OVERVIEW OF LATE CENOZOIC FAULTING IN THE SIERRA NEVADA FOOTHILLS
(INCLUDING A REASSESSMENT OF FAULTS NEAR NEW BULLARDS BAR DAM)

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TABLE OF CONTENTS

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1.0 INTRODUCTION

It has been 50 years since the late Cenozoic fault displacement at the Tuolumne Table Mountain latite lava flow (Photo 1) near Sonora was first recognized by Erick and others (1955) and discussed by Bateman and Wahrhaftig (1966) and 30 years since the initial seismic hazard investigations along the Foothills fault system in the western Sierra Nevada pointed to potential activity (Woodward-Clyde Consultants, 1975) and the suspicion that the strong lineaments later called the Paynes Peak (Photo 2) and Swain Ravine lineaments near Marysville as well as other structures were possibly Quaternary faults (Woodward-Clyde Consultants, 1975). However it was the 1975 Oroville earthquake that made the geologic community aware of earthquake potential within the Sierra Nevada. This magnitude 5.7 earthquake was accompanied by a few inches of surface rupture (normal and right-lateral oblique slip) on the Cleveland Hill fault (Photos 3a and 3b) that extended for 8 km south of Oroville (Hart and Rapp, 1975; California Department of Water Resources, 1979, 1989; Woodward-Clyde Consultants, 1978a). The rupture occurred on a fault in the Foothills fault system, an ancient structure formed by subduction during the Mesozoic (Clark, 1960; Schweickert, 1981; Sharp, 1988). This ancient suture zone juxtaposes different metamorphic rock units and extends in the foothills of the Sierra Nevada from Oroville to Mariposa, but probably extends from the Klamath Mountains to south of Porterville Figure 1-1). The system is comprised of two separate fault zones, the Melones on the east and the Bear Mountains on the west (Figure 1-1).

The 1975 earthquake raised two questions. What was the earthquake potential of the Foothills fault system? Should the fault system be considered a seismic source from a fault several hundred kilometers long, potentially associated with a large magnitude earthquake, or is it characterized as a zone with short active faults of low to moderate magnitude earthquake? To answer these questions the US Bureau of Reclamation (USBR), California Department of Water Resources (DWR), US Army Corps of Engineers (COE) and the Pacific Gas and Electric Company (PG&E) performed extensive and detailed investigations the surface rupture and other aspects of the Orville earthquake. In particular, trenching investigations of the Cleveland Hill fault documented multiple small displacements in the late Quaternary in the colluvial stratigraphy across the fault (California Department of Water Resources, 1979, 1989; Woodward-Clyde Consultants, 1978a), as well as older displacements in the Pliocene Laguna Formation at the north end of the Swain Ravine fault that are associated with secondary, 1975 ground cracking (Woodward-Clyde Consultants, 1978a; PG&E, 1992b).

This information led to further investigations to identify other potentially active faults for critical facilities near the Foothills fault system. From the beginning the main problem became how to differentiate late Cenozoic faulting with small displacements and low activity rates (0.05 to 0.001 mm/yr) that are superimposed on the ancient shear zones and faults in the Mesozoic Foothills fault system that have had thousands of meters displacement. Complicating the analysis is the geomorphic setting in a hilly to mountainous region where erosion rates are generally moderate to high (0.01 to 0.1 mm/yr) tens to hundreds of times higher than the potential faulting rates that tend to destroy fault features quickly. The exceptions in the Foothills are where erosion rates have remained low (< 0.01 mm/yr) and fault features are preserved. These areas include relict erosion surfaces on interfluves and broad drainage divides, and preserved depositional surfaces of lava flows and volcaniclastic deposits, primarily the Mehrten and Tuscan formations.

Over 20 major investigations since 1975 (Table 1-1) helped achieve an understanding of the geology and tectonics as it pertained to evaluation of potentially active faults. These studies set the tectonic framework for the Sierra Nevada formulated a methodology for assessing low activity faults, established the regional colluvial stratigraphy in Sierra Nevada Foothills north of the Tuolumne River, and set geologic criteria for evaluating faults within the Sierra Nevada.

One convention adopted by first researchers was to name the late Cenozoic faults separately from bedrock faults in order to differentiate them from the individual Mesozoic bedrock faults and shear zones (Figure 1-2). For example, the Melones bedrock fault zone is mapped for 300 kilometers extending from Mariposa to Lake Almanor, yet the late Cenozoic Giant Gap fault, which reactivated only part of the bedrock fault, is less than 25 kilometers long (Alt and others, 1977; Berlogar, 1995).

Because the results of these investigations were published only as consultants' reports and abstracts, and this information is not easily available, this report was prepared to summarize in one document the methodology used and the significant findings. The voluminous details are left for the reader to peruse in the referenced 'gray literature', most of which are available at the government agencies that sponsored the studies, at the California Division of Safety of Dams library, Sacramento, or in the files at PG&E Geosciences Department in San Francisco. The region considered is restricted to the Sierra Nevada west of the range crest, and excludes the Sierra Nevada frontal fault system where faulting rates are much higher and the Central Valley, where Cretaceous, Tertiary and Quaternary deposits mask the evidence of Quaternary faulting.

1.1 ACKNOWLEDGEMENTS

Many geologists have participated in the major field investigations in the Sierra Nevada Foothills, some with years of effort including Jack Alt, Norma Biggar, Lloyd Cluff, Richard Ely, Douglas Hamilton, Katherine Hanson, Richard Harlan, William Lettis, Jeff McCleary, Terry Grant, Mike Perkins, Dave Schwartz, Tom Sawyer, Bert Swan, and John Wakabayashi. Many others also helped but at a lesser level, but are not named herein. More recently Tom Sawyer, Steve Thompson, John Wakabayashi helped construct the geomorphic profiles and analyze the anomalies in the PG&E files. Gary Simpson compiled the trench data. Steven Bacon prepared the graphics for the report.

2.0 TECTONIC SETTING

The Sierran tectonic block (Figure 2-1) is part of the earth's crust that forms a microplate within the broad region between the Pacific and the North American plates (Alt and others, 1977; Woodward-Clyde Consultants, 1978a). The Sierra Nevada block is undergoing right shear of about 13 mm/yr (Argus and Gorden, 1991; Thatcher and others, 1999; Dixon and others, 2000) and extension. The Sierran microplate is bounded on the east by the Sierra Nevada frontal fault system, a set of normal and right-slip faults that form the west margin of the Walker Lane, and on the west by the reverse and thrust faults and folds of Coast Range-Sierran boundary zone, that borders the western side of the Central Valley (Unruh, 1991; Wakabayashi and Sawyer, 2001. The block is also being tilted westward and in the northern and central Sierra Nevada the amount of tilt that has accumulated since the late Miocene (about 5 million years ago) when the current tectonic regime was established (Unruh, 1991; Huber, 1981) is about 70 feet/mile (13 m/km; 1 degree) (Christenson, 1966; Huber, 1981). A more complete description of the tectonic setting is found in Unruh (1991) and Wakabayashi and Sawyer (2001).

Active faulting within the block typically follows the Mesozoic faults and shear zones that are weaker parts of the crust and presumably extend through much of the crustal thickness (Schwartz and others, 1977a,b; Alt and others, 1977). This late Cenozoic faulting tends to be oblique normal-right slip on northwesterly striking faults and normal on the more northerly striking faults.

3.0 RESULTS OF PAST INVESTIGATIONS

The methodology established during the investigations in the 1970s used three approaches:

1. Extensive analysis of lineaments along the Mesozoic Foothills fault system.

2. Assessment of geomorphic/stratigraphic anomalies on Tertiary deposits that cross the Foothills fault system, such as the Stanislaus Table Mountain latite flow, and

3. Trenching possible late Cenozoic faults identified in above analyses.

3.1 LINEAMENTS

Lineament analysis uses various images of the earth to locate linear elements in the landscape that may reflect tectonic deformation. Typically the linear elements are drawn by visual inspection using air photos, space imagery, digital terrane and topographic maps, maps showing geophysical anomalies, and so forth. The first investigations in the Sierra Nevada Foothills concentrated on analysis of lineaments (Schwartz and Others, 1977a; Woodward-Clyde Consultants, 1978a) and these investigations, as well as later studies (e.g., Fea and Jorgensen, 1989; Dames and Moore, 1993), documented hundreds of lineaments in the Foothills of the Sierra Nevada (e.g., Figure 3-1). These studies showed that most lineaments resulted from differential erosion along geologic structures, typically joints, foliation, bedding, and particularly along ancient faults and shear zones. Vegetation enhances many lineaments reflecting bedrock types and groundwater barriers.

However, lineaments that clearly reflected late Cenozoic faulting were not common and very hard to differentiate from erosion lineaments as mentioned above. For example, the Cleveland Hill fault that ruptured in the 1975 Oroville earthquake has a very weak surface expression, yet the adjacent, strong Paynes Peak lineament that displaces the Pliocene Laguna Formation has little evidence of Quaternary offsets is more dramatic (Photos 2 and 3). In contrast, the Spenceville fault, which records late Quaternary displacement, northwest of Auburn, forms a strong lineament reflecting differential erosion along a western strand of the Bear Mountains fault zone, and marked by vegetation lineaments and spring lines (Photos 4, 5 and 6). The Dewitt fault north of Auburn, also a late Quaternary fault, forms a moderate erosion lineament (Photo 7).

The various studies identified significant lineaments along bedrock faults and sheared contacts, but the lineaments by themselves were not sufficient to identify late Cenozoic faults in the Foothills.

3.2 GEOMORPHIC ANOMALIES

Guided by the displacements on the Tuolumne Table Mountain Latite at Sonora (Photo 1) the investigators in the late-1970s showed that late Quaternary displacements from the Rawhide Flat faults were superimposed on the Melones bedrock fault (Woodward-Clyde Consultants, 1978a; Biggar and others, 1978). A detailed alidade survey of the top of Table Mountain latite between Knights Ferry and Columbia documented the displacement at Rawhide Flat and five additional steps and gradient changes (geomorphic anomalies) on the latite's preserved depositional surface; all occur over shear zones, basement faults and contacts in the Foothills fault system (Woodward-Clyde Consultants, 1978a). Subsequent mapping and trenching of several of the lineaments associated with the more prominent anomalies on the Table Mountain Latite proved displacements had occurred in the late Cenozoic and for the Rawhide Flat east fault, Holocene activity (Woodward-Clyde Consultants, 1978a).

Additional analysis of erosional and depositional surfaces on the Valley Springs and Mehrten formations showed displacements over basement shear zones and faults as well (Woodward-Clyde Consultants, 1978a; Dames and Moore, 1993). Analysis of the Lovejoy Basalt flows east of Oroville showed anomalies similar to those on Tuolumne Table Mountain, including Quaternary faulting on the Little Grass Valley fault (Dogwood Peak basement fault) near LaPorte (Lindgren, 1911; PG&E, 1991; Savage and others, 1991; Page and others, 1995).

Because PG&E has over 100 dams in the Sierra Nevada the profiling technique was implemented in 1992 to focus efforts to help identify potentially active faults near the dams. In particular this was done so that not every fault with a significant lineament associated with it had to be investigated to characterize its activity. Geomorphic profiles on remnants of old depositional and erosional surfaces, including lava flows, volcanic tuff, volcanic debris flow deposits, alluvial surfaces, and remnants of ancient erosion surfaces, were constructed using USGS topographic data and air photo analysis as described by Page and Sawyer (2001). Where remnants of the late Cenozoic deposits are extensive, paleogeographic reconstructions have provided evidence of the lateral extent of the late Cenozoic faults, such as at Foresthill east of Auburn (PG&E, 1994a; Page and Sawyer, 2001). Where the profiles are not approximately perpendicular to the axis of the tilting of the Sierra Nevada, then the profile needs to be adjusted (rotated about a horizontal axis) to remove the regional tectonic tilt from the profile. This removes the angular discrepancies caused by the tilting, as was done for the profile on the Eocene 'auriferous gravel' at North San Juan, between the Middle and South Fork Yuba River (Geomatrix Consultants, 2004). PG&E profiled all the interfluves with significant Cenozoic deposits between Deer Creek, north of the Feather River, to the Tuolumne River, near Merced (data in PG&E files). The profile analysis identified 134 geomorphic anomalies (steps and/or gradient changes) on late Cenozoic surfaces (Figure 1-2; Table 3-1). These were classified by a set of criteria discussed in Page and Sawyer (2001). Originally 69 were classified as late Cenozoic faults, 22 as suspected late Cenozoic faults, and 16 as geomorphic anomalies (origin uncertain). After review of the information, Jennings (1994) incorporated the significant data on the fault map of California. Since PG&E completed the initial classification ten years ago, several detailed studies on specific faults and anomalies (e.g., Hamilton and Harlan, 2002; Geomatrix, 2004) have shown that too many of the geomorphic anomalies were classified as late Cenozoic faults. In hindsight the classification should have listed them all as anomalies and given a confidence rating as to their potential to be late Cenozoic faults. Table 3-1 updates the analysis and contains the latest information available on the anomalies.

3.3 MAPPING AND TRENCHING

The anomalies identified from the lineament and/or geomorphic analyses were considered potential targets for additional investigations. Detailed geologic mapping of the bedrock relationships and overlying Tertiary and surficial deposits helped better characterize the anomaly, but extensive exposures are needed to make a confident evaluation. For example, the contact along the base of the Tertiary cap rocks, such as the Mehrten Formation, is typically difficult to map because these rocks filled old valleys and canyons and are rather irregular. Geologic mapping is critical in locating potential trench sites where sufficient Quaternary strata are preserved to characterize the feature. Trenches 8- to 20-feet deep across a potential late Cenozoic fault using the accepted techniques (McCalpin, 1996) help provide the data needed to assess timing of faulting, amounts of displacement and recurrence of faulting events.

3.3.1 Stratigraphy

Establishing the stratigraphy in the Foothills has been critical in the evaluation of faults and hence the sequence is described in some detail below. Below the terminus of Pleistocene glaciers, at about 6,000 feet elevation in the northern Sierra Nevada, surficial deposits consist of alluvium and colluvium. The sequence has been described in several localities in the foothills below about 2,000 feet elevation and correlated to the better dated sequence in the adjacent Central Valley (California Department of Water Resources, 1979; 1989; Woodward-Clyde Consultants, 1978b; Swan and Hanson, 1977; Borchardt and others, 1980a; 1980b; Harden and Marchand, 1980). Correlations of units between different localities are based on geomorphic position, superposition, pedogenic soil development, radiocarbon dates (if available), paleomagnetic measurements, and volcanic ash correlations.

The general stratigraphic sequence in the foothills consists of three general groups (Table 3-2). The first group consists of remnants of two ancient soils. The second and third groups consist of an older and a younger sequence of colluvial deposits that interfinger with and overlie associated alluvial deposits (Figure 3-2). The older sequence consists of at least three different colluvial-alluvial deposits, informally named the Auburn, Bowie Flat, and Oroville formations by Harden and Marchand (1980). These deposits have clay-rich soils, informally called "paleo-B horizons". The age of the older colluvial and alluvial deposits is estimated to be middle and early Quaternary, between 100,000 and 1 million years old. The younger sequence consists of three colluvial and alluvial units, informally named the Wyandotte, Sonora, and Keystone formations by Harden and Marchand (1980). The younger colluvial and alluvial deposits are late Quaternary in age, less than 100,000 years old as a result exhibit less soil development than the older sequence.

In the analysis of the age of the surficial deposits in the foothills it is important to recognize, as the investigators in the 1970's did, that the depositional periods were episodic. Periods of colluviation and alluviation are believed to be associated with climatic transitions from glacial to interglacial (Swan and Hanson, 1977; Harden and Marchand, 1980); the best documented example is the transition at the end of the last glacial period that produced widespread deposition of the Sonora colluvium. Glaciers began waning about 18,000 to 20,000 years ago and had essentially retreated to their present positions by 12,000 to 14,000 years ago (Richmond and Fullerton, 1986; Clark and Gillespie, 1997). Analysis of the regional climatic information for northern California summarized by Spaulding (1994) indicates that the post-glacial conditions, between about 14,000 and 8,000 years ago, were drier and warmer (xerothermic) than the present. Under this climate, extensive juniper and sage extended high on the western slope of the Sierra Nevada. Subsequent climatic conditions similar to the present (cooler and moister than the early Holocene) were established by 4,000 to 6,000 years ago in the Sierra Nevada when the modern vegetation established itself (summarized by Spaulding, 1994). The uppermost colluvium (Keystone) includes the zone of current bioturbation and soil creep and incorporates reworked older colluvium with additional materials infused after fires and other disturbances. The Keystone colluvium was deposited in the late Holocene after about 4,000 years ago when the current vegetation regime established. The upper colluvial sequence of the Keystone and Sonora deposits likely contain a major aeolian component as recorded by the silt-rich character and the grayish-brown color, which separates it from the reddish and yellowish silt derived from the saprolite and weathered bedrock, and presumably weathered aeolian silt.

Because dateable materials are not commonly found in colluvial deposits, correlations of sequences within the foothills are typically made using geomorphic and stratigraphic position and pedogenic soil development. Such correlations have proved reasonable, in spite of widely different conditions for soil development on colluvial deposits (i.e., variable parent materials, different micro climates and slope aspect, pre-weathering of rock, and reworking of earlier colluvium). The age of the sequence is estimated from correlation to the equivalent stratigraphic sequence in the northeastern San Joaquin Valley (Table 3-3) (Harden and Marchand, 1977; Marchand and Allwardt, 1981) and in the Sacramento Valley (Shlemon, 1971; Busacca, 1982).

The stratigraphic units are described below so the reader can become familiar them. For more complete, but earlier, discussions of the Quaternary units see Woodward-Clyde Consultants (1978b) and PG&E (1994a).

Ancient Soils

Pisolithic Soil - The oldest soil preserved in the Foothills is known only in a few places where relict erosional and depositional surfaces that are millions of years old remain. These soils have not been studied in detail, but are typically a dark red, silty soil with a lag of iron pisoliths. Shallow exposures found on the Forest Hill Divide about 1 mile east of Foresthill show a pisolith-rich relict soil developed on the original depositional surface of the Mehrten Formation that is believed to be at least 6 million years ago (Wagner, 1981; Wagner and Saucedo, 1990). The Mehrten volcaniclastic deposits have been extremely weathered to a deep saprolite, making the pisoliths millions of years old. Another pisolithic soil that is developed on serpentine bedrock occurs on the divide between Challenge and Clipper Mills, east of Oroville where the upland terrain is interpreted to be the degraded remnants of an ancient landscape. This landscape has Eocene “auriferous gravels” locally preserved along the surface (Turner, 1898). This upland landscape is characterized by planar to gently rounded surfaces and broad flat valleys underlain by a strongly developed, red (10R), soil with a lag deposit of small siliceous gravel and rounded iron pisoliths up to about 5 mm in diameter. The Natural Resources Conservation Service (NRCS, 1998) maps the area as Ultisols, which are also strongly developed, old soils, but the NRCS does not classify soils that are incompatible with the current climate. Iron pisoliths develop in Oxisols, soils that form in warm, humid tropical climates (Bueno and others, 2002) and are incompatible with the present more arid, Mediterranean climate of the northern Sierra

Nevada. Landscapes associated with Oxisols are old, measured in millions of years (Birkeland, 1999).

Saprolite Formation - Extreme weathering of bedrock to saprolite (thoroughly decomposed rock to silt and clay that contains preserved rock structures and fabric that were present in the unweathered rock) in the Foothills occurs in many places. For example, the Mehrten Formation is weathered to saprolite on the ridge south of Foresthill. There the Mount Hope trench (Figure 3-3a-G) exposed several colluvial units overlying the saprolite (PG&E, 1994a). Rodent burrows carved into the saprolite and lower colluvial units contained organic materials older than 45,000 years (i.e., radiocarbon 'dead'), showing that the saprolite is older than that. Regional soil-stratigraphic correlations show that the Auburn colluvium is about 550,000 years old and, although highly weathered, is not a saprolite. The saprolite is also older than the older (Bowie Flat) paleo B deposit that is older than several hundred thousand years and probably older than 790,000 years. Hence, saprolites of significant thickness, more than 5 feet, are considered older than 500,000 years, and probably are older than 1 million years.

Older Colluvial-Alluvial Sequence

Oroville, Bowie Flat and Older Colluvium (Paleo-B deposits) - Several older colluvium in the foothills are capped by an old, well-developed fossil soil (paleosol) that is a clay-rich B-horizon (B_t) that resists erosion. An excellent example is the Vizard Creek trench near La Grange (Figure 3-4a). The soil has been informally termed the "paleo-B" deposit (Swan and Hanson, 1977; Woodward-Clyde Consultants, 1978a). The paleo-B deposit generally has well-developed prismatic structure and thick, ubiquitous clay skins. In most places it occurs as a type of textural B horizon (B), called a "beta" horizon, that is the accumulation of pedogenic clay at the top of a relatively impermeable layer, such as the top of bedrock as illustrated in the Vizard Creek trench (Figure 3-4a) (Birkeland, 1999).

The paleo-B deposit has formed in colluvial deposits of at least two different ages. Although not commonly preserved, where they can be differentiated they are separated into the Oroville and Bowie Flat deposit, for example, at Bowie Flat, west of Sonora (Figure 3-3a-C) (Woodward-Clyde Consultants, 1978a). The older colluvium commonly occurs at or near the bedrock contact and can only be separated where they are in stratigraphic sequence. Typically the paleo-B consists of sandy, silty clay with resistant gravel clasts and strong prismatic structure. The clay mineralogy of the paleo-B from x-ray diffraction analysis shows that the clays consist dominantly of quartz, kaolinite, and illite/smectite (PG&E, 1994a). Typically the paleo-B deposit also is preserved as remnants in pockets and as clay-filled fractures that may extend a meter or more into bedrock, as illustrated in the Wolf Creek and Big Hill trenches (Figure 3-3a-B and –D). The paleo-B deposit correlates to one of the early or middle Pleistocene clay rich deposits of the Riverbank and Turlock Lake units in the Central Valley. The youngest paleo-B deposit was estimated to be older than 100,000 years (Swan and Hanson, 1977; Woodward-Clyde Consultants, 1978b), but it is probably older than 140,000 years because locally a "red" colluvium overlies it. Other paleo-B soils are estimated to be several hundred thousand years old or older because they are in a stratigraphic sequence. In the Vizard Creek Trench 1 (Woodward-Clyde Consultants, 1978a) the Paleo B deposit (Figure 3-4a) is associated with a strath terrace that projects between the Riverbank and Turlock Lake terraces on the nearby Tuolumne River. From these relationships the age of this paleo B is likely older than early Riverbank (~300,000) and based on heavy mineral etching in soils is equivalent to soils on the Turlock Lake Formation (Woodward-Clyde Consultants, 1978b), indicating that it formed during and shortly following Turlock Lake time, but before Riverbank time, making it at least 300,000 thousand years old. In a few places the Paleo B is paleomagnetically reversed making it older than 790,000 years (Johnson, 1982; Morrison, 1991), as shown in the Sweetland trench (Figure 3-3b-H) northeast of Grass Valley (PG&E, 1991).

