

HOLOCENE ACTIVITY AND TECTONIC SETTING OF THE MAACAMA FAULT ZONE, MENDOCINO COUNTY, CALIFORNIA

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ABSTRACT

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The Maacama fault zone is a north-northwest trending, right-lateral zone of structural weakness in eastern Sonoma and Mendocino Counties, California, and fault-related landforms along its trace suggest that it may well have been active during Holocene time. Urbanization and dam construction in the vicinity of the zone have made it especially desirable to determine the extent and history of such geologically recent movements in order to better understand the seismic capability of faults within the zone.

The Maacama fault zone is a segment of one of two north-northwest trending zones of right-lateral faulting that diverge as major branches from the easterly side of the San Andreas fault zone north of Hollister. These branches extend at least as far north as Eureka and may mark the eastern boundaries of slivers of a separate tectonic plate.

This investigation was conducted to evaluate Holocene activity along the part of the Maacama fault zone in Mendocino County. The investigation shows that this zone comprises discontinuous, subparallel fault strands which extend from points south of the Sonoma–Mendocino county line to points north of Laytonville. Some fault segments are expressed by alignments of topographic features clearly caused by Holocene strike-slip movements. Other topographic features are less distinct and may well represent fault segments with pre-Holocene activity.

The Maacama fault zone creeps at a current rate of possibly as high as 2 mm/yr. The total amounts of Holocene offset are unknown.

Evidence obtained from exploratory trenches indicates that at least two surface rupture events have occurred within the past 16,200 years, that at least one has occurred within the past 8,310 years, and that there probably has been no surface rupturing within the past 1,140 years.

I conclude that surface offsets have occurred along major portions of the Maacama fault zone during Holocene time, and that this fault zone should be regarded as capable of producing a moderate to strong future earthquake with accompanying surface rupture in Mendocino County.

ENCLOSURE (Folded in envelope inside back cover)

Fig.19. Strip map folding instructions.

INTRODUCTION

The Maacama fault zone in Mendocino and Sonoma Counties about 150 km NNW of San Francisco, California, is one of several large faults in a broad

zone 100 to 125 km wide along the northern coast of California (Fig.1). There are few markers with which to identify sense or magnitude of offset across the Maacama fault zone, but the fault zone apparently offsets a belt of Sonoma volcanics in a right-lateral sense approximately 20 km (McLaughlin, 1981), so

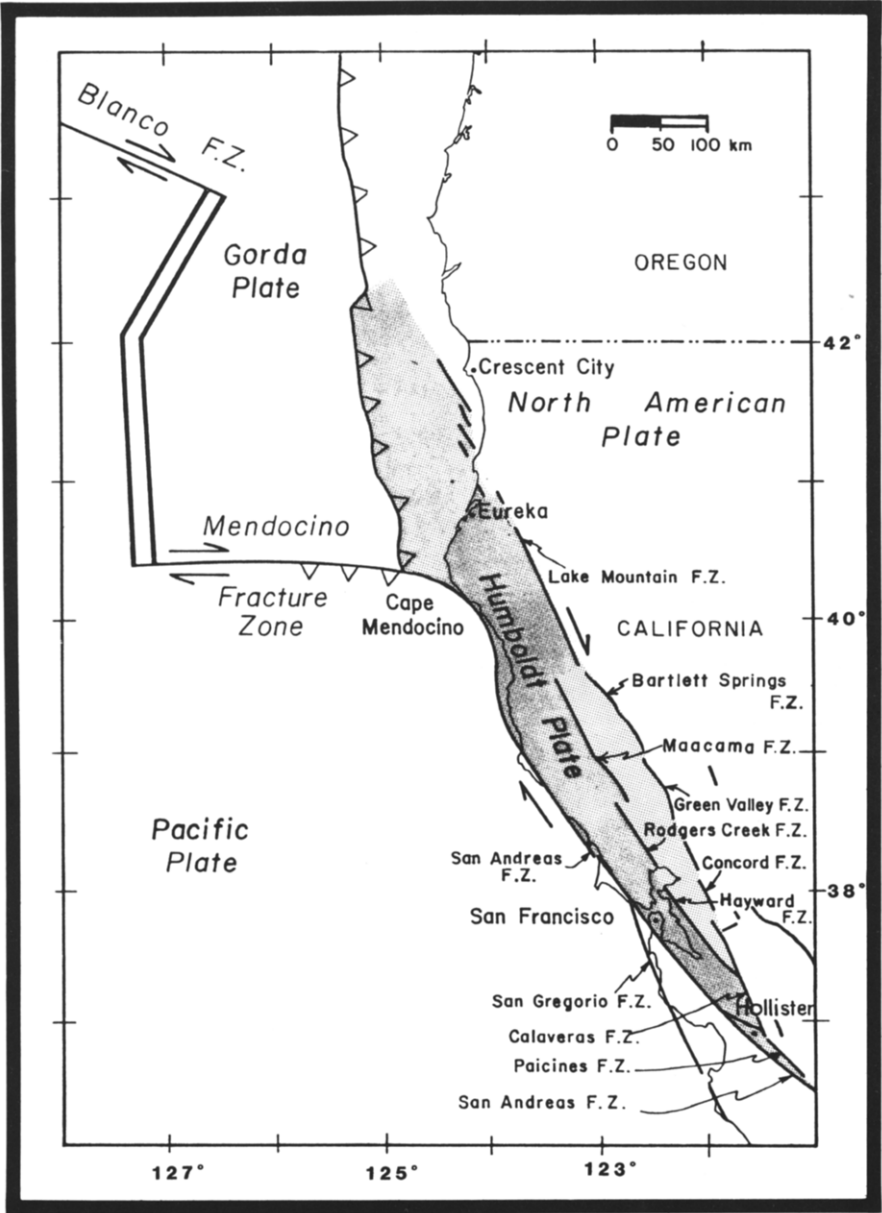


Fig.1. Map showing recently active wrench fault zones in northern California (modified from Herd, 1979).

the fault zone appears to be a major one. Furthermore, at Willits, in Mendocino County (Fig.2), the Maacama fault zone creeps at a rate estimated to be 2 mm/yr., based on maximum amount of offset of a reference curb (Simon et al., 1978), and measurements of microseismic activity in the area during 1980 and 1981 indicates that the Maacama fault zone is active at depth (Dames and Moore, 1977; Cockerham and Herd, 1982).

Thus, parts of the Maacama fault zone in Mendocino County had been recognized prior to my investigation, and evidence suggesting Holocene activity along the fault zone also had been noted. Unknown, however, were the extent of geologically recent movements and the history of Holocene activity along the Maacama fault zone. Increasing urbanization in parts of the region, along with major engineering efforts such as the construction of Warm Springs Dam near Healdsburg and the dynamic response analysis of Coyote Dam near Ukiah, emphasized the need to better know the Holocene activity of the Maacama fault zone as a structural element of possibly great significance.

