The Point Sal–Point Piedras Blancas correlation and the problem of slip on the San Gregorio–Hosgri fault, central California Coast Ranges

Joseph P. Colgan1 and Richard G. Stanley2
1U.S. Geological Survey, Denver Federal Center, Lakewood, Colorado 80225, USA
2U.S. Geological Survey, Menlo Park, California 94025, USA

ABSTRACT

Existing models for large-magnitude, right-lateral slip on the San Gregorio–Hosgri fault system imply much more deformation of the onshore block in the Santa Maria basin than is supported by geologic data. This problem is resolved by a model in which dextral slip on this fault system increases gradually from 0–10 km near Point Arguello to ~150 km at Cape San Martin, but such a model requires abandoning the cross-fault tie between Point Sal and Point Piedras Blancas, which requires 90–100 km of right-lateral slip on the southern Hosgri fault. We collected stratigraphic and detrital zircon data from Miocene clastic rocks overlying Jurassic basement at both localities to determine if either section contained unique characteristics that could establish how far apart they were in the early Miocene. Our data indicate that these basins formed in the early Miocene during a period of widespread transtensional basin formation in the central Coast Ranges, and they filled with sediment derived from nearby pre-Cenozoic basement rocks. Although detrital zircon data do not indicate a unique source component in either section, they establish the maximum depositional age of the previously undated Point Piedras Blancas section to be 18 Ma. We also show that detrital zircon trace-element data can be used to discriminate between zircons of oceanic crust and arc affinity of the same age, a potentially useful tool in future studies of the California Coast Ranges. Overall, we find no characteristics in the stratigraphy and provenance of the Point Sal and Point Piedras Blancas sections that are sufficiently unique to prove whether they were far apart or close together in the early Miocene, making them of questionable utility as piercing points.

INTRODUCTION

The San Gregorio–Hosgri fault system along the central California coast (Fig. 1) is an integral component of the greater San Andreas Fault system that accommodates right-lateral shear between the Pacific and North American plates. It is also one of the most poorly understood major faults in California in terms of its slip history, with estimates of the magnitude of right-lateral slip ranging from as great as 80–180 km (e.g., Graham and Dickinson, 1978; Clark et al., 1984; Burnham, 1998; Dickinson et al., 2005) to as little as 4–5 km (Sedlock and Hamilton, 1991; Sorlien et al., 1999). Widely variable estimates of the total amount of slip have widely different implications for the role of the fault in deformation of the central California Coast Ranges and for the degree of seismic hazard it poses (e.g., Hanson et al., 2004; Dickinson et al., 2005).

The San Gregorio–Hosgri fault system forms the western boundary of a triangular area of the central California Coast Ranges that is bounded to the east by the San Andreas Fault and to the south by the western Transverse Ranges (Fig. 1). The eastern part of this region is underlain by Cretaceous granitic and metamorphic rocks of the Salinian block, offset from southern California by the San Andreas Fault, together with their Cretaceous and early Cenozoic sedimentary cover (e.g., Page et al., 1979; Barbeau et al., 2005; Sharman et al., 2013). The western part is underlain by Mesozoic Franciscan complex and Jurassic ophiolites of the Nacimiento block, juxtaposed with the Salinian block along the Nacimiento fault (Fig. 1) sometime in the Cretaceous or early Cenozoic (e.g., Dickinson, 1983; Vedder et al., 1983; Jacobson et al., 2011). Mesozoic basement is overlain by widespread sedimentary basin deposits formed during Miocene extension (e.g., Graham, 1978), including the Santa Maria basin (Fig. 1) near the south end of the San Gregorio–Hosgri fault system.

Controversy over the magnitude of slip on the San Gregorio–Hosgri fault system centers on the southern segment, mapped as the Hosgri fault, which runs north from Point Arguello offshore of the Santa Maria basin (Fig. 1). The Santa Maria basin formed during Miocene transtension (e.g., McClory et al., 1999; Stanley et al., 1996) coeval with ~90° clockwise rotation of the western Transverse Ranges immediately to the south (Fig. 1; Hornafius et al., 1986; Luyendyk, 1991). The San Gregorio–Hosgri fault translated northward movement of the west end of this rotating block into “excess” slip on the San Andreas Fault north of San Francisco. There is good geologic evidence for >100 km of offset on the northern (San Gregorio fault) segment of the San Gregorio–Hosgri fault (e.g., Clark et al., 1984; Stanley and Lillis, 2000; Dickinson et al., 2005). However, it remains unclear how Miocene and younger slip on the Hosgri fault can increase from near zero at Point Arguello to 80–100 km at Point Sal only ~35 km to...
the north (e.g., Hall, 1975; Dickinson et al., 2005) without vastly more deformation of the Santa Maria basin than is apparent from other geologic data.

In this paper, we propose an alternative model for the San Gregorio–Hosgri fault system that accounts for large-magnitude slip on the northern part of the fault while requiring much less slip on the southern part adjacent to the Santa Maria basin. We then attempt to test this model by investigating the stratigraphy and detrital zircon provenance of early Miocene sedimentary rocks involved in a key piercing point across the Hosgri fault west of the Santa Maria basin.

