PREPRINT

SPECIAL PUBLICATION 56

GEOLOGIC EVALUATION OF THE GENERAL ELECTRIC TEST REACTOR SITE VALLECITOS, ALAMEDA COUNTY, CALIFORNIA

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August, 1979

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PURPOSE OF THIS REPORT

The purpose of this report is to provide an outline of the California Division of Mines and Geology (CDMG) conclusions regarding the site geology of the General Electric Test Reactor (GETR) facility at Vallecitos, Alameda County, California.

This report incorporates the staff observations and conclusions which have been developed over a period of approximately two years. The CDMG staff have provided oral commentary to the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Geological Survey (USGS) at various times during this period. This report summarizes the siting implications of the staff analysis; see Section V, "Interpretation of Evidence for Design Criteria". It outlines only the elements of the geology which are, in the opinion of the staff, pertinent to the development of design criteria for the reactor.

The general geology of the area is presented in the Earth Sciences Associates (ESA) reports 1978-A and 1979, and the work of Herd (1977), Hall (1958), Jahns (1979), Rogers (1966) and others; see Section VI, "References".

The geologic observations that were made in the course of the staff analysis described a number of low angle thrust displacements of sedimentary materials in this portion of the Vallecitos Valley. In this report the comparison of evidence for a landslide origin as compared with the tectonic genesis of these features is considered. The displacements are referred to as faults regardless of interpretation of mechanism of origin.

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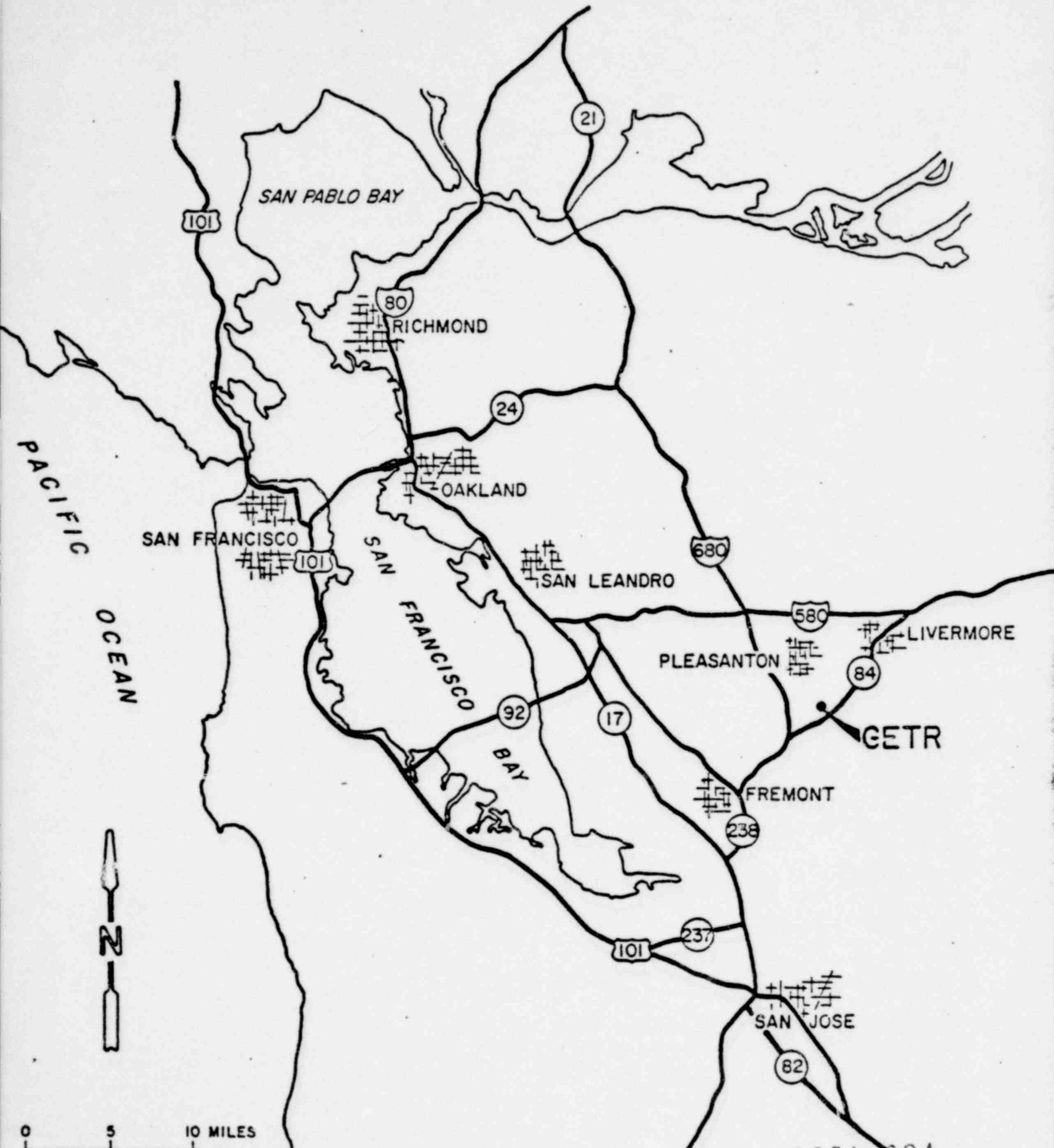
I BACKGROUND INFORMATION AND SUMMARY

The GETR is a 50 MW thermal test reactor used primarily for the production of radioisotopes for medical diagnosis and therapy and for industrial purposes. One of the first commercial reactors in the United States, it was originally licensed in 1959, and is currently up for renewal of operating license. Because of the recent issuance of a geologic map (Herd, 1977) that shows a potentially active fault (the Verona) passing within a few hundred feet of the reactor, the NRC suspended operations of the GETR in October 1977 pending studies and hearings.

Since that time, extensive bulldozer and backhoe trenching in the vicinity of the GETR has revealed at least three, but perhaps four or more northwest-trending low angle, thrust faults that bracket the reactor site (Figure 3). All of these thrusts displace Plio-Pleistocene Livermore Gravels, and also displace Pleistocene colluvium and paleosols that overlie the Livermore. Some displace younger colluvium and soils of possible early Holocene age.

Given their attitudes, evidence of displacements, and relations to local topographic features, there are at least two plausible explanations for the origin of the thrust faults exposed in the trenches. These are: 1) tectonic thrust faulting, and 2) large scale landsliding (see Figure 5).



