Factors Affecting the Recognition of Faults Exposed in Exploratory Trenches

U.S. GEOLOGICAL SURVEY BULLETIN 1947

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By M.G. BONILLA and J.J. LIENKAEMPER

Summary and analysis of data on the visibility of fault strands, implications for interpretations of the timing of rupture events, and the frequency of occurrence of some phenomena related to faulting

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CONTENTS

APPENDIXES

FIGURES

TABLES

Factors Affecting the Recognition of Faults Exposed in Exploratory Trenches

By M.G. Bonilla *and* J.J. Lienkaemper

Abstract

Trenching—a widely used method for evaluating fault activity—has limitations that can mislead investigators. Some segments of fault strands in trench walls may not be visible, and this nonvisibility can lead to incorrect interpretations of time of most recent displacement and recurrence intervals on a fault.

We examined the logs of 163 trench exposures and tabulated data on more than 1,200 fault strands to investigate three categories of nonvisibility: (1) strands with obscure (invisible or poorly visible) segments, (2) strands that die out upward, and (3) strands that die out downward. About 14 percent of all the strands have obscure segments. Of the 143 strands on which it is possible to recognize dieout up (limited to strands for which position of ground surface at time of faulting is known), 45 percent do die out upward, and the fraction exceeds 70 percent for strike-slip and reverse faults. Thus a fault strand overlain by an apparently undisturbed deposit is not necessarily older than the deposit. More than 30 percent of all the strands die out downward, providing more evidence that fault strands can end for reasons other than being covered by deposits younger than the fault.

Analysis of trench-log data revealed various relations between geologic factors and nonvisibility of fault strands. For example, fault type affects the incidence of nonvisibility, which is generally most common on strike-slip faults, less common on reverse faults, and least common on normal faults. The type of material penetrated by the fault also influences nonvisibility, which tends to be more common in soil horizons and sand, and less common in gravel. Dieout down is weakly influenced by fault displacement, decreasing in frequency with increase in displacement; the frequencies of obscure segments and dieout up do not vary consistently with fault displacement. Frequency of obscure segments generally decreases with increase in length of obscure segments, and frequency of dieout up generally decreases with depth of dieout up. Length of obscure segments and depth of dieout up are typically less than the effective thickness of associated beds. On the basis of few data, obscure segments seem to be more common on faults with younger, rather than older, ages of latest displacement.

Our study revealed additional relations not directly related to nonvisibility. For example, the median widths of faults crossed by the trenches vary by fault type, strike-slip faults being narrower than dip-slip faults. In the shallow and mostly unconsolidated materials cut by the trenches, fault widths show only an erratic and, at best, weak relationship to fault displacements. Hanging walls are deformed more frequently than footwalls in dip-slip faults, but both walls are deformed at more than 30 percent of the exposures.

We tabulated several phenomena that may indicate faulting or provide evidence of prehistorical earthquakes. Rotation of pebbles was identified in 41 percent of the exposures having gravel in the fault zone; type of fault has no strong influence on the incidence of pebble rotation. Fissures were recorded at 52 percent of the exposures and were more common in strike-slip and normal faults than in reverse faults. Gouge was reported at 15 percent of the exposures; fault type has no significant influence on its frequency. Slickensides were noted at 10 percent of the exposures, and fault type has an unknown influence on their incidence. Slickensides in unconsolidated materials were restricted to clay, silt, and gouge. Other mechanical or hydrologic effects related to faulting or earthquakes—rubble, breccia, mixing, crushing, polishing, water barriers, and probable liquefaction effects—were reported at fewer than 10 percent of the exposures.

INTRODUCTION

During excavation of the reactor shaft at the proposed Bodega Head nuclear reactor in California, a fault was found in the sediments overlying bedrock. On the south side of the shaft, the fault could be traced downward to a fault that crossed the entire shaft in bedrock. When traced toward the northeast side of the shaft, however, the fault in the sediments disappeared horizontally and downward in massive clay. This apparent lack of a complete connection with the bedrock fault led to disagreement as to whether the fault in the sediments was of tectonic or landslide origin. An important observation applied to this controversy was that on the side of the

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shaft where the fault could be traced into bedrock, the parts of the fault that crossed massive clay were not visible. Furthermore, when followed upward from bedrock, the fault made an en echelon stepover, then gradually disappeared in the sediments; the result was ambiguity as to whether the most recent displacement on the fault was older than the upper sediments or had merely failed to entirely penetrate them (Schlocker and Bonilla, 1963, 1964; Tocher and Marliave, 1964). In another example, ten trenches across surface traces of faulting that occurred during the 1971 earthquake in San Fernando, California, revealed clear evidence of the faulting, but six other trenches showed no distinct evidence of the 1971 ruptures (Bonilla, 1973). These examples show that trenching, which is widely used in the investigation of faults and is among the most definitive of methods (Taylor and Cluff, 1973; Hatheway and Leighton, 1979), has limitations that researchers should keep in mind when evaluating fault activity.

This report provides information on some of the conditions under which fault strands in trench walls are either difficult to see or die out, and the frequency of occurrence of these phenomena. Information is also provided on the widths of fault zones, on the deformation of the hanging wall and footwall of dip-slip faults, and on the frequency of occurrence of pebble rotation, open fissures, gouge, slickensides, mixing, fault breccia, fault rubble, crushing, polishing, water barriers, and liquefaction effects. Short summaries of information relating to fault strands that are poorly expressed or that die out have already been published (Bonilla and Lienkaemper, 1988, 1990).

Methods

The principal method of study was examination of trench logs and accompanying reports. In addition, the writers made field examinations, ranging from reconnaissance to detailed mapping, of 52 (49 percent) of the trench exposures in the U.S. analyzed in this study. (Of the 163 trench exposures whose logs we studied, 107 were in the U.S.) Interpretations and measurements on each log were made independently by two geologists who reviewed each other's results. Fault displacements were derived from statements given in the reports, records of historical displacement at the site, or measurement on the trench walls or on the trench logs of the distance between displaced units. The displacements obtained by the trench measurements are separations and, because nearly all the trenches are perpendicular to the faults, are dip separations. For dip-slip faults the measured displacements are essentially equal to net fault slip, but for strike-slip faults the measured displacements are generally less than the net fault slip.

The selection of trench logs was based primarily on quality and secondarily on availability. The logs in various U.S. Geological Survey collections in Menlo Park were scanned, as were more than 800 Alquist-Priolo Special Studies Zones reports on file at the California Division of Mines and Geology office in San Francisco. From these, 119 published and unpublished logs judged by us to be of sufficiently high quality and detail for this study were selected in 1983, and an additional 44 published and unpublished logs—obtained from the sources named above, from consulting firms, and from university theses—were added to the data base in 1987. Included in the study are 163 trench exposures, 107 from seven states in the United States, and 56 from Nicaragua, New Zealand, Algeria, Japan, Peru, Guatemala, and Israel. Although far from containing all existing logs, the selection was made from a broad base and probably is a representative sample.

The trench exposures are listed in table 1, and the basic information compiled in the study is given in appendix A. The exposures are identified by a code consisting of a letter that indicates the fault type of the principal fault at the site followed by a number that is based on the chronological order in which the logs were examined and tabulated. Individual fault strands at each exposure are also numbered, generally from left to right as the log is viewed, and are listed in appendix A. The classification of fault types is the same as that used by Bonilla and Buchanan (1970), but some of the letter designations have been changed as follows: N, normal slip; R, reverse slip; C, normal-oblique slip; D, reverse-oblique slip; and E, strike slip.

Special Terms Used in This Report

Special terms were adopted to describe some of the conditions found during this study. The term "obscure segment" is applied to part of a known fault strand where the fault is not clearly visible in a trench wall. The existence of the fault must be known from visible displacement of materials above and below the segment, from historical records of displacement of the ground surface, or from definite statements made in the source report. The conclusion that the fault segment is not clearly visible is based on field observations by the writers, statements in the source report, the absence of a line on the trench log, or the use of a dashed line on the trench log. The use of a solid line, dashed line, or no line to represent a fault segment on a trench log varies among investigators; however, a dashed line is usually good evidence, and the absence of a line excellent evidence, that the fault segment was not clearly expressed. Segments that have contrasting materials on either side are not considered obscure even though no line or a dashed line is shown on the log (fig. 1), unless the investigator reports particular difficulty in identifying the fault in that segment. Chaotic faulted zones in which bedding or other features are disrupted are also excluded from the obscure designation even though no line is shown on the log. Examples of obscure segments are illustrated in figures 2 and 3.

"Dieout up" and "dieout down" refer to the process or condition in which a fault strand ends or seems to end upward or downward, respectively, and is not visible at the time of trenching in a layer that existed at the time of faulting. Dieout up and dieout down can come about in at least three ways: (1) The strand, although it may have been visible immediately after the event, has lost its visibility. Loss of visibility may result from processes such as bioturbation, human activities, freeze-thaw, shrink-swell, plastic flow in clay, or rearrangement of grains in granular material. (2) The strand was never visible as a discrete trace because it was distributed over a zone in the form of small ruptures, intergranular movements, or bending of the affected layer. (3) The strand actually terminated by decrease in displacement.

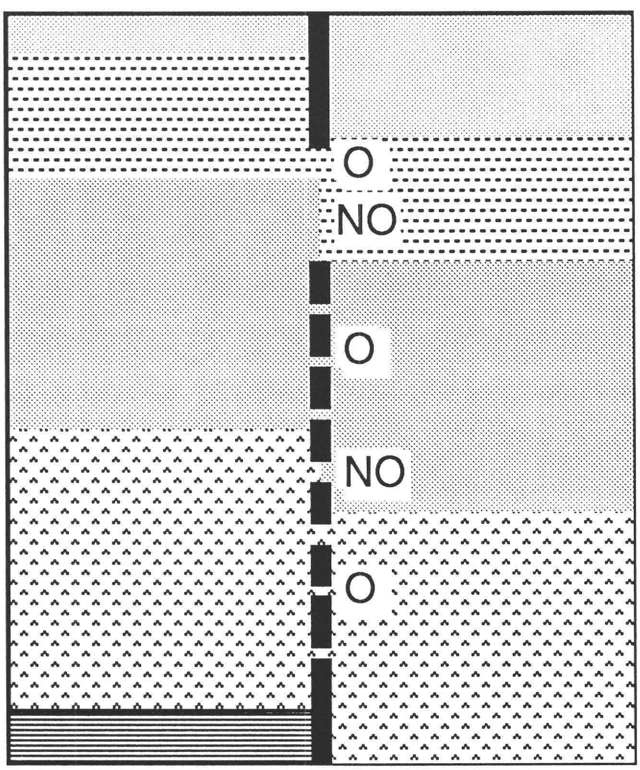


Figure 1. Diagram of a simple fault showing designation of obscure segments. Segments considered obscure where no line is shown on trench log or where a dashed line is used and the same unit is on both sides of the fault. Segments not considered obscure where contrasting units are on the two sides of the fault, even though no line is shown on log. See text for further discussion. O, obscure; NO, not obscure.

In order to eliminate strands that end upward because they are covered by younger deposits, the compilation of data on dieout up was limited to strands for which the position of the ground surface at time of faulting is known or can be inferred from good evidence. If rupture is known or can reasonably be inferred to have reached the ground surface in a particular faulting event, a strand that dies out upward below that surface has been counted as an instance of dieout up and also as an obscure segment (for example, strand 1 in fig. 4). Only segments for which *no* line is shown on the trench log were tabulated as dieout up or dieout down, in contrast to obscure segments, for which dashed lines were also tabulated. Examples of dieout up and dieout down are shown in figures 4, 5, 6, 7, and 8.

From the definitions above, it follows that dieout up and dieout down can represent either concealment of fault offset or the actual termination of fault offset. Obscure segments, in contrast, are unlikely to represent the termination of offset; wherever they occur, obscure segments almost certainly represent concealment of part of a fault.

"Nonvisibility" and "nonvisible" were adopted as general terms to encompass obscure segments, dieout up, and dieout down.

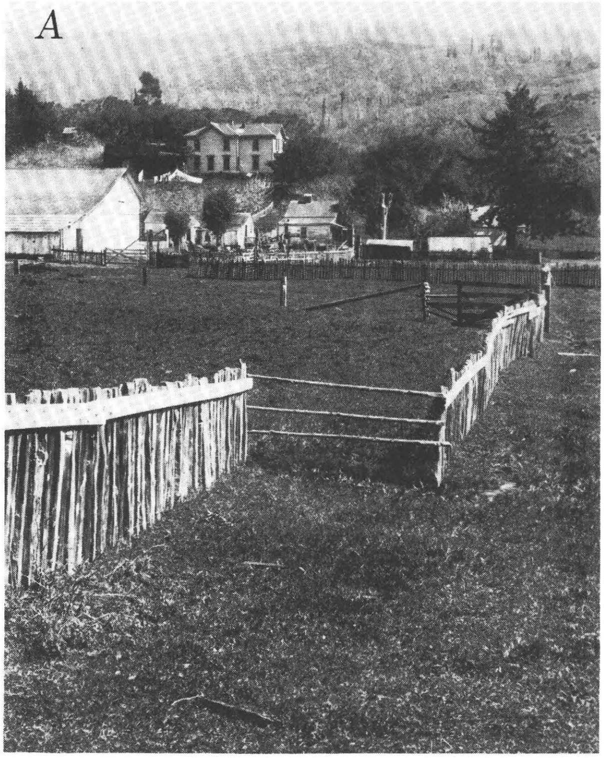
"Depth of dieout up" refers to vertical distance from the ground surface at the time of faulting to the top of the visible part of the strand. "Length of obscure segment" refers to distance between two visible parts of the strand or between the top of the visible part of the strand and a ground surface known to have been displaced at the time of faulting. Distances were measured on the trench wall or trench log.

For convenience in data analysis, the dimensions of fault displacements, the lengths of obscure segments, and the depths of dieout up have been placed into the classes given in tables 3, 8, and 10, respectively. Although the class intervals are in meters, they closely approximate multiples of one-half foot.

The "principal strand" is the strand that has the largest real or apparent displacement in a given exposure. In 23 percent of the exposures, two or more strands of nearly equal displacement are termed principal strands because they have substantially larger displacements than the others.

Statistical Treatment of Data

We calculated frequencies of the observed features and compared them to the total number of sampled fault strands. These comparisons give insights into how a strand's concealment is influenced by such factors as fault type and the material the fault strand penetrates. (In the comparisons, "fault type" refers to the character of



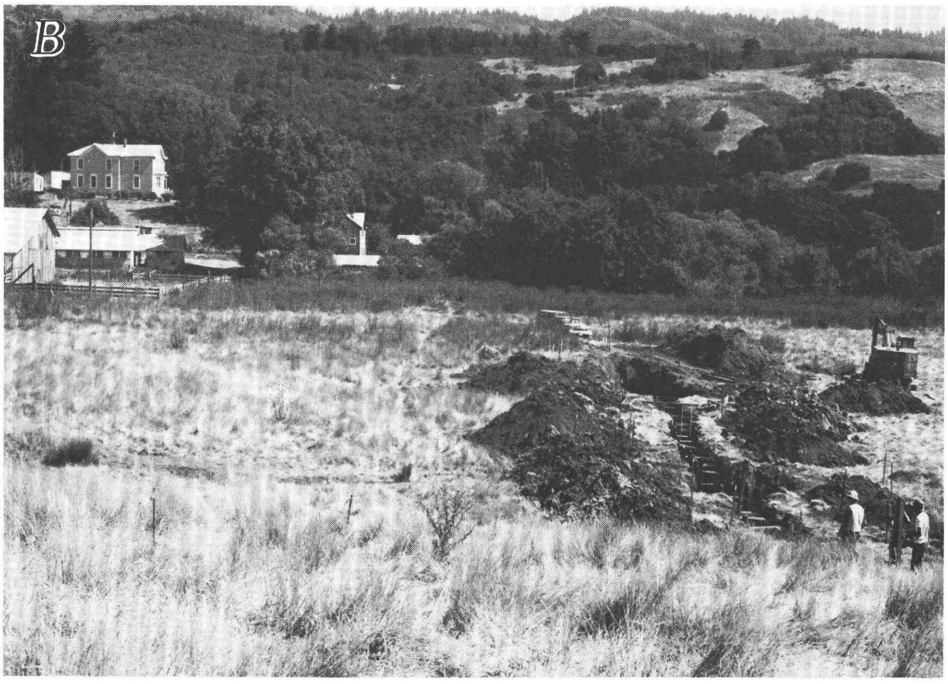
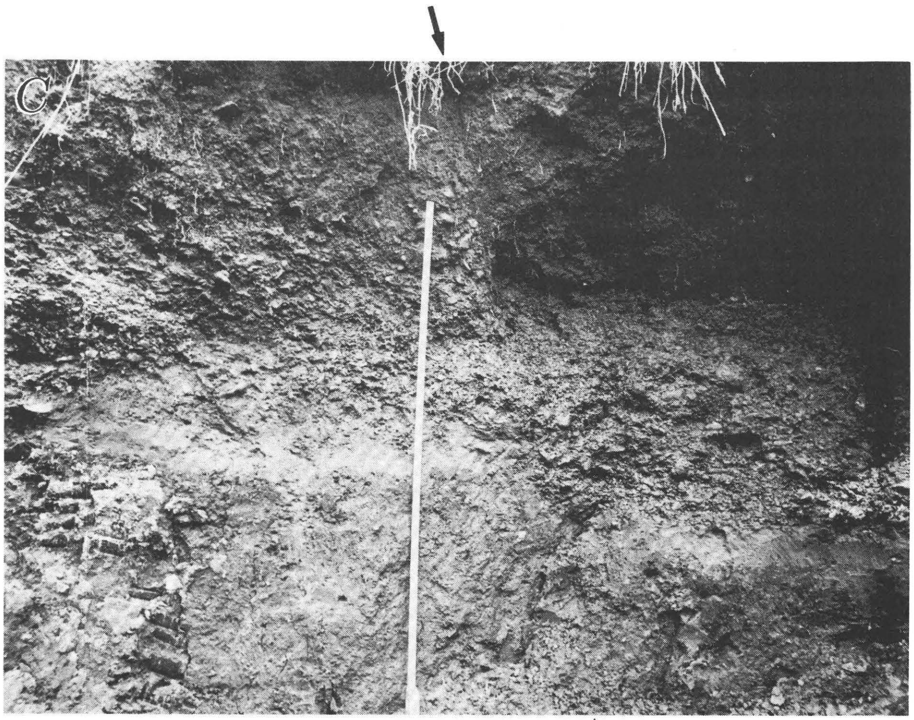
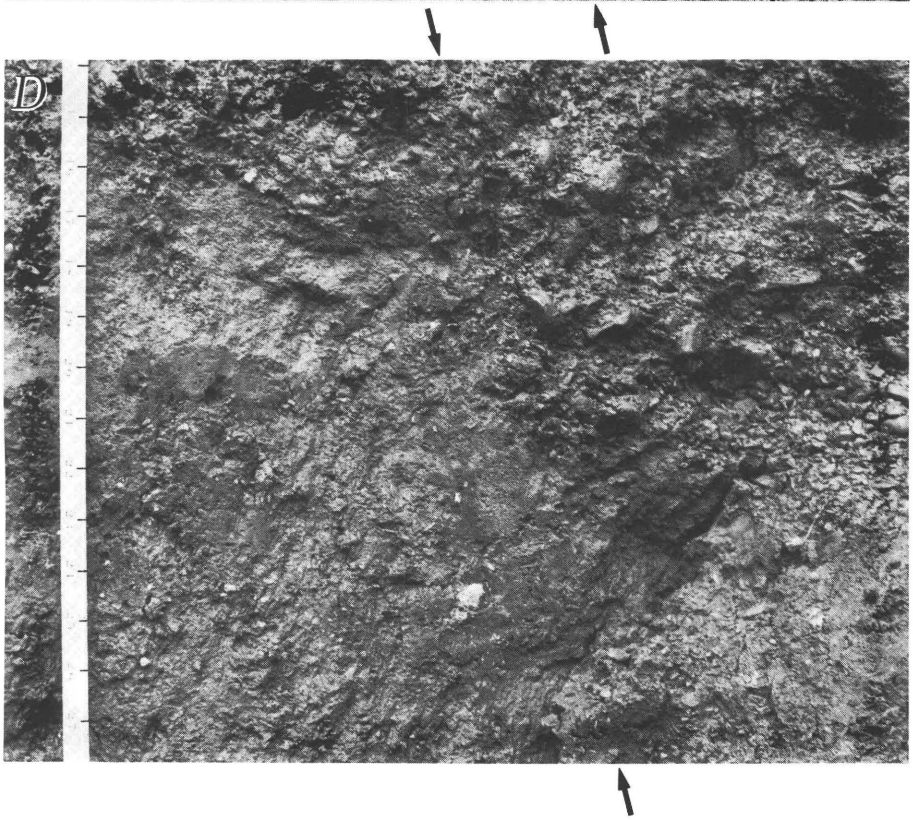


Figure 2. Examples of use of term "obscure segment." *A*, Fence broken and displaced 2.6 m (foreground) and warped 0.8 m (middleground) by the San Andreas fault in 1906. Photograph by G.K. Gilbert, 1907 (Lawson and others, 1908, pl. 49A). Site is the Strain ranch of the report by Lawson and others (1908) and is now part of the Point Reyes National Seashore. View to northeast. *B*, Site of fence shown in figure 2*A* showing exploratory trench, exposure E9 (app. A). Trench is parallel to and about 10 m to right of location of former fence. Note house and barn visible in both photographs. Gilbert's photo station was at location of stake that is in foreground and just left of centerline of photo. Photograph taken in 1975. *C*, Left (northwest) wall of trench shown in figure 2*B*. Trace that displaced fence shown in figure 2*A* is to right of tape; its approximate location is indicated by arrows. Vertical separation of light-colored silty sand is about 14 cm. Although in-





conspicuous, most of the trace within the photo was not classed as obscure because it is marked by rotated pebbles, juxtaposition of different sediment types, and contrasting resistance to excavation using a knife. However, despite a careful search, the trace could not be found in the upper 0.2 m of the trench in the A soil horizon (at upper edge of photo) or in the lower 0.6 m of the trench in clay (below photo), and those segments are listed as obscure in appendix A (exposure E9). Tape extends about 0.75 m above its case. Photograph taken September 30, 1975; for a view of this trench wall a week later, see figure 23. *D*, Close view of part of figure 2*C* where light-colored bed is displaced. No distinct shear surfaces were found here, but contrasting lithology indicated location of the trace, whose approximate position is shown by arrows. Light-colored pebble to right of tape can also be seen in figure 2*C*. Divisions on tape are in inches (2.54 cm).

the principal fault at the exposure rather than the separation or slip observed on individual fault strands.)