**SAN GREGORIO–HOSGRI FAULT OFFSET**

With the exception of a few small blocks along the coast (Fig. 1), the west side of the San Gregorio–Hosgri fault lies under the Pacific Ocean and offers few piercing points compared to the major on-land faults in California. The most robust piercing point on the northern segment of the fault is a distinctive early Eocene conglomerate overlying Cretaceous granite at Point Reyes that correlates with similar rocks on the Monterey Peninsula (Fig. 1), a distance of 150–160 km (Clark et al., 1984; Dickinson et al., 2005). A magnetic anomaly on the east side of the Hosgri fault at Cape San Martin (Fig. 1) appears to have a cross-fault counterpart located ~148–154 km to the northwest near Point Año Nuevo (Fig. 1; Langenheim et al., 2013). Franciscan basement and overlying Miocene sedimentary rocks at Point Sur (Fig. 1) are inferred to correlate with similar rocks exposed near Cambria (e.g., Hall, 1991; Dickinson et al., 2005), which Langenheim et al. (2013) refined using geophysical data to indicate ~125 km of offset.

The most well-established piercing point on the southern (Hosgri fault) segment of the fault is a Jurassic ophiolite overlain by Cenozoic sedimentary rocks exposed at Point Piedras Blancas near San Simeon, which is inferred to correlate with similar rocks east of the fault at Point Sal (Fig. 1), ~100 km to the south (e.g., Hall, 1975; Dickinson et al., 2005). Correlation of the ophiolites is supported by high-precision U-Pb dating, which found them to be of identical age (165 Ma; Mattinson and Hopson, 2008), and by their very similar aeromagnetic expression (Langenheim et al., 2013). No basement piercing points have been identified south of Point Sal, but Sorlien et al. (1999) used detailed seismic data to reconstruct folded and faulted Miocene sedimentary rocks in the offshore Santa Maria basin (Fig. 1) and found only ~4 km of post-Miocene right-lateral offset. South of Point Arguello, right-lateral offset on the San Gregorio–Hosgri fault goes to zero as it curves east and dies out into the western Transverse Ranges block (e.g., Sorlien et al., 1999; Langenheim et al., 2013).

Dickinson et al. (2005) proposed that the decrease in shortening from Point Sal to Point Arguello was accommodated by NW-SE—parallel to the Hosgri fault—middle Miocene and younger shortening across the Santa Maria basin as the western Transverse Ranges block rotated clockwise (Fig. 2). Although they did not explicitly state the amount of shortening required, their reconstruction (fig. 12 in Dickinson et al., 2005) suggests ~80 km, or ~100% strain...
across the basin since ca. 16 Ma. Their reconstruction also implies fault-parallel extension offshore in order to move the Piedras Blancas block ~50 km closer to Point Arguello (Fig. 2B). Langenheim et al. (2013) used a combination of geologic and geophysical data to restore the major right-lateral strike-slip faults between the Salinian block and the San Gregorio–Hosgri fault, and they found that the magnitude of slip on the Hosgri fault decreased to the south. However, they were still left with a large “space problem” north of the western Transverse Range block (Fig. 2C) as a result of restoring ~90 km of right-lateral offset from Point Sal to San Simeon. As with the Dickinson et al. (2005) model, resolution of this space problem implies large-magnitude, NW-SE shortening across the Santa Maria basin from 16 Ma to the present, concurrent with rotation of the western Transverse Ranges block.

How much Miocene shortening has there been across the Santa Maria basin? Namson and Davis (1990) found ~10 km of shortening across that part of the central Coast Ranges along a balanced cross section oriented NNE-SSW (perpendicular to the Hosgri fault), beginning between 4 and 2 Ma. Clark et al. (1991) examined the offshore portion of the Santa Maria basin and also found SW-NE shortening that began ca. 5–3 Ma. Graymer et al. (2010) looked specifically at the shortening component parallel to the Hosgri fault and found only ~4–5 km of Neogene shortening between Point Sal and Point Arguello. Moreover, studies of sedimentary fill in the Santa Maria basin indicate an extensional setting in the early to middle Miocene (McCrory et al., 1995; Stanley et al., 1998), during early rotation of the western Transverse Ranges block; latest Miocene and younger shortening is superimposed on these older extensional structures and basins. The timing, magnitude, and orientation of crustal shortening across Santa Maria basin are thus too little, too young, and in the wrong orientation to account for the drastic increase in the apparent offset along the Hosgri fault from Point Arguello to Point Sal northward to its present position.

An Alternative Model for Slip on the San Gregorio–Hosgri Fault

Here, we propose an alternative model for the evolution of the San Gregorio–Hosgri fault system that does not require major NW-SE shortening across the Santa Maria basin, while still permitting a full ~150 km of offset on the northern part of the fault (Fig. 3). We make the following kinematic assumptions, all well supported by geologic data.

1. The San Gregorio–Hosgri fault does not extend south past the west end of the western Transverse Ranges block (Point Arguello) as a Miocene and younger strike-slip fault (e.g., Steritz and Luyendyk, 1994; Sortien et al., 1999; Langenheim et al., 2013).

