Summary Table of Terrace Elevations and Approximate Ages**

Unit	Elevation Range (m)	Elevation Above Sea level at Coast (m)	Approximate Age
Qt1	3 – 7 (San Gregorio)	0	Modern/ Historical
	0 – 3 (Pomponio)		Modern/ Historical
	1 – 5 (Bradley)		Modern/ Historical
Qt2	3 – 25 (San Gregorio)	12	10 to 4 ka (Holocene)
	3 – 25 (Pomponio)	12	10 to 4 ka (Holocene)
	18 – 40 (Bradley)	24	unknown
Qt3	18-75 (San Gregorio)	25	Late to Mid Pleistocene (103 ka)
	35 – 55 (Pomponio)	50	Late to Mid Pleistocene (103 ka)
	70 – 120 (Bradley)	85	Late to Mid Pleistocene (103 ka)
Qt4	215 – 260 (San Gregorio)	110 – 120	Mid Pleistocene (320 ka?)
	135 – 200 (Pomponio)	170	Mid Pleistocene (320 ka?)
	n/a (Bradley)	n/a	n/a

Evidence For Tectonism

San Gregorio Creek

Terrace profiles of San Gregorio Creek do not show offset except perhaps on the terrace Qt3 (Plate 2). If Qt3 is offset, then the correlation of terraces of Qt4 from high stripped surfaces on B-C to surfaces along A-B may be incorrect. The terraces of Qt3 could actually be two sets of terraces, leading to an unwarranted interpretation of offset. The youngest historical and Holocene terraces do not appear offset. If the Coastways fault is responsible for disruption of the Qt3 profile, then the deformation occurred before the deposition of Holocene and modern terraces.

Pomponio Creek

The profile of Pomponio Creek (Fig. 8; Plate 2) does not show significant offset of terraces. The oldest level, Qt4, does not extend across the fault zone in Pomponio Creek, so it cannot be used to make statements about fault activity. Levels Qt2 and Qt3 do not appear to be discontinuous or uplifted across the fault, even though the stream profile contains a nickpoint at the fault from bedrock juxtaposition.

Bradley Creek

Two pairs of terrace remnants appear to correlate across the Coastways fault, which roughly coincides with the stream profile. Locations 5 and 10 (Qt2) and Locations 11 and 12 (Qt3) correlate in terms of elevation and horizontal distance along the profile. However, within the limits of detection of 20-foot contours (County of San Mateo, 1996), neither pair shows horizontal or vertical offset across the Coastways strand. Thus, negligible slip has occurred on the Coastways since deposition of these terraces.

Summary

Qt1

Terraces of Qt1 are underlain by sediments of historic age. They lie 1 to 7 meters above stream thalwegs, and grade to modern sea level. The sediments associated with Qt1 are generally unsorted, unconsolidated sand and silt.

The lowest terrace surfaces of each creek are cut into historical sediments, and the modern terraces in San Gregorio and Bradley Creeks are at least partly a result of 19th and 20th century land-use practices. Historical deposits are abundant in San Gregorio and Bradley Creeks, but much less common in Pomponio

Creek. No major surface-faulting event has occurred on the San Gregorio fault in historical times, and the terrace profiles of Qt1 are not offset.

Qt2

Terraces of Qt2 lie 3 to 25 meters above modern stream channels and grade to about 12 meters above sea level. These surfaces are Holocene. They vary in the type of sediments that are present beneath the surfaces. In San Gregorio Creek, rounded cobbles are interspersed in the top meter of soil. In Pomponio Creek, deeply incised deposits of angular gravels interbedded with mud are common. In Bradley Creek, reworked sand from the Purisima Formation underlies many Qt2 terrace surfaces. Terraces of Qt2 do not show evidence of significant offset.

Qt3

Level Qt3 lies 18 to 75 meters above San Gregorio and Pomponio Creeks, and lies 70 to 120 meters above Bradley Creek. Terraces of Qt3 grade to 25 meters above sea level in San Gregorio Creek, 50 meters above sea level in Pomponio Creek, and 85 meters above sea level in Bradley Creek. In San Gregorio Creek, many Qt3 terraces are marked by a thin scattering of rounded cobbles at the surface, but in Pomponio and Bradley Creeks, most terraces of Qt3 are stripped bedrock surfaces.

