Tectonic uplift of a middle Wisconsin marine platform near the Mendocino triple junction, California

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ABSTRACT

An uplifted wave-cut marine platform eroded across bedrock of the Franciscan Complex at Point Delgada, northern California, is overlain by 0.5 to 5 m of wave-worked pea gravel, which is in turn directly overlain by fluvial gravel and silt deposited as alluvial fans. Woody plant debris at the base of the fluvial deposits includes cones of Brewer spruce (*Picea breweriana*), which today are found only at higher elevations and latitudes. Fossil wood debris from this horizon yields a ^{14}C date of 44,800 ± 1,300 yr. The 44,800 yr radiocarbon age for the base of the fluvial deposits establishes an approximate age for the immediately underlying marine gravels and wave-cut platform. We tentatively correlate this terrace with the middle Wisconsin high sea-level stand at −37 m, dated at about 45,000 yr B.P. If this age is correct, the tectonic uplift since middle Wisconsin time has been 44 m, and the average rate of uplift has been at least 1.0 m/1,000 yr. This relatively high rate is probably related to interaction among the Pacific, Gorda, and North American plates at the Mendocino triple junction.

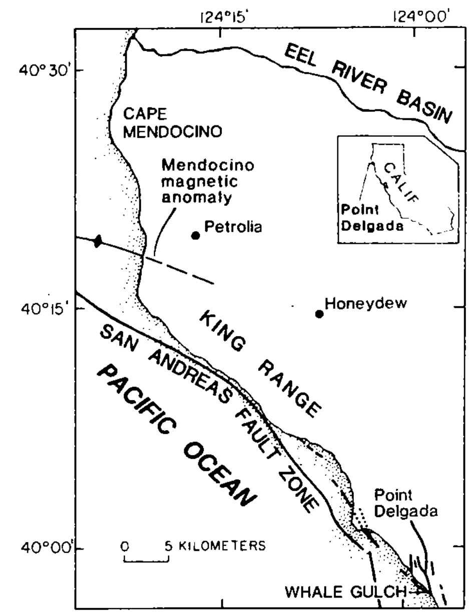


Figure 1. Location of Point Delgada marine terrace, San Andreas fault zone, and Mendocino magnetic anomaly in northern California. Modified from Beutner and others (1980).

INTRODUCTION

Point Delgada, on the northern California coast 80 km south of Eureka and about 45 km southeast of Cape Mendocino, is a low, broad, nearly planar, seaward-sloping headland (Fig. 1). This headland consists of Upper Cretaceous rocks of the Franciscan Complex, truncated by a flat wave-cut platform. The wave-cut platform is overlain by wave-worked marine and fluvial deposits of late Quaternary (Wisconsin) age (Fig. 2). In the eastern part of the point, the fluvial deposits interfinger with and are overlain by thick landslide deposits. The coastal mountains northwest and southeast of Point Delgada are composed of Tertiary rocks of the Franciscan Complex, and these mountains rise abruptly from the coastline, reaching elevations of as much as 1,200 m.

STRATIGRAPHY

Wave-cut Platform

The wave-cut platform upon which Quaternary sediments were deposited was eroded across Upper Cretaceous rocks of the Franciscan assemblage (McLaughlin and others, 1979a; Beutner and others, 1980). The edge of the wave-cut platform is well exposed in sea cliffs from Shelter Cove to the mouth of Humboldt Creek 3 km to the north. The platform rises from 2 to 3 m above sea level at Shelter Cove to about 7 m, and then descends again to 2 to 4 m at the mouth of Humboldt Creek (section A–A′, Fig. 2). The highest part of the platform is cut into basaltic pillow flows and flow breccias, which are relatively resistant to erosion, compared to the sedimentary rocks of the Franciscan Complex. Pholad borings in the platform on the southeast side of Point Delgada are evidence of its marine origin.

The back edge or shoreline angle of the platform is not exposed, so its maximum elevation is not known. Local irregularities in the platform surface are probably surge channels and sea stacks formed by differential erosion along joints and shears in the Franciscan bedrock. A few isolated exposures of the eroded platform occur on sea stacks in the present beach around the point.