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Index Map to GETR Site

FIGURE 1

COMPOSITE OF FAULTS MAPPED NEAR THE GETR SITE

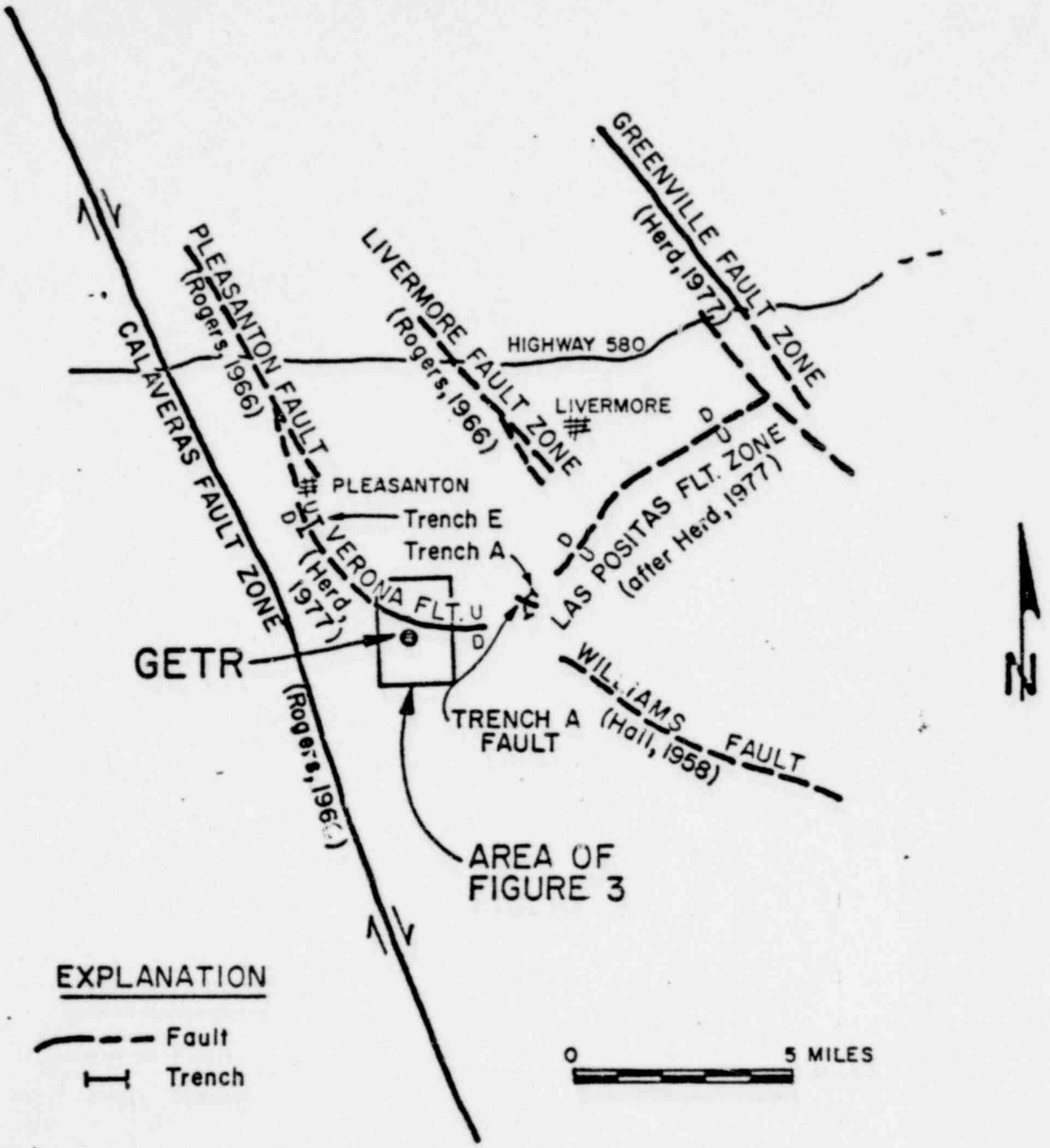

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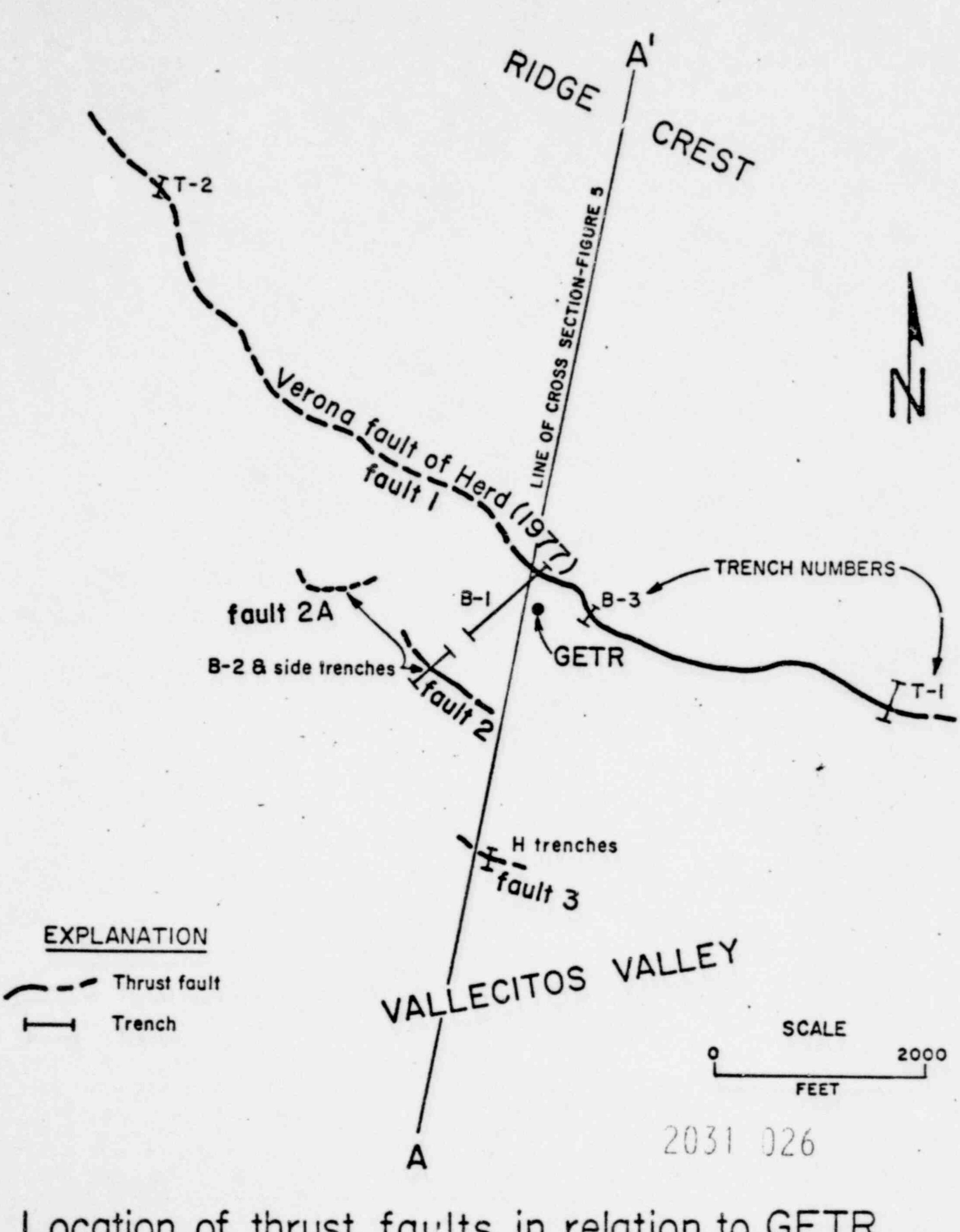
FIGURE 2