To test the significance of differences in frequencies, we used an approach based on the principle that it is easier to disprove than to prove a hypothesis. For example, we might assume that no differences exist between the frequency of obscure segments on strike-slip faults and the frequency of obscure segments on dip-slip

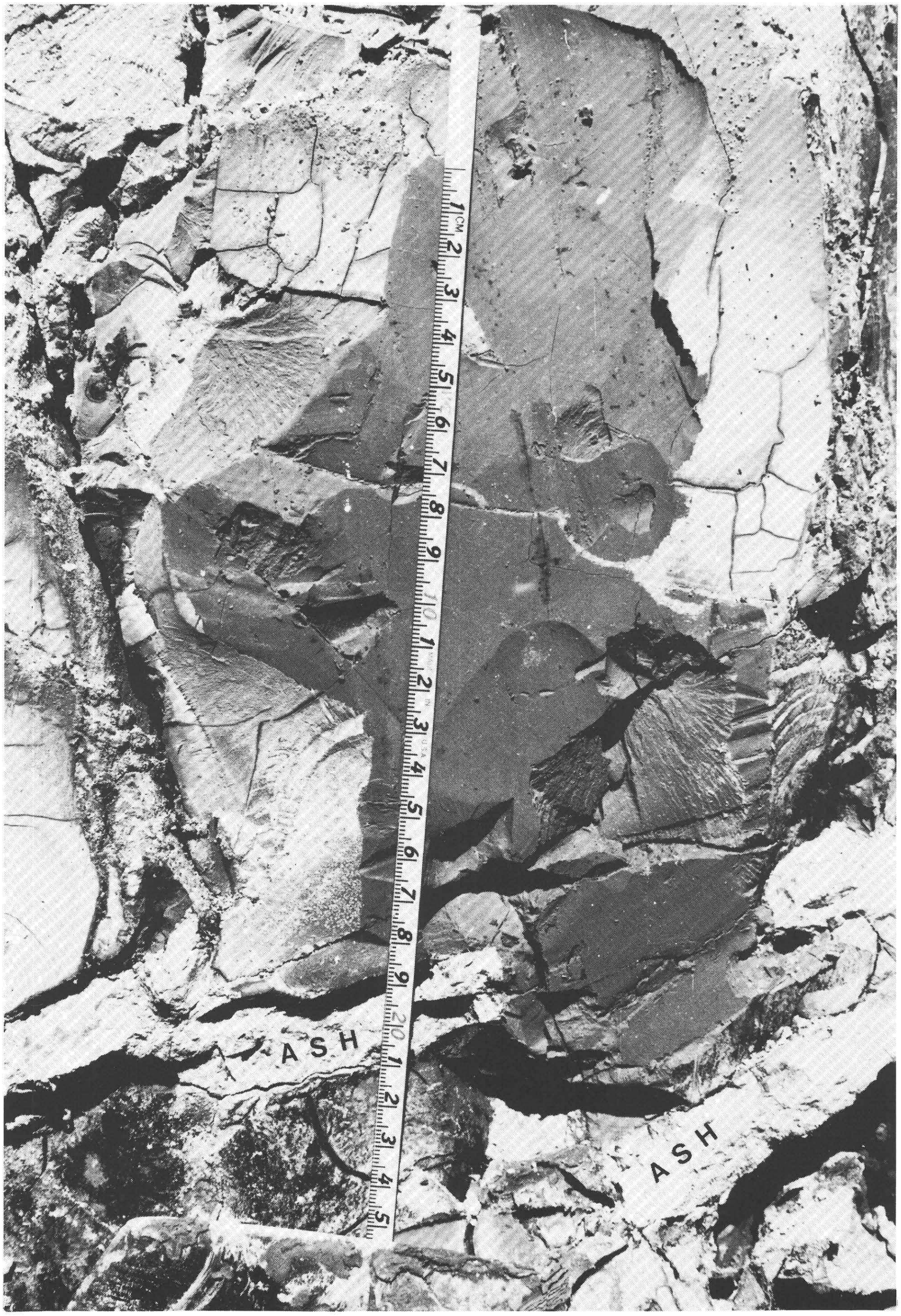


Figure 3. Discontinuously obscure fault strand in silty clay. Strand is visible as dark streak about 2 cm to right of 8-cm mark on tape. Light-colored volcanic ash bed in lower part of photo is displaced about 4 cm. The fault strand is visible only where it has dark material along it, but investigator (Dodge, 1982) was able to trace the strand from top to bottom of the trench wall, a distance of 0.8 m. Exposure N11, strand 25 (app. A).

faults. If the differences we observed have a probability of occurring of 0.05 or less, we rejected our original hypothesis (that no differences exist) and concluded that differences *do* exist at the 0.05 significance level. A discussion of the rationale for using this statistical method is given by Weinberg and others (1981).

Error values given in the tables in this report are binomial (also called dichotomous) standard deviations. They are less rigorous than ordinary standard deviations, because they depend primarily on the number of observed cases rather than observed variation within the sampled data. Examples of their use are given by Hoel (1966) and Fienberg (1980).

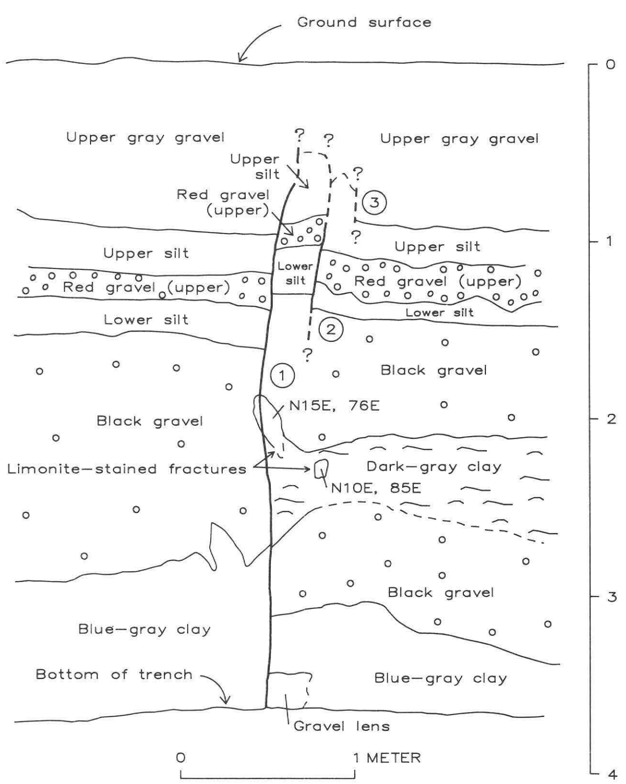


Figure 4. Examples of dieout up and dieout down. Northwest wall of trench across the main trace of the San Andreas fault near Dogtown, Marin County, California. At this site, about 4 m of right slip extended to the ground surface in the 1906 earthquake, and the surface trace was mapped by G.K. Gilbert. The upper part of the trace was not visible in this trench excavated in 1979, nor in 12 of 14 other exposures excavated in 1979 and 1981 in a 60-m length of the fault. Strand 1 was tabulated in appendix A (exposure E46) as dieout up, but strands 2 and 3 were not so tabulated because they may not have extended to the ground surface in 1906. Strands 2 and 3 are examples of dieout down. A distinct A soil horizon (not separately mapped) has developed on the upper gray gravel (Cotton and others, 1982, p. 16). Redrawn from Cotton and others (1982, pl. 1). Contacts dashed where approximate. Heavier fault lines dashed where approximate, queried where uncertain.

Description of Materials

The amount of detail provided by researchers describing geologic materials in the trench exposures varies greatly. In summarizing the data (app. A), we had to adopt simple, unmodified terms in order to include all the descriptions; thus silty sand or clayey silt were classified in this study as sand or silt, respectively. Soils can be weakly to strongly developed and the parent material altered to various degrees. If units were called soils in the trench report or log, they were classified as soil horizon, unless soil development was known to have had only a slight effect on the parent material; in the latter case, the parent material was tabulated. The soil horizons may have a wide range in organic content, grain size, and induration. Fossil soils are included.

Acknowledgments

The U.S. Nuclear Regulatory Commission provided the principal support for the early phases of this study, including several trenching investigations. Geologist Kenichi Takeyama of the Japanese Science and Technology Agency, who was on a one-year study program at the U.S. Geological Survey in Menlo Park, played an important role in the compilation of data by examining and making measurements on a large fraction of the trench logs and by translating Japanese reports on trenching. Sarah Beanland, J.W. Bell, W.R. Lund, M.N. Machette, D.P. Schwartz, and R.V. Sharp provided logs of trenches prior to publication.

VISIBILITY AND NONVISIBILITY OF FAULT STRANDS

Obscure Segments

Frequency and Fault Type

As discussed in the "Introduction," the type of line shown on the trench log was the principal basis for identifying an obscure segment. The type of line indicated on each trench log for which a fault is interpreted as having an obscure segment is given in appendix A. The following table shows the percentage of obscure segments that are indicated by a dashed line or no line on the trench logs used in this study. An obscure segment can have a dashed line in one part and no line in another part.

No line	36 percent
Dashed line	51 percent
Both	14 percent

As can be seen in figure 9 and table 2, 14 percent of all the fault strands include one or more obscure segments. Applying the results given in the table above, one can infer that about 5 percent of all strands had segments in which the evidence for faulting was so obscure that the investigators did not draw any line on the trench log, and about 7 percent had segments in which the evidence was equivocal and a dashed line was used. The frequency of obscure segments on reverse faults is about the same as on strike-slip faults, and it is significantly greater on each of these than on normal faults (fig. 9). Obscure segments were found on 34 percent of principal strands, but on only 10 percent of subsidiary strands. For principal strands, strike-slip faults have a higher proportion of obscure strands than dip-slip faults (table 2), and the difference is significant at the 0.05 level.

Displacement and Material

Obscure segments occur on fault strands with displacements ranging from a few centimeters on many faults to about 10 m on a reverse fault in New Zealand whose trace on the trench log is labeled "very faint evidence of fault" (Beanland and others, 1983, p. 11, Trench DC 504; app. A, exposure R23). We compared the frequency of obscure segments to the amount of displacement on faults, expecting that the frequency would be higher on faults with small displacements. Our expectations were not confirmed. Most of the obscure segments we tabulated do occur on strands with small displacements (app. B1), but this pattern seems to reflect only that faults with small displacements are more common in the trench logs we studied than faults with large displacements (app. B2).

To investigate the matter more closely, we tabulated the number of obscure segments on fault strands within each displacement class as defined in tables 3 and 4. Comparing the number of obscure segments to the number of all fault strands within each displacement class (see fig. 10, table 3), we found no consistent relation between amount of displacement and the frequency of obscure segments.

Statistical analysis of the results in figure 10 and table 3 reveal some interesting patterns. The data points

Figure 5. Example of fault strand that dies out upward. Although clearly defined in lower part of trench (center and lower part of photo), this trace of the San Andreas fault, which had about 4.3 m strike-slip displacement here in 1906, could not be followed to the ground surface in 1981 even though it reached the surface in 1906. Strand dies out in an A soil horizon developed in silty sandy gravel. The vertical shoring is 20 cm wide. Trench 10 of Cotton and others (1982) and exposure E57 of appendix A.

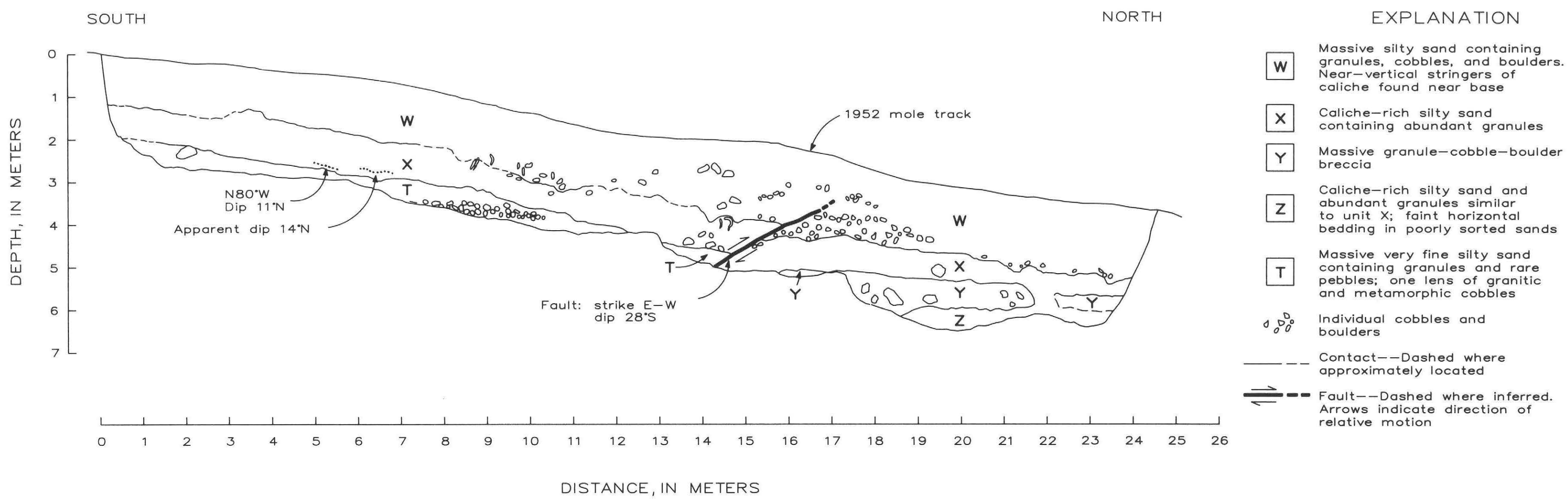


Figure 6. Simplified log of trench (app. A, exposure R10) across the 1952 surface trace of the White Wolf fault, showing example of dieout up. Trench was logged in 1975 by W.R. Cotton, N.T. Hall, and E.R. Hay (1976), who specifically stated that they could not trace the fault to the ground surface. The surface faulting at this point in 1952 was described as follows by Buwalda and St. Amand (1955): "At point 10, the trace developed a clear vertical uplift of 3 to 4 feet on the southeast side, probably indicating uplift of the mountain. Here the trace is a single pressure ridge [mole track] with a few cracks on the southeast side. The ridge is essentially a buckle, or a broken warp, without great evidence of shortening. There was some evidence of right lateral strike slip movement at this point." Short dotted lines within unit X are traces of bedding.

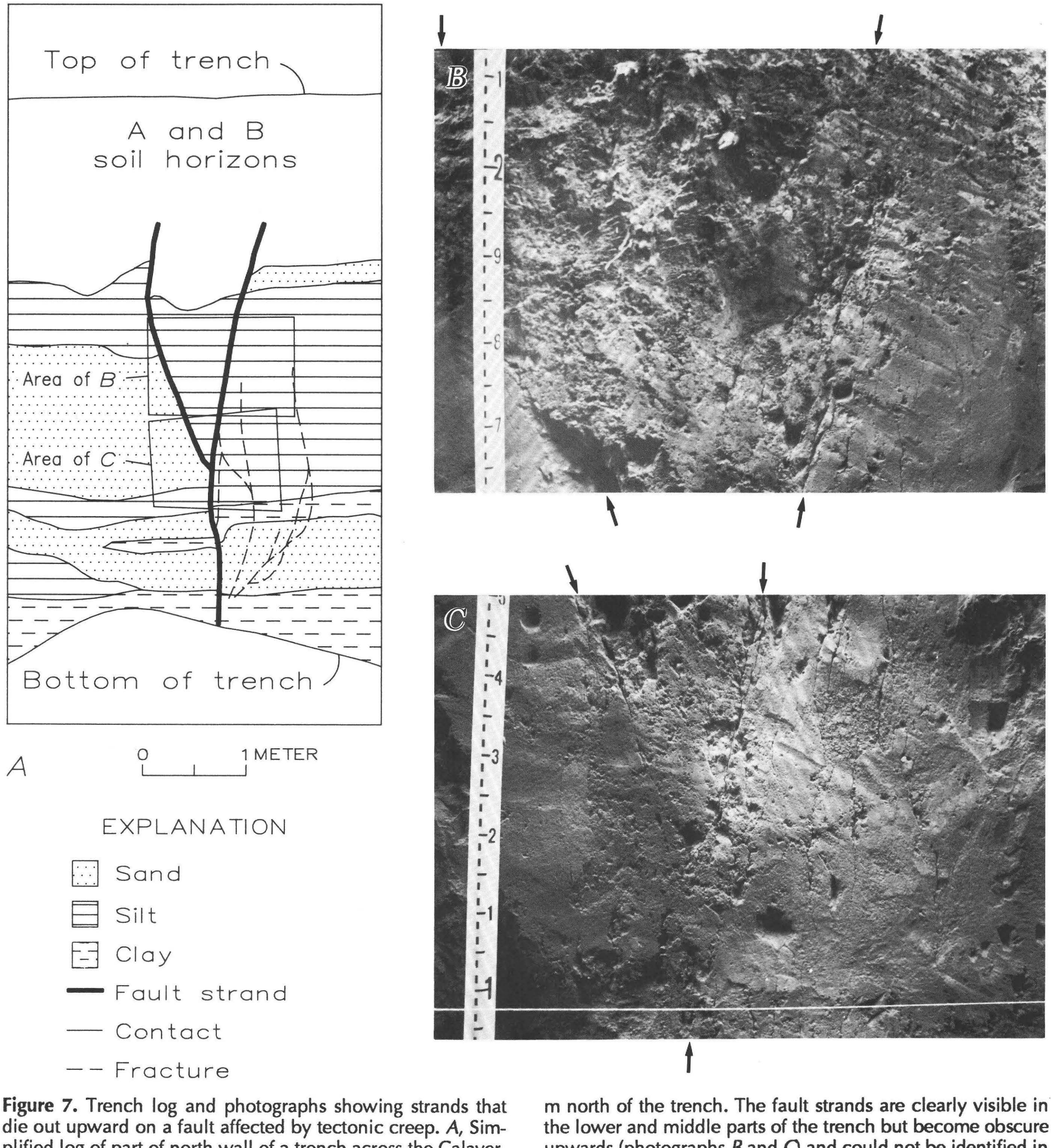


Figure 7. Trench log and photographs showing strands that die out upward on a fault affected by tectonic creep. *A*, Simplified log of part of north wall of a trench across the Calaveras fault 5.6 km north of Hollister, California, showing dieout up of active fault strands (app. A, exposure E13). Tectonic creep at a rate of 12 mm/yr has been measured at a creepmeter 9.7 m north of the trench wall (Schulz and others, 1982). The gradual slip on the fault has deformed a barn that is 4.5 m south of the trench and a house that is less than 100 m north of the trench. The fault strands are clearly visible in the lower and middle parts of the trench but become obscure upwards (photographs *B* and *C*) and could not be identified in the upper part of either wall of the trench. They were tabulated both as obscure segments and as instances of dieout up. Arrows on photographs show approximate locations of fault strands. Numbers on stadia rod in the photographs are 0.1 m apart. Trench log modified from D.G. Herd, M.G. Bonilla, and D.B. Burke, 1975, unpublished data.

in classes 5 through 10 (fig. 10) are too few for valid comparisons; however, the percentages in classes 2 through 4 and class 11 are significantly larger than in class 1 at the 0.05 level. This is surprising because one would expect larger displacements to produce more and better developed evidence of faulting. The rather high incidence of obscure segments in the largest displacement class was suspected to result from the fact that the data include eight exposures from one small area near Pallett Creek, California, and 15 exposures from another small area near Dogtown, California (app. A, exposures E30–37 and E44–58), where similar large historical displacements applied to several of the exposures, all of which are on the strike-slip San Andreas fault. In a test, all but one randomly selected exposure from each of these areas were discarded. The percentages in classes 2 through 4 remained significantly larger than in class 1. The percentage in class 11 also remained larger than in class 1, but the difference was not significant at the 0.05 level. The reasons for the apparent increase in obscurity with increase in displacement for classes 1 through 4 are unknown. The data do not permit an appraisal of

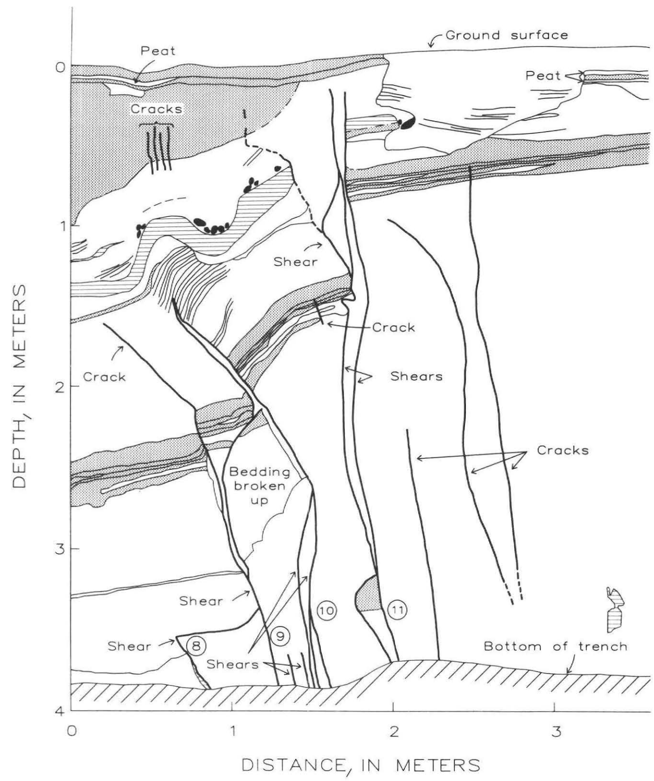


Figure 8. Trench log showing dieout up. Simplified log of part of southeast wall of trench excavated in 1978 across the Coyote Creek fault in California at a site where surface faulting occurred in 1968 (Sharp, 1981, fig. 15; Clark, 1972, pl. 1). Although the uppermost layers were displaced in 1968, no obvious tectonic disturbance of them could be found in either of the trench walls in 1978 despite a careful examination. Black ovals represent pebbles, horizontal-line pattern represents clay, shaded areas represent silt, unpatterned and unlabeled areas represent coarse to fine sand that is locally clayey. Unlabeled light lines, dashed where uncertain and having a dash-dot pattern where gradational, represent contacts and bedding, not all of which are shown. Heavy lines, dashed where uncertain, represent shears (fractures showing evidence of faulting) and cracks (fractures not showing evidence of faulting). Circled numbers refer to fault strands tabulated in appendix A, exposure E69. From unpublished data of R.V. Sharp, 1978.

