My Life with the San Andreas Fault

by Henry Walrond

"Unfortunately, large ranges of error are inherent in estimates of San Andreas displacements on cross fault correlations. Therefore, several alternative interpretations of San Andreas slip history are possible."
—Graham and others (1989)

Introduction

The San Andreas fault (hereafter SAF) is, if not the biggest and longest, the most famous fault in the world — in both fact and fiction. It extends northwesterly almost 1300 km from the Gulf of California to the Point Arena area north of San Francisco Bay, usually leaving a visible scar marking significant and puzzling cross-fault geologic differences through out its length. Although the SAF has been investigated for more than a hundred years by earth scientists of all persuasions, the dominant nature of its movement and its relationship to, and effect on, the bordering geology remain controversial. Since the early 1950s, most geologists have subscribed to the belief that the slippage is old, lateral, large, and active. However, the opinions even of advocates of the timing and extent of displacement are not always harmonious.

Recent displacement measured in feet on portions of the SAF is firmly established, a fact that has probably energized the big-slip proponents. Several very large earthquakes have been associated with the SAF over the years, and because of the future potential for devastating repeats, the SAF continues to be the focus of mainly government-supported research, all predicated on the foregone conclusion of large past and future lateral slip.

As I myself "slipped" into my 80s, two thoughts came to mind. The first was that I have had geological experiences in areas that few, if any, contemporaries have had or, in light of the nature of most current work, are apt to have. Some of these experiences dealing directly with the SAF may throw a different light on the prevailing views. The second was that now is the time to tell my story.

The Issue Becomes Focused

At a meeting of the Pacific Section of AAPG in 1952, Mason L. Hill presented his and Thomas W. Dibblee's proposal that said, in essence, certain apparent correlations across the SAF could be accounted for by strike-slip movement. He went on to suggest several possible right-lateral offsets, ranging from 22 km for the upper Miocene to over 560 km for the basement rocks. Earlier investigators had proposed significant strike-slip offsets on the fault. Although the Hill-Dibblee proposal (published by the Geological Society of America in 1953) was introduced as merely a theory, it became the watershed study that launched a series of pro-slip investigations and, prematurely, textbooks that presented the theory as fact (Oakeshott, 1965).

Following the 1952 talk, the mediator asked for a show of hands of those who were impressed with Hill's presentation, and most of the audience responded favorably. I remember that, although the presentation was persuasive, I did not raise my hand, and this was the moment when my life with the fault took on special meaning. My response to Hill's talk was not arbitrary or based on youthful brashness, but was a reaction to a proposal that conflicted with my geologic experiences.

My Hollister Experience (before Hill-Dibblee)

As it so often happens, a convergence of events can shape our lives in a lasting fashion. A combination of new oil discovery, a test yielding high-gravity oil from Franciscan basement, the acquiring of a favorable land block near the town of Hollister by my employer (General Petroleum Corp.), and my being single and mobile, gave me the opportunity to evaluate the oil and gas potential of what was at that time a modest exploration "hot spot." My assignment involved a detailed surface and subsurface study of the Pliocene-age

"Hollister basin", followed by a compilation and field check of all the published geology of an area that extended south from Palo Alto to the Pinnacles volcanic field. This also included the northerly portion of the Vallecitos syncline, which extended into the area from the southeast.

The following geologic information was derived from my work on that area, and was the bases of my reluctance to raise my hand at Hill's 1952 lecture. (Relevant figures are addressed in detail on pages 75-89.)

1. Several exposures of Eocene sand east of the SAF near Palo Alto are similar to the Eocene-age Butano of the La Honda basin, located immediately across the fault to the west (Figure 12).

2. Early and Middle Miocene-age sediments are also present on both sides of the SAF from San Juan Bautista northward as far as Palo Alto (Figure 7).

3. Over this same (above-cited) distance, rocks of late Miocene age are absent on both sides of the fault.

4. Just north of San Juan Bautista, Pliocene sediments on both sides of the SAF lie unconformably on rocks of Middle and Early Miocene age (Figure 5).

5. A few miles southeast of Hollister, westerly dipping Tres Pinos sandstones and associated shales of Early Eocene age (Allen, 1946) form what appears to be the east flank of an extension of the Vallecitos syncline. Plio-Pleistocene sands and gravels cover the intervening twelve miles, but a northerly projection of the syncline is in accord with the age and structure of the Tres Pinos sediments. At the time of my investigation, it seemed reasonable to assume that the succession of Lower Eocene outcrops exposed through Morgan Hill to Stanford were remnants of the Vallecitos syncline. The lower Eocene beds near Coalinga and their connection to the Vallecitos were then unknown at time, and I did not foresee the big picture of a La Honda-Vallecitos-San Joaquin basin seaway, which would come later. It was obvious even then, however, that the similarity in age and lithology of Eocene sands east of the SAF near Palo Alto, and Eocene sands in the bordering La Honda basin west of the SAF posed a challenge to large lateral movement in the area.

6. A highly compressed (not rifted) Plio-Miocene graben southeast of Hollister is squeezed between the SAF on the west and the Paicinas-San Benito fault system on the east. Toward the south end of this graben, near the Pinnacles National Monument, Upper Miocene sands and shales occur on both sides of the SAF (Figure 6).

These were the observations of a young geologist, made on the basis of his own and published area geology. This — the straightforward, uncomplicated correlation of rocks contiguous to one another, on either side of the SAF ranging in age from the Early Eocene to Pliocene, and extending over a distance of 126 km — created the doubts about the Hill-Dibblee proposal.

Paso Robles

For a short time in 1953, I studied the Salinas basin. The SAF was not directly involved in this investigation, but I do recall tracing the overlap contact of the Middle Miocene by the Upper Miocene south along the westerly flank of the Gabilan crystalline basement high and then easterly almost to the SAF. I speculated at that time about the possibility of a counterpart of that well-defined overlap (piercing point?) existing across the SAF, and the light it might throw on the SAF controversy (Figure 7, South Portion).

Bitterwater

In early 1959, I consulted on a project along the SAF south of the Pinnacles volcanic field. The aim of this project was to map the Mio-Pliocene formations east of the SAF, southeast to Priest Valley, and to then combine the surface geology with a subsurface study of what was then called in the oil community the "Bitterwater basin," a narrow area of thick upper Miocene sediments lying west of the SAF. This included the Bitterwater oil field, a small anticlinal structure bordering the SAF on the west, which was discovered in 1953. The following excerpt from my 1959 report to my clients clearly states my concept of the Bitterwater basin's relationship to the SAF:

> "The amount of movement on the SAF is currently a matter of wide divergence among California geologists, and although the fault system cuts through the center of the Bitterwater basin, the simplest interpretation and the one most harmonious with the observable data is that the basin is one and not two juxtaposed halves of separate basins. The thickness and age of the sedimentation on both sides of the fault are in close agreement. And the general conformation of the basin is seemingly unaffected by the fault. Lithologic correlations across the fault are difficult, but this can be accounted for by differences in basement and other pre-Tertiary source areas, and the local influence of basement on shape and depth of the basin during deposition." (See Figure 6.)

In 1962, Gerald Fletcher led a field trip through the southern Temblors in conjunction with the 1962 San Joaquin Geological Society guidebook, titled "The Carrizo Plains and the San Andreas Fault." One memorable feature observed and discussed was the granitic detritus in the Santa Margarita formation. It ranges in size from sand to blocks the size of a house to masses 300 ft long. Although a matter of some debate, it was the consensus that these huge clasts were not *in situ*, but resulted from two likely methods of emplacement — either by thrust faulting across the SAF or landsliding from a prominent high source west of the fault. The possibility that these huge clasts or exposures might be i*n situ* did not seem to be an option. Related to this issue of the granite's rightful source and place in the Temblors was cross section G–G' in the (Fletcher, 1962) guidebook. This cross section showed the several hundred feet of granite penetrated by a well drilled east of the SAF by Western Gulf Oil Co. This was interpreted as being a faulted wedge(?) of granite lying below the Santa Margarita and above the Monterey; again unclear as to origin and, not recognizing the *in situ* basement possibility.

Still rejecting, or suspicious of, the large lateral movement concept, my interpretation leaned toward simplicity, or that the combination of the large size of the granite exposures combined with the thick cored section of granitic basement in the Gulf well indicated a source of granite basement underlying the western Temblors east of the SAF.

In the 1963 AAPG-SEPM Guidebook "Geology of the Salinas Valley and San Andreas Fault" (Walrond and Gribi, 1963), I compiled the surface geology and a series of five cross sections that traverse a 120-km strip extending south from the Pinnacles. These sections clearly and consistently confirmed the existence of Upper Miocene sediments contiguous on both sides of the SAF. This contiguity reinforced my negative feelings about the need for large lateral displacements on the SAF.

Two compelling papers relevant to the proposal of large displacement on the SAF were published in the 1970s. First, Huffman's (1972) paper, which essentially built on Fletcher's (1962) study, proposed the Gabilan Range granitic and metamorphic exposures as the source for most of the coarse arkosic sands found 240 km to the south in the Santa Margarita and Antelope of the Temblor–Midway-Sunset area. Second, Matthews (1976) proposed a displacement of 315 km since early Miocene time based on a correlation between the Pinnacles and Neenach volcanic sequences.

Huffman gave a talk at a 1970 meeting of the San Joaquin Geological Society, which I attended. His supporting evidence for his Gabilan-Temblor match was impressive. However, I did ask these related questions:

> First, why resort to a source 240 km away when abundant large clasts and blocks of granite in the Temblor Range might be remnants suggesting a previously exposed local area of basement rocks?
>
> Second, in as much as his map of the Upper Miocene Bitterwater basin was essentially the same as mine, showing the SAF slicing through the axis of the basin with no apparent offset, how did he account for the similar age and thickness of the Upper Miocene sediments on either side of the SAF (Figure 6)?
>
> And third, what was his opinion of the Matthews' Neenach-Pinnacles correlation?

Huffman's response to the first question was that the volume of all of the upper Miocene clastics in the Midway-Sunset–Temblor area was too large to be accounted for by the potential area of granite exposures east of the SAF. He next said that, although Upper Miocene sediments at Bitterwater were indeed on both sides of the SAF, giving the apparent configuration of one basin, the lithologies on each side were diverse enough to preclude the prospect of a single basin. In short, he said that it was merely coincidence that after more than 150 km of right-lateral slip, the two sets of rocks of the same age now happened to rest opposite each other. Although his explanation of the lithologic discrepancy seemed reasonable at the time, I remained concerned about the coincidence of the final offset. Before disclosing Huffman's response to my third question, a discussion of Matthews' (1976) paper is in order.

Matthews believed that his correlation of two sequences of presumed Lower Miocene volcanics was conclusive evidence of large-lateral (257 km) separation on the SAF because (in his words) "both areas are directly adjacent to traces of the fault." A review of his proposal revealed some serious flaws. The Neenach volcanics are indeed in contact with the SAF on their southwest; but the Pinnacles volcanics lie more than 3 km west of the fault, and thus do not represent a direct fault contact. Matthews avoided this inconvenience by proposing two things:

> First, to account for the absence of a SAF contact, the Parkfield volcanics (located 80 km south of the Pinnacles and actually lying in contact with the SAF) were proposed as the "stepping-stone" from the Neenach to Pinnacles (i.e., Neenach to Parkfield to Pinnacles).
>
> Second, to complete the offset journey to the Pinnacles, Matthews employed the pre-Pliocene Chalone Creek fault (which defines a portion of the easterly limits of the Pinnacles volcanics) as an older branch of the SAF along which the Parkfield to Pinnacles portion of the Neenach volcanics had to be transported. He also proposed that the Peach Tree Valley is the prominent topographic indicator of the course of the older branch (Figure 1).

Aside from Matthews' claimed equivalency of the volcanics, there are other problems with his proposal. First, geologic maps show the Chalone Creek fault, although pre-Pliocene in age, to be a minor feature, with no apparent contact with the SAF, either north or south. Exploratory well and geophysical data suggest that the trace of the Cholame Creek fault trends considerably east of Matthews' projection to the south. Also, the Plio-Pleistocene age of the Peach Tree Valley is not compatible with the pre-Pliocene age of the Chalone Creek fault. The valley is most likely an erosional feature associated with Plio-Pleistocene drainage along the course of the SAF, and does not indicate a fault scarp.

In other words, although Matthews' correlations of two or three volcanic fields may appear to offer a close fit, his effort to use a young erosional feature that is not associated with faulting, in conjunction with an older and minor fault, to skirt some basic problems in his thesis casts considerable doubt on his whole concept.

In responding to my third question, Huffman agreed with my concerns about the match of the Neenach and Pinnacles volcanics. He had no quarrel with the proposal that the Neenach volcanics had been displaced. It was the amount of displacement suggested by Matthews that did not fit his own estimate, and he did not feel that the Pinnacles field was the correct match. Instead, he correlated the Parkfield volcanics, which like the Neenach are actually in contact with the SAF, as the match most harmonious with his concept.

A final thought arises here: Aside from Matthews' adding involved and conflicting adjustments, and the lithologic disagreement among other investigators (e.g., Paschall, 2007; this volume, pages 1-30), does not the presence of two widely separated matching volcanic areas west of the SAF trend diminish the exclusiveness of the original match and, indeed, the original proposal?

To my mind, Matthews' theory therefore lost credibility, but Huffman's claims and convincing answers to my concerns essentially obliterated all my objections, leaving me with profound doubts about my long-held SAF convictions. Using the boxing metaphor, I was on the ropes, down for the count. And there I remained, with the subject in limbo, until my experience with the San Gabriel fault.

