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Continuity and Tectonic Implications of the San Simeon-Hosgri Fault Zone, Central California

By

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ABSTRACT

Continuity and Tectonic Implications of the San Simeon-Hosgri Fault Zone, Central California

by

Rob. B. Leslie

Geological and geophysical studies over the last ten years have shown that the western limit of the active North American-Pacific plate boundary off central California lies west of the San Andreas fault, on the continental shelf. Controversy exists, however, both as to the geometry of the faults and as to the amount of lateral displacement these faults have undergone. The absence of geophysical data in shallow near-shore areas has made it difficult to demonstrate suggested connections between faults on which large lateral displacements have been proposed.

This investigation involved acquisition and interpretation of high-resolution seismic reflection data off central California. The new data were interpreted in conjunction with pre-existing seismic and aeromagnetic data and are interpreted to demonstrate a connection between the offshore Hosgri fault, the major southern fault of the San Gregorio-Hosgri fault system, and the onshore San Simeon fault. This connection allows, but does not prove, large right lateral offset along the San Simeon-Hosgri fault trend.

Refolded en-echelon folds mapped offshore south of San Simeon are oriented, relative to the San Simeon-Hosgri fault trend, in a direction consistent with a right lateral shear couple. Possible offset reflectors in young marine sediments

(<15,000 years old) and the linear trend of landward-facing scarps on the seafloor suggest that active faulting has migrated from fault strands farther offshore to the near-shore San Simeon-Hosgri strand and that faulting may have occurred, at least locally, within the last 11,000 years.

The spatial orientation of the San Gregorio-Hosgri fault trend and timing of major movement suggests that it may have acted as an intermediate boundary between the Pacific and North American plates during the transition from oblique subduction to the present transform boundary of the San Andreas fault. Recent seismicity studies, however, indicate that it is now active and suggest that it is accommodating at least a small amount of right lateral shear between the North American and Pacific plates.

INTRODUCTION

Geological mapping and earthquake studies over the last decade have shown that the western limit of the active margin between the North American and Pacific plates off central California lies west of the San Andreas fault, on the continental shelf (Hoskins and Griffiths, 1971; Cooper, 1971; Greene and others, 1973; and Gawthrop, 1975, 1978). There is, however, controversy both as to the geometry of the faults and to the amount of lateral displacement these faults have undergone. Undemonstrated connections between faults have made it difficult to prove the possibility of large lateral displacement postulated for some of the faults. This investigation demonstrates a connection between the offshore Hosgri fault (Wagner, 1974a), the major southern fault of the system, and the onshore San Simeon fault (Figure 1; Hall, 1975). This connection has been proposed by some (Hall, 1975, 1978) and denied by others (Earth Sciences Associates, 1975). On the basis of aeromagnetic data and the linear stretch of coast between Cambria and Pt. Estero (Figure 2) Earth Sciences Associates (1975) suggested that the San Simeon fault extends to the south. This proposed extension, however, lies landward of the Hosgri fault and is inferred to die out just north of Pt. Estero.

The relationship between the San Simeon and Hosgri fault zones is of particular importance to the Neogene tectonic evolution of central California. Models for this evolution

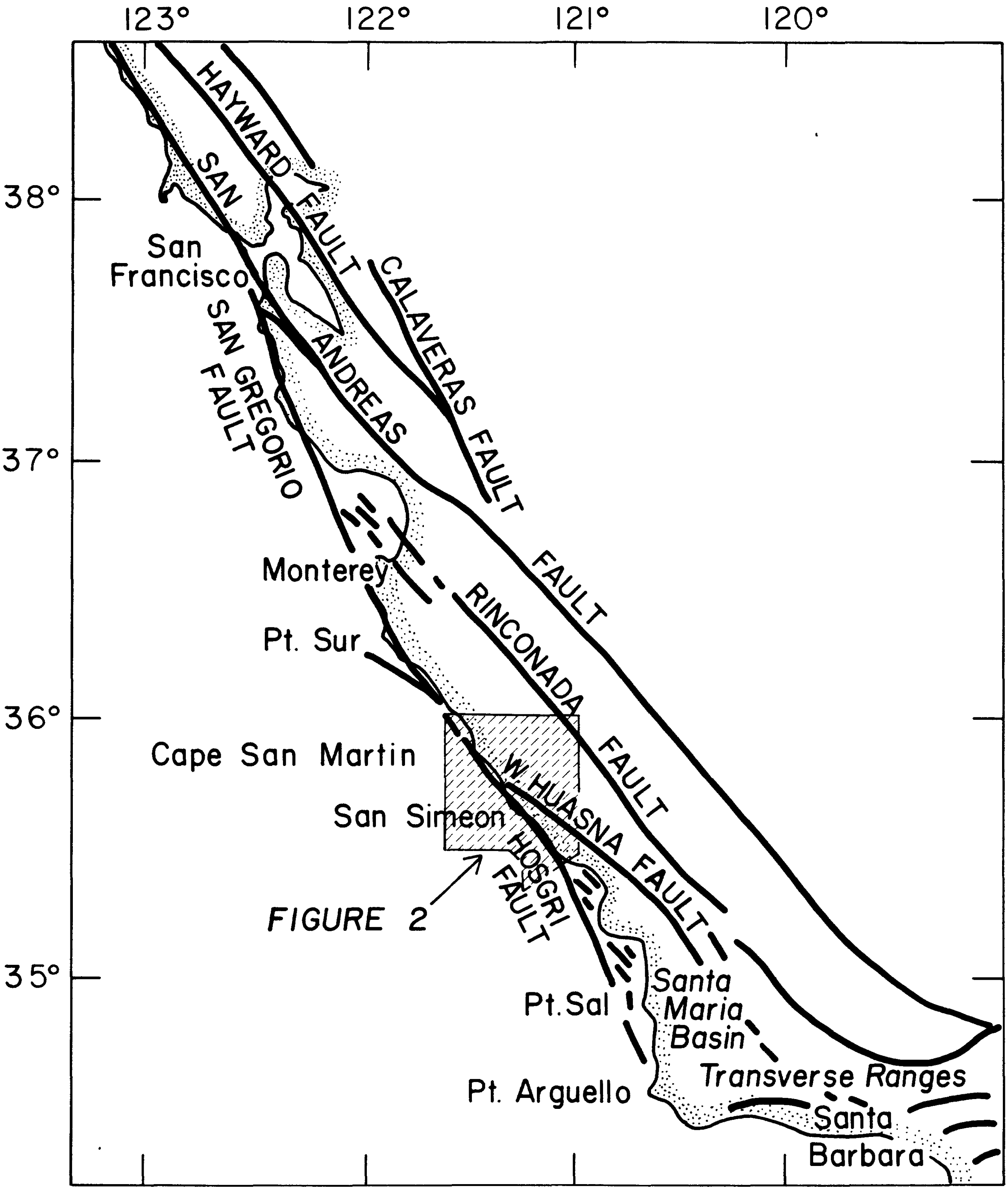

Figure 1. Map of central California coastal region showing major fault systems and geographic locations cited in text and location of figure 2 (after Silver, 1978).

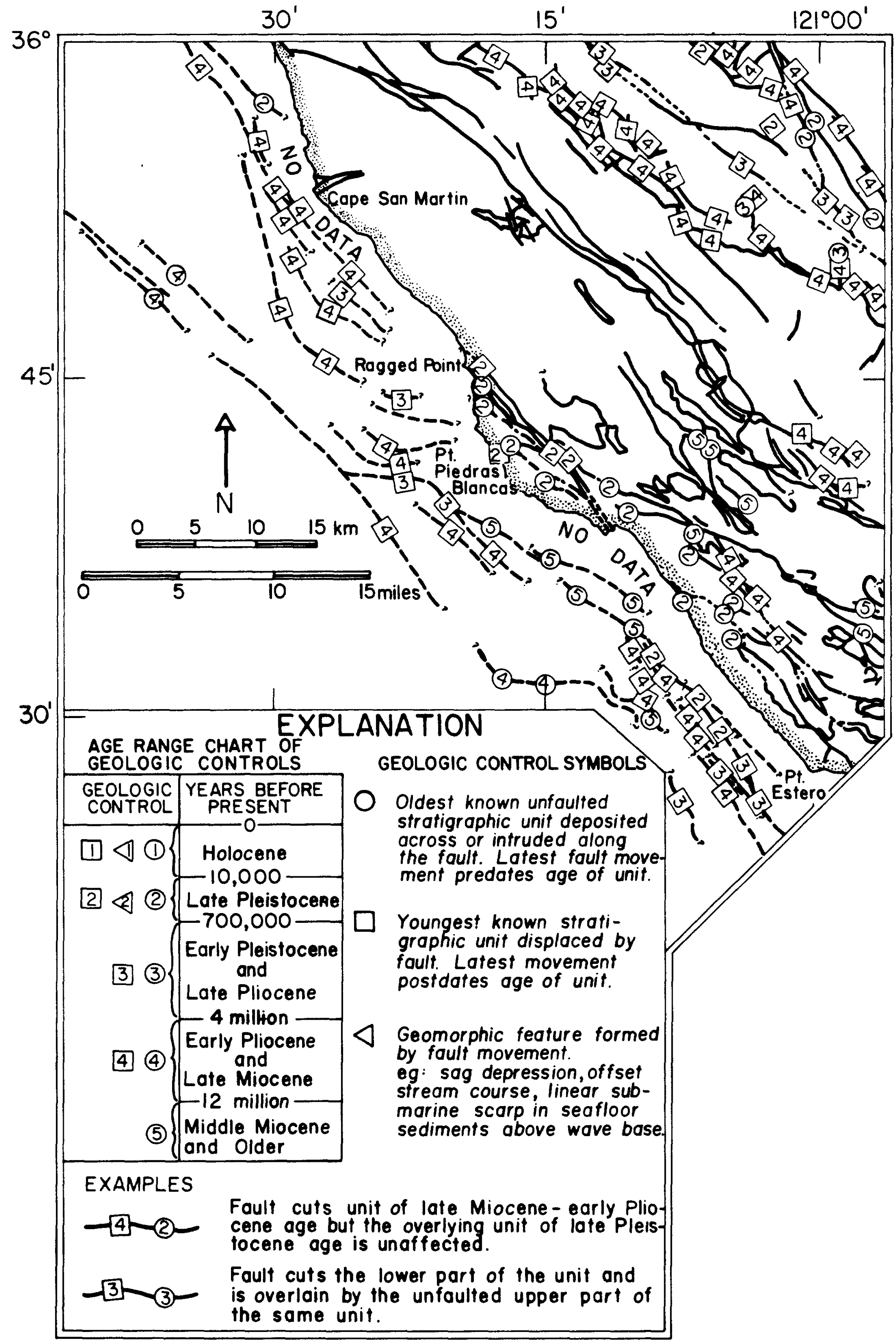

Figure 2. Map showing location and age range of faults between Cape San Martin and Pt. Estero. Location of faults and generalized age range classification after Buchanan-Banks and others, 1978.

incorporate estimates of right lateral offsets along the San Gregorio-Hosgri fault trend which range from less than 20 km (Hamilton and Willingham, 1977) to as much as 115 km (Graham and Dickinson, 1978a, 1978b). The models proposed by Silver, (1974); Hall (1975, 1978); Graham and Dickinson (1978a, 1978b); and Dickinson and Seely (1979), require a continuous San Gregorio-Sur-San Simeon-Hosgri fault system (Figure 1) during its most active period.

The San Gregorio, Sur, San Simeon, and Hosgri faults appear to represent the largest subsidiary of the San Andreas fault system, although the precise nature of the contact between the seaward extension of the Sur fault to the south with the northerly extension of the San Simeon fault is unclear. The questionable nature of this contact is primarily due to absence of data in the near-shore area in this region. The most recent U.S.G.S. fault map (Buchanan-Banks and others, 1978) shows a linear, although queried, connection between the Sur and San Simeon faults for this area.

Recent studies (Gawthrop, 1975, 1978; Greene and others, 1973; and Coppersmith and Griggs, 1978) indicate that the central California coastal region is seismically active along the San Gregorio-Hosgri fault trend. First motion studies by Gawthrop (1975, 1978) showed that many earthquake focal mechanism solutions for the central California coastal region indicate right slip along the San Gregorio-Hosgri fault trend.

Differing views on the rate of displacement on the San Gregorio-Hosgri fault zone have been proposed on the basis of various geological and geophysical investigations. Gawthrop (1978) noted that calculated North American-Pacific plate motion is approximately 5.5 cm/yr as shown by Atwater (1970) and Minster and Jordan (1978). Savage and Burford (1973) proposed that the San Andreas fault accommodates only about 3.2 cm/yr of this motion. From these calculations, Gawthrop (1978) suggested that about 2.3 cm/yr of relative plate motion is being absorbed by subsidiary faults of the San Andreas fault system which would include the San Gregorio-Hosgri fault zone. In contrast to the 3.2 cm/yr slip rate (Savage and Burford, 1973), Hall and Sieh (1977) suggested a slip rate of 3.7±.3 cm/yr along the San Andreas fault in central California. Furthermore, Sieh (1977) proposed a minimum late Holocene slip rate of 3.7 cm/yr in the Carrizo Plain and, in 1978, suggested a long-term slip rate of about 6 cm/yr for this same area (Sieh, 1978). These higher slip rates on the San Andreas fault would substantially reduce the expected rate of slip on subsidiary faults of the San Andreas system.

A Neogene right slip rate of 1.6 cm/yr has been proposed for the San Gregorio (Graham and Dickinson, 1976) and San Simeon-Hosgri (Hall, 1976a) fault systems. Late Quaternary right slip of 1.6 cm/yr has been suggested for the northern portion of the San Gregorio fault (Weber and Lajoie, 1979). This late Quaternary slip rate has, however, been questioned (Hamilton and others, 1979). For this same region, Hamilton and others (1979) determined a late Quaternary slip rate of .1 cm/yr. A slip rate for the Sur fault zone has not been calculated; however, Neogene activity that probably included strike-slip movement modified the Sur-Nacimiento fault zone in the Pt. Sur area (Gilbert, 1971; Gilbert, 1973).

Silver (1974) proposed 90 km of right slip along the San Gregorio fault in the Monterey Bay region on the basis of gravity and geologic interpretation. Hall (1975) suggested that at least 80 km of right lateral slip had occurred along a continuous San Simeon-Hosgri fault zone, in order to explain the similar sequences of Jurassic ophiolite and overlying Tertiary formations in the Pt. Sal and San Simeon areas. Offset drainages in the San Simeon area were interpreted by Hall (1975) to represent right lateral offset of 150 to 450 meters along the Arroyo Laguna fault (Figure 4), which is relatively younger than the San Simeon fault. Cross-cutting relations between faults and marine terraces for this same area indicate that the San Simeon fault, to which the Arroyo Laguna fault joins, has been active within the last 130,000 years (Hall, 1975).

The 115 km of Neogene right slip proposed by Graham and Dickinson (1978a, 1978b) is supported by recognition of apparently offset onland and offshore geologic features across the San Gregorio-Hosgri fault trend and include: (1) Tertiary sequences at Point Reyes and in the southern Santa Cruz Mountains which are nearly identical, (2) Cretaceous and Oligocene-

Miocene sediments in the western Santa Cruz Mountains and the northern Santa Lucia Range which appear quite similar, (3) the structural contact between granitic basement rock of the Salinian block and Franciscan Complex in the northern Santa Cruz Mountains and an area north of Bodega Head, (4) compositionally similar potassium feldspar-bearing sandstones in the Franciscan Complex which occur on the southwest side of the Sur fault in the Pt. Sur area and on the northeast side of the Hosgri fault at Cambria (Cambria Slab), (5) Miocene sandstone near Pt. Sur which was derived from a Franciscan terrain and potential source terrains to the south, (6) the previously mentioned Jurassic ophiolite and overlying Tertiary units at Pt. Sal and near San Simeon (Hall, 1975), and (7) Silver's (1974) proposed right slip offset of 90 km of a gravity high which occurs on the southwest side of the San Gregorio fault at Pt. Ano Nuevo and on the northeast side of the Sur fault where it extends offshore north of Pt. Sur.