In Bradley Creek, Qt2 and Qt3 probably originated in gullies that fed Bradley Creek rather than with Bradley Creek itself. Hence, although the terraces Qt2 and Qt3 grade to an older level of Bradley Creek, they do not represent the actual past profile of Bradley Creek.

Qt4

Terraces of Qt4 are not present in Bradley Creek. In San Gregorio Creek, they lie 215 to 260 meters above the thalweg, while in Pomponio Creek, the terraces lie at 135 to 200 meters above the stream channel. These surfaces are mostly stripped bedrock surfaces cut into the Pomponio Member of the Purisima Formation.

Qt4 is shown on the profiles of both San Gregorio and Pomponio Creeks. On each profile, the terraces correlate well and grade to an elevation above sea level – about 120 meters (400 feet) in San Gregorio Creek and about 170 meters (560 feet) in Pomponio Creek. A few members of this terrace unit clearly belong to the Pomponio Creek watershed, while few downstream terraces in San Gregorio Creek watershed share the characteristics of this terrace. However, when plotted with San Gregorio Creek, Qt4 may extend a little further west across the fault zone. If terraces of Qt4 west of the fault indeed correlate with Qt4 terraces east of the fault, then fault slip did not occur or cannot be shown definitively with this method.

PALEOSEISMIC TRENCH AT BRADLEY CREEK

Introduction

Along Bradley Creek, four kilometers north of Pescadero, modern alluvial sediments have partially filled a 700 m-wide valley (Fig. 12). Three tributaries to Bradley Creek converge in a gently sloping, north-northwest-trending valley. The Coastways segment of the San Gregorio fault lies within this valley (Fig. 2; Plate 1; Brabb, 1980, Weber et al., 1995). The location of the fault is constrained on the north and south ends of the valley, but its exact location within the valley is not known.

South of the sediment-filled valley, the fault is mapped through a pond (Fig. 12; Brabb, 1980, Weber et al., 1995). The pond is man-made, but 1943 air photos show it as a marsh, indicating that it marks a fault-related depression (USGS, 1943). North of the trench site, the valley narrows, and the fault is mapped through a notch in the hills (Brabb, 1980, Weber et al., 1995). East of the mapped fault strands, alluvial fans of three tributaries to Bradley Creek coalesce on the eastern margin of Bradley Creek.

A northwest-trending topographic break marks the inferred trace of the fault along the western edge of the Bradley Creek valley. Old Stage Road (Fig. 12) was built on this topographic break in 1869 and used until 1916, when landowners asked the county to choose an easier route up the hills to Pomponio

Figure 12 The Bradley Creek area, including the San Gregorio fault as mapped by Brabb (1980) and Weber et al. (1995). Locations of paleoseismic site, GPR and seismic reflection transects, and bucket auger sample sites are also shown.

Canyon. In 1917, Old Stage Road was abandoned, and the current route (Stage Road) was developed (G. Chasey, San Mateo County Department of Public Works, personal communication, 1999). The topographic break was not severely modified for use as a road, because the mechanical grader was not invented until after the county abandoned this portion of Old Stage Road. The topographic break is not clearly visible on air photos, because Old Stage Road is lined with eucalyptus trees. Near the trench site, the topographic scarp has nearly a meter of relief and trends close to the mapped trend of the fault. To the north and south of the trench site, the relief diminishes and the scarp is cut away by Bradley Creek.

Site Characterization

A variety of techniques helped to constrain the location of the fault in the valley and to site the trench. Bucket auger samples helped to characterize the sediments in the valley. Ground Penetrating Radar transects, performed by Walter Barnhardt of the United States Geological Survey, showed subsurface anomalies at depths less than 2 meters, but these anomalies were determined to be the product of interference. A seismic reflection profile performed by the Seismic Imaging Group of the United States Geological Survey constrained the zone of potential faulting.

Bucket Auger Samples

Bucket auger samples helped to broadly characterize the top two meters of sediment. Charcoal samples helped to date the sediments and ascertain that sediments in the top two meters are not purely of historic age.

Bucket auger sample 1 was collected in the southern end of the valley, near Stage Road, and very close to Bradley Creek (Fig. 12). The sediments are very fine silty clay containing ubiquitous organic matter. These sediments may be overbank fine deposits of Bradley Creek. The clay is mottled and oxidized, indicating that the sediments may be older than historical.

Bucket auger sample 2 was collected about 100 meters east of Sample 1 (Fig. 12), and consists of dark clayey silt with abundant organic material, and contains more sand and less clay than Sample 1.