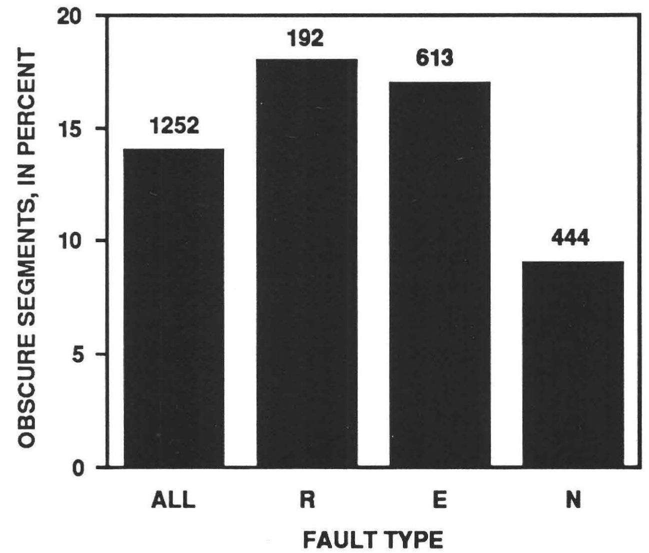


Figure 9. Frequency of fault strands with obscure segments as percent of all strands in given fault type. Total number of strands in each fault type shown above each bar. Abbreviations for fault types are R, reverse (includes reverse oblique); E, strike slip; N, normal (includes normal oblique). Based on table 2.

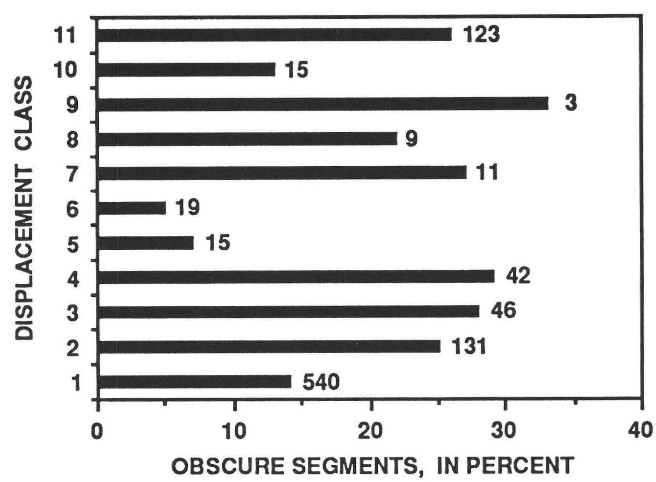


Figure 10. Frequency of obscure segments as percent of all strands in given displacement class. Includes data for all fault types. Total number of strands in each class shown to right of each bar. Displacement class 1 is the smallest and class 11 is the largest. Based on data in tables 3 and 4.

whether the increase is affected by the number of slip events that contributed to the recorded displacements.

To see if certain geologic materials are more likely than others to conceal fault traces, we calculated the frequency of obscure segments in various materials (table 5). A larger proportion of obscure segments occurs in coarse (sand size or larger) than in fine materials, particularly in sand. The percentage of obscure segments in gravel, however, is less than in silt or clay, and the percentage in each of these three is less than in soil horizons, which contain 19 percent of all the obscure segments.

To investigate whether the results in the previous paragraph may reflect the frequency of occurrence of the various materials cut by the trenches rather than differences in material behavior, a sampling was made of the materials in the trenches. For each exposure having one or more obscure segments, at least one representative section was measured on the trench logs. Where materials on the two sides of the fault are substantially different or where separate strands cut different materials, two or more sections were measured. Generally sections were chosen near the strands that have obscure segments in order to minimize the effects of variables such as dip and strike of the strand, type and amount of slip on the strand, and, for subsidiary strands, the distance of the strand from the principal strand. Thicknesses were measured normal to bedding where possible. Materials known to be younger than the faulting were not included in the measurements. The results of this sampling are given in table 6.

A comparison of the sampling results with the frequency of obscure segments in various materials is given in table 7. This table shows that obscure segments really are more common in some materials than in others. Even after the prevalence of certain materials in the trench exposures is taken into account, the ranking of materials most likely to contain obscure segments is essentially unchanged: the incidence of obscure segments is highest in sand, followed in order by soil horizons, silt, clay, and gravel. The incidence of obscure segments is higher in coarse than in fine materials, but the difference is less than suggested by table 5.

Length of Obscure Segments

Most obscure segments are of substantial length (as measured in the plane of the trench wall), 60 percent of them being longer than 0.3 m and 18 percent longer than 1.0 m (calculated from table 8). The frequencies of obscure segments in various length classes are grouped by fault type in figure 11. Obscure segments on dip-slip faults show a rather uneven distribution of lengths (figs. 11*A*–*C*), perhaps because of the rather small amount of data in each fault type. Obscure segments in the strike-slip group and the group of all faults taken together, each of which has more than 100 data points, show a distribution that one intuitively expects: a decrease in frequency with increase in length (figs. 11*D*, *E*).

Length of Obscure Segments Compared to Bed Thickness

A comparison was made between the thickness of beds containing obscure segments and the length of the obscure segments. The reason for making this comparison was the expectation that, on dip-slip faults, segments larger than the bed thickness would encounter bedding planes and juxtapose different materials, thus decreasing the chances that the segment would remain hidden. We measured bed thickness parallel to the fault trace as shown on the log, thus obtaining an apparent or effective thickness penetrated by the fault. Where a fault cuts beds of several thicknesses, the thicknesses were averaged, and where beds are of different thickness on the two sides of the fault, thicknesses on each side were averaged and an average then taken of the averages of the two sides. Thus we assigned to each fault strand one number representing average effective bed thickness at that strand. Actual effective bed thickness is probably less than the measured thickness because trench logs are generalized representations of trench walls, and the tendency is to show fewer bedding planes than actually exist. Very few descriptions give thicknesses of beds within mapping units. A plot of bed thickness versus length of obscure segments for all fault types (fig. 12) shows that the length of an obscure segment is generally but not always less than the associated bed thickness. This statement applies equally well to plots of data grouped by fault type.

Age of Most Recent Displacement

Only a limited amount of information is available on the relation between the incidence of obscure segments and the age of most recent displacement. The available data suggest that more obscure segments occur on younger than on older ruptures. The data permit the age of most recent displacement on the principal strands to be classified as historical, prehistorical Holocene, and prehistorical Quaternary. The data are summarized in table 9, which shows that principal strands with historical displacement have a significantly larger percentage of obscure segments than do prehistorical Holocene strands. The incidence of obscure segments in the Quaternary group is smaller than in the historical group but about the same as in the Holocene group.

The reasons for the greater incidence of obscure segments on faults having more recent displacement are not clear. One possibility is that considerable time is required for certain fault-produced changes in permeability and small-scale structure to become apparent. Secondary changes that are time-dependent include changes in color, organic content, compaction, cementation, and the local development of clay, iron oxide, or manganese coatings on grains. Younger faults have had less time for such changes to develop and therefore could be expected to have more obscure segments. The possible effect of the number of slip events cannot be rigorously evaluated; however, many of the obscure segments on historical ruptures (41 out of 51) coincide with strands that die out upward and probably represent only the historical slip event.

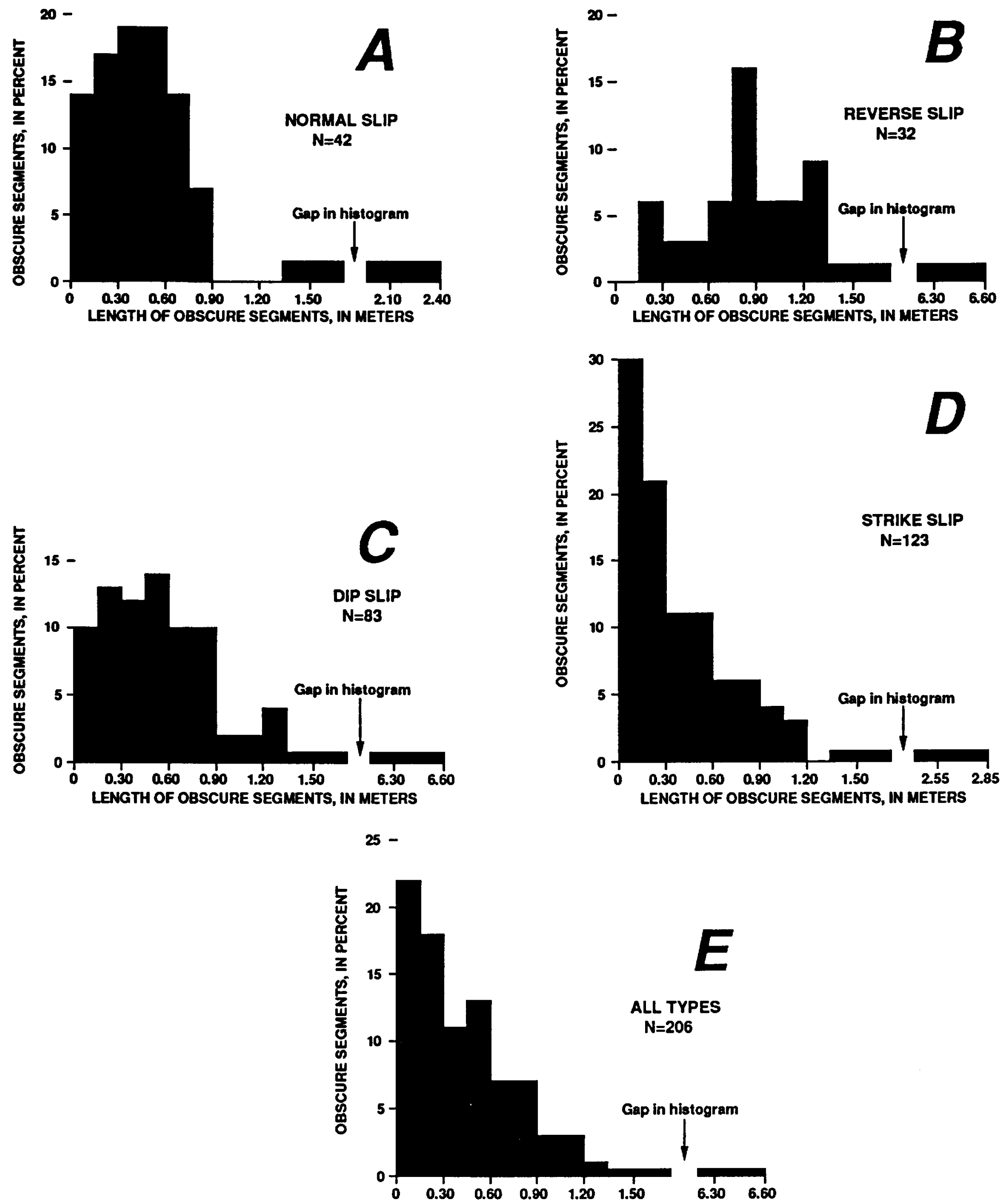


Figure 11. Distribution of lengths of obscure segments in various fault types (*A–E*), calculated as percent of all obscure segments in given fault type. N indicates number of obscure segments in each fault type. Height of bar in largest length class has been reduced in proportion to its greater width compared to the other length classes. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Histograms based on tables 4 and 8.

Strands That Die Out Upward

Many fault strands end or seem to end when traced upward; as discussed in a preceding section, this circumstance is referred to as dieout up. The previously discussed origins of dieout up—loss of visibility, distributed deformation, and actual termination—cannot be readily distinguished at most sites. For some traces on which surface rupture has occurred in historical time, dieout up can probably be explained by loss of visibility. Distributed deformation and loss of visibility can probably explain dieout up at the site on the White Wolf fault illustrated in figure 6. Distributed deformation accounts for dieout up in at least five exposures on strike-slip faults where tectonic creep was slowly distorting buildings at the ground surface when the trenches were excavated (app. A, exposures E13, E26, E17, E64, and E65). Actual upward termination by decrease in displacement seems to be the cause of dieout up of six strands on normal faults where the lower beds but not the upper beds are visibly displaced (app. A, strands N8-8, N8-25, N8-28, N23-4, N24-5, and N36-21); all of these are on subsidiary fault strands.

Frequency and Fault Type

As discussed in a preceding section, recognition of whether a fault strand dies out upward or not depends on knowledge of the position of the ground surface at the time of faulting. On the basis of this criterion, the presence or absence of dieout up is recognizable only on 143 principal and subsidiary strands, of which 45 percent die out upward (table 2). The frequency of dieout up in various groupings of fault types is shown in figure 13. The frequency of dieout up on principal and subsidiary strands of strike-slip faults (73 percent) and reverse faults (75 percent) is significantly greater than for normal and normal-oblique-slip faults (15 percent). The frequency of dieout up on strike-slip and reverse faults is surprisingly high. If the many exposures at Pallett Creek and Dogtown are reduced to one at each place and if one exposure (app. A, exposure R2) having an unusually large number of strands that die out upward is removed from the data set, the frequency remains high—67 percent for strike-slip faults and 61 percent for reverse faults. The differences between dieout up on principal strands compared to dieout up on principal and subsidiary strands combined is not significant at the 0.05 level, but the data are too limited to compare principal strands with subsidiary strands alone.

Displacement and Material

The incidence of dieout up shows no clear relation to displacement on the strand (table 3; apps. C1, C2). As with obscure segments, this result is surprising because one would expect that larger displacements would produce more readily visible evidence of faulting, hence smaller displacements would produce more instances of dieout up. Despite our expectations, no significant differences at the 0.05 level were found. The multiple exposures at the Pallett Creek and Dogtown sites have

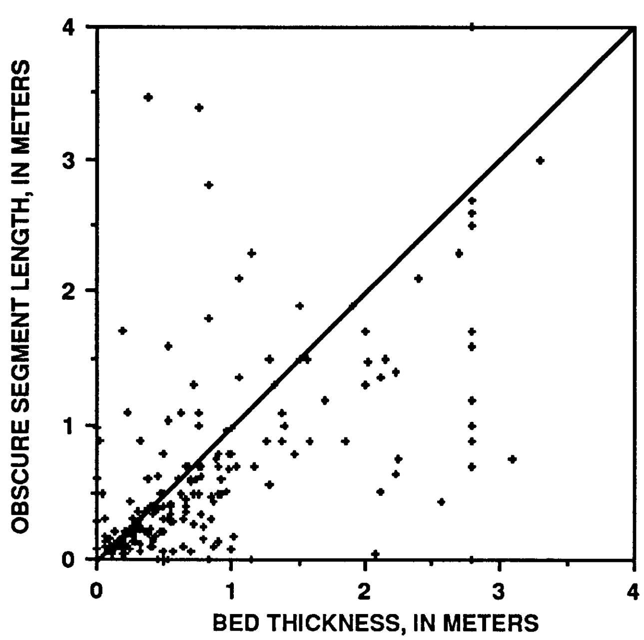


Figure 12. Bed thickness versus length of obscure segment for all fault types. Diagonal line is where bed thickness is equal to length of obscure segment. One point above the line lies outside the graph.

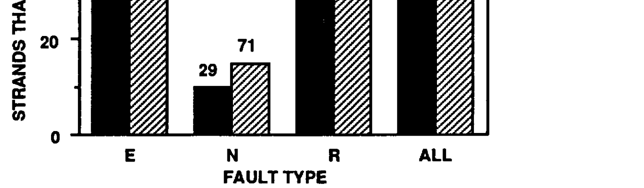


Figure 13. Frequency of strands that die out upward as percent of all strands of given fault type that allow recognition of dieout up (that is, strands for which position of ground surface at time of faulting is known or reasonably inferred). P, principal; S, subsidiary; E, strike slip; N, normal and normal-oblique slip; R, reverse and reverse-oblique slip. Total number of strands in each group on which dieout up could have been recognized shown above each bar. Based on table 2.

affected the statistical results but not in an important way. When only one randomly selected exposure from each of these sites was included in the data, the frequency in the largest displacement class was reduced from 44 percent to 21 percent, but the difference between the smallest and largest classes was still not significant.

Information relating dieout up to material was investigated. If dieout up occurs on a strand, the material in which the strand actually or apparently dies out was tabulated (app. A). If dieout up does not occur, the material at the top of the trench was tabulated. Examination of figure 14 and the data in table 5 shows that on the basis of this small sample, dieout up is largely independent of the material involved.

Depth

As noted earlier, "depth of dieout up" is defined as the vertical distance from the ground surface at the time of faulting to the top of the visible part of the strand. In the trench logs we examined, the depth of dieout up ranges from a few centimeters to 5.5 m (tables 4, 10). The frequency of dieout up at different depths for various fault types is illustrated in figure 15 and listed in table 10. The plots for strike-slip faults and all faults together (figs. 15*D*, *E*) suggest a decrease in frequency of dieout up with increase in depth of dieout up.

Depth and Bed Thickness

A comparison was made between the thickness of beds and the depth of dieout up. Bed thickness was determined as described above in the section "Obscure Segments." Dieout up is more likely to occur in thick beds than in thin beds because the chances of dissimilar materials being brought together is smaller in thick beds; the expectation, therefore, was that bed thickness would generally be greater than depth of dieout up, and that proved to be so (fig. 16). The same relation is true when data from strike-slip, normal, and reverse faults are plotted separately.

Strands That Die Out Downward

Many fault strands end or seem to end when traced downward on trench walls. In compiling data on dieout down, we tabulated only fault strands for which no line is shown on their downward projection. Dieout down occurred on 34 percent of all strands for which the presence or absence of dieout down could be determined, that is, strands that do not join strands of greater displacement when traced downward (table 2). Almost all dieout down (98 percent) occurs on subsidiary fault strands (calculated from table 2). Considering the principal and subsidiary strands together, significantly more strands on strike-slip faults die out downward than on reverse or normal faults (table 2 and fig. 17). The difference between normal and reverse faults is not significant. Considering principal strands only, the data are too sparse to compare the various fault types.

The frequency of strands that die out downward shows a general relation to amount of displacement, in contrast to the frequencies of obscure segments and segments that die out upward. The incidence of dieout down is more common on strands having small displacement than on strands having large displacement (fig. 18; table 3; apps. D1, D2). The frequency of dieout down in displacement class 1 is significantly higher than in classes 2–4 and class 11. The frequency of dieout down is also significantly higher in classes 2 and 3 than in class 11. These statements apply equally well when the large number of similar exposures at Pallett Creek and Dogtown are reduced to one at each place. (Displacement classes 5–10 contain too few strands to permit significant comparisons.)

The effect of material on dieout down was investigated. The material listed in appendix A is the material in which the strand actually or apparently dies out. An ambiguity arises for logs in which the strand is shown ending downward at an undisplaced bedding plane, a circumstance that occurs on several strands. In this situation the material in which the strand is last seen was tabulated, a procedure that assumes the strand actually

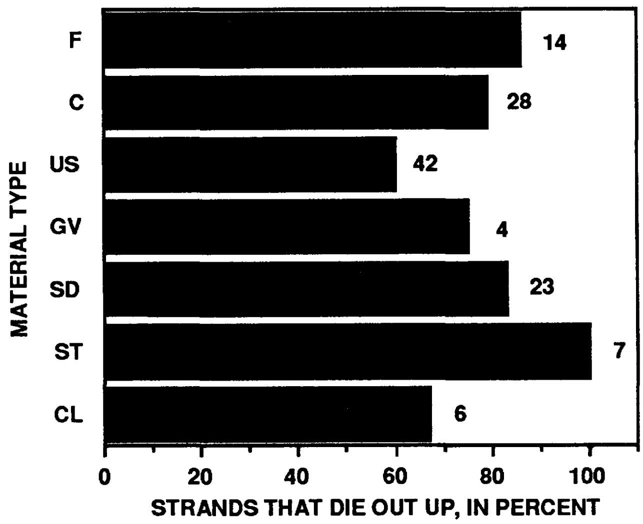
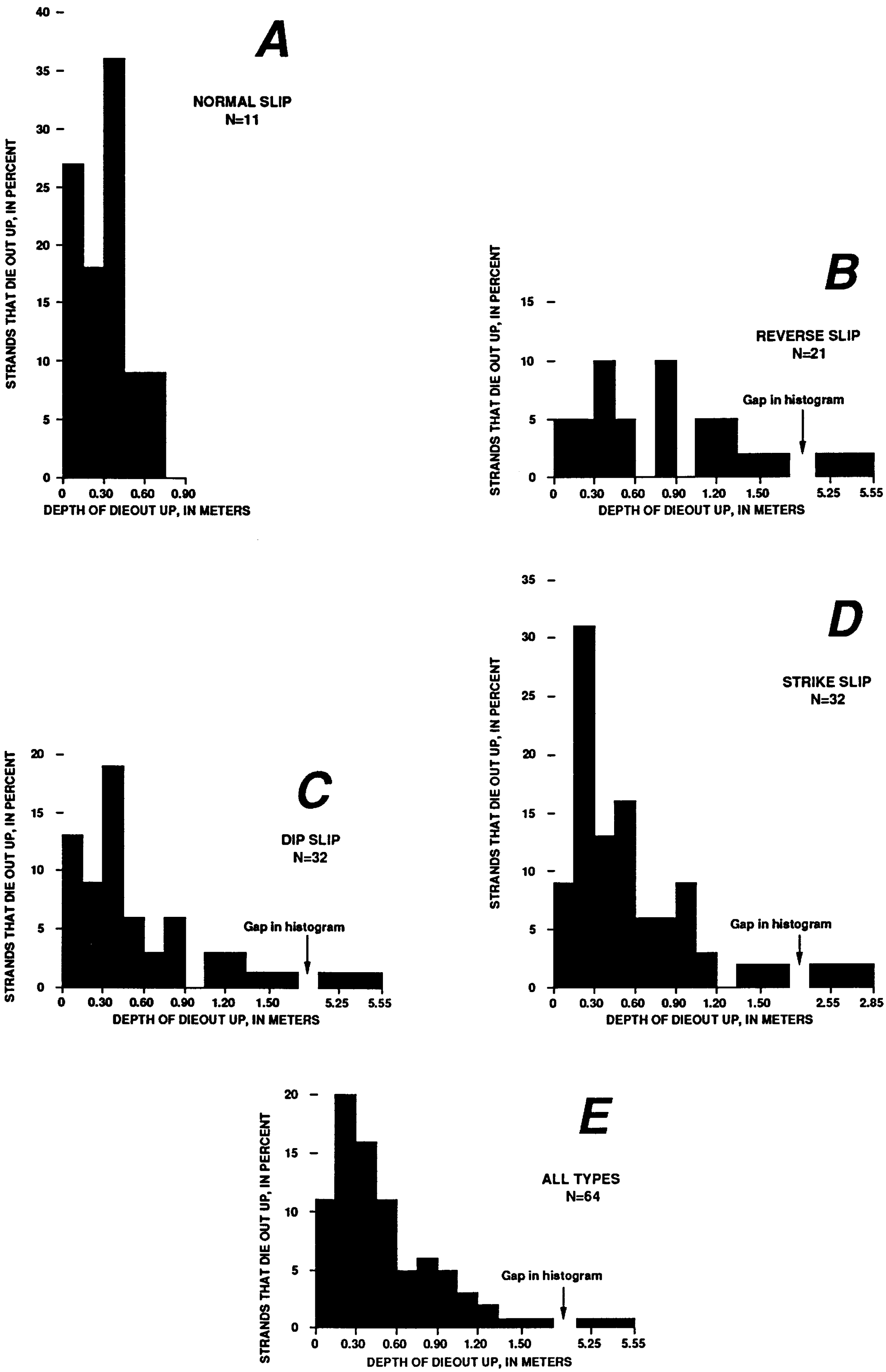


Figure 14. Frequency of strands that die out upward as percent of all strands in given material that allow recognition of dieout up (that is, position of ground surface at time of faulting is known or reasonably inferred). Some materials that occur infrequently are omitted from the graph but are listed in table 5. Abbreviations are F, fine; C, coarse; US, soil horizon; GV, gravel; SD, sand; ST, silt; CL, clay. Number of strands on which dieout up could have been recognized shown to right of each bar.