Right lateral offset of only 20 km suggested by Hamilton and Willingham (1977) is supported by comparison of stratigraphic sections on either side of the fault in the San Luis Obispo Bay area. Hamilton and Willingham (1977) compared the stratigraphic column from an offshore exploratory well (Oceano Well) located west of the Hosgri fault opposite the Santa Maria Valley, with onland sections east of the fault from San Simeon southward to San Miguel Island. From their investigation of thickness of recognizable lithologic units within these stratigraphic sections, they concluded that right slip of more than 20 km is precluded and that essentially no lateral slip is required along the Hosgri fault trend.

Seiders (1979) suggested that post-late Miocene movement on the San Simeon-Hosgri fault has not exceeded 30 km and that post-Oligocene offset must be less than 50 km. Seiders' (1979) interpretations are based upon field relations he observed in the area between Monterey Bay and Pt. Sal and also upon correlations of stratigraphic sections on opposite sides of the San Simeon-Hosgri fault trend. Many of these observations are in sharp contrast with field work and interpretations done by Hall (1975, 1976b) and Hall and others (1979).

A distinct conflict exists between the interpretations of large offset and those of very little or no lateral offset. Of direct pertinence to these interpretations is the nature of continuity between the various fault segments along the San Gregorio-Hosgri fault trend.

An en-echelon relationship between the onland San Simeon and offshore Hosgri fault zones has been proposed by Hoskins and Griffiths (1971), Earth Sciences Associates (1975), and Buchanan-Banks and others (1978, Figure 2). A connection between the San Simeon and Hosgri faults was suggested by McCulloch and others (1977).

The question of continuity between the San Simeon and Hosgri fault zones is of critical importance to the models utilizing large offset. If a discontinuous or en-echelon relationship between the San Simeon and Hosgri fault zones is confirmed, it would throw doubt on models utilizing large offset unless the en-echelon system was established following the offset. Continuity between the San Simeon and Hosgri fault zones would allow, although not prove, large offset along a through-going San Gregorio-Hosgri fault system.

The existence or lack of a connection between the San Simeon and Hosgri fault zones has been difficult to demonstrate previously due to the lack of data in the shallow near-shore areas (Figure 2) where seismic work must be done from shallow draft vessels. This study utilizes new and pre-existing geophysical data to focus on the question of continuity between the San Simeon and Hosgri fault zones.

METHODS

High-resolution seismic reflection data were collected in shallow near-shore areas where the San Simeon fault zone projects seaward, that is, northwest of Ragged Pt. and southeast of San Simeon (Figure 3). Most track lines were run at an approximate 1 km spacing normal to the trend of geological structures which subparallel the coastline. This spacing appears to be adequate to map the structural trends.

Because the prime objective of the cruise was to collect data in shallow water, both the size of the research vessel and the acoustic-reflection system had to be small. The 38 foot U.C. Santa Cruz R/V Scammon was used during April 1979. The small acoustic system was able to resolve near-surface reflectors and therefore provide information relevant to determining recency of faulting.

High-resolution reflection profiles are limited to shallow penetration because the high frequencies which dominate their signal are rapidly attenuated. When used in conjunction with deeper penetration records, however, the high-resolution records can provide a more complete picture of the shallow subsurface. The high-resolution reflection profiles were obtained using a 500 joule mini-sparker system with either .5 or .25 second fire/sweep rate (Leslie, 1980). The quality of the data varied with sea conditions, but in general is very good. Maximum penetration obtained is approximately .5 seconds with a mean effective

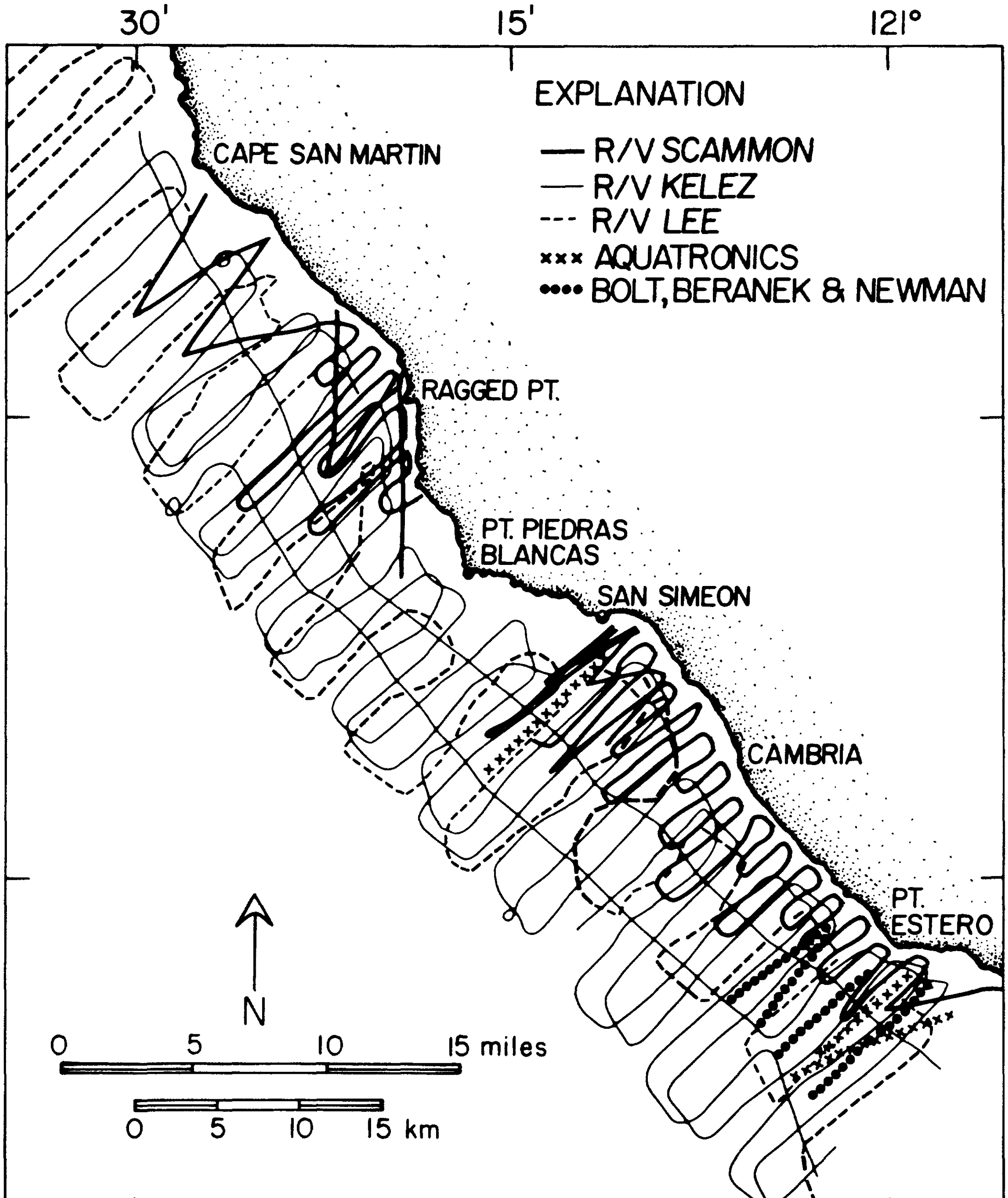

Figure 3. Track chart showing reflection profile coverage for the area between Cape San Martin and Pt. Estero.

penetration of about .25 seconds two-way travel time. Navigation was accomplished by means of a land based range-range electronic transponder system (Del Norte). It has a claimed system accuracy of 3 meters and the overall accuracy of line locations is about 75 meters.

The high-resolution data were interpreted in conjunction with previously run deep-penetration and high-resolution reflection profiles (Figure 3) (Wagner, 1974b; McCulloch, 1976; Bolt, Beranek, and Newman, data collected December 1973 and April 1974; Aquatronics, data collected July 1974).

GEOPHYSICAL DATA

Seismic Stratigraphy

The seismic stratigraphy for the Cape San Martin to Pt. Estero area is divided into four mappable units. These units generally show distinct reflection characteristics and deformation styles. Ages have been assigned to the four units based on correlations with offshore drilling reported by Hoskins and Griffiths (1971), regional acoustic correlations by Wagner (1974a), and from dart core samples collected by McCulloch on a 1975 U.S.G.S. cruise. The dart core samples were dated by David Bukry, also of the U.S.G.S. (written communication to David McCulloch, 1979). The four units will be referred to as 1) unit Mz, 2) unit Tm, 3) unit Tp, and 4) unit Q.

Unit Mz is pre-Cenozoic in age and is inferred to be composed of Franciscan assemblage and Great Valley Sequence rocks (suggested by Howell and others, 1978). The Franciscan rocks generally exhibit no reflectors due to the chaotic nature of the unit. The Cambria Slab, however, which Smith and others (1979) believe to be correlative with Great Valley Sequence rocks deposited in a trench slope basin, locally exhibits well-defined bedding in profiles obtained south of the San Simeon area on the northeast side of the fault (Figure 4). Franciscan assemblage rocks crop out along much of the coastal region from north of Cape San Martin to north of Cambria (Figure 4). The Cambria Slab is exposed along the coast from north of Cambria to south of Pt. Estero.

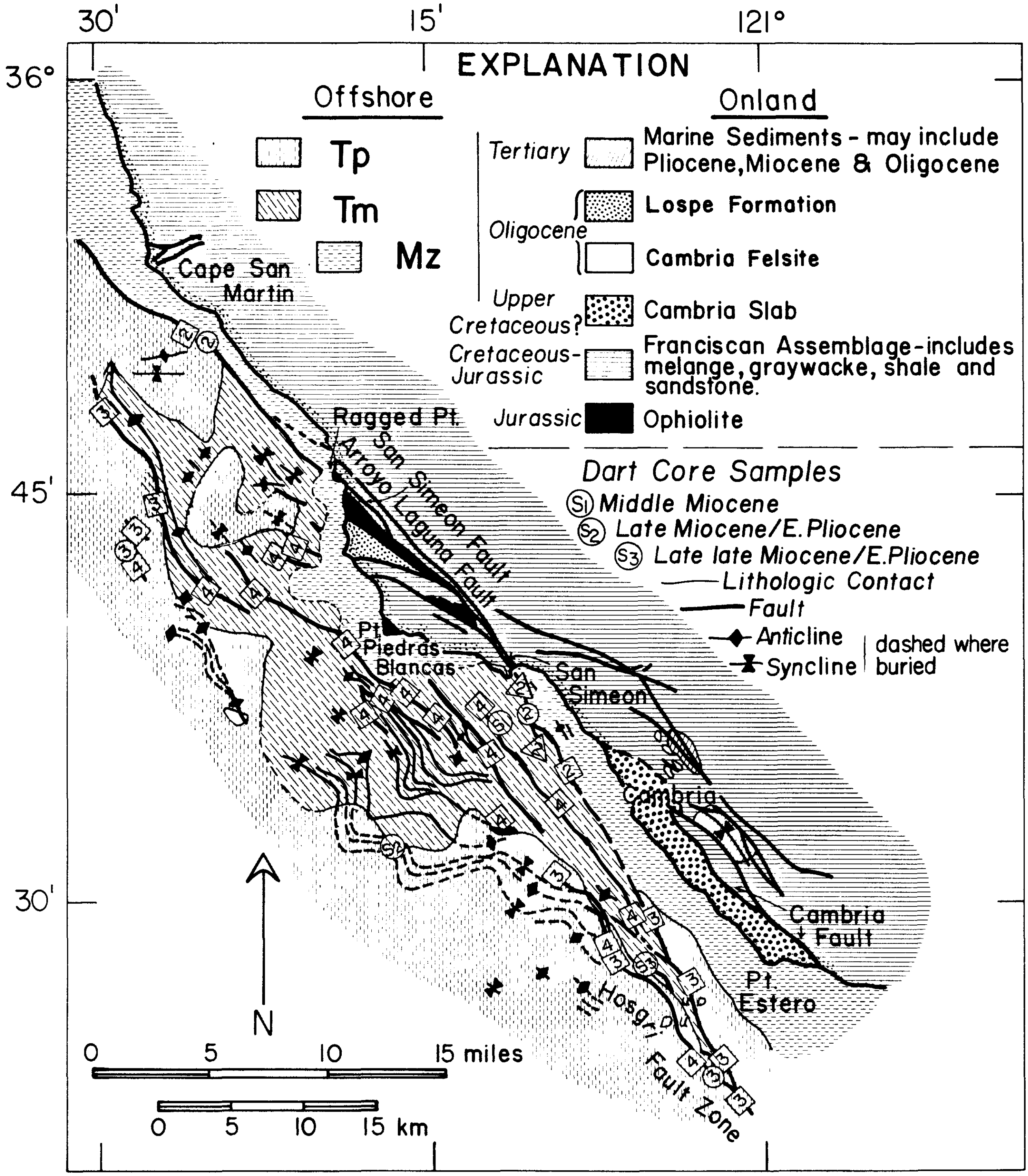

Figure 4. Geologic map and age range classification (see figure 2 for explanation) constructed from reflection profiles shown in figure 3. Onland geology generalized from Hall and others, 1979.

The lithology of unit Mz is constrained by these coastal exposures which lie very near the eastern terminations of reflection profiles collected along this stretch of coast (Figures 3 and 4). Farther offshore the Mesozoic basement beneath units Tm and Tp is observed on deep-penetration records. This basement rock has been described as Franciscan by McCulloch and others (1977) and Page and others (1979) and probably as granite by Hoskins and Griffiths (1971) on the basis of the structural style of deformation and the occurrence of granite-derived clastic rocks of Late Cretaceous and Eocene age from the Santa Lucia Bank high.

Unit Tm overlies unit Mz unconformably and is of early, middle, and late Miocene age, although rocks of probable Eocene age may occur locally at the base (Hoskins and Griffiths, 1971). Unit Tm is generally characterized by evenly spaced reflectors, and is broadly (> 3km) to tightly (<.2 km) folded. The middle Miocene rocks exhibit poorly defined bedding in the high-resolution records obtained from the R/V Scammon and locally appear acoustically similar to unit Mz.

The middle Miocene unit probably represents the cherty shale of the Monterey Formation which crops out at San Simeon Pt. (Figure 4). Deep-penetration records indicate that this unit extends southeastward from San Simeon Pt. to the latitude of Pt. Estero. In areas where middle Miocene and Mesozoic units are indistinguishable on high-resolution records, deep-penetration records were used to define these units. Abrupt terminations of reflectors in the Cambria Slab are also useful in delineating fault contacts between the middle Miocene section of unit Tm and unit Mz along the coastal stretch between San Simeon and Pt. Estero.

The previously mentioned dart core samples (locations shown in Figure 4) were also used to constrain the age assignments given to the offshore units. The ages given for these samples are based upon foraminifers, diatoms, coccoliths, and silico flagellates (D. McCulloch, personal communication, 1979).

Two formations of Oligocene age, the Cambria Felsite and the Lospe Formation, occur on land in the study area. The Cambria Felsite occurs as relatively small outcrops north of Cambria (Figure 4). Clasts from the Cambria Felsite are present in the Lospe and Oligocene and lower Miocene rocks near Cambria and a few kilometers east of San Simeon. No clasts from the Cambria Felsite, however, occur within the Lospe Formation west of the San Simeon fault (Hall, 1975).