Bucket auger sample 3 was collected near Chandler Gulch (Fig. 12). It consists of dark gray and light rust-brown clay, with sparse to common organic material.

Bucket auger sample 4 was collected about 20 meters east of Sample 3 (Fig. 12). This mottled dark gray and rust-colored, very fine sandy clay is darker with depth. Rare sand lenses are about 3 millimeters across, and rare organic material is more abundant with depth. A carbon sample from 1.3 meters was dated at 290 to 500 years before present (Sample 57631, Table 2), indicating that the sediments below 1 meter depth might be prehistoric.

Although most of the retrieved sediment was very fine-grained, stratigraphic variability showed that: 1) the area is not blanketed by historical sediment as

thickly as is the San Gregorio Creek valley; 2) a trench would cut through sediments that were not merely massive and that would display fault features such as shears, rotated clasts, or bed truncations; and 3) there is enough organic material to constrain ages in a trench.

Ground Penetrating Radar

Ground Penetrating Radar (GPR) sends a high-frequency radar pulse into the earth and records the elapsed time of reflection off buried discontinuities (Conyers and Goodman, 1997). A sleigh with a signal source and receiver is slowly dragged along the ground, and each signal reading is imaged in real time. In saturated sediments or over water bodies, the signal is rapidly attenuated, and penetration beyond the water level is not usually possible. Large buried objects, such as tree roots or a nearby hill, can interfere with the signal. This precluded the use of GPR to image the subsurface along the topographic break at Old Stage Road, which is lined with eucalyptus trees.

Transects were concentrated on the southern end of the valley near where the fault is constrained to pass through a pond, and to the north, near the trench site (Fig. 12). The transects were oriented nearly perpendicular to the mapped trend of the fault. GPR imaged subsurface anomalies at depths of less than 2 meters that were probably facies contrasts, buried roots, or other features unrelated to faulting.

Table 2 Radiocarbon data for Bradley Creek site.

LLNL Sample Number	Sample Number	^{14}C Age (y.b.p.)	Sample Size	Sample Description	Calibrated Date[†]	Calibrated y.b.p.
59511	T1S-14	680 ± 50	0.13 mg	Very small organic fragments from an area of ~ 300 cm ² .	AD 1260 to AD 1410	540 to 690
59512	T1S-16	2800 ± 40	N/a	Small dark organic fragments.	BC 1070 to BC 830	2780 to 3020
59513	T1S-17	3370 ± 50	N/a	Very small organic fragments from an area of ~ 300 cm ² .	BC 1770 to BC 1500	3020 to 3450
59514	T1S-18	4020 ± 80	0.08 mg	Very small organic fragments from clay at base of west end of trench.	BC 2870 to BC 2230	4180 to 4870
59515	T1S-25	130 ± 40	N/a	Single small piece of charcoal.	AD 1670 to AD 1960*	0 to 280
59516	T1S-26	190 ± 40	N/a	Charcoal	AD 1650 to 1950*	0 to 300
57631	Bucket Auger Sample #4	330 ± 40	N/a	Charcoal from Bucket Auger samples at Butler Ranch	1450 AD to 1660 AD	290 to 500
56582 [‡]	Sample found at loc. 2	9070 ± 50	N/a	Charcoal from gravel at base of southern buttress of Highway One bridge over San Gregorio Creek	8440 BC to 8200 BC	10,150 to 10,390

* Calculations assume a Libby half-life of 5568 years. Sample and standard ^{13}C values are normalized to -25⁰/00. Uncertainties are one standard deviation counting errors.

[†] Dendrochronologically calibrated calendar age ranges from program of Stuiver and Reimer (1993), Method B, 10 yr calibration curve, 2 standard deviation uncertainty.

[‡] Calibration from Stuiver et al., 1998

Seismic Reflection

In July 1999, the Seismic Imaging Group of the United States Geological Survey conducted a seismic reflection survey at Bradley Creek (Fig. 12). The seismic survey was designed to locate the near-surface trace of the San Gregorio fault, and to determine whether multiple strands of the fault are present at Bradley Creek. Using a modified shotgun source, they imaged a 210-meter line perpendicular to the mapped trace of the fault. The line included 88 shot points and 102 geophones spaced at 2 meter increments. The seismic sources were generated from a Betsy® firing rod inserted into 0.3 meter deep holes. About 1 second of data was acquired at a sampling rate of 5 ms. The valley was imaged to a depth of about 350 meters (Hansen et al., 1999).