The primary purpose of this investigation, therefore, is to identify and evaluate evidence of Holocene activity along the Maacama fault zone in Mendocino County. The investigation comprised two phases, one dealing with surface and the other with subsurface features. The purposes of the surface investigation were to produce a detailed map showing the distribution of fault-related topographic features, to look for evidences of direction, amount, and recurrence of the late Quaternary fault movement, and to select sites for special subsurface exploration. This work included a detailed analysis of aerial photographs, extensive field checking along traces of suspected fault segments, and examination of exposed fault breaks.

The subsurface investigation required the excavation of exploratory trenches across the fault traces to permit three-dimensional examination of important relationships and collection of samples. The trench walls were carefully inspected to determine the exact locations of fault breaks, and to obtain evidence for the direction, magnitude, and relative timing of fault movements. Samples were obtained for radiocarbon dating of key stratigraphic horizons.

MENDOCINO HIGHLANDS

Mendocino County is centered in the part of the northern Coast Ranges known as Mendocino Highlands, which is characterized by ridges and valleys with a general north-northwest trend that is subparallel to the coastline farther to the west. The altitudes of the highest peaks exceed 1200 m, and the altitudes of valley floors are below 200 m. The study area is elongate and encompasses a series of narrow, north-northwest trending valleys in the eastern part of the county (Fig.2). Redwood Valley (near center of Fig.2) and valleys farther south are drained by the southerly flowing Russian River system; Little Lake Valley and valleys to the north are drained by the northerly flowing Eel River system.

The bedrock exposed in the Mendocino Highlands is limited to rocks of Late

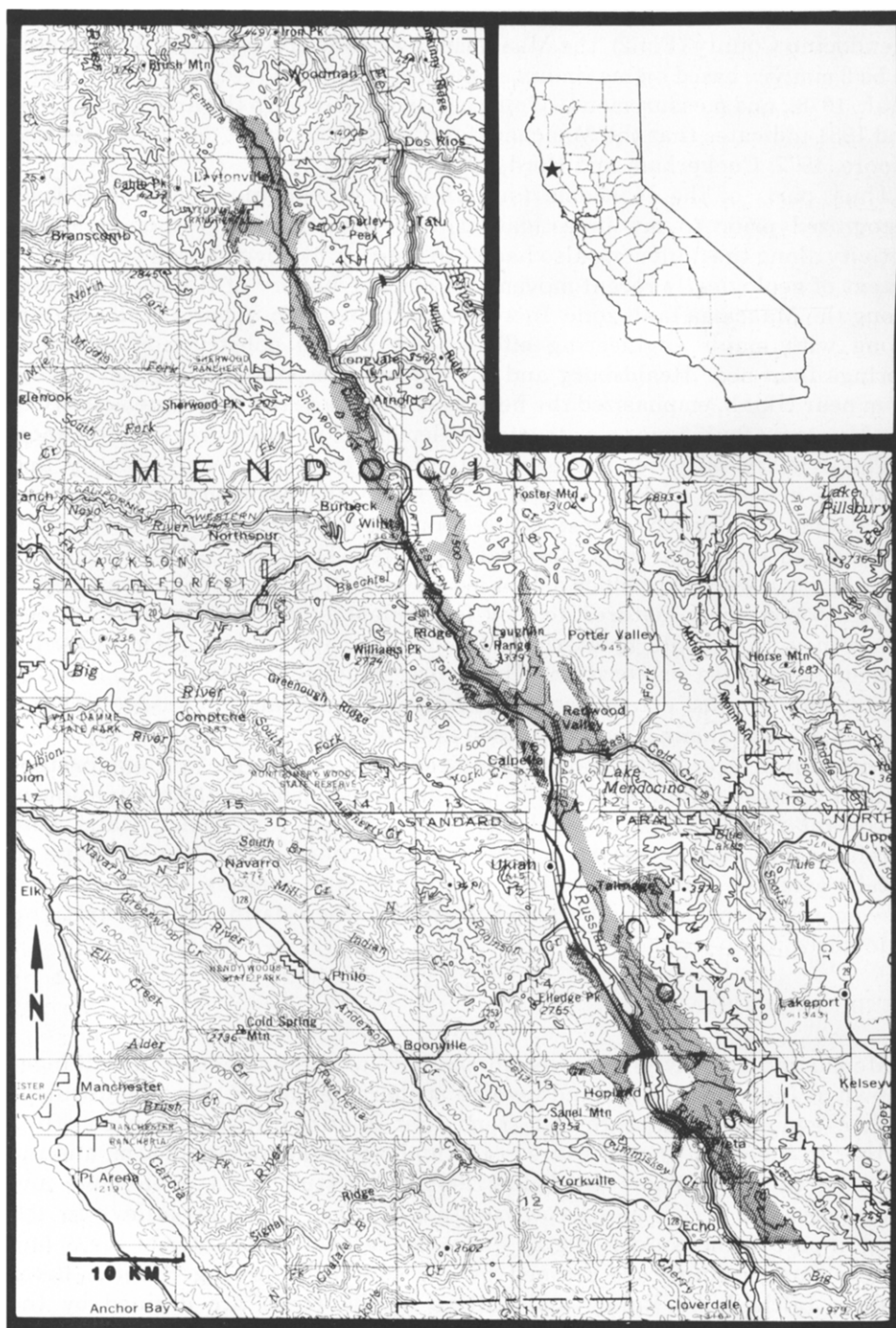


Fig.2. Area of field investigation. Shaded portions represent the areas field-checked for evidence of active fault traces.

Mesozoic and Late Cenozoic age, so most of the region is underlain by slightly metamorphosed graywacke sandstone, conglomerate, shale, schist, chert, and serpentinite, representing the Franciscan Assemblage of Late Jurassic to Early Cretaceous age. Erosion of the Franciscan rocks has produced large volumes of gravelly sediments, referred to as the Ukiah Beds of Pliocene to Pleistocene age (Treasher, 1955) that were deposited in the main valleys to estimated thicknesses on the order of 300 m (U.S. Army Corps of Engineers, 1955). Subsequent reworking of these sediments has produced a series of terrace deposits and has contributed to the Holocene alluvium that occupies the bottoms of many valleys.

The geologic history of the Mendocino Highlands can be inferred from studies elsewhere in the Coast Ranges. Sediments of the Franciscan Assemblage were deposited during the Late Jurassic time in a sinking geosynclinal basin. The basin was elevated above sea-level during Cretaceous time, the rocks were intensely folded and faulted, and they were subsequently elevated to form the Mendocino Highlands where they have since remained largely exposed.