Rocks with similar compositions (conglomerate, tuff, and landslide deposits) and stratigraphic relationships occur west of the San Simeon fault and 80 km to the south near Pt. Sal (Figure 1) where the nature of the southern termination of the Hosgri fault is in question. Hall (1975) inferred that strata west of the San Simeon fault were not in the Cambria area during the time that they were deposited due to the absence of Cambria Felsite clasts in the Lospe Formation west of the San Simeon fault. Furthermore, Hall (1975) suggested that the similarity between the unique assemblage of rock types, structural styles, and stratigraphic relationships of rocks west of the San Simeon fault and near Pt. Sal is evidence that these two separate localities were once contiguous and have since been displaced by at least 80 km of right lateral slip on an unmapped San Simeon-Hosgri fault. Seiders (1979), however, based upon his own field work for the San Simeon to Pt. Sal region, argued that Hall's (1975) interpretations are inconclusive and that right lateral offset along the Hosgri fault trend is restricted to less than 30 km since the Miocene.

Unit Tp is late Miocene and Pliocene in age and laps unconformably onto units Mz and Tm. Bedding is well-defined and folding is generally minor or absent, with the exception of the area northwest of Pt. Piedras Blancas where a zone of chaotically deformed Tp strata occur (Scammon line 87, Figure 11). Unit Tp appears to be equivalent to the Miocene-Pliocene age unit of the Santa Maria Basin illustrated by Hoskins and Griffiths (1971), and is defined in seismic records by its stratigraphic position and generally undeformed structure.

An outcrop of Careaga Formation (Pliocene age) has been mapped by Hall and others (1979) in the San Simeon Bay area but is not shown on the geologic map (Figure 4) due to its small size. This outcrop, which lies within the San Simeon fault zone, apparently represents a small isolated block which is neither observed elsewhere nearby on land nor in seismic records obtained in San Simeon Bay.

A relatively thin sequence of sands and gravels was deposited following the Wisconsin low stand of sea level (<15,000 years ago). This unit will be referred to as the post-Wisconsin unit (Q) and has been omitted from the geologic map (Figure 4) for sake of clarity, but is included in the line drawing interpretations which follow. Because these sediments were deposited during the most recent transgressive event, there are no onland equivalents. These strata, which are not ubiquitously present on the shelf, are probably equivalent to the Pleistocene to Recent unit of Hoskins and Griffiths (1971). Although the post-Wisconsin sediments are not folded, interpretation of high-resolution seismic lines suggest that the base of this unit may be disrupted locally due to faulting. This possibility will be discussed in the section on recency of faulting.

Aeromagnetic Data

Another important source of information on structural relations is the detailed aeromagnetic map of the coastal region shown in Figure 5 (McCulloch and Chapman, 1977). The aeromagnetic survey was flown with a line spacing of 1 mile and the lines run approximately normal to the coast. Aeromagnetic maps are useful in that they provide a means of bridging the data gap between onland geologic mapping and offshore seismic surveys. This data gap is particularly important in coastal studies such as this one. The aeromagnetic map allows one to observe magnetic trends and gradients which are unaffected by the water-land interface.

When known geologic trends such as faults have been mapped, one can study the aeromagnetic map to observe the response of the magnetic field to the rocks which abut the fault. Therefore, when magnetic gradients or trends are known to correspond to specific geologic structures or rock types adjacent to faults, structural inferences can be made on the basis of magnetic gradient continuity in areas where other geologic data fail to define the structure.

Between Pt. Estero and San Simeon various splays of the Hosgri fault strike parallel or subparallel to the dominant trend of the relatively steep northwest-trending magnetic gradient (Figure 5). Interpretation of reflection profiles for this region indicates that the fault that parallels the magnetic gradient has experienced large vertical separation (southwest

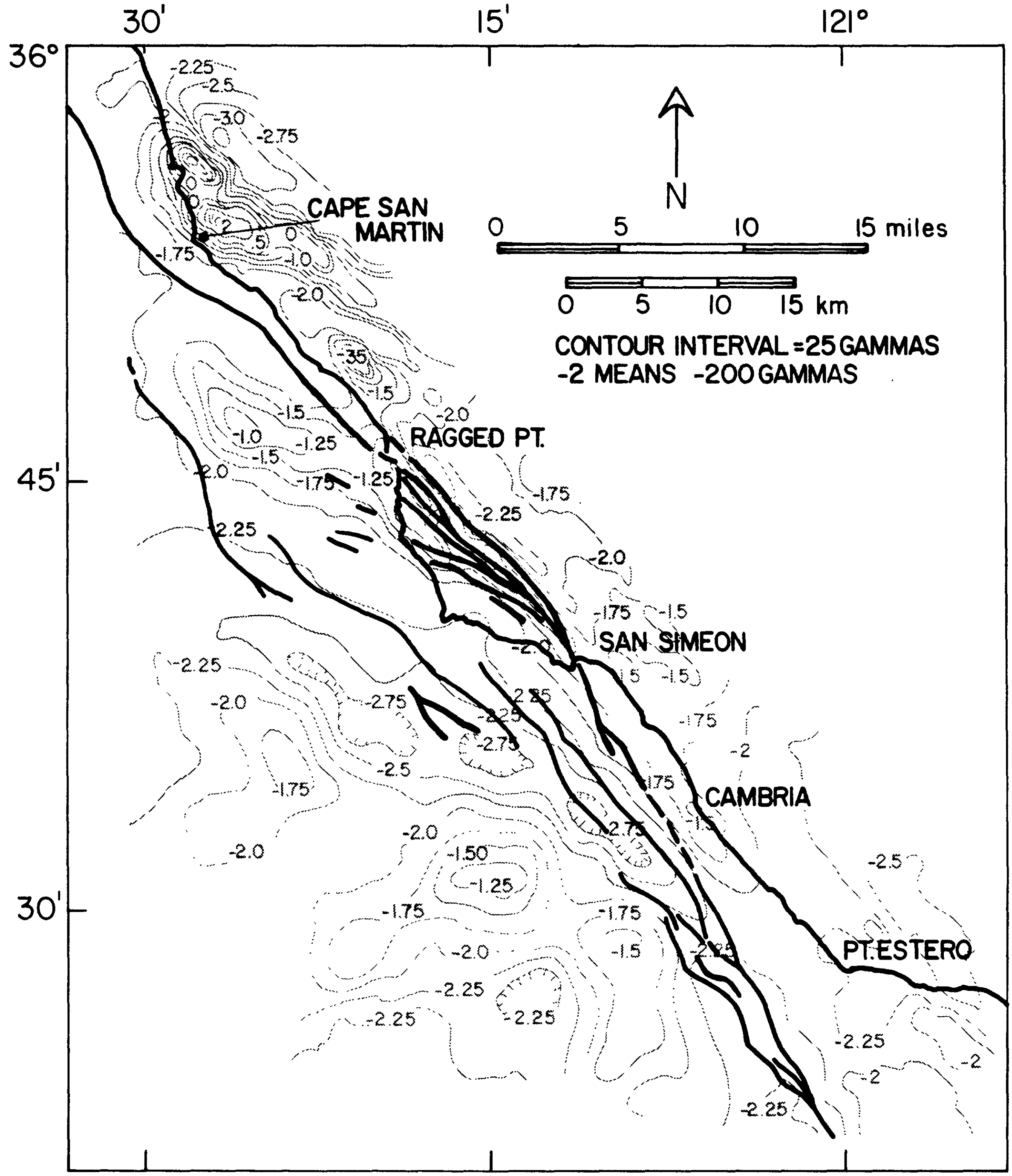

Figure 5. Detailed aeromagnetic map of central California coastal area between Cape San Martin and Pt. Estero. Location of faults determined from interpretation of reflection profiles. (Aeromagnetic map modified from McCulloch and Chapman, 1977). Further discussion in text.

side down) and is older than the landward-most San Simeon-Hosgri fault. This gradient probably reflects the difference in magnetic intensity between the shallow Mz unit to the northeast of the fault and the deeper Mz and Tm units to the southwest of the fault. The landward-most fault between Pt. Estero and San Simeon, which is relatively younger than adjacent faults and represents the through-going San Simeon-Hosgri fault, cuts the low part of the gradient where it is steep and the high part of the gradient where it becomes more gentle toward San Simeon. Because large vertical separation has occurred on the older and more seaward fault, the magnetic gradient parallels the strike of the older fault. The younger San Simeon-Hosgri fault, however, cuts across this gradient and does not show evidence for large vertical separation. The fact that the magnetic gradient is unaffected by the San Simeon-Hosgri fault also suggests that this is the more recently active segment. Evidence for vertical separation and recency of faulting will be discussed in the section entitled Tectonic Framework.

Offshore of Cambria (Figures 4 and 5) a short segment of the San Simeon-Hosgri fault is inferred because units Mz and Tm are not clearly distinguishable on high-resolution records in this area, and no deep-penetration records cross this inferred fault segment. Continuity between this inferred fault segment with segments along strike to the northwest and southeast, however, is supported by the constant low angle relationship between the northwest-trending magnetic gradient and the direction of faulting in segments of the fault where known offset is documented (Figure 5).

The San Simeon fault zone, which generally includes the San Simeon and Arroyo Laguna faults between San Simeon and Ragged Pt., separates magnetic highs associated with ophiolitic rocks southwest of the fault zone from scattered features with generally lower magnetic values to the northeast (Figure 5). These lower values are associated with Franciscan assemblage rocks. Numerous splay faults trend west-northwestward from southern terminations at the San Simeon fault. These west-northwestward trending faults strike subparallel to the southern contours of a magnetic high that occurs offshore between Ragged Pt. and Cape San Martin. This magnetic high may reflect uplifted basement rocks associated with an anticline in this area, or possibly, the seaward projection of ophiolitic rocks observed on land between Pt. Piedras Blancas and Ragged Pt. (Figure 4).

A large magnetic high which reaches a maximum amplitude at the coastline north of Cape San Martin, is apparently terminated by the northerly extension of the San Simeon fault. Serpentine bodies crop out on land in this area and are assumed to be responsible for the slight seaward projection of the observed magnetic high.

TECTONIC FRAMEWORK

The generalized geology for the Cape San Martin to Pt. Estero region is shown in Figure 6 which also illustrates the location of seismic profile lines referred to in the following discussion (Figures 7-17). These profiles are organized from south to north in the order that they are shown in Figure 6. The distances shown in km on the profiles are generalized from location times given on original track charts, and therefore may not correspond exactly with distances shown in Figure 6. This discussion will focus on the questions of:

(a) Continuity of the San Simeon-Hosgri fault trend.

(b) Recency of faulting.

(c) Significance of apparantly refolded en-echelon folds southwest of San Simeon.

Continuity of the San Simeon-Hosgri Fault Trend

Segments of the San Simeon and Hosgri faults are interpreted to represent a linear through-going fault system. A relatively short fault segment is inferred for the offshore area near Cambria. This short segment occurs between much longer linear fault strands to the northwest and southeast, subparallels a strong magnetic gradient, and will be included in the following discussion of the San Simeon-Hosgri fault trend.

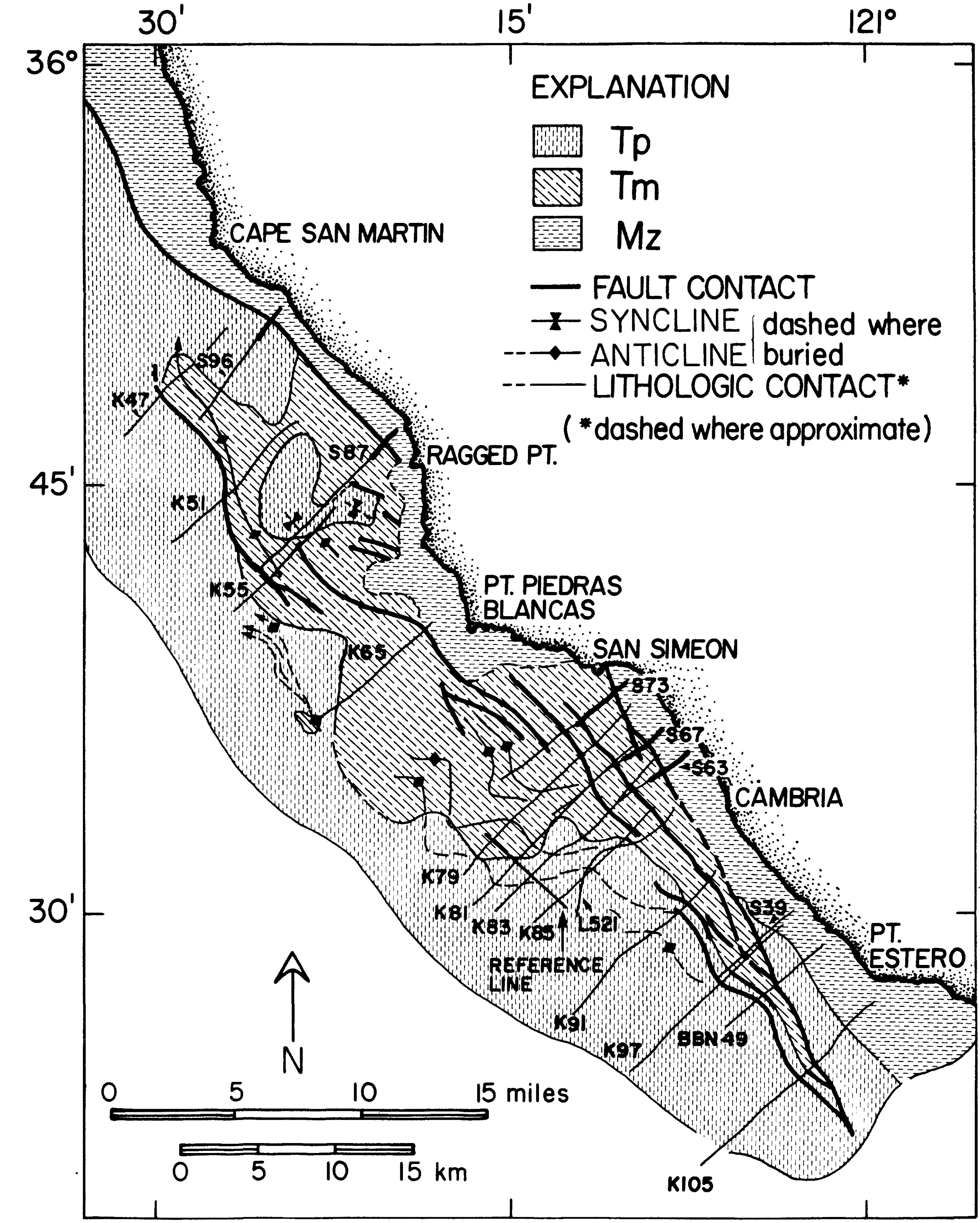

Figure 6. Generalized geologic map showing location of profiles referred to in text (figures 7-12). S = R/V Scammon; K = R/V Kelez; L = R/V Lee; BBN = Bolt, Beranek, and Newman. Heavy portions of profile lines indicate locations of original data shown in figures 13-17.