Preliminary observations of shot gathers showed a steeply dipping reflector near the west end of the seismic survey line, coincident with the scarp at Old Stage Road. The stacked and migrated image of the upper 200 meters (Fig. 13) reveals two potential zones of disturbance in the upper ~10 meters of sediment. At the west end, a zone of disturbance in the shallow reflectors lies between meters 28 and 32 of the seismic line, possibly extending as far east as meter 35. A second possible zone of deformation lies at meter 80 of the seismic line. A third zone of disturbance in the near-surface between meters 120 and 160 is attributed to unconsolidated sand present in the modern-day river channel (R. Catchings, United States Geological Survey, personal communication, 1999).

West

East

Figure 13 Stacked and migrated data of the upper 200 m. This image was filtered to emphasize the top 10 m. From Hansen, et al. (1999).

A seismic velocity inversion model (Fig. 14) made by Rufus Catchings from first arrival refractions shows a change in velocity between meters 35 and 50, at a depth of 20 to 30 meters, and may correspond to disruptions in shallow reflectors at meter 28 to 32. It could indicate that a fault at depth connects with the near-surface disruptions. A warping of velocities in the east end of the model at horizontal meter 180 is probably due to basin edge effects rather than to structural disturbance (R. Catchings, United States Geological Survey, personal communication, 1999).

Paleoseismic Trench

To look for fault deformation, I excavated a two to three meter-deep, 50 meter-long trench across the alluvial valley perpendicular to the mapped trend of the fault (Plate 1). Seismic data from Hansen et al. (1999) reveal an imaged zone of deformation between meter 28 and meter 35 of the seismic line. This corresponds to meter 0 to 4 of the trench and up to four meters to the west of the trench that were not excavated. The trench did not extend across the entire zone of disturbance at the west end of the seismic survey, because the processed seismic data was not available until after the trench was already closed.

Figure 14 Velocity inversion derived from first arrival refractions of the seismic data (see Figure 12 for location of seismic line). Velocities range from about 400 m/s at the surface to about 2300 m/s at 50 m depth. Velocities from this model were used to stack the seismic reflection data of Figure 13. Changes in velocities between horizontal meters 35 and 45 and 20 to 30 meters depth project upwards to the shallow reflection disruptions in Figure 13. From Hansen et al. (1999).

Sediments

I present the sediments found in the trench from youngest to oldest. The younger sediments of Qa1 and Qa2 are coarser-grained than the older Qa3 deposits.

Qa1 A tan sand with ubiquitous roots and little evident sedimentary structure blankets the trench throughout its length (Plate 3). This sand is unequivocally historic in age, as it buries part of a barbed wire fence (Fig. 15; Plate 3), yet it is sedimentologically distinct from the darker silty sand of Qa2. At meter 48, Qa1 contains an abandoned telephone cable placed in a shallow trench perpendicular to this trench.

Qa2 Beneath the tan sand at the top of the trench are interbedded sand, silt, and gravel horizons. Qa2 thickens to the east, and its base is not exposed in the easternmost 30 meters of the trench. Qa2 has variable lithology, but consists chiefly of silt or fine sand units near the top, and finer silt and clay with depth. A prominent sandy silt horizon extends from meter 8 to meter 42, overlain by sandy beds with common silt rip-up clasts. At meter 44, a sandy river channel deposit is preserved.

Figure 15 Enlarged view of meters 0 to 7 of south wall of paleoseismic trench at Bradley Creek. The trench location is shown on Figure 12. Detailed trench log is shown in Plate 3. Carbon dates are shown with sample number and age.

Qa3 At the base of the trench in the western 30 meters is a chocolate brown to black clayey silt at least 1.5 meters thick (Plate 3). The exposure of Qa3 thins to the east. At about meter 30, the contact between Qa2 and Qa3 dips down below the trench floor.

Between horizontal meters 0 and 14, the bottom 0.5 to 1 meter of the clayey silt shows evidence of incipient soil formation (Fig. 15; Plate 3). Mottled lighter rusty-brown strands of sediment interfinger vertically with dark brown to black clayey silt and probably mark the position of roots. The clay content is lower in the mottled zone, perhaps due to the addition of silt sized organic matter, and increases with depth. The silty clay unit was probably exposed at the surface for some period of time before sedimentation resumed and buried the incipient soil. The boundary between the incipient soil and the overlying massive silty clay is wavy yet continuous.