2. The offshore block of the San Gregorio–Hosgri fault has not substantially changed length (parallel to the fault) since the early Miocene, i.e., the Point Arguello–Piedras Blancas–Point Sur–Pigeon Point–Point Reyes distance...
has not changed significantly. Steritz and Luyendyk (1994) suggested ~60 km of right slip on the Santa Lucia Bank fault, but they did so to explain the Point Arguello to Point Sal slip discrepancy on the Hosgri fault, which our model renders unnecessary.

(3) To a first order, the western Transverse Ranges behaved as a rigid block—i.e., the western Transverse Ranges did not significantly change length along their long axis—during ~90° clockwise rotation from 16–17 Ma to the present (Hornafius et al., 1986; Luyendyk, 1991).

(4) To a first order, the western Transverse Ranges behaved as a rigid block—i.e., the western Transverse Ranges did not significantly change length along their long axis—during ~90° clockwise rotation from 16–17 Ma to the present (Hornafius et al., 1986; Luyendyk, 1991).

(4) The northern part of the Salinian block (east of the San Gregorio fault) has not undergone a major change in length parallel to the San Andreas Fault since the middle Miocene. The Salinian block was mostly deformed by Miocene extension and late Miocene to Pliocene and younger shortening perpendicular to the San Andreas Fault (e.g., Compton, 1966; Graham, 1978; Page et al., 1998; Colgan et al., 2012). It is cut by some strike-slip faults subparallel to the San Andreas Fault, but these account for minor Miocene offset (tens of kilometers) at the scale of the ~500 km long block (e.g., Langenheim et al., 2013).
Figure 3 illustrates the kinematic consequences of this model by stripping the central Coast Ranges down to their essential geometric elements: a rotating western Transverse Ranges block at the south end, a relatively little-deformed Salinian block, a triangular area of Franciscan basement cut by right-lateral strike-slip faults, and an effectively rigid offshore block linked to the west end of the western Transverse Ranges block and separated from the central Coast Ranges by the right-lateral San Gregorio–Hosgri fault system.

As the western Transverse Ranges block rotates clockwise, the triangular region between the San Andreas and San Gregorio–Hosgri fault systems undergoes minor changes in width perpendicular to the major strike-slip faults—first extension as the end of the rotating block swings outward from 16 to 10 Ma, and ultimately compression as the block swings back inward from 5 to 0 Ma. The region of Franciscan basement west of the Salinian block—especially the Santa Maria basin—undergoes a profound shape change accommodated primarily by internal strike-slip faults subparallel to the Hosgri fault (e.g., Luyendyk, 1991; Stanley et al., 1996; Langenheim et al., 2013), but its area and volume (e.g., crustal thickness) do not change drastically. The granitic Salinian block is comparatively much less deformed. Points on the offshore block west of the San Gregorio–Hosgri fault system are translated northward across the north end of the Salinian block and ultimately onto the San Andreas Fault. Meanwhile, their offset equivalents on the landward side of the Hosgri fault are brought closer together as the western part of the central Coast Ranges changes shape by right-lateral strike-slip faulting. The net effect is that slip on the San Gregorio–Hosgri fault increases more or less linearly from a few kilometers at Point Arguello to a maximum value close to where the Salinian block intersects the Hosgri fault, and it is constant from there northward.

To first order, this model is consistent with nearly all of the documented Miocene and younger deformation in the central Coast Ranges. Rather than major NW-SE shortening from the middle Miocene to the present, this area was deformed primarily by strike-slip faulting beginning in the middle Miocene. From 16 Ma into the late Miocene, deformation had a strong transtensional component, with a transition to transpression sometime in the latest Miocene to Pliocene (Fig. 3B). The one exception is well-documented middle Miocene to late Pliocene NW-SE shortening immediately north of the western Transverse Ranges (Onderdonk, 2005), which is a predicted consequence of the shape change required between the rotating block and unrotated crustal blocks to the north. Offset of the Point Reyes block from Monterey (150–180 km; Clark et al., 1984) is approximately equal to the offset of the Año Nuevo block from Cape San Martin (~148–154 km; Langenheim et al., 2013), consistent with predicted near-constant offset on the San Gregorio fault across the north end of the Salinian block. The decrease in slip on the Hosgri fault from Cape San Martin southward documented by Langenheim et al. (2013) is consistent with the model prediction of decreasing slip on this segment, with the exception of 90–100 km offset between Point Sal and Point Piedras Blancas. No variation of the model proposed here can account for such a drastic increase in slip over such a short length of the fault—from zero to 90 km of offset in only 35 km along strike—without invoking geologically unreasonable deformation on one or both sides of the fault. Given the problems posed by this single piercing point, we undertook a reexamination of the evidence for such large post–16 Ma displacement between Point Sal and San Simeon.