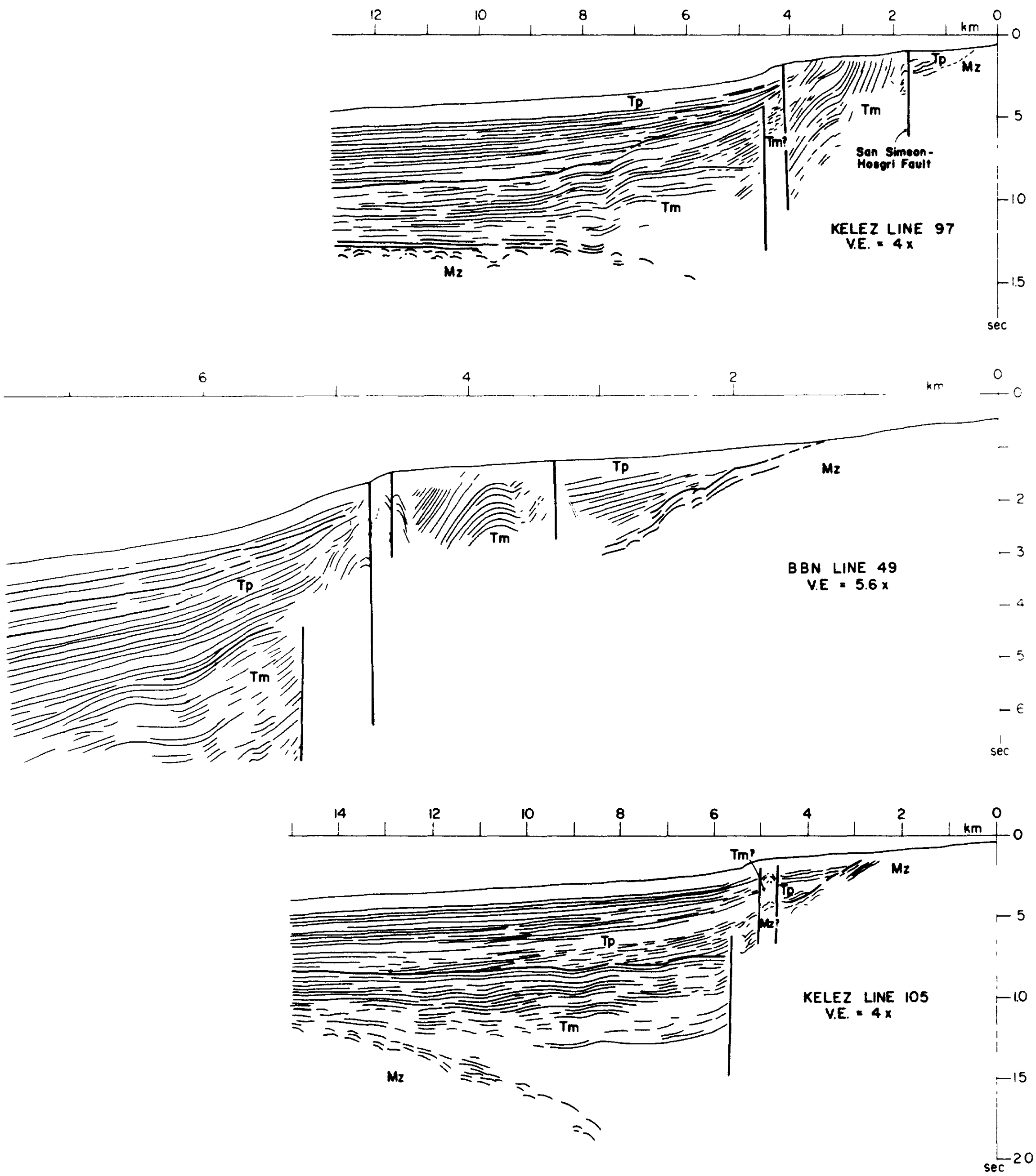

Figure 7. Line drawings of seismic profiles; Kelez 97, Bolt, Beranek, and Newman 49, and Kelez 105. Vertical scale is two-way travel time.

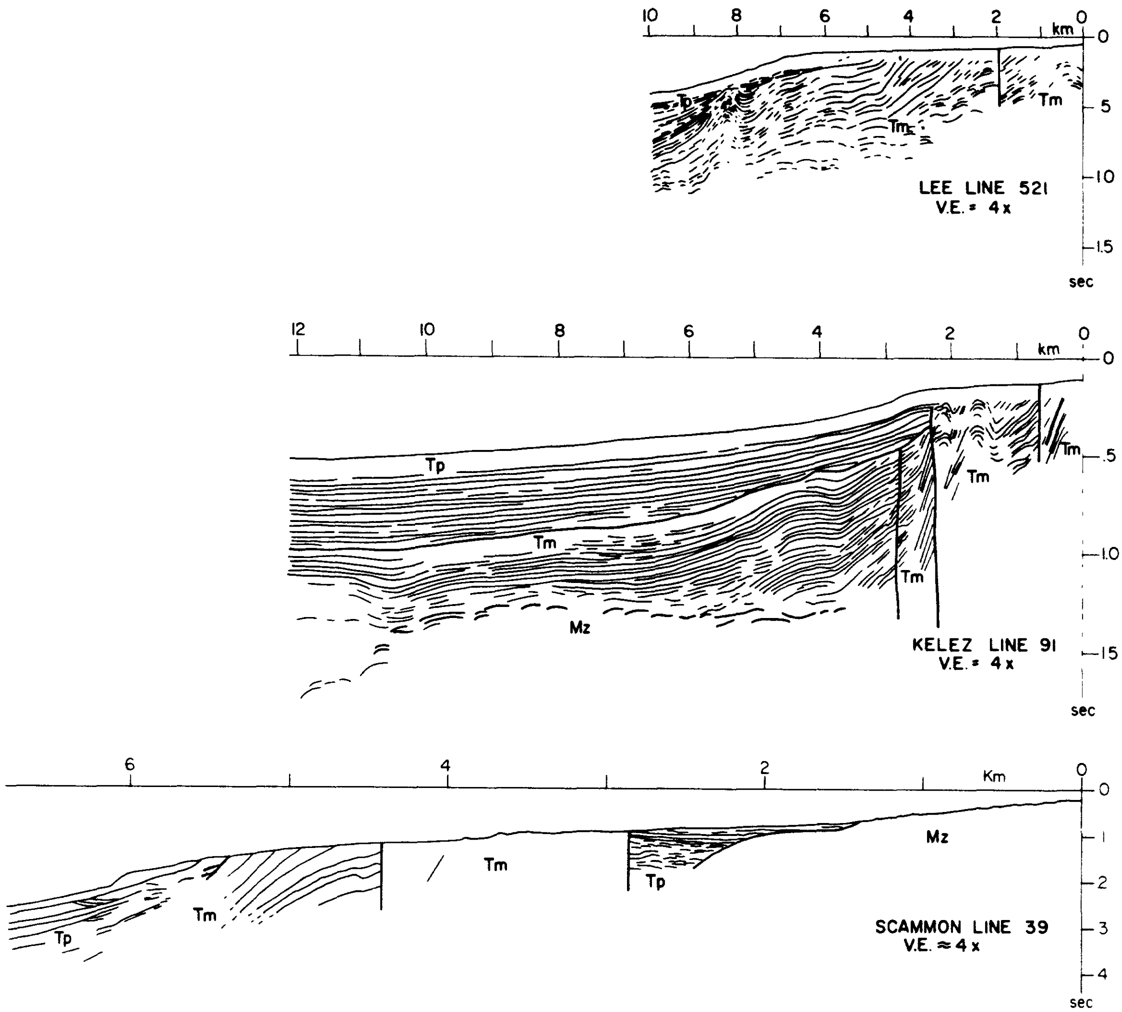

Figure 8. Line drawings of seismic profiles; Lee 521, Kelez 91, and Scammon 39. Vertical scale is two-way travel time.

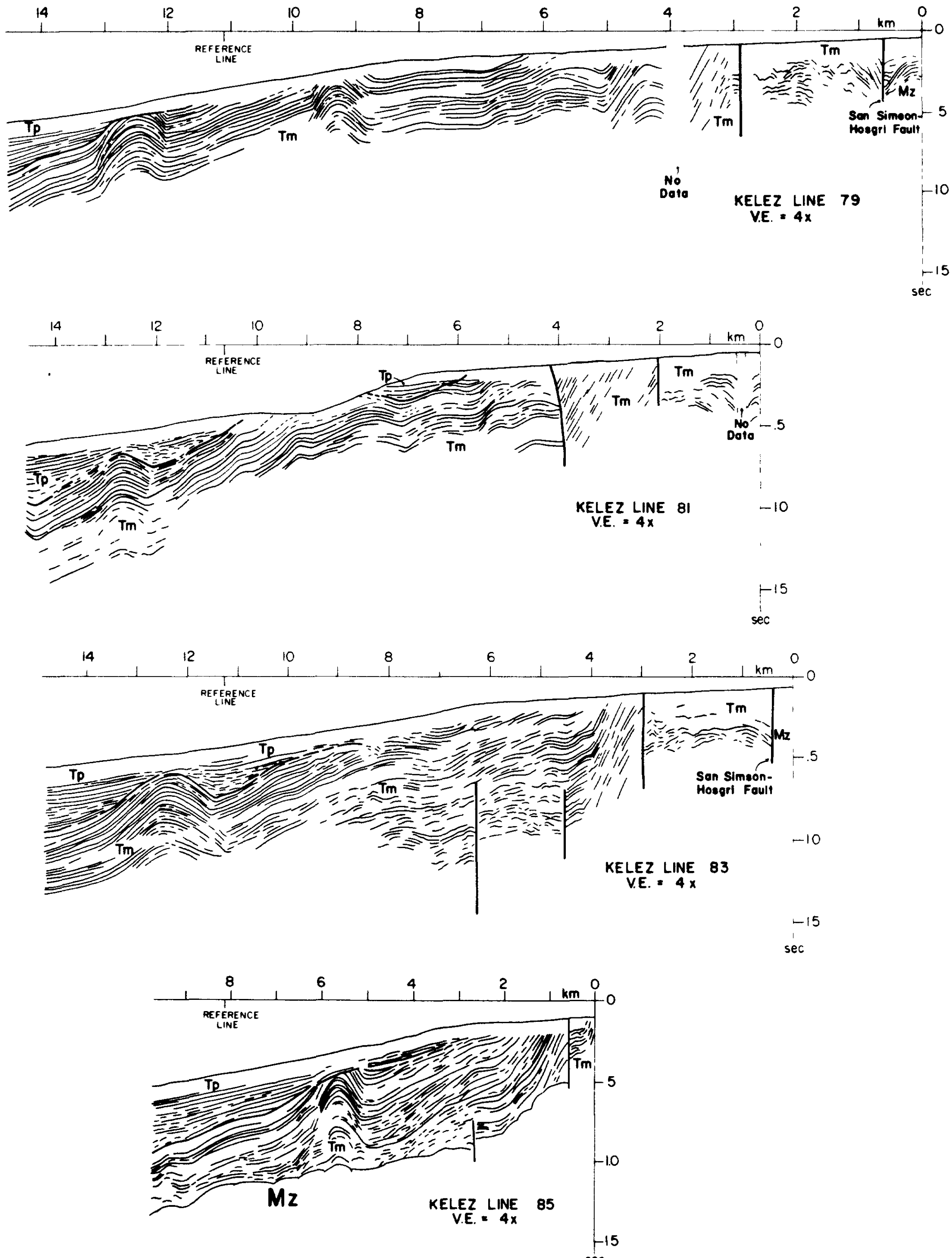

Figure 9. Line drawings of seismic profiles; Kelez lines 79, 81, 83, and 85. Vertical scale is two-way travel time.

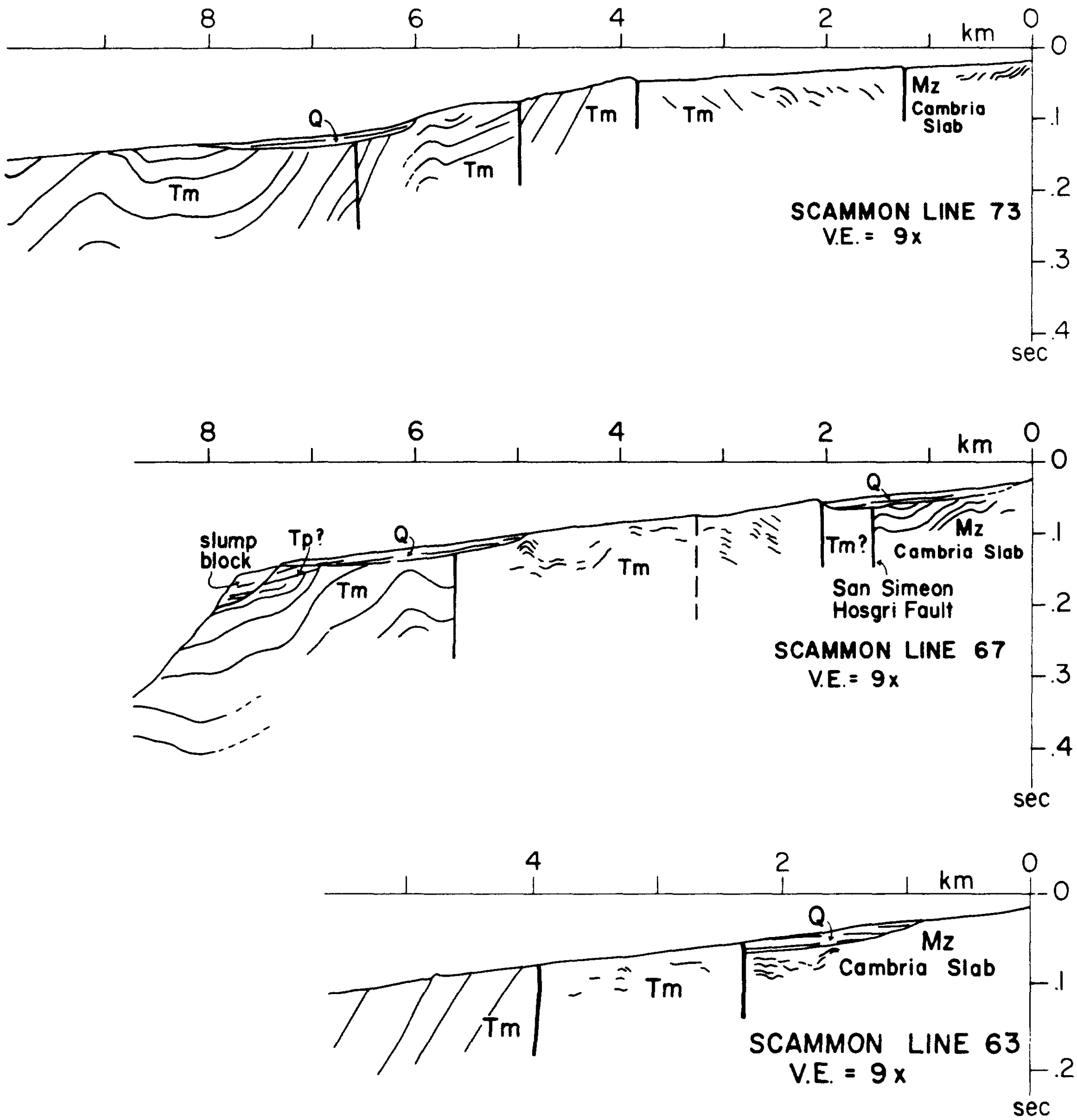

Figure 10. Line drawings of seismic profiles; Scammon lines 73, 67, and 63. Vertical scale is two-way travel time.