Marine Terrace Deposits

Directly overlying the wave-cut platform is 0.5 to 5 m of littoral marine gravel, typically with less than 1 m of cobbly to bouldery lag gravel at the base. The coarse bouldery clasts were probably derived from ancient landslide deposits. The lag gravel, which typically fills ancient swash-zone surge channels and tide-pool depressions, is imbricated locally with tabular clasts dipping seaward. As much as 5 m of well-sorted, wave-winnowed, pebble- and pea-size gravels (2 to 15 mm) and grit, texturally similar to deposits on the modern beaches of the area, overlie the lag gravels. A large percentage of this detritus is round to subround and wave polished. The littoral deposits on the platform are distinguished texturally from overlying fluvial deposits of similar grain size by much better sorting, a scarcity of fine-grained material, and well-rounded clasts.

Quaternary Fluvial and Landslide Deposits

Locally, 1 to 20 m of poorly sorted, angular gravel and silt of nonmarine origin overlie the veneer of marine strata that rests on the wave-cut platform. These gravels locally display faint lenticular stratification and tangential cross-stratification and have a roughly uniform-size coars[illegible]

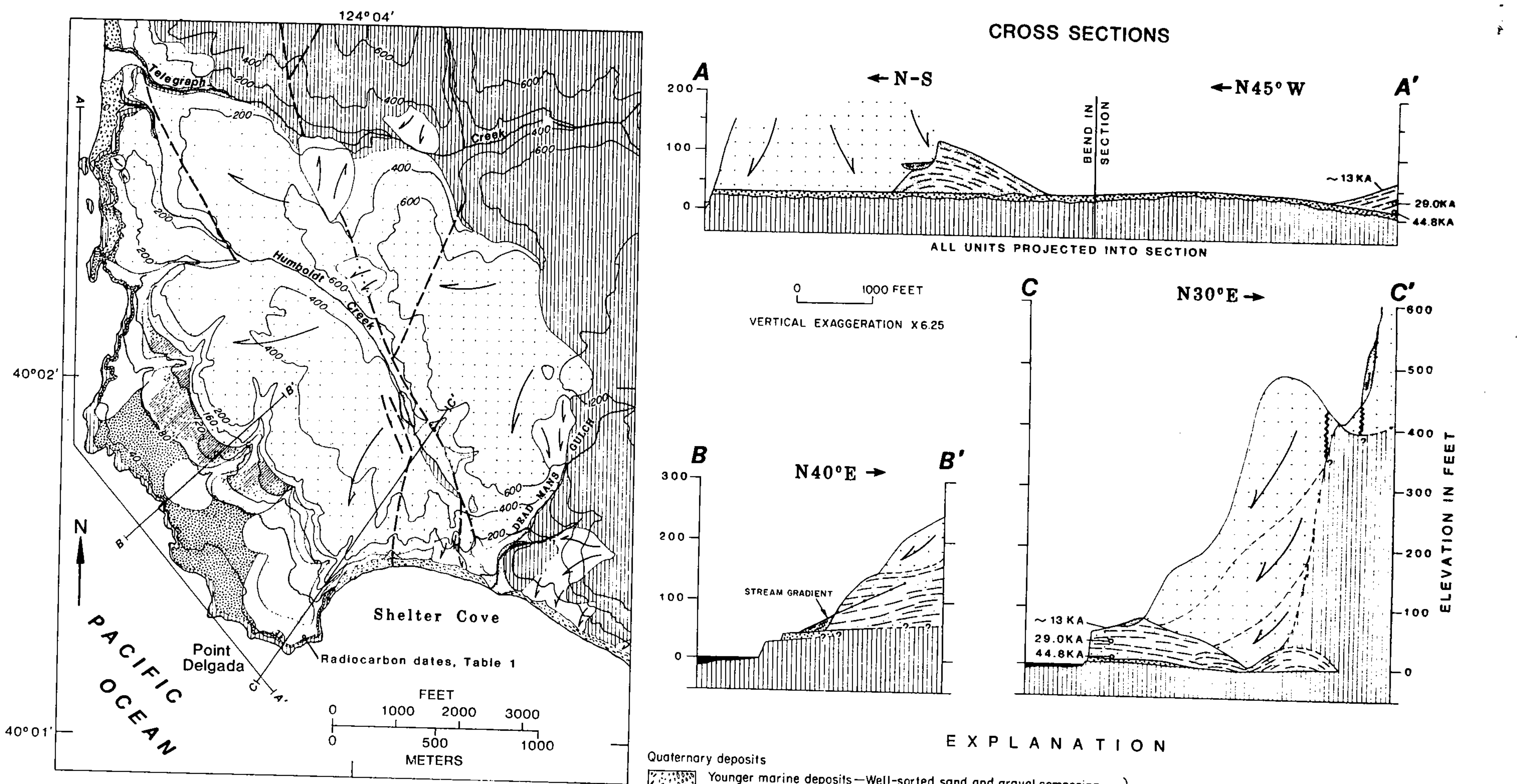
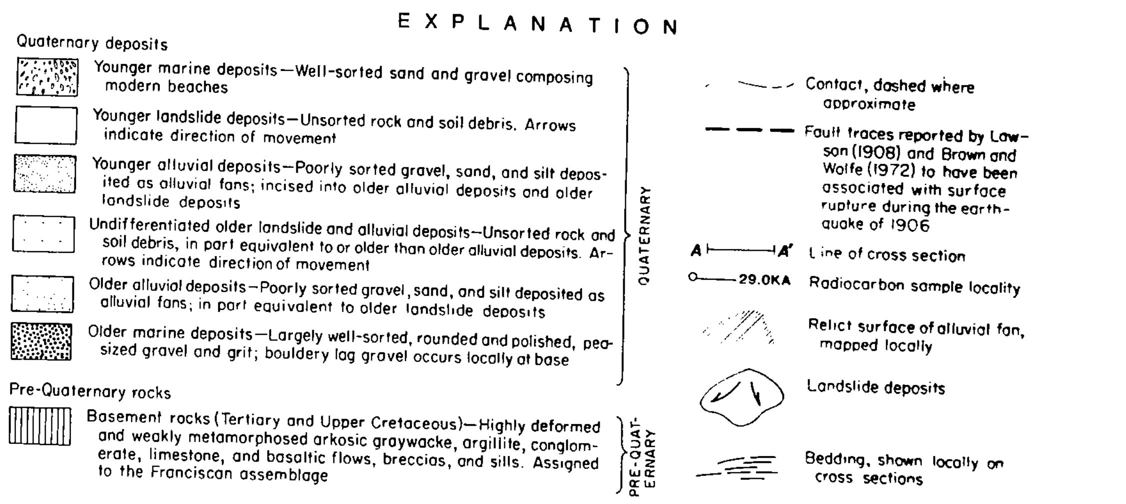


Figure 2. Geologic map and cross sections of Point Delgada area, showing locations of samples used for radiocarbon dating of fluvial deposits overlying marine terrace.



(20 to 80 mm) mode, mixed with poorly sorted sand and silt modes. Several interbeds of muddy silt and silty sand from a few centimetres to more than 1 m thick are present at several stratigraphic levels and are traceable for tens of metres laterally. These fine-grained interbeds commonly contain dispersed carbonized wood and local concentrations of woody plant debris. The gravel and silt are interpreted as distal alluvial fan or fan-delta deposits, similar to those along rapidly downcutting modern streams draining the recently uplifted mountainous coastline. The silty horizons, which contain charcoal but no marine or brackish-water megafauna or microfauna, appear to be entirely of nonmarine origin. The silt may represent local overbank or pond deposits.