A
NORMAL SLIP
N=11
STRANDS THAT DIE OUT UP, IN PERCENT
DEPTH OF DIEOUT UP, IN METERS
B
REVERSE SLIP
N=21
Gap in histogram
STRANDS THAT DIE OUT UP, IN PERCENT
DEPTH OF DIEOUT UP, IN METERS
C
DIP SLIP
N=32
Gap in histogram
STRANDS THAT DIE OUT UP, IN PERCENT
DEPTH OF DIEOUT UP, IN METERS
D
STRIKE SLIP
N=32
Gap in histogram
STRANDS THAT DIE OUT UP, IN PERCENT
DEPTH OF DIEOUT UP, IN METERS
E
ALL TYPES
N=64
Gap in histogram
STRANDS THAT DIE OUT UP, IN PERCENT
DEPTH OF DIEOUT UP, IN METERS

ended above the bedding plane. This may have been the real but unreported case, or the strand may have continued as undetected bedding-plane slip or undetected distributed slip across, and below, the bedding plane. If dieout down did not occur, the material at the bottom of the trench wall was listed in appendix A.

Some differences in incidence of dieout down among different materials are apparent. In contrast to dieout-up data, which are nearly all from principal strands, the record of dieout down is dominated by data from subsidiary strands. For all unconsolidated materials the incidence of dieout down is 11 percent for principal strands and 50 percent for subsidiary strands (table 5). For principal strands alone the data are too few to compare the effects of the various unconsolidated material types (table 5), so principal strands have been combined with subsidiary strands in figure 19. Some of the differences in dieout down shown in figure 19 are significant at the 0.05 level both for subsidiary strands alone and for subsidiary strands combined with principal strands. The frequency of dieout down is significantly lower in clay than in silt, sand, or soil horizons; and it is significantly lower in gravel than in silt, sand, or soil horizons. The other possible comparisons do not yield significant differences. These statements apply equally well when the large number of similar exposures at Pallett Creek and Dogtown are reduced to one at each place. Another exposure (app. A, exposure E2) has an unusually large number of subsidiary strands that die out downward in silt, and if it also is omitted from the count, the significant comparisons are reduced to clay versus sand and soil horizons, and gravel versus sand and soil horizons.

To determine whether the differences described above simply reflect the prevalence of certain materials in the trenches, we compared the frequency of dieout down in various materials with the frequency of occurrence of those materials in the exposures (table 11). For this comparison, we used results from the previously described sampling of materials (table 6). Although this sampling was primarily for application to obscure strand segments, it was considered sufficiently representative to apply as well to dieout down because one or more complete sections were measured in a large fraction (55 percent) of the exposures. The comparison in table 11 shows that dieout down really is more common in some materials than others. The ranking of materials in table 11 suggests that dieout down is most common in silt and

◄ **Figure 15.** Distribution of depths of dieout up in various fault types (*A–E*), calculated as percent of all strands that die out upward in given fault type. Where necessary, height of bar in largest depth class has been reduced in proportion to its greater width compared to other depth classes. N is number of strands that die out upward in each fault type. Histograms based on tables 4 and 10.

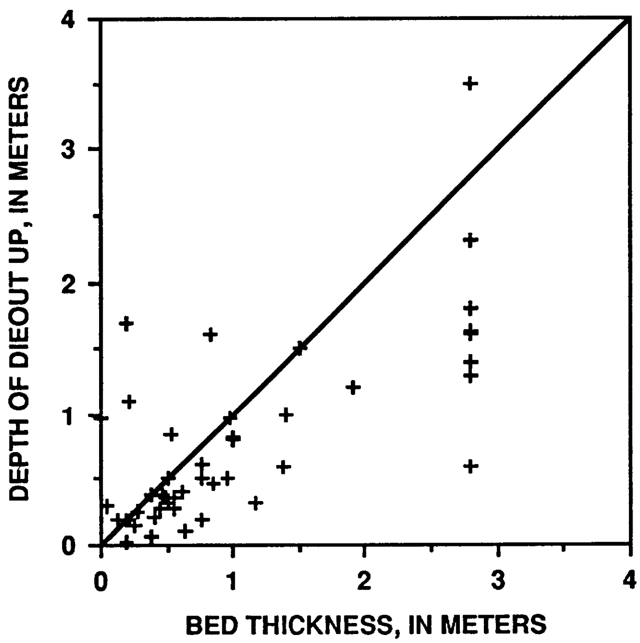


Figure 16. Bed thickness versus depth of dieout up for strike-slip, normal, and reverse faults. Diagonal line is where bed thickness is equal to depth of dieout up.

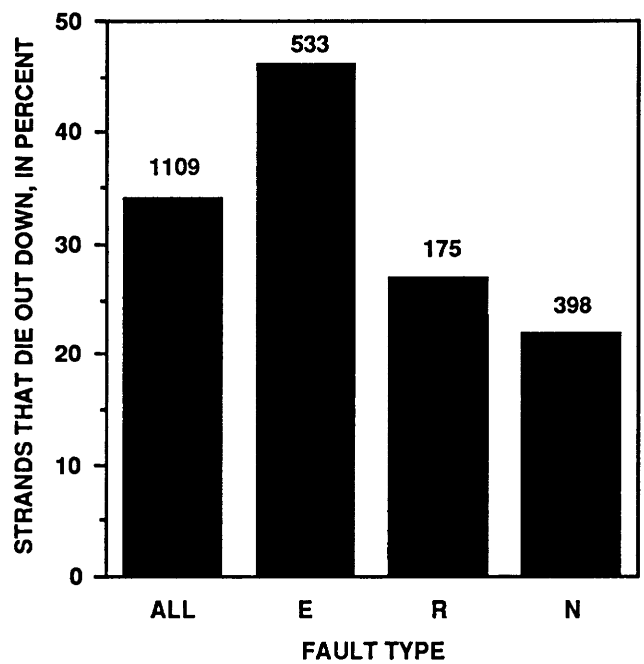


Figure 17. Frequency of strands that die out downward as percent of all strands of given fault type that allow recognition of dieout down (that is, strand does not join a strand of greater displacement when traced downward). Number of strands in each fault type shown above each bar. Abbreviations for fault types are E, strike slip; R, reverse (includes reverse oblique); N, normal (includes normal oblique). Based on table 2.

progressively less common in soil horizons, sand, clay, and gravel. This ranking is the same as that in figure 19 for all strands, except for the ranking of clay and gravel. Although the frequency of dieout down (in all strands) is equal in clay and gravel in figure 19, the frequency of dieout down is lower in gravel in table 11. The high ranking of silt in both cases reflects the inclusion of data from exposure E2, described above, in which an unusual number of strands die out downward in silt. If the unusually high incidence of dieout down in silt at exposure E2

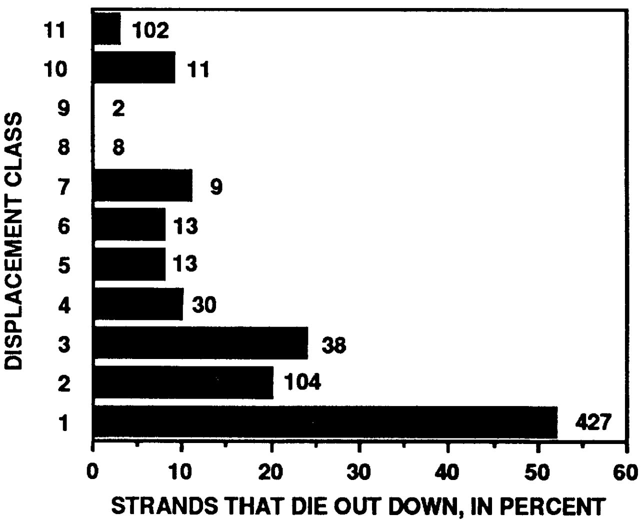


Figure 18. Frequency of strands that die out downward as percent of all strands in given displacement class that allow recognition of dieout down (that is, strand does not join a strand of greater displacement when traced downward). Number of strands in sample shown to right of each bar or displacement class. Displacement class 1 is the smallest and class 11 is the largest. Based on tables 3 and 4.

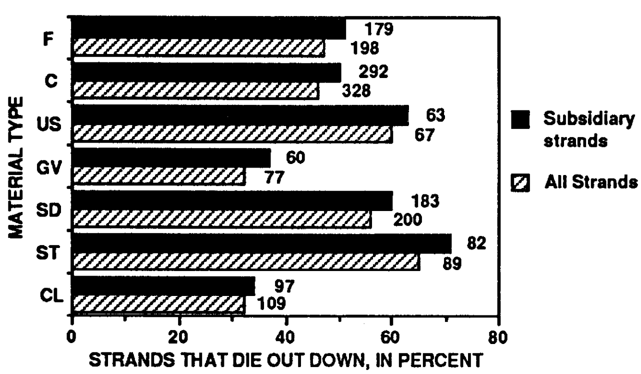


Figure 19. Frequency of strands that die out downward as percent of all strands in given material that allow recognition of dieout down (that is, strand does not join a strand of greater displacement when traced downward). Some materials that occur infrequently are omitted from the graph but are listed in table 5. Abbreviations are F, fine; C, coarse; US, soil horizon; GV, gravel; SD, sand; ST, silt; CL, clay. Number of strands on which dieout down could have been recognized shown to right of each bar.

is omitted, the data show that dieout down is significantly more common in soil horizons and sand than in gravel or clay.

Generalizations About Nonvisibility of Fault Strands

The frequency of nonvisibility (defined earlier as including dieout up, obscure segments, and dieout down) and the principal factors related to nonvisibility are summarized in this section. As discussed in the "Introduction," the nonvisibility may have existed initially or may have resulted from postfaulting changes.

Nonvisibility Versus Fault Type

The frequencies of nonvisibility for several categories of fault types are shown graphically in figure 20, and the significance of the differences in nonvisibility is indicated numerically in table 12, discussed below. For principal strands, shown in figure 20*A*, dieout up occurs with higher frequency on strike-slip and reverse faults than on normal faults, but dieout-up frequencies on strike-slip and reverse faults are not significantly different. Obscure segments occur more frequently on strike-slip than on reverse faults and more frequently on reverse faults than on normal faults; these differences are

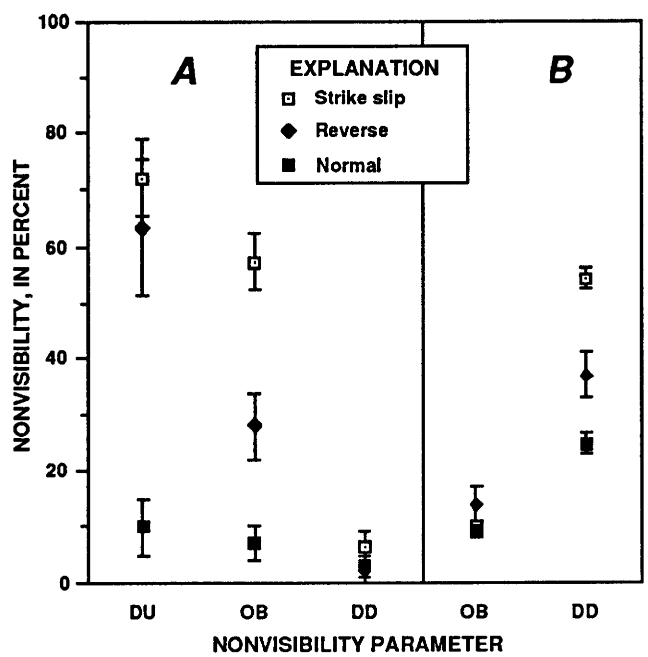


Figure 20. Frequency of nonvisibility of faulting in various fault types. *A*, Principal strands. *B*, Subsidiary strands. DU, dieout up; OB, strands having obscure segments; DD, dieout down. Normal includes normal-oblique-slip faults; reverse includes reverse-oblique-slip faults. Lines show standard deviations.

significant at the 0.05 level. No significant differences occur between the frequencies of dieout down on principal strands in the different fault types. For subsidiary strands, shown in figure 20*B*, the only significant differences are in frequencies of dieout down, of which strike-slip faults show the highest incidence, reverse faults an intermediate incidence, and normal faults the lowest incidence.

Table 12 lists only those comparisons between fault groups that are significantly different at the 0.05 level or less. The Z scores (distance from the mean divided by the standard deviation—see Weinberg and others, 1981; Fienberg, 1980) indicate the degree of confidence that the listed differences are real, with higher Z scores indicating greater confidence. All but one of the Z scores in the table are greater than 2.58, indicating significance at the 0.01 level, or that the chances are 1 percent or less that no differences exist in the listed variables. (For comparison, significance at the 0.05 level is indicated by a Z score of 1.96.)

Where significant differences are shown in table 12, strike-slip faulting is markedly less visible than other types of faulting. Several factors may contribute to this lower visibility. In general, the bedding of the sediments exposed in the trenches has a low dip, and therefore individual beds are more likely to remain in contact and present fewer lithologic contrasts across the fault after strike-slip displacement than after dip-slip displacement. Dip-slip faulting is also more likely to be recognizable because of distinctive scarp-derived rubble and colluvium that generally forms. Furthermore, tensional openings produced during normal faulting are commonly visible because the open fissures have been preserved or have been filled with materials that contrast with their surroundings.

Table 12 also shows that where significant differences exist, the incidence of nonvisibility is greater for reverse faults than for normal faults. Possibly this too is related to a greater tendency to produce tensional openings during normal faulting.

Although not shown in table 12, for principal strands the incidence of dieout up is distinctly higher than the incidence of dieout down in both the strike-slip and dip-slip groups. Part of the explanation for the lower incidence of dieout down may be that lower beds in the trenches, being older, record more episodes of faulting. For subsidiary strands no valid comparisons can be made between dieout up and dieout down.

For all types of faults as a group some significant differences are apparent in the nonvisibility of principal strands compared to subsidiary strands. Principal strands are distinctly more likely to have obscure segments (34 percent) than are subsidiary strands (10 percent; table 2). Part of the explanation may be that the subsidiary strands are generally short and that few data are available on them regarding one subset of the obscure segment group: dieout up during historical ruptures. Our data suggest that dieout up is more common on principal strands than on subsidiary strands, but the difference is not significant. Dieout down is rare on principal strands (4 percent), much more common on subsidiary strands (41 percent; table 2).

Nonvisibility Versus Material Type

The effect of material type on the incidence of nonvisibility is shown in figure 21. The diagram is based only on obscure segments and dieout down on combined principal and subsidiary strands, because dieout-up data were too sparse for significant distinctions among material types. The results are summarized and compared using nonvisibility quotients (that is, frequency of occurrence of a nonvisibility parameter—such as dieout down—divided by frequency of occurrence of a given material; see tables 7 and 11). Soil horizon has a high nonvisibility quotient, and clay and gravel have low nonvisibility quotients for both obscure segments and dieout down. The explanation for the high rank of soil horizons probably is that the commonly massive but fractured, blocky nature of soils makes it difficult to identify fault strands, as do the modifications that occur in soils as the result of moisture changes, temperature changes, root growth and decay, and the activity of invertebrate and vertebrate animals including humans. Gravel has a unique property, the ability to display fault-

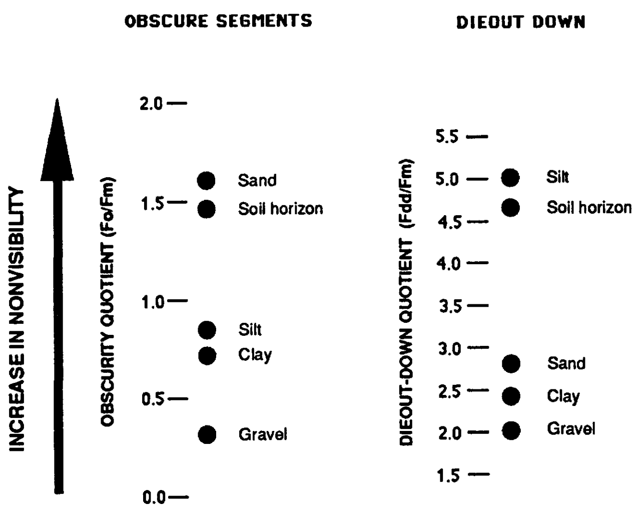


Figure 21. Comparison of nonvisibility of faulting in various materials. Fo/Fm (from table 7) is frequency of obscure segments in the given material divided by frequency of occurrence of the given material; Fdd/Fm (from table 11) is frequency of dieout down in the given material divided by frequency of occurrence of the given material. Includes data for both principal and subsidiary strands. Dieout-up data too sparse to determine any significant contrasts related to material.

ing by the rotation of pebbles. Whether, in our sample, the clay has more distinct bedding than the sand and silt and therefore tends to reveal faulting is unknown.

Sand and silt have inconsistent positions in the two parts of figure 21. For obscure segments sand is in first position and silt in third position, but for dieout down these positions are reversed. Use of only one randomly selected exposure at Pallett Creek and at Dogtown from the several exposures at those sites results in a similar reversal of the relative ranks of sand and silt. The obscure-segment data probably are the more reliable of the two because they are more numerous and because the data on dieout down no doubt include many strands that are actually terminated rather than merely concealed.

The necessary grouping of the materials into simple classes (see "Introduction") may have affected the rankings of materials with regard to nonvisibility. Clayey sand may actually respond to faulting more like clay than like clean sand, for example. Nevertheless, the rankings do represent typical response to faulting under the variety of field conditions represented by our sample.

MISCELLANEOUS ASPECTS OF FAULTING

Although the emphasis of this study was on the visibility and dieout of fault strands, data on other aspects of faulting were also gathered. Some of these aspects, such as fault-zone widths and the deformation of the hanging wall versus the footwall, have applications in engineering. The other aspects are primarily useful in the recognition of faults and prehistorical earthquakes.

Widths of Faults

Information on widths of the faults crossed by the trenches may be useful for various purposes such as preliminary selection of lengths for exploratory trenches. We measured the widths horizontally, choosing the level that gave the maximum width. For the few trenches that were excavated obliquely to the fault, the width was trigonometrically corrected. A few widths are from statements in the reports rather than the logs. A summary of the data giving the minimum, maximum, and median widths for the principal strand(s) and the principal and subsidiary strands together is given in table 13. The principal strand, as used here, is the strand that has the largest real or apparent displacement in a given exposure. However, in 23 percent of the exposures, two or more strands of nearly equal displacement are termed principal strands because they have substantially larger displacements than the others. Where these strands have a branching or subparallel arrangement and clearly constitute the most important zone in the exposure, the width across them was tabulated as the width of a principal strand; but if they do not clearly form a main zone, their widths were included in the "Principal and subsidiary strands" group (table 13).

The median width of the principal strand(s) for all fault types is 0.4 m, for strike-slip faults it is 0.2 m, and for dip-slip faults it is 0.7 m. The median width of principal and subsidiary strands as a group is considerably larger, being 7.9 m for all fault types, 5.5 m for strike-slip faults, and 12.1 m for dip-slip faults (table 13). Note the wide ranges in the maxima and minima given in the table.

The widths of fault strands given in table 13 have some limitations. The minimum width for some strands is less than can be drawn to scale or properly measured on the trench logs, and therefore some of the median widths listed in the table are larger than the true widths. Because about 10 percent of the fault zones are wider than the length of the trenches, the median widths given in the table for principal plus subsidiary strands are somewhat smaller than the true widths. Secondary faults, which in historical surface ruptures have occurred several kilometers from the main fault (Bonilla, 1970), are of course not included in the trench width data.

Relation of Width to Displacement

Several investigators have reported a positive correlation between fault displacement and the thickness of gouge and breccia, and others have questioned such a correlation (Robertson, 1983, 1984; Wallace and Morris, 1986; Waterman, 1984; Wilder, 1984). In a summary of data from outcrops, mines, and laboratory experiments Robertson (1983) found that, with considerable variation, the displacement is about 100 times the thickness of gouge and breccia for faults in rock. Because most of the trenches we studied are in unconsolidated materials in which gouge and breccia are uncommon, a direct comparison with Robertson's results cannot be made; however, the widths of the principal and subsidiary strands can be compared to displacement for some fault types. For this comparison the individual displacements across multiple strands, if present, were added together. As described above, some of the fault widths we measured include unbroken material, in contrast to the widths measured in Robertson's study.