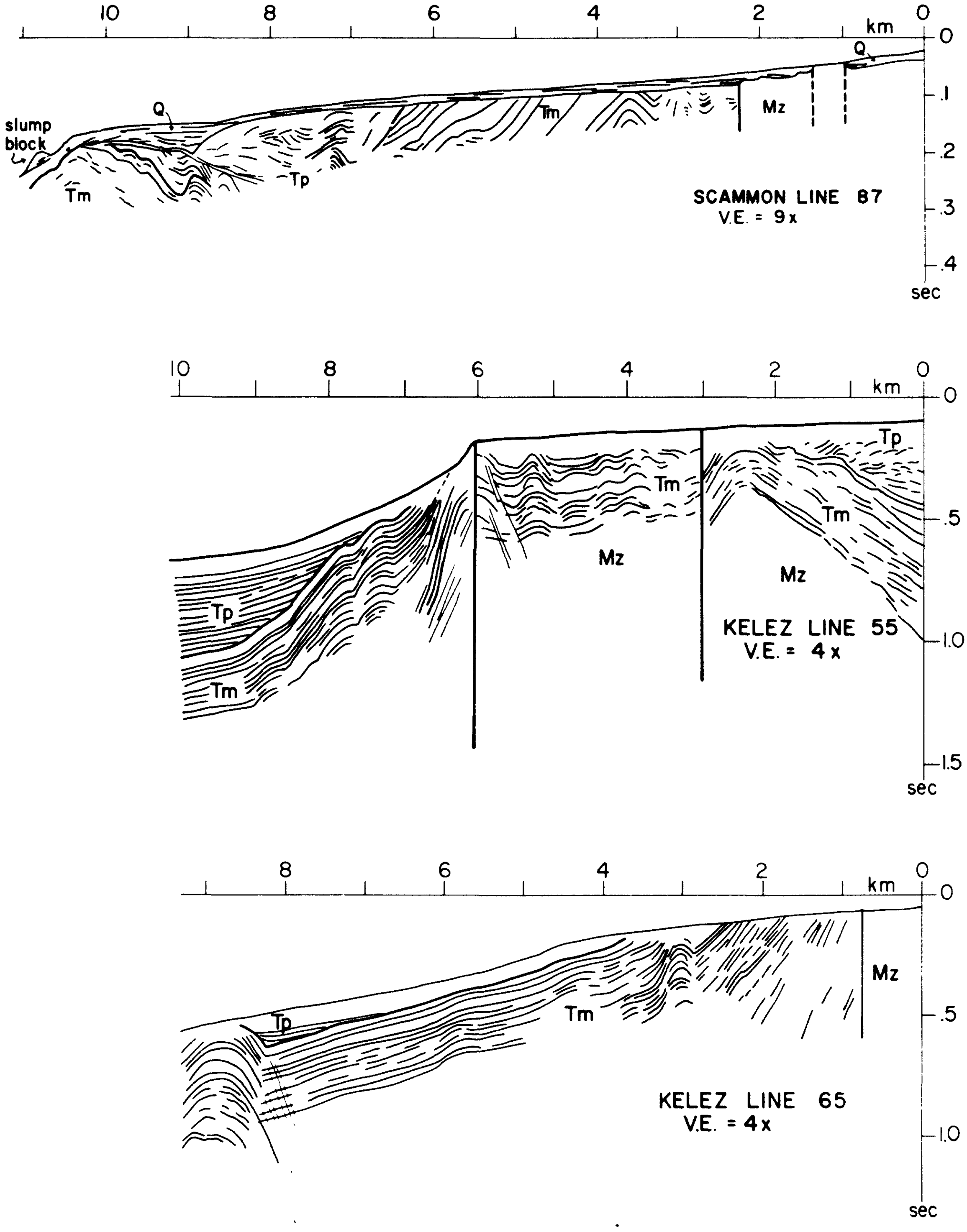

Figure 11. Line drawings of seismic profiles; Scammon 87, Kelez 55, and Kelez 65. Vertical scale is two-way travel time.

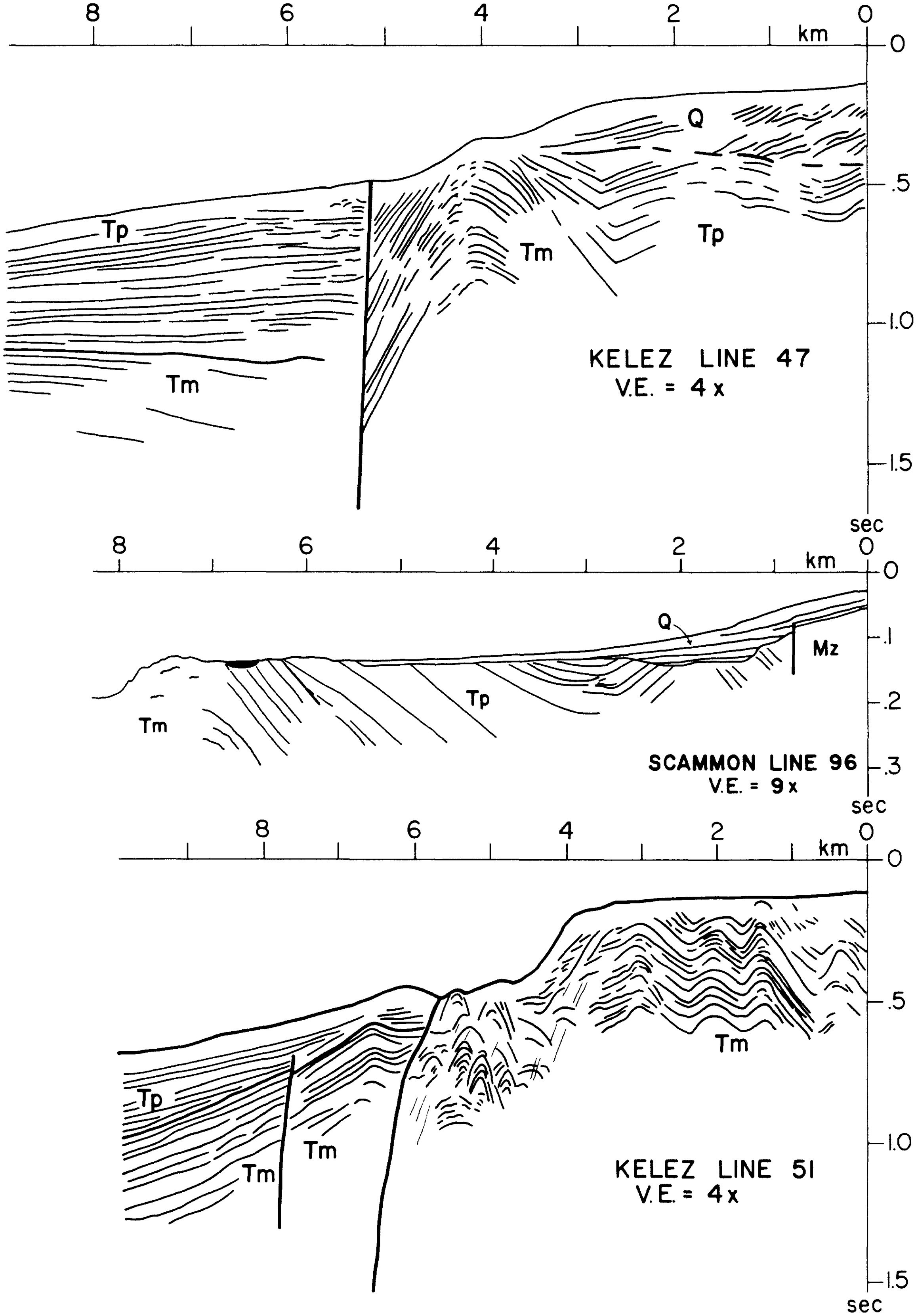

Figure 12. Line drawings of seismic profiles; Kelez 47, Scammon 96, and Kelez 51. Vertical scale is two-way travel time.

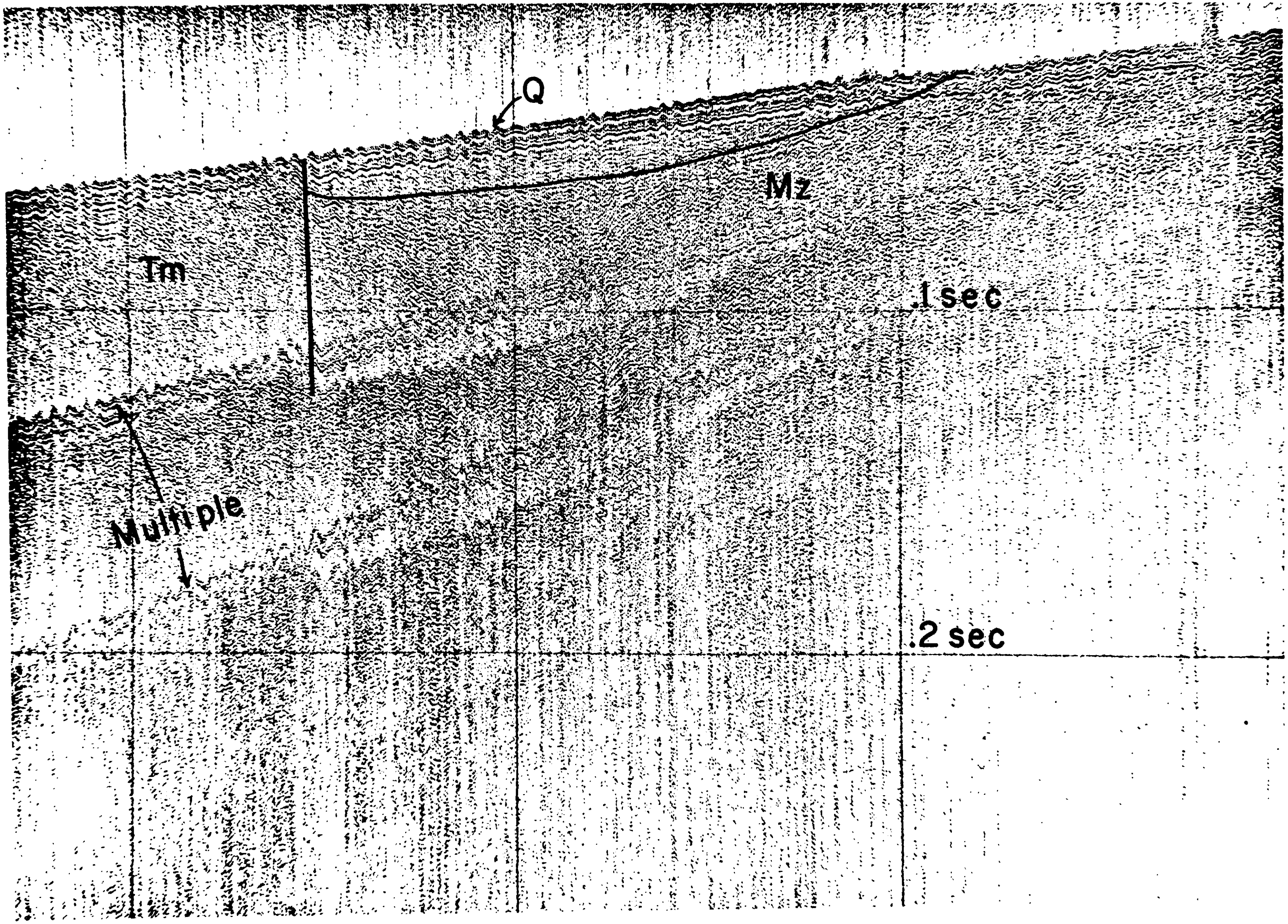

Figure 13. Photograph of part of Scammon line 63 illustrating abrupt termination of post-Wisconsin unit (Q). Location of photograph shown in figure 6.

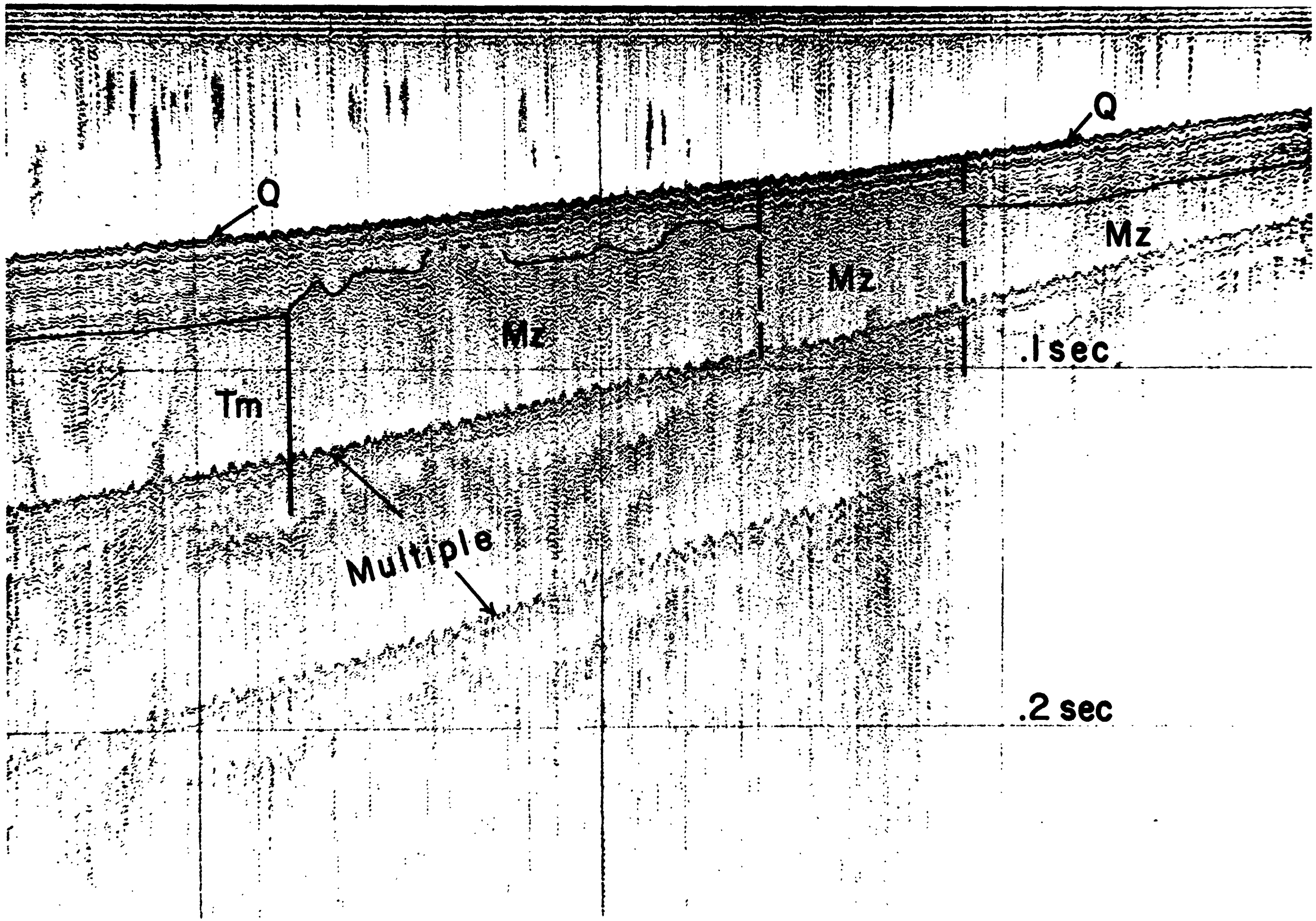

Figure 14. Photograph of part of Scammon line 87 illustrating irregular contact at base of post-Wisconsin unit (Q) and absence of post-Wisconsin unit along the projected strike of the Arroyo Laguna fault. Location of photograph shown in figure 6.