At least three sets of alluvial fans are preserved in the area between Shelter Cove and Humboldt Creek (Fig. 2). In Shelter Cove on the northeast side of Point Delgada, primary dips of bedding in two alluvial fans whose mutually adjacent margins dip toward each other are clearly visible in the sea cliff. The two fans overlie the marine deposits and are overlain by unsorted landslide debris (see cross section C–C′, Fig. 2). Landslide and talus breccia interfinger with and overlap the fan deposits along the east side of Shelter Cove. South of Humboldt Creek (Fig. 2), alluvial-fan deposits have prograded over and are incised into the marine-terrace deposits. At least two younger alluvial fan deposits, complexly intercalated with landslide debris, are visible above the older alluvial-fan deposits in this area.

Prominent block-type landslides derived from an upland of highly sheared Franciscan rocks to the east overlie the fluvial deposits and older landslide debris. Numerous shear planes and faults associated with the upland Franciscan terrain have acted as slip surfaces for many of the large intact masses of rock involved in the landsliding. Some of this sliding may have been triggered by large earthquakes generated along the San Andreas fault zone.

TABLE 1. STABLE ISOTOPE DATA AND RADIOCARBON AGES OF WOOD AND CHARCOAL FROM POINT DELGADA, CALIFORNIA

Locality no.	Laboratory no.	Material	$\delta^{13}C/^{12}C$	^{14}C half-life (yr)	Corrected age yr ± 1σ
SK 79-2	UM-1632	charcoal	-24.48	5,568	29,040 + 610-570
SK 79-1	UM-1631	wood	-26.83	5,568	34,380 + 730-670
SK 79-1	USGS-1308	wood	-27.0	5,570	44,800 ± 1,300

Note: UM = University of Miami; J. J. Stipp. USGS = U.S. Geological Survey, Menlo Park, California; S. W. Robinson.

Dated charcoal (UM-1632) was concentrated by elutriation of disaggregated silt. Concentrated charcoal and woody materials were hand picked to remove root hairs and noncarbonaceous contamination. Root fibers were estimated to compose less than 0.6% by volume of the cleaned sample.

Samples dated by University of Miami were pretreated with 10 % HCl solution to remove any minor mineral-grain carbonate contamination and then neutralized with deionized water. Radiocarbon ages were calculated relative to 0.95 times the National Bureau of Standards oxalic acid radiocarbon dating standard. Quoted precision is one standard deviation and includes the counting errors on samples, background, and modern standard.

San Andreas Fault Zone

Lawson and others (1908) reported that surface ruptures occurred at Point Delgada during the earthquake of 1906. Since that time, the area has been cited as having the northernmost on-land traces of the San Andreas fault (Curray and Nason, 1967; Nason, 1968; Brown and Wolfe, 1972). Curray and Nason (1967) and D. S. McCulloch (unpub. data) have located faults in the offshore area south of Point Delgada which they associate with the San Andreas fault zone. However, other studies (Beutner and others, 1980; McLaughlin and others, 1979b) cast some doubt on the presence of a major trace of the San Andreas fault onshore at Point Delgada.

The tectonic significance of the surface ruptures reported at Point Delgada in 1906 is problematic for several reasons. All of these surface ruptures are within massive, rotational block-type landslide deposits that interfinger with and locally override the Quaternary marine and fluvial deposits. The physiographic features and surface breakage that were ascribed to surface faulting (Lawson and others, 1908), are as easily explained by seismically activated rotational movement of blocks within the landslide deposits. No active bedrock fault traces relatable to the San Andreas fault have been identified at Point Delgada, although the bedrock cut by one major steeply dipping fault was shown to have sustained no significant lateral offset since middle Miocene time (McLaughlin and others, 1979a, 1979b). No lateral offset has been documented along any of the 1906 surface ruptures at Point Delgada, although right slip is inferred from the orientation of the surface ruptures and rotation of blocks of torn sod along the ruptures. About 1 m of vertical displacement, west side down, is compatible with landsliding and well documented with photographs (Lawson and others, 1908, Plate 31A). From the available evidence, major active traces of the San Andreas could lie inland, to the east or southeast of Point Delgada (Beutner and others, 1980), or perhaps immediately to the west, offshore (see for example, Curray and Nason, 1967).

