# FAULT ACTIVITY AND ITS SIGNIFICANCE ASSESSED BY EXPLORATORY EXCAVATION

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## ABSTRACT

Exploratory excavations often provide the most positive and detailed evidence needed to: (1) assess fault activity and its significance, and (2) confidently site structures in the vicinity of active faults. Before confident siting can be accomplished, it is necessary to understand the factors that determine the location and extent of surface fault rupture and exploratory excavations aid in this understanding. Observation and interpretation of exploratory trenches across active fault traces: (1) provide confidence that significant fault features are identified, (2) provide confidence in evaluating active faults and siting structures in relation to active faults, and (3) aid in understanding the factors that determine the location and extent of surface fault rupture. By conducting exploratory excavations across fault zones in conjunction with conventional geotechnical studies, it is possible to differentiate between active and inactive faults, determine the location of active fault traces, establish zones of maximum potential surface displacement, and evaluate the effects of active faults on works of man.

## INTRODUCTION

In seismically active areas, the potential for surface faulting across a proposed site may be the most critical consideration in determining project feasibility. This is because surface fault offset or rupture is the most difficult problem to accommodate in design when structures are in the vicinity of active faults. Before confident siting can be accomplished, it is necessary to determine the location and extent of future surface fault rupture. Aerial photographic interpretation, remote sensing, surface mapping, and geophysical exploration can sometimes provide an assessment of fault location and activity, but exploratory excavations often provide the most positive and detailed evidence needed to assess fault activity and its significance. An assessment of fault activity and its significance is needed to confidently site structures in the vicinity of active faults. Experience gained from more than forty exploratory trenches excavated across faults belonging to the San Andreas fault system is the basis of this paper.

Figure 1. A typical backhoe trench excavated across the active San Jacinto fault zone.

EXPLORATORY EXCAVATION

The exploratory excavation is commonly made by a backhoe, a dozer, or some other means of exposing the subsurface materials. A typical backhoe excavation is shown in Figure 1. Selection of the excavation equipment depends upon accessibility, depth of excavation, difficulty of excavation, cost, length of the time excavation is to remain open, and the environmental impact of the excavation.

The purpose of the excavation is to expose the subsurface materials to a depth sufficient to enable individuals to make a detailed inspection and evaluation of the excavation walls to determine if there are any fault features which will influence the feasibility of the project. In order to insure that the maximum information is obtained from each excavation, the following procedures are necessary:

1. The excavation must be as deep as possible, or at least 10 to 20 feet deep. This is necessary because fault features are better exposed in the deeper materials and because the deeper excavations often provide age relationships which are useful in establishing the activity of faults.

2. The excavation must be safe. The excavation must comply with local, state, or federal requirements for safety and permits. This may require that the excavation be shored, walls layed back, or the excavation be

widened. The State of California, Division of Industrial Safety, now requires a permit for all trench excavation over 5 feet deep in which men are to work.

3. The detailed inspection should be made by individuals experienced in logging fault features in test trenches. Since some of the significant fault features are difficult to recognize, experience is invaluable.

4. Sufficient time should be allowed to inspect and log the excavation. Once the excavation is backfilled, the excavation log is the only evidence available. Therefore, it is very important that the log reflect the actual conditions observed in the excavation.

5. The excavation, or a series of excavations, should extend a significant distance on either side of the fault and generally more than one excavation should be made across a fault or suspected fault.