"Red" Colluvium and Alluvium

A dark red colluvium and alluvium occur locally in the foothills, but were not recognized as a regional deposit by Harden and Marchand (1980). It overlies the paleo-B deposit and is overlain by the Wyandotte and younger colluvium and has soil characteristics similar to that of the late Riverbank deposit in the San Joaquin Valley.

At Baker Ranch trenches near Foresthill the "red" colluvium consists of a paleosol developed on a colluvium (PG&E, 1994a). The B-horizon of the soil is dusky red to dark reddish brown to red, silt loam to silty clay loam. It has moderate to strong, blocky to prismatic structure. Clay films on ped faces and in pores are common to distinct. Radiocarbon dates from the "red" colluvium in the Mt. Hope and Baker Ranch trenches near Foresthill indicate that the colluvium is older than 40,000 years (PG&E, 1994a). Although these dates are all from krotovina (i.e., secondary deposits) in saprolite on the Mehrten Formation, the deposit is clearly a basal part of a colluvium whose top part has been stripped and eroded prior to the deposition of the colluvium above it. The dates therefore provide a minimum age for the "red" colluvium. This colluvium also appears in the Big Hill trench (Figure 3-3a-D) near Auburn (PG&E, 1994b) and the Waters Peak South trench 6 near Valley Springs (Figure 3-3a-E) (U. S. Army Corps of Engineers, 1994).

Wyandotte Colluvium

The Wyandotte colluvium is not extensive in the Sierra Nevada Foothills. It locally overlies the paleo-B deposits, the "red" colluvium, and weathered bedrock and is overlain by the Sonora colluvium. The deposit is nearly identical with the Sonora colluvium except that it has a slightly better developed soil, primarily more clay accumulation and better-developed clay skins.

Stratigraphic data and pedogenic relationships indicate that the Wyandotte colluvium is late Pleistocene in age. The Sonora colluvium (14,000 to 8,000 years old) overlies the Wyandotte colluvium as illustrated in the Waters Peak South trench (Figure 3-3a-E) and the Big Hill trench (Figure 3-3a-D). Because the Wyandotte soil is slightly better developed than the Sonora soil, the soil on Wyandotte colluvium probably developed over a somewhat longer period of time, more than 10,000 years suggesting that the Wyandotte colluvium is older than 25,000 years. Swan and Hansen (1977) and Harden and Marchand (1980) correlate it to the late period immediately following deposition of the lower Modesto Formation in the San Joaquin Valley that is estimated to be contemporaneous with the period immediately following the end of the early Wisconsin (Tenya?) glacial epoch. By analogy with the Sonora colluvium, deposition of the Wyandotte colluvium probably occurred in the period about 65,000 to 50,000 years ago when a slight warming caused the glaciers to retreat and presumably altered the vegetation enough in the Sierra Nevada foothills to cause colluviation.

Sonora Colluvium and Alluvium

The Sonora colluvium is an extensive regional deposit in the foothills of the Sierra Nevada. It commonly underlies the surficial colluvium (Keystone) that covers most slopes in the upland areas. It consists of a heterogeneous mixture of sandy, gravely silt that is up to 1 meter thick. Clasts are angular to subangular and are commonly concentrated in the lower part of the deposit and a stone line occurs locally at the base of the deposit. Because of the gray-brown silty nature of the Sonora deposits throughout the Foothills region, it appears that they consist of, at least in part, windblown material derived from glacial outwash in the Central Valley. The colluvium has a weak soil developed on it.

Where locally preserved in the upland valleys the Sonora colluvium interfingers with and overlies the Sonora alluvium, which consist of silty gravel and gravely silty sand (Harden and Marchand, 1980; Swan and Hanson, 1977; Woodward-Clyde Consultants, 1978b). This relationship is evident in the Big Hill trench near Auburn (Figure 3-3a-D) (PG&E, 1994a) and the Waters Peak South trench 6 at Valley Springs (Figure 3-3a-E) (U. S. Army Corps of Engineers, 1994).

Harden and Marchand (1980) argued that the Sonora deposits formed 14,000 to 8,000 years ago based on several lines of evidence: the carbon-14 date of 9,130 years from the lower part of the Sonora alluvium in a test pit at the Bailey House trench locality southeast of Auburn (Swan and Hanson, 1977) and later supplemented by dates from the Dogwood Peak trench north of La Porte (Page and Sawyer, 2001) (PG&E, 1994b); the stratigraphic position of the colluvium in the foothills and the field relationship that shows the Sonora colluvium overlying late Modesto alluvium in the San Joaquin Valley; and the soil developed on the Sonora colluvium, which is similar to that on the late Modesto deposits along the eastern margin of the San Joaquin Valley. On the basis of carbon-14 dates and correlation to glacial advances around the world, the late Modesto deposits are estimated to be 20,000 to 14,000 years old (Marchand and Allwardt, 1981).

Harden and Marchand (1980) recognized the length of the climatic transition and, on the basis of radiocarbon dates on glacial outwash in the Central Valley, selected about 14,000 to 8,000 years ago as the probable age range of the Sonora colluvium. This transition has been confirmed by the detailed investigation of the sediments from a deep borehole in Clear Lake in the Coast Ranges. At Clear Lake, elevation 1,300 feet and similar to the Sierra Nevada Foothills, a rapid vegetation change from conifer forest to oak woodland associated with a change from sandy silt to clayey silt with increased organic content occurred 14,000 to 15,000 years ago (Adam, 1988a, 1988b; Gardner and others, 1988). The colluvium in different places in the foothills was probably deposited at slightly different times during this interval, reflecting local changes in the vegetation as it adjusted to changes in climate.

Keystone Colluvium

The Keystone colluvium overlies the Sonora colluvium and is the uppermost surficial deposit throughout much of the Sierra Nevada Foothills. Harden and Marchand (1980) and Swan and Hanson (1977) considered it to be include historical colluvium related to farming and mining and other local deposits less than about 1,500 years old. Although the Keystone colluvium is generally mapped as a single deposit, in more heavily forested areas several colluvial units have been deposited on top of the Sonora colluvium during the late Holocene. Judging from the large amounts of charcoal in some of the deposits, mobilization and deposition of these colluvium apparently followed major forest fires that destroyed the vegetation cover. For example, three Holocene colluvial deposits occur in the Milk Ranch Road trench near Challenge in the Yuba River drainage (Figure 3-3a-A) (PG&E, 1991; 1992b).

Analysis of the stratigraphic position of carbon-14 dates from colluvial deposits found in several trenches in the Sierra Nevada (Table 3-2) shows that much of the charcoal found in the upper colluvium in the foothills is from animal burrows, burned roots, and other intrusive material. Nonetheless, these carbon-14 dates provide minimum ages for the Keystone colluvium. Analysis of the dates from the Keystone colluvium indicates that there are at least two distinct depositional periods, one about 2,000 years ago and the other at about 4,000 years ago (PG&E, 1994b).

In many places the Keystone colluvium is superimposed on and mixed with the upper part of the Sonora colluvium, and the contact between the two is difficult to define. However, the Sonora colluvium commonly has more rock clasts, and the Keystone colluvium is finer grained. In the cases where the Keystone colluvium and the upper part of the Sonora colluvium have blended, the base of the colluvium is considered to be Sonora in age, with deposition starting between about 10,000 and 14,000 years ago. In many places it appears that the Keystone colluvium has completely remobilized the Sonora colluvium with few remnants of the Sonora remaining in pockets on bedrock.

Correlations
Stratigraphic correlations for selected trenches in the Foothills are shown in Table 3-3.

3.4 CHARACTERISTICS OF QUATERNARY FAULTING

The criteria used to characterize the late Quaternary faulting in the Sierra Nevada were developed during investigations of surface faulting on the Cleveland Hill and other faults after the 1975 Oroville earthquake (Schwartz and others, 1977a; Woodward-Clyde Consultants, 1978a,b; Page and others, 1978) that are updated and presented in Table 3-4. Since recent activity of faults in the Sierra Nevada is generally difficult to recognize, Page and others (1978) recommend the use of multiple criteria for evaluating late Cenozoic faulting in the Sierra Nevada. Except for clear evidence of faulting in Quaternary deposits, no one criteria is relied upon, but commonly several are used to make a judgment on recent activity of an individual fault. The use of colluvium in evaluating faults is discussed first, followed by examples of different fault features.

3.4.1 Use of Colluvium to Evaluate Faults
Because colluvial deposits, which are ubiquitous in the foothills of the Sierra Nevada, are generally the only deposits available to assess the activity of a fault, they are discussed below to provide information about their use and limitations in evaluating faults.

Origin of Colluvium

Colluvium is a deposit that has accumulated on a slope and consists of weathered rock, organic matter, materials transported from upslope, and a component of aeolian dust. The main processes active in the formation of colluvium include weathering, soil creep, biologic mixing, rain splash, and overland transport by running water (Selby, 1993). These processes only affect the active layer, which in the Sierra Nevada Foothills commonly only affects the upper 20 to 50 centimeters and in places up to one meter.

Colluvial deposits can be separated into the active, near surface layer and the deeper stable layers below the active layer. The active layer is found from near the crest of the hill to the bottom of the slope, but most of the erosion occurs on the higher and mid parts of the slope. The active layer, particularly on moderate and steep slopes, is subject to slow downhill creep that affects the underlying weathered bedrock, which can also be deformed so that bedrock layering, compositional zones, or other structures are bent down slope. The "curved" line of quartz pebbles in the School House Creek trench near New Bullards Bar Dam (PG&E, 1991) is a good example. Clasts from individual layers also can be strung out at the base of a colluvium as stone lines that are planar and laterally aligned around bedrock outcrops and not arched over them. This relationship suggests that creep in bedrock is mostly active during the periods when surficial deposits have been mostly stripped from the landscape and during wetter periods when the upper part of the weathered rock becomes saturated. Most stonelines appear to be lag deposits that formed on eroding slopes that are only covered with shallow colluvium. .

The reach at the base of the slope is commonly a zone of accumulation unless it is flushed out by stream erosion. Colluvium builds up slowly over a period of time by the addition of organic detritus, aeolian silt, and fine materials moved down slope by sheet wash accreting materials to the surface similar to a cumulic soil. For example, even though colluvial deposits have little to no textural stratification, small carbon fragments in colluvial deposits in the Coast Ranges of northern California show that the lower part of a colluvium was formed thousands of years before the upper part (Reneau and others, 1989; 1990). Although this has not been documented for the colluvial units in the Sierra Nevada foothills, the evidence strongly indicates that this is the case .

Buried colluvium is preserved with little modification by surficial processes. The colluvium commonly is superimposed, with the buried ones clearly distinguished from each other by texture and soil development that indicates stability after the colluvium was deposited. General lack of disturbance below the active colluvium is demonstrated by the undisturbed, buried colluvial deposits such as those preserved at the Sweetland trench (Figure 3-3b-H) near North San Juan, north of Grass Valley (PG&E, 1991). However, vertical mixing of materials from the surface colluvium into older colluvium occurs locally by infillings of voids left by decayed and burned roots and holes made by burrowing animals (krotovina). Such mixing creates irregular contacts along foliation, bedding, joints, and faults. This relationship is well illustrated by the colluvium in the Mt. Hope trench 1 near Georgetown in the Middle Fork American River drainage (Figure 2-3b-G).

The deep pockets and "fissure fills" of colluvium along irregular bedrock contacts are generally old krotovina or infillings along rotted roots. If the landscape is stable and the colluvium is not eroded or creeping, the colluvium becomes a patchwork of krotovina, some of which can be several tens of thousands of years old, as at the Mt. Hope trench near Georgetown (Figure 3-3b-G).

Colluvial deposits are eroded from slopes when factors controlling their stability change. Rapid erosion of the surface can occur under intense rainfall, particularly when the vegetative cover is reduced or changed, such as during variations in climate. They are particularly susceptible to erosion following wildfire that destroys the vegetation cover (Florsheim and others, 1991). In some places during intense storms, colluvial deposits are mobilized into soil slides and debris flows and may be completely removed from the slope (Reneau and others, 1990).

Preservation of Fault Features

As discussed above, the lower part of active colluvium is more stable than the upper part, because it is much less affected by the surficial processes that continually disturb the upper 20 to 50 centimeters of the deposit. Hence, the lower part of the active layer and the underlying, deposits where it directly overlies a fault or shear, would generally record and preserve evidence of faulting, even though such features would be modified and eventually destroyed by bioturbation and soil creep in the upper part.

The analysis of potential fault features in a colluvium must be made with caution because alternative mechanisms may produce features similar to faulting (Page and others, 1978). For example, slickensided surfaces are also produced by shrink-swell, the contraction of clay in the dry season followed by swelling and compression in the wet season, and called stress cutans (U.S. Department of Agriculture, 1975). In other places, where the slopes are moderate to steep, clay fault gouge may creep downhill and appear to overlie a younger colluvium.

Unlike alluvial deposits, which generally remain stable after deposition, active colluvium generally moves downslope and hillslope soils may continually undergo renewal through erosion, deposition, and downslope movement. The preservation of fault features in colluvium depends on the stability of the colluvium. For example, the active part of a colluvium may be capable of preserving evidence of faulting for tens of years before bioturbation and downslope movement erase shear fabric and offsets. The less active basal part of the colluvium may preserve evidence of faulting for a few hundred to a few thousand years. A stable colluvium, such as one that has been buried, would preserve faulting for tens of thousands of years or as long as it remained below the active slope layer. However, if saturated the colluvium will tend to move down slope and modify fault features.

3.4.2 Results of Trenching

Since the Oroville earthquake in 1975, over 150 trenches have been excavated across 59 potential targets (Figure 1-2; Table 3-4). Of these 29 were identified by geomorphic anomalies and 30 from analyses of lineaments. The trenching confirmed that 8, or possibly 9, faults had displacements in the latest Pleistocene or Holocene: Little Grass Valley, Cleveland Hill, Spenceville, Dewitt, Giant Gap, Ione (possible), Negro Jack Point, Poorman Gulch, and Rawhide Flat East.

Examples that illustrate the subtleties of interpretation of Quaternary faulting in the colluvial deposits are discussed below. These include from north to south the Cleveland Hill, Swain Ravine, Spenceville, Dewitt, Deadman, Rescue, Baker Ranch, Negro Jack Point, and Rawhide Flat East.

Cleveland Hill fault

The Cleveland Hill fault had surface displacement from the 1975 Oroville earthquake (Photo 3b) (Hart and Rapp, 1975; Rapp and others, 1975; Clark and others, 1976). It was trenched in a number of places to characterize the fault and to use as a calibration for active fault features elsewhere in the Foothills fault system. Two trenches, Grubbs trench 2 and Lorraine trench 1 (Woodward-Clyde Consultants, 1978a) illustrate the type of fault features encountered. The important implication is that these trenches record several Quaternary events in the surficial deposits. All have small displacements, similar to the 1975 event.

Grubbs Trench 2 (Figures 1-2 and 3-4c) exposes metavolcanic and sheared metavolcanic bedrock. Gouge zones of faults #2 and #3 contain a slickensided surface that extends through the paleo-B deposit. At fault #2 open cracks from the 1975 earthquake cut through the Sonora, Keystone and paleo B deposits and extend to the slickensided surface in the fault gouge along the slickensided surface. A small step in bedrock occurs at the fault. The wedge of the paleo-B deposit preserved on hanging wall at fault #2 and the wide paleo-B deposit that merges into fault gouge in a 'tornado shape' at fault #3 are evidence of an older event. The colluvial wedge of Wyandotte (?) colluvium preserved on hanging wall at fault #3 is interpreted to record another older event.

Loraine Trench 2 (Figures 1-2 and 3-4c) exposes greenstone and metadiorite bedrock. Fault gouge zones have a slickensided surface that extends through the paleo B. Similar to the Grubbs trench, open cracks extend through the Keystone colluvium and to the slickensided surface at the top of the paleo-B deposit. Older events are recorded by the small colluvial wedge of Wyandotte colluvium and the wedge of paleo-B preserved on hanging wall. The wide Paleo-B deposit merges into fault gouge in a 'tornado shape'. Slope creep at the base of the Keystone colluvium is evident west of the fault in the 'rollover' of paleo B at base of colluvium, presumably at a time when the deposit was saturated.

Swain Ravine fault

The Swain Ravine fault was investigated in several trenches where ground cracks were found from the 1975 Oroville earthquake (Schwartz and others, 1977a). These cracks are developed over the north end of the Swain Ravine fault (Photo 3a) that displaces the Pliocene Laguna Formation (Figure 3-5).

The results from Orange Road trenches 2 and 4 (Schwartz and others, 1977a) are discussed below. In Trench 2 (Figures 1-2 and 3-4d) the clay fault gouge with slickensided surfaces in metavolcanic bedrock is similar to that found in the trenches across the Cleveland Hill fault. Evidence of pre-1975 faulting is interpreted in the thickening of the Keystone/Sonora colluvium on hanging wall and the wedge of older colluvium and presumed older (Bowie Flat) paleo-B deposit preserved on hanging wall. The slickensided surface in fault gouge extends through paleo B and merges into the 1975 ground crack in the Keystone colluvium.

The Orange Road trench 4 (Figure 3-4d) records faulting in the sandstone and claystone conglomerate of the Laguna Formation. Fault features in this trench include slickensided surfaces and shearing in Laguna Formation (station 76 to 80). The clay fault gouge has intruded into the Laguna Formation along the fault. The paleo-B deposit does not appear faulted, and it is presumed to be the younger paleo B because the paleo-B in trench 3 is faulted. Soil creep has placed the paleo B over colluvium east of the fault at station 52.

Spenceville fault

The Spenceville fault was exposed in several trenches (Photos 5 and 6) (Schwartz and others, 1977a), three of which, Spenceville trenches 1a, 3 and 4, are presented below. Bedrock is sheared and fractured Jurassic metavolcanic rock. In Spenceville Trench 1a (Figure 3-4g) the fault features include a slickensided surface in the fault gouge that extends through paleo-B deposit into the Keystone/Sonora colluvium, and projects upslope, counter to potential soil creep (Figure 3-7g). The paleo B deposit (probably younger paleo B) merges into fault gouge in a 'tornado shape' but does not appear offset across fault, suggesting that the fault is a strike-slip fault.

In Spenceville trench 3 (Figures 1-2 and 3-4g), olive-gray sandy-clay fault gouge cuts metavolcanic bedrock. A slickensided surface in fault gouge extends through the paleo B deposit and into Keystone colluvium; however the shear has been deformed downslope by slope creep. The paleo-B deposit, however, is preserved on the foot wall, on upslope side of fault that is interpreted to reflect strike-slip faulting on the Spenceville fault.

In Spenceville trench 4 (Figure 3-4g) the fault features in bedrock are similar to the other trenches: shearing and clay filled joints in bedrock and the Paleo B thickens across fault zone. The slickensided surface that extends from the fault into and through the thicker part of the paleo-B deposit and extends to near the ground surface where the paleo B cuts out the lower part (unit #2) of the Keystone/Sonora colluvium that is interpreted to be related to faulting, but the relationship appears to have been modified by downslope creep that has deformed the slickensided surface downslope.

Dewitt fault

The Dewitt fault was trenched in two places across a weak vegetation lineament (Photo 7) at the Big Hill locality (PG&E 1994b). The Big Hill trench 1 (Figures 1-2 and 3-4b) exposed fractured and sheared metasedimentary bedrock. The main fault, F-2, has a slickensided surface that extends from the gouge zone into the paleo-B deposit (Figure 3-7b). The Sonora colluvium 'arches' over bedrock on the footwall and thickens (partial colluvial wedge) on hanging wall, and the Keystone colluvium is missing at the fault. These features are interpreted to represent a late Pleistocene or possible a Holocene event. An earlier event is recorded by a colluvial wedge of paleo B is preserved on a down dropped bedrock block-between two faults.

Deadman fault

The Deadman fault was trenched across a swale on an erosion lineament at the Mt. Vernon locality northwest of Auburn (PG&E 1994b). The one trench, Mt Vernon Trench 1 (Figures 1-2 and 3-4j) exposed several faults in metavolcanic bedrock (Figure 3-7j). The main fault, F-5, has a 10 cm wide clay gouge zone. Wyandotte colluvium (unit C3) and lower Modesto alluvium (unit A2) on hanging wall (possible colluvial 'wedge'), and two colluvial wedges of older colluvium, C5 and C6, are interpreted to be fault features.

Rescue fault

The Rescue fault was investigated in several trenches at the Luneman Road site (Schwartz and others, 1977a). One trench is discussed below. The Luneman Road trench 3 (Figures 1-2 and 3-4h) exposes schist, metavolcanic rock, altered dike, and metasedimentary rock. Fault 2 has a clay-filled gouge zone (Figure 3-7h). Past displacements are interpreted from the Keystone/Sonora colluvium that thickens (partial colluvial wedge) across the fault and the paleo B deposit that is preserved on hanging wall as a colluvial wedge between slickensided faults; these are up slope of the fault, counter to creep direction. Slickensided surfaces extend from clay gouge to base of Keystone/Sonora colluvium. At the shear zone in the west end of the trench colluvium 2 appears juxtaposed against the Paleo B deposit by the fault, but this may be a krotovina.

Baker Ranch Fault

The Baker Ranch Fault was investigated with three trenches (PG&E 1994b), two of which are discussed below. In Baker Ranch trench 3 (Figures 1-2 and 3-4i) crosses the main fault below a degraded fault scarp with no geomorphic expression at the trench. The trench exposed Mehrten Formation faulted and juxtaposed against metamorphic rocks of the Calaveras complex (Figure 3-7i). Both these units have been weathered to saprolite. The Keystone/Sonora and Wyandotte (?) colluvium are not offset. The faults preserved in the saprolite bedrock are relict and predate the saprolite formation; i.e., post-saprolite faulting would have different expression, such as a slickensided surfaces and/or fracturing of the soft saprolite on the hanging wall.

Baker Ranch trench 1 (Figure 3-4i) was excavated across a fault that is antithetic to the main Baker Ranch fault at a four-meter-high fault scarp in the Mehrten Formation. Fault 10A separates two weathered lahar conglomerate units in the Mehrten and is below the base of the scarp. Fault 10A has slickensided surfaces in breccia and pre-Sonora (?) soil-filled fractures and breccia. The Wyandotte (?) colluvial pocket above the fault is interpreted to record an earlier event. The Keystone/Sonora colluvium are not offset at fault (Figure 3-7i).

The interpretation of the Quaternary faulting at the Baker Ranch fault is as follows: No displacement has occurred at the surface on the main fault in the past 500,000 to 1 million years. However, younger displacements are recorded on the antithetic fault; the filled fractures record at least one event in the middle to late Pleistocene, which occurred prior to the deposition of the Sonora colluvium in the late Pleistocene. The antithetic fault scarp records several earlier events that are post saprolite formation.

Rawhide Flat east fault

Several trenches were excavated by Woodward-Clyde Consultants (1978a) across the Rawhide Flat east fault north of the 15 m offset in the Table Mountain latite (Photo 1). Rawhide Flat Trench 1 (Figures 1-2 and 3-4e) exposed phyllite, slate, metasedimentary rock, and gabbro as well as a clay gouge fault zone with a slickensided surface that extends from the fault gouge through the paleo-B deposit and into the Sonora colluvium. The more extensively preserved paleo-B deposit on hanging wall is interpreted to be a colluvial wedge formed from an earlier event. In addition a slice of Paleo B has intruded into Sonora colluvium with the slickensided surface, both are directed upslope counter to the direction of slope creep.