PALEONTOLOGIC AND RADIOMETRIC DATA

Woody plant remains yield somewhat ambiguous radiocarbon ages for two horizons in the fluvial part of the Point Delgada terrace deposits (Fig. 2; Table 1). One of the dated horizons, about 2.0 m above the wave-cut platform, is a 0.5-m-thick lens of nonmarine sand and silt (Fig. 2, section C–C′) that probably accumulated in ponded fresh water. The lens displays prominent load structures, contains abundant woody debris, including the cones of Brewer spruce (*Picea breweriana*), and many seeds and beetle remains. From this horizon, different samples of fossil wood yielded discordant ages of 34,380 (+730, −670) yr (UM 1631) and 44,800 ± 1,300 yr (USGS 1308). These ages so closely approach the upper limit for the respective laboratories that both might be regarded as minimum limits. Consequently, the older (USGS) date should better approximate the true age of the sample. This conclusion leads us to doubt the accuracy of a date of 29,040 (+610, −570) yr (UM 1632) on charcoal from a thin lens of silty sand 5 m above UM 1631. Until corroborated by additional dates, UM 1632 might, like UM 1631, best be regarded as a minimum age.

Discussion of Data

The radiocarbon date of about 44,800 yr, determined for the freshwater pond deposits at the base of the fluvial section, provides a minimum age for the underlying marine wave-cut platform. The pond deposits lie directly on and locally grade down into marine gravels that show no sign of extensive weathering or erosion. Therefore, deposition of the pond deposits most likely occurred shortly after the marine regression that exposed the wave-cut platform. We tentatively correlate the formation of the marine platform with the 45,000-yr-old middle Wisconsin high sea-level stand at 37 m below present sea level (Fig. 3), recognized by Bloom and others (1974) in New Guinea.

The presence of cones from Brewer spruce (*Picea breweriana*) in fluvial sediments overlying the marine platform is entirely consistent with middle Wisconsin climatic conditions implied by sea-level (Bloom and others, 1974) and stable isotope (Shackleton and Opdyke, 1973) curves. This conifer is not native to the Point Delgada area today; it now exists only in cooler climates at least 120 km to the northeast, at elevations above 100 m, and usually above 1,500 m (Griffin and Critchfield, 1972). Thus, the local climate represented by the Brewer spruce was slightly cooler than the present climate, like that expected during the middle Wisconsin, when sea level was lower than at present (Fig. 3).

TECTONIC SIGNIFICANCE

If the 45,000 yr age assignment for the marine terrace at Point Delgada is correct, and if it was cut about 37 m below modern sea level, there has been at least 44 m (37 m + 7 m) of tectonic uplift in this area since middle Wisconsin time. The uplift rate of at least 1 m/1,000 yr exceeds that derived from dated marine terraces along most of coastal California; most rates are typically around 0.3 m/1,000 yr (Wehmiller and others, 1978; Lajoie and others, 1979, 1982; Lajoie and Sarna-Wojcicki, 1982). Only near Ventura in southern California and Cape Mendocino in northern California are long-term coastal-uplift rates greater than 1.0 m/1,000 yr (Lajoie and others, 1979). Both of these areas are in regions where relative motion between crustal plates changes markedly (Fig. 4). In the Ventura area, north-south compression and resultant vertical motion occur adjacent to a major eastward bend in the San Andreas fault north of the Transverse Ranges. At Cape Mendocino, the San Andreas fault terminates at the Pacific, Gorda, and North American plates triple junction, where right-slip is taken up by eastward motion of the Gorda plate relative to the Pacific and North American plates.