POINT SAL–POINT PIEDRAS BLANCAS CORRELATION REVISITED

The strongest evidence for correlation of Point Sal with the Point Piedras Blancas block is the similar age and geologic and geophysical characteristics of the Jurassic ophiolites exposed at both localities (Hall, 1975; Mattinson and Hopson, 2008; Langenheim et al., 2013). However, the fault offset in question is only early to middle Miocene and younger. Given the long and complex history of strike-slip faulting along the plate margin (e.g., Nilsen and Clarke, 1975; Vedder et al., 1983, 1991; Dickinson, 1983; Ernst et al., 2011; Jacobson et al., 2011; Sharman et al., 2013), it is possible that the Jurassic ophiolites were offset from each other at least partway sometime between 160 and 16 Ma, with the Hosgri fault later reactivating a strand of a preexisting fault. Jurassic ophiolites are scattered throughout the California Coast Ranges for over 800 km along strike, and all fall into a narrow age range of ca. 161–168 Ma (Hopson et al., 2008). Another possibility—unsatisfying as it may be—is that the similar ages and character of the ophiolites at Point Sal and San Simeon are simply a coincidence. With respect to post–16 Ma slip on the Hosgri fault, the relevant parts of the Point Sal–Point Piedras Blancas piercing point are the Cenozoic sedimentary rocks that overlie the Jurassic basement in both localities, and these would only record Miocene and younger slip. Since Hall (1975) proposed this correlation, both Sedlock and Hamilton (1991) and Stanley et al. (1996) noted significant differences between the Cenozoic sections at Point Sal and San Simeon. Stanley et al. (1996) presented a detailed study of the section at Point Sal, but the section at San Simeon has not been studied or directly dated.

We undertook a combined stratigraphic and detrital zircon provenance study of the Lospe Formation in the Point Sal and Point Piedras Blancas sections to determine if they had any unique characteristics that could prove that they could only have been deposited a few kilometers apart, or prove that they could only have ever been far apart in separate basins. The first part of this study involved compilation of existing stratigraphic data with new field observations to document the nature and depositional environment of the Lospe Formation at Point Sal and Point Piedras Blancas. The second part involved detrital zircon provenance studies to see if either section had a unique source they both lacked, or if there was a unique source they both shared. The most promising candidate for a unique source is the ca. 27 Ma (U-Pb zircon; Ernst et al., 2011) silicic igneous rocks of the Cambria Felsite and Morro Rock–Islay Hill complex exposed near Cambria (Fig. 1). These rocks are just a few kilometers south of San Simeon and could have provided zircon to the Point Piedras Blancas section if it were already far north of Point Sal in the Miocene, while no potential sources of comparable age are exposed close to Point Sal.
Stratigraphy of Lospe Formation Outcrops Adjacent to the Hosgri Fault

Point Sal–Casmalia Hills

The Point Sal ophiolite and overlying Cenozoic sedimentary rocks are well exposed along the coast at Point Sal and in the Casmalia Hills on the northwest corner of Vandenberg Air Force Base. Basement rock consists of the Jurassic (165 Ma) Point Sal ophiolite (Hopson and Frano, 1977; Mattinson and Hopson, 2008), locally overlain by the Jurassic and Cretaceous Espada Formation (Dibblee and Ehrenspeck, 1989). Cenozoic rocks, including the Lospe, Point Sal, and Monterey Formations, are exposed in an E-W-trending syncline in the Casmalia Hills, partly bounded on the north by the Point Sal fault (Fig. 4).

The type Lospe Formation (Woodring and Bramlette, 1950) is located along the south flank of Mount Lospe in the Casmalia Hills (Fig. 4). In this area, the Lospe Formation depositionally overlies the Jurassic ophiolite and is overlain by the Miocene Point Sal Formation (Figs. 4 and 5). Here, the Lospe Formation is up to 830 m thick (Fig. 5) and consists of a lower conglomeratic member and an upper mudstone and sandstone member (Stanley et al., 1996). The lower member is ~150–200 m thick and consists of reddish-brown to greenish-gray alluvial-fan and fan-delta conglomerates, sandstones, and mudstones. The conglomerates contain clasts derived from the nearby ophiolite, as well as nonophiolitic clasts including sandstone and chert derived from the Franciscan complex and Great Valley sequence (McLean and Stanley, 1994).
Figure 5. Stratigraphic columns of rocks mapped as Lospe Formation at Point Sal, Cambria, and Piedras Blancas. Chute Creek and North Beach sections are modified from Stanley et al. (1996). Cambria section is modified from description of Hall (1974) based on new mapping by Graymer et al. (2014), and Corralitos Canyon and Piedras Blancas sections are from this study. California benthic foraminifer stages are from McDougall (2007). Note that strata near Cambria assigned to the Lospe Formation by Hall (1974) are actually >5 m.y. older than the type Lospe and therefore belong to a different unit (denoted by quotation marks in figure). J ophiolite—Jurassic ophiolite.
The lower member grades upward into a 250–600-m-thick upper member (Fig. 5) consisting of interbedded greenish-gray mudstone and sandstone that Stanley et al. (1996) interpreted as deposited in a lacustrine basin, possibly with intermittent connection to the ocean. Vitric tuffs occur in thick beds (up to 20 m) throughout both members of the Lospe Formation (Figs. 4 and 5) and are interpreted as the products of subaqueous, high-density sediment gravity flows that closely followed pyroclastic eruptions from vents near Tranquillion Mountain (Fig. 1), located ~35 km south of Point Sal (Cole and Stanley, 1994, 1998). Stanley et al. (1996) reported \(^{40}\)Ar/\(^{39}\)Ar dates of 17.70 ± 0.02 Ma (sanidine) and 17.39 ± 0.06 Ma (plagioclase) from two tuffs exposed in the section at North Beach (Figs. 4 and 5).