Negro Jack Point fault

The Negro Jack Point fault offsets the Tuolumne Table Mountain lava flow about 20 feet (6 m). It was exposed in several trenches, including the Negro Jack Point trenches 3 and 6 (Woodward-Clyde Consultants, 1978a). The bedrock in trench 6 (Figures 1-2 and 3-4f) is latite and weathered latite (units S-7, S-8, S-9) that has been displaced 33 feet vertically along the Negro Jack Point fault. The fault features include a possible colluvial wedge of Keystone/Sonora colluvium and several fracture fills and weathered fractured zones (now highly weathered and saprolitized) in the latite that are interpreted to be features formed by faulting events. The weathered zones (units S5 and S6) and fills (units S3 and S4) predate the fracture fill 2 (unit S6) that appears to be equivalent to the paleo B clay deposit. Fracture fill 1 (unit S2) records a younger event and the colluvial wedge of Keystone/Sonora colluvium may record a late Pleistocene event.

The bedrock in Negro Jack Point trench 3 (Figures 1-2 and 3-7f) is volcanic breccia of the Relief Peak Formation that underlies the Table Mountain latite (unit R1). It has been offset about 44 feet at the trench. Fault features include several colluvial wedges and fracture fills, similar to the features in trench 6. A colluvial wedge of Keystone colluvium, a wedge of Sonora colluvium, and a wedge/fracture fills (unit S4), colluvial unit S5, fracture fill 2 (unit S6), and a probable fracture fill 4 (unit S7), or possibly weathered volcanic breccia are interpreted to record separate faulting events that are preserved on the hanging wall. The late Cenozoic fault in the Relief Peak volcanic breccia is characterized by clay gouge that appears to be intruded from the underlying gouge in the metamorphic bedrock under the breccia.

4.0 CONCLUSIONS

Based on analysis of the investigations performed to evaluate the activity of faults in the Sierra Nevada, the following conclusions are made. They generally agree with the conclusions made at the end of the 1970s studies.

1. Late Cenozoic faults, including late Quaternary active faults, occur within the Sierra Nevada. These are identified using several techniques
   a. Geomorphic expression in areas of low erosion rates
   b. Displacement of Cenozoic deposits
   c. Trenching to identify small displacements in colluvium and/or alluvium
2. The use of geomorphic analysis provides the most successful screening technique to identify potential late Quaternary faults. Areas where the basement rocks are covered by Cenozoic deposits without anomalies provide compelling evidence of no late Cenozoic reactivation on basement faults. Conclusive evidence for the cause of a geomorphic anomaly, be it late Cenozoic fault or not, in some cases can be achieved by detailed field mapping if the exposures allow, or by trenching if needed.
3. In many cases lineaments that are associated with geomorphic anomalies require trenches to evaluate the potential for late Cenozoic faulting, if a faulting origin is suspected or if faulting needs to be proved or disproved for a critical facility. The excavation of trenches has proved successful: for geomorphic anomalies 3 out of 4 targets have proved to be Quaternary faults and 1 in 4 targets are latest Pleistocene-Holocene faults. When targets were based only on lineament analysis 1 in 4 sites proved to be Quaternary faults and 1 in 7 to be latest Pleistocene-Holocene faults.
4. Proof of the activity of a late Cenozoic fault requires trenching completely across the zone of potential faulting. Commonly several trenches are required to demonstrate consistent relationships, both stratigraphic and structural.
5. A recognizable regional colluvial/alluvial stratigraphic framework has been established in the Foothills of the Sierra Nevada and is important in assessing fault activity. Careful mapping, however, by geologists with an understanding of Quaternary stratigraphy is essential because the stratigraphic relationships in colluvial deposits are commonly difficult to interpret and features indicative of past fault displacements are subtle and may have alternate explanations.
6. Many late Cenozoic faults, but not all, are reactivated faults, shear zones and contacts within the Mesozoic Foothills fault system, particularly where they are optimally oriented in the contemporaneous regional stress regime.
7. The Late Cenozoic faults are associated with lineaments that generally less than 20 km long that reflect repeated small displacements in the current transtensional tectonic regime within the Sierran tectonic block that began within the past 5 million years.
8. Slip rates (vertical) on the late Cenozoic faults within the Sierran tectonic block are very low. Long term rates measured from displaced Pliocene and Miocene units are commonly 0.001 to 0.01 mm/yr. Middle and late Quaternary slip rates measured from offset Quaternary deposits are similar.
9. Slip rates on the late Cenozoic faults that ‘bleed’ off faults from the Sierra Nevada frontal fault system into the range west of the range crest are somewhat higher. Long term rates measured from displaced Pliocene and Miocene units are commonly 0.01 to 0.1 mm/yr.

10. Recurrence intervals between faulting events are long, commonly longer than 10,000 years; some are longer than 100,000 years.
11. While this study presents data from the Central and Northern Sierrra Nevada, similar late Cenozoic faults are suspected in the southern Sierra Nevada (south of the Tuolumne River). However, only the Kern Canyon fault near Lake Isabella (Nadin and Saleeby, 2001; Page, in progress) and the associated Breckenridge fault (Jennings, 1994) are recognized as late Cenozoic faults. This may be because of a lack of late Cenozoic deposits in the region, or because the granitic bedrock weathers to easily eroded grus that destroys the tectonic geomorphic expression, or because the style of uplift, block uplift with a steep monoclinal slope on the western side, is different than the generally uniform tilting of the Sierra Nevada north of the San Joaquin River.

5.0 REASSESSMENT OF FAULTS NEAR NEW BULLARDS BAR DAM

Using the criteria and analysis discussed above, the several faults, lineaments and geomorphic anomalies investigated in the past for New Bullards Bar Dam are reassessed in this section. These include from north to south, the Sanborn Mine fault, Maynards Ranch lineament, Sucker Run lineament, Oroleve lineament, Oroleve-Woodleaf lineament, Marys Ravine fault, Pine Grove fault, and the Highway 49 fault.

5.1 SANBORN MINE (CAMEL PEAK) FAULT

Alt and others (1977) identified two geomorphic anomalies on the Lovejoy basalt on Lumpkin and Mooreville ridges that occur where the bedrock Camel Peak fault passes beneath these ridges. They associated the anomalies with a probable late Cenozoic fault with down-east displacement that they name the Sanborn Mine fault. PG&E (1991) on a more detailed profile showed that a 30 to 55 meter anomaly on the Mooreville Ridge and 60 meter anomaly on Lumpkin Ridge. The anomalies are coincident with a west steepening of gradient of the Lovejoy basalt across the anomaly, but no field mapping was done to confirm the relationships. The lineament associated with the Sanborn Mine fault extends southeast from Camel Peak to the canyon of Slide Creek, a distance of 12 kilometers and continues along the canyon of the North Fork Yuba River and additional 8 kilometers.

Hamilton and Harlan (2002) mapped the geology in detail at and near these anomalies. In the Camel Peak area the geology is well exposed and shows that the late Cenozoic deposits are not displaced across the potential zone of faulting. Hence, the stratigraphic evidence indicates that no late Cenozoic fault occurs at Camel Peak, perhaps reflecting a change to the westward strike to the north of the peak. At Lumpkin Ridge the geology as mapped by Hamilton and Harlan (2002) is very complex and it is not possible to confidently evaluate if the fault has displaced late Cenozoic deposits or not. At Mooreville Ridge Hamilton and Harlan (2002) conclude that the base of the Lovejoy is not faulted. However, the base of the Lovejoy flow sequence is not completely exposed and is too irregular to be certain that there are no offsets (Figures 10 and 14 in Hamilton and Harlan, 2002). The Harlin and Hamilton (2002) profile (their Figures 10 and 14), as well as on the PG&E profile (PG&E, 1991; Figure 3 in Page and others, 1995), the top (porphyritic) Lovejoy flow appears to be offset 30 to 55 m, if the regional gradient is used.

The southern projection of the Sanborn Mine fault intercepts the Slate Creek Diversion tunnel at Fancy Ravine where the Bechtel Corporation tunnel log shows a fault/shear that strikes 15° northwest and dips 60° northeast (shown as Figures 3 and 15 of Hamilton and Harlin, 2002) in the contact zone between diorite gneiss and serpentine. This is consistent with a potential late Cenozoic fault.

<u>Conclusion</u>: Although Hamilton and Harlan (2002) find no evidence for a late Cenozoic Sanborn Mine fault, the evidence is not conclusive. The Sanborn Mine fault is considered a potential seismic source for New Bullards Bar Dam. Its length is 12 to 20 kilometers.

5.2 MAYNARDS RANCH LINEAMENT

PG&E (1991, their Figure 3; Page and others, 1995, their Figure 3) inferred a fault, the Maynards Ranch fault (it should be referred to as a lineament), from a down to the west anomaly on the geomorphic profile of the Lovejoy basalt between Mooreville and Fields ridges, 30 kilometers east-northeast of Oroville. The anomaly shows a possible offset of 20 to 50 meters, west down, and an approximate 6 m/km shallowing of the gradient of the basalt. The discontinuous lineaments that are associated with the anomaly start south of the confluence of the South Fork Feather River at Lost Creek and extend northwesterly as aligned short linear drainages and along the base of the west-facing linear mountain front between the South and Middle Forks Feather river north of Fields Ridge, a distance of 12 kilometers. The bedrock along the lineament is Mesozoic to Paleozoic metasedimentary and ultramafic rock (Saucedo and Wagner, 1992). The lineament appears to die out in the canyon wall south of the South Fork Feather River and although the projection of the southern end of the fault aligns with a prominent bedrock shear zone in the Woodleaf tunnel (shown on Figure 9 and 12 of Hamilton and Harlan, 2002), the shear dips east, opposite to the west dip inferred on the Maynards Ranch lineament, and hence, the shear is not considered to be the Maynards Ranch lineament.

The Maynards Ranch geomorphic anomaly (lineament) is at the south end of a prominent north trending ridge that clearly diverted the Lovejoy lava flows through a narrow canyon, a condition that could have caused the anomaly to be a depositional feature, i.e., the shallowing of the gradient below the constriction. A similar depositional feature has been documented at Tunnel Hill, east of Georgetown (Page and Sawyer, 2001). Or Maynards Ranch anomaly may result from a combination of deposition and faulting as was found at Baker Ranch on the Forest Hill Divide (PG&E, 1994a; Page and Sawyer, 2001).

No fieldwork has been performed at the anomaly or along the associated lineaments and the information on the Maynards Ranch lineament is inconclusive as whether the anomaly reflects a late Cenozoic and if so, whether or not it has had a late Quaternary displacement.

Conclusion: The overall evidence, although not conclusive, indicates that the Maynards Ranch geomorphic anomaly and associated lineament is not a late Cenozoic fault. For this reason and because it is distant from New Bullards Bar Dam, the Maynards Ranch lineament is not considered a potential seismic source for New Bullards Bar Dam.

5.3 SUCKER RUN LINEAMENT

PG&E (1991) mapped moderately expressed lineaments, aligned hillside benches, linear gullies and streams, from topographic maps and air photos trending through the Sucker Run geomorphic anomaly at Fields Ridge. The bedrock along the lineament is Mesozoic to Paleozoic metasedimentary and Jurassic rock of the Smartville Complex and the northern part of the lineament may coincide with the Big Bend-Wolf Creek bedrock fault (Saucedo and Wagner, 1992).

PG&E (1991, their Figure 3; Page and others, 1995, their Figure 3) identified the Sucker Run geomorphic anomaly from a relatively small, 15 to 20 meters, east-down separation and a 14 m/km shallowing of the gradient on the Lovejoy basalt geomorphic profile at Fields Ridge north of Challenge and inferred it was possibly caused by late Cenozoic faulting. Their confidence that the anomaly is a late Cenozoic fault is low because the estimated separation (15 to 20 m) is relatively small, close to the limit of resolution of the technique, the projection across the "Sucker Run gap" is relatively long, and the extent of remnants of the Lovejoy west of the gap is small. PG&E made a reconnaissance of the anomaly and found that the Lovejoy flows are significantly eroded along Fields Ridge increasing the uncertainty of the anomaly being a late Cenozoic fault.

Hamilton and Harlan (2002) analyzed the Sucker Run feature and showed that the geological log of the Forbestown tunnel lacked any faulting or shear zones in the black slate beneath the Sucker Run geomorphic anomaly as mapped by PG&E (1991), and the lineament as shown by PG&E (1991) and concluded that the Sucker Run geomorphic anomaly is caused by differential erosion. However, the Robertson fault ("1 to 2 foot wide with water"), even though it is not below the mapped lineament, may possibly be related to the Sucker Run geomorphic anomaly. It has a 75° southeast dip consistent with down-east normal faulting of the Sucker Run anomaly, but the strike of the fault diverges 65 degrees from the strike of the geomorphic lineament. Late Cenozoic faulting might also be located along the slate-serpentine contact, similar to the documented displacement on the Negro Jack Point fault that occurs along a major contact in the metamorphic rocks at Stanislaus Table Mountain (Woodward-Clyde Consultants, 1978a).

<u>Conclusion</u>: The overall evidence, although not conclusive, indicates that the Sucker Run geomorphic anomaly and associated lineament is not a late Cenozoic fault, but this should be confirmed by field mapping. It is not considered a seismic source for New Bullards Bar Dam.

5.4 OROLEVE LINEAMENT

PG&E (1991) originally mapped the Oroleve lineament (inaccurately called a fault in PG&E, 1991) across the old upland relict landscape whose remnants follow the ridge crest Challenge and Clipper Mills. The lineament was originally interpreted from air photos and the USGS topographic map to be an old alluvial deposit that had been "ponded" against the low ridge west of Oroleve. This expression of the lineament with "ponded alluvium" is similar in strength to other lineaments that have been trenched elsewhere in the Sierra Nevada foothills that reflected Quaternary faulting. The bedrock along the lineament is serpentine and ultramafic rock (Saucedo and Wagner, 1992). However, the inferred alluvial deposits were not field checked to confirm the interpretation. Hamilton and Harlan (2002) pointed out that the Oroleve area appeared to them as an area that had been mined in the 1800s and correlated the Oroleve area with the Eocene gravels mapped at Clipper Mills by Turner (1898) that are one half mile to the east. They inferred similar gravel deposits to the west at Woodleaf and New York Flat (Figures 5 and 6 of Hamilton and Harlan, 2002). Their profile through these deposits does not show an anomaly.

The Oroleve fault as mapped by PG&E (1991) at Oroleve has an inferred down on the east separation. The projection of the Oroleve fault (shown as east branch in Hamilton and Harlin, 2002) to the Woodleaf tunnel aligns with a strong 50-foot-wide shear zone that dips 75 degrees east, as shown by Hamilton and Harlan (2002, their Figures 9 and 12). This indicates that the Oroleve lineament coincides with a bedrock fault.

To resolve the issue the site was inspected on May 14, 2002 with Robert Wright, Senior Geologist with Geomatrix Consultants. We confirmed that the upland area is a degraded, relict Eocene(?) landscape characterized by very gently rolling hills and wide flat upland valleys, rather than an ancient alluvium. We traversed the field across the Oroleve lineament south of the La Porte Road where we noted a very low, one-foot-high scarp on the projection of the lineament. This scarp was clearly erosional and probably formed where farming or mining that have stripped the surface stopped because thin soil with a lag deposit of small siliceous rocks and iron pisoliths extended east of the scarp but not west of it. The ancient landscape is capped by an ancient relict paleosol that has developed on extremely weathered serpentine bedrock. The soil is deep red and characterized by a lag of round, iron pisoliths that are up to 5 mm in diameter. By soil correlation the pisolithic soil at Oroleve is considered to be older than several million years ()Table 3-2).

Conclusion: The Oroleve lineament appears to be related to a bedrock fault because it projects to the bedrock shear zone because mapped in the Woodleaf tunnel. It is not considered a late Cenozoic fault because it has not had any displacement in at least several million years. Hence, the Oroleve lineament is not potential seismic source for New Bullards Bar Dam

5.5 OROLEVE-WOODLEAF LINEAMENT

PG&E (1991) mapped the Oroleve-Woodleaf lineament (inaccurately called a fault in PG&E, 1991) south from the upland surface at Oroleve and Woodleaf into the more eroded hills south of the junction of the Oroleve and Woodleaf lineaments. The lineament is moderately weak to weakly expressed along most of its length as discussed by Geomatrix (2004). PG&E trenched across the lineament at the Milk Ranch trench site and found only localized weak shearing in the bedrock, and no fault with characteristics of a late Cenozoic fault (Table 3-4). Several colluvial deposits, the oldest of which has a radiocarbon age of ~20,000 years, overlie the shear (Figure 2-6a). PG&E (1994b) interpreted the age to be older than 35,000 years based on soil-stratigraphic correlations with other colluvial units in the Sierra Nevada foothills developed during the extensive earlier investigations (Table 3-2). In reviewing the trench log, however, the oldest colluvium, by stratigraphic position is Wyandotte or older (unit C-4 in Figure 3-3a-A) making the last faulting event older than 50,000 years (the C-14 dates of 13,500 and 20,300 years BP are believed to be from intrusive materials). The overlying colluvium (unit 3 in Figure 3-3a-A) is interpreted to be the Sonora colluvium, but the high clay content from soil development is much higher than is typical of the Sonora deposits elsewhere in the Foothills; moreover, the shattered quartz vein that protrudes through the colluvium is much more decomposed than possible for a colluvium that was active 10,000 to 15,000 years ago (the C-14 date of 5,100 years is at the top of the deposit and is believed to be from intrusive materials). This degree of weathering is interpreted to be over 100,000 years. Supporting the antiquity of the colluvial deposits is the geomorphic setting: the trench site is in a broad flat saddle that is a remnant of an old landscape that reflects low erosion rates and a stable geomorphic setting. The greenstone bedrock is weathered to a deep saprolite that is estimated to be at least 500,000 years old based on the correlation of saprolite formation to other areas in the Foothills (Table 3-2). Any faulting that would have cut the saprolite would have produced features such as slickensides, smooth fault planes, or jumbled materials in the fault zone, that would be preserved in the saprolite. None of these are seen at the Milk Ranch trench.

Conclusion: The Oroleve-Woodleaf lineament is discontinuous and has very weak morphology. Moreover, the weak shear in the Milk Ranch trench associated with the lineament does not have the characteristics of a late Cenozoic fault and it is overlain by a sequence of unfaulted colluvium, the oldest of which is at least Wyandotte in age, older than 50,000 years. The bedrock is weathered to a deep saprolite that would have recorded any post saprolite formation by slickensided surfaces and deformation of the saprolite; none of these features are present. Hence, the Oroleve-Woodleaf lineament, hence the shears associated with the lineament have not had displacement in more than 500,000 years. Hence, the Oroleve-Woodleaf lineament is not a seismic source for New Bullards Bar Dam.

5.6 MARYS RAVINE LINEAMENT

The Marys Ravine lineament (termed the Marys Ravine fault by PG&E, 1991) is a strong lineament marked by linear stream segments that extends between the Sebastopol Diggings on the south to New Bullards Bar Reservoir on the north, a distance of 5 kilometers. Much of its length follows the Bear Mountains (Wolf Creek) fault shown by Saucedo and Wagner (1992), but in this area this fault appears to be an intrusive contact that generally follows and disrupts the ancient Mesozoic shear zone. The south end of the lineament is covered by Tertiary "auriferous gravels" at the Sebastopol Diggings. These were not found to be offset in a field inspection made by Woodward-Clyde Consultants (1981), nor is there a geomorphic anomaly in the Eocene 'auriferous gravels' at the south end of the lineament (PG&E, 1991; Hamilton and Harlan, 2002; Geomatrix, 2004) that indicates any post Eocene displacement.

PG&E (1991) trenched the northern end of the lineament near Schoolhouse Creek. The trench exposed a sheared contact between granitic rock on the east and phyllite on the west, but no faults and the sheared contact does not have features indicative of late Cenozoic faulting (Table 3-4) and is overlain by unfaulted Sonora colluvium based on soil properties that correlate to the Sonora colluvium elsewhere in the Foothills (the C-14 dates of 4,132 $\pm$ 57 years B.P. and 4,610 $\pm$ 110 years B.P are from the upper part on the colluvium and are either intrusive or part of mixing of the Keystone and Sonora colluvium in the upper part of the deposit). Field inspection made with Robert Wright, Senior Geologist with Geomatrix Consultants, of remnants of the upland surface in the ridge-crest saddle between the New Bullards Bar Reservoir and the Middle Fork Yuba River found no evidence of late Quaternary faulting at or near the projection of the lineament.

Conclusion: The Marys Ravine lineament is caused by differential erosion along the sheared intrusive contact between granitic and metamorphic rock and is not a late Cenozoic fault. In addition the Eocene 'auriferous gravels' and late Pleistocene Sonora colluvium are not displaced. Hence, the Marys Ravine lineament is not considered to be a potential seismic source for New Bullards Bar Dam.

5.7 PINE GROVE FAULT (NORTH EXTENSION OF JONES RAVINE BEDROCK FAULT)

In response to questions raised concerning the recency of activity of the Pine Grove fault by DSOD (2003), the apparent offset of the Eocene gravels between the Sweetland and Sebastopol diggings at Sweetland Creek (Figure 6 in PG&E, 1991) and referred to herein as the 'Sweetland anomaly' was reassessed. The offset was based on a geomorphic profile constructed by picking contour intercepts from the USGS French Corral and Nevada City Quadrangles (25 foot contour spacing) along the base and top of the 100 foot thick gravel deposits. Both the top and bottom showed an approximate 80-foot down-on-the-south anomaly across Sweetland Creek. Hamilton's and Harlan's (2002) profile of the channel (their Figure 5) shows a smaller anomaly that they attributed to a steep rapid that they state is similar to the present day rapids on the Yuba River to the north.

PG&E (1991) mapped lineaments along and near the Mesozoic Wolf Creek fault shown on Saucedo and Wagner (1992) that forms the contact between the Jurassic granite and granodiorite of Yuba Rivers pluton to the east and Jurassic volcanic rock of the Smartville Complex to the west that projected toward the anomaly. PG&E presumed that this lineament followed a strand of the Foothills fault system and that it was a potential late Cenozoic fault that they called the Pine Grove fault (north extension of the Jones Ravine bedrock fault). They trenched the fault south of the Sweetland anomaly and showed that it was a late Cenozoic fault but that it had not displaced deposits that are paleomagnetically reversed, making them older than 790,000 years. To the north of the trench PG&E assumed that the fault continued along weak lineaments and through the Sweetland geomorphic anomaly and plotted it east of the margin of the Sebastopol Diggings and connected it to the lineaments along the Marys Ravine fault to the north of the diggings (Figure 4 in PG&E, 1991). A subsequent lineament analysis by Geomatrix (2004) identified a strong, but short, lineament at the anomaly along Sweetland Creek; this lineament was at a high angle to the lineaments mapped by PG&E along the Pine Grove fault.