LOGGING OF EXPLORATORY EXCAVATIONS

Since the fault-related features used to assess fault activity and its significance are sometimes obscure, detailed inspection and logging is necessary to assure that everything significant has been considered. The obscure fault features exposed in a test trench across the San Jacinto fault are shown in Figure 2. The results of detailed inspection and logging of a test

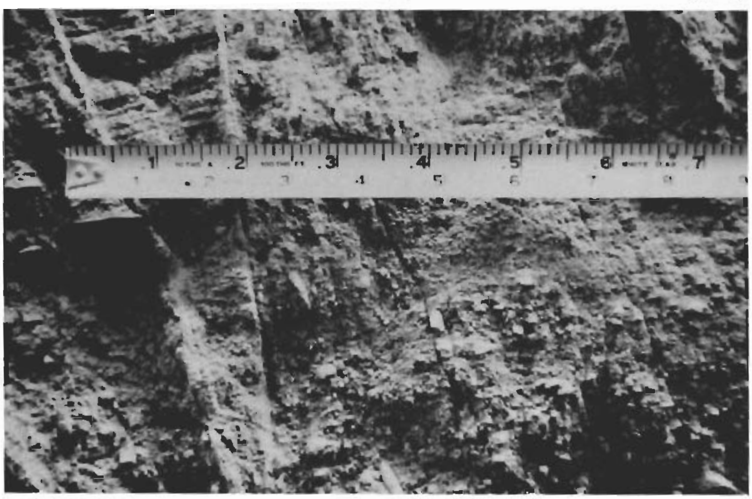

Figure 2. Fault planes of the active San Jacinto fault exposed in granular alluvial deposits.

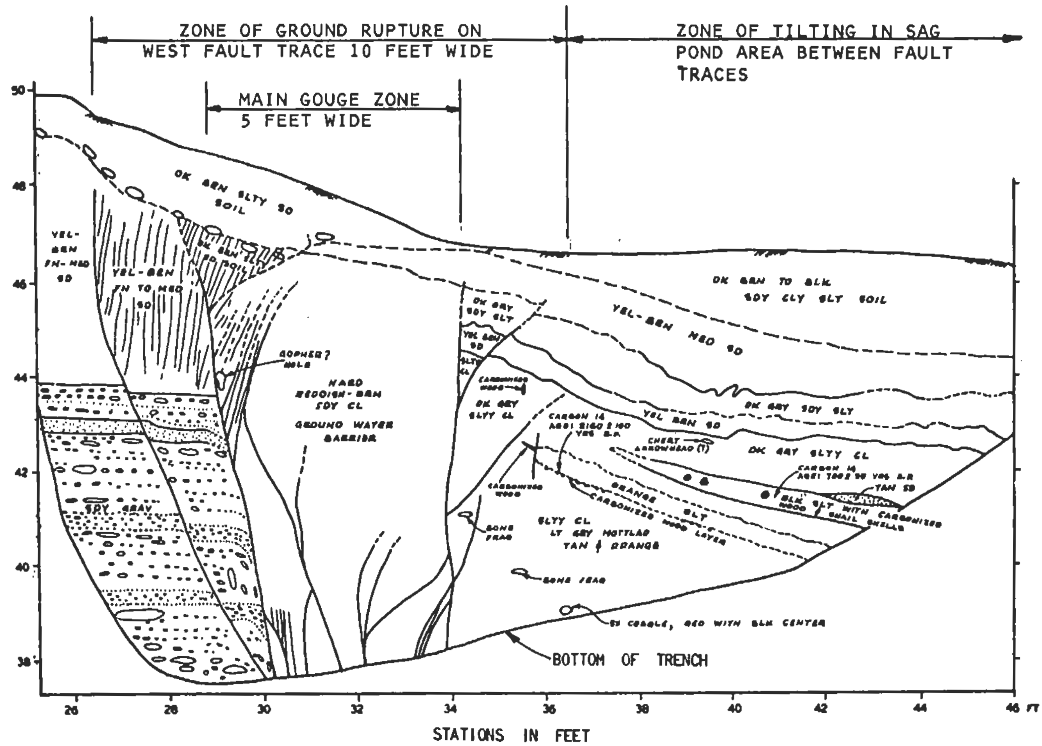


Figure 3. Log of an exploratory excavation across the active Hayward fault.

trench are shown on Figure 3. This figure indicates the amount of information that can be obtained from an exploratory excavation. The following procedures have proven satisfactory for detailed logging of excavations:

1. The excavation, or segment of the excavation, is completed and adequate safety measures are taken.

2. For logging purposes, horizontal and vertical control reference lines are established within the excavation. This can be done in many ways: surveying, lead weights on strings, use of a string-level, establishing a grid system with strings, or simply measuring from the ground surface.