The Lospe Formation in the Casmalia Hills is overlain by ~450 m of dark-gray to black silty shale and sandstone of the Point Sal Formation, which record an abrupt transition from the mostly nonmarine Lospe basin to an oxygen-starved bathyal marine basin across the Sauciesan-Relizian benthic foraminiferal stage boundary (Fig. 5). We collected two detrital zircon samples of the Lospe Formation from the section exposed along the coast at North Beach (Fig. 4), one from sandstone at the base of the upper member (11-CA08) and one near the top (11-CA09), from the distinctive “cannonball sandstone” horizon a few meters below the base of the Point Sal Formation.

**Corralitos Canyon**

North of Point Sal Ridge in the Corralitos Canyon area (Fig. 4), the Lospe Formation depositionally overlies Jurassic ophiolite and the Jurassic–Cretaceous Espada Formation and is overlain by the Miocene Point Sal Formation (Fig. 4). Here, the Lospe Formation consists mainly of reddish-brown coarse sandstone and conglomerate composed primarily of material derived from the Jurassic ophiolite, and it likely was deposited in an alluvial-fan setting. The age of the Lospe Formation in the Corralitos Canyon area is not well constrained but must be early Miocene or older because samples from the overlying Point Sal Formation contain benthic foraminiferal assemblages of the Relizian stage, along with palynomorphs of early Miocene to early middle Miocene age (Stanley et al., 1996). Interbeds of felsic tuff are present locally (Woodring and Bramlette, 1950) but have not been dated or studied in detail, and the location of the eruption source is unknown. The thickness of the Lospe Formation in this area is uncertain because of poor exposure, but it may be ~300 m or more. In contrast to the type Lospe Formation on the south side of Mount Lospe, no upper member composed of fine-grained rocks of lacustrine origin is present in Corralitos Canyon— the nonmarine sandstone is overlain directly by the deep marine Point Sal Formation. We collected a detrital zircon sample (11-CA06) from reddish-brown sandstone and conglomerate on the south side of Corralitos Canyon (Fig. 4).

**San Simeon–Point Piedras Blancas**

The San Gregorio–Hosgri fault is exposed onshore for ~15 km near San Simeon, California, where it is mapped as the San Simeon fault (e.g., Hall, 1975; Hall et al., 1979). Basement rock on the southwest side of the fault—the Piedras Blancas block (Graymer et al., 2014)—consists of Jurassic ophiolite and Jurassic to Lower Cretaceous shale. A sequence of conglomerate and sandstone that was correlated by Hall (1975) with the Lospe Formation crops out in a NNW-trending syncline and is well exposed along the sea cliff north of Point Sierra Nevada (Fig. 6). The Lospe Formation in this area is interpreted to unconformably overlie the Jurassic ophiolite (Hall et al., 1979; Stanley et al., 1996) and is unconformably overlain by Quaternary deposits.

In this area, the Lospe Formation consists of red, green, and gray conglomerate and sandstone that were likely deposited in a nonmarine, proximal alluvial-fan setting. The conglomerate consists mainly of angular to rounded ophiolitic debris and generally is poorly organized; in places, the conglomerate includes boulders as large as 200 cm in longest dimension. Interbeds of volcanic tuff were reported by Hall et al. (1979) and Hall (1975) but have not been found by subsequent workers (Stanley et al., 1996; this study). No fossils have been found. Hall et al. (1979) assigned an Oligocene age to this unit but did not describe the basis for this age. In contrast to the type Lospe Formation near Point Sal, there is no upper member composed of fine-grained rocks of lacustrine origin in the Lospe Formation near Point Piedras Blancas. The thickness of the Lospe Formation there is uncertain; we estimate that an ~200 m section is exposed, and that an additional 200–300 m may be covered by the dune field north of Point Sierra Nevada (Fig. 6). We collected two detrital zircon samples (11-CA03, 11-CA05) from coarse sandstone layers interbedded with coarse conglomerate in sea-cliff exposures (Figs. 5 and 6).