To address the uncertainties at the Sweetland anomaly on May 14, 2002, a reconnaissance that mapped geology was made with Robert Wright, Senior Geologist with Geomatrix Consultants, along Sweetland Creek where bedrock is almost continuously exposed. The contact between foliated granitic rocks to the east and steeply dipping foliated phyllite parallels and is coincide with short lineaments on projection of the northerly striking Pine Grove lineament, but no evidence of late Cenozoic fault is evident. A set of joints spaced 2 to 12 feet apart and striking N83ºE controls the location of Sweetland Creek in the massive granitic rocks in the creek channel. No late Cenozoic fault follows the creek. West of there the granite becomes increasingly foliated toward the contact with the metamorphosed shale and sandstone. The foliation strikes N3ºW to N3ºE in and adjacent to the creek channel and the contact zone does not contain any evidence of fault that satisfies the criteria of a late Cenozoic fault (Table 3-4). The conclusions from the mapping was that the short lineament identified by Geomatrix (2004) along Sweetland Creek is controlled by joints in the granitic rock and the Pine Grove fault probably does not pass through the creek (there was only one 50-foot-wide area in the creek bed where bedrock was not exposed that could have hidden the fault).

A new profile was drawn independently Geomatrix (2002), Hans Abrahamson Ward, Staff Geologist at Geomatrix Consultants, using the geology from maps by Turner (1894), Lindgren (1911) and Yeend (1974) and reinterpretation of the air photos. In this profile the upper (solid line) profile is the modern ground surface along the thalweg as it passes through the central part of the various diggings (assumes the gravels were completely or almost completely removed) that is interpreted as the base of the Tertiary gravel. This method, which is similar to what was done by PG&E (1991), shows a smaller anomaly at Sweetland Creek than found by PG&E (1991).

Because the thalweg of the gravel remnants has a 'S' shape that is at various angles to the post-late Miocene tectonic tilt of the Sierra Nevada (Unruh, 1991), the profile was modified to remove this tectonic overprint. As described by Geomatrix (2002) a straight-line tilt of 70 feet per mile was assumed. This is within the range quoted by Yeend (1974) of 66 to 72 feet per mile and the range of inferred tilt of the Yuba River area reported by Christensen (1966) of 60 to 70 ft/mile in his Table 1 and his Figure 3 map showing uplift contours of about 70 ft/mile at this latitude. An arbitrary axis of tilting somewhere west of the profile was oriented 18 degrees west of north (following the direction of uplift contours shown in Christensen's Figure 3). Each of the hinge points on the profile was lowered according to its distance from the axis of tilt. The hinge points of the current ground surface were matched to the lowered hinge points and sketched the lowered and un-tilted topography between the hinge points by tracing the modern ground surface. Using this method, the elevation of the tilt-corrected profile is arbitrary, but the relative relationships remain accurate. The tilt-corrected profile shows only a small anomaly that is within the range of uncertainty in the elevation of the base of the gravels and is interpreted to be a gradient change in the channel related to the change in bedrock across Sweetland Creek.

Conclusion: The Sweetland anomaly does not appear to be a tectonic offset, but a change in gradient at the base of the ancient channel probably caused by the change in bedrock from granite to phyllite at Sweetland Creek. The late Cenozoic Pine Grove fault appears to die out before it reaches Sweetland Creek. This fault is not considered a potential seismic source for New Bullards Bar Dam because it has not had any displacement in over 790,000 years.

5.8 HIGHWAY 49 FAULT

The Highway 49 fault is 21 kilometers long and consists of two northeast striking segments and a northwest striking segment or splay (PG&E, 1994b). The northeast striking segments include eastern and western parallel strands that are ½ to 1 kilometer apart and 18 km long, extending from south of the Bear River to 4 kilometers south of Grass Valley. Both strike N11°E. The western strand dips about 80ºW and the eastern strand dips about 80ºE. The northwest striking segment splays off the western strand southwest of Grass Valley. It is 8-km long, strikes N15°W, and is inferred to dip 80ºSW. The Highway 49 fault zone coincides in part with the Mesozoic Wolf Creek basement fault (Saucedo and Wagner, 1992). The west parallel strand has strong geomorphic expression consisting of straight stream channels, shallow valleys and low inter-valley divides, vegetation lineations, and local breaks in slope and hillside saddles; the east parallel strand is more prominent, characterized by a continuous set of elongate valleys and low inter-valley divides marked by shorter vegetation lineaments. The north end of the northeast striking fault zone splays into short discontinuous lineaments that die out south of Grass Valley. Projections of these lineaments do not displace the Mehrten volcaniclastic flows at Grass Valley. The northwest striking splay is characterized by shallow valleys, vegetation lineations, and straight stream channels with moderate geomorphic expression. The Mehrten Formation west of Grass Valley overlies the north end of this strand and a geomorphic profile on the Mehrten Formation on the projection of the lineaments associated with the Highway 49 fault indicates that these deposits are not displaced (PG&E, 1994b; PG&E files).

The Highway 49 fault was investigated by Alt and others (1977) at the Smith Property locality. They trenched a secondary cross fault in a small stepover near the north end of the western splay of the main fault. They concluded that the fault had probable late Quaternary displacement because the colluvial deposit that contains the "paleo-B soil horizon" is cut by a slickensided surface that continued from the clay fault gouge into the paleo B deposit. Neither the Wyandotte colluvium-alluvium that overlies the fault on the south wall nor the Sonora colluvium that overlies the fault on the north wall are faulted. Hence, the fault in this trench is older than 50,000 years. My review of their trench log concurs with this interpretation.

PG&E (1994b) trenched both the east and west strands of the Highway 49 fault zone and found that the faults exposed in the trenches have the characteristics of a late Cenozoic faults. In the trench crossing the east strand, the main fault, F-9, and the main splay fault F-4 of the eastern splay, have not displaced the paleo B soil deposit and hence are more than 100,000 years old. In the trench crossing the west strand, the main fault, F-11 of the western splay, is associated with colluvial wedges interpreted to be displacements in the middle to late Quaternary, and a possible fault related fracture fill in the older colluvium, but the overlying younger Wyandotte colluvium estimated to be older than 50,000 years is not displaced. The bedrock shear zone that contains faults F-16 is overlain by unfaulted Wyandotte colluvium and F-17 that is overlain by unfaulted Sonora colluvium; fault F-17, however contains unsheared pedogenic carbonate that is older than the Sonora colluvium, so this fault is considered older that 50,000 years as well. In the fault zones of both the eastern and western splays, several minor faults do not have the stratigraphic layers above them to evaluate their ages except that they are older than Sonora Colluvium (about 14,000 years old); however, their secondary relationship to the main faults make them at least as old as the main faults.

<u>Conclusion</u>: Based the trenching studies by PG&E (1994b) the Highway 49 fault has been active during the middle to late Quaternary after about 300,000 years ago. However, neither fault has had displacement in more than 50,000 years. The Highway 49 fault is not considered to be active using the DSOD criteria of 35,000 years and is not considered a potential a seismic source for New Bullards Bar Dam.

6.0 REFERENCES

Adam, D. P., 1988a, Correlations of the Clear Lake, California, core CL-73-4 pollen sequences with other long climatic records: *in* Sims, J. D., ed., Late Quaternary climate, tectonism, and sedimentation in Clear Lake, northern California Coast Ranges: Geological Society of America Special Paper 214, p. 81 - 95.

Adam, D. P., 1988b, Pollen zonation and proposed informal climatic units for Clear Lake, California, cores CL-73-4 and CL-73-7: *in* Sims, J. D., eds., Late Quaternary climate, tectonism, and sedimentations in Clear Lake, northern California Coast Ranges: Geological Society of America Special Paper 214, p. 63-80.

Alt, J.N., Schwartz, D.P., and McCrumb, D.R., 1977, Regional geology and tectonics, *in* Woodward-Clyde Consultants, Earthquake evaluation studies of the Auburn Dam area, v. 3: report for the U.S. Bureau of Reclamation, Denver, 118 p. plus appendices.

Argus, D.F. and Gordon, R.G., 1991, Current Sierra Nevada-North American motion from very long baseline interferometry: implications for the kinematics of the western United States: Geology, v. 19, p. 1085-1088.

Bateman, P.C. and Wahrhaftig, C., 1966, Geology of the Sierra Nevada, *in* Bailey, E.H., ed., Geology of Northern California: California Division of Mines and Geology Bulletin 190, p. 107-172.

Bechtel Corporation, Geology Group, 1983, Remote sensing lineament analysis: San Francisco, Report to Sacramento Municipal Utility District, 19 p. plus photos and overlays.

Berlogar Geotechnical Consultants, 1995, Giant Gap fault investigation, Yuba-Bear River Project, Nevada and Placer Counties, California: report for the Nevada County Irrigation District, Colfax, California, 15 p. plus plates.

Biggar, N., Cluff, L.S., and Ewoldsen, H., 1978, Geologic and seismologic investigations, New Melones Dam Project, California: report by Woodward-Clyde Consultants for the U.S. Army Corps of Engineers, Sacramento; 246 p. plus appendices.

Birkeland, P. W., 1999, Soils and Geomorphology: Oxford University Press, Third Addition, 430 pages.

Borchardt, G. A., Rice, S. and Taylor, G., 1980a, Paleosols overlying the Foothills fault system near Auburn, California: California Division of Mines and Geology Special Report 149. Originally released as CDMG Open File Report 78-16 SF, 125 p.

Borchardt, G. A., Taylor, G., and Rice, S., 1980b, Fault features in soils of the Mehrten Formation, Auburn damsite, California: California Division of Mines and Geology Special Report 141, 45 p.

Bueno, G. T, Nascimento N. R., Fritsch, E., and Melfi, A. J., 2002, Chronology of Weathering/Pedogenesis in n Oxisol/Spodosal System – Brazilian Amazonia: *in* 17th WCSS, 14-21 August 2002, Symposium No. 25, Paper No. 1401, pages 1041-1 to 1041-10.

Busacca, A. J., 1982, Geologic history and soil development, northeastern Sacramento Valley, California [Doctoral Thesis]: Davis, University of California, 348 p. plus appendices, maps and plate, scale: 1:62,5000.

Busacca, A. J., 1989, Pedogenesis of a chronosequence in the Sacramento Valley, Geoderma, v. 44, n. 1, p. 43-75.

California Department of Water Resources, 1979, The August 1, 1975 Oroville earthquake investigation: California Department of Water Resources Bulletin 203-78, p. 15-121.

California Department of Water Resources, 1989, The August 1, 1975 Oroville earthquake investigation: California Department of Water Resources Bulletin 203-88, 617 p.

Christensen, M.N., 1966, Late Cenozoic crustal movements in the Sierra Nevada of California: Geological Society of America Bulletin, v. 77, p. 163-182.

Clark, L.D., 1960, Foothills fault system, western Sierra Nevada, California: Geological Society of America Bulletin, v. 71, p. 483-496.

Clark, M. M., Sharp, R. V., Castle, R. O., and Harsh, P. W., 1976, Surface faulting near Lake Oroville, California, in August 1975: Seismological Society of America Bulletin, v. 66, p. 1101-1110.

Clark, D.H. and Gillespie, A.R., 1997, Timing and significance of late-glacial and Holocene glaciation in the Sierra Nevada, California: Quaternary International, 38/39, p. 21-38.

Dames and Moore, 1993, Photogeologic and imagery analysis for the geologic and seismologic investigation, New Hogan Dam, Calaveras County, California: Report for the U.S. Army Corps of Engineers, Sacramento District, Contract no. DACW05-92-0027, 51 p. plus tables and figures.

Dixon, T.H, Miller, M., Farina, F., Wang, H., and Johnson, D., 2000, Present-day motion of the Sierra Nevada block and some tectonic implications for the Basin and Range province, North American Cordillera. Tectonics 19:1, pp. 1-24.

Earth Sciences Associates, 1992, Raised Pardee Dam, additional storage alternative, geotechnical investigations, Volume I: report to East Bay Municipal Utility District, Oakland, California 77 p. plus figures.

Ely, R.W., 1992, Late Cenozoic uplift and faulting of the Sierra Nevada in the vicinity of Stanislaus Table Mountain, California (abs.): Geological Society of America, 1992 Abstracts with Program, v. 24, no. 5, p. 22.

Eric, J.H., Stromquist, A.A., and Swinney, C.M., 1955, Geology and mineral deposits of the Angels Camp and Sonora quadrangles, Calaveras and Tuolumne counties, California: California Division of Mines and Geology Special Report 41, 55 p.

Fea, T.W., and Jorgensen, K.E., 1989, Lineament investigation in the western Sierra Nevada foothills belt: California Geologist, December 1989, p. 283-287.

Geomatrix Consultants, 2004, Review of potential seismic sources and potential ground motions**,** New Bullards Bar Dam (CA No. 1034; FERC No. 2206), Yuba County, California: Report to Yuba County Water Agency, Marysville, California, --p. plus tables, figures and appendices

Gardner, J.V., Heusser, L.E., Quintero, P.J., Stone, S.M., Barron, J.A., and Poore, R.Z., 1988, Clear Lake record vs. the adjacent marine record; a correlation of their past 20,000 years of paleoclimatic and paleoceanographic responses: *in* Sims, J. D., ed., Late Quaternary climate, tectonism, and sedimentation in Clear Lake, northern California Coast Ranges: Geological Society of America Special Paper 214, p. 171-182.

Hamilton, D.H., 1994, Investigation of geological basis of seismic hazard to Slab Creek and Brush Creek dams, *in* Bolt, B.A., Ghanaat Y., Hamilton, D.H., and Leps, T.M., (Board of Consultants), Report on safety of Brush Creek and Slab Creek Dams: Federal Energy Regulatory Commission, project no. 2101, 20 p., Appendix A, 46 p. plus figures.

Hamilton, D.H., and Harlan, R.D., 2002, Seismotectonic investigation for the region of Lost Creek Dam, South Fork Feather River, California: report prepared for the Oroville-Wyandotte Irrigation District; 59 p. plus figures.

Hamilton, D.H., Harlan, R.D., and Castle, J.A., 2004, Phase II, Seismic fault investigation for North Fork Stanislaus River Hydro Development Project, FERC Project No. 2409-CA, and Donnells Project, FERC Project No. 2005-CA: Interim report for the Northern California Power Agency and Tri-Dam Project, April 2004; 60p. plus figures.

Harden, J.W., and Marchand, D.E., 1977, The soil chronosequence of the Merced River area, Part VI, p. 22-38. In M. J. Singer (ed.) Soil Development, Geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California. Guidebook for the Joint Field Session, ASA, SSSA, GSA, University of California Press, Davis.

Harden, J.W., and Marchand, D.E., 1980, Quaternary stratigraphy and interpretation of soil data from the Auburn, Oroville, and Sonora areas along the Foothills fault system, western Sierra Nevada, California: U.S. Geological Survey, Open File Report 80-305, 56 p.

Harlan Miller Tait Associates, 1987, Photogeologic interpretation and imagery analysis, Hidden and Buchanan Dams near Merced, California: report to the U.S. Army Corps of Engineers, Sacramento District, Contract no. DAC W05-87-R-0024, 53 p. plus appendix.

Hart, E.W. and Rapp, J.S., 1975, Ground rupture along the Cleveland Hill fault, *in* Sherburne, R.W. and Hauge, C.J., eds., Oroville, California, earthquake 1 August 1975: California Division of Mines and Geology Special Report 124, p. 61-72.

Huber, N.K., 1981, Amount and timing of late Cenozoic uplift and tilt of the central Sierra Nevada, California—Evidence from the upper San Joaquin River basin: U.S. Geological Survey Professional Paper 1197, 28 p

Jennings, C.W., 1994, Fault activity map of California and adjacent areas, with locations of recent volcanic eruptions: California Division of Mines and Geology geologic data map no. 6, scale 1:750,000 with explanatory text, 92 p.

Johnson, R. G., 1982, Brunhes-Matuyama Magnetic Reversal Dated at 790,000 years B.P. by Marine-Astronomical Correlations: Quaternary Research, v. 17, pp. 135-147.

Lindgren, W., 1911, The Tertiary gravels of the Sierra Nevada of California: U.S. Geological Survey Professional Paper 73, 226 pp.

Marchand, D.E. and Allwardt, A., 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California, U.S. Geological Survey Bulletin 1470, 70 p.

McCalpin, J. P., 1996, Paleoseismology: *ed.* J. P. McCalpin, Academic Press, International Geophysics Series, v. 62, 588 p.*

Morrison, R.B., 1991, Quaternary Nonglacial Geology: Conterminous U. S., *in* Morrison, R. B., eds., Geological Society of America, The Geology of North America, v. K-2, p. 9-10.

Nadin, E.S. and Saleeby, J.B., 2001, Relationship between the Kern Canyon fault (KCF) and the Proto-Kern Canyon fault (PKCF), southern Sierra Nevada, California: EOS, Transactions AGU, v. 82, p. 47.

National Resource Conservation Agency, 1998, Soil Survey of Yuba County, California: 437 pages with sheet, Scale 1:24,000.

Page W.D., Swan, F.H., III, Biggar, N., Harpster, R., Cluff, L.S., and Blum, R.L., 1978, Evaluation of Quaternary faulting in colluvium and buried paleosols, western Sierran Foothills, California (abs.): in Abstracts with Program, Geological Society of America, v. 10, no. 3, p. 141.

Page, W.D., 1999, Quaternary faulting on strands of the Foothills fault system and other faults within the Sierra Nevada, California (abstr.): Geological Society of America 1999, Absracts with Programs, v. 31, p. A-84.

Page, W.D., and Sawyer, T.L., 2001, Use of geomorphic profiling to identify Quaternary faults within the northern and central Sierra Nevada, California: *in* Engineering Geology Practice in Northern California: California Division of Mines and Geology, Bulletin 210, pp.

Page, W.D., Gillam, M.L., McCleary, J.R., Lambert, R.S., and Blum, R.L., 1978, Tectonic deformation of Table Mountain near Sonora, California (abstr.): in Earthquake Notes, Eastern Section, Seismological Society of America, v. 49, no. 1, p. 90.

Page, W.D., Sawyer, T.L., and Renne, P.R., 1995, Tectonic deformation of the Lovejoy Basalt, a late Cenozoic strain gage across the northern Sierra Nevada and Diamond Mountains, California: *in* Page, W.D., trip leader, Quaternary geology along the boundary between the Modoc Plateau, southern Cascade Mountains, and northern Sierra Nevada, Friends of the Pleistocene - 1995 Pacific Cell Field Trip, published by PG&E, San Francisco; Appendix 3-3, 11 p. plus tables and figures.

PG&E, 1991, Characterization of potential earthquake sources for Lake Francis Dam, State Dam No. 1034-009: report to the Yuba County Water Agency, Marysville, for the California Division of Safety of Dams, 36 p. plus figures and plates.

PG&E, 1992a, Supplement to characterization of potential earthquake sources for Lake Francis Dam, State Dam No. 1034-009, Volume 1, Section 2, Stratigraphy in the Sierra Nevada Foothills: report to Yuba County Water Agency, Marysville, for the California Division of Safety of Dams, p. 2-1 to 2-18, plus figures.

PG&E, 1992b, Supplement to characterization of potential earthquake sources for Lake Francis Dam, State Dam No. 1034-009, Volume 1, Section 3, Evaluation of the Swain Ravine and Paynes Peak faults, and Section 4, Supplementary seismicity analysis: report to Yuba County Water Agency, Marysville, for the California Division of Safety of Dams, p. 3-1 to 3-14; p. 4-1 to 4-6, plus figures.

PG&E, 1994a, Characterization of potential seismic sources for Ralston Afterbay Dam, State Dam No. 1030-4, FERC Project No. 2079: report to Placer County Water Agency, Foresthill, for the Federal Energy Regulatory Commisson; 93 p. plus appendix, tables, figures and plates.

PG&E, 1994b, Characterization of potential earthquake sources for Rock Creek (Drum) Dam: report for the California Division of Safety of Dams, Sacramento, 93 p. plus figures and plates.

PG&E, 1999, (in progress), Late Cenozoic faulting within the northern and central Sierra Nevada, California: unpublished report by PG&E to the California Division of Safety of Dams, Sacramento, California.

Rapp, J.S., Aune, Q.A., and Buchholz, P.E., 1975, Observations of ground breaks in the Oroville area, California; made during reconnaissance exploration in August 1975: *in* Oroville, California, earthquake 1 August 1975, California Division of Mines and Geology Special Report 124, p. 53-60.

Reneau, S.L., Dietrich, W.E., Donahue, D.J., Jull, A.J.T., and Rubin, M., 1990, Late Quarternary history of colluvial deposition and erosion in hollows, central California Coast Ranges: Geological Society of America Bulletin, v. 102, p. 969-982.

Reneau, S.L., Dietrich, W.E., Rubin, M., Donahue, D.J., and Jull, A.J.T., 1989, Analysis of hillslope erosion rates using dated colluvial deposits: Journal of Geology, v. 97, p. 45-63.

Richmond, G.M. and Fullerton, D.S., 1986, Quaternary glaciations in the United States of America, *in* Sibrava, V., Bowen, D. Q., and Richmond, G. M., eds., Quaternary glaciations in the Northern Hemisphere: Oxford, Pergamon Press, p. 3-200.

Saleeby, J.B., and Busby, C., 1993, Paleographic and tectonic setting of axial and western metamorphic framework rocks of the southern Sierra Nevada, California, In Mesozoic paleogeography of the western United States - II, Dunne, G.C., and McDougall, K.A., eds.: Society of Economic Paleontologists and Mineralogists, Book 71.

Savage, W.U., Page, W.D., McLaren, M.K., and Edwards, W.D., 1991, Approach to seismic hazard analysis for dam safety in the Sierra Nevada and Modoc Plateau of California: Proceedings, Canadian Dam Safety Conference, Sept. 1991: Vancouver, BiTech Publishers, p.203-220.

Saucedo, G.J., and Wagner, D.L., 1992, Geologic map of the Chico quadrangle, California: California Division of Mines and Geology, Sacramento, Regional Geologic Map Series, map no. 7, scale 1:250,000.

Sawyer, T.L. and Page, W.D., in preparation, Late Cenozoic activity of the Little Grass Valley fault, northern Sierra Nevada, California (data in PG&E files).

Sawyer, T.L., Hitchcock, C.S., Knudsen, K.L., Sowers, J.M., Crampton, T., Sawyer, J.E., Wakabayashi, J., Lettis, W.R., and Caskey, S.J., 1996, Middle to late Quaternary strike-slip faulting on the Muleshoe Mine fault, Butt Valley Fault Zone (BVFZ), NE California: Geological Society of America, Abstracts with Programs, v. 28, no.5, p.108-109.

Sawyer, T.L., Page, W.D., Wakabayashi, J., Thompson, S.C., and Ely, R.W., 1993, Late Cenozoic internal deformation on the northern and central Sierra Nevada, California: a new perspective (abs.): American Geophysical Union, Fall Meeting Proceedings, Supplement to EOS, p. 609.

Schwartz, D. P., Swan F. H., Harpster, R. E., Rogers, T. H., and Hitchcock, D. E., 1977a, Surface faulting potential: Earthquake Evaluation Studies of the Auburn Dam Area, Volume 2: report by Woodward-Clyde Consultants to the U.S. Bureau of Reclamation, Denver; 135 p. plus appendices.