Although the silty clay of Qa3 is mostly massive, some layers are apparent. One distinct layer, at horizontal meter 0 to 4.5, is about 15 centimeters thick and is made up of bioturbated wisps of sand (Fig. 15; Plate 3). This layer of light sand in dark clay is diffuse, and lacks sharp boundaries, yet can be traced laterally.

Age of Units

Near the western end of the trench, at meters 0 – 3, the boundary between historic and prehistoric sediments appears to be where coarse gravel of Qa2 cuts into the silty clay of Qa3. Above the gravel lies the tan sand of Qa1, which blankets the entire length of the trench. The sand is unequivocally historical and thickens to the east. The boundary between historic-age deposits and older sediments drops to the east, and the eastern reaches of the trench cut expose only historic deposits of Qt1 and Qt2. The trench cuts through a Qt1 (historic/modern) terrace surface as described in the previous section.

Radiocarbon Dates Carbon samples collected in the trench were sent to the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory. Six samples from the trench were dated, and descriptions of the samples and their ages are presented in Table 2.

Four samples from the western end of the trench between meters 0 and 3 (Fig. 15; Table 2) show that the silty clay of Qa3 is between 540 and 4870 years old. This group of carbon dates yields ages that are consistently older with depth. Sample T1S-14 (Fig. 15; Plate 3; Table 2) at 540 to 690 years before present, is significantly younger than the other samples, which range from 2,780 to 4,870 years before present. The younger date may be because the sample was relatively small and was collected over an area of nearly 300 cm², increasing the likelihood of contamination. However, it is stratigraphically higher than the other three samples, and a younger age is consistent with normal stratigraphic

relations. The three older samples, T1S-16, T1S-17, and T1S-18 show increasing age with depth and small standard errors (Table 2).

Two carbon samples between horizontal meters 43 and 46 show that the sediments in the eastern end of the trench are too young to have recorded any seismicity associated with the SGfz, which is not known to have ruptured in historic time. A river channel intersects the trench at horizontal meters 40 to 43 (Plate 3), with interfingering channelized clay, sand, coarse sand, and pebble deposits. Carbon samples retrieved from below the creek channel were historic in age. Sample T1S-25 was dated at 0 to 280 years before present, and Sample T1S-26 was dated at 0 to 300 years before present (Table 2). Both the river channel and the sediments that it cuts may be historic in age. The carbon dates confirm that it is unlikely that any late Holocene faulting would be recorded in the sediments in the eastern end of the trench.

Historical Artifacts In unit Qa2, a number of historic artifacts were present, including part of a shoe, a bottle in a fire pit, a nail, several shards of glass, and some metal slag. The shoe fragment was not preserved well enough to give any clue about its likely age. Most other artifacts, including the glass fragments, slag, and the nail, lack unique characteristics that can be used to date them precisely, except that they must post-date the arrival of European settlers in the mid-1800's.

The bottle (Fig. 16), retrieved whole at a depth of 1.4 meters at horizontal meter 41 of the trench, is a useful indicator of the age of the sediments in the eastern

Figure 16 Bottle found in trench at 1.4 meters depth. Inscription at base reads "IPG Co.". It was probably manufactured between 1925 and 1930. Ruler is 15 centimeters long.

end of the trench. The bottle has an inscription on the bottom that reads "IPG Co". It was manufactured either by the Illinois Pacific Glass Company in 1902-1925, or by the Illinois Pacific Glass Corporation in 1925-1930. Both companies operated out of San Francisco (Toulouse, 1971). Because the bottle is colorless and has a screw top, it is most likely to have been manufactured after 1925 (M. Brodzik, Antique Bottle Collectors Forum, personal communication, 1999). It lay on top of a 2 centimeter-thick and 20 centimeter-wide band of charcoal left from a fire pit. The bottle was the most deeply buried historic artifact and indicates that up to 1.4 meters of sediment have been deposited at Bradley Creek since about 1925.

Evidence of faulting

At the western end of the trench, the seismic line shows disturbances, and the trench cuts through a topographic break. However, no evidence of faulting was observed in trench sediments. Sediment in the eastern end of the trench is too young to show faulting.