**Cambria Area**

Rocks mapped as Lospe Formation by Hall (1974) are exposed a few kilometers east of Cambria (Fig. 1), where they were deposited on Franciscan basement and Oligocene volcanic rocks of the Cambria Felsite. The Cambria Felsite includes rhyolite to dacite tuffs, lava flows, and breccias probably derived from eruptive centers near the Morro Rock–Islay Hill intrusive complex ~30 km to the southeast (Ernst and Hall, 1974). Ernst et al. (2011) reported a 27 Ma U-Pb zircon age from the Cambria Felsite, while Turner (1970) and Buckely (1986) reported K-Ar ages of ca. 22–28 Ma from the Morro Rock–Islay Hill complex (ages recalculated by Cole and Stanley [1998], using the method of Dalrymple, 1979). The overlying Lospe Formation is up to 200 m thick and consists of reddish-weathering, red to greenish-gray conglomerate, sandstone, and mudstone that were deposited in a nonmarine setting (Fig. 5). Conglomerate clasts include chert and graywacke derived from underlying Franciscan rocks and dacite presumably derived from the Cambria Felsite (Hall, 1974; Graymer et al., 2014). The Lospe Formation is overlain by 50–250 m of white, medium-to coarse-grained, marine sandstone of the late Oligocene to early Miocene Vaqueros Sandstone (Fig. 5; Hall, 1974; Graymer et al., 2014). Conglomerate beds near the base of the Vaqueros Sandstone contain abundant clasts of silicic volcanic rock presumably derived from the Cambria Felsite. The fact that the “Lospe Formation” near Cambria is overlain by Oligocene rock means it...
does not correlate with the type Lospe of early Miocene age at Point Sal and should be considered a different unit.

When Hall (1975) first proposed correlation of the Lospe Formation at Point Sal and Point Piedras Blancas, he noted the absence of Cambria Felsite clasts in the Piedras Blancas Lospe Formation, compared to their relative abundance in the rocks he correlated with the Lospe Formation near Cambria. The Cambria Felsite and Morro Rock–Islay Hill intrusive complex represent the one potentially unique and geographically specific zircon source along the central California coast between Point Sal and Point Piedras Blancas, in contrast to the broadly similar Mesozoic basement rocks throughout the area. Even in the absence of actual dacite clasts, the presence of 27 Ma zircons in samples from Point Piedras Blancas would suggest a location close to the Cambria area in the early Miocene. In order to compare the detrital zircon signature of the Lospe Formation near Cambria with that of the Lospe Formation at Point Piedras Blancas and Point Sal, and to test the efficacy of the Cambria Felsite as a source of zircon in younger Cenozoic sandstones, we collected detrital zircon samples from sandstones in both the Lospe Formation (11-CA01) and Vaqueros Sandstone (11-VL200) a few kilometers east of Cambria (Fig. 1).

**Detrital Zircon Analysis of Lospe Formation Strata**

**Analytical Methods**

Zircons were separated from crushed and ground samples using standard magnetic and heavy liquid techniques, handpicked under a binocular microscope, and mounted in epoxy discs. A random assortment of zircons
was poured onto the mount from each sample in order to avoid biasing the resulting age patterns. Zircon mounts were ground to expose grain interiors, polished, and imaged with cathodoluminescence (CL) on a JEOL 6500 scanning electron microscope to identify internal structure (rims, core, etc.). Zircon U-Pb ages were obtained with the Stanford–U.S. Geological Survey (USGS) sensitive high-resolution ion microprobe with reverse geometry (SHRIMP-RG) at Stanford University. The SHRIMP-RG was operated with an O₂ primary ion beam that varied in intensity from 4.0 to 5.5 nA, with a typical spot diameter of 20–25 μm. Zircon surfaces were rastered by the primary beam for 120–180 s before data were collected. For all samples, the following peaks were measured sequentially: 89Y, 139La+, 140Ce+, 147Sm+, 153Eu+, 155Gd+, 172Yb16O+, 90Zr2⁺, 180Hf16O+, 204Pb+, a background measured at 0.045 mass units above the 204Pb+ calibration for sputtering bias (Williams, 1997). Radiogenic U-Pb ratios were determined by sputtering Cretaceous grains and a few Cenozoic zircons in some samples. Detrital zircon are the dominant post-Paleozoic fraction in most samples, with subordinate Jurassic (mostly Late Jurassic) grains. The sample from the base of the upper member of the Lospe Formation at North Beach (11-CA08) contained a single 18.2 ± 0.4 Ma grain and a mix of Cretaceous, Jurassic, and Precambrian zircon not notably dominated by a single age (Fig. 7), although relatively few (n = 48) grains were analyzed from this sample compared to the others. The youngest sample from Point Sal, from the “Cannonball Sandstone,” near the top of the upper member of the Lospe Formation at North Beach (11-CA09), is dominated by Cretaceous zircon, with subordinate Jurassic grains and ~15% Precambrian zircon in the ca. 1400–1700 Ma range (Fig. 7). The four youngest grains from this sample yielded a weighted-mean age of 18.0 ± 1.0 Ma (Fig. 7), in good agreement with the 17.7–17.4 Ma ⁴⁰Ar/³⁹Ar ages determined by Stanley et al. (1996) from the same sample. The two samples from the Cambria area yielded nearly identical age populations dominated by Late Cretaceous zircon (Fig. 7), with the remainder consisting mostly of Early Cretaceous and Jurassic zircon and less than 10% Precambrian zircon, i.e., distinctly less than the other samples (Fig. 7). Notably, neither sample yielded a single Cenozoic zircon grain (out of 140 total), despite the Lospe Formation (sample 11-CA01) being deposited directly on the 27 Ma Cambria Felsite within 4 km of our sample site, and the Vaqueros Sandstone sample (12-VL200) actually containing clasts of volcanic rock inferred to be derived from the Cambria Felsite. The Cambria Felsite thus appears not to have been a major source of zircon in younger Cenozoic sedimentary deposits.