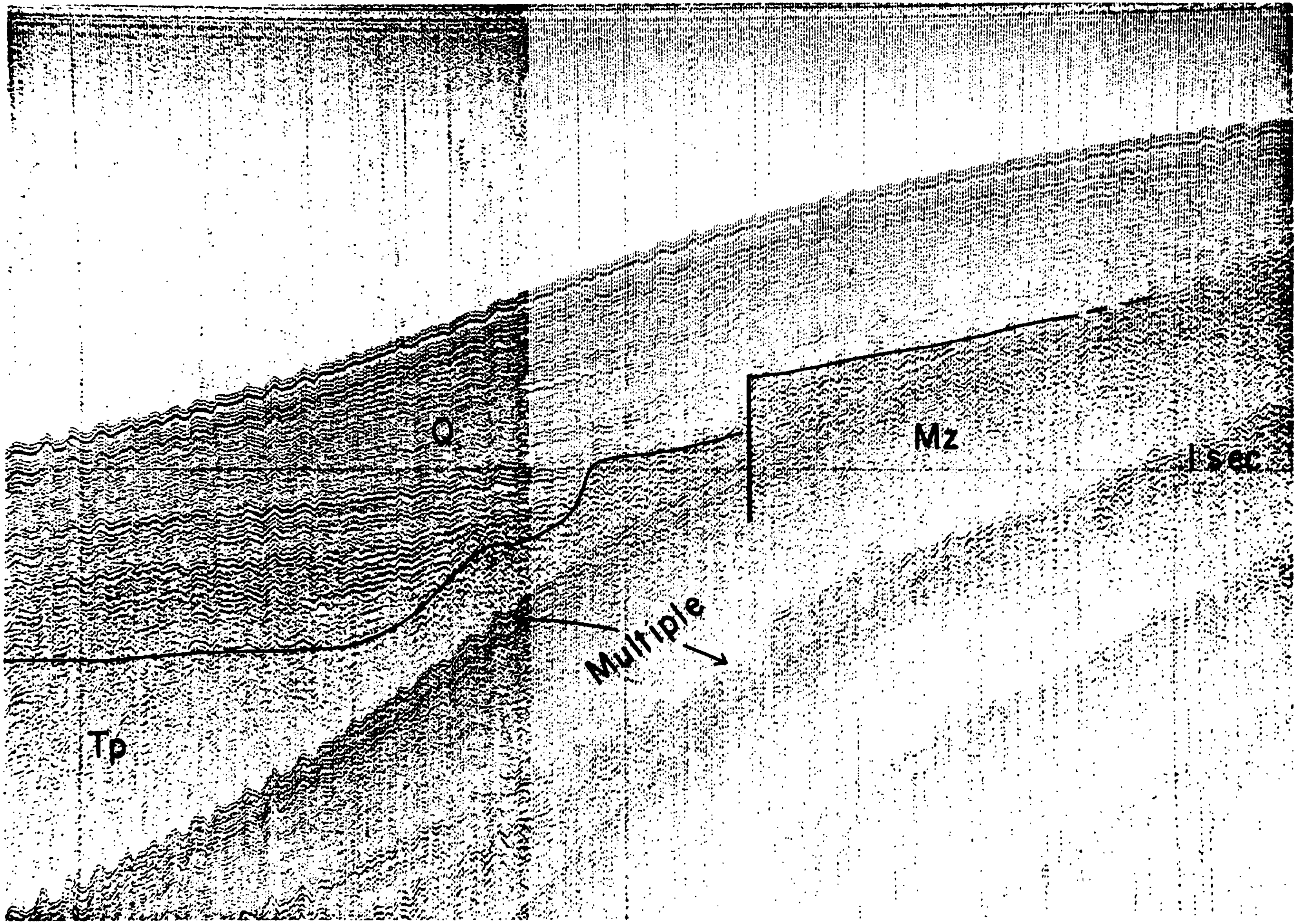

Figure 15. Photograph of part of Scammon line 96 illustrating apparent offset of base of post-Wisconsin unit (Q). Location of photograph shown in figure 6.

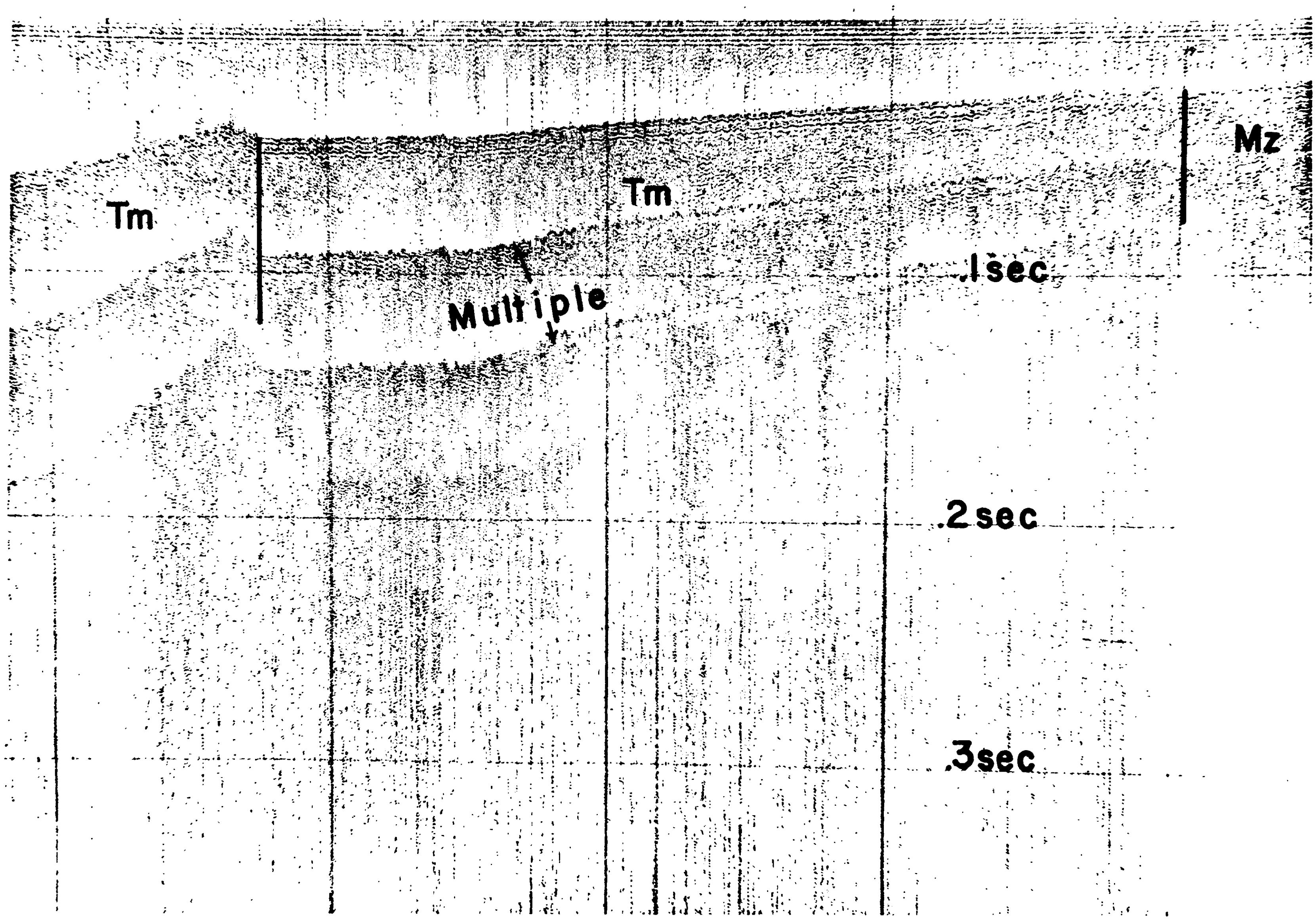

Figure 17. Photograph of part of Scammon line 73 illustrating landward-facing scarps on the seafloor. Location of photograph shown in figure 6.

The following discussion begins with features in the southern part of the study area and then moves northward with descriptions of the interpretations and the evidence used to support those interpretations.

The Hosgri fault zone changes from a relatively narrow zone of faulting with apparently large vertical separation at the latitude of Pt. Estero to a broad zone of folding and faulting to the north. This change in deformation style is observed between Kelez line 105 (Figure 7) and Kelez lines 79, 81, 83, and 85 (Figure 9).

Kelez line 105 (Figure 7) illustrates vertical separation associated with the Hosgri fault in this area. Vertical separation of the base of unit Tm is approximately 1100 meters using an interval velocity V = 2440 m/sec as determined for rocks of this age in the exploratory well (Oceano Well) previously mentioned (David McCulloch, personal communication, 1980).

The structural and stratigraphic relationships between the seismic units in the area between Pt. Estero and Cambria are shown on BBN line 49 and Kelez line 97 (Figure 7) and Kelez line 91 and Scammon line 39 (Figure 8). Unit Tp laps onto and unconformably overlies unit Tm. Reflectors in the Tm unit are terminated at approximately km 4.5 on line 39 and the block between km 3 and 4.5 is interpreted to represent the cherty middle Miocene and shows only a hint of bedding. A fault contact between units Tm and Tp is observed along the seaward-most ends of lines 49 and 97.

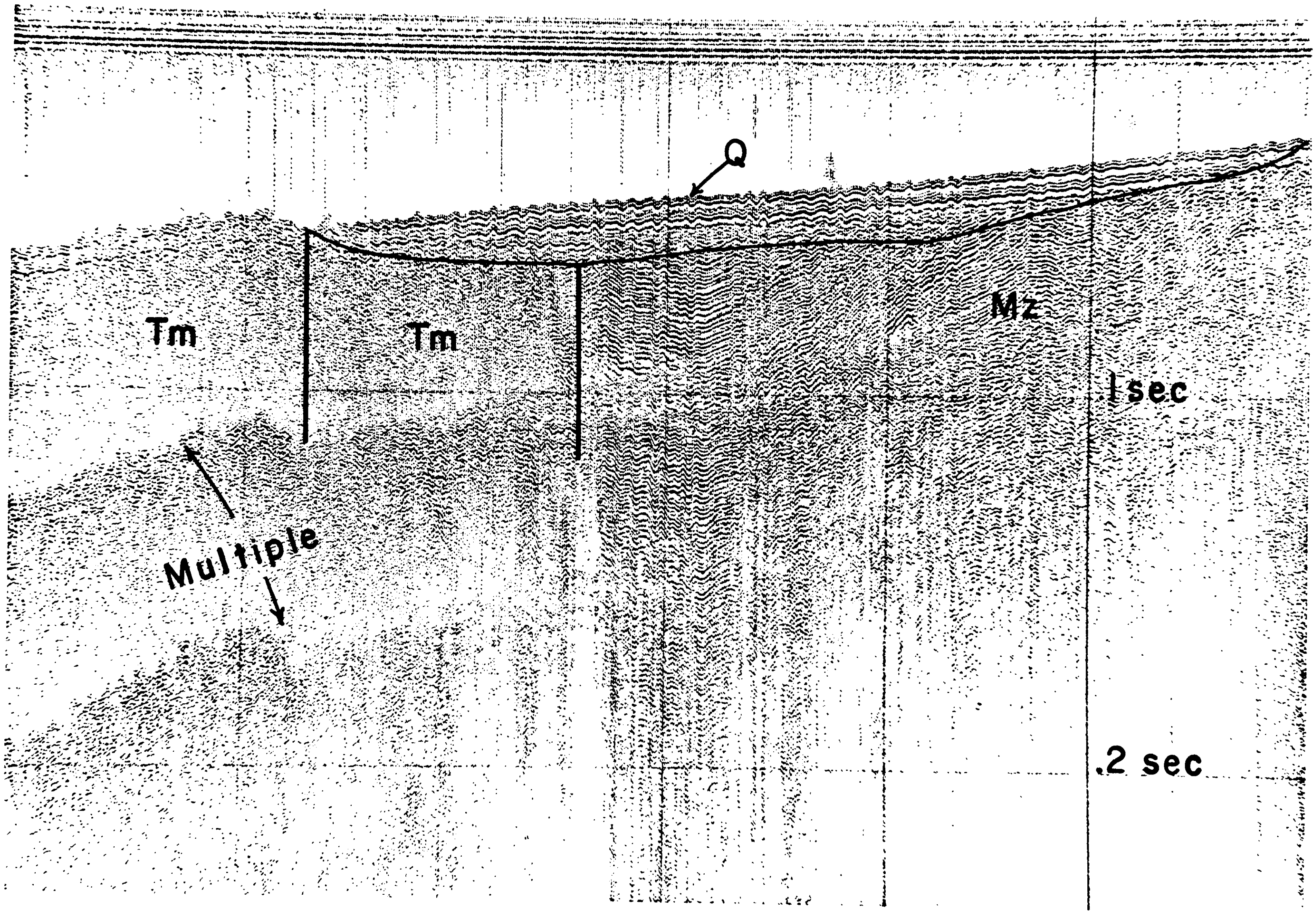

Figure 16. Photograph of part of Scammon line 67 illustrating landward-facing scarps on the seafloor. Location of photograph shown in figure 6.

The high-resolution line 39 shows unit Tp onlapping unit Tm at this same boundary. This ambiguity may be the result of lack of data for the near surface on the deep-penetration line 97. The bubble pulse averages approximately 90 m thick on the deep-penetration Kelez records (Wagner, 1974a) and hence masks the geology of the subbottom near the seafloor. Therefore, the offset observed on line 97 probably occurs at depth on line 39 below the onlapping unit Tp; that is to say, the base on unit Tp is offset but the younger overlying sediments of this same unit are not. Kelez line 91 illustrates this onlapping relationship along the fault located at about km 2.

Unit Tm is interpreted to extend to the eastern end of line 91 and because Mesozoic rocks crop out on the nearby coast, unit Tm is inferred to be in fault contact with unit Mz east of this line, offshore from Cambria. Other deep-penetration records for this area, which do not cross the inferred fault segment, show bedding in unit Tm which extends at least to the easternmost end of the profiles (Lee line 521 and Kelez line 91, Figure 8). Based on the high-resolution profiles which cross this area offshore from Cambria, it is not possible to distinguish between units Tm and Mz.

The nature of the fault contact between units Tm and Mz to the northwest of the inferred segment is best observed on the high-resolution Scammon records (Scammon lines 67 and 73, Figure 10). Reflectors on the northeast side of the landward-most fault south of San Simeon Bay (Scammon lines 63, 67, and 73, Figure 10) are interpreted to represent bedding in the Cambria Slab.

The majority of seismic lines interpreted for this study illustrate a relatively smooth and undisrupted seafloor. Two of the high-resolution Scammon lines (67 and 73, Figure 10), however, indicate distinct scarps on the seafloor. Although a non-tectonic origin for these topographic features may be fluvial processes which eroded the shelf during a low stand of sea level, the location of these seafloor scarps coincides with changes in dips of reflectors in the subbottom, and therefore the scarps probably represent faults or fault-line scarps. Seaward facing seafloor scarps may be attributable to marine erosion during lower sea level still-stands, but these face landward, and it is unlikely they are due to marine erosion. The onshore San Simeon fault (Figure 4) acts primarily as a structural boundary between Jurassic ophiolite and overlying Tertiary rocks southwest of the fault, and Franciscan assemblage rocks northeast of the fault (Hall, and others, 1979). Numerous branch faults splay off the San Simeon fault in a west-northwestward direction. Faults with similar trends have been mapped from seismic reflection profiles in the offshore region (Figure 4). The Arroyo Laguna fault (Hall, 1976b), trends approximately parallel to the San Simeon fault and the two faults merge onshore about 1 km north of San Simeon Bay (Hall and others, 1979).

Folding is the dominant type of deformation which occurs in the offshore area west of the San Simeon fault near Pt. Piedras Blancas. A fault contact, however, is observed between units Mz and Tm in the near-shore region for this same area (Kelez line 65, Figure 11).

The northern offshore extension of the San Simeon fault can be seen on Scammon lines 87 and 96 (Figures 11 and 12). Kelez lines 55, 51, and 47 (Figures 11 and 12) illustrate the deeper structure observed between Ragged Pt. and Cape San Martin. These deeper penetration Kelez profiles show an eastward thickening section of Tertiary sediments which are in fault contact with unit Mz along the offshore San Simeon fault. Details of the fault contact are best observed on Scammon profiles. Reflectors in unit Tm are terminated by unit Mz at about km 2.2 on line 87 (Figure 11). Unit Q does not appear to be broken above the main trace of the fault in this area. Landward of km 2.2 the base of unit Q is irregular and unit Q is apparently absent between km 1 and 1.5. A zone of chaotically deformed unit Tp sediments overlies the anticlinal unit Tm between about km 6.5 and 11. These structures may have resulted from mobilization of unlithified Tp sediments during formation and uplift of the underlying anticline. The anticlinal structure associated with unit Tm is again illustrated on Scammon line 96 (Figure 12). Unit Tp is broadly folded (λ > 3 km) landward of the anticline and is truncated by the San Simeon fault at about km 1 where reflectors at the base of the overlying unit Q may be offset by the fault. On Kelez line 47 the Tm anticline is fault bounded on its southwest side, and it appears to have acted not only as a structural high but also as a topographic high during the deposition of acoustic unit Tp. This relationship is indicated on the geologic map (Figure 4) by the lithologic contacts between the Miocene and Pliocene units.

Folding is less well-developed at the latitude of Cape San Martin than to the south, and faulting along the northerly extension of the San Simeon fault zone is the dominant deformational style. North of Cape San Martin the offshore San Simeon fault trends northwestward toward the southern extension of the onland Sur fault zone (Buchanan-Banks and others, 1978).