Several lines of evidence show that sediments in the trench are not faulted. First, continuous sediment layers are present across the westernmost five meters of the trench (Fig. 15). These include a diffuse sandy layer in the clayey silt of Qa3, and the boundary of incipient soil within Qa3. This is the area where the zone of deformation imaged on the seismic line coincides with a topographic break. If the zone of disruption on the seismic line is caused by a fault, it has not been

active within the last 4,000 years. Second, the radiocarbon dates from the unfaulted silty clay at the western end of the trench are good-quality dates that show a progression of increasing age with depth. Third, the absence of shears, aligned cracks, or preferred orientation in the silty clay is additional evidence that the sediments at the western end of the trench are not faulted. During the two months the trench was open, drying cracks developed in the walls of the trench, but lacked preferred orientation, and no shear-like features were revealed as the trench walls dried out.

IMPLICATIONS FOR ACTIVITY ON THE COASTWAYS FAULT

In the trench site at Bradley Creek, no evidence of faulting was observed in sediments older than 4,000 years. In lower San Gregorio, Pomponio, and Bradley Creeks, Holocene and younger terraces lack offsets. Both lines of evidence suggest that deformation on the Coastways has been negligible in the Holocene.

The Coastways segment of the San Gregorio fault, as mapped by Jennings (1994) connects with faults at Seal Cove that have been active in Holocene time. However, the San Gregorio and La Honda topographic quadrangles were dropped from active faulting status by the CDMG, which used air photo reconnaissance to determine that an active trace could not be accurately located as required by the Alquist-Priolo law (Smith, 1981). Smith (1981) wrote:

"It is tempting to conclude that, because Holocene movement has been demonstrated along the Seal Cove fault to the north...as well as near Point Año Nuevo, an active strike-slip fault must traverse the area studied. Thus, it is distinctly possible that the Coastways segment may not be everywhere active, or at least not well-defined."

Ross et al. (1999 a, b) show that the relations of the Frijoles and Coastways fault strands with the Seal Cove fault are complex. North of the study area, sidescan sonar and seismic reflection data in Half Moon Bay show structural features that are discontinuous along strike, suggesting many strands in a wide fault zone.

The Seal Cove fault projects to a reef in Half Moon Bay that dies out as a bathymetric feature to the south. Fault-related features are present about 1 kilometer west of the Seal Cove fault projection. The Seal Cove fault may step over onto these structures, and thus would not be continuous with the Coastways or other onshore faults to the south. The lack of deformation seen in the study area suggests that the Coastways fault does not have a history similar to that of the Seal Cove fault or the Frijoles fault.

CONCLUSIONS

Remnant terrace surfaces record the downcutting history of creeks. Three or four correlative terrace levels are found in lower San Gregorio, Pomponio, and Bradley Creeks. Terrace levels Qt1 and Qt2 correlate across all three creeks as historical and Holocene in age, respectively. Late Pleistocene terrace Qt3 is also present in all three creeks. Terrace Qt3 may be late to mid Pleistocene, and Qt4 may be mid Pleistocene. The correlation of terraces based on relative elevation does not provide conclusive evidence of fault offset across the fault.

Late Holocene sediments exposed in the paleoseismic trench do not show evidence of faulting, indicating that the Coastways segment of the San Gregorio fault may have not ruptured in the last 4000 years. The trench did not extend across the entire length of a zone of disturbance imaged with seismic reflection, but this zone of disturbance could be the result of sedimentological contrast rather than fault disturbance.

Watersheds in southern San Mateo County have experienced aggradation as a result of 19th and 20th century land use practices. In Bradley Creek, up to 1.4 meters of sediments were deposited since about 1930, probably partly as a result of cattle grazing.

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**Oversize maps and charts are microfilmed in
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UMI

Martins
Beach

CANADA DE VERDE
Y ARROYO
DE LA PURISIMA

BM 139

BM 242

Tunitas
Beach

Mussel Rock

579x STAR

401

Q14

POMPONIO
STATE BEACH

LEGEND

☐ Quaternary Fluvial Terrace Surface

Qt1 Terrace surface of historic age. Lies 3 to 9 meters above stream and grades to modern sea level. Generally unsorted, unconsolidated sand and silt.

Qt2 Terrace of Holocene age. Lies 3 to 25 meters above stream, grades to

- Watershed boundary
- Quaternary fan mapped by Br...
- Quaternary fan as mapped by Weber et al., 19...
- Trench Site
- Terrace Profile

Location 1 Locality disc...