The lower sample from the Point Piedras Blancas section (11-CA03) is dominated by Jurassic zircon (Fig. 7) with a peak age around 165 Ma, close to the age of the underlying ophiolite. The remaining grains are mostly Cretaceous, with ~13% pre-Mesozoic (mostly Proterozoic) zircons. The stratigraphically slightly higher sample (11-CA05) is more heterogeneous, with a dominant Late Cretaceous peak (Fig. 7) and ~22% pre-Mesozoic (mostly Proterozoic) zircon, with the remainder scattered between ca. 110 and 200 Ma (Fig. 7). Four young grains from sample 11-CA05 yielded a weighted-mean age of 178 ± 0.6 Ma (Fig. 7), and a single younger grain yielded an age of 14.6 ± 1.1 Ma. The section at Point Piedras Blancas is therefore at least as young as early Miocene, not Oligocene as it was originally interpreted (Hall, 1975; Hall et al., 1979).

Grimes et al. (2007) demonstrated that U/Yb ratios are useful for distinguishing zircons formed in oceanic crust from those formed in a typical continental arc. Zircons from mafic oceanic crust (e.g., mid-ocean-ridge basalt [MORB]) have low U/Yb ratios that reflect their origin in depleted mantle-sourced
Figure 7. Probability density plots (bottom) and cumulative probability plot (top) of detrital zircon age data from all samples. Data from Cretaceous basement rocks near Cambria and Atascadero are from Jacobson et al. (2011). Note scale change at 300 Ma.
magmas (Grimes et al., 2007), whereas continental arc zircons tend to be more enriched in U and Th and have higher U/Yb ratios due to fluids derived from the subducting slab (e.g., Barth et al., 2013). The Point Piedras Blancas section contains a distinctive population of low U/Yb zircons that are not present in other samples (Fig. 8). They are present in both samples from Point Piedras Blancas, although relatively more abundant in sample 11-CA03 from the lower part of the section (Fig. 8A). When plotted versus zircon age (Fig. 8B), the low U/Yb zircons at Point Piedras Blancas are clearly Jurassic, and we interpret them to be derived from the 165 Ma ophiolite that underlies the Cenozoic section there. Late Cretaceous zircons in all samples trend toward higher U/Yb ratios (Fig. 8B), consistent with Barth et al.’s (2013) data showing an increase in zircon U/Yb ratios from Jurassic to Cretaceous plutons in the California arc, which they attributed to an enhanced fluid component in the Cretaceous magmas.

**Correlation of the Lospe Formation at Point Sal and Point Piedras Blancas**

Do the Cenozoic sections at Point Sal and Point Piedras Blancas have any unique characteristics that could definitively prove whether they were deposited adjacent to each other or far apart? The section at Point Piedras Blancas is thinner than the type Lospe Formation at Point Sal and lacks the finer-grained upper member that makes up the majority of the section at Point Sal (Fig. 5). However, the Point Piedras Blancas section is folded and overlain by Quaternary deposits on an erosional unconformity (Fig. 6), so it is possible that the finer-grained upper member was once present but removed by erosion as the San Simeon block moved north along the Hosgri fault. The section at Point Piedras Blancas also lacks the vitric tuffs present in the type Lospe section. Since these were originally delivered as air fall from a southerly source before washing into the basin, one would expect them to be present if the San Simeon block had been adjacent to Point Sal in the early Miocene. Given the potential for postdepositional erosion of the San Simeon block and the potential for poor tuff preservation in coarse clastic rocks, however, this by itself is not proof of great separation between the two sections. After all, the Corralitos Canyon section contains significantly less tuff than the type Lospe Formation despite being deposited only a few kilometers away (Fig. 4). The Corralitos Canyon section also lacks the finer-grained upper member present in the type Lospe section, instead transitioning directly from coarse conglomerate directly to the deep-water Point Sal Formation (Fig. 5). We attribute these differences to the Corralitos Canyon and type Lospe sections being deposited in distinct subbasins separated by the Point Sal Ridge basement block (Fig. 4).

Although the relative proportions of each component vary from sample to sample, detrital zircon populations from all samples are broadly similar to each other and to potential basement sources (Fig. 7), including Cretaceous sedimentary rocks and underlying Jurassic ophiolites. The 27 Ma Cambria Fel-site did not contribute zircon to nearby overlying deposits (samples 12-VL200 and 11-CA01; Fig. 7), so the absence of this population from the Point Piedras Blancas section is not evidence for the San Simeon block being ~100 km farther south in the early Miocene. Trace-element data from one sample in the Point Piedras Blancas section (11-CA03; Fig. 7) contain a significant and unique population of ophiolite-sourced Jurassic zircon not present in either the other sample from the same section (11-CA05; Figs. 7 and 8) or any of the Point Sal samples. However, ophiolite clasts are present in the Lospe Formation at Point Sal despite the absence of ophiolite zircon in those samples, indicating that an ophiolite source will not necessarily manifest itself in the zircon record. A young detrital zircon age peak indicates a ca. 18 Ma maximum depositional age for the Piedras Blancas section, identical to the Point Sal section (Figs. 5 and 7). Sedimentary basins were forming throughout the central California Coast Ranges at this time, however, so there is nothing about this age that requires these sections to have been laid down in the same basin.