Strike-slip faulting since Late Pliocene time, which has dislocated and distorted evidence of early structure, has been primarily responsible for the general north-northwest structural grain of the Mendocino Highlands. Parts of the Highlands were down-dropped by movement along these faults to form principal valleys. As these valleys slowly sank, they were partly filled with gravelly sediments of the Ukiah Beds. North-northwestward dips of the sediments, generally ranging from two to ten degrees (U.S. Army Corps of Engineers, 1955), reflect subsequent tilting of many of the valleys. Strike-slip faulting along north-northwest trends has continued to the present time, and the most recent ruptures appear as traces of the Maacama fault zone.

GEOMETRY OF THE MAACAMA FAULT ZONE

The northern part of the Maacama fault zone appears in Mendocino County as a zone of discontinuous, subparallel fault segments or strands that extend for a distance of more than 100 km from the Sonoma County line to an apparent termination north of Laytonville (Figs. 3 and 19). The fault zone has a remarkably linear trend of about N27W. Individual active fault segments, however, range in trend from N8W to N47W. The rose diagram of Fig. 4 shows how closely the trends of most of the active fault segments approximate the trend of the main fault zone.

The entire fault zone can be divided into four major reaches or subzones, each with one to as many as eleven recognizable fault segments (Fig. 19). Each subzone is in most places a more or less continuous assemblage of subparallel fault strands with a consistent general trend. The individual active fault segments, however, are distinguished by a different trend or by a distinct separation from adjoining segments.

The longest subzone is the Talmage, which extends for a distance of about 15 km with an average trend of N25W. The Willits subzone, about 9 km long and trending N28W, is the second longest. It is separated from the Talmage by

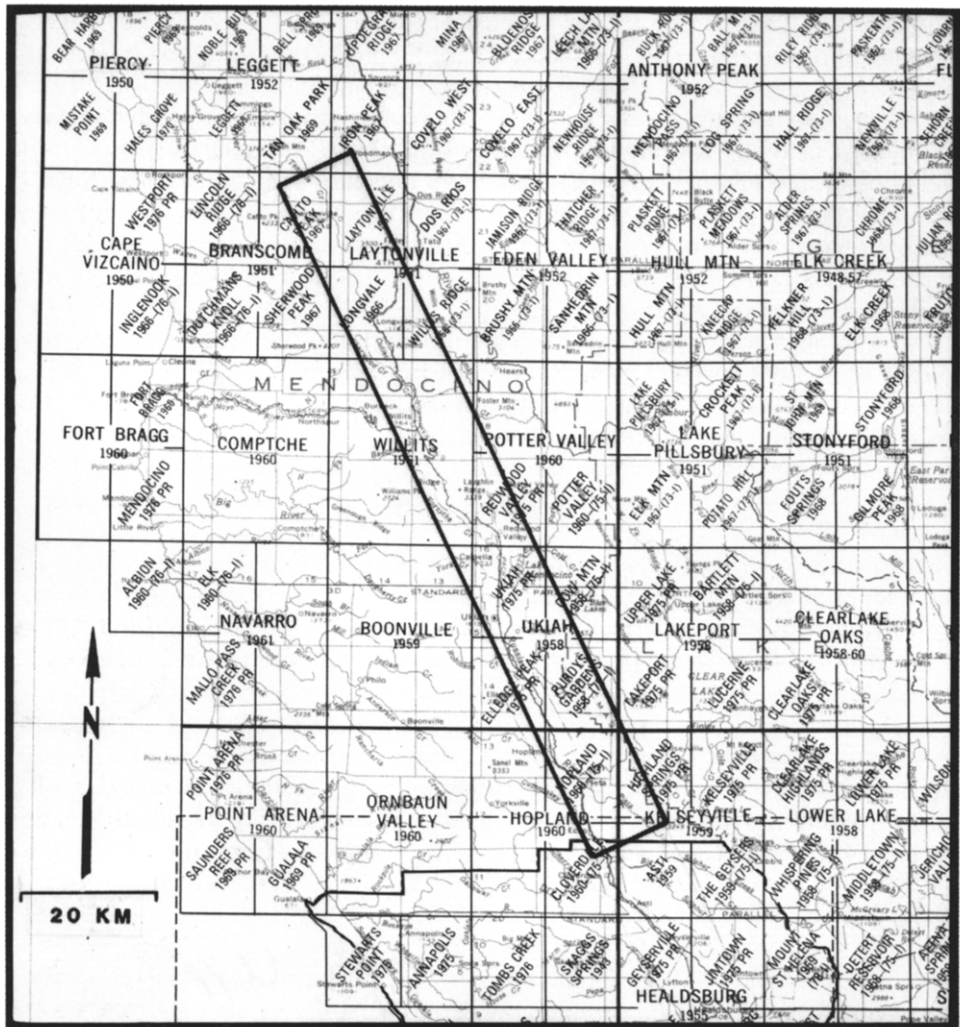


Fig.3. Location of the strip map (Fig.19) and index to 7.5 Minute Quadrangle maps used in this study.

an interval of about 1 km on the west side of Laughlin Range, where a mantle of massive landslide deposits lacks expressions of recent fault movement. The fault zone may well be continuous beneath the landslide deposits, and despite their slightly divergent trends, the Talmage and Willits subzones probably should be considered as one continuous fault about 24 km long.

It would be more difficult to regard the Laytonville and Willits subzones as parts of a continuous break. The gap between them is about 4 km long and shows no clear evidence of faulting. Although the trends of the subzones are subparallel, there appears to be an eastward step of about 0.7 km from the Willits fault subzone to the Laytonville fault subzone.

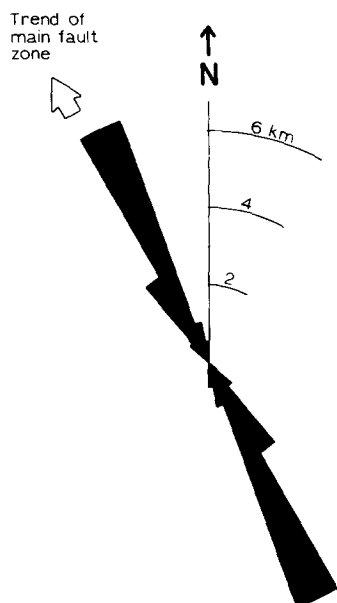


Fig.4. Distribution rose diagram of active fault segments, Maacama fault zone, Mendocino County, California. Diagram shows total length of active faults trending in each 10 degrees of azimuth.

It is even less likely that the Squaw Rock fault subzone is continuous with the Talmage fault subzone. These two fault subzones have markedly divergent trends and are separated by about 2 km of ground with no observable fault features. In addition, the south end of the Talmage fault subzone is stepped to the west by about 0.5 km from the Squaw Rock fault subzone.

FAULT INVESTIGATIONS

Two trenching sites were chosen where the fault trace could be accurately located, where a high probability of Holocene fault movement could be inferred, and where several meters of Holocene sedimentary deposits might provide a stratigraphic record of fault movements. One site is at the crest of the Laughlin Range south of Willits, and the other is in the Upp Creek drainage near Twin Lakes north of Willits. The locations of these sites are shown in Fig.5.