Reflections

I should remark here that the controversy about the SAF was for me and many petroleum geologists a matter of varying personal interest, and it was not an issue that could be pursued or justified on company time. Except for the fact that the impetus behind the large right-lateral offset proposal was from two of California's most visible and respected petroleum geologists, most of the subsequent efforts were inspired not by petroleum

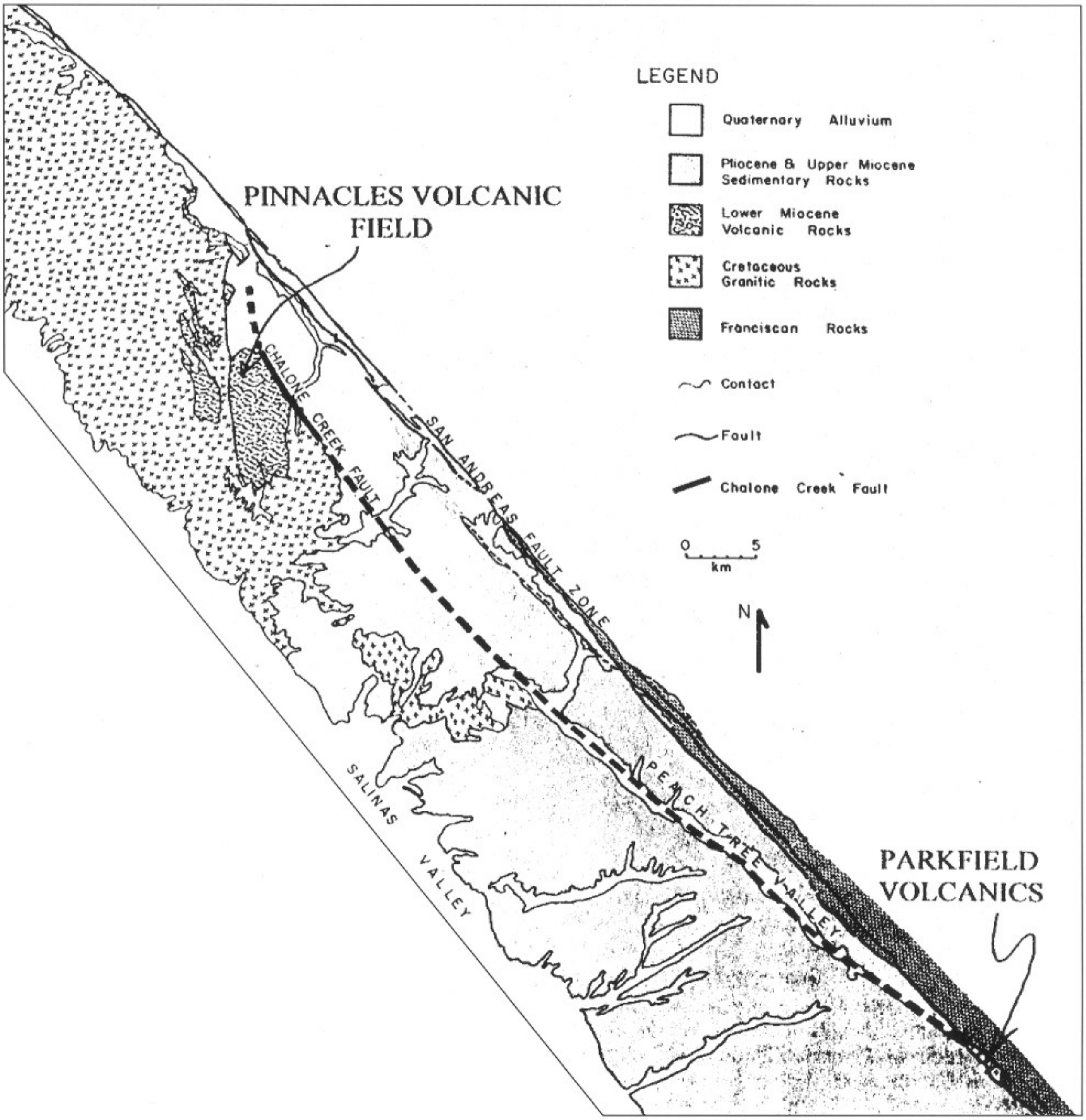


Figure 1. Location map of the Parkfield and Pinnacles volcanic areas showing Matthews' proposed trace of an older, San Andreas fault route, Peach Tree Valley to the Chalone Creek fault. He proposed this older branch to explain the inconvenient fact that the Pinnacles, not in contact with the SAF, raised doubts about their actually being the northerly offset portion of the Neenach volcanic field. To overcome this, he proposed the Pinnacles to be northerly offset of the Parkfield volcanics (in contact with the San Andreas fault and therefore the offset portion of the Neenach) via the older Chalone Creek fault. The problem with this is that the Chalone Creek fault where it borders the Pinnacles volcanic field does not connect with the San Andreas to the north, and the proposed southern fault projection associated with the Peach Tree Valley is suspect because the Chalone Creek is a pre-Pliocene-age fault, and the Peach Tree Valley is an erosional remnant of the early Pleistocene Salinas river. (From Matthews, 1976)

geologists with SAF experience, but by academic and government professionals. I might add that these subsequent workers, because of the credentials of Hill and Dibblee, seemed to be the ones most captivated by this bold and exciting new concept. In other words, the wellspring for further and ongoing research, building on the Hill-Dibblee concept, came from sources often with little initial background on the subject. For me, although the subject slumbered, and work went on, it was not dead.

San Gabriel

Two outstanding features of the SAF are its imprint on the landscape and its straightness, hardly wavering throughout the State. In striking contrast to the SAF, the San Gabriel fault (hereafter SGF) makes a pronounced loop to the south around the flank of the San Gabriel Mountains (violating the linear signature of the SAF) and, most important of all, does not connect visibly with the SAF at either end. In addition, the connection of the trend requires the extension of the SGF from the south, and connecting it with what was previously mapped as the Palomas Canyon fault to complete the northern end, even though it is unlike the SGF in age or type of displacement (Figure 2). This connection is considered highly unlikely based on subsurface work presented in my "San Gabriel Faults" paper (Walrond, 2007b; this volume, page 95).

The discerning reader might ask why the SGF is being brought into a discussion of the SAF. That is because John C. Crowell, in 1952, shortly after the Hill-Dibblee proposal, opened the door on this issue by proposing that the SGF is a former branch, or detour so to speak, of the SAF with as much as 55 km of Upper Miocene

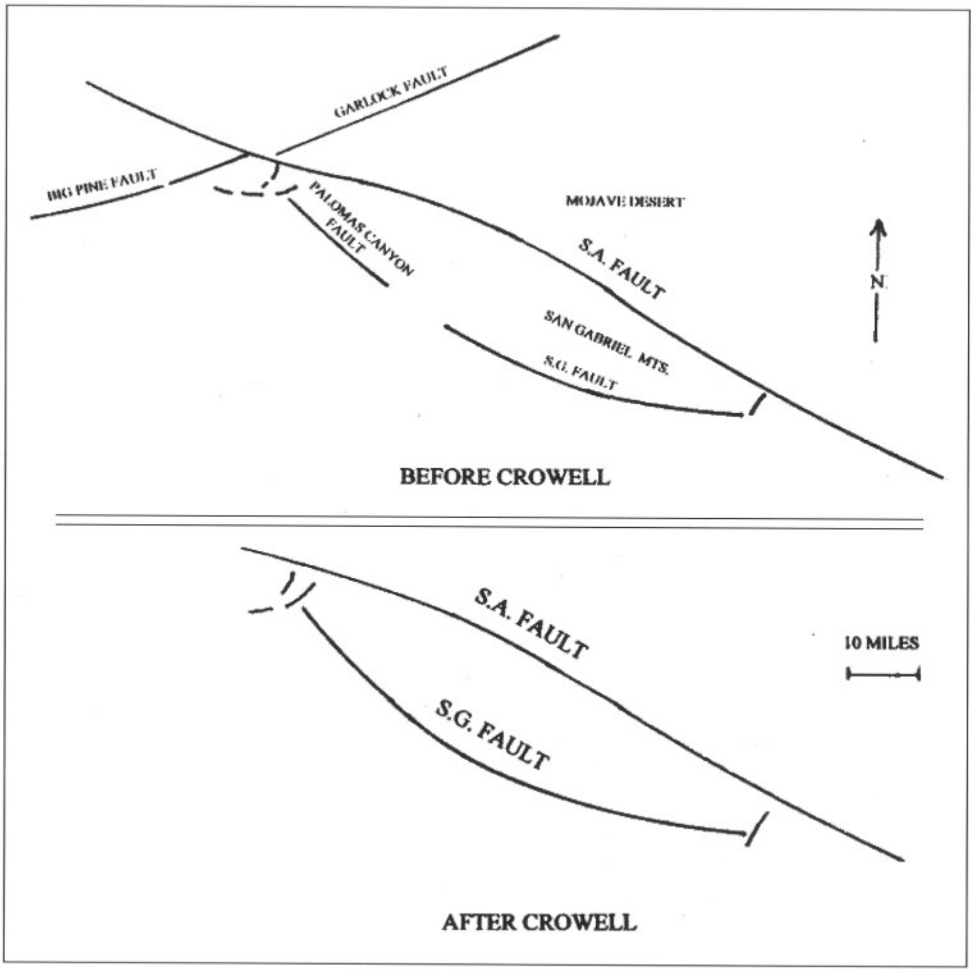


Figure 2. Diagrammatic sketches depicting the history of mapping of the San Gabriel fault area before and after Crowell (1952). Top sketch shows the original mapping, which defined two separate faults — the Palomas Canyon and San Gabriel, neither of which, it is worth noting, is connected visibly with the San Andreas fault. Bottom sketch depicts Crowell's interpretation, which is based on embracing the entire San Gabriel-Palomas Canyon trend as a branch of the San Andreas fault to complete the loop.

right-lateral displacement. He based his thesis primarily on his correlation of anorthosite in the San Gabriel Mountains north of the SGF with clasts in the Upper Miocene conglomerates located 55 km to the northwest and on the other side of the fault. His proposal also relied on the connection, as mentioned above, of the SGF with the Palomas Canyon fault to the northwest, and the eventual northerly connection of the Palomas to the SAF. Although a subject of later debate, the lithologic offset aspect of his proposal was based on solid evidence; and like the Hill-Dibblee-SAF theory, the Crowell SGF proposition was also followed by a series of supporting studies that also propelled it into acceptance by most of the geologic community.

I will not dwell here on the details and ramifications of the SGF controversy, which is well covered elsewhere in this volume. But the SGF became a part of my story when I worked in the Newhall area of the eastern Ventura basin between 1979 and 1995. What I found affected my subsequent thinking about the SAF.

The thrust of my report (Walrond, 2004), which was based on a series of cross sections through the Newhall-Honor Rancho area, was that the Palomas and SGF very likely do not connect, nor are they time or structurally related. My report, in concert with reports by Paschall and Off (1961) and Weber (1982), revealed that the displacement issue of the SGF is far from settled. Also, the uncertainty of the SGF-Palomas connection (the keystone of the Crowell proposal) leaves his entire concept in doubt.

Finally, the proposal to embrace the SGF as an ancestral branch of the SAF, regardless of obvious discrepancies and weak evidence, adds unsupportable and controversial baggage to an already complex problem.

San Gabriel Epilogue

One result of my Newhall work was a re-energized basis for doubt. The realization that a highly investigated and entrenched concept could, on the basis of more and critical scrutiny, turn out not to be so solid, encouraged me to reconsider the possibility that the same might be true of Huffman's seemingly unassailable Gabilan-Temblor connection that had been so deflating to my prior convictions.

The Poster

Sometime after the Newhall experience, Jack Clare (a fellow consulting geologist) and I found that we were of a like mind regarding the SAF. It was also apparent that we had a story to tell and that a poster session depicting the issues might be a good way to start. Our ensuing collaboration, which was completed in 1999, carried this introduction:

> "For many years Jack Clare and I shared concerns about the thrust and conclusions of most San Andreas Fault investigations. The emphasis of most studies has been on seeking evidence to justify large lateral displacements, possibly ignoring conflicting data. This study presents a contrarian viewpoint. The strength and beauty of science is that it is self correcting. For a concept to endure, it must embrace all current evidence and be able to harmoniously adjust to new data. We submit herewith several exhibits covering geologic features, grand and small, that we feel are at odds with the many, often times conflicting studies depicting large-scale strike-slip displacements. All references relating to offsets are based on the generally accepted Gabilan-Temblor Range connection which calculates about 135 miles of separation since late Miocene time."

The following geologic features (Figures 3 through 9 and 12) , ranging in age from Plio-Pleistocene to Eocene, are not compatible with large-scale offsets. They were the topic of a poster session that was presented in Bakersfield in 1999 and in Long Beach in 2000 (Walrond and Clare, 2000).