---

**Figure 8.** Select trace-element data from detrital zircons analyzed in this study. (A) U/Yb vs. Y plot (all zircons). (B) U/Yb vs. age plot (Mesozoic zircons only).
Based on their stratigraphy, source, and depositional setting, the Point Sal and Point Piedras Blancas sections could have been deposited within a few kilometers of each other in the same basin, with any differences explained by along-strike variation in the basin and postdepositional erosion. Based on the same criteria, the Point Sal and Point Piedras Blancas sections could just as easily have been deposited ~90 km apart in separate basins, with any similarities explained by their age, tectonic setting, and underlying Nacimiento block base-
ment lithologies being common to a large area of the central Coast Ranges. We prefer abandoning the Point Sal–Point Piedras Blancas correlation in favor of the model presented in Figure 3, but we conclude that Miocene sedimentary rocks of the Lospe Formation are not robust indicators of the amount of post-16 Ma slip on the Hosgri fault between Point Sal and San Simeon, be it large or small. Given the problems posed by requiring such a large increase in slip on this segment of the Hosgri fault, however, future models that attempt to accommodate the Point Sal–Point Piedras Blancas correlation must be explicit about how to accommodate deformation of the onshore block across the Santa Maria basin.

CONCLUSIONS

Existing models for right-lateral slip on the southern Hosgri fault require much more shortening of the onshore block across the Santa Maria basin than is supported by geologic data. This problem can be resolved by abandoning the Point Sal–Point Piedras Blancas correlation in favor of a model in which slip on the Hosgri fault increases more gradually from south to north, but the stra-
tigraphy and provenance of early Miocene sedimentary rocks at both localities are not sufficiently unique to robustly evaluate their utility as piercing points. Detrital zircons in this case were of limited utility for discriminating unique sediment sources, but they did establish the age of a section that could not be dated otherwise. Trace-element data can be used to discriminate oceanic from arc sources for Jurassic detrital zircon, which may be useful for future detrital zircon studies (of any age rocks) in California or other areas where sources may exist of similar ages but vastly different tectonic affinities.

ACKNOWLEDGMENTS

This research was supported by the U.S. Geological Survey’s National Cooperative Geologic Mapping Program. Vicki Langenheim, Russell Graymer, and Michelle Roberts assisted us in the field with sample collection. We thank the California Department of Parks and Recreation for allowing us to collect samples on state park lands near San Simeon, and Kathleen Gerber for facilitating access to Vandenberg Air Force Base. We are grateful to Joseph Wooden, Jorge Vazquez, and Matthew Coble for help with the U-Pb dating and data reduction. Vicki Langenheim reviewed an access to Vandenberg Air Force Base. We are grateful to Joseph Wooden, Jorge Vazquez, and San Andreas Faults, in Elder, W.P., ed., Geology and Tectonics of the Gualala Block, Northern California: Los Angeles, Pacific Section, Society for Sedimentary Geology (SEPM), Book 84, p. 95-119.

REFERENCES CITED

Barth, A.P., and Wooden, J.L., 2010, Coupled elemental and isotopic analyses of polygenetic zir-
cons from granitic rocks by ion microprobe, with implications for melt evolution and the sources of granitic magmas: Chemical Geology, v. 277, p. 149-158, doi:10.1016/j.chemgeo.2010.07.017.


Burnham, K., 1986, Preliminary comparison and correlation of two Cretaceous conglomerates, the strata of Anchorage Bay and an unnamed unit in the Placitos block, across the San Gregorio and San Andreas Faults, in Elder, W.P., ed., Geology and Tectonics of the Gualala Block, Northern California: Los Angeles, Pacific Section, Society for Sedimentary Geology (SEPM), Book 84, p. 95-119.

search, v. 96, p. 6435-6457.


Cole, R.B., and Stanley, R.G., 1984, Sedimentology and origin of subaqueous pyroclastic sedi-


Colgan, J.P., McPhie, D.K., McDougall, K., and Hourigan, J.K., 2012, Superimposed extension and shortening in the southern Salinian basin and La Panza Range, California: A guide to Neo-


Dibblee, T.W., and Minch, J.A., 2002, Geologic Map of the Piedras Blancas and San Simeon Quad-
ranges, San Luis Obispo County, California: Dibblee Geological Foundation Map DF-366, scale 1:24,000.


ey of America Special Paper 391, 43 p.


Ernst, W.G., Martens, U.C., McLaughlin, R.J., Clark, J.C., and Moore, D.E., 2011, Zircon U-Pb age of the Pescadero felsite: A Late Cretaceous igneous event in the western, west-central Cali-