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Location of thrust faults in relation to GETR

(Modified after EDAC, 1979, Figure A-1)

FIGURE 3

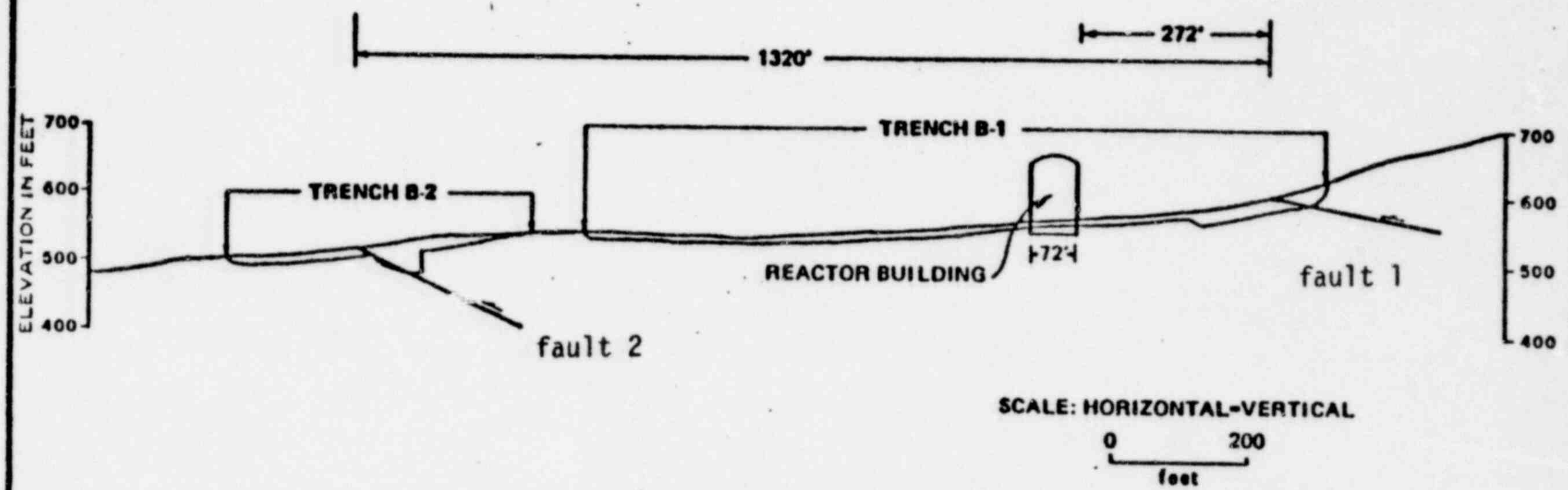
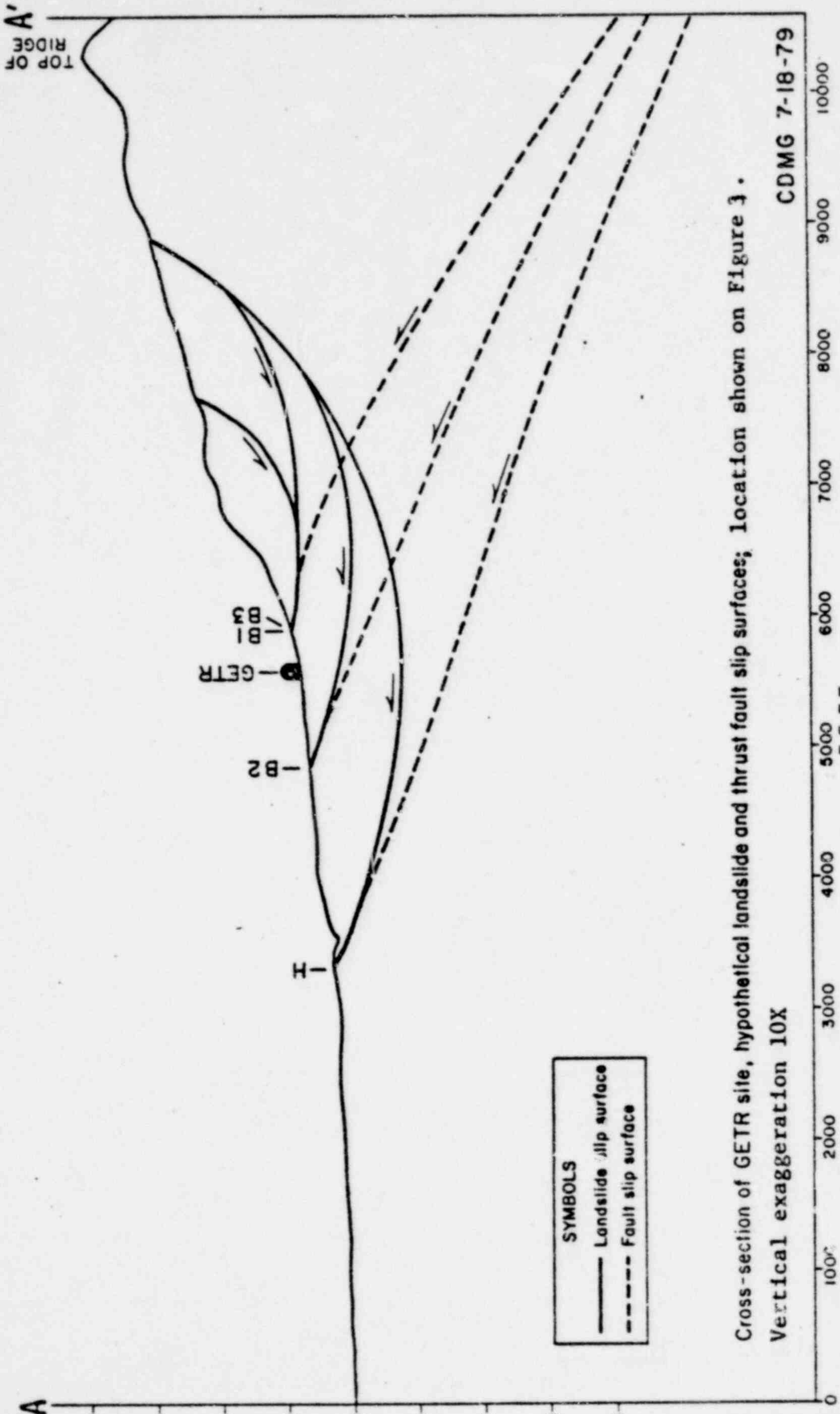