Figure 3: Plio-Pleistocene

Tom Baldwin published a paper in1963 showing a Plio-Pleistocene drainage pattern of what he called the "Salinas province" that was surprisingly different from the current pattern. This was accomplished by removing the regional westerly Pleistocene tilt of the Gabilan mesa or highland. This reconstruction showed a reversal of the flow of the Salinas River and of several now-westerly flowing tributaries as well. Baldwin's work made clear why several physiographic features seemed curiously out of concordance with the present intermittent drainage system — these features are the beheading of the three tributaries against the SAF, of well-developed terraces and terrace deposits bordering the course of the now-west-flowing Estrella-Cholame Creek drainage,

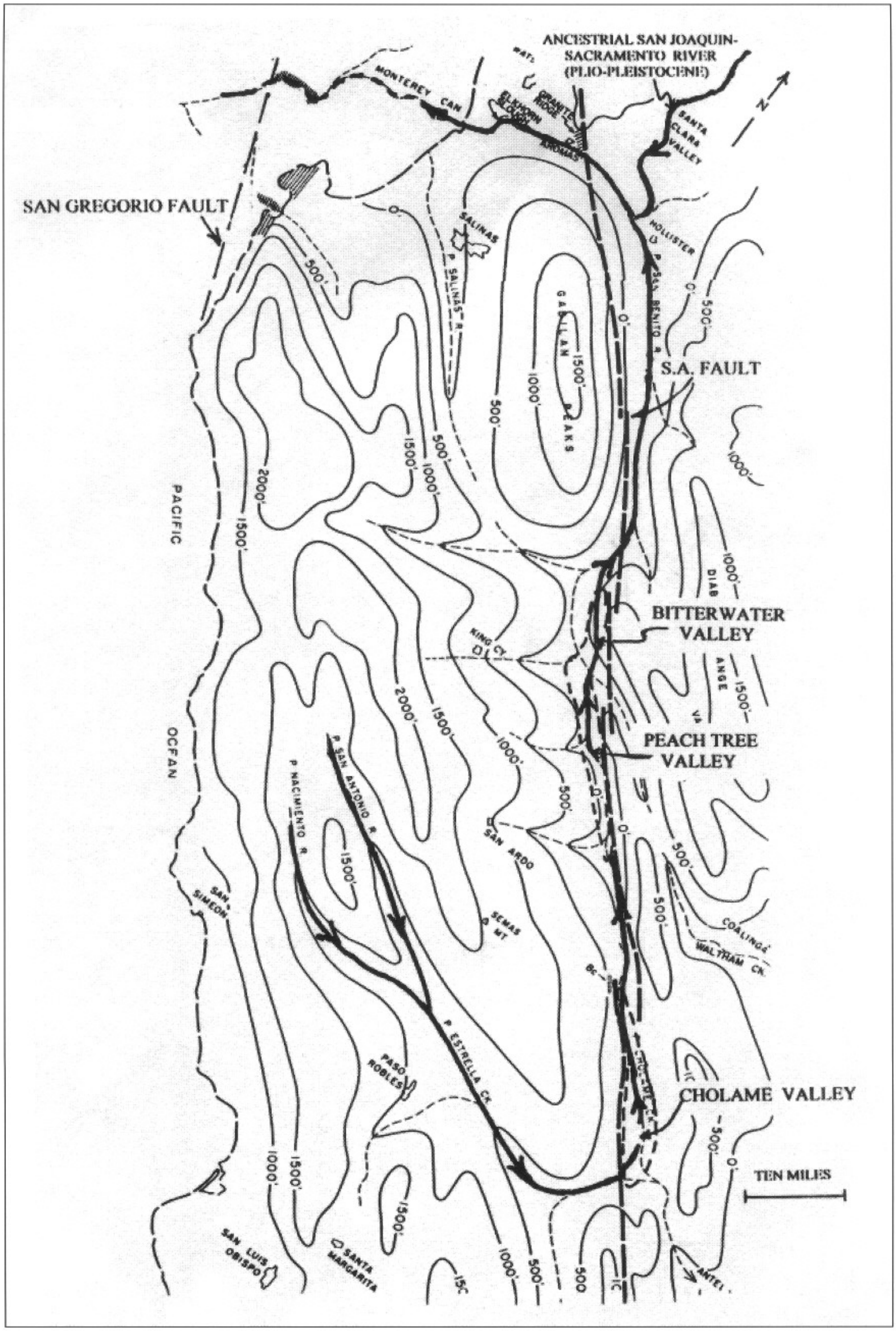


Figure 3. Plio-Pleistocene topography of the Salinas province. (From Baldwin, 1963)

as well as the prominent Cholame, Peach Tree, and Bitterwater valleys that follow the SAF trend to the north. All of these relict landforms not only support Baldwin's reconstruction but are also evidence for a major Plio-Pleistocene drainage system that probably extended as far north as Hollister.

The significance of Baldwin's reconstruction is twofold. First, the easterly course of the ancestral Salinas river (now Cholame Creek) has been offset by the SAF as it enters the Cholame Valley by no more than 1 km in the past million or so years. According to several suggested rates of displacement, that offset should be more on the order of 29 km.

The second, and in many ways most important, concept resulting from his reconstruction is the ultimate combining of the old Salinas with the Sacramento-San Joaquin river systems to supply the huge hydraulic source that scoured Monterey Canyon (see Martin and Emory, 1947). Monterey Canyon is considered to be one of the largest submarine canyons in the world. It has been said that, if it were not under water, it might rival the splendor of the Grand Canyon. It may have had an earlier complex history, but its current topography is by most accounts believed to be Plio-Pleistocene in age. The combined drainage of the Sacramento-San Joaquin rivers probably extended south from the San Francisco Bay area down the Santa Clara Valley, where it joined the old Salinas (now San Benito) river north of the town of Hollister. From there, the system then poured due west across the SAF along the course of the old, but still-visible, Elkhorn slough. Both the timing and volume of the ancestral river system make a compelling case, in terms of both timing and the volume of water, for the formation of the submarine canyon.

An additional factor could have enhanced the erosional capability of this great river system — i.e., intermittent fault-controlled ponding and flooding. This is suggested by the large area of San Benito gravels, a Plio-Pleistocene floodplain/lake deposit located east of the SAF in the Hollister area. Finally, as in the case of the west-to-east Cholame crossing to the south, the proposed much-enlarged east-to-west river crossing near Hollister reveals no significant offset by the SAF in the last million or so years.

[An aside: Although not directly related to the SAF, it is worth mentioning here that the San Gregorio fault is often held to be part of the SAF system, even though it lies well off the coast of Monterey, is far from the SAF, and trends more northerly than the great fault. Its claimed northerly juncture with the SAF allegedly justifies its inclusion in the SAF in order to account for some inconsistencies of offset matches of the "parent" fault to the east. Regardless of its possible affiliation, and a purported current activity and displacement of 19 km in the past 3 million years, there is no evidence of its offsetting the younger Monterey Canyon since it formed 1 to 2 million years ago.]

Figure 4: Plio-Pleistocene San Benito Gravels

The San Benito lake-bed deposits south of Hollister are another contribution to the SAF picture besides the effect a sudden release of a lake full of sediments could have on the erosional capabilities of the aforementioned combined river system. A study of the San Benito gravels by William L. Griffin (1967) shows a distinct contrast in gravel composition that is tied to source. The lithology on the easterly portion of the basin is mostly volcanic (Quien Sabe), Franciscan, and Cretaceous; and the lithology on the western side, directly across the SAF from the crystalline Gabilan exposures, reflects a granitic derivation. The high concentration of granitic-sourced clastics in the gravels offsetting the granitic Gabilan precludes the need for any significant offset on the SAF in this area. (Proposed slip: 37 mi in 2 million years)

Figure 5: Pliocene

The Waltham Canyon trough is a narrow and deep synclinal accumulation of Pliocene marine sediments. It runs along the east side of the SAF from just north of Hollister south to near Coalinga, giving every indication of being the marine connection between the San Joaquin basin and the Pacific Ocean. Both subsurface and outcrop evidence support the extension of this Pliocene seaway northwesterly across the SAF and into the La Honda basin without any significant fault offset.

It is important to note that, in addition to the compelling regional paleogeology, Pliocene sediments lie unconformably on the Lower Miocene in this region on both sides of the SAF. Further support for an unfaulted seaway across the SAF is the presence of extremely coarse and abundant Franciscan clasts in the basal Pliocene Purisima Formation just west of the SAF in the area of the Pajarro River Gap (Allen, 1946). The

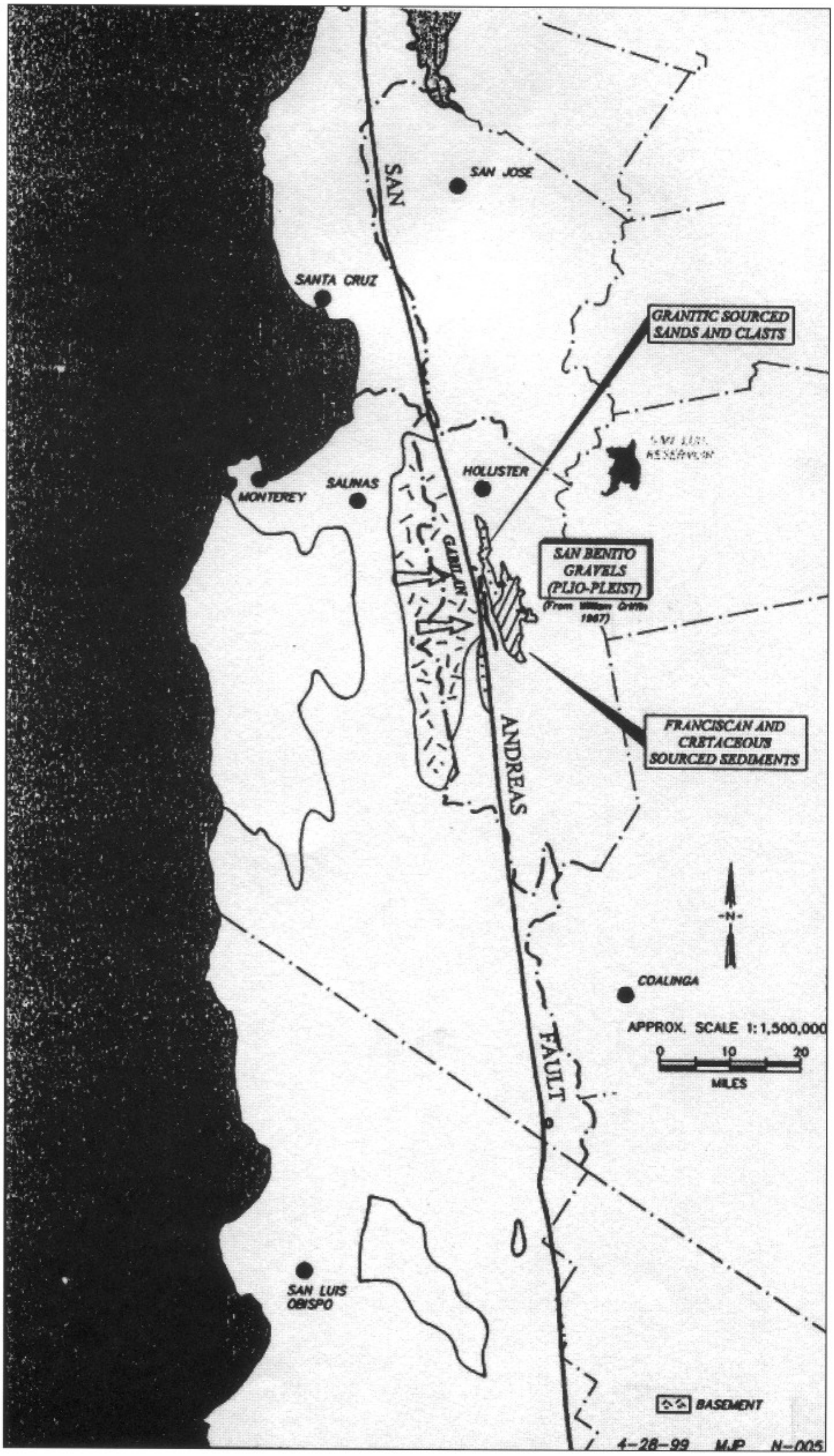


Figure 4. Map based on a lithologic breakdown of the San Benito gravels showing the easterly portion to be derived from a volcanic, Franciscan, and Cretaceous source, and the westerly portion, directly across the San Andreas fault from the Gabilan, to reflect that bordering source. The high concentration of granitic clasts directly across from the source precludes the need for any significant offset on the fault.