TRENCH SITE ON LAUGHLIN RANGE

The site of the trench across the Maacama fault zone at Laughlin Range is on the top of a ridge separating Walker Valley to the south from Little Lake Valley to the north (Fig.6). In this area the most recently active segment of the fault is marked by a series of elongate ridgetop valleys, several with local

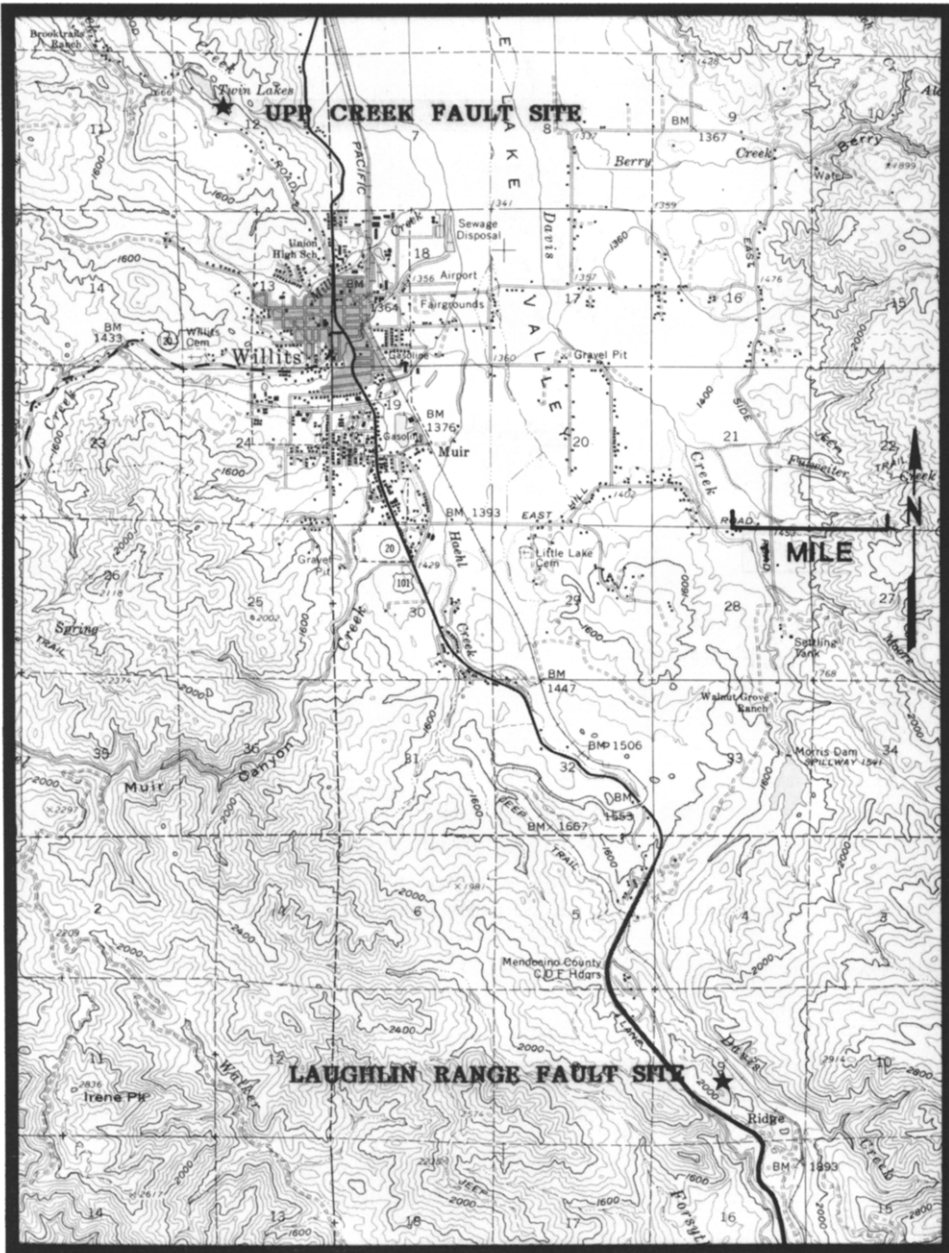


Fig.5. Locations of the two exploratory trench sites.

closed depressions. When flooded, these depressions become sag ponds that accumulate sediment. Two of them were selected for trenching.

A single trench initially was excavated across the bottom of each sag, but neither trench intersected the fault. The trenches then were extended across existing ranch roads and up the hillsides beyond the pond limits (Fig.6).