Schwartz, D.P., Alt, J. N., Packer, D.R., 1977b, Relationship of Paleozoic and Mesozoic structures to late Cenozoic faulting in the northern and western Sierra Nevada, California: Geological Society of America, Abstracts with Programs, v. 9, p. 1165.

Schweickert, R.A., 1981, Tectonic evolution of the Sierra Nevada: *in* Ernst, W.G., ed., The geotectonic development of California, Rubey Volume I: Englewood Cliffs, Prentice-Hall, p. 88-131.

Schweickert, R.A., Bogen, N.L., and Merguerian, C., 1988, Deformational and metamorphic history of Paleozoic and Mesozoic basement terranes in the western Sierra Nevada metamorphic belt, *in* Ernst, W.G., ed., Metamorphism and crustal evolution, western conterminous United States, Rubey Volume VII: Englewood Cliffs, Prentice-Hall, p. 789-822.

Sharp, W.D., 1988, Pre-Cretaceous crustal evolution in the Sierra Nevada region, California, *in* Ernst, W.G., ed., Metamorphism and crustal evolution, western conterminous United States, Rubey Volume VII: Englewood Cliffs, Prentice-Hall, p. 823-865.

Shlemon, R.J., 1971, The Quaternary deltaic and channel system in the Central Great Valley, California, Annals of the Association of American Geographers, v. 61, n. 3, p. 427-440.

Selby, M.J., 1993, Hillslope materials and processes: Oxford University Press, Oxford, p. 219-298.

Spaulding, W.G., 1994, Postglacial environmental change in central and northern California: briefing paper by Dames & Moore, Inc. to PG&E, 17 p.

Swan, F.H., III, and Hanson, K., 1977, Quaternary geology and age dating, *in* Woodward-Clyde Consultants, Earthquake evaluation studies of the Auburn Dam area, v. 4: report for the U.S. Bureau of Reclamation, Denver, 83 p. plus appendices.

Tierra Engineering Consultants, Inc., 1983, Geologic and seismologic investigations of the Folsom Dam, California area: Report to the U.S. Army Corps of Engineers, Sacramento District, contract no. DACW-05-82-C-0042, 146 p. plus figures, tables, and appendices.

Thatcher, W., Foulger, G., Julian, B., Svarc, J., Quilty, E., and Bawden, G., 1999, Present day deformation across the Basin and Range province, western United States: Science, v. 283, p. 1715-1718.

Turner, H. W., 1898, Geologic Atlas of the Bidwell Bar Folio, California: U. S. Geological Survey Folio 43, Scale 1:125,000.

U.S. Army Corps of Engineers, 1977, Fault evaluation study, Marysville Lake Project, Parks Bar alternative, Yuba River, California: report by Sacramento District, 25 p.

U.S. Army Corps of Engineers, 1982, Geologic reconnaissance of Englebright Dam and Lake area, California: report by Sacramento District, 5 p. plus plate and figures.

U.S. Army Corps of Engineers, 1988a, Geologic and seismologic investigation, Hidden and Buchanan Dams, Hensley Lake and Eastman Lake, Fresno and Chowchilla Rivers, California: report by Sacramento District, 62 p. plus appendices, figures, and plate.

U.S. Army Corps of Engineers, 1988b, Geologic and seismologic investigation, Success and Terminus Dams, Lake Success and Lake Kaweah, Tule and Kaweah Rivers, California: report by Sacramento District, 59 p. plus appendices and figures.

U.S. Army Corps of Engineers, 1994, Geologic and seismologic investigation (fault study), New Hogan Dam and Reservoir (New Hogan Lake), Calaveras River, California: report by Sacramento District, 44 p. plus figures, sheets, tables, and appendices.

U.S. Army Corps of Engineers, 1998, Geologic and seismologic investigation (fault study), Pine Flat Dam and Reservoir, Kings River, California: report by Sacramento District, 51 p. plus figures, sheets, tables, and appendices.

U.S. Bureau of Reclamation, 1977, Auburn dam study: reports and data in USBR files.

U.S. Bureau of Reclamation, 1978, Seismic study of Sugar Pine damsite: Central Valley Project, American River Division, Auburn-Folsom South Unit, Division of Design and Construction, Geology Branch, 46 p., general geology and fault map.

Unruh, J.R., 1991, The uplift of the Sierra Nevada and implications for late Cenozoic epeirogeny in the western cordillera: Geological Society of America Bulletin, v. 103, p. 1395-1404.

Wagner, D.L. and Saucedo, G.J., 1990, Age and stratigraphic relationships of Miocene volcanic rocks along the eastern margin of the Sacramento Valley, *in* Ingersoll, R.V. and Nilsen, T.H., eds., Sacramento Valley symposium and guidebook: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 65, p. 143-151.

Wagner, H.W., 1981, Geochronology of the Mehrten Formation in Stanislaus County, California: Riverside, University of California, Ph.D. dissertation, 342 p.

Wakabayashi, J., and Sawyer, T.L., 2001, Stream incision, tectonics, uplift, and evolution of topography of the Sierra Nevada, California: Journal of Geology, v. 109, p.1395-1404.

Wheeldon and Associates, 1980, Geologic and seismologic investigation of the El Dorado Hills School site: report to El Dorado Hills School District, 14 p. plus tables, figures and photographs.

William Lettis and Associates, 1994, Drum Penstocks and siphon, geologic and geotechnical evaluation, Penstock Safety Program: report to PG&E Geosciences Department, 29 p. plus figures, tables, photographs, drawings and notes.

William Lettis and Associates and PG&E, 1996, Lake Almanor and Butt Valley dams, seismic stability assessment, Volume 1, Seismic source characterization and estimated ground motions: report for Pacific Gas and Electric Company, San Francisco, 271 p. plus figures and appendices.

Woodward-Clyde Consultants, 1975, Phase II report: Regional seismicity and fault study, Foothills fault system study: Report for Pacific Gas and Electric Company, San Francisco, v. 6, 94 p. plus plate.

Woodward-Clyde Consultants, 1976, Evaluation for potential for earthquakes and surface faulting, Parks Bar Afterbay Dam, Yuba County, California: report to U.S. Army Corps of Engineers, Sacramento, 45 p. plus figures.

Woodward-Clyde Consultants, 1977, Site geology, *in* Early site review report for the Stanislaus Nuclear project, section 2.5.1: report prepared for Pacific Gas and Electric Company, San Francisco, California.

Woodward-Clyde Consultants, 1978a, Foothills fault system study: Stanislaus Nuclear Project, Site Suitability/Site Safety Report, Appendix C.4, v. 6, report for Pacific Gas and Electric Company, San Francisco, 166 p. plus tables and figures.

Woodward-Clyde Consultants, 1978b, Quaternary studies - Sierran Foothills: Appendix C.5 of Volume 7, Stanislaus Nuclear Project, Site Suitability - Site Safety Report; report to the Pacific Gas and Electric Company, San Francisco, 71 p. plus tables and figures.

Woodward-Clyde Consultants, 1981, Appendix D, Seismic geology report, FERC 10-year safety inspection report, New Bullards Bar Dam and Reservoir, Yuba County, California: report to Yuba County Water Agency, Marysville, 24 p. plus figures.

Woodward-Clyde Consultants, 1995, Seismic hazards assessment for the City of Redding, California

Yeend, W.E., 1974, Gold-bearing gravel of the ancestral Yuba River, Sierra Nevada, California: U.S. Geological Survey Professional Paper 772, 44 p. plus plate, scale 1:62,500.

7.0 TABLES

TABLE 1-1
MAJOR INVESTIGATIONS OF FAULTS WITHIN THE SIERRA NEVADA

PROJECTS	OWNER (REFERENCE)
Siting for Nuclear Power Plants in Central Valley Investigation of the Foothills Fault system	PG&E (Woodward-Clyde Consultants, 1975)
Oroville Dam Yuba River	State of California (Department of Water Resources, 1979; 1989)
Parks Bar Afterbay Dam Yuba River	U. S. Army Corps of Engineers (U. S. Army Corps of Engineers, 1977; Woodward-Clyde Consultants, 1976)
Auburn Dam American River	U.S. Bureau of Reclamation (U.S. Bureau of Reclamation, 1977; Schwartz and others, 1977; Alt and others, 1977)
Stanislaus Nuclear Project Central and Northern Sierra Nevada	PG&E (Woodward-Clyde Consultants, 1978a)
New Melones Dam Stanislaus River	U. S. Army Corps of Engineers (Biggar and others, 1978)
Sugar Pine Dam Shirtail Creek (American River)	U.S. Bureau of Reclamation (U.S. Bureau of Reclamation, 1978)
New Bullards Bar Dam Yuba River	Yuba County Water Agency (Woodward-Clyde Consultants, 1981)
Folsom Dam American River	U. S. Army Corps of Engineers (Tierra Engineering Consultants, Inc., 1983)
Hidden and Buchanan Dams Fresno and Chochilla Rivers	U. S. Army Corps of Engineers (U. S. Army Corps of Engineers, 1988a)
Success and Terminus Dams Tule and Kewah Rivers	U. S. Army Corps of Engineers (U. S. Army Corps of Engineers, 1988b)
Lake Francis Dam Dobbins Creek (Yuba River)	Yuba County Water Agency (PG&E, 1991; 1992b)
Pardee Dam Mokelumme River	East Bay Municipal Utility District (Earth Sciences Associates, 1992)
Sierra Nevada Fault Project Northern and Central Sierra Nevada	PG&E (PG&E, Geosciences Department, Completed in 1992, data in PG&E files)
New Hogan Dam Calaveras River	U. S. Army Corps of Engineers (Dames and Moore, 1993; U. S. Army Corps of Engineers, 1994)
Rock Creek (Drum) Dam Rock Creek (Bear River)	PG&E (PG&E, 1994b)
Ralston Afterbay Dam American River	Placer County Water Agency (PG&E, 1994a)
Giant Gap Fault Study American and Yuba Rivers	Nevada Irrigation District (Berlogar, 1995)
North Fork Stanislaus River and Donnells Project North and Middle Forks, Stanislaus River	Northern California Power Agency and Tri-Dam Project (Hamilton and others, 2004)
Sly Creek and Brush Creek Dams South American River	Sacramento Municipal Utility District (Hamilton 1994)
Lost Creek Dam South Feather River	Oroville-Wyandotte Irrigation District (Hamilton and Harlan, 2002)

Table 1-1, p. 1

TABLE 3-1
GEOMORPHIC ANOMALIES IDENTIFIED FROM PROFILES ON RIDGE CRESTS IN SIERRA NEVADA

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Anderson Mill (AM)	2b Cohasset Ridge	~30-40 m, down north, Tpcb, ~14 m/km, steepens south, top of Tpcb ***Uncertain***	
Arnot Creek (AC)	32u Stanislaus Table Mountain-Arnot Peak	~40-60 m, down east, base of Tmt, ~40 m/km, western block is backtilted, base of Tmt ***Suspected fault***	Appears to be distributed across three closely spaced parallel faults. Associated with an air photo lineament that crosses Holocene talus slopes.
Baker Ranch (BR)	21b Forest Hill Divide	~30-40 m, down west, top of Tmm, ~30-35 m, down west, rhyolotic tuff (Tov) , ~25 m, down west, base of Teg, ~6 m/km, steepens west; top of Tmm ~30-35 m, down west, rhyolitic tuff (Tov) separation crosses both the Baker Ranch and the suspected Chicken Hawk faults ***Fault***	PG&E, 1994a; Page and Sawyer, 2001 Some of vertical separation caused by paleotopographic highland. Trench exposures show main fault - Tmm /metamorphic rocks faulting older than 500 ka; Antithetic fault within Tmm displacements in middle to late Pleistocene; overlying late Pleistocene deposits unfaulted. (~0.006-0.008 mm/yr, main fault)
Balderson Station (BS)	24b Bottle Hill - Stumpy Meadows Lake	~10 m, down west, top of Tmm ***Uncertain***	PG&E, 1994a Tmm remnant probably is mismapped
Bangor (B)	12c Bangor	~20-25 m, down west, top of Tpl, ≤40 m, down west, base of Tpl, ~11 m/km, western block is backtilted, top of Tpl ***Probable fault***	PG&E, 1992 Tpl unit used for separation is the Lower Laguna Formation as mapped by Busacca, 1982. (~0.004-0.008 mm/yr)
Beaver Creek (BC)	1d Deer Creek	~85 $^{+5}/_{-0}$ m, down east, top of Qdb, ~16 m/km, shallows west, top of Qdb ***Probable fault***	(~0.08 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
	1e Deer Creek	~135$^{+5}/_{-15}$ m, down east, top of Tpcb, ~23 m/km, steepens west, top of Tpcb ***Probable fault***	Cohasset Ridge basalt (Tpcb) outcrop shown by Saucedo and Wagner, 1992, was not field checked in this study. Alt and others, 1977, report a 30 m down-northeast offset of gravels and overlying Tuscan Formation in a mine ~1 mi NE of Dix mine related to a similar striking Magalia fault n (~0.06 mm/yr)
Big Dipper (BD)	20a Iowa Hill Divide	≤95-110 m, down west, top of Tmm, ~65-85 m, down west, base of Teg, ~9 m/km, steepens west, top of Tmm ***Probable fault***	Saucedo and Wagner, 1992, show Mesozoic Foresthill fault at anomaly The Chandra (1961) map indicates that base of Tov appears to be separated ~75 m down west (not shown on profile). Brown (1890) shows the fault at the west end of Roach Hill, at the California Morning Star Mine. Little or no gradient change of base Teg, suggesting gradient change of top of Tmm may be related to erosion of western remnant (~0.01-0.02 mm/yr)
Big Tunnel Spring (BT)	16c Nevada City - Washington Ridge	~30$^{+20}/_{-10}$ m, down west, top of Tmm, ~170 m, down west, base of Tmm ***Probable fault***	Kato (1982) identified a fault cutting Tmm near Skillman Flat. Fault lies in vicinity of basement Melones fault. (~0.006 mm/yr)
	18a Chalk Bluff Ridge	~25-35 m, down west, top of Tmm, ~35-90 m, down west, base of Tmm ***Probable fault***	Kato (1982) identified a fault cutting Tmm at Big Tunnel Spring. Fault lies in vicinity of basement Melones fault. (~0.005-0.007 mm/yr)
Birchville (BV)	15a French Corral - San Juan Ridge	~40 m, down west, top of Teg <10 m, down west, base of Teg ***Anomaly is not a fault***	Teg top and base show small anomalies that are at the limit of the technique Hamilton and Harlan, 2004, show no anomaly on their profile Geomatrix, 2004, show no anomaly, but location coincides with a linear mining channel
Bird Creek (BDC)	8k Oroville - Monitor Flat	~145-180 m, down northwest, base of Tml ***Probable fault***	

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Bottle Springs (BSP)	4d Bear Creek – Claremont	~245-270 m, down east, top of Tmm ~30 m/km, shallows west, top of Tmm ***Probable fault***	Coincides with basement Rich Bar fault (Saucedo and Wagner, 1992). Alt and others, 1977, noted faulted Quaternary lakebeds in western margin of Meadow Valley (~0.05 mm/yr)
	5c Mount Ararat – Claremont	≤230 m, down east, top of Tmm, ~8m/km, steepens west, top of Tmm ***Probable fault***	Coincides with basement Rich Bar fault (Saucedo and Wagner, 1992). (~0.05 mm/yr)
	8g Oroville - Monitor Flat	~100-105 m, down east, base of Tmm ***Probable fault***	Woodward-Clyde Consultants (1978a) and Lindgren (1911) identified down-on-east displacement of Teg at La Port Our data on the base of Teg was projected 1-2 km form the south, and does not appear to require much if any displacement (noy shown on profile). Page and others, 1995, duscuss profile (~0.02 mm/yr)
Bottle Springs *Eastern splay (ES)*	8h Oroville - Monitor Flat	≥40 m, down west, top of Tml, ~40 m, down west, base of Tml ***Probable fault***	Page and others, 1995, duscuss profile (~0.008 mm/yr)
Bowie Flat (BF)	32c Stanislaus Table Mountain - Arnot Peak	~20 m, down east, top of Tmt, ~5 m/km, steepens west, top of Tmt ***Fault***	Identified by Woodward-Cyde Consultants (1978a) as displacing and flexing the Table Mountain latite on geologic profiles and displacing late Quaternary deposits (paleo-B horizon) exposed in trenches. (~0.004 mm/yr)
Bowman Lake (BL)	15e French Corral - San Juan Ridge	~55 m, down west, top of Tmm ***Suspected fault***	Northern Tmm basal contact allows ~50 m down west; southern Tmm base is inconclusive. Mapping by Schweickert and others (1984) (not shown on profile).
Burnt Flat (BUF)	19b Roseville - Emigrant Gap	~50 m, down east, top of Tmm ***Uncertain***	Remnants are eroded, Tmm base data contradicts surface

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Butt Creek (BU)	3f North Fork Feather River	~20 m, down east, top of Qfyb, ***Fault***	Sawyer and PG&E (1996) mapped and image faults in Butte Valley reservoir 2 to 3 km to the north on projection of anomaly. (0.02 to 0.03 mm/yr)
Cascade (C)	7a Lava Top at Cascade	~35 m, down east, base of Tml ***Anomaly appears to be caused by deposition and/or differential erosion***	Ponded alluvium upstream of fault on Cascade Creek to north of anomaly and on Fall River to south of anomaly. PG&E profile in files shows Lovejoy basalt offset Hamilton and Harlan (2002) field mapping shows that the top Lovejoy flow is found on east but not on the west side of anomaly; their 2 trenches in Cascade Gap at the anomaly expoxed only sheared gneiss, but trench does not completely cover the potential locations of the fault.
Chicken Hawk (CH)	21c Forest Hill Divide	~15-40 m, down west, top of Tmm, ~20-30 m, down west, top of Tmm on a spur ridge 2.2 km north (not shown on profile), ~30-35 m, down west, rhyolotic tuff (Tov) ~30-35 m, down west, rhyolitic tuff (Tov) separation crosses both the Chicken Hawk and Baker Ranch faults. ***Suspected fault***	PG&E, 1994a Page and Sawyer (2001) No separation on Teg channel projection is apparent within the resolution of the elevation data.
Chico Monocline (CM)	1a Deer Creek	~54 m/km, steepens west, top of Qdb; ~84 m/km, steepens west, top of Tpt ***Monocline***	Burnett (1963) identified fractures along monocline Biggar (1974), Alt and others (1977), and Harwood and others (1981) described them further. Monocline may be is the surface expression of a blind, east dipping reverse/right slip fault (Woodward Clyde Consultants, 1995).
	2a Cohasset Ridge	~80 m/km, steepens west, top of Tpcb ***Monocline***	
Cohasset Ridge (CR)	1b Deer Creek	~$35^{+20}/_{-25}$ m, down east, top of Qdb, ~30 m/km, steepens west, top of Qdb ***Probable fault***	Aune, 1974, identified Cohasset Ridge fault and later Alt and others, 1977, described fault

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
	1c Deer Creek	~$105^{+10}/_{-15}$ m, down east, top of Tpcb, ~20 m/km, shallows west, top of Tpcb ***Probable fault***	30 m down-northeast offset of gravels and overlying Tuscan Formation in a mine ~1 mi NE of Dix mine near the related Magalia fault
Crablouse Ravine (CLR)	3d North Fork Feather River	~30-50 m, down west, top of Qfyb, ~40-70 m, down west, top of Qfob ***Suspected fault***	May follow eastern Feather River ultramafic contact to south, but diverges to north
	3e North Fork Feather River	~20 m, down east, top of Qfyb ***Suspected fault***	Short antithetic splay to Crablouse Ravine fault
Cornish Flat (CF)	14e Pliocene Ridge - Keystone Mountain	≥115-150 m, down east, top of Tmm, ~25-29 m/km, steepens west, top of Tmm ***Uncertain***	Tmm base does not support fault
Crow's Nest (CN)	not on profile	***Fault***	Displaced Cenozoic deposits identified, but not named, by Harwood (1980).
Crystal Springs Mine (CS)	32g Stanislaus Table Mountain - Arnot Peak	~30 m/km, southeastern block appears backtilted, top of Tmt ***Suspected fault***	
Dardanelles (DN)	32s Stanislaus Table Mountain - Arnot Peak	~35 m, down west, top of Tmt ~35-40 m, down west, base of Tmt ~7 m/km, steepens west, top of Tmt ~5 m/km, steepens west, base of Tmt ***Uncertain, field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary field investigation mapped the volcanic strata at the Dardanelles Cone and conclude that that the anomaly is based on miscorrelation of strata from different eruptive centers and found no evidence of a fault.
Dardanelles Cone (DNC)	32t Stanislaus Table Mountain - Arnot Peak	~66 m/km, eastern block appears backtilted, base of Tmt ***Uncertain, field relationships need to be confirmed.***	The magnitude of the gradient change and the ~13 m/km east-sloping gradient of the eastern block suggest a deep seated fault represented as an anticline at the surface.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Davis Creek (DC)	3i North Fork Feather River	~15-20 m, down east, top of Qfyb, ~20-50 m, down north, top of Qfob ***Suspected fault***	
Devils Gate (DG)	31b Comanche Reservoir - Mokelumne Hill	~12 m, down west, Castle Rock Tuff (Tov) ***Suspected fault***	
Douds Landing (DL)	32l Stanislaus Table Mountain - Arnot Peak	~6 m, down west, base of Tmm ***Not a late Cenozoic fault***	Small basins filled with Qutaternary deposits formed upstream of fault on the Moran Creek and Love Creek drainages northwest of anomaly. Apparent Tmt channel margin at anomaly raises questions about fault relationship. Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and confirmed the channel margin, but found no evidence of faulting and pointed out that remnants of Mehrten as mapped and used to define the anomaly do not exist.
Drivers Flat (DF)	21a Forest Hill	≤90-100 m, down west, on bedrock, ~14 m/km, steepens west ***Uncertain, possible fault***	Anomaly coincides with basement Weimar fault, but anomaly is a step on erosion surface developed on bedrock
Drum (D)	19f Roseville - Emigrant Gap	~50-60 m, down east, top of Tmm ***Probable fault***	Exposures poor so the base of Tmm for potential fault relationship cannot be evaluated Fault exposed in road cut ~2 km south of anomaly William Lettis & Assoc. (1994) mapped antithetic fault at Drum siphon (~0.01 mm/yr)
Faggs Ranch (FR)	5a Mount Ararat – Claremont	~80 m, down west, top of Tmm, ~75 m, down west, base of Tmm ***Probable fault***	Tmm capped by Pliocene basalt (Tpb) on west block. (~0.02 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
	6a Camel Peak - Haskins Valley	~80 m, down south, top of Tmm, ~50-100 m, down south, base of Tmm ***Probable fault***	Tmm capped by Tpb on south block. (~0.02 mm/yr)
Emigrant Gap (EG)	16d Nevada City - Washington Ridge	~40-45 m, down west, top of Tmm ***Uncertain***	Tmm basal contact, as mapped by Schweickert and others (1984), is too irregular to assess separtion.
Eureka (E)	11a Bald Top - Bunker Hill	~35 m, down east, base of Tmm ***Uncertain***	Tmm base is too irregular to be confident; feature can be explained depositionally
Forest (F)	14d Pliocene Ridge - Keystone Mountain	~15 m, down east, top of Tmm ~20 m/km, shallows west, top of Tmm ***Uncertain***	Separation not discernible on profile but permissible; offset identified by Alt and others (1977).
Giant Gap (GG)	19e Roseville - Emigrant Gap	≥20 m, down east, top of Tmm, at Spaulding Point Ridge; ~20 m, down east, top of Tmm, ~8 m/km, shallows west, top of Tmm, at Moody Ridge ***Fault***	Alt and others (1977) pointed out offset in Mehrten surface, alluvium in the N. Fork American River upstream of fault, and suspected faulting in colluvium in a railroad cut near Alta. PG&E (1994a) documented anomalies on three ridges and showed that the faulted colluvium was a old roadcut in the Mehrten Fm. Berlogar (1995) trenched the fault and concluded that it is late Pleistocene or Holocene (~0.004 mm/yr)
	20c Iowa Hill Divide	≤65-85 m, down east, top of Tmm, ~23 m/km, steepens west, top of Tmm ***Suspected fault***	USBR (1978) survey of base near this locality does not show any displacement of the basal contact but contact not well exposed and slopes east; trenches may have missed fault.
Gold Run (GR)	19c Roseville - Emigrant Gap	>60-70 m, down east, top of Tmm, ~14 m/km, shallows west, top of Tmm ***Uncertain***	Resolution of Teg base not sufficient to confirm Gold Run fault; Yeend (1974) shows ~120 m of relief on Tmm base. Fault is in vicinity of basement Foresthill fault.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Goodyears Bar (GB)	13b Camptonville - Old Mountain House Ridge	~110-155 m, down east, top of Tmm, ~27 m/km, steepens west, top of Tmm ***Suspected fault***	Terrace deposits upstream of fault along North Yuber River. Coincides with Mesozoic Goodyears Creek fault at location of anomaly (Saucedo and Wagner, 1992) Base of Tmm at this locality not evaluated.
Gopher Gulch (GOG)	30c Ione - Cooks Station	$\sim 15^{+10}/_{-5}$ m, down east, top of Tmm, ~14 m/km, shallows west, top of Tmm ***Probable fault***	Fracturing in Mehrten reported on projection of lineament by William Fraser, Geologist at DSOD, to northwest of profile anomaly. (~0.003 mm/yr)
Green Spring Run (GS)	32b Stanislaus Table Mountain - Arnaut Peak	<10 m, down east, top of Tmt, ~52 m/km, western block is backtilted, top of Tmt ***Fault***	Woodward-Clyde Consultants (1978a) identified faulted Table Mountain latite on geomorphic profiles and unfaulted late Pleistocene (<20 ka) alluvium and colluvium in trench exposures. (~0.002 mm/yr)
H&G Mine (HG)	8j Oroville - Monitor Flat	~80 m, down northeast, base of Tml ***Possible fault***	
Happy Hollow Ravine (HHR)	10c Port Wine Ridge - Mount Fillmore	~15 m, down northeast, base of Teg ***Possible fault***	
Haskins Valley (HV)	6b Camel Peak - Haskins Valley	~120-135 m, down west, base of Tml ***Probable fault***	Appears to strike east-west and form northern margin of Haskins Valley, a valley filled with Quaternary sediments. (0.02 to 0.03 mm/yr)
Icehouse (IH)	26b Peavine Ridge	>200 and <320 m, down west, top of Tmm, ~225 m, down west, base of Tmm ***Uncertain***	Tmm remnants are separated by ~5 km, so confirmation is difficult. Anomaly is very large and is probably at least in part cause by deposition around bedrock ridges.
Howell Hill (HH)	19a Roseville - Emigrant Gap	~35 m, down west, top of Tmm ***Uncertain***	coincides with basement Weimar fault