Figure 4: Cross section of GETR site showing position of the reactor relative to faults 1 and 2, exposed in trenches B-1/B-3 and B-2, respectively. Dips of thrusts are not known to depths indicated, but angles indicate average dips in trench exposures. (Adapted from EDAC, 1979, Figure 3-1)

FIGURE 4



Cross-section of GETR site, hypothetical landslide and thrust fault slip surfaces; location shown on Figure 3.
Vertical exaggeration 10X

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FIGURE 5

Evidence exposed in the various trenches, as well as the regional and local geologic and topographic settings, is discussed and illustrated in considerable detail by Earth Sciences Associates, the principal geologic consultants to General Electric Company, in their February 1979 report (ESA, 1979). In that report they discuss arguments for and against both landslide and tectonic origins for the thrusts (pp. IV 1-10), and conclude, "...we believe that the landslide hypothesis remains the more reasonable, if not conclusive, explanation." (p. IV-1). R.H. Jahns, another geologic consultant to G.E., reached a similar conclusion (Jahns, 1979).

Informal communications indicate that NRC advisors (the U.S. Geological Survey and David B. Slemmons) may favor a tectonic origin for the thrusts.

In a CDMG memorandum to T.E. Gay Jr. on December 22, 1977, Rice, Hart, and Kilbourne outlined the initial interpretations of Quaternary tectonic faulting in the area. The conclusion was expressed that the features observed to that date could have been caused by large scale landslide phenomena. That judgment was heavily influenced by the interpretation from air photos that topographic features of the southwest slopes of the ridge just north of the GETR were caused by massive slope failure to the southwest. Low angle thrust faults exposed in Trenches T-1 and T-2 were interpreted as likely to be the sole thrust at the toe of the massive slope failure.

Since that initial CDMG evaluation, trench series designated A, B, D, E, F, G, and H were excavated by General Electric Company in response to requests from the NRC. The B and H series trenches exposed much more evidence of thrust displacements that have occurred in the vicinity of the GETR during late Quaternary time. The other trenches revealed limited or negative evidence regarding these thrusts or their origin.

Although exploration to date has not yielded conclusive evidence in favor of one or another origin of the faults observed in the T, B, and H series trenches, it is still our judgment, based on available evidence, that the observed thrust features probably were caused by large scale landsliding.

Our calculations (see page 20) indicate that without seismic influence, these landslide masses are stable under present climatic conditions. However, calculations also indicate that the upper landslide mass, above fault 1 (Figure 3), could be activated by an earthquake generating an acceleration greater than 0.3g at the site; and that the landslide mass above fault 2 (Figure 3) could be activated by an acceleration of about 0.6g. Amounts of displacements to be expected by such seismic reactivation along these slip surfaces should be on the order of a few feet per event.

We conclude there is no evidence that a fault intersects the GETR foundation; conversely, there is good evidence from exposures in Trench B-1 that such a condition does not exist.

II EVIDENCE OF FAULTS EXPOSED IN THE TRENCHES

Trenches T-1, T-2, B-1, and B-3

The principal zone of thrusts intersects the surface in the immediate vicinity of the relatively sharp break in slope at the base of the ridge north of the reactor The GETR is about 400 feet from this break in slope. All four trenches (T-1, T-2, B-1, and B-3, see Figure 3) along this zone exposed low angle thrust faults dipping northeast (into the ridge). These trenches are distributed along the break in slope from about 3400 feet southeast of the GETR to 5400 feet northwest of it, and the presence of similar thrusts in each strongly suggests continuity of displacement along this zone. This thrust fault zone, referred to in this report as fault 1, corresponds to Herd's Verona fault (Herd, 1977).

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TABLE 1 CHARACTERISTICS OF THRUSTS EXPOSED IN THE TRENCHES

ench mber	General location of thrusts	Principal thrust		Associated thrusts		Materials displaced	Total apparent displacement, and comments
		Strike	Dip	Strike	Dip		
T-1 t 1	At base of main ridge, 3400 ft. ESE of GETR identify faults	N 80 W	10 NE	EW ±	0-20 N	Livermore Gravels Older colluvium Paleo-B Stone line equivalent?	Offsets Livermore Gravels at least a few 10's of fee perhaps as much as 100 ft. or so (based on general appearance).
T-2	Base of main ridge, 5400 ft. NW of GETR Fault 1	Principal thrust not identified		Many thrusts, complex, chaotic, highly variable in attitude, but mainly low angle dips. Bedding chaotically disturbed over a distance of at least 100 ft.		Livermore Gravels older colluvium Paleo-B (?)	" "
B-1	Base of main ridge, 420 ft. N of GETR Fault 1	N 30 W	0-15 NE (concave upward)	NW	10-35 NE (Imbrications of main thrust)	Livermore Gravels ----- Older colluvium Paleo-B -------------- Stone line equivalent--	> 40 feet 8-10 feet about 2 feet
B-3	Base of main ridge, 450 ft. E of GETR Fault 1		15-20 NE	N 60 W	10-15 NE	Livermore Gravels ----- Older colluvium Paleo-B--------------- Stone line------------	> 28 feet 10-11 feet ~ 2 feet
B-2	1300 ft. SW of base of main ridge, 1050 ft. SW of GETR Fault 2, 1	N 35 W	15-30 NE	N 40 W	35 NE	Livermore Gravels------ Older colluvium Paleo-B--------------- Stone line------------	> 80 feet 6 feet ~ 3 feet
H H-1 H-2	2400 ft. SW of base of main ridge, 2400 ft. SSW of GETR Fault 3	N 85 W	10-25 NE	None noted		Livermore Gravels Older colluvium Paleo-B (several) (No surface soils in H) Adjacent H_1 and H_2 indicate probable displacements of stone line by a foot or so)	Offsets Livermore Gravels at least about 30 ft., perhaps much more. At least paleosols present below thrust. Well expressed slicks striking N 30-40 E.

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Dips of the thrusts exposed in these trenches are low, mostly 10 to 20 degrees. Abundant slickensides indicate predominantly dip slip displacements, with components of oblique movement being minor where present. In all of these exposures, Livermore Gravels are thrust over older colluvium and paleosols. In at least some (B-1 and B-3) the stoneline, probably 10,000 to 20,000 years old,[1] is offset up to about 2 feet. The swelling nature of the overlying surface soil does not preserve displacement evidence, and there is no specific topographic evidence where these thrusts project to the surface.