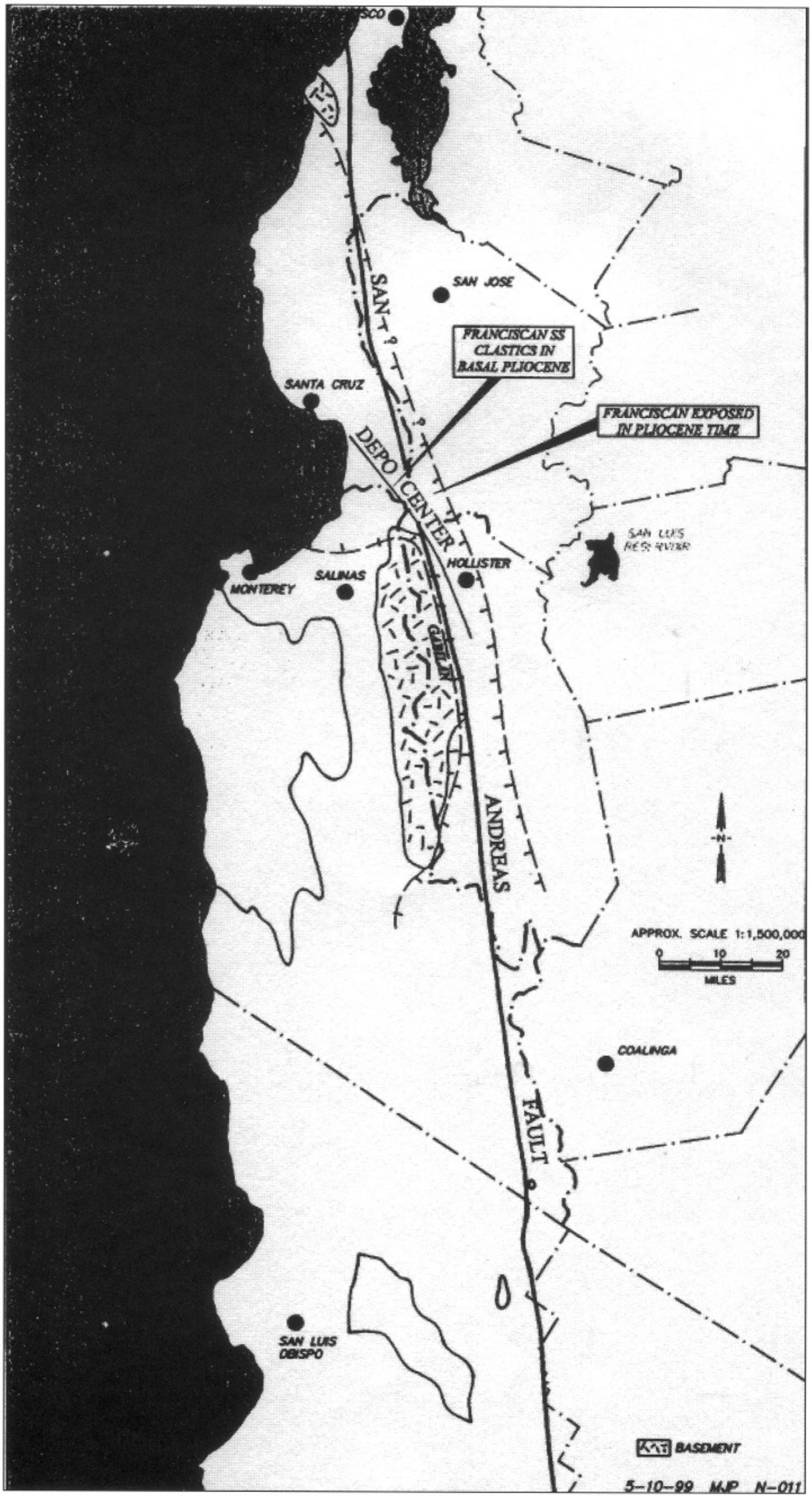


Figure 5. Map showing the Pliocene depocenter through a localized portion of the marine arm connecting the Pacific Ocean and the San Joaquin basin, where it crosses the San Andreas fault. This extension of the uninterrupted basin axis (from the Hollister area across the fault into the La Honda basin) does not indicate any significant offset. The presence of coarse and abundant Franciscan clasts just west of the fault (and close to a Franciscan source just to the east) also argue against significant offset.

Purisima also rests on a convenient Franciscan source less than 5 km across the fault to the northeast. All of these factors combine to suggest there is no indication of the 75 mi offset proposed for these 4-m.y.-old sediments.

Figure 6: Upper Miocene Bitterwater Basin

The Bitterwater basin, as viewed by most petroleum geologists, is restricted to the long, narrow, and thick accumulation of upper Miocene and Pliocene marine sediments that lie adjacent to the SAF on the west. This semi-isolated deep is the site of one small oil field and has been the focus of most local exploratory drilling in the area. However, Figure 6 shows a Bitterwater basin that lies on both sides of the SAF, which very nearly bisects it. The subject has been touched on previously in two separate parts of this paper: my 1959 Bitterwater study and my Gabilan-Temblor discussion with Huffman. To summarize: What constitutes the Bitterwater basin — the westerly side only or the inclusion of Upper Miocene sediments on both sides of the fault — has become an issue in the SAF debate.

Figure 6 portrays the concept of one basin, with no impressive lateral offset; whereas Huffman and others rely on the coincidental alignment of matching halves after a strike-slip journey of 160 or so km. Both the age of the rocks and the shape of the basin show there is no need for any appreciable lateral displacement. There are two added relevant points here. First, on both sides of the SAF the Pliocene overlaps the Upper Miocene on the flanks of the basin, giving the appearance of unified subsidence. Second, Huffman's main objection to a unified Late Miocene basin (even though his and the poster map are almost identical) was the incompatibility of the lithologies on opposite sides of the basin (read fault). Regarding the diverse lithologies argument, the work done by Griffin (1967) on the San Benito gravels (Figure 4) demonstrates that in a narrow basin with different source rocks on each side (as is the case with the Bitterwater basin, with granite on the west and Franciscan- Cretaceous on the east), different lithologies on the two sides of the basin are to be expected.

Figure 7: Middle and Lower Miocene

<u>South</u>: Figure 7 shows that Middle Miocene deposits are overlapped along the westerly and southerly flank of the Gabilan-basement high by Upper Miocene sediments. The connection with the equivalent overlap east of the SAF is less precise because post-Miocene tectonic activity and erosion, associated with a more plastic basement, have left only scattered residual outcrops. This reduces the certainty of matching the overlap line east of the fault with the more precise overlap to the west. In spite of this, the connection is close enough to preclude a need for a suggested offset of 240 km.

<u>North</u>: Middle and lower Miocene sediments occur on both sides of the SAF from Gilroy to Palo Alto. The coinciding northern limits of these sediments on opposite sides of the SAF make it difficult to claim substantial lateral displacement.

Figures 8 & 9: Lower through Upper Miocene

The southern Temblor range is particularly important in this story because it was not only the scene of Huffman's geologic *tour de force* that was so deflating to my prior concepts, but it is one of the more critical settings in the ongoing SAF debate. Both Fletcher and afterwards Huffman, as cited earlier, proposed with some minor differences that the Gabilan Range crystalline rocks, now 240 km to the north, were offsetting the Temblor Range in Upper Miocene time. They also proposed that this granitic-metamorphic terrain was the source of the upper Miocene complex of submarine and delta sand deposits of the Midway-Sunset oil field. Fletcher differed from Huffman in that he included the Pinnacles volcanics located at the southern end of the Gabilan in his source area; whereas Huffman restricted his source to the northern portion (Figure 11). Both concepts were based on an apparently compelling correlation between source rock and sediments, and on the premise that no other likely source appeared to exist across the SAF from Midway-Sunset. Also, as noted earlier, Huffman felt that any exposure of basement east of the SAF would have been inadequate to supply the large volume of highly granitic clastics present in the Temblor–Midway-Sunset sands.

The poster for this area was a joint effort spearheaded by Jack Clare, who had engaged in extensive field and subsurface work in the Cuyama Valley and the San Joaquin basin for Superior Oil Company. Figure 8 is Clare's paleogeologic map, whose three-combined features portray an area that was unrifted during all of Miocene time. Figure 9 consists of three cross sections (jointly constructed) that illustrate sequential structural-

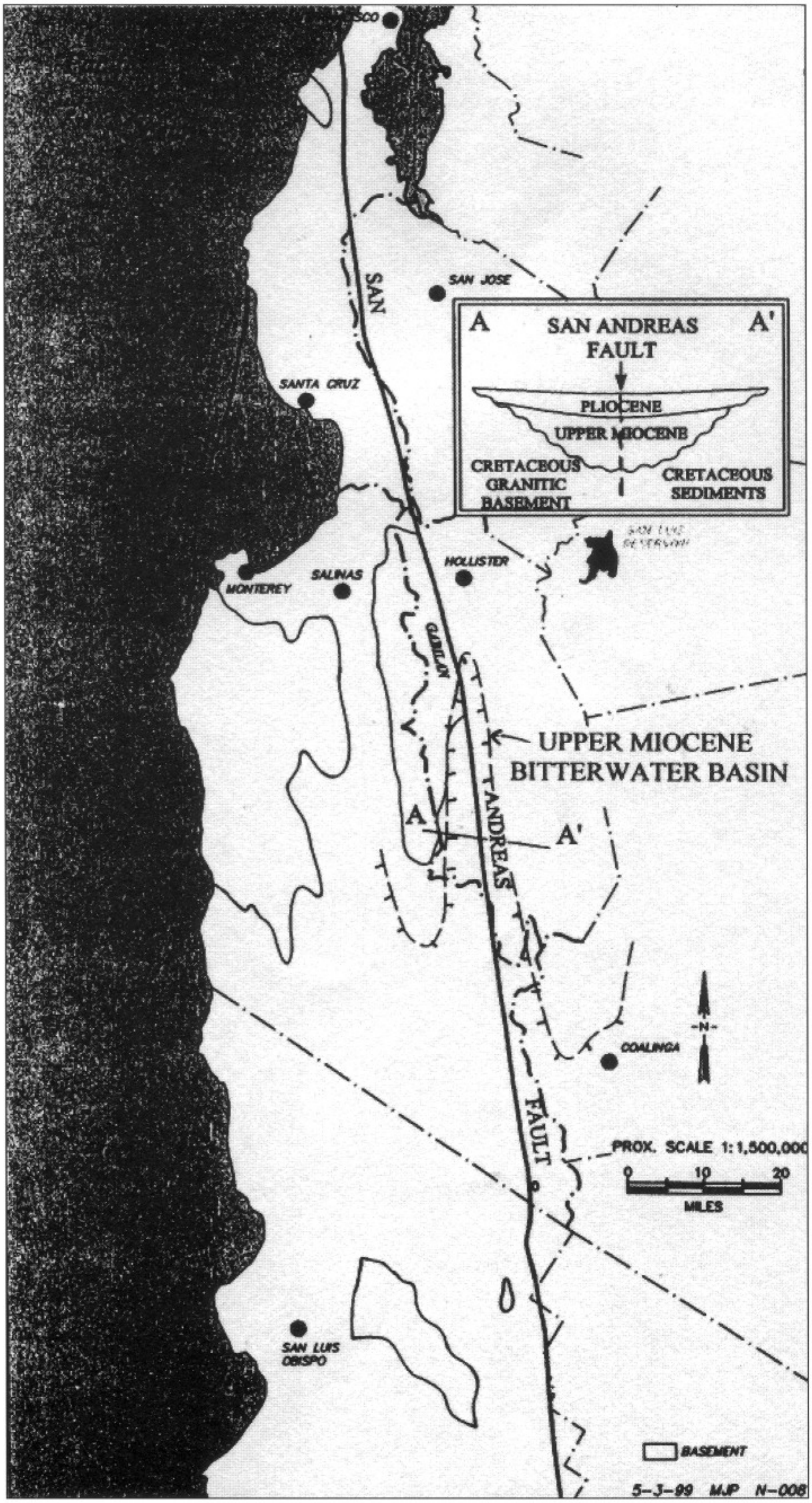


Figure 6. Map of the Late Miocene Bitterwater basin, as depicted on both the map and cross section, clearly showing its association with the San Andreas fault, but also showing no indication of lateral displacement. The similarity of deposits on both sides of the fault is supported by the corresponding overlap of Pliocene strata on both sides of the basin.

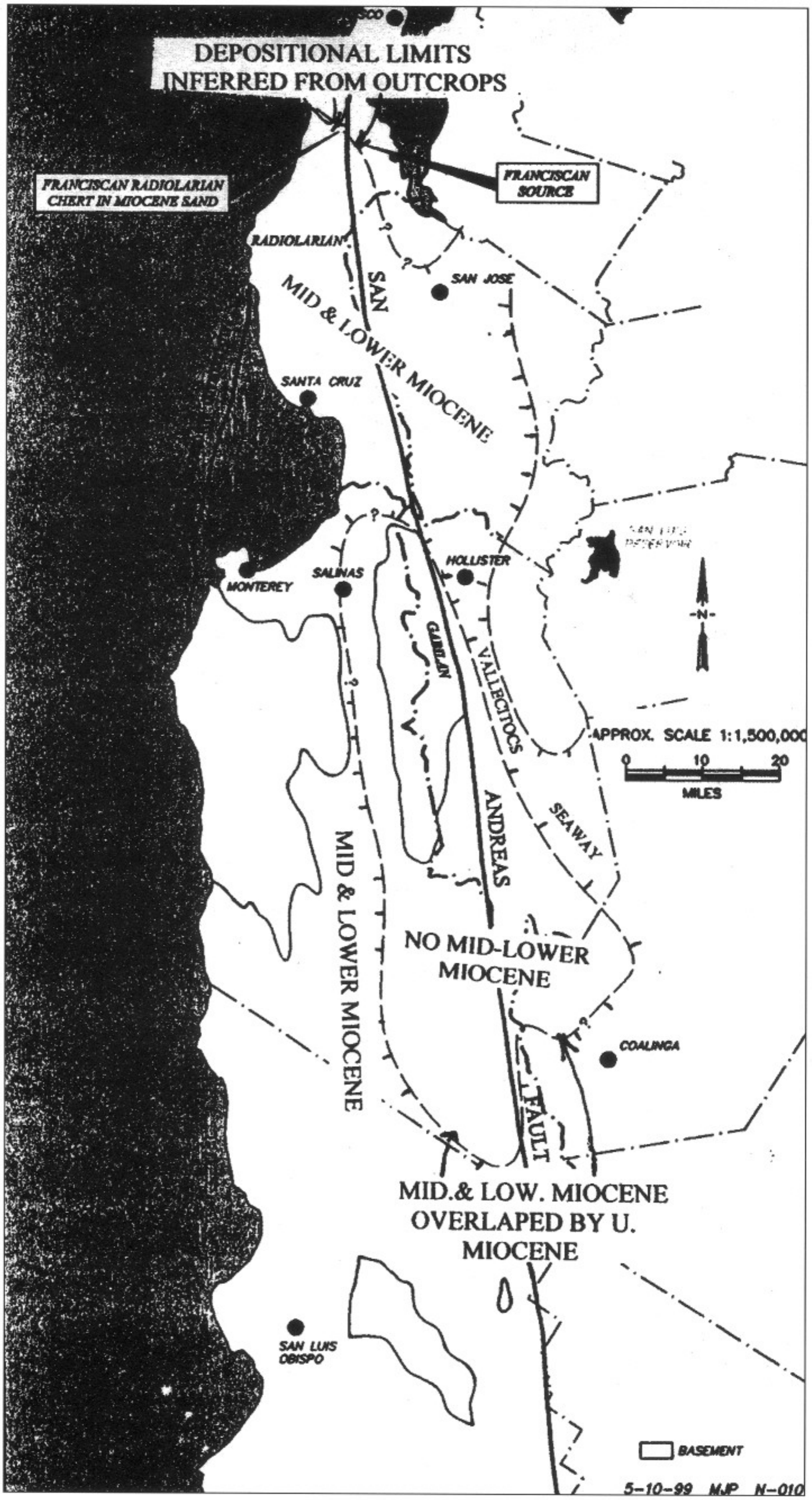


Figure 7. Paleogeologic map clearly showing a large paleohigh straddling the San Andreas fault, which is surrounded by Middle and Lower Miocene sediments with no indication of lateral offset at either end of the high. Similarly, at the far north and south, Middle and Lower Miocene outcrops match on both sides of the fault and indicate no offset.

stratigraphic activity through the Upper Miocene and Plio-Pleistocene.