Note: Surfaces that appear fl...
map may not have been...
air photo assessment.

Base Map: USGS digital 7.5-m...
San Gregorio (1953, revised 19...
(1953, revised 1991), scale 1:24...

la Honda Quad

☐ **Quaternary Fluvial Terrace Surface**

- Qt1** Terrace surface of historic age. Lies 3 to 9 meters above stream and grades to modern sea level. Generally unsorted, unconsolidated sand and silt.
- Qt2** Terrace of Holocene age. Lies 3 to 25 meters above stream, grades to ~12 meters above sea level. In San Gregorio Creek, rounded cobbles in top meter of sediments. In Pomponio Creek, angular gravels. In Bradley Creek, reworked sand.
- Qt3** Lies ~18 to 75 meters above San Gregorio and Pomponio Creeks, and 70 to 120 meters above Bradley Creek. Grades to 25 meters above sea level in San Gregorio Creek, 50 meters above sea level in and Pomponio Creek, and to 85 meters above sea level in Bradley Creek. In San Gregorio Creek, a thin scattering of rounded cobbles. Mostly stripped surfaces in Pomponio and Bradley Creeks.
- Qt4** Oldest terrace. Present only in San Gregorio and Pomponio Creeks. Lies 215 to 260 meters above San Gregorio Creek, and 135 to 200 meters above Pomponio Creek. Grade to 120 meters above sea level in San Gregorio Creek and 170 meters above sea level in Pomponio Creek. Most surfaces are stripped Pomponio Member mudstone.

**Anna Sojourner
San José State University
2000**

QUADRANGLE LOCATION

terrace surfaces of lower San Gregorio Creek, Pomponio

Location 1 Locality discussed in text

Note: Surfaces that appear flat on 40 foot contour map may not have been included after air photo assesment.

Base Map: USGS digital 7.5-minute Quadrangles: San Gregorio (1953, revised 1991) and La Honda (1953, revised 1991), scale 1:24,000.

Anna So
San José Stat
20

omponio Creek, and Bradley Creek, with faults, trench

~12 meters above sea level. In San Gregorio Creek, rounded cobbles in top meter of sediments. In Pomponio Creek, angular gravels. In Bradley Creek, reworked sand.

Qt3 Lies ~18 to 75 meters above San Gregorio and Pomponio Creeks, and 70 to 120 meters above Bradley Creek. Grades to 25 meters above sea level in San Gregorio Creek, 50 meters above sea level in and Pomponio Creek, and to 85 meters above sea level in Bradley Creek. In San Gregorio Creek, a thin scattering of rounded cobbles. Mostly stripped surfaces in Pomponio and Bradley Creeks.

Qt4 Oldest terrace. Present only in San Gregorio and Pomponio Creeks. Lies 215 to 260 meters above San Gregorio Creek, and 135 to 200 meters above Pomponio Creek. Grade to 120 meters above sea level in San Gregorio Creek and 170 meters above sea level in Pomponio Creek. Most surfaces are stripped Pomponio Member mudstone.

**Anna Sojourner
San José State University
2000**

QUADRANGLE LOCATION

with faults, trench location, and creek profile lines.

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

**LEFT TO RIGHT, TOP TO BOTTOM, WITH
SMALL OVERLAPS**

This reproduction is the best copy available.

UMI

LOWER SAN GREGORIO CREEK TERRACES

POMPONIO CREEK TERRACES

EAST

LEGEND

—◆— Mo

◆ Qt1

Qt2

— Qt3

■ Qt4

? Cor

Vertical Exaggera

C

25000

30000

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8000

9000

LEGEND

—◆— Modern Channel

◆ Qt1

Qt2

■ Qt3

● Qt4

? Correlation uncertain

Vertical Exaggeration: 10x

—

30000

POMPONIO CREEK TERRACES

BRADLEY CREEK TERRACES

LEGEND

—◆— Modern Channel

◆ Qt1

Qt2

— Qt3

■ Qt4

Vertical Exaggeration: 10x

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BRADLEY CREEK TERR

SOUTH

BRADLEY CREEK TERRACES

NORTH

tions 11 and 12

ns 5 and 10

LEGEND

—◆— Modern Channel

◆ Qt1

Qt2

■ Qt3

**Plate 2 Terrace profiles for lower San Gregorio Creek,
Letters at base of distance axes are inflection points in the**

BRADLEY CREEK TERRACES

San Gregorio Creek, Pomponio Creek, and Bradley Creek. Profile lines show the elevation of the terraces. The dots represent collection points in the profile lines.