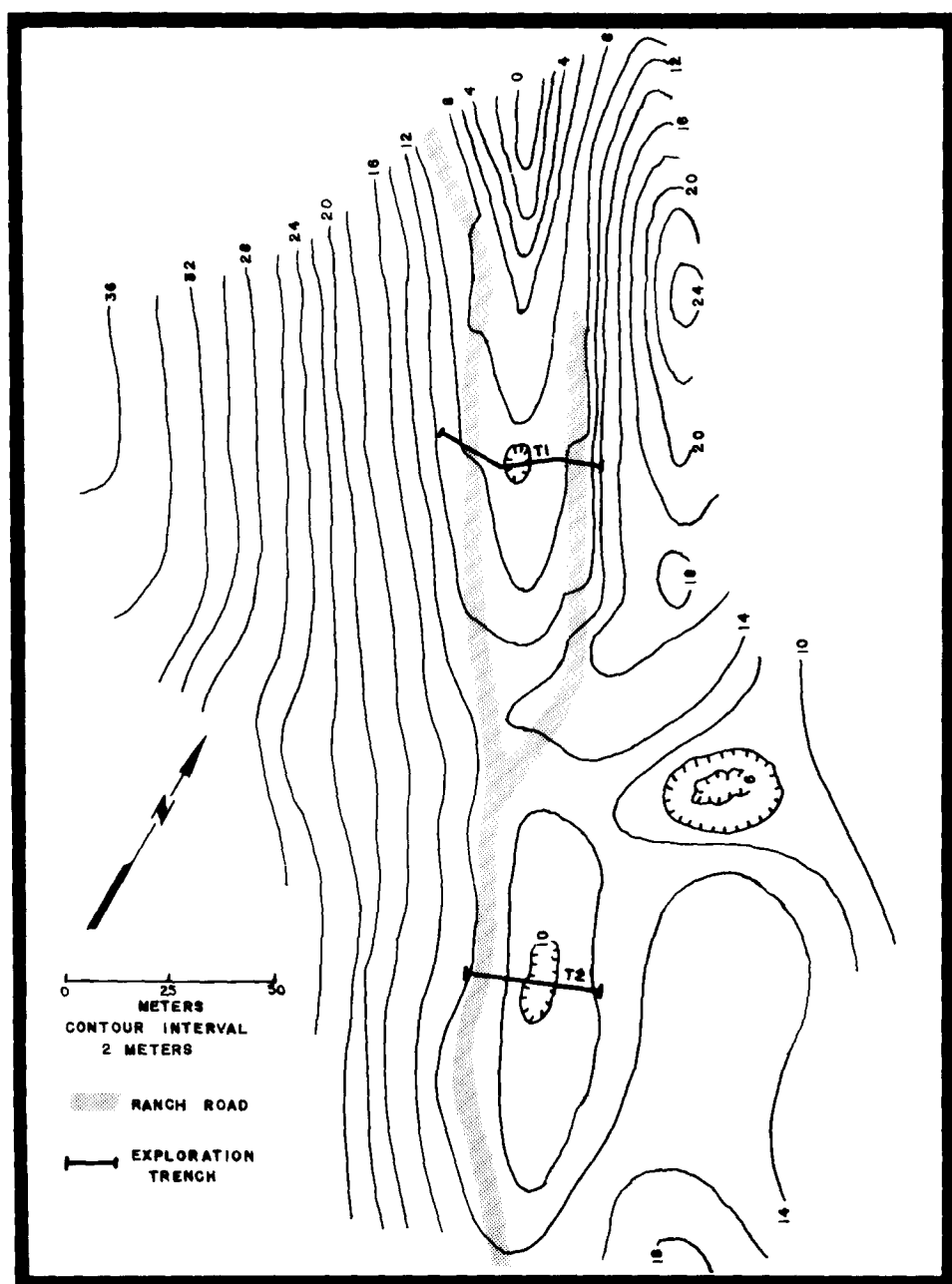


Fig.6. Locations of exploratory trenches at Laughlin Range site.

Trench 1 showed that the northern sag contains a thick accumulation of colluvial and lacustrine deposits consisting of clayey and sandy silt and sandy and silty clay with various amounts of angular to subangular gravel; cobbles, primarily of sandstone and siltstone, are in the gravel deposits (Figs.7 and 8).

EXPLANATION OF SYMBOLS USED ON EXPLORATORY TRENCH LOGS

Geologic Contacts

	Distinct contact, well located
	Indistinct contact, approx. located
	Gradational contact, approx. located

Symbols

	Fault surface
	Location of sample for radiocarbon dating

Materials

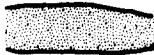
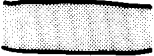
	Alluvial sand or gravel
	Clay
	Gray sedimentary layers (value = 5 or less, chroma = 2 or less)

Fig.7. Explanation of symbols used on exploratory trench logs.

Below a depth of about 2 m, there are additional clayey lacustrine deposits, along with irregular lenses of alluvial sand and gravel.

The western flank of the depression is underlain by as much as 3 m of colluvial sandy clay deposits, with subangular fragments of sandstone and claystone 10 cm in maximum dimensions. The colluvium overlies massive sandstone of the Franciscan Assemblage.

The roadcut on the east side of the pond exposes Franciscan bedrock consisting of thinly interbedded sandstone and siltstone that strikes N35W and dips 40 NE. In the trench, this bedrock is in fault contact with sandy colluvium containing as much as 40% of angular to subangular gravel with

cobbles of sandstone and siltstone. The fault zone was exposed as a thin wedge of dark gray, sandy clay gouge. The fault surface, which was observed within this wedge at the bottom of the trench, strikes N27W and dips 64 SW; it is marked by near-horizontal striations that evidently reflect strike slip.

The top of the wedge appeared to be truncated by colluvial deposits about 2 m below the original ground surface. At this location, excavation for the ranch road had removed more than 1 m of the original ground, hence the relationship between the fault and the natural ground surface could not be determined.

At least one possible buried soil horizon is at a depth in the trench of about 2 m and it appears to have developed in a depression adjacent to an area of periodic active erosion and alluvial deposition. The irregular boundaries observed between some of the units near the 20-m mark (Fig.8) reflect depositional processes, and there is no evidence to suggest that they are fault-related.

Trench 2 showed that the southern sag also is filled with a thick accumulation of colluvial deposits that consist primarily of sandy clay with various amounts of angular sandstone fragments (Fig.9). To the east, these deposits are draped over weathered sandstone of Franciscan bedrock.

Two buried soil horizons were exposed in the trench, one at a depth of about 1.0 m and the other at about 2.5 m. These soils have gradational boundaries with adjacent deposits and there is no evidence to suggest that they had been offset or disturbed by faulting.

The slope to the west is mantled with as much as 2.5 m of colluvial deposits overlying weathered Franciscan sandstone. Both the colluvial deposits and the bedrock are truncated on the east by the fault zone, which is about 2.5 to 3.0 m wide. The fault zone appeared on the trench walls as two or three bands of sandy or silty clay with about 30% subangular to subrounded sandstone fragments and a few subrounded sandstone boulders. The bands are successively overlain, from west to east, by higher colluvial layers.

The relationships suggest at least two, and possibly three, episodes of fault movement, as shown in Figure 10. The fault surface was exposed in the eastern, youngest band of the fault zone (Zone C of Fig.10) near the 25-m mark. At the trench bottom, the fault surface strikes N22W and dips 56 W. Slickenlines rake 18 degrees to the south, indicating large horizontal and small vertical components of recent movement, west-side-up, on the right-lateral strike-slip fault. The upper 3 m of sediments apparently have been affected by soil creep, causing the fault zone and the fault surface itself to curve downhill as shown between the 22-m and 29-m marks in Fig.9.

Minute specks of organic carbonaceous matter are scattered throughout the sediments, and two fragments of sufficient size for radiometric dating were found. One piece of charcoal, sample AF, was obtained at a depth of 1.25 m on the west side of the fault. The sedimentary layer in which it was found is truncated by the fault zone (Fig.9) indicating it definitely pre-dates the latest episodes of fault movements. The other piece, sample 79-V, was taken from a depth of about 2.25 m on the east of the fault; it probably also pre-dates the fault movement.

Both samples were analyzed at the U.S. Geological Survey Radiocarbon Laboratory. The western sample (AF) was age-dated as $16,200 \pm 150$ years before present, and the eastern sample as $8,310 \pm 95$ years before present. The younger age for the deeper sample reflects a more rapid accumulation of sediment in the depression than on the hillside.

A bulk sample of the undisturbed colluvial soil overlying the fault zone yielded a mean residence radiocarbon age of 1140 ± 70 years before present. This is a rough approximation of the minimum age of the undisturbed colluvium, and hence of the minimum length of time since the latest fault movement at this locality.

TRENCH SITE AT UPP CREEK

About 2 km northwest of Willits, the main fault trace extends through an elongate hillside valley that contains one of the Twin Lakes (Fig.5). This lake is probably a sag pond and has been enlarged by damming. To the southeast is the site of a former sag pond that has been naturally drained through erosional breaching of the adjoining ridge to the east. This drained sag pond was selected as a site for trenching across the fault. Three trenches were excavated at this site (Fig.11).