A well developed paleosol in these trenches is displaced up to 10 or 11 feet, perhaps more. Apparent truncation or dissipation upward of some of the thrusts that displace this paleosol in these four trenches suggests that multiple events may have occurred to accumulate its total displacement. According to Shlemon (1979A, p. A-16), this paleosol probably formed 70,000 to 125,000 years ago. Maximum displacements of the oldest unit, the Livermore Gravels, is indeterminate because of lack of identifiable offset horizons in these trenches. However, it is certainly greater than about 40 feet. Several paleosol horizons in Trench B-3 indicate that the older of the colluvial deposits over which the Livermore Gravels are thrust range in age from at least about 70,000 to perhaps 350,000 years (Shlemon, 1979B, p. B-16).

Conclusion

Similarity of topographic positions and angles of dip of the faults exposed in these four trenches strongly suggest one zone of low angle thrust faulting (fault 1 of this report) between them along the base of the ridge.

The probable range of displacement events on this fault is early Holocene (younger than about 9,000 years) to more than 125,000 years. There have been at least two displacement events within about the last 70,000 years, but probably more.

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[1] Shlemon, 1979B.

Trench B-2 and 36 backhoe trenches lateral to it

A second thrust zone, which dips 15 to 30 degrees northeast, is exposed in bulldozer Trench B-2 and in 12 of the 36 backhoe trenches lateral to it, for a known length of more than 1200 feet (see Figure 3). This thrust, fault 2 of this report, intersects the surface about 1350 feet southwest of fault 1, and is approximately parallel to the latter over its explored length. Fault 2 displaces the stoneline underlying the modern soil about 3 feet. An underlying 70,000 year old paleosol is displaced about 6 feet, and the Livermore Gravels are thrust a minimum of about 80 feet over alluvium-colluvium along this fault.

Some 1200 feet northwest of B-2, and on the strike of the thrust exposed in it, there is a low angle thrust exposed in several shallow backhoe trenches (fault 2A on Figure 3). This thrust appears to be arcuate to the northeast in trend. It cuts Livermore Gravels, but does not displace the stoneline horizon underlying the youngest colluvium and soils. Thus it is not likely to be contiruous with the fault 2 in Trench B-2.

Conclusion

Two separate faults are exposed in the B-2 group of trenches.

Fault 2 is similar to fault 1 in its range in age of displacements, and in its evidence of two or more displacements during the last 70,000 years, the youngest probably since about 9,000 years ago.

Fault 2A has not been active since formation of the stoneline horizon, estimated to be 9,000 to about 20,000 years old.

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Trenches H, H-1, and H-2

About 2400 feet southwest of the base of the main ridge, a low angle, northeast dipping thrust (fault 3 on Figure 3) is exposed in bulldozer Trench H and in nearby backhoe Trenches H-1 and H-2. For its exposed length of about 200 feet it has a northwest strike. In H, this thrust dips 10 to 25 degrees northeast and has well defined dip slip slickensides where Livermore Gravels are thrust over colluvium-alluvium a minimum of about 30 feet. Several paleosols are certainly displaced in these trenches, but the amounts of these displacements are not apparent. Because of surface creep, plowing, and other human related activities, a definite determination cannot be made as to whether or not the surface colluvium has been displaced. However, exposures in backhoe Trenches H-1 and H-2, the stoneline horizon appears to have been displaced a foot or so.

Conclusion

Although details of amounts of displacements of paleosols are not apparent in the H trenches, the gross appearance of fault 3, and its displacement characteristics, is similar to that of faults 1 and 2.

Trenches A, A-1, and A-2 (See Figure 2 for location)

One of the arguments in favor of a tectonic origin for the thrust features exposed in the T, B, and H trench series is that the upper member of the Livermore Gravels just north of the GETR is very thick compared to that about 2 miles along strike to the east. Based on ESA's geologic mapping, thinning of this unit could amount to as much as 4,000 feet over that distance. This anomaly could be accounted for by faulting or by relatively abrupt stratigraphic thinning toward the edge of the basin of deposition. Such an abrupt variation in thickness is relatively common in Cenozoic nonmarine deposits in California.

Trench A was dug across the apparent thinnest exposure of the upper member, about 2 miles east of the GETR, to explore for evidence of a fault that might be continuous with Herd's Verona fault to the northeast and account for the mapped variation in thickness. A fault was found in Trench A (later also exposed in nearby Trenches A-1, and A-2), but it could not be projected to the area of the GETR site. This fault is nearly vertical, striking at about N70°W (at a high angle to the searched for fault), with lateral displacement indicated by horizontal slickensides. It is a newly discovered fault at the site, but may be an unmapped continuation of the Williams fault to the southeast (Hall, 1958).

Amount of displacement along this fault is unknown, for undistinguished Livermore Gravels are present on both sides. Nor is the recency of displacement apparent, for landsliding and soil creep have modified evidence in Trench A-2, the best exposure we saw.

Conclusion

A newly discovered (for the site) vertical fault with horizontal displacement was found in the A trenches, some 2 miles east of the GETR. Its strike (about N70°W), dip, and sense of displacement are all incompatible with those required for continuity with fault 1 (the Verona fault of Herd, 1977).

Trench E (See Figure 2 for location)

Bulldozer Trench E, more than 1,000 feet long, was excavated across the mapped trace of Herd's postulated Verona fault almost 3 miles northwest of the GETR. No evidence was found for a fault that might be continuous with the Verona. Several minor faults were found that dip to the southwest. These are probably related to local folding deformation, and all are overlain by undisturbed Pleistocene paleosols.

A syncline, exposed in the trench, trends northwest with a warp to nearly due west in the vicinity of the end of Sycamore Road. This warp is the probable reason for near vertical beds at the end of Sycamore Road that have been interpreted as being suggestive of faulting.

Conclusion

Unfaulted continuity of paleosols in Trench E significantly restrict the probability that fault 1 (Herd's Verona fault) continues from the GETR area to connect with any fault to the northwest.

Discussion

The faults found in the T, B, and H series trenches are all very similar. In all cases the angle is low, mostly ranging from 10 to 30 degrees, dipping to the northeast, with dip slip slickensides. Movement has occurred in multiple events, indicated by successively larger displacements of successively older units.