The correlations of width to displacement range from moderate to very poor. For principal strands the best correlation is for reverse faults, which have a correlation coefficient of 0.7, on the basis of 18 widely scattered data points (table 14). Principal strands of normal faults have a very low correlation coefficient—only 0.3, on the basis of 20 data points.

For principal and subsidiary strands as a group, the normal faults show the best correlation between width and displacement, having a correlation coefficient of 0.6, on the basis of 20 data points. Principal and subsidiary strands of reverse faults show a wide scatter, and the regression of width on displacement based on 11 data points yields a negative slope (that is, the width decreases as the displacement increases) (table 14). Regression analyses of width on displacement for strike-slip faults yielded negative slopes using either width of principal strands or width of principal and subsidiary strands, perhaps because the strike-slip displacement on them is poorly known.

Although some of the trench data weakly favor a positive correlation between fault displacement and fault width, the analyses indicate that other factors must be important at these shallow depths and in mostly unconsolidated materials. The highest correlation coefficient ($r=0.69$) indicates that only about 48 percent ($r^2 \times 100$) or less of the variation in the width is accounted for by the variation in displacement. More data could of course change that fraction, but some aspects of the trench exposures show clearly that other factors must be involved. In some trenches the width does not differ from top to bottom although the displacement does differ (a dip-slip example is shown in fig. 22). In other trenches the width does vary from top to bottom of the trenches, which average perhaps 3.5 m deep. In two exposures, both of them across the strike-slip San Andreas fault, the fault-zone width increases downward; however, the width increases *upward* in six exposures across reverse faults and in eight exposures across strike-slip faults, an example of which is shown in figure 7. If a difference in displacement exists between the upper and lower parts of the trench, the lower and older parts would be expected to have the larger displacements; thus at 14 exposures the width apparently varies inversely with change in displacement.

Deformation of Hanging Wall and Footwall

Although deformation of the hanging-wall block of dip-slip faults tends to occur in preference to deformation of the footwall block (Cluff and Plafker, 1966; Sherard and others, 1974, fig. 21 and p. 393; Taylor and Cluff, 1977, fig. 1), the footwall block or both blocks have been deformed in some historical surface faulting (M.G. Bonilla, unpub. data, 1980; McCalpin, 1987). The trench logs were examined for evidence on this subject, and the results are summarized in table 15. In this compilation the block was considered deformed if it contains fault strands or drag effects. The table shows that, where a determination can be made, the hanging wall is indeed deformed in the majority of cases, but the footwall or both walls are deformed in a substantial fraction of cases. A similar result was obtained by McCalpin (1987) for trenches across normal faults in the western United States; however, his study showed that the deformation zone on the hanging wall of normal faults was in general substantially wider than on the footwall.

Mechanical Effects of Faulting

Rotation of Pebbles

Pebble rotation is commonly used as a criterion for faulting, and the trenching data were examined for evidence of this phenomenon. At least three processes can lead to rotation of pebbles from their initial depositional orientation: (1) individual pebbles that span a shear surface can be reoriented by differential movement of their edges as shearing occurs; (2) groups of pebbles can be rotated by distributed shearing or by drag that affects them and their enclosing matrix; and (3) individual pebbles or groups of pebbles in a block can rotate by falling into openings created by faulting or other processes. Deposition on steep slopes created by faulting can result in steep pebble orientations that are not the direct result of tectonic slip. When recognized, steep orientations caused by blocks falling or by deposition of clasts were not tabulated.

Gravel is present in the fault zones in 99 of the exposures, and rotation of pebbles is reported for 41 percent of them (table 16). Subdivided by fault type, pebble rotation is more common in normal faults than in strike-slip faults, but no other comparisons between fault types yielded significant differences. Many trench logs do not indicate whether the pebbles were rotated or not. Considering only the 53 exposures for which the question of pebble rotation can be answered with a yes or no, 77 percent of them show pebble rotation, and no significant differences are apparent among the various fault types (table 16). An example of pebble rotation is shown in figure 23. That figure also shows that conclusions about pebble rotation require knowledge of the initial orientation of the pebbles.

An attempt was made to find a threshold fault displacement at which pebbles become clearly rotated from their initial positions. Reasoning suggests that a displacement approximately equal to the long dimension of the pebbles could be sufficient, and the trench data suggest the same: The smallest displacement accompanied by pebble rotation is about 0.05 m in a zone where the long dimension of the pebbles is about 0.02 m. With a larger set of data, pebble rotation at even smaller displacements probably would appear.

Fissures

Openings caused by faulting or related folding occur in 52 percent of the exposures (table 17). The

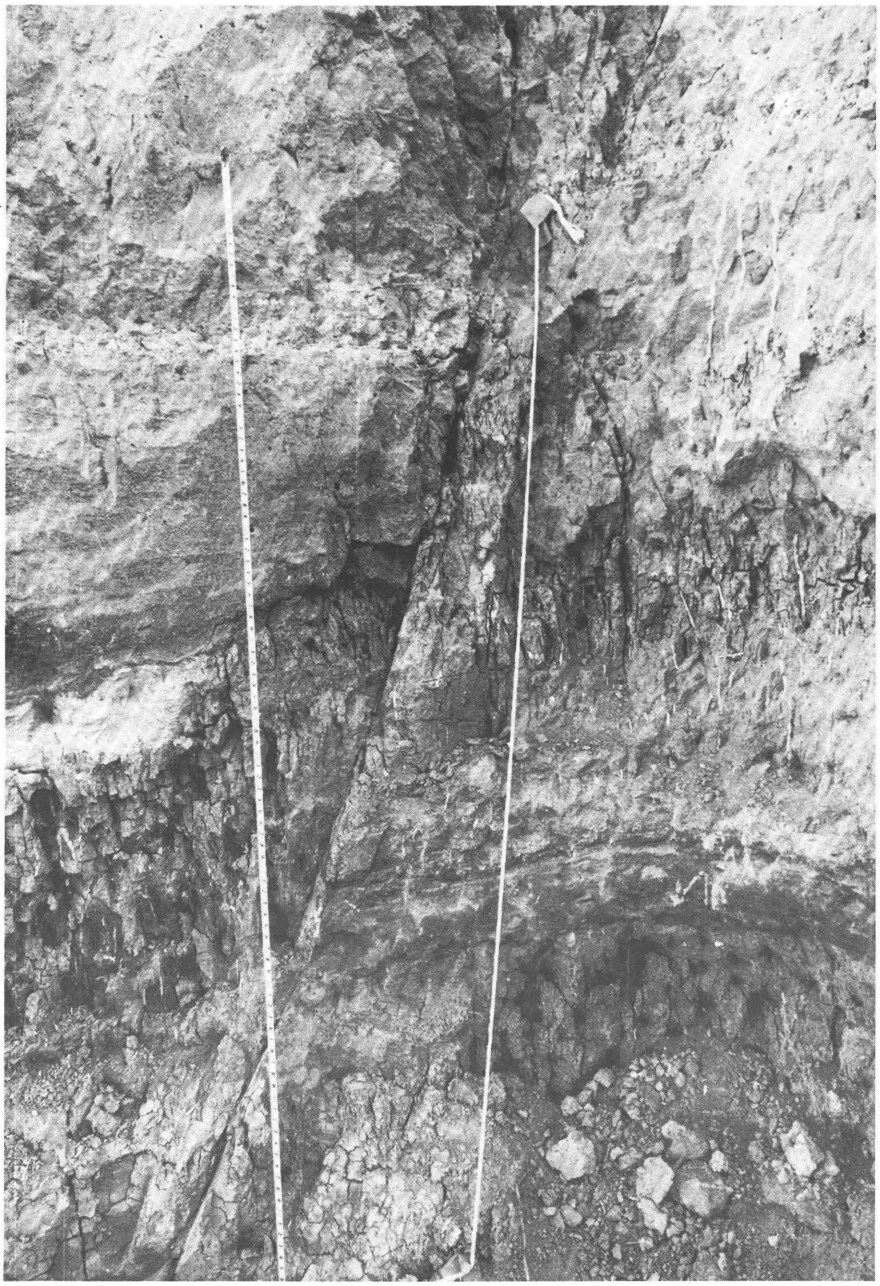


Figure 22. Normal fault in silt and clay. Lower units in photograph have been displaced several meters, but upper units, which are separated from lower units by one or more unconformities (not apparent in photograph), have only been displaced 0.2 m. Despite the difference in displacement, the fault shows no difference in width from top to bottom (Dodge, 1982, p. 158–164, fault A; app. A, exposure N16). Numbers on tape represent centimeters.

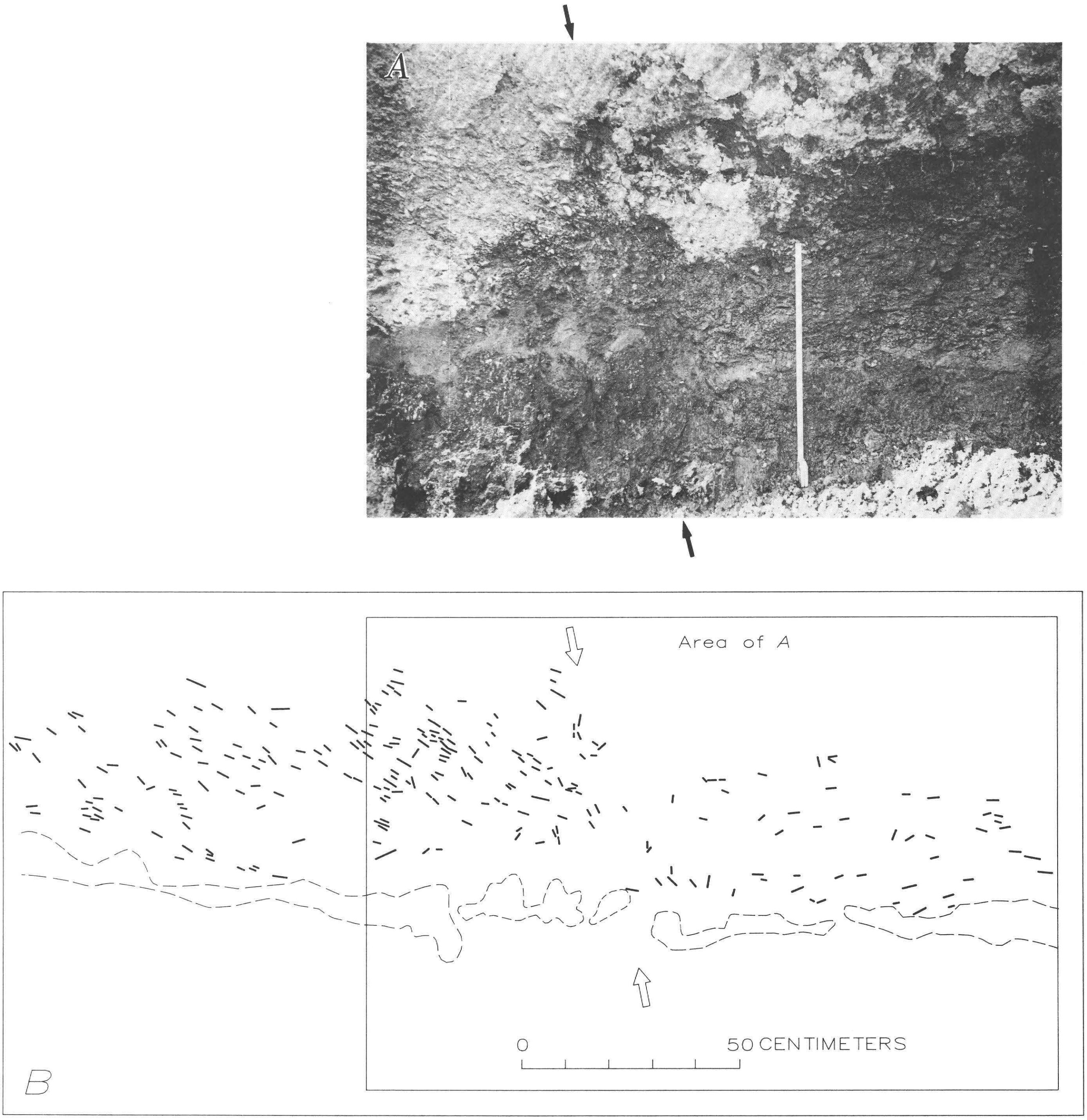


Figure 23. Pebble rotation at the 1906 trace of the San Andreas fault. *A*, Photograph of same trench wall as shown in figure 2*C*, but taken a week later, on October 7, 1975, after an additional 15 cm of the trench wall had been removed. Approximate center of principal zone of deformation indicated by arrows. A few pebbles in and near the principal strand have been rotated to near-vertical positions. Tape extends 50 cm above its base. *B*, Tracing of long axes of pebbles shown in figure 23*A* and in two adjacent photographs not printed here. Approximate center of principal zone of deformation in 1906, about 20 cm wide, is indicated by arrows. The orientation of most of the pebbles to the left of the zone of deformation is a characteristic of the gravel deposit and not a result of tectonic rotation. Outline of figure 23*A* shown by rectangle; outline of light-colored silty sand bed shown by dashed lines. Scale is approximate.

fissures are more common in strike-slip and normal faults than in reverse faults (table 17), and the differences are significant at the 0.05 level. The fissures may be open or filled to various degrees with material from nearby sources, usually from higher in the section.

Gouge

Material called gouge is indicated on many trench logs. How much of it derived from crushing and grinding of rock materials or from weathering or other alteration is usually unknown. Some of it may have been emplaced from nearby areas, like the gouge filling joints in fresh rock described by Buwalda (1942), and may have a very indirect relation to faulting.

Gouge was reported in 15 percent of the exposures (table 17). It ranges from millimeter- to centimeter-thick tabular bodies along shear planes (fig. 24) to large irregular masses like that shown in figure 25. The differences in occurrence of gouge in various fault types are not significant at the 0.05 level.

Slickensides

Slickensides were observed by us, mentioned in the source reports, or noted on the logs of 10 percent of the exposures (table 17). The data are too sparse for valid comparisons between fault types. All of the slickensides in unconsolidated materials are in clay, silt, or gouge. About one-half of the slickenside striations and grooves reported on the dip-slip faults are inclined at a high angle (greater than 45° from the horizontal, measured on the fault surface). About three-quarters of the striations and grooves reported on the strike-slip faults are inclined at a low angle (less than 45° from the horizontal).

Mixing

Mixing was reported in 4 percent of the exposures (table 17). The term "mixing" as applied to the trench exposures refers to mixtures of various materials brought together by faulting or, less commonly, by faulting and gravity transport. Phrases used by investigators to describe this phenomenon include "mixture of adjoining materials," "mixed rock," and "tectonic mixing." In nearly all exposures the component materials are unconsolidated, but in one of them (app. A, exposure R17), rock fragments are also included in the mixtures.

Fault Breccia and Fault-Related Rubble

Fault breccia was reported in 6 percent of the exposures (table 17). Although most of it was developed in rock, some of it was developed in unconsolidated but coherent materials. Its frequency is higher in reverse faults than in normal faults; other differences between fault types are not significant. Fault rubble, the unconsolidated equivalent of fault breccia (Bates and Jackson, 1987), is indistinguishable at many sites from rubble formed by collapse of fault walls or fault scarps. The term "fault-related rubble" is used in this report to include both fault rubble and nontectonic rubble that is closely related to faulting. Fault-related rubble (figs. 26, 27) was reported in 9 percent of the exposures (table 17). Fault-related rubble is significantly more common in normal faults than in reverse or strike-slip faults. Under the proper conditions, fault-related rubble and colluvium can leave a distinct record of individual prehistorical events (fig. 27; Malde, 1971; Bonilla, 1973; Weber and Cotton, 1981; Schwartz and Coppersmith, 1984; Schwartz and Crone, 1985). Fault-related rubble at most sites was developed in unconsolidated materials.

Crushing and Polishing

Crushing of rock was reported in four exposures, one on a normal fault, two on reverse faults, and one on a strike-slip fault (table 17). The affected rock in the four exposures is metavolcanic rock, diorite, siliceous mudstone, and greenstone, respectively.

Polishing of pebbles by tectonic deformation has been described by Clifton (1965). Polishing and rounding of rock fragments in clay-size matrix were reported at two exposures (table 17), both on the San Andreas fault. The polishing in those exposures is the result of shearing, but some of the shearing may result from landsliding as well as faulting (Bonilla and others, 1978).

Hydrologic Effects of Faulting and Earthquakes

Water Barriers

Faulting can impede the movement of ground water by juxtaposing impermeable and permeable materials or by forming impermeable gouge (Clark, 1924; Louderback, 1950; Allen, 1957). Water barriers were rarely reported in the trench data. Such barriers were reported at only one reverse fault and two strike-slip faults. Part of the reason for this low frequency is no doubt the fact that nearly all the trenches were excavated above the water table.

Probable Liquefaction Effects

Water-saturated sediments sometimes liquify during earthquakes. Effects interpreted as related to liquefaction were reported at 15 (9 percent) of the trench exposures. The evidence is of two kinds: irregular bodies of granular materials and soft-sediment deformation. Typically reported are discordant bodies of sand or silt that cut across or disrupt bedding and are approximately cylindrical, tabular, or canoe-shaped. Near-vertical laminations occur in some of them. Many of the bodies of granular material connect upward to irregular beds, wedges, or lenses representing sediment that has spread horizontally and locally covers irregular surfaces. The soft-sediment deformation includes distorted beds, and forms referred to as flame or flare structures. Reports by Sims (1975) and Sieh (1978) illustrate these features. The available data are inadequate to estimate what percentage of the exposures had conditions suitable for the occurrence of liquefaction.

Figure 24. Normal fault in lacustrine silty clay. Fault has vertical grooves along its walls and a 6-cm-wide soft zone of clay gouge. Vertical displacement at this site (app. A, exposure N11) on the Black Rock fault, Nevada, has been 4 m, of which about 1 m occurred after 1,100 yr B.P. (Dodge, 1982, p. 151, 154). Hammer handle visible in bottom of photo.

SUMMARY OF RESULTS

The principal focus of this study has been on the three parameters of nonvisibility called obscure segments, dieout up, and dieout down. Additional effort was applied to other aspects of faulting that are useful in engineering applications, fault identification, and documentation of prehistorical earthquakes. The frequency of occurrence of these phenomena was tabulated and attempts were made to relate them to various factors including type of faulting, material penetrated, fault displacements, thickness of beds, and age of most recent displacement.

The most important result of the study is documentation that a significant fraction of fault strands penetrated by trenches may not be readily visible or may terminate for reasons other than being covered by younger deposits. Researchers misled by such nonvisibility may underestimate a fault's activity and the recency of its movement. In the trench exposures studied, 14 percent of 1,252 strands have obscure segments, 45 percent of 143 strands die out upward, and 34 percent of 1,109 strands die out downward. Although these percentages probably are affected by the particular exposures that were sampled and to a lesser extent by the interpretations of the data, they indicate that obscure segments and dieout are common and should be considered by researchers evaluating the activity of faults.

Some factors that may relate to nonvisibility are summarized in table 18, the background for the following discussion. The factors and relations for which the data are sufficient to allow tentative conclusions are shown in boldface type. The "ID" (insufficient data) entries in the table indicate that the sample was too small to draw conclusions.

Fault type influences the frequency of nonvisibility. For most nonvisibility parameters, strike-slip and reverse faults have a higher incidence of nonvisibility than normal faults have.

Conclusions about the effect of material on nonvisibility could be reached only for certain parameters. The largest data set is for obscure segments of principal

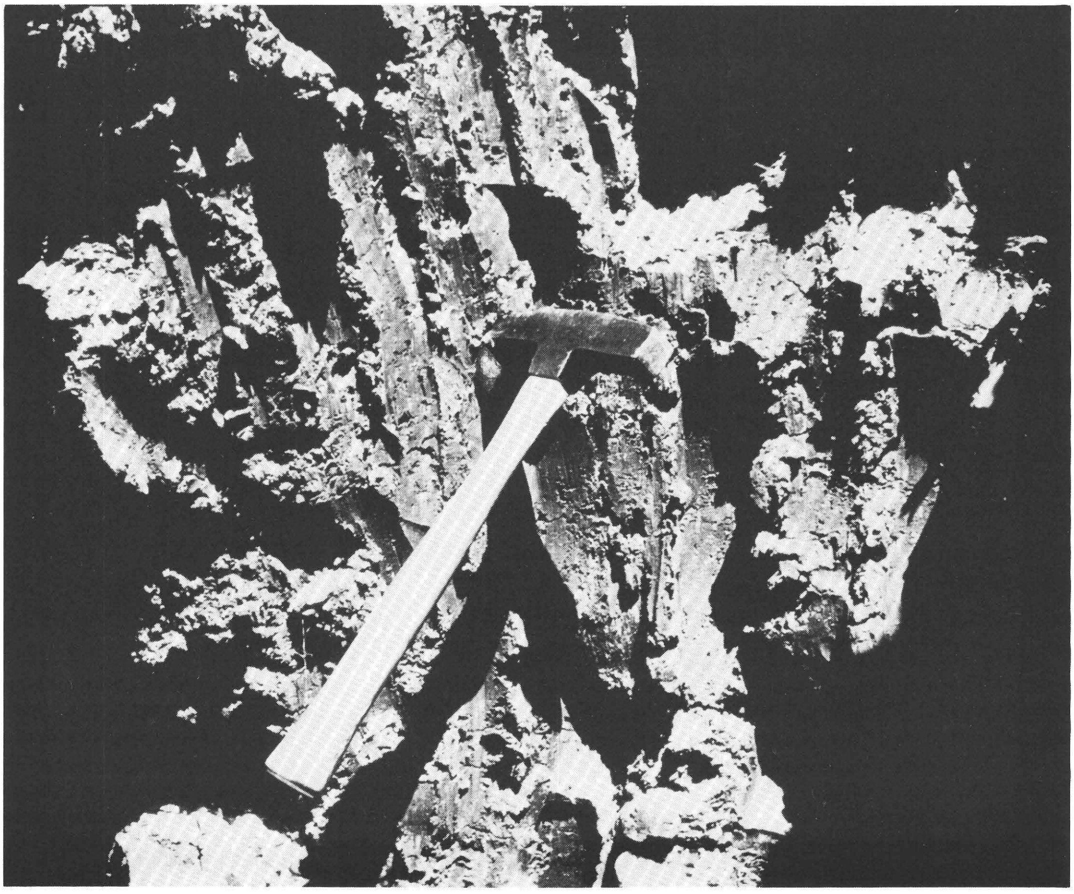


Figure 25. Gouge in San Andreas fault zone in San Bruno, California. The dark-colored, plastic gouge contains light-colored irregular masses of crushed friable sandstone from a formation that here bounds the fault zone on the east. The gouge was exposed along several meters of a trench excavated for a sewer line in 1956.

and subsidiary strands taken together; soil horizons and sand have nearly the same high incidence of such segments, silt and clay have an intermediate incidence, and gravel has the lowest incidence. This ranking is partly supported by dieout down on principal and subsidiary strands, of which soil horizons have high incidence, and gravel and clay have low incidence.