Trench 3A (Fig.11) revealed interlayered alluvial and colluvial deposits consisting primarily of sandy clay and clayey gravel toward the southwest end of the trench and lacustrine deposits of massive clay toward the valley center. A distinctive gray horizon at a depth of 2 to 3 m could be traced across the entire length of the trench. This marker horizon showed no indications of offset or other disturbances that could be attributed to fault movement.

Trench 3C (Fig.11) revealed a thick sequence of colluvial deposits consisting primarily of sandy clay with various amounts of gravel. A distinctive dark gray layer of silty clay was observed along most of the trench at a depth of about 2.5 m. No evidence of an active fault trace could be seen in the trench.

The northeastern end of Trench 3B exposed severely weathered sandstone and siltstone bedrock (Fig.12, pp.395–398), in which the stratification strikes subparallel to the ridge line and dips about 50 degrees to the east. The bedrock is truncated to the southwest by a fault zone that is about 0.5 m wide. This zone consists of two or three nearly vertical bands of gravelly sandy clay, each with a different color ranging from yellowish brown to dark brown. Cracks observed in the clay near the bottom of the westernmost layer are not slickenlined and probably are not fault-caused, although they could be tension cracks produced by simple shearing.

West of the fault is a thick sequence of older colluvial deposits that consist of gravelly sandy clay. The entire slope is covered by 0.25 to 0.5 m of younger colluvial deposits consisting of sandy silty clay with as much as 15% angular gravel and cobbles 20 cm in maximum dimension. Immediately northeast of the fault, these younger colluvial deposits are underlain by a prominent stony layer that rests upon the bedrock. This stony layer appears to be truncated by the fault zone.

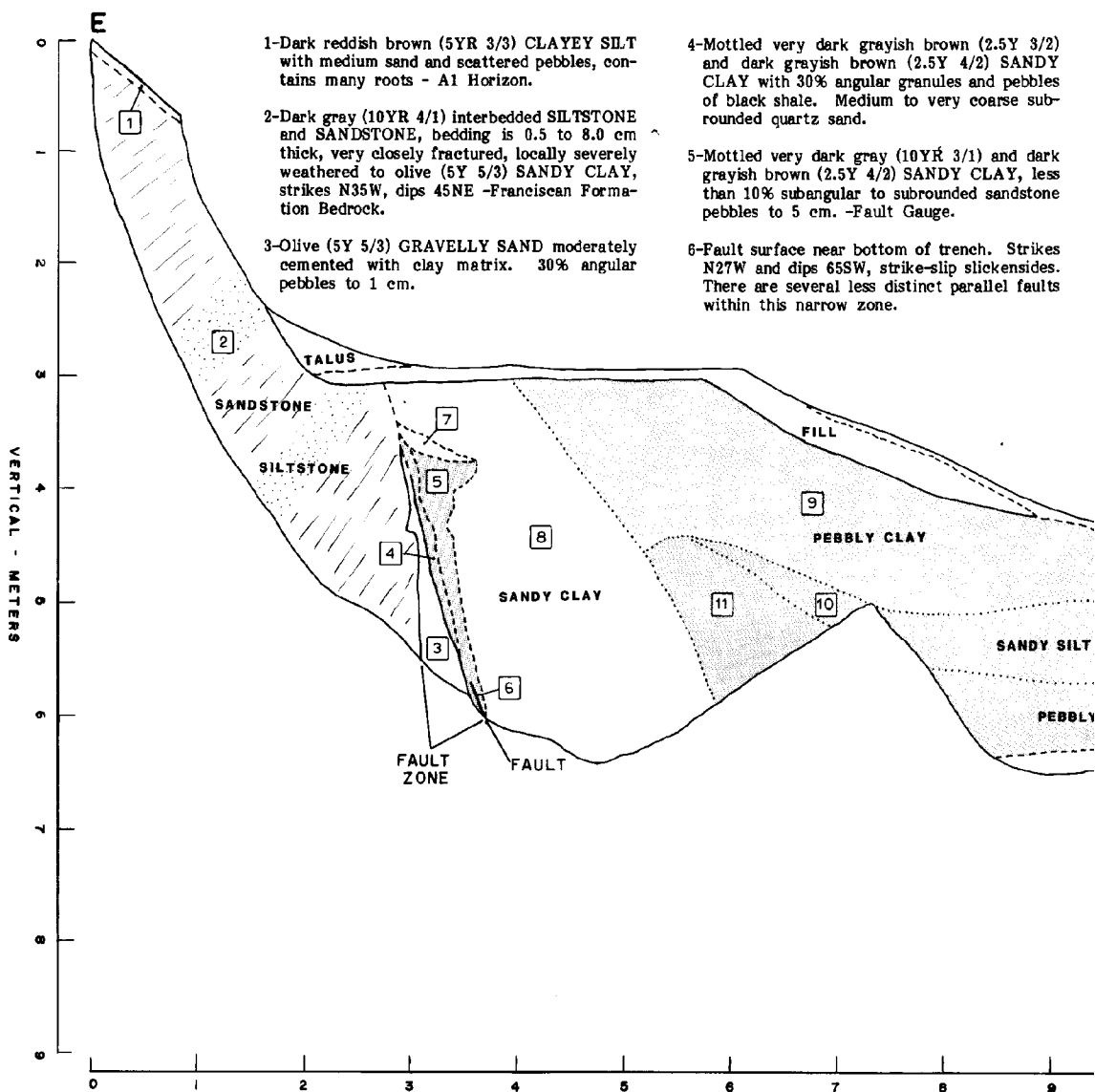


Fig.8. Log of north fault exploration trench (trench 1) at Laughlin Range site. See Fig.7 for explanation.

7-Dark brown (10YR 3/3) SANDY CLAY, color grades more gray towards unit (5). 10% subangular granules to 4 mm.

8-Dark brown (10YR 3/3) SANDY CLAY. 40% angular and subangular sandstone and shale pebbles and cobbles to 15 cm, many fine pores, friable - Colluvium.

9-Very dark gray brown (10YR 3/2) PEBBLY CLAY with sand and silt. Subrounded to subangular pebbles to 4 cm, porous and friable - Colluvium.

10-Very dark gray (10YR 3/1) SANDY SILT, 25% subangular coarse sand, 15% subangular to angular sandstone granules and pebbles to 3 cm, porous and friable - Colluvium.

11-Very dark grayish brown (10YR 3/2) PEBBLY CLAY, weak columnar structure, many thick clay films on ped surfaces and in pores, angular to subangular coarse sand and pebbles to 1 cm.

12-Organic layer - massive roots and plant debris.

13-Black (10YR 2/1) SILTY CLAY, moderate angular blocky structure, 10% subangular pebbles to 3 cm. - Colluvium.