3. Logging is done at a detail scale. A scale of 1 inch equals 2 feet produces the desired results. This scale permits enough area on a log sheet to log all significant features and produces a detailed record. Sketching of a trench wall is not a substitute for detailed logging.

4. The walls of the trench are cleaned prior to logging. This is one of the important items in trench logging. During excavation operations, the walls are generally disturbed and smeared with a layer of clay and silt. The cleaning of the walls removes this material and at the same time exposes structure present in the native material. The best way to remove the smeared surface in clayey materials is to use a broad-bladed hand pick. A sharp-pointed pick is absolutely unsatisfactory. The material is removed by forcibly thrusting the blade through the surface smear into the native materials and then pulling a small wedge of the material into the trench. Experience with this technique will reveal many planes not otherwise recognized.

In silty or granular materials, a pick may be needed to remove the surface smear, but a trowel and brush are commonly used to expose the fault planes. Figure 4 is an example of fault planes exposed by using a trowel and brush to expose the native features.

In some cases, it is necessary to clean the entire wall before the logging can begin. This is a very time-consuming task. Another method, which is

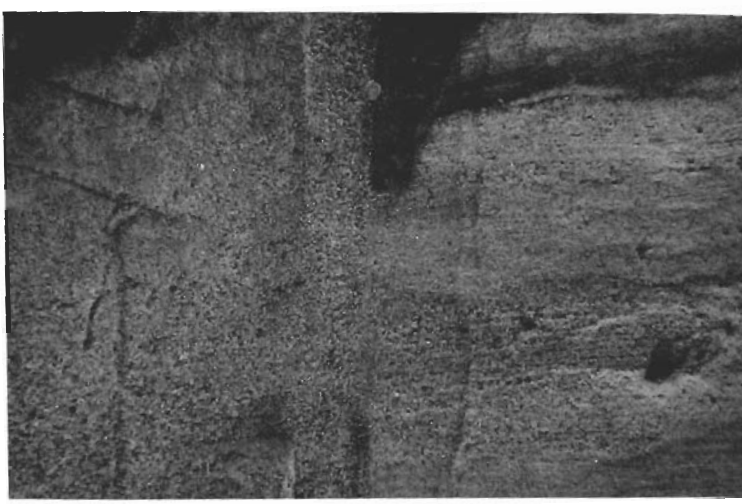

Figure 4. Vertical fault planes exposed in granular materials. For scale note the head of a six-penny nail exposed along the fault plane, just to the left of the dark (clay) zone near the top of the photograph.

less time consuming and very effective, is to clean the trench by the grid method. This is done by: (1) cleaning 2-foot-wide vertical swaths from top to bottom at 5-foot intervals along the wall, (2) cleaning 2-foot-wide horizontal swaths at 5-foot intervals down the wall, and (3) observing marker beds or planes exposed in the swaths. Thus, by using this grid system, it is possible to identify continuous structures which traverse the excavation. Once these features are identified in one of the swaths, they can be exposed more fully for detailed inspection and logging.

5. During the logging stage, attention is paid to details, especially those that may not seem important. Particular attention is paid to: vertical cracks or joints, abrupt changes in materials, soil thickness or profile, thin clay seams, caliche layers, and moisture changes.

6. Special attention is paid to the areas outside of the main zone of faulting to assure that all fault planes are recognized. During future episodes of surface faulting, major movement will most likely occur along the more prominent planes, as shown on Figure 3; but it is necessary to determine if there are other potential planes of displacement.

Once the logging has been completed and all subsurface fault features have been identified, inspected, evaluated, and logged; the factors that determine the location and extent of surface fault rupture can be evaluated. This evaluation forms a basis for confident siting in the vicinity of active faults. Some observations of active faults that aid in this evaluation and in establishing confident siting are described in the following section.