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Jenkinson East (JE)	27b Placerville - Pollock Pines	~32 m/km, shallows west, top of Tmm ***Possible fault***	Down west vertical separation possible. Projection of this fault to the southwest forms eastern side of possible graben occupied by Jenkinson Lake. Tmm basal/ Tov upper contact as mapped by Bedrossian (1979) inconclusive.
Jenkinson West (JW)	27a Placerville - Pollock Pines	~15 m/km, shallows west, top of Tmm ***Possible fault***	Down east vertical separation probable. Projection of this fault to the southwest forms western side of possible graben occupied by Jenkinson Lake. Tmm basal/ Tov upper contact as mapped by Bedrossian (1979) inconclusive.
Junction House (JH)	16b Nevada City - Washington Ridge	~35-45 m, down east, top of Tmm, at Junction House ~50 m, down east, base of Tmm, at Junction House ~25-40 m, down east, top of Tmm, at Burlington Ridge ~7 m/km, shallows west, top of Tmm, at Burlington Ridge ***Suspected fault***	Mapping of Tmm base by Yeend (1974) allows for ~50 m down-east separation in the vicinity of the Giant Gap fault. Kato (1982) shows a fault in Tmm at Junction House with roughly 145 m down-*west* separation on base of Tmm (i.e., opposite sense).
Little Grass Valley (LGV)	Spanish Peak area	Elevation of Tmm remnants indicates 600 m down east separation ***Probable fault***	Evidence for down east displacement(s) just east of Spanish Peak noted by Alt and others (1977). Field reconnaissance of Tioga lateral moraines east of Spanish Peak do not appear offset across fault
	4a Bear Creek - Claremont	roughly 250 m, down east, top of Tml ***Probable fault***	Horizontal gradients assumed for projection of Tml remnants (~0.05 mm/yr)
	5b Mount Ararat - Claremont	$\geq 210^{+15}/_{-20}$ m, down east, top of Tmm, ~17 m/km, shallows west, top of Tmm ***Probable fault***	(~0.04 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Little Grass Valley (LGV) continued	8e Oroville - Monitor Flat	~180 m, down east, top of top flow Tml; ~180 m, down east, top of Tmm, ~10m/km, shallows west, top of Tmm ***Fault***	Evidence for down east displacement(s) east of Dogwood Peak 1st noted by Lindgren (1911) and subsequently by Alt and others (1977). Little Grass Valley fault locally follows the Dogwood Peak basement fault south of Middle Fork Feather River. Page and others (1995) reproduce profile PG&E (data in files) trenched fault and concluded it had multiple late Pleistocene displacements. Total station survey of Tioga lateral moraines east of Dogwood Peak show that moraines are not offset (~0.04 mm/yr)
	9c Mooreville - Gibsonville Ridge	~70 m, down east, base of Teg ***Fault***	Woodward-Clyde Consultants (1978a) identified down-east displacement of Tml Coincident with Mesozoic Dogwood Peak fault at anomaly locality (Saucedo and Wagner, 1992). (~0.01 mm/yr)
	10a Port Wine Ridge - Mount Fillmore	~15-45 m, down east, base of Tmm ***Probable fault***	Poorly defined down east separation of Teg of approximately 70 m. Coincident with Mesozoic Dogwood Peak fault at anomaly locality (Saucedo and Wagner, 1992). (~0.003-0.009 mm/yr)
Black Rock splay (BRS)	8f Oroville - Monitor Flat	~60 m, down east, base of Tmm ***Fault***	Page and others (1995) reproduce profile Field mapping confirms fault at base of Lovejoy (~0.012 mm/yr)
Lexington Hill splay (LHS)	9b Mooreville - Gibsonville Ridge	roughly 70 m, down east, top of Tmm ***Probable fault***	Assumed gradient for top of Tmm remnants on both sides of the fault. (~0.01 mm/yr)
Mountain Boy splay (MBS)	10b Port Wine Ridge - Mount Fillmore	~40 m, down east, base of Tmm ***Probable fault***	(~0.008 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Lovers Leap (LL)	19d Roseville - Emigrant Gap	~10-15 m, down east, top of Tmm, ~19 m/km, steepens west, top of Tmm ***Uncertain***	No mapping of base of Tmm base to evaluate anomaly
Martell (MR)	30b Ione - Cooks Station	~16 m/km, steepens west, top of Tmm ***Uncertain***	Anomaly is suspected to be a fault based on the presence of a change in the gradients of the top and basal contacts of Tmm. However, little, if any, vertical separation is suggested. Mapping by Taliaferro and others (1950).
McKays Point (MP)	32m Stanislaus Table Mountain - Arnot Peak	~40-45 m, down east, top of Tmt ***Uncertain; field relationships need to be confirmed.***	Field mapping places channel margin containing several flows at anomaly that may follow the suspected fault. Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and conclude that the anomaly is caused by differential erosion of the latite prior to deposition of the overlying Mehrten Formation. No fault in tunnel or dam foundation.
Meadow Valley (MV)	Eastern Margin - Meadow Valley	~250 m, down west, top of Tmm ***Probable fault***	Fault forms the east side of basin filled with Quaternary sediments along Spanish and Meadow Valley creeks (~0.05 mm/yr)
	4e Bear Creek – Claremont	~400 m, down west, top of Tmm ***Probable fault***	Meadow Valley fault locally follows the eastern border of the Feather River ultramafic body (Saucedo and Wagner, 1992). Tmm capped by Pliocene basalt on east block (~0.08 mm/yr)
	5d Mount Ararat-Claremont	≤250-285 m, down west, top of Tmm ***Probable fault***	Tmm capped by Pliocene basalt on east block (~0.05-0.06 mm/yr)
	8i Oroville - Monitor Flat	~175 m, down west, base of Tml ***Probable fault***	Fault appears to extend southeastward, crossing eroded part of Gibsonville Ridge profile, but remnant surfaces on Gibsonville Ridge inadequate to evaluate offset. Page and others (1995) reproduce profile (~0.04 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Meeker Bar (MB)	3h North Fork Feather River	~90 m, down east, top of Qfyb, ***Possible fault***	
Miller Ranch (MRH)	13a Camptonville - Old Mountain House Ridge	~0 to 35 m, down east or down west, top of Tmm, ~37 m/km, shallows west ***Suspected fault***	Displacement cannot be defined on this profile: may be either down east or down west. Coincides with Mesozoic Ramshorn fault at this anomaly.
	14c Pliocene Ridge - Keystone Mountain	~25-30 m, down east, top of Tmm, ~5 m/km, shallows west ***Suspected fault***	Coincides with Mesozoic Ramshorn fault at this anomaly.
	15c French Corral - San Juan Ridge	~15-25 m, down east, top of Tmm, ~7 m/km, steepens west, top of Tmm ***Suspected fault***	Coincides with Mesozoic Ramshorn fault at this anomaly.
Moaning Caves East (MCE)	32j Stanislaus Table Mountain - Arnot Peak	~25 m, down west, top of Tmt, ~36 m/km, shallows west ***Uncertain, may be related to karst***	Mapped by Woodward-Clyde Consultants (1978a) Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and concluded that the anomaly may be caused by karst.
Moaning Caves West (MCW)	32i Stanislaus Table Mountain - Arnot Peak	~20 m, down east, top of Tmt ***Uncertain, may be related to karst***	Mapped by Woodward-Clyde Consultants (1978a) and referred to it as a graben. Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and concluded that the anomaly may be caused by karst or landsliding.
Montgomery Meadow (MM)	32r Stanislaus Table Mountain - Arnot Peak	~285 m, down west, base of Tmt, ~50 m/km, western block is backtilted, base of Tmt ***Uncertain; field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and concluded that the stratigraphic relations are not mapped correctly across the anomaly and the channel gradients are oblique to the line of profile. They conclude that the anomaly is not a fault.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Mosquito Creek (MC)	3c North Fork Feather River	~20-25 m, down east, top of Qfyb, ~25-35 m, down east, top of Qfob ***Probable fault***	May follow eastern Feather River ultramafic contact along part of its northern extent. (~0.02-0.04 mm/yr)
Mount Fillmore (MF)	10e Port Wine Ridge - Mount Fillmore	Roughly 60 m, down west, top of Tmm ***Fault***	Assumed gradient on top of Tmm to estimate separation. Fault mapped in Mt. Fillmore vicinity by Strand (1972). (~0.01 mm/yr)
Mount Fillmore East (MFE)	not profiled	down west ***Fault***	Fault mapped in Mt. Fillmore vicinity by Strand (1972).
Muleshoe Mine (MSM)	3g North Fork Feather River	~85 m, down east, top of Qfyb, ~85 m, down east, top of Qfob ***Fault***	Fault trenched by Sawyer and others (1995) and PG&E (1996) and shown to be a late Pleistocen/Holocene fault (~0.08-0.1 mm/yr)
Mulligan Slide (MS)	not profiled	down east ***Fault***	Woodward-Clyde Consultants (1978a) during ground reconnaissance identified down-east displacements of early to middle Quaternary deposits. Follows western border of Feather River ultramafic body west and north of Meadow Valley; elevation of Tmm remnants suggest ~200 m down-east separation along western margin of Meadow Valley; ~30 m down-east separation on ridgecrest overlooking east branch North Fork Feather River Canyon.
Maynards Ranch (MY)	8c Oroville - Monitor Flat	~20-50 m, down west, top of Tml, ~6 m/km, shallows west ***Uncertain; probably a depositional anomaly of the Lovejoy basalt below a channel restriction***	Page and others (1995) reproduce profile Hamilton and Harlan (2002) and Geomatrix (2004) conclude that anomaly is not a fault. Page and Sawyer, 2004, conclude that the anomaly is probably caused by change in depositional environment below a topographic restriction, but field confirmation needed.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Negro Jack Point (NJ)	32a Stanislaus Table Mountain - Arnot Peak	<10 m, down east, top and base of Tmt, base of Tmm, ~45 m/km, eastern block is backtilted, top of Tmt ***Fault***	Identified by Woodward-Clyde Consultants (1978a) as having moved before and after deposition of the Table Mountain Latite and as displacing late Pleistocene deposits older than about 20 ka. (~0.003 mm/yr)
Nevada City (NC)	16a Nevada City - Washington Ridge	~50-60 m, down west, top of Tmm ***Anomaly is caused by* deposition around a bedrock high.**	Field mapping shows that the base of Tmm, Tov and Teg are continuous across step (i.e., no anonaly at bases)
North Fork (NF)	32o Stanislaus Table Mountain - Arnot Peak	~40 m, down west, top of Tmt ~12 m/km, shallows west, top of Tmt ***Uncertain, possible fault; field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary analysis of this and the other anmalies related to the northeast trend of the North Fork Stanislaus River conclude that the overall trend of the river reflects bedrock joints and not a late Cenozoic fault. They relate the anomaly to the profile changing paleochannels across the North Fork.
Omo Ranch (OR)	29b Coyote Ridge - Armstrong Hill	~90-105 m, down west, top of Tmm, ~21 m/km, steepens west, top of Tmm ***Uncertain***	Basal contacts of Tmm & Tov very irregular as mapped by Bedrossian (1979). The contact overall favors possible down-west separation.
Ohio Creek (OC)	3k North Fork Feather River	~25-35 m, down east, top of Qfyb, ~45-55 m, down east, top of Qfob, ***Probable fault***	(~0.05 mm/yr)
Oregon Gulch (OG)	29c Coyote Ridge - Armstrong Hill	~25 m, down west, top of Tmm, ~70-100 m, down west, base of Tmm, ~45 m/km, shallows west, top of Tmm ***Anomaly is caused by differential erosion and construction of profile using eroded remnants.***	Anomaly coincides with a 70-100 m down-west step in the base of Tmm as mapped by Bedrossian (1979). Field reconnaissance by W.D. Page in October 1997 showed disconnected short lineaments with no evidence of faulting in the Mehrten Fm and badly eroded remnants of Mehrten surface.
Oroville (O)	8a Oroville - Monitor Flat	≥30 to ≤105 m, down east, top of Tml, ~23 m/km, steepens west, top of Tml ***Probable fault***	Page and others (1995) reproduce profile

GEOMORPHIC ANOMALY (A0) [1]	**ANOMALY No.** [2] **Profile Name**	**CHARACTER OF ANOMALY** [3] ***Category*** [4]	**COMMENTS** **(long term vertical separation rate)** [5]
Parrotts Ferry (PF)	32h Stanislaus Table Mountain - Arnot Peak	~20 m, down southeast, top of Tmt, ~15 m/km, southeastern block is backtilted, top of Tmt ***Anomaly is caused by projection that does not account for tectonic tilting of the Sierra Nevada and is not a late Cenozoic fault***	Anomaly and apparent backtilting 1st noted by Woodward-Clyde Consultants (1978a) Hamilton and others (2004) in a preliminary analysis of this and the other anmalies related to the northeast trend of the North Fork Stanislaus River conclude that the overall trend of the river reflects bedrock joints and not a late Cenozoic fault. They conclude that the Parrots Ferry anomaly is an artifact in plotting and projection.
Paymaster Mine (PM)	23a Volcanoville - Nevada Point	Roughly ≤105-125 m, down west, top of Tmm Roughly ≤155 m, down west, base of Tmm ***Suspected fault***	Horizontal gradient assumed for top and base of Tmm on west block. Paymaster Mine fault lies in the vicinity of the Mesozoic Volcano Canyon fault at this locality Hudson (1965) reports 80 m down west faulting of the Mehrten on two faults on the south flank of Forest Hill Divide. The Forest Hill Divide geomorphic profile permits a maximum of ~25m on the Tmm surface.
	24a Bottle Hill - Stumpy Meadows Lake	~10-15 m, down west, top of Tmm; ~15 m, down west, base of Tmm ***Fault***	Base of Tmm field checked by Sawyer, 1993. (~0.002-0.003 mm/yr)
	25a Georgetown Divide	Uncertain separation ***Suspected fault***	Possible separation cannot be evaluated on profile, but must be less than 30 m.
Peoria Pass (PP)	32d Stanislaus Table Mountain - Arnot Peak	~20 m, down west, top of Tmt ***Probable fault***	Identified by Woodward-Clyde Consultants (1978a)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Pine Grove (PG)	15b French Corral - San Juan Ridge	~ 30-50 m, down west, top of Teg, ~30 m, down west, base of Teg ***Anomaly is not a fault but a change in gradient caused by a change in rock types across the feature.***	Assumed gradient on Teg west of the fault. PG&E (1991) in the Sweetland trench showed a late Cenozoic fault that did not displace deposits older than 790,000 yrs. Geomatrix (2002) reconstructed the profile with tectonic tilt removed; the result showed only a small steepening of the gradient that they attribute to a change from granitic rock to the northeast to metamorphic rock to the southwest at the anomaly. Mapping proved no late Cenozoic fault at the anomaly.
Plum Valley (PV)	14a Pliocene Ridge - Keystone Mountain	~2-3 m, down east, in Tmm ***Fault***	Alt and others (1977) identified and mapped faults in estimated 20-22 million year old volcanic rocks with small down east displacement; separation too small to be resolved on profile. (< 0.001 mm/yr)
Poorman Gulch (POG)	31d Comanche Reservoir - Mokelumne Hill	~80 m, down east, top of Chili Hill Tuff (Tov); ~30 m, down east, base of Tmm, ~21 m/km, steepens west, Chili Hill Tuff ***Fault***	Poorman Gulch fault lies in the vicinity of the Mesozoic Melones fault zone at this locality. Woodward-Clyde Consultants (1978a) identified faulted late Pleistocene colluvium, Mehrten Formation, and the Valley Springs Formation, with progressively greater displacements with age. (~0.006-0.02 mm/yr)
Post Corral (PC)	32p Stanislaus Table Mountain - Arnot Peak	~70 m, down west, top and base of Tmt ***Uncertain, field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary field investigation mapped the lineaments associated with the anomaly and fond no evidence of faulting and concluded that the fault does not exist.
Queen City (QC)	9d Mooreville - Gibsonville Ridge	Roughly 40 m, down east, top of Tmm ~60 m, down east, top of Tml ***Probable fault***	(~0.01 mm/yr)
Queen Lily (QL)	3b North Fork Feather River	~10-20 m, down west, top of Qfyb, ~15-30, down west, top of Qfob ***Possible fault***	

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Quinn Ranch (QR)	15d French Corral - San Juan Ridge	~40-60 m, down east, top of Tmm, ~17 m/km, shallows west, top of Tmm ***Uncertain***	The projection required for the separation is too long to retain confidence in the anomaly
Randolph Flat (RF)	17a Grass Valley - Quaker Hill	≤10-40 m, down west, top of Tmm, ~15-30, down west, base of Tmm ***Possible fault***	Tmm base mapped by Tuminas (1983).
Rawhide Flat East (RFE)	32f Stanislaus Table Mountain - Arnot Peak	~15 m, down east, top of Tmt ***Fault***	Woodward-Clyde Consultants (1978a) surveyed displacement of the Table Mountain latite and documented in trenches small displacments in mid to late Pleistocene deposits ("paleo-B" deposit and overlying Sonora colluvium), but no displacements in alluvium younger than about 20,000 yrs. (~0.003 mm/yr)
Rawhide Flat West (RFW)	32e Stanislaus Table Mountain - Arnot Peak	~30 m, down east, top of Tmt ***Fault***	Woodward-Clyde Consultants (1978a) surveyed displacement of the Table Mountain latite Biggar and others (1978) trenched fault and showed possible displacements in middle Pleistocene deposits ("paleo-B" deposit). (~0.006 mm/yr)
Round Mountain (RM)	29a Coyote Ridge - Armstrong Hill	~25-30 m, down west, top of Tmm ***Uncertain***	Tmm base shows no evidence for separation as mapped by Busacca (1979).
Salmon Creek (SA)	3j North Fork Feather River	~15 m, down south, top of Qfyb ~0-15 m, down south, top of Qfob ***Suspected fault***	

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Sanborn Mine (SBM)	8d Oroville - Monitor Flat	roughly 40 m, down east, top of Tmm, ~60 m, down east, top of Tml ***Uncertain, may not be late Cenozoic fault***	Alt and others (1977) first recognize anomaly as coinciding with Mesozoic Camel Peak fault at this locality. Parallel gradient assumed for west block, top of Tmm Page and others (1995), reproduce profile Hamilton and Harlan (2002) mapped area in detail and found no evidence of faulting, Page and Sawyer (2004), reviewed the Hamilton and Harlan (2002) evidence and believe that the geology is too complex to be certain of the evaluation
	9a Mooreville - Gibsonville Ridge	~30-55 m, down east, top of Tml ~21m/km, steepens west, top of Tml ***Uncertain, possible fault***	Alt and others (1977) first recognize anomaly as coinciding with Mesozoic Camel Peak fault at this locality. Hamilton and Harlan (2002), mapped area in detail and found no evidence of faulting, Page and Sawyer (2004), reviewed the Hamilton and Harlan (2002) evidence and believe that exposures are insufficient to evaluate base of flow and top Lovejoy remains anomalous if regional tilt is used in the profile
Schneider Creek (SC)	4c Bear Creek - Claremont	≥20 m, down east, top of Tmm ***Suspected fault***	Roughly 170 m vertical separation of Tml base crosses both the Spanish Peak and Schneider Creek faults.
Skinner Flat (SF)	3l North Fork Feather River	~30 m, down east, top of Qcb ***Fault***	Additional 30 m down east separation on Qcb is possible due to tilting. William Lettis and Associates and PG&E (1996) trenched and confirmed fault at Rush Hill site (~0.1 mm/yr)
Skunk Gulch (SG)	32k Stanislaus Table Mountain - Arnot Peak	~40 m, down east, top of Tmt, ~26 m/km, steepens west, top of Tmt ***Uncertain, field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary field investigation mapped the area of the geomorphic anomaly and found no evidence of faulting and that the latite cliffs on each side of the anomaly projected across without appreciable change in elevation.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Snow Mountain (SM)	not profiled	roughly 250 m, down west, top of a Tertiary rhyolite unit ***Probable fault***	Fault based on mapping by Harwood (1980).
Spanish Peak (SP)	4b Bear Creek - Claremont	~ 170 m, down east, base of Tml ***Probable fault***	Vertical separation of base of Tml includes both Spanish Peak fault and Schneider Cr. fault. (~0.03 mm/yr)
Spring Valley (SV)	26a Peavine Ridge	~40 m, down west, top of Tmm, ~40 m, down west, base of Tmm ***Probable fault***	Tmm base mapped by McJunkin and Taylor (1979a,b) (~0.008 mm/yr)
Squaw Hollow (SH)	32n Stanislaus Table Mountain - Arnot Peak	~15 m, down west, top of Tmt ***Uncertain; field relationships need to be confirmed.***	Joins possible North Fork fault to south Hamilton and others (2004), in a preliminary field investigation mapped the lineaments associated with the anomaly and fond no evidence of faulting and concluded that the fault does not exist.
Squirrel Creek (SQ)	14b Pliocene Ridge - Keystone Mountain	~2 m, down east, in Tmm ***Fault***	Pliocene Ridge - Keystone Mountain profile permits 0 - 40 m down-west displacement. Identified by Alt and others (1977) who map small faults with minor displacements in Mehrten Fm as the Pliocene Ridge fault zone. (<0.001 mm/yr)
Studhorse Ravine (SHR)	10d Port Wine Ridge - Mount Fillmore	Roughly 100 m, down west, top of Tmm ***Uncertain, possible fault***	Assumed gradient on top of Tmm to determine separation.