Clare's map reveals three large-scale paleogeologic features:

1. The uninterrupted connection between thick middle and lower Miocene depocenters on either side of the SAF in the southwestern San Joaquin and eastern Cuyama basins,

2. The absence of any marine Middle Miocene strata on both sides of the SAF over a distance of more than 55 km with no evidence of lateral offset, and

3. Farther north, a large area of Plio-Pleistocene(?) nonmarine sediments that lie on basement, again showing no horizontal displacement.

Clare concluded that there was no indication of significant strike-slip faulting, and that any theory of large lateral offsets would have to account for the features on his map. To quote a portion of Clare's early memo on the subject: "The Caliente and Temblor ranges contain a tremendous thickness of lower and middle Miocene marine section, 12,000 feet in the Caliente Mt. area and at least 10,000 feet in the Temblor-San Emigdio area — no such deep basins holding thick sections of equivalent sediments is known anywhere along the [San Andreas] fault." With the above compelling connection in mind, one might wonder whether, in this game of vertical versus horizontal displacement, what trumps — a lithologic or basinal match-up?

These three orogenic and depositional features alone constitute impressive evidence that disputes large lateral displacement on the SAF. Of equal importance, and in response to Huffman's concerns, they also illustrate a 140-km^2 paleohigh exposing a potential basement source area straddling the fault. This, in conjunction with the removal of thousands of feet of surrounding Lower and Middle Miocene sands, is adequate to match Huffman's estimates for the volume of Upper Miocene clastics at Midway-Sunset.

Clare's convincing paleogeology suggests that there is little evidence of any large-scale lateral movement on the SAF in this area. Huffman's thesis, which has been strongly embraced and built on by almost all subsequent investigators as the model for the Midway-Sunset depositional system, is primarily predicated on the close correlation between source and clastics composition. But a close review of the literature reveals several omissions and discrepancies that call his concept into question:

1. Basalt boulders in the Temblors are not present in the Gabilans (Simonson and Krueger, 1942), but occur in the Caliente range to the west of the Temblors.

2. Sedimentary clasts in Temblor conglomerates have no counterpart in the Gabilan Range (Barbat and Weymouth, 1931), but thousands of feet of eroded middle and lower Miocene rocks offer a huge source of clasts for the basin.

3. Metavolcanics and dark andalusite hornfels are present in the Temblors, but not in the Gabilan Range (Ross, 1980).

4. Clasts of dark granodiorite and tonalite, widespread in the north, are absent in the south (Ross, 1980). In a closing statement regarding the above, Ross said:

"Even discounting the andalucite-bearing and metavolcanic lithologies, the overall appearance of the metamorphic clasts makes a poor match with the presently exposed metamorphic terrain in the Gabilan Range."

The poster cross section was modified from a section by Simonson and Kruger (1942) on the Crocker Flat Landslide. The original section (Figure 9, Top) showed a pronounced Upper Miocene westerly uplift (probably associated with more folding and faulting than indicated), erosion, and a later transgression by the Santa Margarita over upturned middle and lower Miocene beds — all of this occurring in concert with the onset of the deposition of the Antelope and Santa Margarita sands of the Midway-Sunset oil field.

Figure 9, Middle, modified from Simonson and Kruger (1942), is based on the supportable assumption that the late Miocene uplift occurred on both sides of the SAF. And with the local absence of Eocene or Cretaceous deposits, the westerly advance of erosion would eventually expose a core of basement before it was finally overridden by the transgressing Santa Margarita. In short, sufficient uplift and erosion would inevitably expose

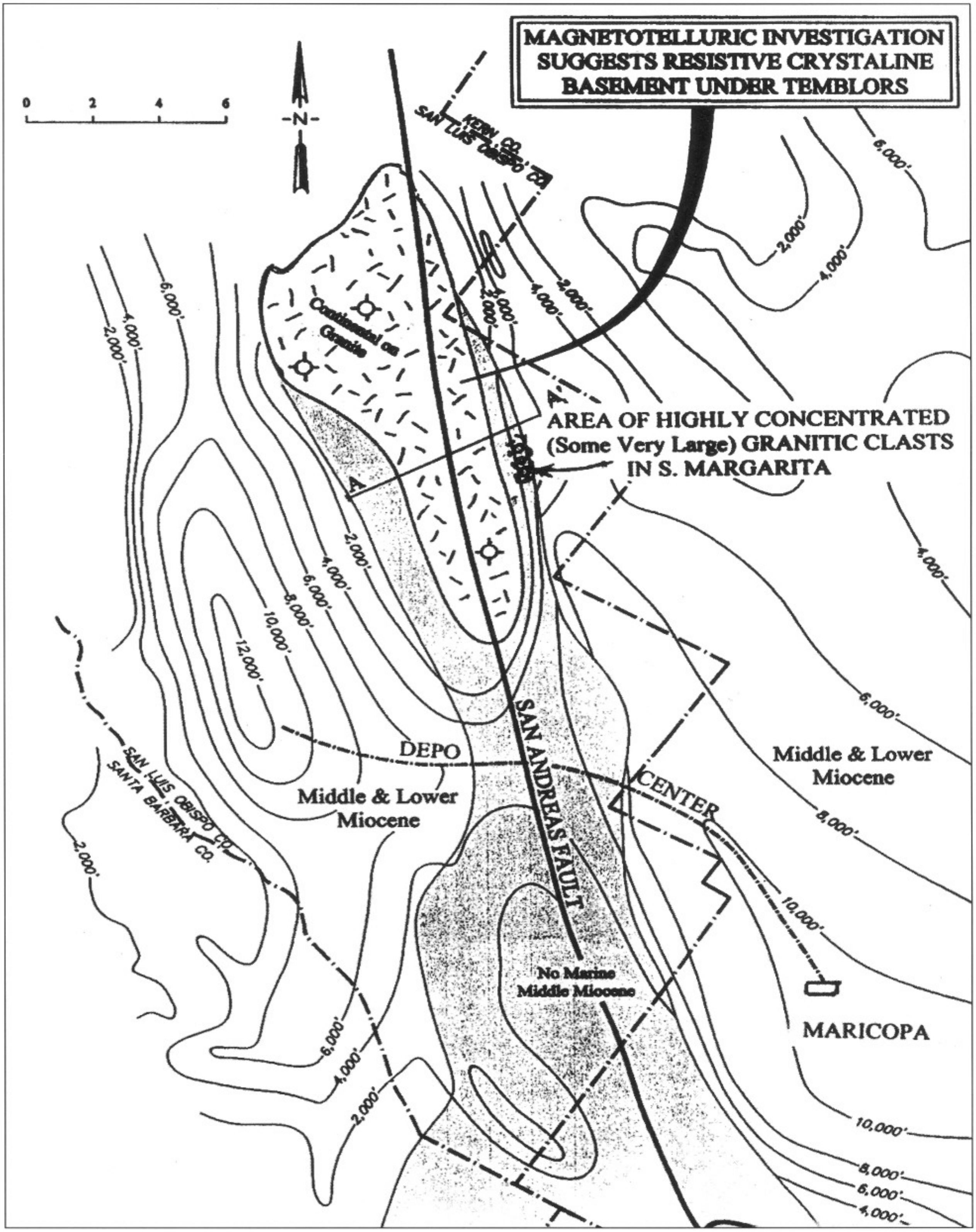


Figure 8. Isopach map of marine Middle and Lower Miocene strata showing several significant features that raise doubts about any lateral displacement on the San Andreas fault: 1) The thickest accumulations of Middle and Lower Miocene strata in California occur in areas adjacent to each other across the fault, 2) An extensive area without Middle and Lower Miocene straddles the fault, and 3) A large area of granite overlain by Plio-Pleistocene(?) nonmarine sediments also straddles the fault; it is significant that this basement, probably exposed in late Miocene, borders the vicinity of the huge blocks of granite found in the Santa Margarita of the Temblors. (Map by Jack Clare)

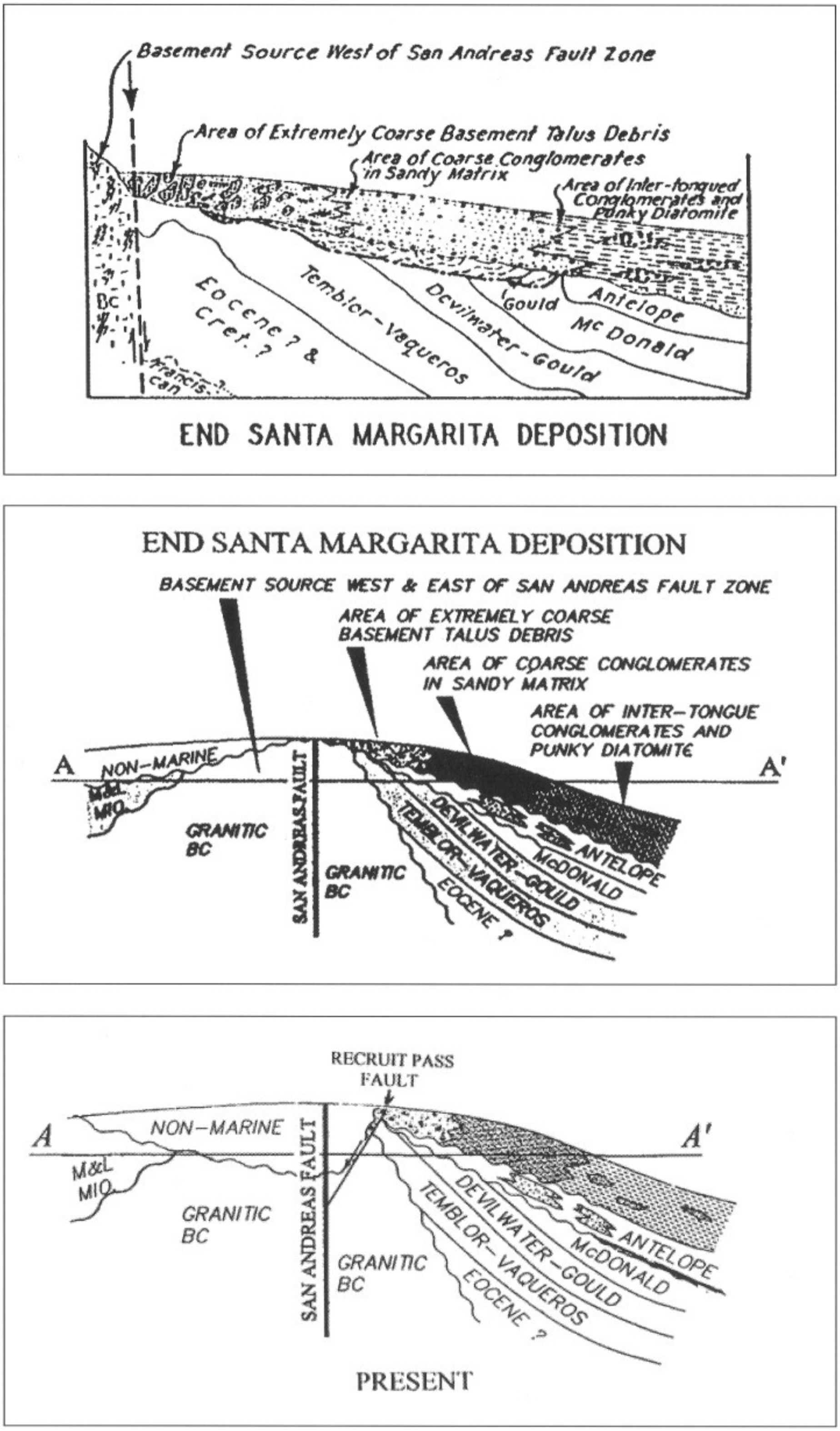


Figure 9. Cross sections showing geology in the Temblor Range near the San Andreas fault. Top section shows Late Miocene (Antelope) uplift and Middle and Early Miocene erosion in the Temblors (from Simonson and Krueger, 1942). Middle section assumes little or no Eocene and no Cretaceous, and is a simple explanation for the source of the huge blocks of granite in the Santa Margarita of the Temblors, two miles east of the fault (modified from Simonson and Krueger, 1942). Lower section shows present geology, with the Recruit Pass fault as the easterly limit of the nonmarine Plio-Pleistocene(?) basin that now covers the granitic area that was exposed in the Late Miocene (modified from Simonson and Krueger, 1942).

granitic basement, and thus most easily explain the enormous granitic clasts associated with the Santa Margarita Formation in the western Temblor Range. It is interesting to note that the greatest concentration of these impressive "outcrops," as they were called by some of the original investigators, is clustered quite near the east margin and midpoint of Clare's exposed "granitic" area.