14-Very dark grayish brown (10YR 3/2) CLAYEY SILT, moderate columnar structure, 15% subround to subangular sandstone pebbles to 3 cm.

15-Dark yellowish brown (10YR 4/3) CLAYEY SAND, 40% subangular to subrounded granules to 4 mm, 10% subangular pebbles to 2 cm, 5% voids with thin clay films.

16-Mottled very dark grayish brown (10YR 3/2) and grayish brown (10YR 5/2) SANDY CLAY, 40% angular to subangular pebbles to 3 cm, a few voids between pebbles.

17-Mottled very dark grayish brown (10YR 3/2) and grayish brown (10YR 5/2) SANDY CLAY, 20% subrounded to subangular sandstone and siltstone pebbles to 2 cm, scattered charcoal fragments to 3 mm.

18-Mottled black (10YR 2/1) and dark grayish brown (10YR 4/2) CLAYEY GRAVEL, 50% pebbles to 2 cm, loose, porous - Alluvial Gravel Deposit.

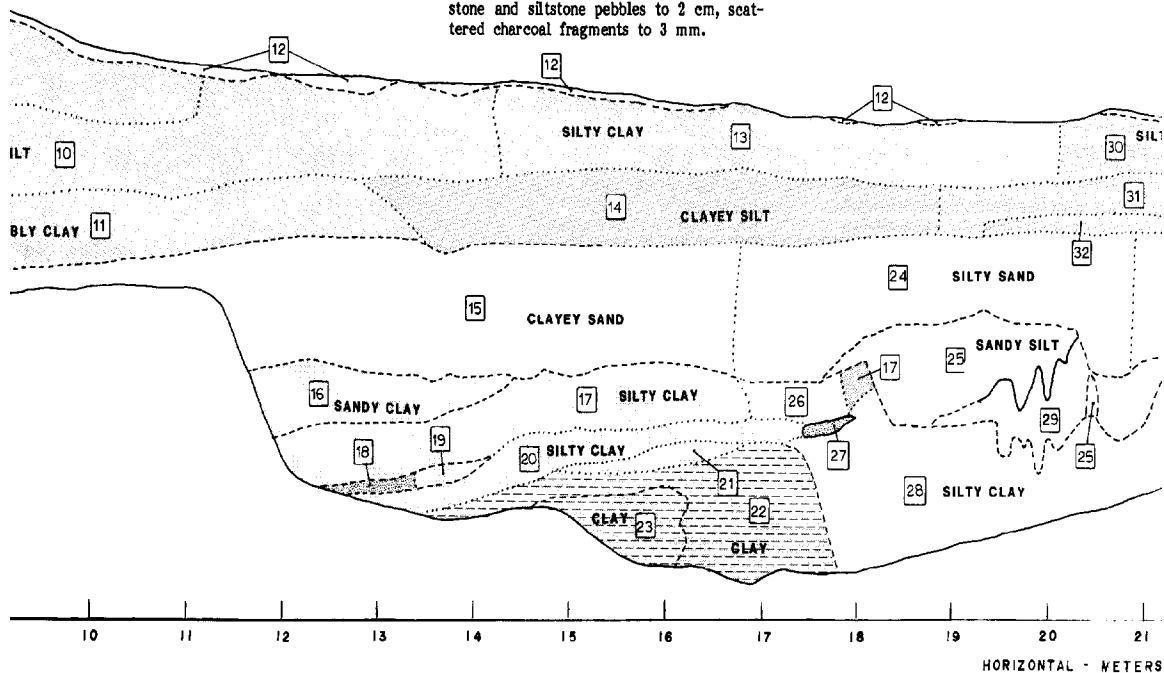
19-Mottled dark grayish brown (10YR 3/2) and reddish yellow (7.5YR 6/8) PEBBLY CLAY, 40% subrounded to subangular pebbles to 2 cm.

20-Mottled very dark gray (10YR 3/1) and dark yellowish brown (10YR 4/6) SILTY CLAY with 20% medium sand.

21-Mottled gray (5Y 5/1) and yellowish brown (10YR 5/8) SILTY CLAY, local pockets of coarse sand.

22-Mottled gray (5Y 5/1) and dark yellowish brown (10YR 4/6) CLAY, scattered angular to subrounded siliceous sandstone and chert pebbles, slightly silty.

23-Gray (5Y 5/1) CLAY.



24-Pale brown (10YR 6/3) SILTY SAND, 20% subrounded to subangular pebbles to 2 cm.

25-Yellowish brown (10YR 5/4) SANDY SILT with vertical streaks of gray (5Y 5/1), scattered subangular to subrounded coarse sand and pebbles to 3 cm, local pockets of 40% coarse sand.

26-Yellowish brown (10YR 5/4) SILTY CLAY with scattered coarse sand and pebbles to 2 cm.

27-Light yellowish brown (10YR 6/4) SAND, medium to coarse grain, no clay - alluvial deposit.

28-Dark yellowish brown (10YR 4/6) SILTY CLAY, scattered angular granules and pebbles of sandstone to 4 cm, local pebble rich pockets.

29-Dark yellowish brown (10YR 4/4) CLAYEY SAND, medium sand, subrounded pebbles of sandstone and quartz to 3 cm.

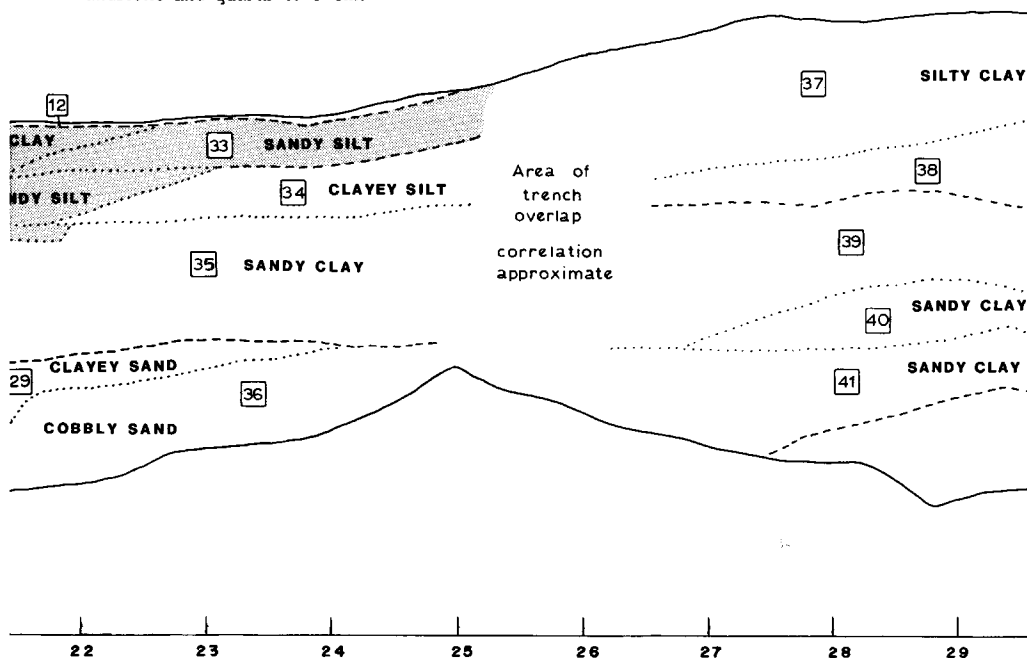
30-Very dark grayish brown (10YR 3/2) SILTY CLAY, moderate columnar structure with cracks deeper than 1 m, 20% subrounded to subangular pebbles to 1 cm.