ORTH

s 11 and 12

and 10

L

Vertic

ley Creek. Profile lines are shown on Plate 1.

LEGEND

—◆— Modern Channel

◆ Qt1

Qt2

— Qt3

Vertical Exaggeration: 10x

Anna Sojourner
San José State University
2000

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UMI

24

23

22

17

16

15

SHOE FRAGMENT

10

9

8

4

3

2

1

WEST

Vertical Scale

LEGEND

LITHOLOGY

Gravel

Coarse to very coarse sand

Medium sand

Fine to very fine Sand

Pebbly silt

Sandy Silt

Root / Krotovina

Carbon Sample

Clast

Incipient soil formation

Bioturbated Sandy Layers

Water Table

LEGEND

UNITS

bot/Krotovina

Carbon Sample

Clast

incipient soil formation

turbated Sandy Layers

Water Table

Historical

Tan sand, ubiquitous roots,
generally massive.

Variable lithology, historic age
but older than Qa1.

Late Holocene

Thick, dark colored clayey silt at
west end of trench. Incipient soil
formation and sandy layers show
continuity across area of topographic
relief.

EAST

50

hic

AST

50

49

48

47

abandoned telephone
cable & trench

gray / brown sand
opens down

28

Vertical Scale

LITHOLOGY

Gravel

Coarse to very coarse sand

Medium sand

Fine to very fine Sand

Pebbly silt

Sandy Silt

Clayey Silt

Silt

Clay

Clay with sand and gravel

Root/Krotovina

Carbon Sample

Clast

Incipient soil formation

Bioturbated Sandy Layers

Water Table

Scale: 1 met
No vertical

Logged by

UNITS

Root/Krotovina

Carbon Sample

Clast

Incipient soil formation

Bioturbated Sandy Layers

Water Table

Historical

Tan sand, ubiquitous roots, generally massive.

Variable lithology, historic age but older than Qa1.

Late Holocene

Thick, dark colored clayey silt at west end of trench. Incipient soil formation and sandy layers show continuity across area of topographic relief.

Scale: 1 meter = 5 centimeters
No vertical exaggeration

ITS

Historical

ubiquitous roots,
massive.

hology, historic age
han Qa1.

Holocene

rk colored clayey silt at
of trench. Incipient soil
a and sandy layers show
y across area of topographic

EAST

48

47

46

45

45

44

43

42

Bottle (c
no

43

42

41

40

oxidized pebbles

decreased silt content
brighter color

oxidized pebbles

CAVE-IN

oxidized pebbles

Fract

Bottle (collected from
north wall)

40

39

38

37

37

36

35

34

35

34

33

32

31

32

31

30

29

Oxidized Pebbles

Oxidized Pebbles

clay silty sand

clay silty sand
to sandy silt

Clayey silt of Qa3 in
gradational contact with
overlying sandy clay of Qa2

Coarse to very coarse sand

Medium sand

Fine to very fine Sand

Pebbly silt

Sandy Silt

Clayey Silt

Silt

Clay

Clay with sand and gravel

Clast

Incipient soil formation

Bioturbated Sandy Layers

Water Table

Scale: 1 meter
No vertical ex

Logged by: Ar
Ca
Jo
August/Sept

oot/Krotovina

Historical

Carbon Sample

Clast

incipient soil formation

oturbated Sandy Layers

Water Table

Tan sand, ubiquitous roots,
generally massive.

Variable lithology, historic age
but older than Qa1.

Late Holocene

Thick, dark colored clayey silt at
west end of trench. Incipient soil
formation and sandy layers show
continuity across area of topographic
relief.

Scale: 1 meter = 5 centimeters
No vertical exaggeration

Logged by: Anna Sojourner
Carol Prentice
John Hamilton
August/September 1999

rical

uitous roots,
ive.

gy, historic age
Qa1.

ene

lored clayey silt at
nch. Incipient soil
sandy layers show
oss area of topographic

**Bottle (collected from
north wall)**

Plate 3

Log of paleose

g of paleoseismic trench at Bradley Cr

at Bradley Creek.

Anr
San José

gradational contact with
overlying sandy clay of Qa2

Anna Sojourner
San José State University
2000

Additional Contact with
lying sandy clay of Qa2

rsity