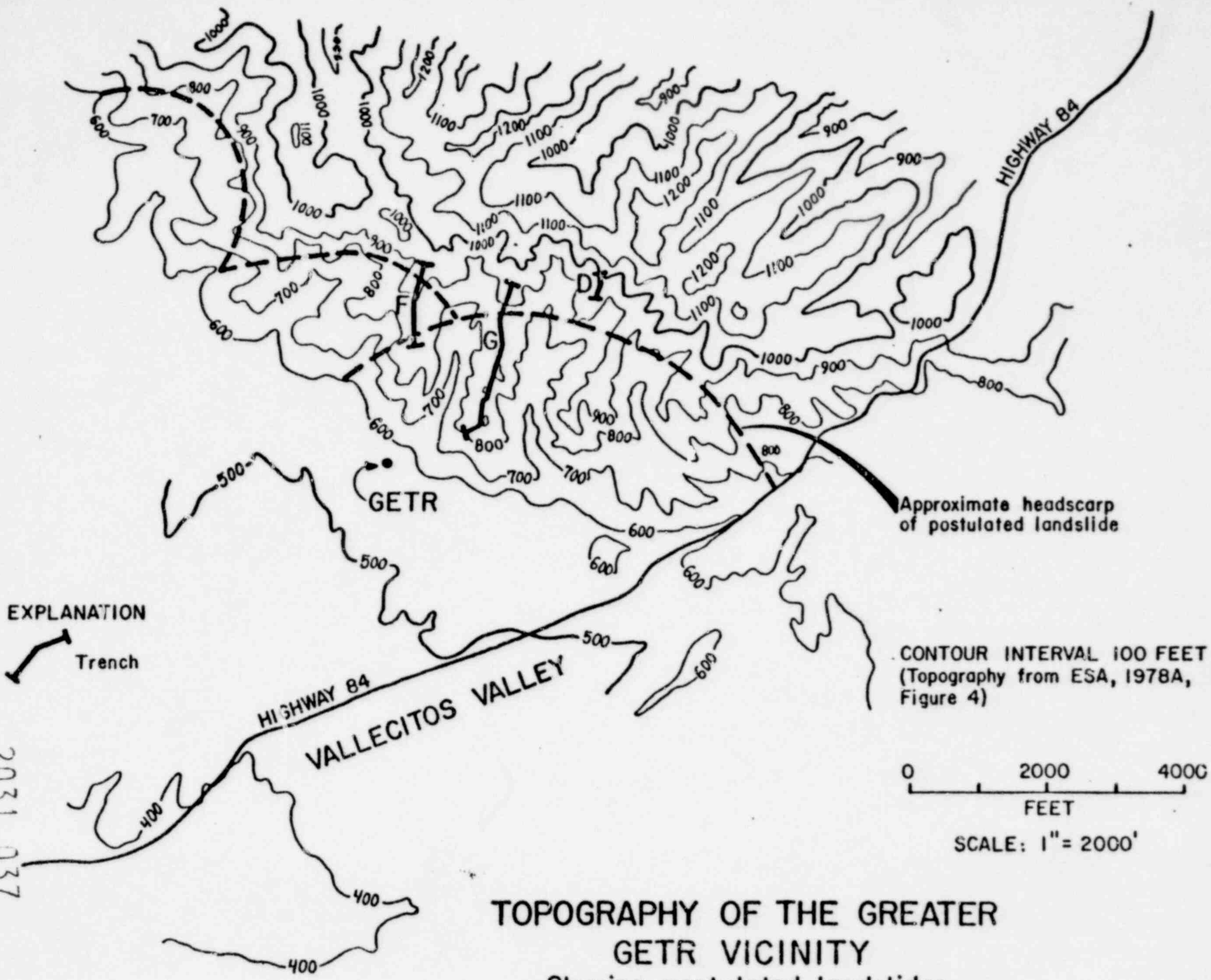
Although the characteristics of the modern soil would not permit preservation of fault displacement features within it for more than a few decades at most, lack of specific topographic expressions of faults 1, 2, and 3 (see Figure 3) strongly suggest that there has been no displacement in recent geologic time. However, based on evidence of as much as a few feet of offset of the stoneline horizon, which is older than about 9,000 years, the youngest displacements on these faults probably was early Holocene time.

A well developed paleosol, with a probable minimum age of about 70,000 years, is offset as much as 11 feet, with some evidence of more than one event accounting for this total. This, plus the stoneline offset, indicates at least two, but probably more displacements of the paleosol.

The alluvium-colluvium on which the paleosol developed was deposited more than about 125,000 years ago. Livermore Gravels have been thrust over these deposits more than 80 feet in Trench B-2. Total maximum displacement of this unit was not observable in the trenches, but general considerations suggest it may be 100 to a few hundred feet. Thus, the maximum displacement on all of the thrusts was more than about 125,000 years ago.

An important aspect of these observations is that displacements were repeated along the same shear zones in weakly consolidated materials over a very long period of time.

The hilly area above the GETR site is a large, dissected, amphitheater-like feature (see Figure 6). This amphitheater appears to be of ancient



TOPOGRAPHY OF THE GREATER GETR VICINITY

Showing postulated landslides

FIGURE 6

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landslide origin when viewed on aerial photos, certain contour maps of the right scale and interval and on the ground from certain points. Considerable erosion has taken place since the time the slide occurred, for the headscarp area appears to have migrated upslope, and there has been extensive dissection of the slide mass by ephemeral streams flowing downslope across the beds.

III ORIGIN OF THE FAULTS

There is no conclusive evidence in the trench exposures that proves the origin of the thrust shears, for both tectonic thrust faulting and large scale landsliding could cause these structures. However, other aspects of the geologic and topographic setting are helpful in making a judgmental evaluation of their probable cause. Some or all of these aspects will be weighed differently by different geologists, thus the various judgments will also differ.

Arguments for and against tectonic faulting

A principal argument in favor of a tectonic origin of the thrust faults is the fact that the area is within an active tectonic regime. Three major, historically active faults pass southeast of the GETR site: the Calaveras at about 2 miles, the Hayward at about 8 miles, and the San Andreas at about 27 miles. The Livermore and Greenville fault zones pass about 5 and 11 miles, respectively, northeast of the GETR. All five of these fault zones strike north northwest, and the historically active ones have exhibited right lateral displacements.

The only way for an arcuate, west northwest trending, low angle thrust fault like the proposed Verona to fit into this tectonic framework is for it to occupy a zone of compression between the Calaveras fault and the Livermore Valley region to the north and northeast. However, Livermore Valley is a young, downwarped or downfaulted area, suggesting tensional stresses during recent geologic time. Thus, the Verona fault north south compression hypothesis does not appear to be compatible with the ongoing tectonic regime.

Another argument not favorable to a tectonic origin of the thrust faults is the lack of evidence of continuity of such faulting along the trend of the proposed Verona away from the area of postulated landsliding. If the Verona exists as a significant structural feature (e.g., sufficient to uplift the ridge front several hundred feet as suggested by Herd, 1977), then certain conditions or relationships with other faults should also exist. From the GETR area fault 1 should continue to the northwest to join the Calaveras fault zone or some other strike slip fault (such as the controversial Pleasanton fault) lying northeast of the Calaveras. Bulldozer Trench E, more than 1000 feet long, explored for such a continuation across the mapped trace of the Verona fault (Herd, 1977) about 3 miles northwest of the GETR, but did not expose any appropriate fault of shear. A much longer seismic traverse across Happy Valley in the vicinity of Trench E (ESA, 1979, Appendix C) did not definitely indicate a fault, but the quality of part of the record was not adequate to disprove the presence of a fault at depth south of Trench E.