## OBSERVATIONS OF ACTIVE FAULTS

Observation and interpretation of exploratory trenches across active fault traces provide confidence in evaluating active faults and siting structures. The more important observations include the following:

1. Active fault traces can be identified in alluvial deposits (including granular materials) even if non-stratified. Figures 2 and 4 show active fault traces in granular materials and Figure 3 shows active fault traces in clay, silt, and gravels.

2. Active fault traces in rock are sometimes difficult to identify. The active fault trace and age of displacement generally cannot be determined in rock without a younger deposit covering the surface, topographic fault features, fault creep, or other positive evidence.

3. Several different ages and episodes of displacement can sometimes be recognized. Displacement may be greater in some older and deeper layers than it is in younger near surface layers indicating continuous displacement in the same area for a considerable period of time. See the following

observation (#4).

4. The age of displacement often can be documented. Figure 3 shows a thin yellow-brown sand layer which has been displaced by faulting. About one foot below the sand, a layer of black silt with carbonized wood has been dated at about 700 years, and about one foot below this, another layer has been dated at about 2200 years. Based on this evidence, it is clear that at lease one episode of faulting occurred within the last 700 years. Since the sand is above and therefore younger than the 700-year-old layer, displacement has probably occurred much more recently. The last historical fault movement on this fault occurred in 1868. Figure 3 clearly documents that fault displacement has not occurred just east of the main trace in at least 2000 years. It is likely this fault trace has been in the same location for more than 2000 years.

5. Width, orientation, and configuration of a fault trace often vary along its length. Figure 5 shows how the fault trace varies in five trenches excavated along about 800 feet of its length. The fault trace width varies from 10 to 78 feet with the major zone of displacement representing only a fraction of this amount.

6. The individual fault planes are generally very thin and are often overlooked by an inexperienced observer. The width of typical fault planes are shown on Figures 2 and 4. In general, this same width is noted in all excavations.

7. The fault planes usually become better developed and are more easily recognized with depth. This is because the deeper materials are less subject to surface weathering, surface modification, moisture change, and because they are below the active soil zone.

8. The orientation of individual fault planes changes both with depth and along the strike. The change in strike of a fault trace is shown on Figure 5. The fault trace trend shown on Figure 5 was obtained by joining the limits of fault zones within the individual trenches. The strike of the individual boundary fault planes exposed in trench 4 of Figure 5 does not agree with trend shown but strikes slightly eastward of the fault trace trend. Thus, extreme care must be taken in projecting the strike of a fault trace from a single excavation.

The complex orientation of fault planes within an active fault zone are shown on Figure 6. The strike orientation is different west of, east of, and within the zone of most active faulting. The orientation also changes along the individual planes from the bottom of the most active zone of faulting toward the top. The change is a clockwise rotation of the fault planes. The surface projection of the fault trace agrees more closely with the strike near the bottom of the trench than with the strike near the top.

9. The width of the zone of faulting usually becomes greater with depth. This increased width is shown on Figure 6. Only the most active fault planes project near the surface. While fault displacement may occur along the deeper fault planes on either side of the main fault zone, there is no doubt that the displacement is less and more infrequent than along the main fault zone.

10. The width, orientation, and configuration of the zone of surface displacement varies along its length. This can be seen in the trench logs shown on Figure 5.