At Cape Mendocino, about 50 km northwest of Point Delgada, emergent Holocene terraces have been uplifted at a rate of 2.8 m/1,000 yr (Lajoie and others, 1979, 1982; Lajoie and Sarna-Wojcicki, 1982). Higher rates up to 4.0 m/1,000 yr are recorded for the area between Cape

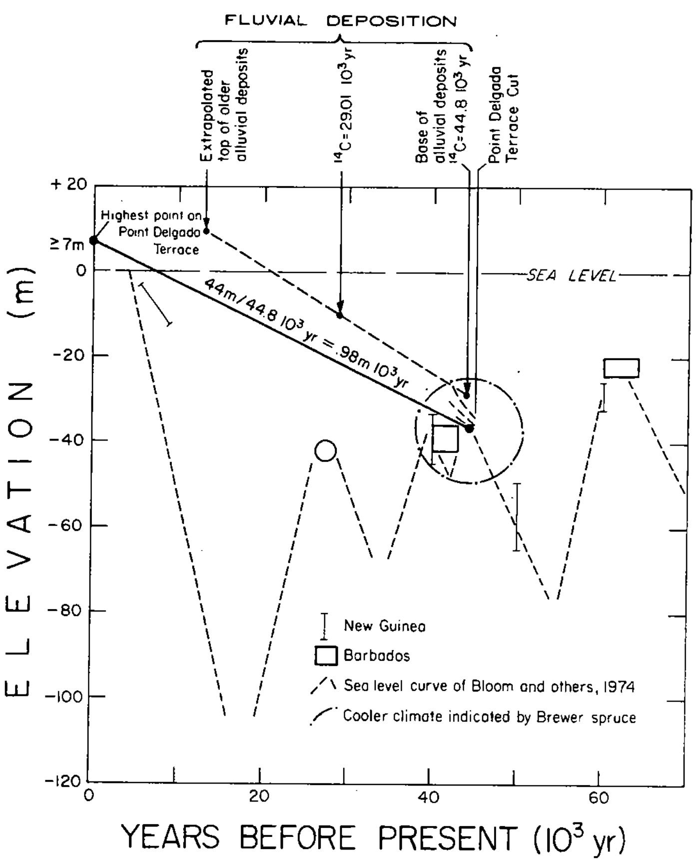


Figure 3. Sea-level curves relating Point Delgada marine terrace to Wisconsin marine high-stands and glacial regressions, relative to modern sea level. Modified from Bloom and others (1974).