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Succor Flat (SUF)	20b Iowa Hill Divide	~15-25 m, down west, top of Tmm, at Succor Flat ~10-20 m, down west, base of Tmm ~45m/km, shallows west, top of Tmm, at Succor Flat ~10-15 m, down west, top of Tmm, at Roach Hill ~28 m/km, shallows west, top of Tmm, at Roach Hill ***Possible fault***	Mapping by Chandra (1961) in the Succor Flat area permits 10 to 20 m of down-west separation on the base of Tmm
Sucker Run (SRN)	8b Oroville - Monitor Flat	~0-20 m, down east, top of Tml ~14 m/km, shallows west, top of Tml ***Uncertain, probably not a late Cenozoic fault***	Page and others (1995) reproduce profile Hamilton and Harlan (2002) attribute anomaly to differential erosion and point out that no fault occurs in the Forbestown tunnel at the lineament. Geomatrix (2004) reviewed data and concludes that anomaly is not a late Cenozoic fault. Page and Sawyer (2004) reviewed the data and conclude that the anomaly is probably not a fault, but field confirmation needed.
Sunnybrook East (SE)	30a Ione - Cooks Station	~0 to 10 m, down east or down west, top of Tmm, ~21 m/km, shallows west, top of Tmm ***Uncertain, possible fault***	Woodward-Clyde Consultants (1978), Earth Sciences Associates (1992), and Pacific Gas & Electric Company (1978). Dames and Moore (1993) called fault down east; our profile permits both, but favors down west displacement. Mapping of Tmm base supports gradient change, but little or no separation (could be pre-Tmm relief).
Swain Ravine (SR)	12b Bangor	~$20^{+5}/_{-10}$ m, down west, top of Tpl, ~20m/km, eastern block is backtilted, top of Tpl ***Fault***	Tpl unit used for separation is the Lower Laguna Formation as mapped by Busacca (1992). PG&E (1992) showed offset on geomorphic profile Woodward-Clyde Consultants (1978a) confirmed faulting in Laguna Formation and middle Pleistocene deposits; ground cracks in 1975 Oroville earthquake (~0.004 mm/yr)

GEOMORPHIC ANOMALY (A0) [1]	ANOMALY No. [2] Profile Name	CHARACTER OF ANOMALY [3] *Category* [4]	COMMENTS (long term vertical separation rate) [5]
Waller Creek (WC)	3a North Fork Feather River	~20-30 m, down west, top of Qfyb ***Suspected fault***	
Waters Peak (WP)	31a Comanche Reservoir - Mokelumne Hill	~60-120 m, down east, Castle Rock Tuff (Tov), ~79-4 m/km, eastern block is backtilted, Castle Rock Tuff ***Fault***	(~0.01-0.02 mm/yr)
Weber (W)	28a Ridge South of Placerville	≥55-70 m, down east, top of Tmm <10 m, down east, base of Tmm ~17 m/km, shallows west ***Not a late Cenozoic fault based on Hamilton's mapping***	Step in Tmm disappears along strike in remnant. Hamilton (1994) mapped the contacts of the Mehrten and along the lineament associated with the geomorphic anomaly and found no evidence of faulting and concluded it is not a late Cenozoic fault.
Whittakers Dardanelles (WD)	32q Stanislaus Table Mountain - Arnot Peak	~35-40 m, down east, base of Tmt, ~56 m/km, shallowing east (apparent backtilt), base of Tmt ***Probably not a fault, field relationships need to be confirmed.***	Hamilton and others (2004) in a preliminary field investigation mapped the stratigraphy of the volcanic rocks across the anomaly and found no evidence of faulting, related the back tilting to a projection anomaly and concluded that the fault does not exist.
Wyandotte Creek (WYC)	12a Bangor	~10-15 m, down west, top of Tpl marker unit ~10 m, down west, base of Tpl marker unit ~8 m/km, steepens west, top of Tpl ***Suspected fault***	
Youngs Creek (YC)	31c Comanche Reservoir - Mokelumne Hill	~5 m, down east, Chili Hill Tuff (Tov) ~5 m, down east, Tmm marker bed ***Suspected fault***	

Notes:

1. Anomaly, except those indicated as uncertain, are located on Figure 1-2.
2. Reference number refers and fault descriptors used to the locate the anomaly on profiles and maps; profile numbers progress from North to South from Deer Creek and the North Fork Feather River near Chico to the Stanislaus River near Sonora (in PG&E files).
3. Stratigraphic units are Tmm – Mehrten Fm.; Tml – Lovejoy Basalt; Tvs – Valley Springs Fm.; Teg – 'auriferous gravels'; Tov – Valley Springs Fm. including Castle Rock Tuff and Chili Hill Tuff members; Tpcb – Cohasset Ridge basalt; Qdb – older basalt; Qfyb – younger basalt; Ocb – basalt
4. Category:
   Fault – anomaly proven to be late Cenozic fault
   Probable fault – anomaly has strong overall evidence of being formed by late Cenozoic faulting
   Suspected fault – anomaly has moderate overall evidence of being formed by late Cenozoic faulting
   Possible fault - anomaly has low overall evidence of being formed by late Cenozoic faulting
   Uncertain– anomaly origin uncertain, may be formed by faulting, differential erosion, depositional constraints, or other mechanism
5. Long-term separation rate (vertical) shown for anomalies that are faults or probable faults. Rate assumes that the duration of vertical separation has taken place in the past 5.0 Ma for Tmm, Tml, Tvs, Teg, Tov (Castle Rock Tuff, Chili Hill Tuff); 2.4 Ma for Tpcb; 1.1 Ma for Qdb; 1.0 Ma for Qfob; 0.6 Ma for Qfyb; 0.3 Ma for Qcb.

TABLE 3-2
QUATERNARY STRATIGRAPHY,
NORTHERN AND CENTRAL SIERRA NEVADA FOOTHILLS

TIME - (years B.P.)	**SIERRA NEVADA FOOTHILLS**
Present	**Keystone** colluvium and alluvium
	< 1,325 yrs*
4,000	<~4,000 yrs
	Several colluvial units at higher elevations
	soil formation
9,000	**Sonora** colluvium and alluvium
	(2 colluvial units)
	9,130 ± yrs*
10,000	13,510 and 20,360 yrs*
14,000	
20,000	soil formation
35,000	
	Wyandotte colluvium and alluvium
70,000	
	"red" soil formation
100,000	"red" colluvium
~ 140 ka	soil formation (paleo-B)
	Oroville colluvium and alluvium
	soil formation (paleo-B)
~ 260 ka	**Bowie Flat** colluvium and alluvium
	soil formation (paleo-B ?)
~ 550 ka	**Auburn** colluvium and alluvium
> 730 ka	Thick Saprolite formation in bedrock
> 1 my	Residual soils with iron pisoliths

Modified from Harden and Marchand, 1980

* Dates are radiocarbon dates.

Table 3-2, p 1.

TABLE 3-3

CORRELATION OF QUATERNARY STRATIGRAPHY - SIERRA NEVADA FOOTHILLS AND SAN JOAQUIN VALLEY

NORTH	Foothills Sierra Nevada Harden and Marchand, 1980	Dogwood Peak Trench PG&E, 1994d	Milk Ranch Road Trench PG&E, 1991a; 1992b	School-house Creek Trench PG&E, 1991, 1992b	Sweetland Trench PG&E, 1991; 1992b	Wolf Creek-49 Trenches PG&E, 1994 (this study)	Big Hill Trench PG&E, 1994 (this study)	Baker Ranch Trench PG&E, 1994a	Mt. Hope Trenches PG&E, 1994a	Ione U.S. Army Corps of Engineers, 1994	Waters Peak South T-6 U.S. Army Corps of Engineers, 1994	SOUTH San Joaquin Valley Marchand and Allwardt, 1981
River Basin	Feather to Stanislaus	Feather River, N. of Laporte	Yuba River, S. of Challange	Yuba River, N. of North San Juan	Yuba River, S. of North San Juan	Bear River, N. of Auburn	Bear River, N. of Auburn	American River, N. of Foresthill	American River, S. of Foresthill	Mokelumne River, S. of Ione	Calaveras River, S. of Valley Springs	Mokelumne to Tuolumne rivers
Elevation	800 - 2,000 ft	5,600 ft	2,700 ft	1,900 ft	2,100 ft	1,400 ft	1,150 ft	3,600 ft	3,400 ft	300 ft	600 ft	100 to 500 ft
Ecosystem	Oak and pine woodland	Fir forest	Fir and pine forest	Fir and pine forest	Oak and pine woodland	Oak woodland	Oak woodland	Fir and pine forest	Fir and pine forest	Oak Woodland	Oak Woodland	Grassland and Oak Woodland
Slope	mod. to low	mod. to low	low	steep	mod. to low.	mod. to low	low	low	low	moderate	mod to low	low
TIME- YRS Present	Keystone Colluv./Alluv. < 1,325 ±						Incision	na	na	Incision Debris Flow 5	Incision	
2,000		Colluv. 1	Colluv. 1	Colluv. 1	? Colluv. 1		Colluv. C-1 ?			Debris Flow 4 2,540 1,460		
4,000		Colluv. 2 3,866 ± 3,001 ± 1,616 ±	Colluv. 2 2,575 ± 2,025 ±	Colluv. 2 4,132 ± ; 4,610 ±	? Colluv. 2	Colluv. C-1 3,713 ± 360 ± 413 ± 1 582 ± 200 ±		Colluv. C-1a	Colluv. C-1a	Debris Flow 3 2,805 3,360		
	soil formation				weak soil	soil	weak soil	weak soil	weak soil	weak soil	soil	soil
8,000 10,000 30,000	Sonora Colluv./Alluv. 9,130 ±	Colluv. 3 9,063 ± 8,802 ±	Colluv. 3 6,485 ± / ? 5,075 ± / ?	Colluv. 3	? Colluv. 3	Colluv. C-2 1,118 ± / ? 774 ± / ? 715 ± / ? 858 ± / ? 447 ± / ?	Colluv. C-1 ?	Colluv. C-1b 2,000 ± / 1,800 ± /	Colluv. C-1b 7,600 ± 5,231 ± / 2,400 ± /	Debris Flow 2 Debris Flow 1	Colluv. Qcmu Alluv. Qamu	Upper Modesto
	soil formation	?			weak soil	soil	soil				soil	soil
35,000 70,000	Wyandotte Colluv./Alluv.	Colluv. X-1 ? Colluv. X-2	Colluv. 4 20,360 ± 13,510 ±		Colluv. 4	Colluv C-3 200 ± / ? 409 ± / ? Coluv. C-4 X? Coluv. C-5 X?	Colluv. C-2 Alluv. A-1				Colluv. Qcml Alluv. Qaml	Lower Modesto
	soil formation						soil	soil	soil		soil	
~ 140,000	"red" Colluv./Alluv.						Colluv. C-3 Alluv. A-2	Colluv. C-2 25,000 ± / 2,300 ± / 3,400 ± / 7,600 ± /	Colluv. C-2 45,400 ± / 40,200 ± / 40,200 ± / 39,000 ± / 39,000 ± v 29,000 ± / 25,100 ± / 16,700 ± / 14,000 ± / 7,500 ± / 6,600 ± / 5,200 ± / 2,500 ± / 2,400 ± /		Coluv. Qcrb(u) Alluv. Qarb(u)	Riverbank 3
	soil formation	?										soil
~ 260 ka	Oroville Colluv./Alluv. soil formation	Colluv. X-3					Colluv. C-3 Alluv. A-2	Colluv. 4 4,200 ± /n				Riverbank 2 soil
–	Bowie Flat Colluv./Alluv. soil formation						Paleo-B					Riverbank 1 soil
~ 550 ka	Auburn Colluv./Alluv.				Channel 3 ?						Alluv. Qat (?)	Turlock Lake 2
> 730 ka					paleo-B soil Paleomag-reversed	paleo-B soil/ Colluv. C-4 Alluv. A-3 Paleomag-reversed	paleo-B soil/ Colluv. C-4 Alluv. A-3					
~ 1 my					Channel 2							
~ 2 my					Channel 1							

Note:
Table unmodified from PG&E, 1994a

TABLE 3-4
CRITERIA FOR EVALUATING THE ACTIVITY OF FAULTS IN THE SIERRA NEVADA

A. Criteria in Bedrock

1. Narrow clay gouge zone in older, broad shear zone.
2. Fault cuts across regional foliation.
3. Tilting or warping of adjacent rock units.
4. Intrusion of gouge into bedrock.

B. Criteria in Cenozoic Deposits

1. Fault displacement of Cenozoic deposits.
2. Significant change in the gradient of Cenozoic deposits.

C. Criteria in Surficial Deposits

1. Displaced alluvial or other deposits.
2. Ground cracks related to surface rupture.
3. Colluvium-filled cracks that extend into the fault zone in bedrock.
4. Slickensided surfaces extending from gouge into surficial deposits.
5. Steps in bedrock-overburden contact and thickening of surficial deposits on the footwall.
6. Displacement and discontinuous stone lines between colluvial units.
7. Sags in paleo-B deposit often found over clay gouge.
8. Sequence of colluvial/alluvial deposits on footwall (down dropped side) that is missing or thinner or hanging wall of fault.
9. Intrusion of gouge into surficial deposits.

D. Topographic Criteria

1. Subtle topographic anomalies over faults in metamorphic terrain.
2. Faults associated with lineaments characterized by sheared bedrock, spring lines, vegetation changes, broad topographic changes, lithologic contacts, linear valleys and stream segments, saddles, notches, etc.
3. Displaced erosional surfaces.

Table 3-4, p. 1

TABLE 3-5
LINEAMENTS AND STRUCTURES TRENCHED IN THE SIERRA NEVADA

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure [2]**	**References, comments**
Baker Ranch fault American River; 6 km northeast of Forest Hill	Moderate Linear streams, aligned saddles, degraded scarp (12 km)	Main fault • Sonora colluvium • Wyandotte (?) Colluvium • Bedrock has no evidence of post-saprolite faulting Antithetic fault • Keystone/Sonora colluvium	Main fault • Mehrten faulted against metamorphic rock Antithetic fault • Mehrten Fm • Pocket of Wyandotte (?) Colluvium	Pre-late Pleistocene	PG&E, 1994a Baker Ranch site: 3 trenches aligned to cross fault, SW ¼, Sec.8, T14N, R10E
Bowie Flat fault Stanislaus River; 15 km northeast of Knights Ferry	(31 km)	• Sonora colluvium	• Relief Peak Fm (16-22 ft) and monoclinal structure in scrapedown • Table Mountain Latite (20-50 ft) • 'Paleo B' deposit truncated • Fractures in cemented Wyandotte (?) colluvium • Clay filled fractures in bedrock	Pre-latest Pleistocene; late Pleistocene ?	Biggar and others, 1978 Trench , NW ¼, Sec 17, T1N, R13E Woodward-Clyde Consultants, 1978 11 trenches at Shotgun Creek scrapedown at isolated flow and at Bowie Flat: SE ¼, Sec 28, T1N, R13E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Cascade anomaly South Fork. Feather River; 40 km northeast of Oroville	Weak -Moderate Linear valley, straight stream reaches, alluvial deposits at fault in Fall River at Quartz creek (8 to 10 km)	• No Quaternary deposits in trench	• Offset Lovejoy Basalt (?) • Sheared contact of dike rock in granitic bedrock; without characteristics of a late Cenozoic fault (trenches did not completely cross potential fault location) •Fault exposed in road cut NW of Fall River Campground that projects toward the anomaly	Pre-late Cenozoic (?) May not be late Cenozoic fault	PG&E profile in files Lovejoy basalt appears offset Hamilton and Harlan, 2002 2 trenches in the Cascade Gap, NE ¼, Sec. 10, T21N, R7E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Cleveland Hill fault Feather River; 8 km southeast of Oroville	Weak Shallow break in slope on west side of linear hill (12 to 18 km)	• Laguna Fm at projection of south end not faulted	• Surface rupture during 1975 Oroville earthquake • Sonora and Wyandotte colluvia • 'Paleo B' deposit (s?)	Historical • 1975 Holocene	Clark and others, 1976 Woodward-Clyde Consultants, 1976;1978 Cleveland Hill site: 1 trench, NW ¼, Sec 7, T18N, R5E Grubbs site: 1 trench, NW ¼, Sec 31, T19N, R5E Sims site: 1 trench in SW ¼, Sec 31, T19N, R5E Lorraine site: 3 trenches, SW ¼, Sec 6, T18N, R5E Department of Water Resources, 1978 10 trenches, Sec 19 and 30, T19N, R5E 3 trenches, SW 1/4 Sec 6, T18N, R5E U.S. Army Corps of Engineers, 1977 Grubbs site: 1 trench, NW ¼, Sec 31, T19N R5E Cleveland Hill site: 2 trenches, NW ¼, Sec 6, T18N, R5E Schwartz and others, 1977 Reassessed work of others
Clovis lineaments Kings River; 7.5 km north of Clovis • **Southern lineament** • **Middle lineament** • **Northern lineament**		• Turlock Lake Fm • lower (?) Riverbank Fm • Turlock Lake Fm		Non-tectonic • No fault encountered in trenches	U.S. Army Corps of Engineers, 1997 Southern lineament: 1 trench, NE ¼, Sec 6, T11S, R20E Middle lineament: 2 trenches, SE ¼, Sec 15, T11S, R21E Northern lineament: 1 trench, NE ¼, Sec 5?, T11S, R20E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Deadman fault Bear River; 5 km northwest of Auburn	Moderate Linear valleys, straight streams, saddles, vegetation lineations (14 km)	• Keystone/ Sonora colluvium •Wyandotte colluvium • Mehrten Fm at south end	• 'Paleo B' deposit • bedrock fault has late Cenozoic characteristics	Pre-latest Pleistocene	Schwartz and others, 1977 Henriques-Wilson site: test pits PG&E, 1994b Mt. Vernon Rd. site: 1 trench, SE ¼, Sec 31, T13N, R8E
Del Orto 'fault' (Mokelumne Hill Quartz diorite contact) Mokelumne River; 5 km northwest of San Andreas				Non-tectonic • No fault encountered in trenches; quartz diorite contact	Biggar and others, 1978 Del Orto site: 1 trench, SE ¼, of Sec 14 T5N, R11E
Dewitt fault Bear River; 8 km northwest of Auburn	Weak-Moderate Linear valley and streams, spring lines, vegetation lineament (14 km)		• Keystone colluvium deformed •Sonora colluvium deformed, shears at base •'Paleo B' deposit • bedrock fault has late Cenozoic characteristics	Latest Pleistocene or Holocene	Alt and others, 1977 Schwartz and others, 1977 Bean Road site: 1 trench, SE ¼, Sec 32, T13N, R8E St. Joseph site: 3 trenches, SE ¼, Sec 32, T13N, R8E Hubbard Rd. site: 2 trenches, NW ¼, Sec 19 T13N, R8E PG&E, 1994b Big Hill site: 2 trenches, NW ¼, Sec 13, T13N, R7E
Empire Creek structure Stanislaus River; 15 km west of Sonora	Linear topographic high (7 mi)	•Sonora colluvium •'Paleo B' deposit •Table Mountain Latite	• sheared serpentine against metamorphic rock • No late Cenozoic fault characteristics	Pre-late Cenozoic Not a late Cenozoic fault	Biggar and others, 1978 Nelson site: 1 trench, NW ¼, Sec 6, T1N, R13E Woodward-Clyde Consultants, 1978

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Frazier Valley lineament Tule River; 17 km northeast of Porterville		• Turlock Lake age paleosols not displaced	• No faulting observed in bedrock	Non-tectonic (referred to as lineament H-54)	U.S. Army Corps of Engineers, 1988b Frazier Valley site: 3 trenches, SE ¼, Sec 9, T21S, R28E
Giant Gap fault North Fork American River 35 km northeast of Auburn	Moderate-Strong Linear streams, aligned saddles, ponded alluvium (13 to 25 km)		• Alluvium and terraces on North Fork American River above Giant Gap indicate Quaternary displacement • Mehrten Formation • Sonora colluvium?	Late Pleistocene or Holocene? USBR Trenches may have missed fault	Alt and others, 1977 US Bureau of Reclamation, 1978 Giant Gap ridge site: 2 trenches; one in NW ¼, Sec 13, one in SW ¼, Sec 18, T15N, R10E Berloger Geotechnical Consultants, 1995 Mule Spring site: 2 trenches, plus Naylor Pit exposure, NW ¼, of Sec 24, T16N, R10E
Green Spring Run fault (east side of O'Byrne Ferry monocline) Stanislaus River; 12 km northeast of Knights Ferry	Weak-Moderate Linear Valley, (53 km)	• Sonora colluvium, older alluvium, and 'Paleo B' deposit not displaced	• Table Mountain Latite (20 ft.)	Pre-late Pleistocene	Woodward-Clyde Consultants, 1978 1 trench near Keystone, SW ¼, Sec 24, T1S, R13E Biggar and others, 1978 Reassessed fault