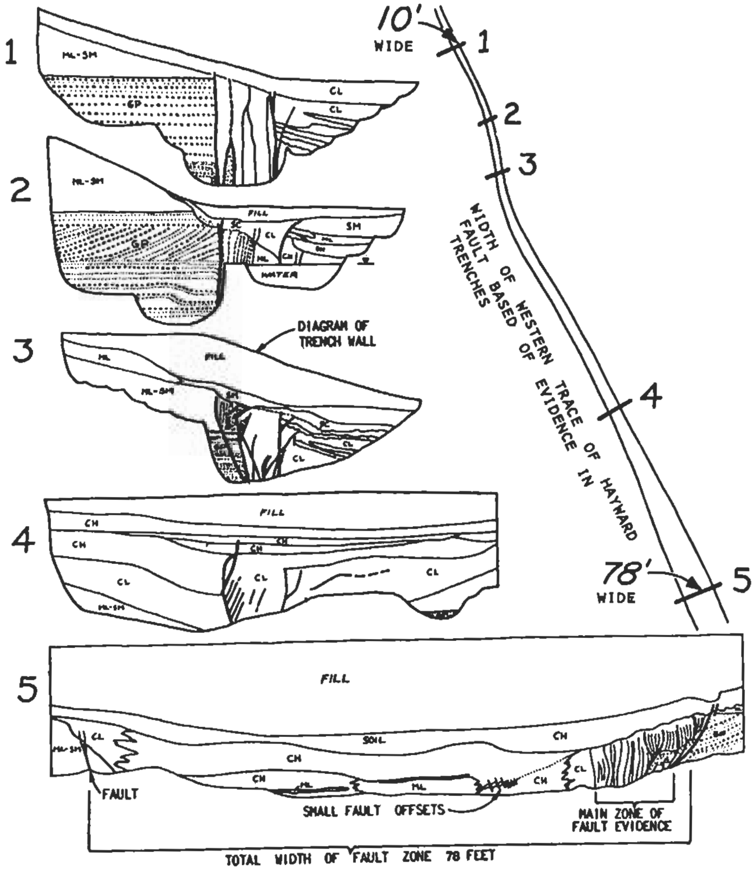


Figure 5. Logs of five trenches excavated across a trace of the active Hayward fault zone.

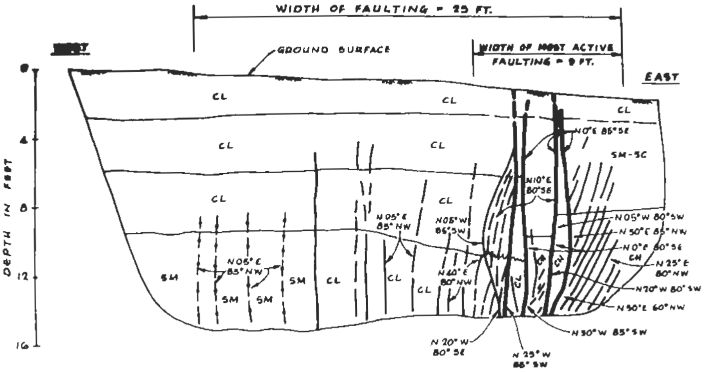


Figure 6. Configuration of an active fault zone.
Note changes in strike of fault planes.

Based on the information presented above, each segment of a fault and each exploratory excavation can be expected to be different thus requiring more extensive exploration before confident siting can be accomplished. However, exploratory excavation can aid in providing the information needed for confident siting.

## CONCLUSIONS

Aerial photographic interpretation, remote sensing, surface mapping, and geophysical exploration provides invaluable data in evaluating the activity and location of active faults. However, to confidently site structures in the vicinity of active faults, exploratory excavations often provide the most positive and detailed evidence that is needed to assess fault activity and evaluate its significance. Exploratory excavations provide a means of understanding the factors that determine the location and extent of future surface fault rupture, which may be the most critical consideration in determining project feasibility in seismically active areas.

It should be realized that exploratory excavations are only tools in fault evaluations and may not always provide the desired results. There are two factors which limit the application of exploratory excavations in fault evaluation studies: (1) the excavation and logging is time consuming and costly, and (2) in order to obtain the maximum information, experienced individuals are required to inspect, evaluate, and log the excavations. Because of its cost and the time required to do an adequate study, the exploratory excavation should not be undertaken until other geological exploratory tools have been used to define the general location of suspected faults.