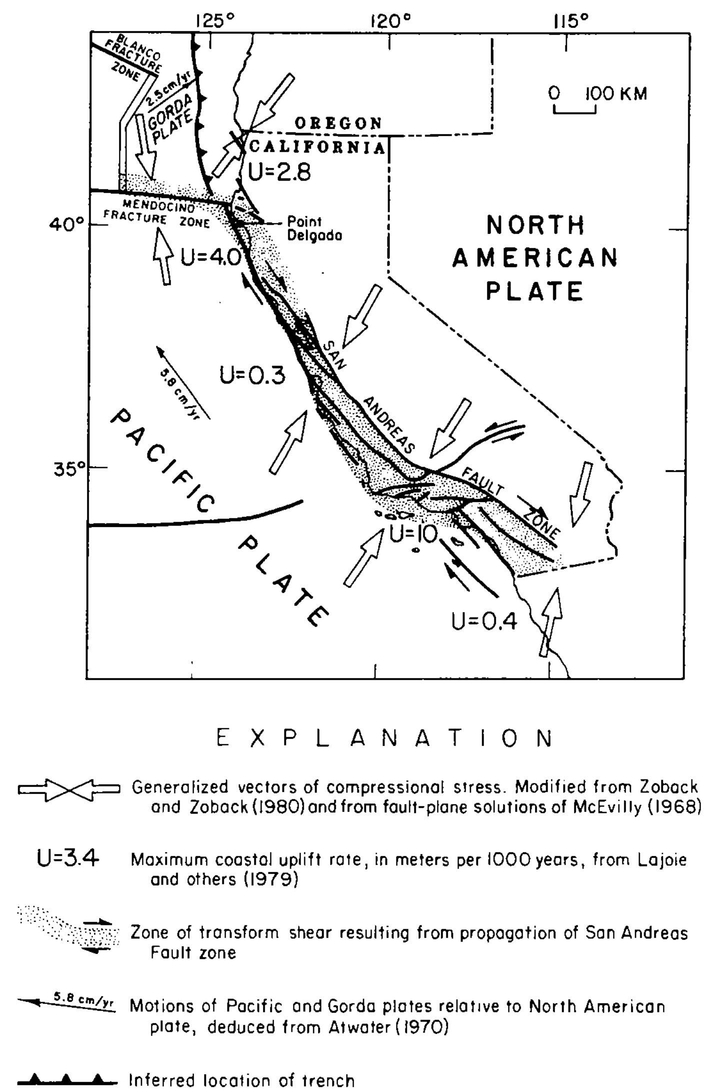


Figure 4. Regional stress pattern and plate motions for California, compared to variation in rates of coastal uplift.

Mendocino and Point Delgada (Lajoie and others, 1982). At Whale Gulch, about 11 km southeast of Point Delgada (see Fig. 1), geologic relations are similar to those at Shelter Cove (Hines, 1976). There, a wave-cut platform 3 m above sea level is overlain by 3 m of marine deposits and a thick sequence of debris-flow deposits. Fossil wood near the base of the lowest debris-flow deposit yields a ^{14}C date of 39,000 yr (Hines, 1976). Hines interpreted this radiocarbon age as infinite and correlated the emergent platform with the 105,000-yr-ago high sea-level stand of Bloom and others (1974). This age assignment yields an uplift rate of about 0.2 m/1,000 yr for the Whale Gulch terrace. However, the similarity of geologic field relations and of the radiocarbon ages of wood at the Point Delgada and Whale Gulch localities suggests to us that the Whale Gulch terrace instead may be about 40,000 to 45,000 yr old. If this younger age is correct, the derived uplift rate would be about 1.1 to 0.9 m/1,000 yr; this rate is virtually identical to the 1.0 m/1,000 yr uplift rate determined for Point Delgada.

The northern limit of the Cape Mendocino area of rapid uplift must lie near the cape, because the Eel River basin, just 20 km north, is subsiding tectonically. The southern limit is not precisely known, but at Fort Bragg, 70 km south of Point Delgada, the uplift rate is probably only 0.3 m/1,000 yr (K. R. Lajoie, 1981, unpub. data). Whale Gulch may be near the southern end of the area of rapid uplift.

The area of rapid coastal uplift approxiately corresponds to an area along the coast where a prominent magnetic lineament along the south side of the underthrust Gorda plate projects eastward beneath North America (Griscom, 1980). The rugged mountains and coastal hills of the King Range flank the southwest side of the projection of this lineament, whereas steep coastal ridges also flank the north side, between the King Range and Cape Mendocino. Resistant Franciscan rocks that form the >1,200-m-high central part of the King Range were elevated less than 15 m.y. ago along southwest-dipping thrusts and north-south–oriented anticlinal warps (McLaughlin and others, 1982). Rapid Quaternary uplift rates in this area may reflect warping in the North American plate over the underthrust south side of the Gorda plate. Alternatively, this uplift could also reflect still-active northeast-directed thrusting and north-south–oriented warping in response to regional compression and to right slip between the North American and Pacific plates (Fig. 4).

CONCLUSIONS

We correlate the emergent marine terrace at Point Delgada with the 45,000-yr-ago middle Wisconsin high sea-level stand, cut at about 37 m below present sea level. We correlate this terrace with a similar emergent terrace at Whale Gulch, 11 km south of Point Delgada. If the age we assign to the Point Delgada and Whale Gulch terraces is correct, then this part of the coastline has been rising at a rate of at least 1.0 m/1,000 yr since middle Wisconsin time. We attribute this high uplift rate to warping in the North American plate over magnetic rocks along the underthrust south side of the Gorda plate. Active northeast-directed thrusting and north-south–oriented warping are possibly additional mechanisms of rapid uplift compatible with the present orientation of regional compression and relative motion between the North American and Pacific plates.

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