Fault displacement has a weak influence on dieout down, and this influence is of the type one intuitively expects: a decrease in frequency of dieout down with increase in displacement. The frequencies of obscure segments and dieout up do not consistently vary with fault displacement.

Many of the obscure segments are of substantial length, 60 percent of them being more than 0.3 m long and 18 percent more than 1.0 m long. The frequencies of obscure segments and dieout up have a weak relation to length of obscure segment and depth of dieout up, respectively, of the type one intuitively expects: a decrease in frequency with increase in length or depth. Length of obscure segment and depth of dieout up are generally less than the thickness of the associated beds, also as one would expect. On the basis of very limited data, obscure segments seem to be more common on faults with younger, rather than older, ages of most recent displacement.

Information was compiled on the widths of fault zones and the frequency of deformation of the footwall compared to the hanging wall of dip-slip faults. The median widths of faults crossed by the trenches vary by fault type, strike-slip faults being narrower than dip-slip faults, but the data show substantial deviations. For principal strands, the median widths are 0.2 m for strike-slip faults compared to 0.7 m for dip-slip faults, and for principal and subsidiary strands combined, the median widths are 5.5 m for strike-slip and 12.1 m for dip-slip faults. At the shallow depths and in the mostly unconsolidated materials cut by the trenches, fault widths

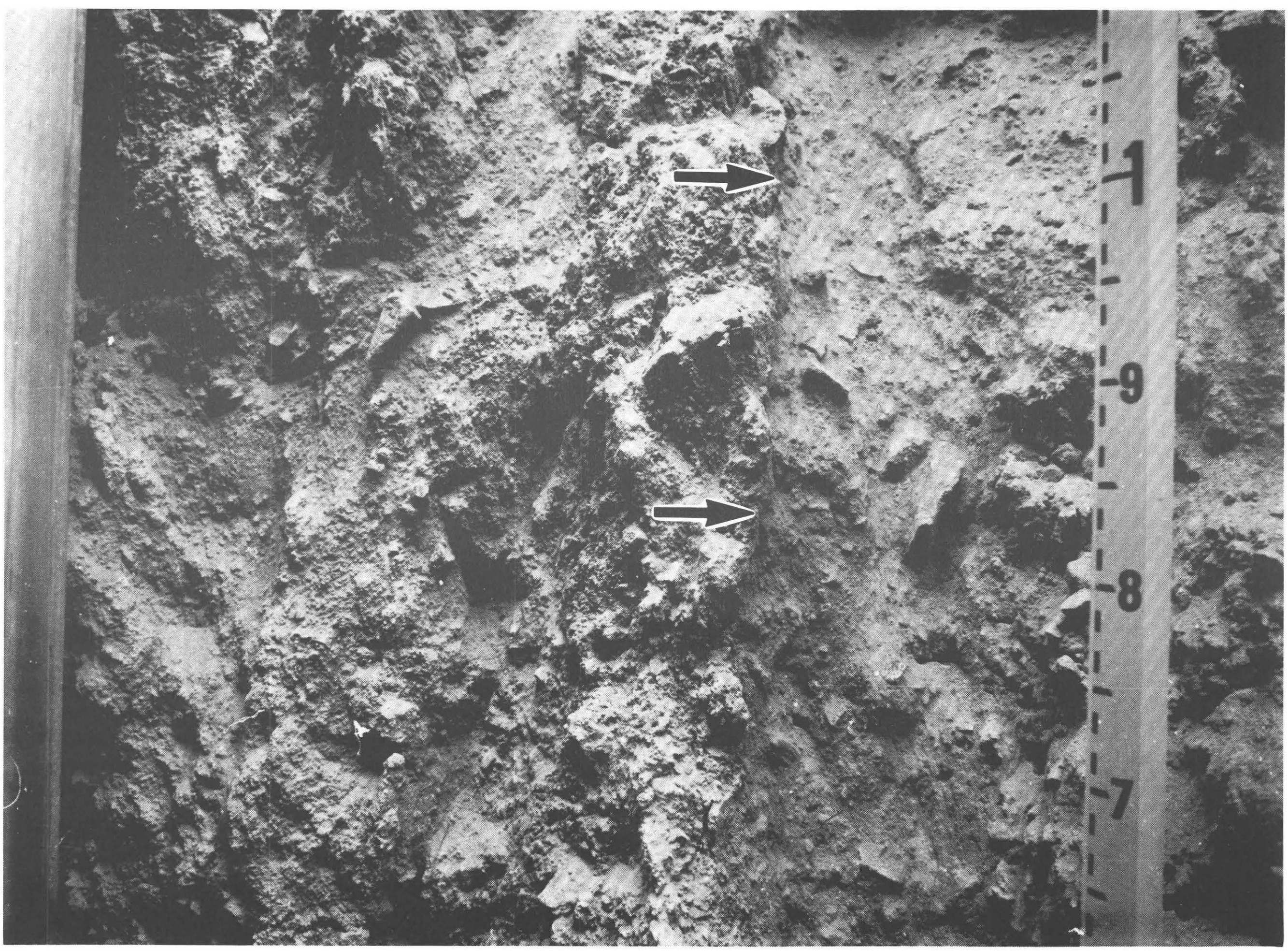


Figure 26. Photograph of fault rubble in normal fault zone. Southwest wall of trench across 1915 trace of Pleasant Valley fault, Nevada (exposure N7). On left is coherent fault rubble (arrows show right-hand edge) from an old displacement. Between the coherent rubble and the stadia rod is loose fault rubble formed by later displacements, including about 1.5 m in 1915 (Bonilla and others, 1984). Numbers on rod are 0.1 m apart. Photograph by T.A. Kaplan-Henry, 1977.

show only an erratic and, at best, weak relation to fault displacement. The hanging wall is deformed more frequently than the footwall of dip-slip faults, but both walls are deformed at many sites.

The frequency of occurrence of some phenomena that may indicate faulting or prehistorical earthquakes was compiled. Rotation of pebbles was reported for 41 percent of the exposures having gravel in the fault zone and for 77 percent of the exposures having both gravel in the fault zone and definite information on whether the pebbles were rotated. Type of fault has no strong influence on the incidence of pebble rotation. Fissures are rather common, being reported at 52 percent of the exposures, and are more prevalent in strike-slip and normal faults than in reverse faults. Gouge was recorded at 15 percent of the exposures; fault type has no significant influence on its frequency of occurrence. Slickensides were reported at 10 percent of the exposures, and fault type has no significant influence on their incidence. Slickensides in unconsolidated materials were restricted to fine-grained materials—clay, silt, and gouge. Other mechanical or hydrologic effects related to faulting or earthquakes—rubble, breccia, mixing, crushing, polishing, water barriers, and probable liquefaction effects—were reported at fewer than 10 percent of the exposures.

DISCUSSION AND IMPLICATIONS

This study shows that the ability to recognize many fault segments can be severely limited, even in the excellent exposures provided by trenches. These limitations should be considered in interpreting the recency of fault displacement and inferring recurrence intervals.

Upon seeing a fault strand end upward in a trench wall, researchers commonly infer that the overlying materials were deposited after the faulting occurred; however, the information presented above shows that this inference may be erroneous and that incorrect conclusions about the fault's history may follow. The obscure segments and some of the strands that falsely appear to terminate upward demonstrate that a fault can

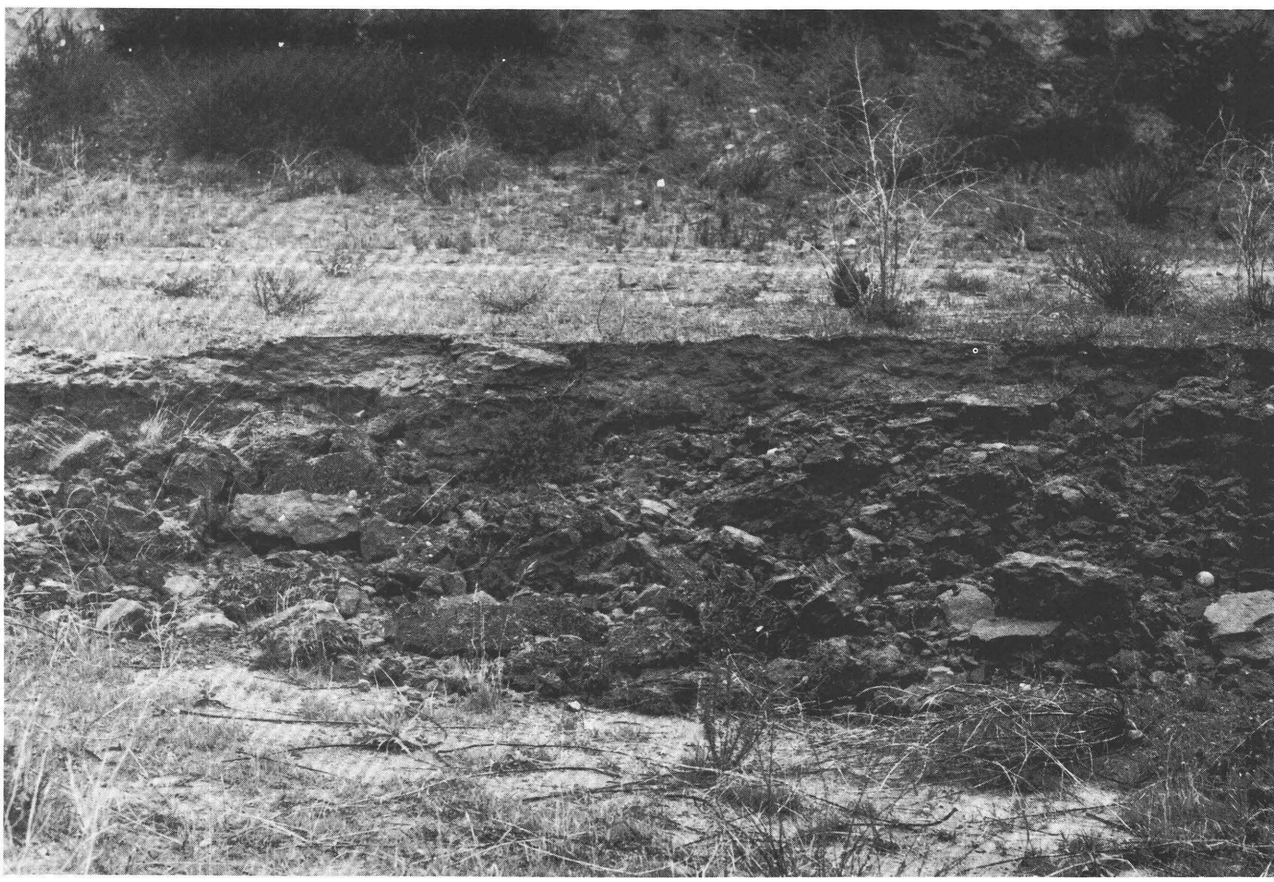


Figure 27. Fault-related rubble from collapse of reverse fault scarp that formed in the 1971 San Fernando, California, earthquake. In one place the rubble extended 3 m from the top of the remaining scarp, a distance three times the vertical component of displacement. Similar rubble preserved in the stratigraphic record near here (app. A, exposure R5) was used to date an earlier rupture (Bonilla, 1973). Material in scarp is weathered sandstone with a thin veneer of slope wash and artificial fill. In this view, scarp is approximately 1 m high. Photograph by V.A. Frizzell, 1971.

pass through the materials commonly found in trenches and not be visible, and that some strands that visibly die out upward are younger than the overlying materials. The many strands that die out downward provide additional evidence that strands can die out for reasons other than being covered by younger deposits. Some ways in which strands can die out downward are (1) they enter materials in which they are not visible, (2) they actually end, or (3) they abruptly change direction and follow a bedding plane. Reasoning indicates that faults must actually end somewhere, and observational evidence supporting this conclusion is provided by experimental fault studies and mine mapping showing fault strands that die out upward, downward, or both (Cloos, 1968; Sanford, 1959; Gay and Ortlepp, 1979; Roth and others, 1981; Wallace and Morris, 1986). Bending-moment faults are expected to die out upward or downward (Yeats, 1986, p. 68-69). A likely place for a fault to end is at a bedding plane, where marked differences in mechanical properties may exist. The termination of a strand at a bed, by dying out or by following a bedding plane, can easily be misinterpreted as deposition of the bed after the faulting. No examples were sought in the trench logs of upward termination of strands at a bed, since no proof would be available that the bed is older than the fault; however, examples of fault strands that end downward at a bed were found in 10 exposures (app. A, exposures N5, E19, E22, E30, E31, E32, E33, E34, E35, and E36), and in these cases the faulting is certainly younger than the bed. Most of these examples are on strike-slip faults, and although the vertical separations on the strands are small, ranging up to 0.17 m, the strike-slip displacements could be much greater. By analogy with these examples, a strand that dies out upward at a bed could also be younger than the bed. Thus the evidence from the obscure segments and the strands that die out upward or downward shows that a strand which seems to end upward may or may not actually end upward and that it may be older or younger than the overlying material. An incorrect inference that a fault strand is older than the overlying material can lead to two kinds of misinterpretation: (1) A researcher dealing with a principal strand may infer a falsely old time of most recent displacement on the fault, and (2) a researcher dealing with a subsidiary strand may infer a separate prehistorical faulting event when in reality the subsidiary strand had displacement at the same time as the principal strand but died out upward. Either or both of these misinterpretations can lead to incorrect estimates of recurrence intervals of faulting and earthquakes.

The tables and graphs in this report suggest the conditions under which fault strands are most commonly nonvisible; however, concealed faulting and the actual termination of strands can occur under a great variety of conditions. Any apparent termination that may be significant should be examined with great care, and independent evidence should be sought regarding the fault's history. To avoid misinterpretation of the apparent upward termination of a fault strand, careful examinations should be made on more than one exposure of the strand, and similar terminations of the same age should be sought. More trenching may be required, and the investigation should include consideration of other pertinent evidence, such as the presence or absence of folding, unconformities, scarp-derived rubble or colluvium, small landslides, sandblow deposits, soft-sediment deformation, fissures, and postrupture weathering or soil formation.

The fault widths given in table 13 have some practical uses. They can be used—together with factors such as local site conditions, the purpose of the trenching, and costs—for preliminary selection of lengths of exploratory trenches. The widths in the table can also be used to make preliminary design and cost estimates for structures, such as pipelines, that must cross faults. Those using the fault widths for such purposes should bear in mind the limitations discussed in the section "Widths of Faults" and the deviations listed in table 13.

Effects of faulting in addition to displacement of beds are useful in identifying faults, and their frequency of occurrence was compiled. These effects, in decreasing order of frequency, are rotated pebbles, fissures, gouge, slickensides, fault-related rubble and fault breccia, mixed materials, crushed materials, tectonically polished clasts, and water barriers. This order of frequency is undoubtedly influenced by (1) the kinds of materials exposed in the trenches (predominantly unconsolidated mixtures of sand, clay, silt, and gravel), (2) the degree to which investigators sought and reported the effects, and (3) the locations of the trenches. For example, the low frequency of water barriers reported in the trench logs we studied probably results from the fact that areas of shallow ground water are generally avoided as sites for exploratory trenches. Studies of different sets of trenches might reveal somewhat different frequencies of the same phenomena.

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TABLES 1–18; APPENDIXES B–D

(APPENDIX A ON MICROFICHE IN POCKET)

Table 1. List of trench exposures

[Exposure code: C, normal-oblique-slip fault; D, reverse-oblique-slip fault; E, strike-slip fault; N, normal-slip fault; R, reverse-slip fault; U, fault type unknown. Age: Age of most recent fault displacement; query indicates uncertainty. CA: California. CZ: Cenozoic. EXP: exposure. F.Z.: fault zone. HI: historical. HO: Holocene. ID: Idaho. I.G.N.: Instituto Geografico Nacional. MT: Montana. NM: New Mexico. NR: near. NV: Nevada. PL: Pleistocene QU: Quaternary. TR: trench. U: unknown. UT: Utah. USA: United States of America]

Exposure code and name		Location	Fault	Age	Source (see list at end of table)
C1	MERCADO NO.1B	MANAGUA, NICARAGUA	TISCAPA F.Z.	PL	2
C2	MERCADO NO.2	MANAGUA, NICARAGUA	TISCAPA F.Z.	HI?	2
C3	MERCADO NO.5	MANAGUA, NICARAGUA	CHICO PELON F.Z.	HI	2
C4	I.G.N. BAPTISTA	MANAGUA, NICARAGUA	CHICO PELON F.Z.	HI	2,28
C5	CHICO PELON NO.1	MANAGUA, NICARAGUA	CHICO PELON F.Z.	HI	2,28
C6	CHICO PELON NO.2	MANAGUA, NICARAGUA	CHICO PELON F.Z.	HO	2
C7	CHICO PELON NO.3	MANAGUA, NICARAGUA	CHICO PELON F.Z.	HO	2
C8	SOUTHWEST NO.4	MANAGUA, NICARAGUA	SAN JUDAS F.Z.	HO	2
C9	SOUTHWEST NO.5	MANAGUA, NICARAGUA	SAN JUDAS F.Z.	HO	2
C10	TR A	LONE PINE, CA, USA	LONE PINE	HI	5,53
D1	CASCADE TR NO.1	SAN MATEO COUNTY, CA, USA	SAN GREGORIO F.Z.	HO	13
D2	CASCADE TR NO.2	SAN MATEO COUNTY, CA, USA	SAN GREGORIO F.Z.	HO	13
D3	BEAN HILL TR	NR CORRALITOS, CA, USA	ZAYANTE-VERGELES	HO?	47
E1	TR NO.3	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	16
E2	TR NO.1	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	17
E3	SOUTH OF WALNUT ST.	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	18
E4	TR 1	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	18
E5	TR 2	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	18
E6	TR 3	SAN BERNARDINO, CA, USA	SAN JACINTO	HO	18
E7	MCDONALD TR 1	LIVERMORE VALLEY, CA, USA	LAS POSITAS	HO	19
E8	CARATI W.	NR LIVERMORE, CA, USA	GREENVILLE	QU	19
E9	STRAIN RANCH, NORTH WALL	NR WOODVILLE, CA, USA	SAN ANDREAS	HI	19
E10	STRAIN RANCH, SOUTH WALL	NR WOODVILLE, CA, USA	SAN ANDREAS	HI	19
E11	TR AT VEDANTA SOCIETY	SOUTHWEST OF OLEMA, CA, USA	SAN ANDREAS	HI	19
E12	DONNELL SITE	NR SONOMA, CA, USA	RODGERS CREEK	HO	19
E13	BERTUCCIO TR	NORTH OF HOLLISTER, CA, USA	CALAVERAS	HI	19
E14	I.G.N. NO. 20	MANAGUA, NICARAGUA	ESTADIO F.Z.	HO	2
E15	SAN SEBASTIAN NO. 3	MANAGUA, NICARAGUA	ESTADIO F.Z.	HO	2
E16	SAN SEBASTIAN NO. 4	MANAGUA, NICARAGUA	ESTADIO F.Z.	HO	2
E17	CALLE COLON NO.5	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HI	2,28
E18	I.G.N. NO. 13	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E19	BANCOS NO. 1	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E20	BANCOS NO. 5	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E21	ESTACION FERROCARRIL NO.1	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HI	2
E22	ESTACION FERROCARRIL NO.2	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E23	ESTACION FERROCARRIL NO.3	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E24	ESTACION FERROCARRIL NO.4	MANAGUA, NICARAGUA	LOS BANCOS F.Z.	HO	2
E25	I.G.N. NO.15	MANAGUA, NICARAGUA	LOS BANCOS, F.Z.	HO	2
E26	NORTH TR	SAN LEANDRO, CA, USA	HAYWARD	HI	20
E27	SOUTH TR	SAN LEANDRO, CA, USA	HAYWARD	HI	20
E28	TR A	SAN MATEO, CA, USA	SAN ANDREAS	HI	21
E29	TR B	SAN MATEO, CA, USA	SAN ANDREAS	HI	21,20
E30	EXP 1	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E31	EXP 2	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E32	EXP 3	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E33	EXP 5	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22
E34	EXP 10	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E35	EXP 10A	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E36	EXP 11	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E37	EXP 11B	PALLETT CREEK, CA, USA	SAN ANDREAS	HI	22,29
E38	TR NE OF KOEHN LAKE	FREMONT VALLEY, CA, USA	GARLOCK F.Z.	HO	23
E39	HORAKUJI TR A	TOTTORI, JAPAN	SHIKANO	HI	24