To the east and southeast of the GETR site, continuity of the postulated Verona fault is constrained by unfaulted continuity of outcrop of the relatively resistant middle conglomerate unit of the Livermore Gravels about 4000 feet easterly of Trench T-1. It might be postulated that the Verona joins the Las Positas fault (Herd, 1977) to the northeast of Trench T-1, but at least two points argue against such continuity. First, the A series trenches cut across the most likely continuation in this direction, and did not expose an appropriate fault. (Such a fault should have a bearing at Trench A of about N 60 E, but as noted earlier, a fault found in the A trenches trends about N 70 W.) Second, the Las Positas fault, as described by Herd (1977), is a steeply dipping one with predominantly vertical displacement, southeast side up. This sense of displacement appears to be incompatible with the low angle, south directed thrusting exhibited by the Verona shears (see Figure 2).

Thus, the thrusting appears to be constrained in both directions away from the postulated landsliding on the southwestern flanks of the main ridge, and the length of the postulated Verona restricted to about 20,000 feet at most.

The dips of the thrust surfaces exposed in the trenches also bear on the judgment of probable mechanism. The low dips at the base of the ridge (Trenches T-1, T-2, B-1, and B-3), compared to the somewhat steeper dips away from the ridge (Trenches B-2 and H) appear to be incompatible with a single thrust fault system (see Figures 4 and 5 for graphic representations of these dips).

Arguments for and against landsliding

The gross topographic expression of the southwest flank of the main ridge is one of the strongest arguments in favor of landsliding as the mechanism that produced the thrust shears seen in the trenches. The large, arcuate, deeply dissected amphitheater on the ridge back of the GETR, along with the bulging, abrupt toe of the slope, in gross form is characteristic of rotational slump landslides (Figure 6). Such slope failures, both large and small, are relatively abundant in the California Coast Ranges. In our judgment, it is highly unlikely that differntial erosion, an alternative explanation for this distinctive topographic form, would produce the geometry that is so characteristic of slope failures.

Also compatible with landsliding is the relatively weak character of the upper unit of the Livermore Gravels that underlies the ridge and the GETR area. This unit consists of a crudely interbedded sequence of weakly consolidated clayey, silty, sandy, and gravelly beds and lenses.

One of the strongest arguments against a landslide origin for the thrust shears is that distinctive pullaway features or steeply dipping shears were found in only one of the three trenches (D, F, and G, see Figure 6) dug to search for such features near the head of the postulated landslide. Only Trench G, the middle one of the three, exposed shears with proper orientation and location for the features sought. Deep dissection of the landslide mass and upslope migration and dissection of the headscarp since the principal slope failure more than 125,000 years ago make location of these original headscarp features much more difficult than location of the sole thrusts at the toe of the landslide mass.

The thrust faults in Trenches B-2 and H have been considered incompatible with landslide origin because they are located far from the base of the ridge. The average slope from base of the ridge to faults 2 and 3 is about 3.5 degrees. A graphic representation of this slope, to scale, between faults 1 and 2 is shown in Figure 4. There are many precedents for landsliding on slopes as low as this, most of them probably induced by earthquakes. One example is the Juvenile Hall landslide triggered by the San Fernando earthquake of 1971. This landslide was about 4000 feet long, with displacements of a few feet on an average slope of about 0.6 degrees (1 percent), and trenching revealed evidence of additional displacements prior to the 1971 event (Smith and Fallgren, 1975, p. 158).

Evaluation of evidence

In sum, it is apparent that the evidence available does not concusively prove or disprove the origin of the fualts exposed in the trenches. It is our judgment, however, that the weight of evidence is strongly in favor of a landslide origin for these features.

IV SIGNIFICANCE OF FAULT VS. LANDSLIDE ORIGIN OF THE FAULTS IN TERMS OF GEOLOGIC HAZARD TO THE SITE

If the faults are tectonic in origin, future displacements on them will occur only after sufficient stress has accumulated locally to require relief by earthquake or creep mechanisms. Such events should be less frequent than the total of those on nearby major faults of this cectonic regime, such as the Calaveras fault.

On the other hand, if the faults are the result of landsliding, further activity might be triggered by various influences or events, especially climatic and seismic ones. Our calculations indicate that without strong seismic stimulation, the postulated landslike masses are stable under the dry climatic conditions that now prevail in the area. However, calculations discussed below also indicate that the upper landslide mass, above fault 1, might be activated by an offsite earthquake generating 0.3 acceleration at the site, and that the landslide mass or masses above faults 2 and 3 could be activated by acceleration at the site of about 0.6g or greater.

Stability analyses were performed using cross-sectional views chosen to represent movement on fault 1 and on fault 2 shear. The first was drawn by ESA along the crest of the north northwest trending spur ridge north of the GETR (ESA, 1978 C, Figure 1). Our analysis was made on the section shown in the ESA report as Figure 2. The strength paramenters used were: cohesion of 300 and 1000 psf, angle of internal friction of 16.5^{o}, and unit weight of 135 pcf. The analysis was made using the simplified method of slices (Lambe and Whitman, 1969, p. 359). These analyses resulted in factors of safety of 2.02 for a cohesion of 300 psf and 2.31 for a cohesion of 1000 psf. The analysis was then repeated using acceleration values of 0.2, 0.25, and 0.5 g, with cohesion value as before.

The acceleration value of 0.2 g gave factors of safety of 1.20 and 1.37 for the two cohesion values. The acceleration value of 0.25 g gave safety factors of 1.09 and 1.25 and that of 0.5 g gave safety factor of 0.58 and 0.66.

Another analysis was made using a cross-section shown on Figure 8 of

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ESA, 1979. This was an assumed slide along the fault found in Trench B-2. Strength paramenters used were a cohesion of 300 psf and others as before. With no acceleration, the factor of safety was 3.3̣. Acceleration values of 0.3 and 0.5 g were then used, and the factor of safety was 1.51 with 0.3 g, and 1.13 with 0.5 g. Again the method used was the simplified method of slices.

(A safety factor of 1 implies the mass is theoretically exactly in balance; greater than 1 implies greater and greater stability, less than 1 implies instability under the assumed conditions.)

Because nearby major earthquakes that could generate such accelerations in the vicinity of the GETR are likely to be more frequent than offset events on a Verona fault, displacement by slope failure mechanisms are more likely than surface fault displacements at the site. For example, during the last 150 years there have been at least 7 severe earthquakes on the Calaveras, Hayward, and San Andreas faults that would have generated significant ground motion at the GETR site. These were in 1836, 1858, 1861, 1868, 1897, 1903, and 1906 (Blume, 1973, p. 11, 12), and probably all were accompanied by surface displacement. The frequency implication of the landslide interpretation should be considered in establishing design criteria for the facility.