The interpretation of *in situ* granite under the Temblor Range, and immediately across the SAF also, as shown on both the map and the cross sections, is supported by several lines of evidence:

1. The concentration of granitic clastics, including blocks (or outcrops?) of granite over 300-ft long, implies that basement is either exposed or very near. It is highly unlikely that such huge blocks could have moved very far from their source.

2. Three wells — the Gulf Oil Corporation's Vishnu No.1 well (Sec.3, T.32S, R.21E), the McCarthy O.& G. well (Sec.3, T.31S, R.20E), and the Arco Blakey well (Sec.20, T.31S, R.20E) — all drilled from continental Plio-Pleistocene sediments into granitic basement. The Gulf well, located over 3,000 ft east of the SAF, penetrated 500 ft of granite at a depth of 6,400 ft. (This well was overlooked in the otherwise comprehensive 1989 USGS report on the southern Temblor Range by Ryder and Thomson).

3. A geophysical survey made in the mid-1990s suggested granitic basement under the Temblors (Mackie and others, 1996). They said:

> "High quality wide-band magnetotelluric data collected along two profiles crossing the San Andreas fault at Carrizo Plain suggests that resistive crystalline rock may be present here as apposed to the more conductive Franciscan assemblage, contradicting the generally accepted geologic model."

Two different lines of evidence converge then that negate any need for a large-scale lateral fault offset, and therefore the Gabilan connection. First, the Clare paleogeographic map is clear in depicting a convincing picture that requires little or no rifting in the area throughout the Miocene. Second, a combination of all the above-listed evidence supports emergence along and straddling the SAF in late Miocene time, thereby effectively removing the entire middle and lower Miocene mostly sand section, and exposing a large core area of basement rocks. This uplift and the associated erosion and exposure of basement coincided perfectly with the onset of upper Antelope and Santa Margarita sand deposition in the basin. Without resorting to a now-distant source (coincidentally passing by the Temblors as they were uplifted), this scenario fits with Ross's source/clasts discrepancies that also pose serious problems with the Gabilan Range connection.

In addition to the curious coincidence if uplift occurring in the Temblor Range on the east just as the northerly moving Gabilan Range was offsetting the Temblors on the west, the implied simultaneous forces — uplift and lateral shortening to the east and large-scale horizontal displacement to the west — appear to be in serious conflict. In other words, one has to accept the concept of an ongoing horizontal stress of continental magnitude moving the entire southern coastal belt (plate) of California as occurring coincidentally with the vertical uplifting and compressive forces east of the SAF.

It should be pointed out that the uplift and associated basinal deposition were not restricted to the area just west of the Midway-Sunset oil field. Late Miocene (Antelope) uplift occurred simultaneously throughout the southwesterly crescent of the San Joaquin basin, including the east-west-trending San Emigdio Mountains as well as the northwesterly trending Temblors. No horizontal forces were associated with, or required, to account for this emergence. Unity of uplift throughout this arc is implied in that all of the Antelope sand deposits in this part of the basin — starting with the Rio Viejo on the east and continuing west and northwest through the entire Midway-Sunset oil field — were derived at least in part from this semicircle of emergent highlands. Distant sources across the SAF were not required (Figure 10).

Two major issues first led to a search for a distant source terrain for Temblor area sands. One is the absence of an obvious basement source directly across the SAF. The other is that the prevailing Hill-Dibblee hypothesis of large lateral offset made the distant and convenient Gabilan-Temblor connection both logical and appealing.

The case for a local source for the medley of upper Miocene sands at Midway-Sunset oil field has now been given, but the same cannot be said for the absence of local and obvious granitic basement. The Recruit Pass fault, which parallels the SAF about a mile to the east, has a reported history of up-and-down displacements.

(It is interesting that, despite its close proximity to the SAF and the fact that some consider it to be part of the SAF system, no evidence of lateral movement has been reported for this fault.) The most recent displacement on this west-dipping fault has been normal. It defines the easterly margin of the Plio-Pleistocene basin that now straddles the SAF and occupies the Carrizo Plain. These sediments cover, except for a few clues, the elusive granitic basement — basement that "wasn't there" according to prevailing offset thinking, and whose apparent absence justified more distant search to the north (Figure 9, Lower).

Source of Huge Granitic Blocks in Temblors

Huffman's (1972) Gabilan Temblors scenario depends not only on a good correlation between source and deposit, but equally importantly on a "highly elevated" (his words) source from which giant basement blocks were transported for at least 3 km. This necessitates a high scarp bordering the SAF, a requirement that is not supported by the current geologic evidence in the Gabilan Range. Huffman's proposal includes the northern two-thirds of the Gabilan Range, which is directly in contact with the SAF with little volcanics or sediments present as his high source terrain. He thus excluded the area of the Pinnacles volcanics and upper Miocene Bickmore arkose, located on the Gabilans' southeast flank, from consideration of source rocks. In contrast, Fletcher (1962) included the volcanics in his source area.

Nothing about the structural-depositional nature of the Bickmore sediments indicates a steep depositional

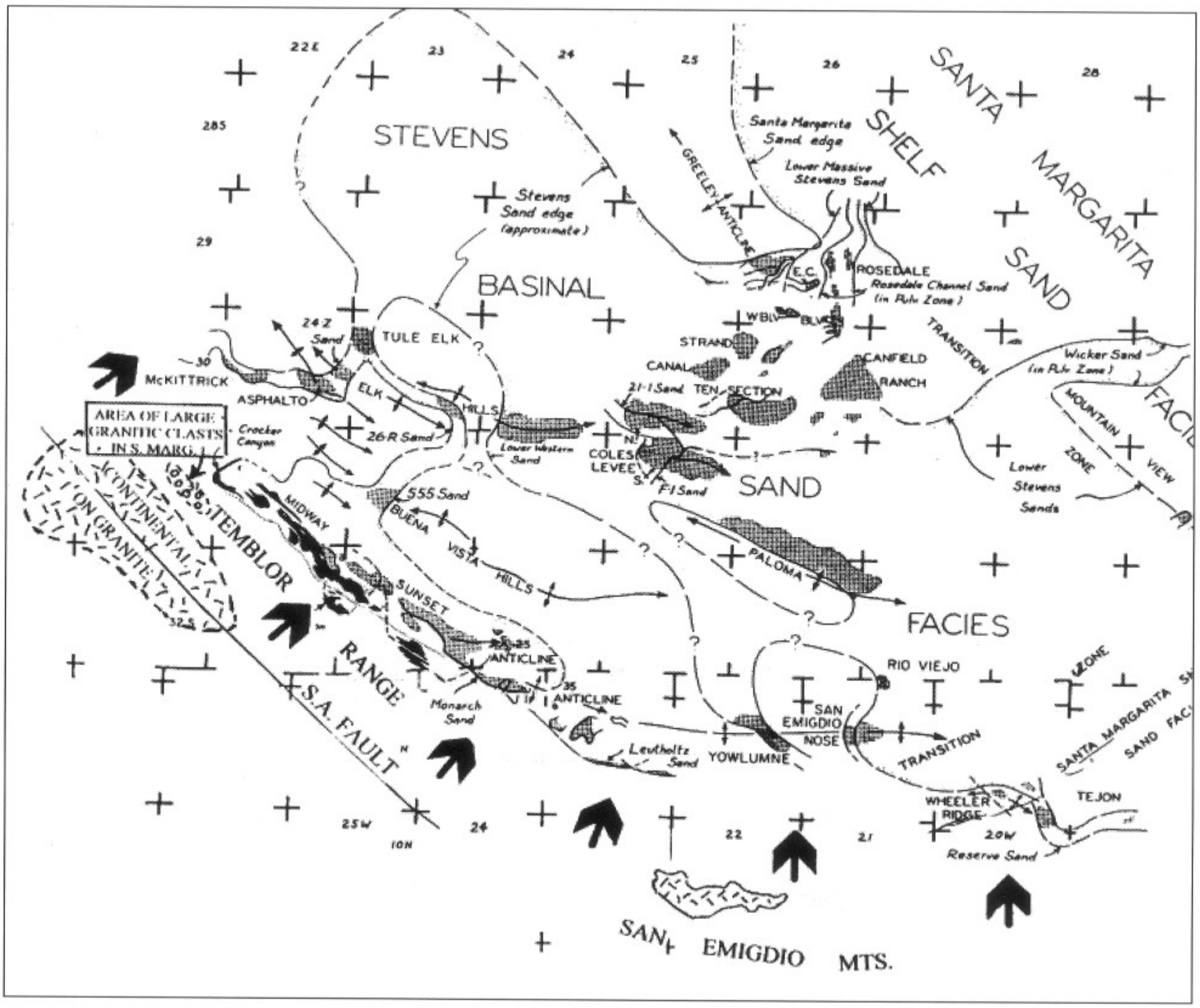


Figure 10. Paleogeographic map showing regional Late Miocene (Antelope) uplift in the southern San Joaquin basin, through the Temblor-San Emigdio Arc and the associated Midway-Sunset–Yowlumne–San Emigdio Antelope horizon oil fields. Note close relationship of the granitic area exposed in the Late Miocene and the area of highly concentrated and large granitic clasts in the Santa Margarita.

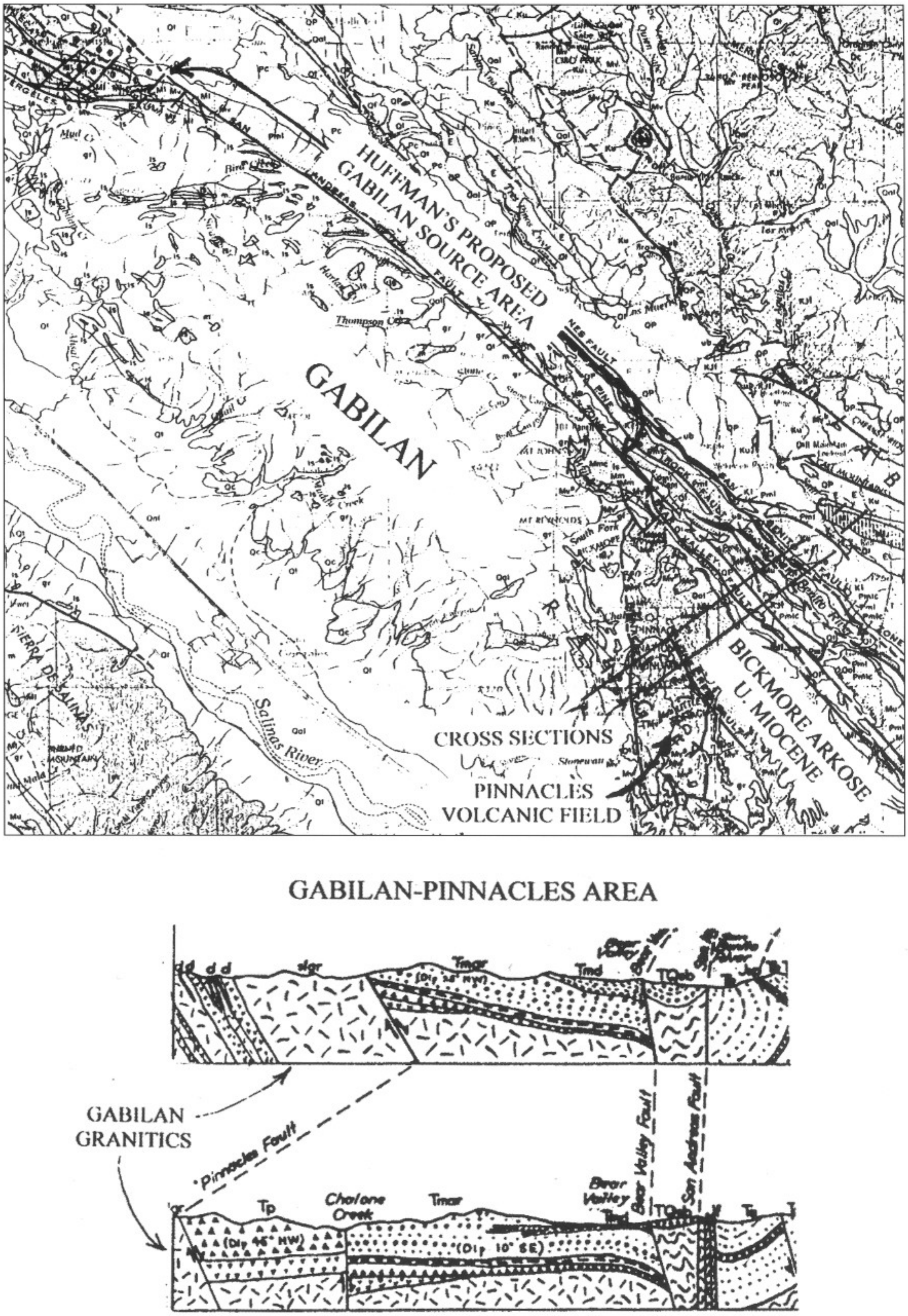


Figure 11. Map and cross sections showing Huffman's proposed Gabilan source area for the Upper Miocene Midway-Sunset sands. Immediately to the south Upper Miocene sands and shales of the Bickmore arkose (see sections), indicate a rather shallow, shelf area of deposition, not the "highly elevated" scarp that Huffman advocated to slide the giant masses of granite at least two miles to the east. (From Wilson, 1943)

gradient, or that the relief of the Gabilan (at least the southern flank) was very pronounced in latest Miocene time (see cross sections, Figure 11).