Table 1. List of trench exposures—Continued

Exposure code and name		Location	Fault	Age	Source (see list at end of table)
E40	HORAKUJI TR B	TOTTORI, JAPAN	SHIKANO	HI	24
E41	TR A	PORTOLA VALLEY, CA, USA	SAN ANDREAS	HI	25
E42	TR E	PORTOLA VALLEY, CA, USA	SAN ANDREAS	HI?	25
E43	TR F	PORTOLA VALLEY, CA, USA	SAN ANDREAS	HI	25
E44	EXP 1NW81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E45	EXP 1SE79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E46	EXP 2NW79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E47	EXP 2SE79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E48	EXP 3NW79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E49	EXP 4NW79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E50	EXP 4SE79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E51	EXP 5NW79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E52	EXP 6NW79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E53	EXP 7NW81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E54	EXP 8NW81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E55	EXP 9SE79	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E56	EXP 9SE81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E57	EXP 10SE81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E58	EXP 11SE81	DOGTOWN, CA, USA	SAN ANDREAS	HI	26
E59	MFT-1	EL TAMBOR, GUATEMALA	MOTAGUA	HI	36
E60	MFT-6	EL TAMBOR, GUATEMALA	MOTAGUA	HI	36
E61	LT-1	LA TINTA, GUATEMALA	POLOCHIC	HO	36
E62	NORTH TR	MANZANAR, CA, USA	OWENS VALLEY	HI	37
E63	TR 3	NR JERICHO, ISRAEL	JERICHO	HI	38
E64	TR 1	FREMONT, CA, USA	HAYWARD	HI	48
E65	TR 3	FREMONT, CA, USA	HAYWARD	HI	48
E66	TR 4	FREMONT, CA, USA	HAYWARD	HI	48
E67	TRANSVERSE TR 2, SE WALL	NR OCOTILLO WELLS, CA USA	COYOTE CREEK	HI	49,50
E68	TRANSVERSE TR 2, NW WALL	NR OCOTILLO WELLS, CA USA	COYOTE CREEK	HI	49,50
E69	TRANSVERSE TR 3, SE WALL	NR OCOTILLO WELLS, CA USA	COYOTE CREEK	HI	49,50
E70	EXP AN	NR ATAMI, SHIZUOKA, JAPAN	TANNA	HI	51
E71	EXP AS	NR ATAMI, SHIZUOKA, JAPAN	TANNA	HI	51,52
E72	EXP MN	NR ATAMI, SHIZUOKA, JAPAN	TANNA	HI	51
N1	SITE A-2	ARCO, ID, USA	ARCO	PL	1,54
N2	SITE H-4	HOWE, ID, USA	HOWE	PL	1,54
N3	SOUTHWEST NO.1A,1B,1C	MANAGUA, NICARAGUA	SAN JUDAS	HO	2
N4	SOUTHWEST NO. 2	MANAGUA, NICARAGUA	B-1	HO	2
N5	SOUTHEAST NO. 6	MANAGUA, NICARAGUA	F.Z.I	HO	2
N6	SOUTHEAST NO. 2C	MANAGUA, NICARAGUA	F.Z.F	HO	2
N7		PLEASANT VALLEY, NV, USA	PLEASANT VALLEY	HI	3
N8	TR A	KAYSVILLE, UT, USA	WASATCH	HO	4
N9	TR HC-1	HOBBLE CREEK, UT, USA	WASATCH	HO	4
N11	SITE 1	SULPHUR, NV, USA	BLACK ROCK	HO	6
N12	SITE 2	SULPHUR, NV, USA	BLACK ROCK	HO	6
N13	SITE 3	SULPHUR, NV, USA	BLACK ROCK	HO	6
N14	SITE 4A	SULPHUR, NV, USA	BLACK ROCK	HO	6
N15	SITE 4B	SULPHUR, NV, USA	BLACK ROCK	HO	6
N16	SITE 5	SULPHUR, NV, USA	BLACK ROCK	HO	6
N17	TR 1	NR SOCORRO, NM, USA	LA JENCIA	HO	27,39
N18	TR 2	NR SOCORRO, NM, USA	LA JENCIA	PL	27,39
N19	TR 3	NR MAGDALENA, NM, USA	LA JENCIA	PL	27,39
N20	TR 4	NR MAGDALENA, NM, USA	LA JENCIA	HO	27,39
N21	TR AT SCARP F-3	WEST YELLOWSTONE, MT, USA	UNNAMED	HI	30,30A
N22	TR NC-1	NR MONA, UT, USA	WASATCH	HO	31
N23	TR NC-2	NR MONA, UT, USA	WASATCH	HO	31
N24	TR NC-3	NR MONA, UT, USA	WASATCH	HO	31
N25	TR P-1	PACHMA BAJO, PERU	CORDILLERA BLANCA	HO	32,55
N26	TR P-2	PACHMA BAJO, PERU	CORDILLERA BLANCA	HO	32,55
N27	TR Q-1	QUEBRADA QUEROCCOCHA, PERU	CORDILLERA BLANCA	HO	32,55

Table 1. List of trench exposures—Continued

Exposure code and name		Location	Fault	Age	Source (see list at end of table)
N28	3 ADJACENT EXPS	NR DELTA, UT, USA	DRUM MOUNTAINS	HO?	33,33A
N29	TR 1A	NR DRAPER, UT, USA	WASATCH	HO	34
N30	TR 1B	NR DRAPER, UT, USA	WASATCH	HO	34
N31	WEST TR	NR DRAPER, UT, USA	WASATCH	U	34
N32		DICKEY, ID, USA	LOST RIVER	HI	35,35A
N33	GRUBBS TR 1	NR OROVILLE, CA, USA	CLEVELAND HILL	HI	40
N34	GRUBBS TR 2	NR OROVILLE, CA, USA	CLEVELAND HILL	HI	40
N35	TR LC-1	SALT LAKE COUNTY, UT, USA	WASATCH	HO	41
N36	TR LC-2	SALT LAKE COUNTY, UT, USA	WASATCH	HO	41,42
N37	TR LC-3	SALT LAKE COUNTY, UT, USA	WASATCH	HO	41,44
N38	ZEBABDJA TR	NR ZEBABDJA, ALGERIA	OUED FODDA	HI	43
N39	TR 1	NR DIXIE VALLEY, NV, USA	DIXIE VALLEY	HI	45,45A
N40	TR 3	NR DIXIE VALLEY, NV, USA	DIXIE VALLEY	HI	45,45A
N41	TR 4	NR DIXIE VALLEY, NV, USA	DIXIE VALLEY	HI	45,45A
R1	GRABER STREET	SAN FERNANDO, CA, USA	VETERANS	HI	7
R2	BA-A	SAN FERNANDO, CA, USA	SAN FERNANDO	HI	7,8
R3	BA-B	SAN FERNANDO, CA, USA	SAN FERNANDO	HI	7,8
R4	BROWN TR	SAN FERNANDO, CA, USA	SAN FERNANDO	HI	7,8
R5	OAK HILL TR	SAN FERNANDO, CA, USA	OAK HILL	HI	7,8
R6	T8	SAN FERNANDO, CA, USA	SAN FERNANDO	HI	9
R7	SOUTHEAST NO. 2A, 2B, & 2C	MANAGUA, NICARAGUA	F.Z. E	HO	2
R8	SOUTHEAST NO.3	MANAGUA, NICARAGUA	F.Z. E	HO	2
R9	TR 1	NR ARVIN, CA, USA	WHITE WOLF	HI	10
R10	TR2	NR ARVIN, CA, USA	WHITE WOLF	HI	10
R11	TR A-A'(HIGH SCHOOL)	SAN MARINO, CA, USA	RAYMOND	HO	11
R12	TR C-C'(HIGH SCHOOL)	SAN MARINO, CA, USA	RAYMOND	HO	11
R13	TR 7	PASADENA, CA, USA	RAYMOND	HO	12
R14	TR 14	SAN MARINO, CA, USA	RAYMOND	HO	12
R15	TR 18A	GLENDALE, CA, USA	SIERRA MADRE F.Z.	HO	12
R16	TR 20-C	PASADENA, CA, USA	SIERRA MADRE F.Z.	PL	12
R17	TR AN-1	SAN MATEO COUNTY, CA, USA	SAN GREGORIO F.Z.	HO	13
R18	FUMAROLE 1	GRAPEVINE, CA, USA	PLEITO	HO	14
R19	FUMAROLE 2	GRAPEVINE, CA, USA	PLEITO	HO	14
R20	TR DC 501	CLYDE, NEW ZEALAND	DUNSTAN	QU	15
R21	TR DC 502	CLYDE, NEW ZEALAND	DUNSTAN	QU	15
R22	TR DC 503	CLYDE, NEW ZEALAND	DUNSTAN	QU	15
R23	TR DC 504	CLYDE, NEW ZEALAND	DUNSTAN	QU	15
R24	TR DC 505	CLYDE, NEW ZEALAND	DUNSTAN	QU	15
R25	TR DC 506	CLYDE, NEW ZEALAND	DUNSTAN	HO	15
R26	TR DC 507	CLYDE, NEW ZEALAND	DUNSTAN	HO	15
R27	TR DC 508	CLYDE, NEW ZEALAND	DUNSTAN	HO	15
R28	TR DC 513	CLYDE, NEW ZEALAND	DUNSTAN	HO	15
R29	TR DC 511	CLYDE, NEW ZEALAND	DUNSTAN	CZ	15
R30	TR BY LEVEL LINE N2	NR COALINGA, CA, USA	NUNEZ	HI	46,46A
R31	TR BY LEVEL LINE N4	NR COALINGA, CA, USA	NUNEZ	HI	46,46A
R32	TR BY LEVEL LINE N7	NR COALINGA, CA, USA	NUNEZ	HI	46,46A
R33	EL ABADIA NO. 1	NR OUED FODDA, ALGERIA	OUED FODDA	HI	43
R34	EL ABADIA NO. 2	NR OUED FODDA, ALGERIA	OUED FODDA	QU	43
R35	EL ABADIA NO. 3	NR OUED FODDA, ALGERIA	OUED FODDA	HI	43
R36	OUED FODDA NO. 1	NR OUED FODDA, ALGERIA	OUED FODDA	HI	43
R37	OUED FODDA NO. 2	NR OUED FODDA, ALGERIA	OUED FODDA	HI	43
U1	NORTHEAST NO.7	MANAGUA, NICARAGUA	F.Z. N	PL	2

See list of sources on following page.

Table 1. List of trench exposures—Continued

SOURCES

1	MALDE (1971)
2	WOODWARD-CLYDE CONSULTANTS (1975)
3	BONILLA AND OTHERS (1984)
4	SWAN AND OTHERS (1980)
5	LUBETKIN (1980)
6	DODGE (1982)
7	BONILLA, M.G., 1971, UNPUB. FIELD NOTES
8	BONILLA (1973)
9	BARROWS (1975)
10	COTTON AND OTHERS (1976)
11	BRYANT (1978)
12	CROOK AND OTHERS (1987)
13	WEBER AND COTTON (1981)
14	COTTON AND OTHERS (1981)
15	OFFICERS OF THE GEOLOGICAL SURVEY (1983)
16	CONVERSE, DAVIS, AND ASSOCIATES (1968)
17	CONVERSE, DAVIS, AND ASSOCIATES (1969)
18	SIEH AND OTHERS (1973)
19	HERD, D.G., BONILLA, M.G., AND BURKE, D.B., 1975, UNPUB. DATA
20	BONILLA, M.G., 1978, UNPUB. FIELD NOTES
21	BONILLA AND OTHERS (1978)
22	SIEH (1978)
23	BURKE (1979)
24	ANDO AND OTHERS (1980)
25	TAYLOR AND OTHERS (1980)
26	COTTON AND OTHERS (1982)
27	MACHETTE, 1988
28	BROWN AND OTHERS (1973)
29	SIEH (1984)
30	NASH (1981)
30A	NASH, D.B., 1986, WRITTEN COMMUNICATION
31	HANSON AND OTHERS (1981)
32	SCHWARTZ (1983)
33	CRONE (1983)
33A	CRONE, A.J., 1986, WRITTEN COMMUNICATION
34	SCHWARTZ, D.P., AND LUND, WILLIAM, 1986, UNPUB. DATA
35	SCHWARTZ AND CRONE (1985)
35A	SCHWARTZ, D.P., AND CRONE, A.J., 1986, UNPUB. DATA
36	SCHWARTZ, D.P., 1986, UNPUB. DATA
37	BEANLAND, SARAH, 1986, UNPUB. DATA
38	RECHES AND HOEXTER (1981)
39	MACHETTE (1986)
40	SCHWARTZ AND OTHERS (1977)
41	SWAN AND OTHERS (1981)
42	HANSON AND SCHWARTZ (1982)
43	WOODWARD-CLYDE CONSULTANTS (1983)
44	SCHWARTZ AND COPPERSMITH (1984)
45	BELL AND KATZER (1987)
45A	BELL, J.W., 1986, UNPUB. DATA
46	RYMER AND OTHERS, 1990
46A	LIENKAEMPER, J.J., AND RYMER, M.J., 1986, UNPUB. DATA
47	COPPERSMITH (1979)
48	WOODWARD-CLYDE CONSULTANTS (1976)
49	SHARP (1981)
50	SHARP, R.V., 1978, UNPUB. DATA
51	TANNA FAULT TRENCHING RESEARCH GROUP (1983)
52	IIHARA AND ISHII (1932)
53	LUBETKIN AND CLARK (1988)
54	MALDE (1987)
55	SCHWARTZ (1988)

Table 2. Frequency of strands with obscure segments and strands that die out upward or downward, grouped by fault type

[P: Principal strand. S: Subsidiary strand. AP: All P strands. As: All strands. AS: All S strands. DD: Dieout down. DDP: Dieout down on P. DDS: Dieout down on S. DDR: Dieout down could have been recognized. DDRP: Dieout down could have been recognized on P. DDRS: Dieout down could have been recognized on S. DU: Dieout up. DUR: Dieout up could have been recognized. DUP: Dieout up on P. DURP: Dieout up could have been recognized on P. DUS: Dieout up on S. DURS: Dieout up could have been recognized on S. Ob: Strands with one or more obscure segments. ObP: P strands with one or more obscure segments. ObS: S strands with one or more obscure segments. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip]

	Strike slip	Dip slip	Normal slip	Reverse slip	Normal-oblique slip	Reverse-oblique slip	Fault type unknown	All fault types
				Dieout up				
DU/DUR	32/ 44	32/ 99	11/ 69	21/ 28	0/ 2	0/ 0	0/ 0	64/143
DU/DUR	73%	32%	16%	75%	0%	0%	0%	45%
	±7%	±5%	±4%	±8%	±0%	--	--	±4%
DUP/DURP	31/43	13/47	3/29	10/16	0/ 2	0/ 0	0/ 0	44/ 90
DUP/DURP	72%	28%	10%	63%	0%	0%	0%	49%
	±7%	±7%	±6%	±12%	±0%	--	--	±5%
DUS/DURS	1/ 1	19/52	8/40	11/12	0/ 0	0/ 0	0/ 0	20/ 53
DUS/DURS	100%	37%	20%	92%	0%	0%	0%	38%
	±0%	±7%	±6%	±8%	--	--	--	7%
				Strands with one or more obscure segments				
Ob/As	105/613	74/636	36/389	32/131	3/ 55	3/ 61	0/ 3	179/1252
Ob/As	17%	12%	9%	24%	5%	5%	0%	14%
	±2%	±1%	±1%	±4%	±3%	±3%	±0%	±1%
ObP/AP	51/ 90	19/115	1/ 45	15/ 50	3/ 16	0/ 4	0/ 1	70/ 206
ObP/AP	57%	17%	2%	30%	19%	0%	0%	34%
	±5%	±3%	±2%	±6%	±10%	±0%	±0%	±3%
ObS/AS	54/523	55/521	35/344	17/ 81	0/ 39	3/ 57	0/ 2	109/1046
ObS/AS	10%	11%	10%	21%	0%	5%	0%	10%
	±1%	±1%	±2%	±5%	±0%	±3%	±0%	1%
				Dieout down				
DD/DDR	247/533	134/573	73/344	29/115	14/ 54	18/ 60	1/ 3	382/1109
DD/DDR	46%	23%	21%	25%	26%	30%	33%	34%
	±2%	±2%	±2%	±4%	±6%	±6%	±27%	±1%
DDP/DDRP	5/ 83	3/108	0/ 43	1/ 45	2/ 16	0/ 4	0/ 1	8/ 192
DDP/DDRP	6%	3%	0%	2%	13%	0%	0%	4%
	±3%	±2%	±0%	±2%	±8%	±0%	±0%	±1%
DDS/DDRS	242/450	131/465	73/301	28/ 70	12/ 38	18/ 56	1/ 2	374/ 917
DDS/DDRS	54%	28%	24%	40%	32%	32%	50%	41%
	±2%	±2%	±2%	±6%	±8%	±6%	±35%	±2%

Table 3. Ratios and percent of obscure segments, dieout up, and dieout down within given displacement class for all fault types as a group

[Recognizable strands: In fourth column, strands on which dieout down could have been recognized; in fifth column, strands on which dieout up could have been recognized (see text). Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Obscure segments versus all strands	Dieout down versus recognizable strands	Dieout up versus recognizable strands
1	0.005-0.154	76 : 540 14%	220 : 427 52%	14 : 31 45%
2	0.155-0.304	33 : 131 25%	21 : 104 20%	3 : 12 25%
3	0.305-0.454	13 : 46 28%	9 : 38 24%	1 : 6 17%
4	0.455-0.604	12 : 42 29%	3 : 30 10%	7 : 12 58%
5	0.605-0.754	1 : 15 7%	1 : 13 8%	1 : 4 25%
6	0.755-0.904	1 : 19 5%	1 : 13 8%	1 : 6 17%
7	0.905-1.054	3 : 11 27%	1 : 9 11%	1 : 2 50%
8	1.055-1.204	2 : 9 22%	0 : 8 0%	0 : 0 0%
9	1.205-1.354	1 : 3 33%	0 : 2 0%	1 : 2 50%
10	1.355-1.504	2 : 15 13%	1 : 11 9%	1 : 5 20%
11	>1.504	32 : 123 26%	3 : 102 3%	20 : 45 44%

Table 4. Maximum values of fault displacement, length of obscure segments, and depth of dieout up

[N: Normal slip. R: Reverse slip. C: Normal-oblique slip. D: Reverse-oblique slip. E: strike slip. U: Fault type unknown. DS: Dip slip, includes normal, normal-oblique, reverse, and reverse-oblique slip. Values in meters]

Displacement, all fault types	
Obscure segments	10.0
All strand segments	25.0
Strands on which dieout down is recognizable	25.0
Strands on which dieout up is recognizable	5.3

Length and depth

	Fault type							
	N	R	C	D	E	U	DS	ALL
Length of obscure segments	2.3	6.6	2.1	0.2	2.8	--	6.6	6.6
Depth of dieout up	0.7	5.5	--	--	1.7	--	5.5	5.5

Table 5. Frequency of obscure segments and strands that die out upward or downward in given material

[P: Principal strand. S: Subsidiary strand. DDm: Dieout down in given material. DDmP: Dieout down in given material on P. DDmS: Dieout down in given material on S. DDRm: Dieout down could have been recognized in given material. DDRmP: Dieout down could have been recognized in given material on P. DDRmS: Dieout down could have been recognized in given material on S. DUm: Dieout up in given material. DUmP: Dieout up in given material on P. DUmS: Dieout up in given material on S. DURm: Dieout up could have been recognized in given material. DURmP: Dieout up could have been recognized in given material on P. DURmS: Dieout up could have been recognized in given material on S. Miscellaneous: Alluvium, unconsolidated mudflow, unconsolidated pyroclastic deposits, peat, or materials of varied grain size. OB: Obscure segments. OBm: Obscure segments in given material. OBmP: Obscure segments in given material on P. OBmS: Obscure segments in given material on S. OBP: Obscure segments on P. OBS: Obscure segments on S. Fine includes clay, silt, and undivided fine; coarse includes sand, gravel, and undivided coarse]

	Unconsolidated Materials												Rock	Consolidation unknown or varied	
	Fine	Clay	Silt	Undivided fine	Coarse	Sand	Gravel	Undivided coarse	Both fine and coarse	Miscellaneous	Soil horizon	Total unconsolidated			Totals
Dieout up															
DUm/DURm	12/14	4/6	7/7	1/1	22/28	19/23	3/4	0/1	4/5	1/4	25/42	64/93	0/2	0/48	64/143
DUm/DURm	86%	67%	100%	100%	79%	83%	75%	0%	80%	25%	60%	69%	0%	0%	45%
	±9%	±19%	±0%	±0%	±8%	±8%	±22%	±0%	±18%	±22%	±8%	±5%	±0%	±0%	±4%
DUmP/DURmP	12/14	4/6	7/7	1/1	11/14	8/10	3/4	0/0	1/2	1/1	19/24	44/55	0/2	0/34	44/91
DUmP/DURmP	86%	67%	100%	100%	79%	80%	75%	–	50%	100%	79%	80%	0%	0%	48%
	±9%	±19%	±0%	±0%	±11%	±13%	±22%	--	±35%	±0%	±8%	±5%	±0%	±0%	±5%
DUmS/DURmS	0/0	0/0	0/0	0/0	11/14	11/13	0/0	0/1	3/3	0/3	6/18	20/38	0/0	0/14	20/52
DUmS/DURmS	--	--	--	--	79%	85%	--	0%	100%	0%	33%	53%	--	0%	38%
	--	--	--	--	±11%	±10%	--	±0%	±0%	±0%	±11%	±8%	--	±0%	±7%
Obscure segments															
OBm	46	21	22	3	82	66	11	5	13	10	39	190	6	10	206
OBm/OB	22%	10%	11%	1%	40%	32%	5%	2%	6%	5%	19%	93%	3%	5%	100%
OBmP	23	11	10	2	29	18	10	1	2	4	25	83	0	3	86
OBmP/OBP	27%	13%	12%	2%	34%	21%	12%	1%	2%	5%	29%	97%	0%	3%	100%
OBmS	23	10	12	1	53	48	1	4	11	6	14	107	6	7	120
OBmS/OBS	19%	8%	10%	1%	44%	40%	1%	3%	9%	5%	12%	89%	5%	6%	100%
Dieout down															
DDm/DDRm	93/198	35/109	58/89	0/0	152/328	111/200	25/77	16/51	14/57	14/29	40/67	313/679	52/188	17/242	382/1109
DDm/DDRm	47%	32%	65%	0%	46%	56%	32%	31%	25%	48%	60%	46%	28%	7%	34%
	±4%	±4%	±5%	--	±3%	±4%	±5%	±6%	±6%	±9%	±6%	±2%	±3%	±2%	±1%
DDmP/DDRmP	2/19	2/12	0/7	0/0	5/36	2/17	3/17	0/2	0/4	0/3	0/4	7/66	0/12	1/114	8/192
DDmP/DDRmP	11%	17%	0%	--	14%	12%	18%	0%	0%	0%	0%	11%	0%	1%	4%
	±7%	±11%	±0%	--	±6%	±8%	±9%	±0%	±0%	±0%	±0%	±4%	±0%	±1%	±1%
DDmS/DDRmS	91/179	33/97	58/82	0/0	147/292	109/183	22/60	16/49	14/53	14/26	40/63	306/613	52/176	16/128	374/917
DDmS/DDRmS	51%	34%	71%	--	50%	60%	37%	33%	26%	54%	63%	50%	30%	13%	41%
	±4%	±5%	±5%	--	±3%	±4%	±6%	±7%	±6%	±10%	±6%	±2%	±3%	±3%	±2%