To summarize the evidence for continuity between the offshore Hosgri fault and the onland San Simeon fault, three lines of evidence exist:

1.) Faulting is well documented on the near-shore shelf from San Simeon Bay southeastward toward the inferred fault segment offshore from Cambria. Southeast of, and along strike with this segement, a fault extends northwestward from near Pt. Estero toward the southerly extent of the inferred fault segment.

2.) The intervening segment is inferred due to the lack of data which might demonstrate no offset along this boundary. Units Tm and Mz cannot be differentiated on the high-resolution records that cross the likely location of the fault, and deep penetration records do not cross the inferred segment. Because unit Tm occurs on deep-penetration records just to the southwest of the inferred fault segment, as it does along the remaining portion of the landward-most fault from near Pt. Estero to San Simeon where it crops out at San Simeon Pt., it is probable that the inferred segment juxtaposes units Tm and Mz.

3.) The constant angular relationship observed between the landward-most fault, where offset is documented, and the inferred fault segment with the northwest-trending magnetic gradient further suggests continuity along this area of the near-shore shelf.

Recency of Faulting

Offset reflectors in the post-Wisconsin unit (post 15,000 years ago) and topographic scarps on the seafloor provide the most definitive determination of recency of faulting, and are best observed in high-resolution profiles.

The seaward-most traces of the San Simeon-Hosgri fault zone, which is considered here to include the continuous San Simeon-Hosgri fault and the discontinuous strands nearby to the southwest between San Simeon and Pt. Estero, are older than the post-Wisconsin unit and do not disturb the young overlying sediments. Three lines of evidence, however, indicate recency of faulting has migrated landward to the near-shore area along the main trace of the San Simeon-Hosgri fault trend. They are:

1. Apparent offset of reflectors of the post-Wisconsin unit observed on Scammon lines 63, 87, and 96 (Figures 10-15). The abrupt termination of the post-Wisconsin unit on line 63 may be attributed to faulting following deposition of that unit. Alternatively, deposition may have occurred along a pre-existing fault line scarp.

2. Topographic scarps on the seafloor form a linear trend extending southeastward from San Simeon Bay (Scammon lines 67 and 73, Figures 10, 16, and 17). These scarps are landward-facing and occur in water depths of less than 40 meters, well within the range of storm-wave erosion (Komar and others, 1972). Because these scarps occur at depths subjected to storm-wave erosion, they may represent young fault features.

3. G. Weber (oral communication, 1979) has mapped faults that offset Holocene dune sands which overlie the San Simeon fault in the San Simeon Bay area. The landward-facing (northeast side down) scarps observed on Scammon lines 67 and 73 (Figure 10,16 and 17) southeast of San Simeon Bay demonstrate the same sense of movement observed by Weber along the onshore San Simeon fault in the San Simeon Bay region. A fault scarp with similar orientation (northeast side down) has been suggested for an area offshore from Pt. Buchon (Earth Sciences Associates, 1975). This scarp occurs along the Hosgri fault near the southern end of Estero Bay.

If the post-Wisconsin sediments observed on line 63 (Figures 10 and 13) were faulted following deposition, a maximum age of faulting can be determined by comparing the depth of these sediments to a sea level curve. Figure 18 shows a sea level curve constructed by Milliman and Emery (1968). The curve from point a to point b represents the transgression of the sea across the shelf following the Wisconsin low stand of sea level. By observing that the post-Wisconsin sediments on line 63 are

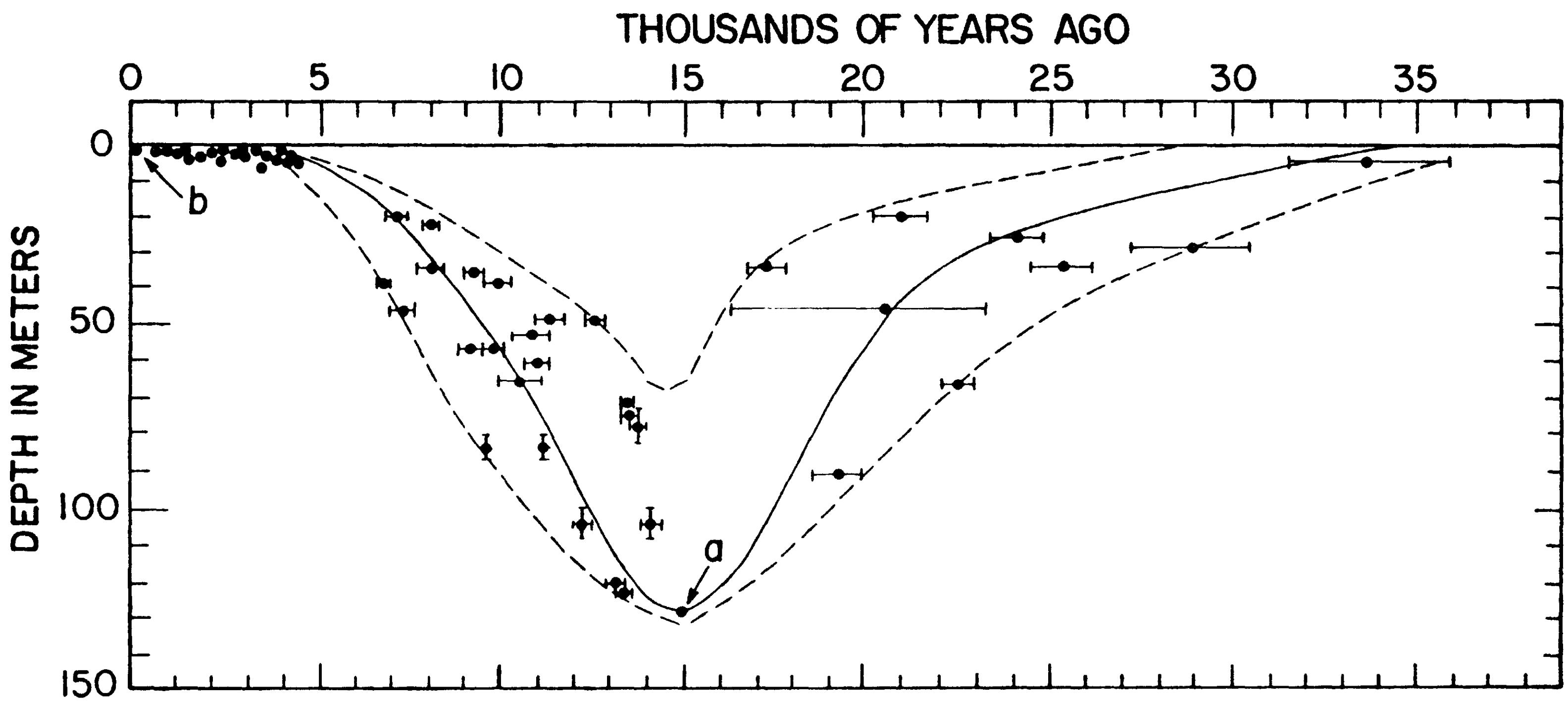

Figure 18. Sea level curve for the past 35,000 years. From Milliman and Emery, 1968. Discussion in text.

terminated at a depth of approximately 40 meters, one can compare that depth with the sea level curve to obtain a maximum time of deposition (9,000 y.a. ± 2,000 years). Therefore, if the sediments are actually displaced due to faulting, this faulting (at least locally) may have occurred within the last 7,000 to 11,000 years. Other sea level curves were considered for determining the time of deposition of the post-Wisconsin sediments (for example; Shackleton and Opdyke, 1973; Emery and Garrison, 1967; Shepard and Curray, 1967). All of these curves show an abrupt rise in sea level between about 15,000 and 5,000 years ago, and the variations between these curves are generally within the envelope of values shown in Figure 18.

As previously mentioned, first motion studies and earthquake focal mechanism solutions also suggest that the central California coastal region is seismically active and is experiencing right slip along the San Gregorio-Hosgri fault trend (Gawthrop, 1975, 1978).

Significance of Apparently Refolded En-Echelon Folds Southwest of San Simeon

The refolded en-echelon folds in unit Tm (first reported by Wagner, 1974a) are terminated by various splays of the Hosgri fault trend (Figure 4). The orientation of these en-echelon folds with respect to the Hosgri fault trend is consistent with a right lateral shear couple (Moody and Hill, 1956; Wilcox and others, 1973). Moody and Hill (1956) developed their model for formation of en-echelon folds adjacent to strike-slip fault systems. The work of Wilcox and others (1973) consisted of clay models which were subjected to strike-slip oriented stresses, and their results are in general agreement with the work of Moody and Hill (1956).

Figure 9 shows line drawing interpretations of Kelez lines 85, 83, 81, and 79 across the refolded folds southwest of San Simeon. The relationship between these lines and a reference line is shown in Figure 6. The anticline at km 5.5 on line 85 is observed at about km 12.5 on line 83. Line 81 shows the anticline again at about km 12.5. The northwest trend of the anticline seen on lines 85, 83, and 81 changes to a more northerly trend between lines 81 and 79 where the anticline is observed at about km 12.5 on line 79.

If these structures are continuous, and the line-to-line correlations are correct, this region has probably undergone two periods of folding as suggested by the amplitude of the bends in the fold axes, and the similarity of the folds in adjacent anticlines.

By late middle Miocene time movement on the San Gregorio-Hosgri fault system had been initiated and coastal pull-apart basins such as the Santa Maria Basin had begun to form (Hoskins and Griffiths, 1971; Crowell, 1974). The refolded folds and Tertiary pull-apart basins are coeval and may have formed in response to a change in stress orientation during the time of transition from compression associated with subduction to shearing along the translational boundary of the San Andreas fault. Alternatively, a wrench-tectonic origin for the late Tertiary basins along the central and northern continental shelf has been suggested by Howell and others (1980). If this hypothesis is true, the refolded folds may represent complex structures that formed due to wrenching of the near-shore shelf.

DISCUSSION

Direct Conclusions of this Study

The geophysical data used in this study are interpreted to represent four direct conclusions concerning the San Simeon-Hosgri fault zone:

1) The San Simeon-Hosgri fault trend represents a through-going fault system between Cape San Martin and Pt. Estero which is geometrically capable of transferring lateral offset.

2) Apparently refolded folds adjacent to the Hosgri fault trend are oriented consistent with a right lateral shear couple, although the amount of lateral offset required to accomplish the refolding cannot be determined from the available data.

3) Major movement occurred along the San Simeon-Hosgri fault zone during Miocene and Pliocene time, and possibly offset reflectors of post- Wisconsin age (< 15,000 years old) and linear trends of landward-facing scarps on the seafloor indicate that faulting may have occurred locally anytime since 7,000 to 11,000 years ago.

4) Recency of movement on traces of the offshore Hosgri fault has migrated landward through time. This is supported by the fact that post-Wisconsin age sediments are not disrupted by faults that lie farther offshore, but in the nearshore area, post Wisconsin age sediments may be disrupted by faulting locally. The previously mentioned scarps on the seafloor occur in shallow

water along this same stretch, within the range of storm-wave erosion, and may represent relatively young fault features.

Tectonic Implications of this Study

The previously mentioned conclusions of this study are used to provide a means of testing pre-existing models for the Neogene evolution of the central California coastal region and specifically the Neogene evolution of the San Andreas fault system.

Two differing views exist on the evolution of the San Andreas fault system. Both views account for the observed difference in amount of offset between Sierran basement (Salinian block) and overlying Tertiary formations. The Salinian block is an allochthonous ensialic crystalline terrain (Howell and others, 1980) which represents part of a late Mesozoic plutonic arc (Ross, 1978). This block, which was probably once a southward continuation of the Sierra Nevada plutonic belt (Page and others, 1979), has apparently been displaced 500 to 600 km along the San Andreas fault. The Tertiary formations which overlie the Salinian block, however, show evidence for only approximately 300 km of right lateral displacement.

The first view is that of a two-stage system with major movement on a proto or ancestral San Andreas fault that occurred during late Cretaceous to early Tertiary time. This earlier offset was followed by a resurgence of movement during the

Neogene (Suppe, 1970; Silver and others, 1971; and Nilsen and Clarke, 1975).

The second view is the one-stage model first suggested by Johnson and Normark (1974) in which all movement on the San Andreas fault occurred during the Neogene. Graham and Dickinson (1978a, 1978b) developed support for this model by reconstructing limits of offset of Salinian basement. Graham and Dickinson (1978b) inferred from their reconstruction that proto-San Andreas offset would be reduced to 175/85 km maximum/minimum when the total offset of the Salinian block along the San Andreas fault included 115 km of right slip along the San Gregorio-Hosgri fault trend. Other faults within the Salinian block may have been responsible for the slivering and northward extension of the remaining 175/85 km of offset unaccounted for.

Proto-San Andreas right slip may also be explained by early Tertiary oblique subduction (Coney, 1978). Fitch (1972) suggested that oblique convergence may result in complete decoupling of the over-riding plate (Figure 19). This decoupling would result in lateral displacement of the block between the decoupled surface and the active trench. If this decoupling model is valid, it may account for tectonic slivering, northwestward migration, and ultimately accretion of numerous anomalous terrains to northwestern North America.

As previously mentioned, apparently offset geologic features discussed by Graham and Dickinson (1978a, 1978b) were used as evidence to support their proposal of 115 km of Neogene right slip on the San Gregorio-Hosgri fault system. These apparent offsets alone do not prove large lateral displacement on the San Gregorio-Hosgri fault system because the observed geologic features do not constitute unique piercing points like those that occur along the San Andreas fault.

The spatial orientation of the San Gregorio-Hosgri fault zone and timing of major movement suggest that it may have acted as an intermediate locus of shearing between the North American and Pacific plates during the transition from oblique subduction to the present transform boundary of the San Andreas fault. The actual amount of offset which the system has undergone, however, is uncertain. While some lines of evidence suggest approximately 115 km of right lateral offset (Graham and Dickinson, 1978a, 1978b), other interpretations include less than 30 km of offset (Hamilton and Willingham, 1977; Seiders, 1979).

The estimates of large Neogene offset on the San Gregorio-Hosgri fault substantially reduce the amount of offset needed on an ancestral or proto-San Andreas fault, whereas the estimates of little or no Neogene offset greatly increase the need for pre-Neogene offset on a proto-San Andreas fault. In either case, the fault zone is geometrically capable of transferring lateral motion. Therefore, detailed studies of areas where the fault is exposed on land will be important in determining the offset history of the San Gregorio-Hosgri fault system.