Fletcher's employment of the Pinnacles volcanics and Bickmore conglomerate as his sources for many of the clasts in the Temblors Range raises some concerns. Although the Bickmore is arkosic and has boulders up to 12 ft in diameter near the source, the formation becomes finer grained and grades into a marine and shaley facies as it approached the SAF to the east. This is not consistent with the huge and sudden increase of clast size in the conglomeratic Santa Margarita Formation allegedly just across the SAF and an easterly, basinward continuation of the Pinnacles-Bickmore rocks. This inconsistency presumably bothered Huffman, who proposed similar volcanic outcrops located 80 km to the south as his source (see Neenach discussion; this volume, pages 71-72).

Figure 12: Eocene

To conclude comments on the poster presented at the AAPG's 2003 Pacific Section meeting in Long Beach: Based on documented outcrop, age, and lithologic evidence, the Lower Eocene pre-Domengine stage is most relevant to the history of the SAF. In brief, the seaway for the Lower Eocene sands demonstrably ran from the La Honda basin southeast across the SAF, through the present site of the Vallecitos, and into the San Joaquin basin. This interpretation of Lower Eocene paleogeography does not require any post-Early Eocene displacement (Walrond, 2007a; this volume, page 52).

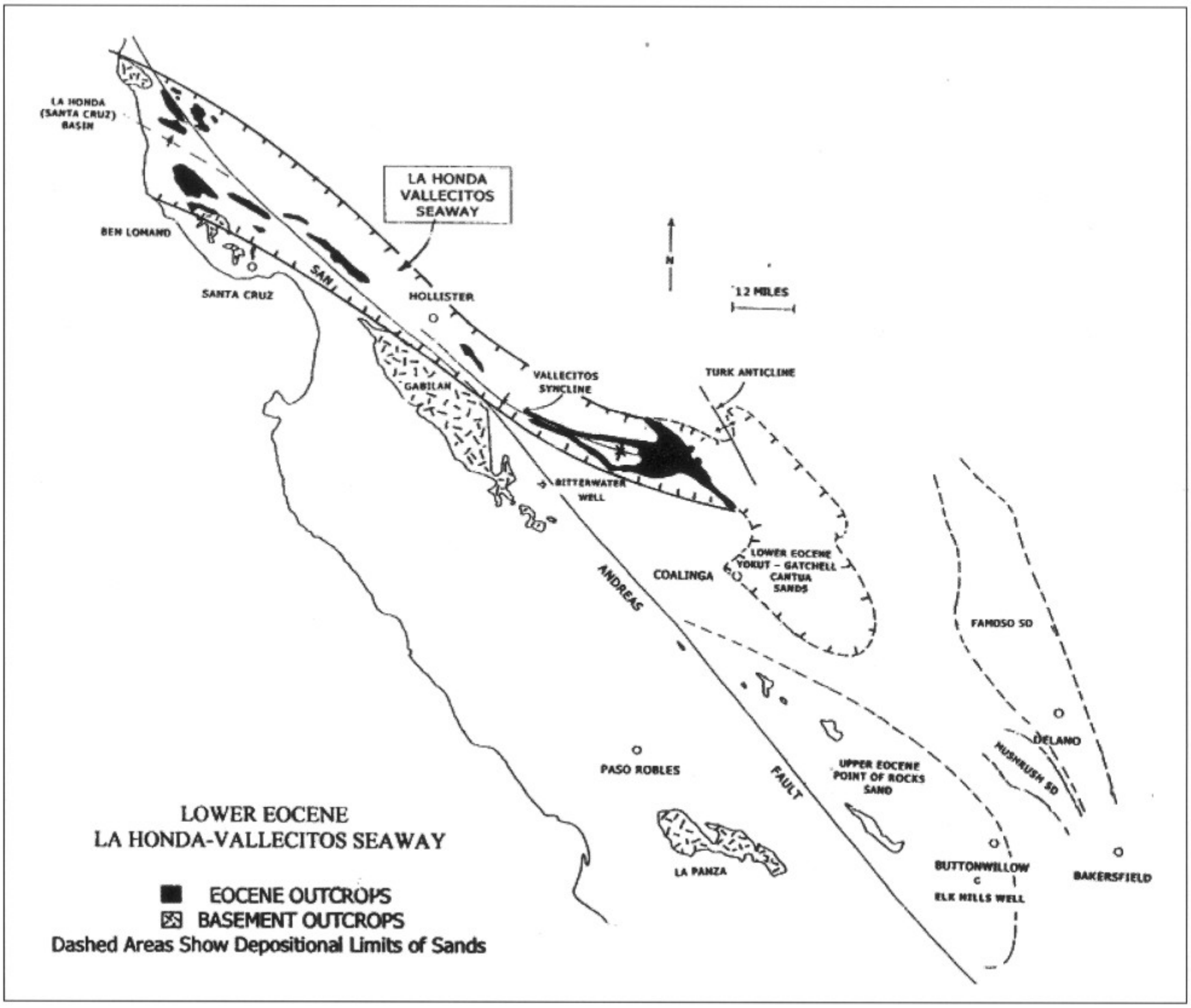


Figure 12. Map showing an unfaulted La Honda-Vallecitos seaway, interpreted by following the trend of outcrops of similar age and lithology that extend gracefully from the La Honda basin, across and down the east side of the San Andreas fault, and into the San Joaquin basin. (From Walrond, 2007a)

The Paso Robles-Cholame Quadrangle Matter

In their 1991 study of the Cholame Quadrangle, Sims and Hamilton commented on certain issues that bear on the displacement of the SAF. They said about the Paso Robles Formation, which lies on both sides of the SAF:

> "Pliocene and Pleistocene (?) rocks northeast of the S.A. fault, consisting of conglomerate and arkosic sandstone, are lithologically similar to the Paso Robles formation southwest of the S.A. fault. Dibblee (1974) included these rocks in the Paso Robles. We do not correlate these rocks with the Paso Robles even though they are lithologically similar. The primary reason for considering them as a separate unit is that since the beginning of Pleistocene time, which is the upper age limit of the two units, the S.A. fault has accumulated about 60 km of slip. This amount of slip is enough to juxtapose stratigraphic units that accumulated in separate basins."

This statement is a good example of preconception prevailing over areal geology, or, it might be said, starting with a conclusion and making the data confirm it. Furthermore, their report describes Paso Robles deposits east of the SAF and opposite the Cholame Creek entrance to the Cholame Valley, and that those deposits contain clastics derived from the La Panza range. These deposits lie 32 km north of the La Panza source, and counter to the direction of the proposed SAF offset. This is a good distance as it stands; but if one adds the "required" 37 additional miles of offset, it suggests that these La Panza clastics traveled a 91-km northerly journey before crossing the fault in Paso Robles time — not a convincing relationship to support large right-lateral offset (Figure 13).

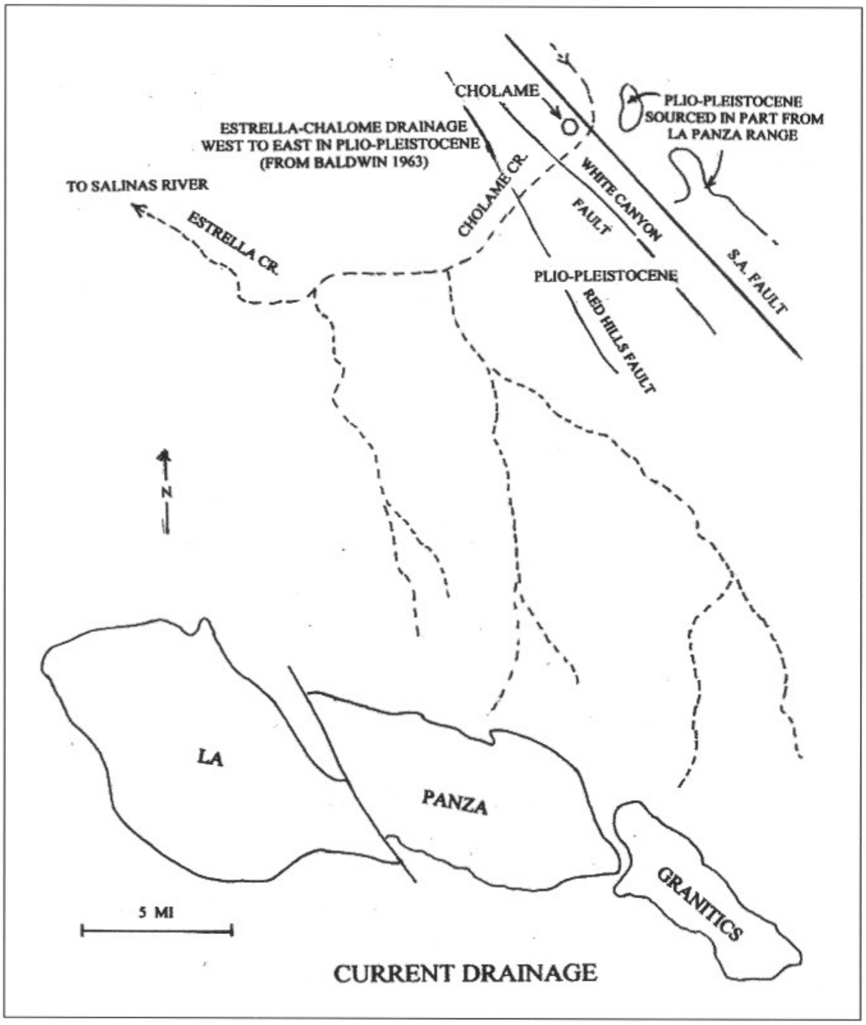


Figure 13. Map of the La Panza basement and a portion of the Estrella-Cholame drainage showing the relationship of the La Panza-derived sands and conglomerates mapped across the San Andreas fault to their source. If the 37 miles of offset required by proponents of large slip is added (or reconstructed), it implies that these clastics traveled approximately 97 miles in Plio-Pleistocene time in order to cross the fault.

Sims and Hamilton (1991) said that the three faults located southwest of and within 10 km of the SAF (White Canyon, Red Hills, and Gillis Canyon faults) "have large components of strike slip movement." They specifically proposed that the White Canyon fault "account[s] for a large fraction of the 6mm/year deficit seen on the San Andreas Fault." In spite of these positive statements, the authors later said that there is no evidence that the White Canyon fault cuts, and therefore displaces, terrace deposits at Cholame Creek (i.e., no evidence of offset). This is not surprising because, as noted earlier, the Cholame Creek follows the course of the ancient easterly flowing Salinas river (Baldwin, 1963), which has not been significantly offset by either the White Canyon or Red Hills faults, or the SAF, in the past million or so years.

I earlier mentioned the absence of evidence for horizontal movement on the Recruit Pass fault even though, because of its proximity to the SAF, it is sometimes referred to as a branch of that fault. This also the case with the White Canyon, Red Hills, and Gillis Canyon faults, which are near and, as clearly stated in the Cholame report, part of the SAF. Of equal importance, in my opinion, is their location on the rift or moving side of the fault, which should favor associated movement.

Back to my First Geologic Endeavor

It is coincidental, but appropriate, it seems, that my final comments end with a SAF-related concept based on my first geologic project — i.e., my Master's mapping assignment located in the Santa Ynez Valley north of Santa Barbara. Remembering a generalized picture of Franciscan, Cretaceous, and Eocene paleogeology through the midpoint of California, as illustrated by Reed's (1943) cross section (Figure 14), I was struck by the similarity between the geology north of the fault and the geology in my thesis area south of the fault. In both areas, the Franciscan, Cretaceous, and Eocene strata are successively limited (by overlap or fault?) to the east, leaving Eocene sediments finally resting on basement rocks.