Table 6. Sample of materials in all the exposures

[Coarse: Sand size or larger. Fine: Silt size or smaller. Miscellaneous: Alluvium, unconsolidated mudflow, unconsolidated pyroclastic deposits, peat, or materials of varied grain size]

Material type	Thickness (m)	Percent of total thickness
Fine	85.61	27
Clay	42.73	13
Silt	42.70	13
Undivided fine	0.18	0
Coarse	132.82	42
Sand	63.16	20
Gravel	49.65	16
Undivided coarse	20.01	6
Both fine and coarse	23.62	7
Soil horizon	41.10	13
Miscellaneous	12.16	4
Total unconsolidated	295.31	93
Rock	16.16	5
Consolidation unknown or varied	7.61	2

Table 7. Comparison of frequency of obscure segments in given material to frequency of the given material

[Fo: Frequency of obscure segments in given material, as percent, from table 5. Fm: Frequency of the given material in the exposures, as percent, from table 6]

Material type	Fo/Fm	Obscurity quotient Fo/Fm	Rank
Common materials			
Sand	32/20	1.60	1
Soil horizon	19/13	1.46	2
Silt	11/13	0.85	3
Clay	10/13	0.77	4
Gravel	5/16	0.31	5
Coarse versus fine			
Coarse	40/42	0.95	1
Fine	22/27	0.81	2

Table 8. Number and percent of obscure segments, grouped by length and fault type

[Percent: Of obscure segments of given fault type, the percent within given length class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of length class 10 given in table 4]

Length class	Length (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	37 30%	8 10%	6 14%	0 0%	1 17%	1 33%	0 0%	45 22%
2	0.155-0.304	26 21%	11 13%	7 17%	2 6%	0 0%	2 67%	0 0%	37 18%
3	0.305-0.454	13 11%	10 12%	8 19%	1 3%	1 17%	0 0%	0 0%	23 11%
4	0.455-0.604	14 11%	12 14%	8 19%	1 3%	3 50%	0 0%	0 0%	26 13%
5	0.605-0.754	7 6%	8 10%	6 14%	2 6%	0 0%	0 0%	0 0%	15 7%
6	0.755-0.904	7 6%	8 10%	3 7%	5 16%	0 0%	0 0%	0 0%	15 7%
7	0.905-1.054	5 4%	2 2%	0 0%	2 6%	0 0%	0 0%	0 0%	7 3%
8	1.055-1.204	4 3%	2 2%	0 0%	2 6%	0 0%	0 0%	0 0%	6 3%
9	1.205-1.354	0 0%	3 4%	0 0%	3 9%	0 0%	0 0%	0 0%	3 1%
10	>1.354	10 8%	19 23%	4 10%	14 44%	1 17%	0 0%	0 0%	29 14%
	Total	123 100%	83 100%	42 100%	32 100%	6 100%	3 100%	0 0%	206 100%

Table 9. Frequency of obscure segments on the principal strand versus age of most recent displacement

[Age: Age of most recent displacement. HI: Historical displacement. HO: Holocene, not known to have historical displacement. QU: Quaternary, not known to have historical displacement. P: Principal. Percent: Of exposures of indicated age, the percent that have an obscure segment on the principal strand]

Age	Number of exposures having an obscure segment on P strand	Total number of exposures	Percent
	Normal slip		
HI	3	8	38±17
HO	0	26	0
QU	0	2	0
	Reverse slip		
HI	9	14	64±13
HO	3	14	21±11
QU	1	6	17±15
	Strike slip		
HI	39	50	78± 6
HO	9	17	53±12
QU	1	1	100
	Combined normal, reverse, and strike slip		
HI	51	72	71± 5
HO	12	57	21± 5
QU	2	9	22±14

Table 10. Number and percent of strands that die out upward, grouped by depth and fault type

[Percent: Of strands of given fault type that die out upward, percent in given depth class. Depth: Depth of top of strand below the known or inferred ground surface at time of faulting. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of depth class 10 given in table 4]

Depth class	Depth (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	3	4	3	1	0	0	0	7
		9%	13%	27%	5%	0%	0%	0%	11%
2	0.155-0.304	10	3	2	1	0	0	0	13
		31%	9%	18%	5%	0%	0%	0%	20%
3	0.305-0.454	4	6	4	2	0	0	0	10
		13%	19%	36%	10%	0%	0%	0%	16%
4	0.455-0.604	5	2	1	1	0	0	0	7
		16%	6%	9%	5%	0%	0%	0%	11%
5	0.605-0.754	2	1	1	0	0	0	0	3
		6%	3%	9%	0%	0%	0%	0%	5%
6	0.755-0.904	2	2	0	2	0	0	0	4
		6%	6%	0%	10%	0%	0%	0%	6%
7	0.905-1.054	3	0	0	0	0	0	0	3
		9%	0%	0%	0%	0%	0%	0%	5%
8	1.055-1.204	1	1	0	1	0	0	0	2
		3%	3%	0%	5%	0%	0%	0%	3%
9	1.205-1.354	0	1	0	1	0	0	0	1
		0%	3%	0%	5%	0%	0%	0%	2%
10	>1.354	2	12	0	12	0	0	0	14
		6%	38%	0%	57%	0%	0%	0%	22%
	Total	32	32	11	21	0	0	0	64
		100%	100%	100%	100%	0%	0%	0%	100%

Table 11. Comparison of frequency of dieout down in given material to frequency of the given material

[Fdd: Frequency of dieout down in given material, as percent, from table 5. Fm: Frequency of the given material in the exposures, as percent, from table 6]

Material type	Fdd/Fm	Dieout-down quotient Fdd/Fm	Rank
	Common materials		
Silt	65/13	5.00	1
Soil horizon	60/13	4.62	2
Sand	56/20	2.80	3
Clay	32/13	2.46	4
Gravel	32/16	2.00	5
	Coarse versus fine		
Fine	47/27	1.74	1
Coarse	46/42	1.10	2

Table 12. Principal contrasts in dieout up, obscure segments, and dieout down between various fault types

[E: Strike slip. N: Normal and normal-oblique slip. R: Reverse and reverse-oblique slip. DS: Dip slip, includes normal, normal-oblique, reverse, and reverse-oblique slip. See text for discussion of Z score]

Dieout up Fault type	Dieout up Z score	Obscure segments Fault type	Obscure segments Z score	Dieout down Fault type	Dieout down Z score
Principal strands					
E v. N	5.32	E v. N	6.28	No differences at 0.05 level of significance	
E v. DS	4.21	E v. DS	6.02		
R v. N	3.84	E v. R	3.37		
		R v. N	3.06		
Subsidiary strands					
R v. N	4.52	No differences at 0.05 level of significance		E v. N	8.10
				E v. DS	7.88
				E v. R	3.43
				R v. N	2.44
Principal and subsidiary strands					
E v. N	6.17	E v. N	3.90	E v. DS	8.03
R v. N	5.70	R v. N	3.41	E v. N	7.70
E v. DS	4.48	E v. DS	2.77	E v. R	4.54

Table 14. Regression analyses of fault width on fault displacement

[a and b are coefficients in regression equations of the form Y = a + bX. R: Correlation coefficient. SD: Standard deviation of the dependent variable Y about the regression line. N: Number of data points. D: Displacement (m). W: Width (m). P: Principal strand. S: Subsidiary strand. W substitutes for Y, and D substitutes for X in the regression equation]

	a	b	R	SD	N
Normal faults					
W on D (P)	0.327	0.106	0.316	0.578	20
W on D (P & S)	-16.522	6.165	0.613	39.576	20
Reverse faults					
W on D (P)	-0.407	0.818	0.694	2.669	18
W on D (P & S)	21.961	-1.111	0.261	15.704	11

Table 13. Fault-width data grouped by fault type

[MAD: Mean absolute deviation from the median. Min.: Minimum fault width. Max.: Maximum fault width. N: Normal slip. No.: Number in sample. R: Reverse slip. C: Normal-oblique slip. D: Reverse-oblique slip. E: Strike slip. U: Fault type unknown. DS: Dip slip, includes normal, normal-oblique, reverse, and reverse-oblique slip. Widths in meters]

Fault type	Principal strand					Principal and subsidiary strands				
	Median	MAD	No.	Min.	Max.	Median	MAD	No.	Min.	Max.
N	0.50	0.44	23	0.01	2.10	7.10	19.34	26	1.00	217.00
R	0.98	1.94	24	0.04	12.40	12.60	16.30	16	1.30	162.00
C	2.10	0.67	3	0.60	2.60	23.20	22.30	8	2.60	106.00
D	2.50	0.00	1	2.50	2.50	18.46	9.34	2	9.12	27.80
E	0.24	0.71	39	0.01	10.20	5.45	14.19	44	0.02	225.00
U	0.30	0.00	1	0.30	0.30	8.30	0.00	1	8.30	8.30
DS	0.66	1.23	51	0.01	12.40	12.05	19.11	52	1.00	217.00
All	0.42	1.02	91	0.01	12.40	7.90	16.98	97	0.02	225.00

Table 15. Deformation of hanging-wall and footwall blocks

[N: Normal slip. C: Normal-oblique slip. R: Reverse slip. D: Reverse-oblique slip]

Fault type	Footwall only		Hanging wall only		Both walls		Total
	Number	Percent	Number	Percent	Number	Percent	
N & C	3	11±6	15	56±10	9	33±9	27
R & D	2	14±9	6	43±13	6	43±13	14
N, C, R, & D	5	12±5	21	51±8	15	37±8	41

Table 16. Exposures with rotated pebbles

[C: Normal-oblique slip. D: Reverse-oblique slip. E: Strike slip. N: Normal slip. R: Reverse slip. U: Pebble rotation unknown. X: Pebbles not rotated. Y: Pebbles rotated]

Fault type	Number of exposures				Percent of exposures with pebbles rotated	
	With pebbles in fault	With some pebbles rotated			Of exposures with pebbles in fault	Of exposures with pebbles in fault and yes-or-no information on pebble rotation
		Y	X	U		
N & C[1]	30	16	5	9	53±9	76±9
R & D	29	13	2	14	45±9	87±9
E	40	12	5	23	30±7	71±11
All	99	41	12	46	41±5	77±6

[1]No pebbles were reported in fault zones in the normal-oblique-slip fault exposures, hence these data are for normal-slip exposures only.

Table 17. Various mechanical effects and products of faulting

[Fraction: Number of exposures with listed effect/Total number of exposures of given fault type. N: Normal and normal-oblique slip. R: Reverse and reverse-oblique slip. DS: Dip slip, includes normal, normal-oblique, reverse, and reverse-oblique slip. E: Strike slip. U: Fault type unknown]

	Fissures		Gouge		Slickensides		Rubble		Breccia		Mixing		Crushing		Polishing	
Fault type	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent	Fraction	Percent
N	30/50	60±7	6/50	12±5	3/50	6±3	11/50	22±6	1/50	2±2	2/50	4±3	1/50	2±2	0/50	0
R	12/40	30±7	7/40	18±6	7/40	18±6	1/40	3±2	5/40	13±5	2/40	5±3	2/40	5±3	0/40	0
DS	42/90	47±5	13/90	14±4	10/90	11±3	12/90	13±4	6/90	7±3	4/90	4±2	3/90	3±2	0/90	0
E	42/72	58±6	11/72	15±4	7/72	10±3	3/72	4±2	3/72	4±2	2/72	3±2	1/72	1±1	2/72	3±2
U	1/1	100	0/1	0	0/1	0	0/1	0	0/1	0	0/1	0	0/1	0	0/1	0
All	85/163	52±4	24/163	15±3	17/163	10±2	15/163	9±2	9/163	6±2	6/163	4±1	4/163	2±1	2/163	1±1

Table 18. Summary of factors possibly related to nonvisibility

[Relations for which data are sufficient to allow tentative conclusions are shown in bold type. Age: Age of most recent displacement. BT: Bed thickness. CL: clay. DD: Dieout down. DU: Dieout up. E: Strike slip. GV: Gravel. H: Depth of dieout up. ID: Insufficient data. L: Length of obscure segment. N: Normal and normal-oblique slip. NC: No consistent correlation between nonvisibility parameter and listed factor. ND: No difference at 0.05 level within fault or material type. NI: Not investigated. OB: Obscure segment. R: Reverse and reverse-oblique slip. SD: Sand. ST: Silt. US: Soil horizon. W: Weak correlation. 1,2,3: Frequency rank within fault type or within material type. Minus sign: Negative correlation]

	Fault type								
	Principal			Subsidiary			Principal and subsidiary		
	E	N	R	E	N	R	E	N	R
OB	**1**	**3**	**2**	**ND**	**ND**	**ND**	**1**	**2**	**1**
DU	**1**	**2**	**1**	ID	**2?**	**1?**	ID	**2?**	**1?**
DD	**ND**	**ND**	**ND**	**1**	**3**	**2**	**1**	**2**	**2**

	Material														
	Principal					Subsidiary					Principal and subsidiary				
	CL	ST	SD	GV	US	CL	ST	SD	GV	US	CL	ST	SD	GV	US
OB	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	**4**	3	1	**5**	**2**
DU	**ND**	**ND**	**ND**	**ND**	**ND**	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
DD	ID	ID	ID	ID	ID	**4**	1	3	**5**	**2**	**4**	1	3	**5**	**2**

	Other Factors			
	Displacement	Length or depth	Length or depth v. bed thickness	Age
OB	NC	**-L (W)**	**BT>L (W)**	**-(W)**
DU	NC	**-H (W)**	**BT>H (W)**	NI
DD	**-(W)**	NI	NI	NI

Appendix B1. Number and percent of obscure segments of given displacement and fault type

[Percent: Of obscure segments with measured displacement and of given fault type, the percent within given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	52 48%	24 35%	19 49%	4 17%	1 17%	0 0%	0 0%	76 43%
2	0.155-0.304	13 12%	20 29%	13 33%	5 22%	2 33%	0 0%	0 0%	33 19%
3	0.305-0.454	6 6%	7 10%	4 10%	1 4%	2 33%	0 0%	0 0%	13 7%
4	0.455-0.604	5 5%	7 10%	3 8%	3 13%	1 17%	0 0%	0 0%	12 7%
5	0.605-0.754	0 0%	1 1%	0 0%	1 4%	0 0%	0 0%	0 0%	1 1%
6	0.755-0.904	1 1%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 1%
7	0.905-1.054	2 2%	1 1%	0 0%	1 4%	0 0%	0 0%	0 0%	3 2%
8	1.055-1.204	0 0%	2 3%	0 0%	2 9%	0 0%	0 0%	0 0%	2 1%
9	1.205-1.354	0 0%	1 1%	0 0%	1 4%	0 0%	0 0%	0 0%	1 1%
10	1.355-1.504	1 1%	1 1%	0 0%	1 4%	0 0%	0 0%	0 0%	2 1%
11	>1.504	28 26%	4 6%	0 0%	4 17%	0 0%	0 0%	0 0%	32 18%
	Total	100%	100%	100%	100%	100%	100%	100%	100%

Appendix B2. Number and percent of all strands or strand segments of given displacement and fault type

[Percent: Of strand segments with measured displacement and of given fault type, the percent in given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	310	228	188	22	17	1	2	540
		71%	45%	51%	24%	41%	10%	67%	57%
2	0.155-0.304	43	87	61	16	9	1	1	131
		10%	17%	17%	17%	22%	10%	33%	14%
3	0.305-0.454	14	32	22	3	7	0	0	46
		3%	6%	6%	3%	17%	0%	0%	5%
4	0.455-0.604	10	32	19	8	5	0	0	42
		2%	6%	5%	9%	12%	0%	0%	4%
5	0.605-0.754	3	12	6	4	0	2	0	15
		1%	2%	2%	4%	0%	20%	0%	2%
6	0.755-0.904	6	13	10	3	0	0	0	19
		1%	3%	3%	3%	0%	0%	0%	2%
7	0.905-1.054	4	7	5	2	0	0	0	11
		1%	1%	1%	2%	0%	0%	0%	1%
8	1.055-1.204	2	7	4	2	0	1	0	9
		0%	1%	1%	2%	0%	10%	0%	1%
9	1.205-1.354	0	3	1	2	0	0	0	3
		0%	1%	0%	2%	0%	0%	0%	0%
10	1.355-1.504	3	12	7	4	0	1	0	15
		1%	2%	2%	4%	0%	10%	0%	2%
11	>1.504	44	79	46	26	3	4	0	123
		10%	15%	12%	28%	7%	40%	0%	13%
	Total	100%	100%	100%	100%	100%	100%	100%	100%

Appendix C1. Number and percent of strands that die out upward, grouped by displacement and fault type

[Percent: Of strands with measured displacement and of given fault type that die out upward, the percent in given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	3 11%	11 48%	6 67%	5 36%	0 0%	0 0%	0 0%	14 28%
2	0.155-0.304	0 0%	3 13%	2 22%	1 7%	0 0%	0 0%	0 0%	3 6%
3	0.305-0.454	1 4%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 2%
4	0.455-0.604	3 11%	4 17%	1 11%	3 21%	0 0%	0 0%	0 0%	7 14%
5	0.605-0.754	0 0%	1 4%	0 0%	1 7%	0 0%	0 0%	0 0%	1 2%
6	0.755-0.904	1 4%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 2%
7	0.905-1.054	0 0%	1 4%	0 0%	1 7%	0 0%	0 0%	0 0%	1 2%
8	1.055-1.204	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
9	1.205-1.354	0 0%	1 4%	0 0%	1 7%	0 0%	0 0%	0 0%	1 2%
10	1.355-1.504	0 0%	1 4%	0 0%	1 7%	0 0%	0 0%	0 0%	1 2%
11	>1.504	19 70%	1 4%	0 0%	1 7%	0 0%	0 0%	0 0%	20 40%
	Total	100%	100%	100%	100%	0%	0%	0%	100%

Appendix C2. Number and percent of all strands on which dieout up could have been recognized, grouped by displacement and fault type

[Percent: Of strands with measured displacement and of given fault type that allow recognition of dieout up, the percent in given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	5 13%	26 30%	20 31%	6 30%	0 0%	0 0%	0 0%	31 25%
2	0.155-0.304	0 0%	12 14%	9 14%	2 10%	1 50%	0 0%	0 0%	12 10%
3	0.305-0.454	2 5%	4 5%	3 5%	1 5%	0 0%	0 0%	0 0%	6 5%
4	0.455-0.604	5 13%	7 8%	4 6%	3 15%	0 0%	0 0%	0 0%	12 10%
5	0.605-0.754	0 0%	4 5%	2 3%	2 10%	0 0%	0 0%	0 0%	4 3%
6	0.755-0.904	2 5%	4 5%	3 5%	1 5%	0 0%	0 0%	0 0%	6 5%
7	0.905-1.054	0 0%	2 2%	1 2%	1 5%	0 0%	0 0%	0 0%	2 2%
8	1.055-1.204	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
9	1.205-1.354	0 0%	2 2%	1 2%	1 5%	0 0%	0 0%	0 0%	2 2%
10	1.355-1.504	0 0%	5 6%	4 6%	1 5%	0 0%	0 0%	0 0%	5 4%
11	>1.504	25 64%	20 23%	17 27%	2 10%	1 50%	0 0%	0 0%	45 36%
	Total	100%	100%	100%	100%	100%	0%	0%	100%

Appendix D1. Number and percent of strands that die out downward, grouped by displacement and fault type

[Percent: Of strands with measured displacement and of given fault type that die out downward, the percent in given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	153 89%	66 75%	47 78%	12 75%	7 58%	0 0	1 100%	220 85%
2	0.155-0.304	10 6%	11 13%	8 13%	2 13%	1 8%	0 0%	0 0%	21 8%
3	0.305-0.454	3 2%	6 7%	3 5%	1 6%	2 17%	0 0%	0 0%	9 3%
4	0.455-0.604	0 0%	3 3%	1 2%	0 0%	2 17%	0 0%	0 0%	3 1%
5	0.605-0.754	0 0%	1 1%	0 0%	1 6%	0 0%	0 0%	0 0%	1 0%
6	0.755-0.904	0 0%	1 1%	1 2%	0 0%	0 0%	0 0%	0 0%	1 0%
7	0.905-1.054	1 1%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 0%
8	1.055-1.204	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
9	1.205-1.354	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%
10	1.355-1.504	1 1%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	1 0%
11	>1.504	3 2%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	3 1%
	Total	100%	100%	100%	100%	100%	0%	100%	100%

Appendix D2. Number and percent of all strands on which dieout down could have been recognized, grouped by displacement and fault type

[Percent: Of strands with measured displacement and of given fault type that allow recognition of dieout down, the percent in given displacement class. Dip slip includes normal, normal-oblique, reverse, and reverse-oblique slip. Upper limits of displacement class 11 given in table 4]

Displacement class	Displacement (meters)	Strike slip	Dip slip	Normal	Reverse	Normal oblique	Reverse oblique	Fault type unknown	All fault types
1	0.005-0.154	249	176	142	18	15	1	2	427
		72%	43%	49%	23%	45%	11%	67%	56%
2	0.155-0.304	32	71	54	10	7	0	1	104
		9%	17%	19%	13%	21%	0%	33%	14%
3	0.305-0.454	11	27	19	3	5	0	0	38
		3%	7%	7%	4%	15%	0%	0%	5%
4	0.455-0.604	4	26	15	7	4	0	0	30
		1%	6%	5%	9%	12%	0%	0%	4%
5	0.605-0.754	3	10	4	4	0	2	0	13
		1%	2%	1%	5%	0%	22%	0%	2%
6	0.755-0.904	3	10	7	3	0	0	0	13
		1%	2%	2%	4%	0%	0%	0%	2%
7	0.905-1.054	4	5	4	1	0	0	0	9
		1%	1%	1%	1%	0%	0%	0%	1%
8	1.055-1.204	1	7	4	2	0	1	0	8
		0%	2%	1%	3%	0%	11%	0%	1%
9	1.205-1.354	0	2	0	2	0	0	0	2
		0%	0%	0%	3%	0%	0%	0%	0%
10	1.355-1.504	2	9	5	3	0	1	0	11
		1%	2%	2%	4%	0%	11%	0%	1%
11	>1.504	37	65	35	24	2	4	0	102
		11%	16%	12%	31%	6%	44%	0%	13%
	Total	100%	100%	100%	100%	100%	100%	100%	100%