V INTERPRETATION OF THE EVIDENCE FOR DESIGN CRITERIA

The trenches at Vallecitos revealed important aspects of the distribution and history of displacements of the thrust faults. In our judgment, these empirical data should be the principal basis for evaluating the significance of the thrusts as they relate to geologic hazards to the GETR structure.

Three principal aspects of the empirical data, summarized as follows, are independent of the mechanism of origin of the thrusts and lead to the inferences and conclusions indicated:

(1) The two thrust faults that bracket the GETR, faults 1 and 2 (see Figure 3), have similar histories of multiple displacements during the last 125,000 years or more. This fact is evident from successively larger displacements of older units along each fault (Shlemon, 1979B, and Earth Sciences Associates, 1979). From this evidence we conclude that any future activity resulting from forces that produced faults 1 and 2 will very likely take place along the same shear surfaces as in the past.

(2) Excellent exposures in Trenches B-1, B-2, and B-3 indicate that the multiple displacements that have occurred during the last 70,000 years probably have occurred in increments of about 3 feet or less per event on each of these two thrusts (Shlemon, 1979B). This evidence strongly suggests that offsets that might result from future activity along these faults will very likely be of the order of a few feet at most.

(3) Trench B-1, some 1080 feet long and with a northeast trend (approximately perpendicular to the thrust shears), passes about 300 feet northwest of the GETR. This trench exposed unfaulted late Quaternary alluvial fan and colluvial deposits that have poorly developed paleosol horizons (see Figure 7). We agree with Shlemon (1979C, p. B-3) that the oldest of these unfaulted sediments "...exposed in Trench B-1, directly opposite the GETR, pertain to (oxygen isotope) stage 6, and thus most likely were laid down between about 128,000 and 195,000 years ago." Thus it is unlikely that any tectonic or landslide-generated faults with displacement activity younger than about 128,000 years cut the foundation site of the GETR structure.

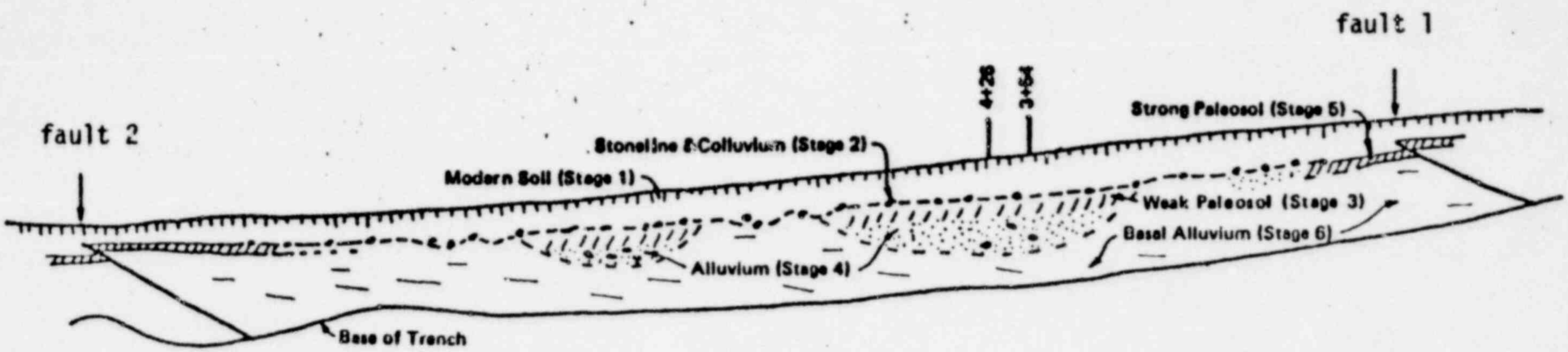

Figure 7: Schematic diagram showing relationship of late Quaternary soils and sediments exposed in Trench B-1 near the GETR site. Not to scale; stages refer to marine isotope chronology. For detailed log see ESA, 1979, Figure E-4. (Adapted from Shlemon, 1979C, Figure 1)

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FIGURE 7

In our judgment, this last inference, combined with the evidence of multiple displacements on faults 1 and 2 during at least the last 125,000 years, suggests a very low probability of a new fault developing in the GETR foundation during the useful life of the structure, regardless of the mechanism of origin of the faults. However, if surface offset should occur at the GETR in the future, evidence mentioned in (2), above, implies that it should amount to a few feet at most, conservatively estimated to be 3 feet.

In general, it is our judgment that a future displacement event in the site area, whether of tectonic or landslide origin, might result in slip on fault 2, exposed in Trench B-2. This would lead to movement of the site on which the GETR is located by as much as a few feet toward the southwest. Because fault 2 is curved, the surface of the moving block (including the GETR site) might be differentially deformed and the GETR might be rotated out of plumb by a small amount.

Ground motion to be expected at the GETR site

Earth Sciences Associates (ESA, 1978D) presented arguments to downgrade the expected peak accelerations at the GETR site relative to the recorded 1971 San Fernando earthquake ground motions. These arguments are based on: (1) higher levels of attenuation in Franciscan rocks as opposed to granite (the basement rocks at seismogenic depths beneath the GETR area and the San Fernando area, respectively); and (2) lower rock strength and confining pressures at the GETR site characterized by low stress drop "interplate" earthquakes. The question arises, however, whether current theory is able to permit quantification of these differences, at least with the confidence necessary to justify lowering design specifications of a nuclear reactor.

Earth Sciences Associates suggested that the maximum "ground" motion

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at the site will most likely be in the range of 0.3 g to 0.5 g, based on theoretical considerations of source and transmission path geology (ESA, 1978D). If we assume that the Calaveras fault generates M7 or M7.5 earthquake at a fault distance of about 2 miles, the corresponding "bedrock" acceleration will be about 0.70g or 0.73g, respectively, using the attenuation curves of Schnabel and Seed (1973). Approximately 0.8 g appears to be an appropriate value for design. It seems that ground motion predicted by Earth Sciences Associates (EAS, 1978D) is too low. It may be more appropriate to use observational data than theoretical estimates at this time.

The mapped length of Herd's Verona fault (Herd, 1977) is less than about 10 km (about 6 miles). As discussed in Section III of this report, available evidence indicates that such a fault likely does not continue to the northwest or east. A 10 km length corresponds to about M6, using Slemmons (1977) surface rupture - earthquake magnitude relationship. Since the postulated Verona fault is less than 400 feet from the GETR, the bedrock acceleration would be not less than about 0.58 g, using the attenuation curves of Schnabel and Seed (1973). Since these curves do not take near field ground motion effects into account, an appropriate value of peak ground acceleration for an on-site event could be somewhat higher.

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