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Haupt Creek fault Stanislaus River; 8 km east of Valley Springs	Weak-Moderate CHECK Spring line, vegetation contrasts (>7 km?)	• Chili Hill tuff in Valley Springs Fm. • Sonora colluvium • Mehrten Formation	Sheared slate/volcanic breccia contact • No late Cenozoic fault characteristics	Pre-late Cenozoic Not a late Cenozoic fault	Biggar and others, 1978 Haupt Creek site: 4 trenches, NW ¼, Sec 10, T4N, R11E Woodward-Clyde Consultants, 1978
Hetch Hetchy Junction structure Stanislaus River; 18 km northeast of Knights Ferry		• Sonora colluvium • 'Paleo B' deposit		Pre-middle Pleistocene	Woodward-Clyde Consultants, 1978 Hetch Hetchy Junction site: 2 trenches, SE ¼, Sec 6, T2S, R14E
Highway 49 fault (east) Bear River; 5 km west of Grass Valley	Moderate-Strong Linear valleys and streams, aligned saddles, braided stream, vegetation linears, possible 'ponded' alluvial deposits (21 km)	• Sonora and older colluvia • 'Paleo B' deposit	• Bedrock fault in metavolcanic, metasedimentary, serpentinite, and gabbro has late Cenozoic characteristics	Pre-late Pleistocene	PG&E, 1994b Wolf Creek East site: 1 trench, NE ¼, Sec 16, T14N, R8E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Highway 49 fault (west) Bear River; 5 km west of Grass Valley	Moderate-Strong Linear hillside bench, aligned saddles, linear valleys, vegetation linears (21 km)	Main fault zone • Sonora and Wyandotte Colluvia Secondary fault at Smith site • Wyandotte alluvium/colluvium	• Colluvial wedges • 'Paleo B' deposit • bedrock fault has late Cenozoic characteristics • Possible fracture fill in older colluvium	Pre-latest Pleistocene	Alt and others, 1977 Smith site: 1 trench plus test pits, NE 1/4 Sec 9, T14N R8E PG&E, 1991; 1994b Wolf Creek West site: 2 trenches, NE ¼, Sec 16, T14N, R8E
Ione fault Mokelumne River; 2 km east of Buena Vista		• Late Holocene debris flows not deformed	• Sonora-aged debris flows possibly deformed	Holocene ?	U.S. Army Corps of Engineers, 1995 Ione site: 2 trenches, NE ¼, Sec 8, T3N, R11E
Keystone structure Stanislaus River; 22 km south of Sonora	Well defined air photo lineament	• Sonora colluvium • 'Paleo B' deposit	Shearing in greenstone, ??	Pre-late Pleistocene Probably not a late Cenozoic fault	Woodward-Clyde Consultants, 1978 Keystone site: 2 trenches, SW ¼, Sec 13, T1S, R13E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Knickerbacher structure American River, -- km southeast of Auburn	(~10 km)		Bedrock fault with late Cenozoic characteristics.	Late Cenozoic No 'paleo B exposed' and no assessment made.	Schwartz and others, 1977 Several test pits, reviewed USBR site with 3 trenches
Linda Creek lineament (Aune's [1973] Linda Creek fault) American River; 5 km west of Folsom Dam in Orangevale	Weak to locally Moderate Linear drainage of Linda Creek; aligned hills and gullies and vegetation anomalies (length not reported; ~6 km along Linda Creek)	• Modesto Alluvium • Laguna Fm • 'Paleo B' developed on Fair Oaks Fm • Fair Oaks Fm	Non tectonic Non shears or faults in trench Few fractures interpreted to be from desiccation	Pre-late Cenozoic No fault found in trenches	Alt and others, 1977 Linda Creek site: 3 trenches: SE ¼, Sec 8, and NW ¼ sect 20, T10N, R7E
Little Grass Valley fault South Fork Yuba River; 5 km north of La Porte	Moderate-Strong Linear drainages, aligned saddles, break in slope at broad scarp along mountain front (15 to 33 km)	• Sonora colluvium • Glacial moraines apparently not displaced (Tioga ~15,000 years)	• Several colluvial wedges interpreted to be fault derived • gouge injected along fault • Mehrten Fm • Lovejoy Basalt	Late Pleistocene	PG&E, in files Dogwood Peak site: 3 trenches, SW ¼, Sec 8, T10N, R8E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Maidu East fault American River; in Auburn	Weak Short tonal contrasts of photos, saddles (4 km)	• Mehrten Fm not displaced on geomorphic profile to North of trenches	• Mehrten Fm (18 ft, dies out to North) • 'Paleo B' deposit • Wyandotte (?) colluvium • Sonora colluvium displaced in trench GT-1	Pre-latest Pleistocene	Schwartz and others, 1977 Maidu E-Connecting Rd. site: 5 trenches; 25+ trenches by USBR, all within Sec 22, 23, 26, and 27, T12N, R8E PG&E, 1994 Geomorphic profile through Auburn
Marys Ravine fault North Fork Yuba River; 3 km west of North San Juan	Moderate- Strong Linear drainages, saddle, straight stream reach (5 km)	• Keystone/ Sonora colluvia • Eocene 'auriferous gravels' at south end	• Sheared intrusive contact, not characteristic of late Cenozoic bedrock fault	Pre-late Cenozoic	PG&E, 1991 Schoolhouse site: 1 trench, SE ¼, Sec 13, T17N, R7E Geomatrix Consultants, 2004, reassessed fault
Merced-Mariposa County Line lineament Bear Creek; 15 km east of Merced				Non-tectonic • No fault encountered • Possible cultural feature	U.S. Army Corps of Engineers, 1988a 1 trench, NE ¼, Sec 5, T7S, R16E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Mill Creek Valley lineament (Foothills lineament) Kings River; 23 km NE of Sanger		• granitic bedrock • Modesto colluvium		Non-tectonic • No fault encountered	U.S. Army Corps of Engineers, in progress 1 trench, SE ¼, Sec 3, T12S, R23E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Mormon Island fault Consumnes River; 3 km west of Latrobe		• Sonora and older colluvia (locally)		Pre-latest Pleistocene	Tierra Engineering Consultants, Inc., 1983 Russell Ranch site: 1 trench, NW ¼, Sec 28, T9N, R7E Dunlap Ranch site: 1 trench, NW ¼, Sec 31, T8N, R8E
Mt. Hope anomaly American River; 25 km northeast of Auburn	Weak Linear drainages, aligned saddles (9 km)	• Mehrten Fm at north and south ends	No shears or faults in trench	Non-tectonic Anomaly caused by differential erosion	Alt and others, 1977 Refer to this structure as Horseshoe Bend fault PG&E, 1994b Mt. Hope site: 2 trenches in NW ¼, Sec 9, T13N, R10E
Muleshoe Mine fault (Butt Valley fault zone) North Fork Feather River; 14 km southeast of Chester	Strong Scarp in basalt, linear valley (15-17 km)	• faults extend to base of bioturbated zone	• Krotovina with charcoal dated at 8,000 is sheared • 100,000 ± 50,000 colluvium • Multiple displacements in older deposits	Late Pleistocene-Holocene	William Lettis and Associates and PG&E, 1996 Prattville site: 1 trench, SW ¼, Sec 14, T27N, R7E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Negro Jack Point fault **(west side of O'Byrne Ferry monocline) Stanislaus River; 11 km northeast of Knights Ferry**	Weak to Strong Linear scarps in latite flow, weak scarp in metamorphic rocks (5 km)	Sonora Colluvium thins over fault	• Sonora colluvium truncated (?) • Colluvial wedges • Multiple fracture fills in fault • Table Mountain Latite (33 ft) • Relief Peak Formation (44 ft) • Slate/greenstone contact, weak shearing	Latest Pleistocene or Holocene? Multiple displacements, oldest is 2 my, youngest is latest Pleistocene or Holocene	Biggar and others, 1978 Negro Jack Pt. site: 4 trenches, NE ¼, Sec 6, T1S, R13E Woodward-Clyde Consultants, 1978 Table Mt. latite site: 2 trenches, SE ¼, Sec 8, T1S, R13E
"New York Creek" fault Consumnes River; 10 km east of Folsom		•Sonora colluviun and alluvium	• shearing and faults in metamorphic bedrock	Pre-latest Pleistocene	Wheeldon and Associates, 1980 El Dorado Hills school site: 3 trenches, SW ¼, Sec 35, T9N, R8E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Orleve-Woodleaf lineament North Fork Yuba River; 4 km east of Challenge	Weak, locally Moderate Linear streams, aligned saddles, 'low scarp' in broad ridgecrest saddle, aligned hillside saddles (22 km with Orleve and Woodleaf lineaments)	• Sonora colluvium • Wyandotte (?) colluvium (>100,000 yrs) • Weathering of quartz vein • Saprolite bedrock does not have evidence of shearing since formation >1my	• Shearing in granitic bedrock does not have characteristics of late Cenozoic faulting	Pre-late Cenozoic Not a late Cenozoic fault	PG&E, 1991 Milk Ranch Rd site: 2 trenches, NW ¼, Sec 34, T19N, R7E Hamilton and Harlan, 2002 Reassessed fault Geomatrix Consultants, 2004 Reassessed fault
Paynes Peak fault Feather River; 7 km east of Oroville	Moderate-Strong Linear valleys separated by low saddles, vegetation contrasts, spring lines (22 km)	•Sonora colluvium •younger 'Paleo B' deposit (possibly)	•Laguna Formation (15-20 ft??) •older 'Paleo B' deposit	Pre-late Pleistocene	Woodward-Clyde Consultants, 1978 Burt site: 2 trenches, SE ¼, Sec 3, T17N, R5E Knapp site: 1 trench, SE ¼, Sec 28, T18N, R5E PG&E, 1992 constructed geomorphic profile and reassessed fault
Peoria Basin structure Stanislaus River; 20 km east of Knights Ferry	Vegetation linear, spring line (~5 km)	• Sonora colluvium • 2 'Paleo B' deposits • Table Mountain Latite	Sheared serpentine; no characteristics of late Cenozoic fault	Pre-late Cenozoic	Biggar and others, 1978 Price site: 1 trench, SW ¼, Sec 24, T1N, R13E Woodward-Clyde Consultants, 1978aassessed fault

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Peoria Pass fault Stanislaus River 15 km southwest of Sonora	Scarp in latite, vegetation lineament, spring line (--)	• 'Paleo B' deposit	• Table Mountain Latite (29 m) • Relief Peak Formation (80 ft) • Paleo B deposit below Relief Peak may be intruded by infilling fractures	<u>Pre-late Pleistocene</u>	Biggar and others, 1978 Martin site: 3 trenches, test pits, NW ¼, and SE ¼, Sec 35, T1N, R13E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Pine Grove fault Middle Fork Yuba River; 3 km southwest of North San Juan	Moderate Linear drainages, aligned sidehill saddles, inflection at base of ridge (7 km)	• Eocene ‘auriferous gravel’ at north end, originally interpreted as displaced, not displaced • Sonora and older colluvia • ‘Paleo B’ deposit and older alluvium paleomagnetically reversed	• Faults in metamorphic rock have characteristics of late Cenozoic fault	Pre-middle Pleistocene	PG&E, 1991 Sweetland site: 2 trenches in NW ¼, Sec 18, T17N, R7E Hamilton and Harlan, 2002 Reassessed fault Geomatrix Consultants, 2004 Reassessed fault

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Poorman Gulch fault Mokelumne River; 6 km northwest of San Andreas	(> 7 --)	• Sonora colluvium	• Wyandotte colluvium • 'Paleo B'' deposit • Mehrten Fm (90 ft)	Pre-late Pleistocene	Biggar and others, 1978 Mother lode site: 3 trenches NW ¼, Sec 26, T5N, R11E Woodward-Clyde Consultants, 1978
Powerhouse fault (New Melones Damsite) Stanislaus River; 12 km west of Sonora	Moderate Shoulders on mountainside	• Sonora Colluvium and stone line at base • Paleo B deposit thickens across underlying clay zone, but within variations elsewhere • Older paleosol in pocket in bedrock	Local features of late Cenozoic fault but not continuous, not considered a late Cenozoic fault	Middle to late Pleistocene	Biggar and others, 1978 Powerhouse site: 2 trenches in S ½, of Sec 10, T1N, R13E
Powerhouse shear (New Melones Damsite) Stanislaus River; 12 km west of Sonora				Non-tectonic •No Quaternary or Tertiary deposits overlying shear	Biggar and others, 1978 Peoria Mt. site: 1 trench in NW ¼, Sec 14, T1N, R13E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Prairie Creek fault Yuba River; 20 km east of Marysville		• Sonora colluvium and alluvium	• 'Paleo B' deposit possibly displaced	Pre-latest Pleistocene	Woodward-Clyde Consultants, 1978 Wilson site: 2 trenches in SW ¼, Sec 33, T17N, R5E O'Brien site: 1 trench in NE ¼, Sec 19, T17N, R5E U.S.Army Corps of Engineers, 1977
Radio tower shear zone Americal River; Auburn damsite in Auburn		•Mehrten Fm	• Channel margin with shears and crenulations; not late Cenozoic fault. • Fractures with colluvial fills in Mehrten interpreted to be topples, and not tectonic.	Non-tectonic	Schwartz and others, 1977 Radio tower site: 5 trenches in Sec 5, T12N, R8W
Rawhide Flat East fault Stanislaus River; 7 km southwest of Sonora	Scarp on latite (>16 km)	• Keystone colluvium	•Sonora colluvium • 'Paleo B' deposit • Table Mountain Latite (55 ft) • Fault in metavolcanic rock and serpentine with late Cenozoic characteristics	Holocene	Woodward-Clyde Consultants, 1978 Rawhide Flat trench 1 in NW ¼, Sec 9, T1N, R14E Biggar and others, 1978 Rawhide Flat trenches 2, 3, and 4 at same locality
Rawhide Flat West fault Stanislaus River; 7 km southwest of Sonora	Scarp on latite (10 km)	•Sonora colluvium •Paleo B deposit (?)	• 'Paleo B' deposit (?) • Table Mountain Latite (75 ft) • Fault in gabbro and sheared serpentine with late Cenozoic characteristics	Pre-late Pleistocene	Biggar and others, 1978 Rawhide Flat trench 5 plus test pits on W side, Sec 9, T1N, R14E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Rescue fault American River; 14 km southeast of Auburn	Moderate- Strong Linear drainages, linear vegetation patterns, spring line (14 km)	• Keystone colluvium (but very thin over fault in one trench)	• 'Paleo B' deposit • Keystone/Sonora colluvium thickens on uphill side of fault • Wyandotte (?) colluvium • Fault in metavolcanic rock and serpentine with late Cenozoic characteristics	Pre-Holocene (?)	Schwartz and others, 1977 Knolls site: 1 trench in SE ¼, Sec 34, T11N, R9E Luneman Rd. site: 3 trenches in E ½, Sec 34, T11N, R9E)
Salt Creek lineament American River; in and southeast of Auburn	Moderate Broad linear valley, linear vegetation contrasts, spring lines (15 km)	• Sonora (?) alluvium • Paleo B deposit		Non-tectonic • Interpreted to be foliation and shearing, weathered to clay along igneous-metamorphic contact, not late Cenozoic fault	Schwartz and others, 1977 Bayley House site: 3 trenches in E ½, Sec 30, T12N, R9E Salt Creek site:

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	Character of associated lineament (length)	Oldest unit not displaced	Youngest units displaced	Assessment of Lineament/ structure [2]	References, comments
Skinner Flat fault North Fork Feather River; 2.5 km south of Canyon Dam	(~16 km)	• 36-38,000 year old colluvium	•50-100,000 year old colluvium • Basalt of Westwood (410 ka)	Late Pleistocene	William Lettis and Associates and PG&E, 1996 Rush Hill site: 4 trenches in SE ¼, Sec 33, T27N, R8E
Slate Creek fault Calaveras River; 6 km east of Oak Grove		•Sonora and locally older colluvia •Paleo B deposit (?)		Pre-late Pleistocene	U.S. Corps of Engineers, 1995 Slate Creek site: 2 trenches in NE ¼, Sec 5, T2N, R10E
Spenceville fault Bear River 22 km east of Marysville	Strong Prominent linear valleys, straight stream segments, spring lines, low intervalley saddles (21 km)		• Keystone colluvium • Slickensided surface extends into Keystone/Sonora colluvium • Paleo B deposit • Fault in metavolcanic rock has characteristics of late Cenozoic fault	Holocene	Schwartz and others, 1977 Spenceville site: 5 trenches. 3 are in the SE ¼, Sec 34, T15N, R6E; 2 are in the NE ¼, Sec 3, T14N, R6E
Spring Valley East structure 4 km east of Valley Springs	(>7 --)	• Sonora colluvium • Mehrten Formation	Sheared serpentine	Pre-late Cenozoic	Biggar and others, 1978 Evans Ranch site: 2 trenches NW ¼, Sec 5 T4N, R11E Woodward-Clyde Consultants, 1978

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Surge Tank fault (at New Melones Damsite) Stanislaus River; 12 km west of Sonora	Weak Saddles and linear drainage	• Sonora colluvium • 'Paleo B' deposit	Mesozoic shear zone; fault does not have late Cenozoic characteristics	Pre-Cenozoic Mesozoic shear zone; fault does not have late Cenozoic characteristics	Biggar and others, 1978 Surge tank site: 1 trench in SE ¼, Sec 10, T1N, R13E

LINEAMENT/ STRUCTURE [1] (alphabetical; general location)	**Character of associated lineament** (length)	**Oldest unit not displaced**	**Youngest units displaced**	**Assessment of Lineament/ structure** [2]	**References, comments**
Swain Ravine fault Yuba River; 23 km northeast of Marysville	Moderate- Strong Linear valleys and drainages, low intervalley saddles, spring lines, vegetation lineaments (30 km)	South end (N side of Yuba River) • Eocene 'auriferous gravels' • Sonora and older colluvia • 'Paleo B' deposit Middle section • Sonora and older colluvia • 'Paleo B' deposit North end • younger 'Paleo B' deposit	Middle section Fault has late Cenozoic fault features North end • Keystone/Sonora colluvium cracked during 1975 Oroville earthquake • Pre-Paleo B colluvium • older 'Paleo B' deposit • Laguna Formation gravel (>14 ft; on profile 17-29 m)	South end Pre-late Cenozoic Middle section Pre-middle Pleistocene Fault has late Cenozoic characteristics North end Historical, Holocene and middle Pleistocene Fault has late Cenozoic characteristics	South end U.S. Army Corps of Engineers, 1977 Four unnamed sites: 5 trenches 4F-1: NW ¼, Sec 1, T16N, R5E 4F-2: NE ¼, Sec 13, T16N, R5E 4F-3 and 4F-4: SE ¼, Sec 13, T16N, R5E 4F-5: NW ¼, Sec 19, T16N, R6E Middle section Woodward-Clyde Consultants, 1978a Loma Rica (Pace) site: 5 trenches in NW ¼, Sec 15, T17N, R5E North end Woodward-Clyde Consultants, 1978a Orange Rd. site at north end of fault: 9 trenches in SE ¼, Sec 20 and NE ¼, Sec 29, T18N, R5E PG&E, 1992, constructed geomorphic profile and reassessed fault
Tennessee Knob fault Deer Creek; 30 km southeast of Porterville		• Modesto colluvium and Turlock Lake age paleosol not displaced		Pre-middle Pleistocene • no fault encountered	U.S. Army Corps of Engineers, 1988b Deep Springs site: 2 trenches in E ½, Sec 20, T22S, R28E

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Twin Gulch fault Stanislaus River; 2 km east of La Grange		• Sonora colluvium • Paleo B deposit • Older colluvium		Pre-middle Pleistocene	Woodward-Clyde Consultants, 1978 Twin Gulch site: 1 trench in SE ¼, Sec 15, T3S, R14E
Vizard Creek shear zone Tuolumne River; 3 km southeast of La Grange		• Sonora colluvium • 'Paleo B' deposit • Auburn (?) colluvium	• Shearing in Metasedimentary rock does not have characteristics of late Cenozoic fault	Pre-middle Pleistocene Not a late Cenozoic fault	Woodward-Clyde Consultants, 1978 Vizard Creek site: 1 trench in NE ¼, Sec 28, T3S, R14E
Waters Peak fault Stanislaus River; 1 km east of Valley Springs		• Early Modesto colluvium and silica soil not displaced	• Riverbank and probable Turlock Lake alluvium displaced with multiple events	Middle Pleistocene	U.S. Army Corps of Engineers, 1995 Waters Pk. North site: 3 trenches in NE ¼, Sec 2, T4N, R10E Waters Pk. South site: 6 trenches in NE ¼, Sec 24, T3N, R10E
West Branch fault American River; 4 km southwest of Auburn		• Sonora and older colluvia not displaced		Pre-latest Pleistocene	Tierra Engineering Consultants, Inc., 1983 Lagoon site: 1 trench in NW ¼, Sec 13, T8N, R7E Sunset site: 2 trenches in NE ¼, Sec 11, T8N, R7E
Youngs Creek fault Stanislaus River; 6 km east of Valley Springs		• Sonora colluvium	• 'Paleo B' deposit (?) • Mehrten Formation (18 ft) • Sheared serpentine, clay filled fractures in Mehrten	Pre-Holocene	Biggar and others, 1978 Youngs Cr. site: 3 trenches in NE ¼, Sec 8, T4N, R11E U.S. Army Corps of Engineers, 1995 Youngs Cr. site: 1 trench

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1F-83 fault (New Melones Damsite) Stanislaus River; 12 km west of Sonora	Very Weak Saddles		• 'Paleo B' deposit possibly displaced • No characteristics of late Cenozoic fault	Non-tectonic • Low angle structure, interpreted as not fault related	Biggar and others, 1978 Peoria Mt. site: 1 trench in SE ¼, Sec 11, T1N, R13E 1F-83 site: 1 trench in SE ¼, Sec 10, T1N, R13E
5 NW Striking Lineaments San Joaquin, Fresno, and Chowchilla Rivers, east side of San Joaquin Valley **Site 1** - SW of Madera near Ave. 11 **Site 2** - SW of Madera near Rd. 36 **Site 3** - East of Madera near Rd. 600 **Site 4** - NE of Madera along Ave. 24 **Site 5** - NE of Madera near Rd. 26		Site 1 • Riverbank Formation • Turlock Lake sediments Site 2 • Turlock Lake sediments Site 3 • Turlock Lake sediments Site 4 • Turlock Lake age paleosol • Turlock Lake age paleosol		Pre-middle to late Pleistocene	U.S. Corps of Engineers, 1988a Site 1: 1 trench in NW ¼, Sec 10, T12S, R20E Site 2: 2 trenches SE ¼, Sec 16, T11S, R19E • Trench exposed a steep-walled channel Site 3: 1 trench in NW ¼, Sec 13, T10S, R18E • Lineament interpreted as fluvial Site 4: 1 backhoe-scraped roadcut, SE ¼, Sec 35, T10S, R17E Site 5: 1 trench in NW ¼, Sec 13, T9S R17E • Lineament interpreted as fluvial

Notes: 1. Trench locations are shown on Figure 1-2
2. Age designations as follows

Holocene	less than 10,000 years
Latest Pleistocene	less than 30,000 to 50,000 years
Late Pleistocene	less than 100,000 years
Middle Pleistocene	less than 500,000 years
Late Cenozoic	less than 5 million years