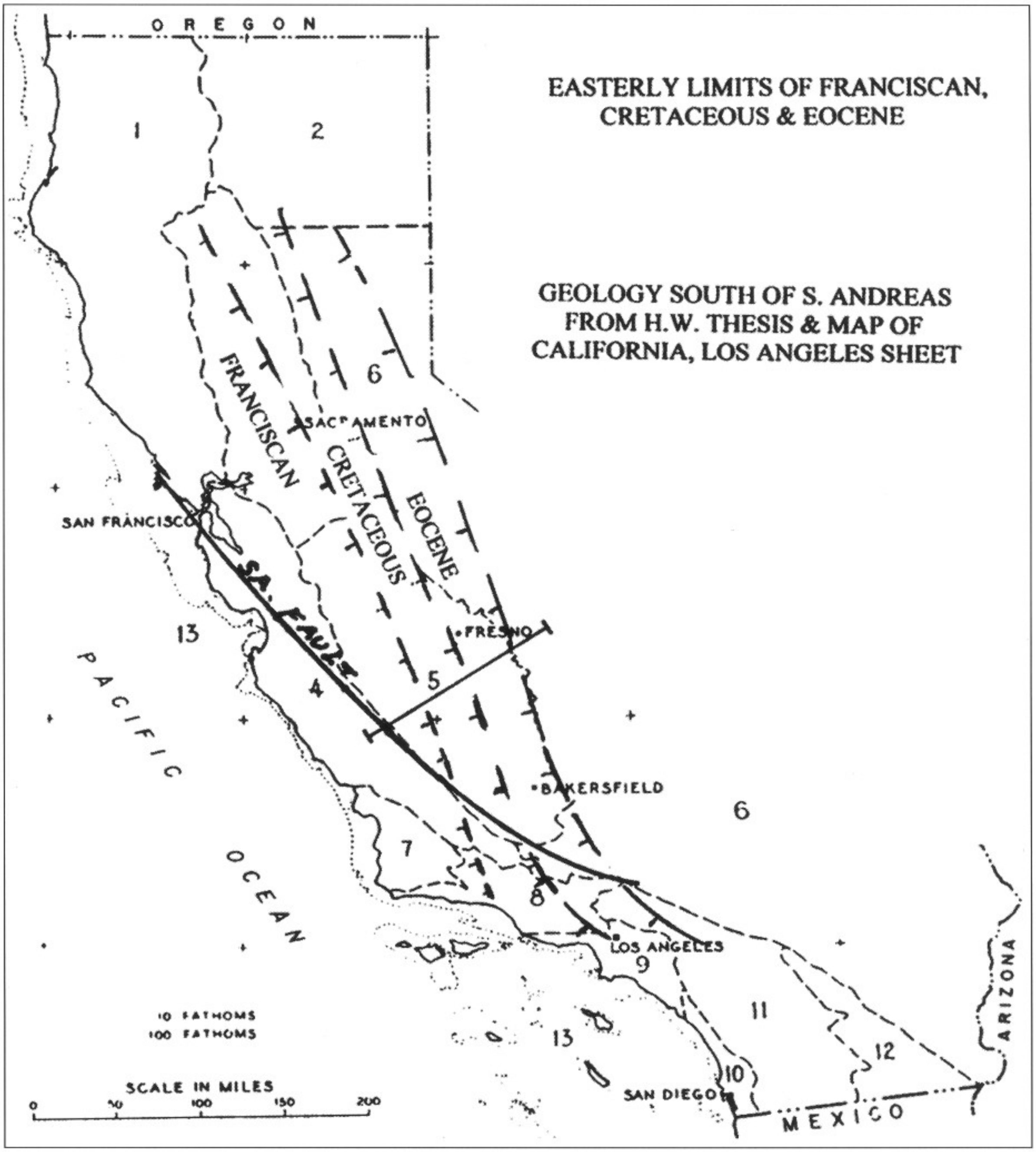
Based on Reed's (1943) cross section, a generalized map can be drawn, which shows the easterly limits of the Franciscan, Cretaceous, and Eocene extending throughout the length of the Great Valley, southerly across the SAF, and then tying with my thesis area — without apparent offset on the SAF.

Two things regarding this interpretation are worth mentioning. First, if the integrity of the large-offset concept is to be maintained, a match for Franciscan rocks south of the fault should also exist on the east side of the SAF some 300 mi to the southeast. Second, using the proposed incremental movement on the fault through time, different offsets for different ages (i.e., 288 km for the Eocene and 480 km for the Jurassic) should reflect in a larger spread between the formation limits on the southwest, or moving side, of the fault.

Admittedly, the wedge of the granitic Salinian block intervening between the SAF and the Santa Ynez block presents an ongoing geologic dilemma for SAF investigators. (Some would transport the granites from the Sierran block by way of the Garlock fault.) Is it possible that sliding this great granitic slab in from distant sources is *not* the answer, and that it simply formed *in situ* and tilted (normally, like the Sierra Nevada in Miocene time) up along the SAF, and was then locally stripped of any overlying Franciscan and Cretaceous? Regardless of the many possible interpretations or explanations for the presence of this enigmatic basement rock in the middle of the Coast Ranges, it does not change the overriding close correlation of the present limits of not just one, but three, formations — representing a time span of over 100 million years — extending southerly through most of the State of California and continuing uninterrupted across the SAF.

Conclusion

This recounting of my SAF experiences clearly expresses the basis of my skepticism regarding the need for large-scale lateral movement on the fault as advocated in the proposals that have dominated the subject over the years. A few others with similar views have preceded me, so the source and substance of what I have written is not a claim for originality or finality. Such a complicated and restless feature as the SAF almost defies finality. My only hope is that presenting this sequence of SAF-related experiences and interpretations will stimulate a more open review and debate of a subject that has all to often lacked or avoided alternate interpretations. In any event, time will be the final arbiter; and through time, hopefully, views will follow facts and not preconceptions.



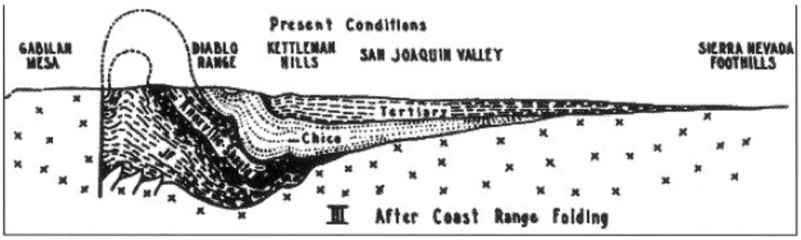


Figure 14. Map and cross section showing similar easterly limits of Franciscan, Cretacous, and Eocene rocks across (north and south of) the San Andreas fault. (Map from Walrond, 1951, with some geology south of the fault from Jennings and Strand, 1969; Cross section from Reed, 1943)

Acknowledgments

It was my very good fortune to have two of California's most experienced and qualified geologists, Otto Hackel and Robert Paschall (both with over fifty years experience, and still working), graciously offer to critique and edit my final manuscript. Paschall, in particular, spent many demanding hours working to maintain the basic integrity and personality of the original, and at the same time shape a lengthy, often repetitious and confusing report into something readable and hopefully enjoyable. They were there at a most needed time, and I thank them for that.

References Cited

Allen, J.E., 1946, Geology of the San Juan Bautista Quadrangle, California: California Division of Mines Bulletin 133, p.9-75, 112 p.

Baldwin, T.A., 1963, Landforms of the Salinas Valley, California, *in* Payne, M.B. (ed.), Guidebook to the Geology of Salinas Valley and San Andreas Fault: Pacific Sections, American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Annual Spring Field Trip, p.11-15.

Barbat, W.F., and Weymouth, A.A., 1931 Stratigraphy of the Borophagus littoralis locality, California: University of California Publications, Bulletin of the Department of Geological Sciences, v.21, n.3, p.25-36.

Crowell, J.C., 1952, Probable Large Lateral Displacement on the San Gabriel Fault, Southern California: American Association of Petroleum Geologists Bulletin, v.36, p.2026-2035.

Fletcher, G.L. 1962, The Recruit Pass Area of the Temblor Range, San Luis Obispo and Kern Counties, California, *in* Hackell, O. (ed.), Geology of Carrizo Plains and San Andreas Fault: San Joaquin Geological Society and Pacific Section, Society of Economic Paleontologists and Mineralogists Field Trip Guidebook, p.16-20.

Graham, S.A., Stanley, R.G., Bent, J.V., and Carter, J.B., 1989, Oligocene and Miocene Paleogeography of Central California and Displacement along the San Andreas Fault: Geological Society of America Bulletin, v.101, n.5, p.711-730.

Griffin, W.L., 1967, Provenance, Deposition and Deformation of the San Benito Gravels, *in* Gabilan Range and Adjacent San Andreas Fault: Pacific Sections, American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists Guidebook, p.61-73.

Hill, M.L., and Dibblee, T.W., Jr., 1953, San Andreas, Garlock, and Big Pine Faults, California, A Study of the Character, History, and Tectonic Significance of their Displacements: Geological Society of America Bulletin, v.64, n.4, p.443-458.

Huffman, O.F., 1972, Lateral Displacement of Upper Miocene Rocks and the Neogene History of Offset along the San Andreas Fault in Central California: Geological Society of America Bulletin, v.83, n.10, p.2913-2946.

Jennings, C.W., and Strand, R.D. (compilers), 1969, Geologic Map of California, Los Angeles Sheet: California Division of Mines and Geology, 1:250,000.

Mackie, R.L., Livelybrooks, D.W., Madden, T.R., and Larsen, J.C., 1996, A Magnetotelluric Investigation of the San Andreas Fault at Carrizo Plain, California: Unpublished report sent to H. Walrond. [Published in 1997 *in* Geophysical Research Letters, v.24, n.15, p.1847-1850]

Martin, B.D., and Emory, K.O., 1947, Geology of Monterey Canyon, California: American Association of Petroleum Geologists Bulletin, v.51, n.11, p.2281-2304.

Matthews, V., III, 1976, Correlation of Pinnacles and Neenach Volcanic Formations and their Bearing on San Andreas Fault Problem: American Association of Petroleum Geologists Bulletin, v.60, n.12, p.2128-2141.

Oakeshott, G.B., 1965, San Andreas Fault: Predominant Lateral or Vertical Displacement?: San Joaquin Geological Society, Selected Papers, v.3.

Paschall, R.H., 2007, The Big Bend Segment of the San Andreas Fault: A Region Dominated by Lateral Shortening rather than by Strike Slip, *in* Reflections on the San Andreas and San Gabriel Faults, Striking Contradictions to Large Lateral Offsets: Pacific Section, American Association of Petroleum Geologists Miscellaneous Publication 50 [this volume], p.1-30.

Paschall, R.H., and Off, T., 1961, Dip-slip versus Strike-slip Movement on San Gabriel Fault, Southern California: American Association of Petroleum Geologists Bulletin, v.45, n.12, p.1941-1956.

Reed, R.D. 1943, California's Record in the Geologic History of the World, *in* Geologic Formations and Economic Development of the Oil and Gas Fields of California: California Division of Mines Bulletin 118, p.94-118.

Ross, D.C., 1980, Basement Rock Clasts in the Temblor Range, San Luis Obispo and Kern Counties, California: California Geology, p.153-157.

Ryder, R.T., and Thomson, A.T., 1989, Tectonically Controlled Fan Delta and Submarine Fan Sedimentation of Late Miocene Age, Southern Temblor Range, California: U.S. Geological Survey Professional Paper 1442, 59 p.

Simonson, R.R., and Krueger, M.L., 1942, Crocker Flat Landslide Area, Temblor Range, California: American Association of Petroleum Geologists Bulletin, v.26, n.10, p.1608-1631.

Sims, J.D., and Hamilton, J.C., 1991, Geologic Map of the Cholame Quadrangle, San Luis Obispo County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF 2170.

Walrond, H., 1951, Geology of the Upper Santa Ynez Valley Area of Santa Barbara County, California: University of Southern California, Master's Thesis.

___, 2004, San Gabriel Faults–Newhall Area, Los Angeles County, California: Pacific Petroleum Geologist Newsletter: Pacific Section, American Association of Petroleum Geologists, May/June, p.8-15. [Reprinted as Walrond, 2007b]

___, 2007a, A Tale of Two Eocene Sands, *in* Reflections on the San Andreas and San Gabriel Faults, Striking Contradictions to Large Lateral Offsets: Pacific Section, American Association of Petroleum Geologists Miscellaneous Publication 50 [this volume], p.52-68.

___, 2007b, San Gabriel Faults–Newhall Area, Los Angeles County, California, *in* Reflections on the San Andreas and San Gabriel Faults, Striking Contradictions to Large Lateral Offsets: Pacific Section, American Association of Petroleum Geologists Miscellaneous Publication 50 [this volume], p.95-103.

Walrond, H., and Clare, J., 2000, The San Andreas Fault: A Revisit, Problems with Large-scale Movements (ab.): Pacific Section, American Association of Petroleum Geologists and Western Region, Society of Petroleum Engineers Joint Conference Program and Abstracts, p.A55. [Reprinted *in* American Association of Petroleum Geologists Bulletin, v.84 (2000), n.6, p.900]

Walrond, H., and Gribi, E.A., Jr., 1963, Geologic Map of Part of the Salinas Valley and San Andreas Fault, *in* Payne, M.B. (ed.), Guidebook to the Geology of Salinas Valley and San Andreas Fault: Pacific Sections, American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Annual Spring Field Trip, Part 1.

Weber, F.H., Jr., 1982, Geology and Geomorphology along the San Gabriel Fault Zone, Los Angeles and Ventura Counties, California: California Division of Mines and Geology Open File Report 82-2 LA, 157 p.

Wilson, I.F., 1943, Geology of the San Benito Quadrangle, California: California Division of Mines and Geology Report of the State Mineralogist of California 39, p.183-270.

Additional References

Clare, J., 1958, Unpublished interoffice correspondence, Superior Oil Company.

Cummings, J.C., Touring, R.M., and Brabb, E.E., 1962, Geology of the Northern Santa Cruz Mountains, California, *in* Bowen, O.E., Jr. (ed.), Geologic Guide to the Gas and Oil Fields of Northern California: California Division of Mines and Geology Bulletin 181, p.179-220.

Dibblee, T.W., Jr., 1966, Geology of the Palo Alto Quadrangle, Santa Clara and San Mateo Counties, California: California Division of Mines and Geology, Map Sheet 8, 1:62,500.

McLaughlin, R.J., Clark, J.C., Brabb, E.E., Helley, E.J., and Colon, C.J., 2001, Geologic Maps and Structure Section of the Southwestern Santa Clara Valley and Southern Santa Cruz Mountains, Santa Clara and Santa Cruz Counties, California: U.S. Geological Survey Miscellaneous Field Studies Report and Map MF-2373.

Nilsen, T.H., Dibblee, T.W., Jr., and Simoni, T.R., Jr., 1974, Stratigraphy and Sedimentation of the Cantua Sandstone Member of the Lodo Formation, Vallecitos Area, California, *in* Payne, M.B. (ed.), The Paleogene of the Panoche Creek-Cantua Creek Area, Central California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Field Trip Guidebook, p.38-68.

Regan, L.J., 1943, Origin of the Eocene Sands of the Coalinga District, California: California Institute of Technology, Ph.D. Dissertation, 73 p.