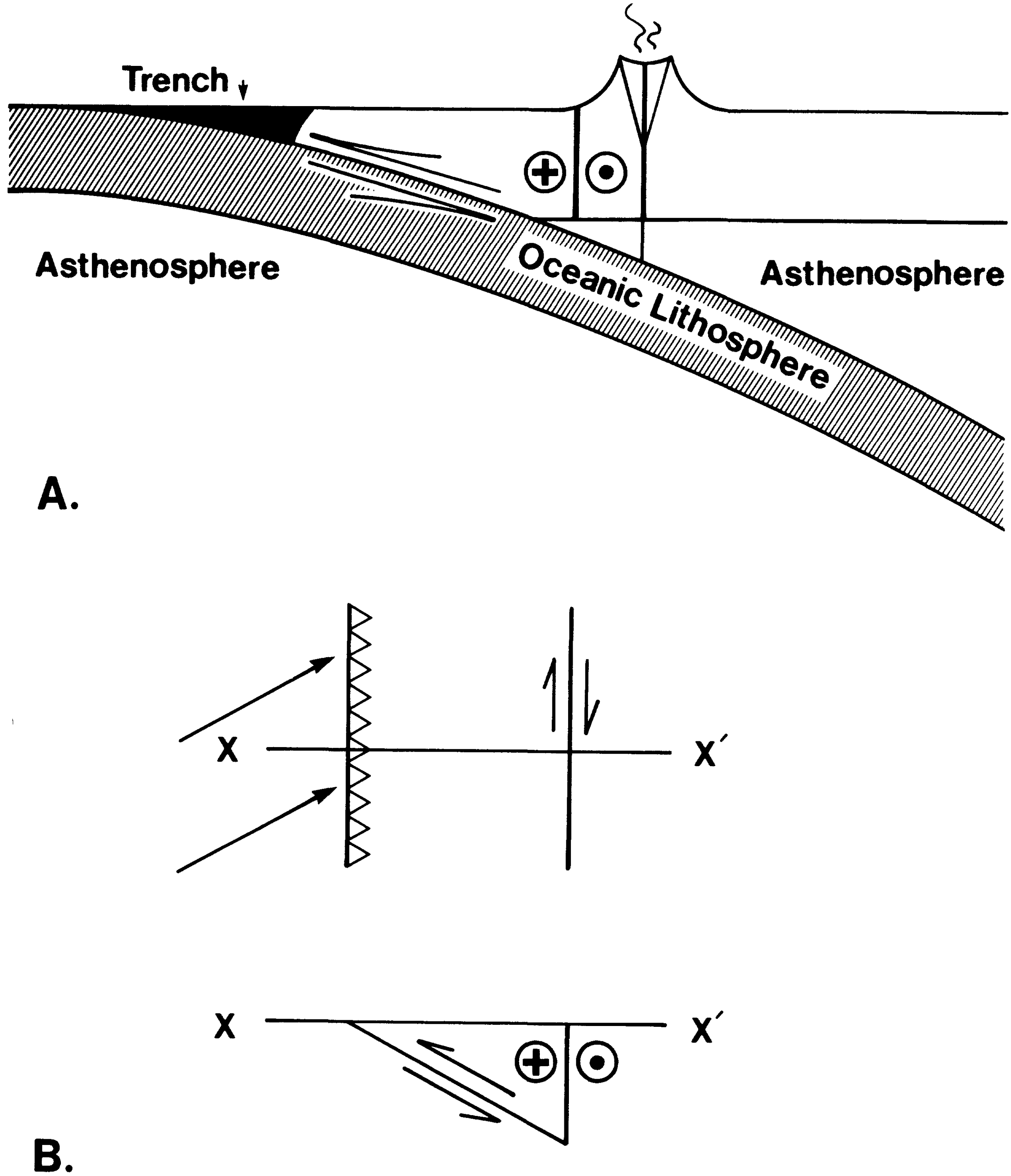

Figure 19. A) Vertical section of a well-developed island arc in a region of oblique convergence. Decoupling hypothesis is illustrated by transcurrent movement on a vertical fault adjacent to the center of active volcanism.
B) Schematic diagram of a zone of oblique convergence- (Top) map view; (Bottom) vertical cross section. Large arrows are slip vectors. Circled dot indicates movement toward viewer; circled cross indicates movement away from viewer. From Fitch, 1972.

SUMMARY

The San Simeon-Hosgri fault zone is a linear through-going fault system which is geometrically capable of transferring lateral slip. Over much of its length, the San Simeon-Hosgri fault zone represents a structural break between Mesozoic basement and a thick section of Tertiary sediments.

The San Simeon-Hosgri fault zone, which is a segment of the much longer San Gregorio-Hosgri fault system, may have acted as an intermediate locus of shearing between the Pacific and North American plates during the Miocene and Pliocene, that is to say, before the San Andreas fault obtained its present configuration.

Although major displacement occurred on the San Simeon-Hosgri fault zone during the Miocene and Pliocene, topographic scarps on the seafloor and apparently offset reflectors in the post-Wisconsin unit suggest that faulting may have occurred locally within the last 9,000 ± 2,000 years. Recognition of disrupted seismic units along the Hosgri fault trend indicates that the locus of faulting has migrated landward through time to the now continuous San Simeon-Hosgri fault trace. Furthermore, focal mechanism solutions and recent seismicity suggest that the San Gregorio-Hosgri fault system may be accommodating residual right lateral shear between the North American and Pacific plates (Gawthrop, 1978).

Clearly a problem exists as to the amount of lateral displacement which the San Simeon-Hosgri fault system has undergone. The nature of the southern termination of the Hosgri fault is also uncertain and has been the subject of recent discussion, for example Dickinson (1979), Luyendyk and others (1979, 1980).

Although the continuity of the San Simeon and Hosgri fault zones does not provide unequivocal evidence for large offset along the San Gregorio-Sur-San Simeon-Hosgri fault trend, the geometry of the fault system is no longer an argument against such offset. In order to better understand the history of the San Gregorio-Hosgri fault system, detailed studies of areas where the fault is exposed on land will be of paramount importance.

REFERENCES CITED

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 84, p. 3513-3536.

Buchanan-Banks, J.M., Pampeyan, E.H., Wagner, H.C., and McCulloch, D.S., 1978, Preliminary map showing recency of faulting in coastal south-central California: U.S. Geological Survey Miscellaneous Field Studies Map MF-910.

Coney, P.J., 1978, Mesozoic Cordilleran plate tectonics, In: Cenozoic Tectonics and Regional Geophysics of the Western Cordillera (Ed. by R.B. Smith and G.P. Eaton). Memoir Geological Society of America 152, p. 344-372.

Cooper, A., 1971, Structure of the continental shelf west of San Francisco, California: U.S. Geological Survey Open-File Report.

Coppersmith, K.J., and Griggs, G.B., 1978, Morphology, recent activity and seismicity of the San Gregorio fault zone: California Division of Mines and Geology, SR 137, p. 33-43.

Crowell, J.C., 1974, Origin of late Cenozoic basins in southern California, Tectonics and Sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 22, p. 190.

Dickinson, W.R., 1979, Dislocation of Paleogene depositional systems by Neogene strike-slip in western Transverse Ranges of southern California: Geological Society of America Abstracts with Programs, v. 11, p. 413.

Dickinson, W.R., and Seely, D.R., 1979, Structure and stratigraphy of forearc regions: American Association of Petroleum Geologists Bulletin, v. 63, no. 1.

Earth Sciences Associates (Palo Alto, California), 1975, Final Safety Analysis Report units 1 and 2 Diablo Canyon Site, for Pacific Gas and Electric Company, appendix 2.5E amendment 31, Aug. 1975; original F.S.A.R. filed July 10, 1973.

Emery, K.O., and Garrison, L.E., 1967, Sea levels 7,000 to 20,000 years ago: Science, v. 157, p. 684-687.

Fitch, T.J., 1972, Plate convergence, transcurrent faults, and internal deformation adjacent to southeast Asia and the western Pacific: Journal of Geophysical Research, v. 77, no. 23, p. 4432-4460.

Gawthrop, W.H., 1975, Seismicity of the central California coastal region: U.S. Geological Survey Open-File Report 75-134. 87p.

_____1978, Seismicity and tectonics of the central California coastal region: California Division of Mines and Geology, SR 137, p. 45-56.

Gilbert, W.G., 1971, Sur fault zone, Monterey County, California (Ph. D. thesis): Stanford University, Stanford, California.

_____1973, Franciscan rocks near Sur fault zone, northern Santa Lucia Range, California: Geological Society of America Bulletin, v. 84, p. 3317-3328.

Graham, S.A., and Dickinson, W.R., 1976, The San Gregorio fault as a major right-slip fault of the San Andreas fault system: Geological Society of America Abstracts with Programs, v. 8, p. 890.

_____1978a, Evidence for 115 kilometers of right slip on the San Gregorio-Hosgri fault trend: Science, v. 199, p. 179-181.

_____1978b, Apparent offsets of on-land geologic features across the San Gregorio-Hosgri fault trend: California Division of Mines and Geology, SR 137, p. 13-23.

Greene, H.G., Lee, W.H.K., McCulloch, D.S., and Brabb, E.E., 1973, Faults and earthquakes in the Monterey Bay region, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-518.

Hall, C. A., Jr., 1975, San Simeon-Hosgri fault system, coastal California: Economic and environmental implications: Science, v. 190, p. 1291-1294.

_____1976a, San Simeon-Hosgri fault system, coastal central California: Economic and environmental implications: Geological Society of America Abstracts with Programs, v. 8, p. 378.

_____1976b, Geologic map of the San Simeon-Piedras Blancas region, San Luis Obispo County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-784.

_____1978, Origin and development of the Lompoc-Santa Maria pull-apart basin and its relation to the San Simeon-Hosgri strike-slip fault, western California: California Division of Mines and Geology, SR 137, p. 25-32.

Hall, C.A., Jr., Ernst, W.G., Prior, S.W., and Wiese, J.W., 1979, Geologic map of the San Luis Obispo-San Simeon region, California: U.S. Geological Survey Miscellaneous Investigations Map, I-1097.

Hall, N.T., and Sieh, K.E., 1977, Late Holocene rate of slip on the San Andreas fault in the northern Carrizo Plain, San Luis Obispo County, California: Geological Society of America Abstracts with Programs, v. 9, p. 428.

Hamilton, D. H., Fisher, D.L., and Jahns, R.H., 1979, Evidence of late Quaternary right slip and other deformation along the San Gregorio fault, California: another view: Geological Society of America Abstracts with Programs, v. 11, p.437.

Hamilton, D.H., and Willingham, C.R., 1977, Hosgri fault zone, amount of displacement, and relationship to structures of the western Transverse Ranges: Geological Society of America Abstracts with Programs, v. 9, p. 429.

Hoskins, E.G. and Griffiths, J.R., 1971, Hydrocarbon potential of northern and central California offshore, In: Future petroleum provinces of the United States: Their geology and potential: American Association of Petroleum Geologists Memoir 15, p. 212-228.

Howell, D.G., McCulloch, D.S., and Vedder, J.G., 1978, General geology, petroleum appraisal, and nature of environmental hazards, eastern Pacific shelf, Latitude 28° to 38° north: U.S. Geological Survey Circular 786.

Howell, D.G., Crouch, J.K., Greene, H.G., McCulloch, D.S., and Vedder, J.G., 1980, Basin development along the late Mesozoic and Cainozoic California margin: a plate tectonic margin of subduction, oblique subduction and transform tectonics: International Association of Sedimentologists Special Publication 4.

Johnson, J.D., and Normark, W.R., 1974, Neogene tectonic evolution of the Salinian block, west-central California: Geology, v. 2, p. 11-14.

Komar, P.D., Neudeck, R.H., and Kulm, L.D., 1972, Observations and significance of deep water oscillatory ripple marks on the Oregon continental shelf: p. 601-619 in: Swift, D.J.P., 1972, Shelf sediment transport: Process and pattern: Dowden, Hutchinson, and Ross, Inc. Strousburg, Pa., 656 p.

Leslie, R.B., 1980, Acoustic reflection profiles, Yankee Point to Estero Bay, April 1979, cruise of the R/V Scammon, central California offshore: U.S. Geological Survey Open-File Report 80-352.

Luyendyk, B.P., Kamerling, M.J., and Terres, R., 1979, Geometric model for Neogene crustal rotations in southern California: Geological Society of America Abstracts with Programs, v. 11, p. 470.

_____1980, Geometric model for Neogene crustal rotations in southern California: Geological Society of America Bulletin v. 91, p. 211-217.

McCulloch, D.S., 1976, Acoustic reflection profiles, R/V Samuel P. Lee, Nov. 1975, Carmel Bay to San Luis Bay, central California offshore: U.S. Geological Survey Open-File Report 76-180.

McCulloch, D.S., and Chapman, R.H., 1977, Maps showing residual magnetic intensity along the California coast Latitude 37° 30' N. to 34° 30' N.,: U.S. Geological Survey Open-File Report 77-79.

McCulloch, D.S., Clarke, S.H., Jr., Field, M.E., Scott, E.W., and Utter, P.M., 1977, A summary report on the regional geology, petroleum potential, and environmental geology of the southern proposed lease sale 53, central and northern California outer-continental shelf: U.S. Geological Survey Open-File Report 77-593.

Milliman, J.D. and Emery, K.O., 1968, Sea levels during the past 35,000 years: Science, v. 162, p. 1121-1123.

Minster, J.B., and Jordan, T.H., 1978, Present day plate motions: Journal of Geophysical Research, v. 83, p. 5331-5354.

Moody, J.D., and Hill, M.J., 1956, Wrench fault tectonics: Geological Society of America Bulletin, v. 67, p. 1207-1246.

Nilsen, T. H., and Clarke, S.H., Jr., 1975, Sedimentation and tectonics in the early Tertiary continental borderland of central California: U.S. Geological Survey Professional Paper 925, 64p.

Page, B.M., Wagner, H.C., McCulloch, D.S., Silver, E.A., and Spotts, J.H., 1979, Tectonic interpretation of a geologic section of the continental margin off San Luis Obispo, the southern Coast Ranges, and the San Joaquin Valley, California: Cross-section summary: Geological Society of America Bulletin, v. 90, p. 808-812.

Ross, D.C., 1978, The Salinian block-A Mesozoic granitic orphan in the California Coast Range, in Howell, D.G., and McDougall, K.A., eds., Mesozoic Paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 2, p. 509-522.

Savage, J.C., and Burford, R.O., 1973, Geodetic determination of relative plate motion in central California: Journal of Geophysical Research, v. 78, p. 832-845.

Seiders, V.M., 1979, San Gregorio-Hosgri fault zone south of Monterey Bay California: A reduced estimate of maximum displacement: U.S. Geological Survey Open-File Report 79-385.

Shackleton, N.J. and Opdyke, N.D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperature and ice volumes on a 10^5 year and 10^6 year scale: Quaternary Research, v. 3, p. 39-55.

Shepard, F.P. and Curray, J.R., 1967, Carbon-14 determination of sea level changes in stable areas: Progress in Oceanography, v. 4, p. 283-291.

Sieh, K,E., 1977, A study of Holocene displacement history along the south central reach of the San Andreas fault: Ph.D. dissertation, 219 p., Stanford University, Stanford, California.

_____1978, Prehistoric large earthquakes produced by slip on the San Andreas fault at Pallet Creek, California: Journal of Geophysical Research, v. 83, p. 3907-3939.

Silver, E.A., 1974, Structural interpretation from free-air gravity on the California continental margin, 35° to 40° N.: Geological Society of America Abstracts with Programs, v. 6, p. 253.

_____1978, The San Gregorio-Hosgri fault zone: an overview: California Division of Mines and Geology, SR 137, p. 1-2.

Silver, E.A., Curray, J.R., and Cooper, A.K., 1971, Tectonic development of the continental margin off central California, in: Lipps, J.H., and Moores, E.M., editors, Geologic guide to the northern Coast Ranges, Point Reyes region, California: Geological Society of Sacramento Annual Field Trip Guidebook, p. 1-10.

Suppe, J., 1970, Offset of late Mesozoic basement terrains by the San Andreas fault system: Geological Society of America Bulletin, v. 81, p. 3253-3258.

Smith, G.W., Howell, D.G., and Ingersoll, R.V., 1979, Late Cretaceous trench-slope basins of central California: Geology, v. 7, p. 303-306.

Wagner, H.C., 1974a, Marine geology between Cape San Martin and Point Sal, south-central California: U.S. Geological Survey Open-File Report 74-252.

_____1974b, Sub-bottom acoustic reflection profiles, Cape San Martin to Point Sal, south-central California offshore: U.S. Geological Survey Open-File Report 74-0.

Weber, G.E. and Lajoie, K.R., 1979, Late Pleistocene rates of movement along the San Gregorio fault zone, determined from offset of marine terrace shoreline angles: in Field Trip Guide - Coastal Tectonics and Coastal Geologic Hazards in Santa Cruz and San Mateo counties, California, by Weber, G.E., Lajoie, K.R. and Griggs, G.B., Geological Society of America Cordilleran Section, p. 101-111.

Wilcox, R.E., Harding, T.P., and Seely, D.R., 1973 Basic wrench tectonics: American Association of Petroleum Geologists Bulletin, v. 57, p. 74-96.