31-Very dark grayish brown (10YR 3/2) SANDY SILT, moderate columnar structure between 19 and 21 meter stations, 50% subrounded very coarse sand, granules and pebbles to 5 mm.

32-Mottled dark grayish brown (10YR 4/2) and yellowish brown (10YR 5/8) SILTY SAND.

33-Very dark brown (10YR 2/2) SANDY SILT, moderate subangular blocky structure, vertical cracks to 1 m, scattered rounded pebbles to 5 cm - A Horizon.

34-Dark brown (10YR 4/3) CLAYEY SILT, moderate columnar structure, many moderately thick clay films on fissures, scattered subrounded pebbles of chert and feldspar to 3 cm - B Horizon.



35-Dark, yellowish brown (10YR 4/4) SANDY CLAY, weak subangular blocky structure, vertical cracks to over 2 m, occasional thin clay films on voids, 10% rounded to subangular sandstone, chert and quartz pebbles to 2 cm.

36-Strong brown (7.5YR 5/6) COBBLY SAND with clay matrix, angular sandstone cobbles to 10 cm in medium grain sand matrix - severely weathered Sandstone Bedrock.

37-Dark brown (7.5YR 3/4) SILTY CLAY, moderate granular structure, many medium roots, friable, porous - A1 Horizon.

38-Strong brown (7.5YR 4/4) SILTY CLAY, moderate granular structure, scattered subangular sandstone and claystone pebbles and cobbles to 8 cm, cobbles are located near bottom of horizon - A2 Horizon.

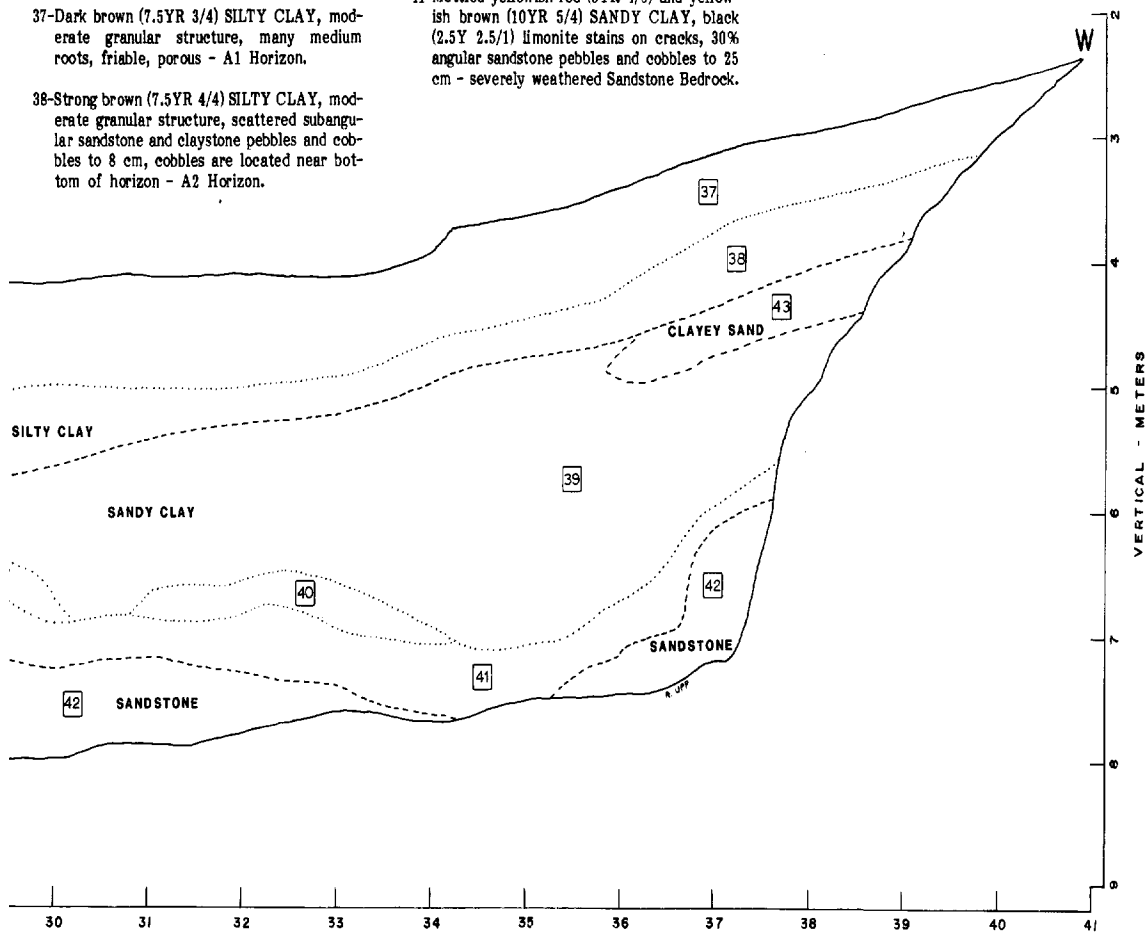
39-Mottled red (2.5YR 4/6) with light yellowish brown (10YR 6/4) SANDY CLAY, moderate columnar structure upper 1 m, massive structure below, 15% subangular sandstone and claystone pebbles and cobbles to 10 cm - Colluvium.

40-Reddish brown (2.5YR 4/4) SANDY CLAY, 40% subangular to subrounded sandstone pebbles and cobbles - Colluvium.

41-Mottled yellowish red (5YR 4/6) and yellowish brown (10YR 5/4) SANDY CLAY, black (2.5Y 2.5/1) limonite stains on cracks, 30% angular sandstone pebbles and cobbles to 25 cm - severely weathered Sandstone Bedrock.

42-Light olive brown (2.5Y 5/6) SANDSTONE, fine sand, very closely fractured, severely weathered - Franciscan Formation Graywacke Sandstone Bedrock.

43-Strong brown (7.5YR 5/8) CLAYEY SAND, massive structure, few thin clay films on voids, porous with 5% voids, scattered subrounded pebbles to 4 cm.



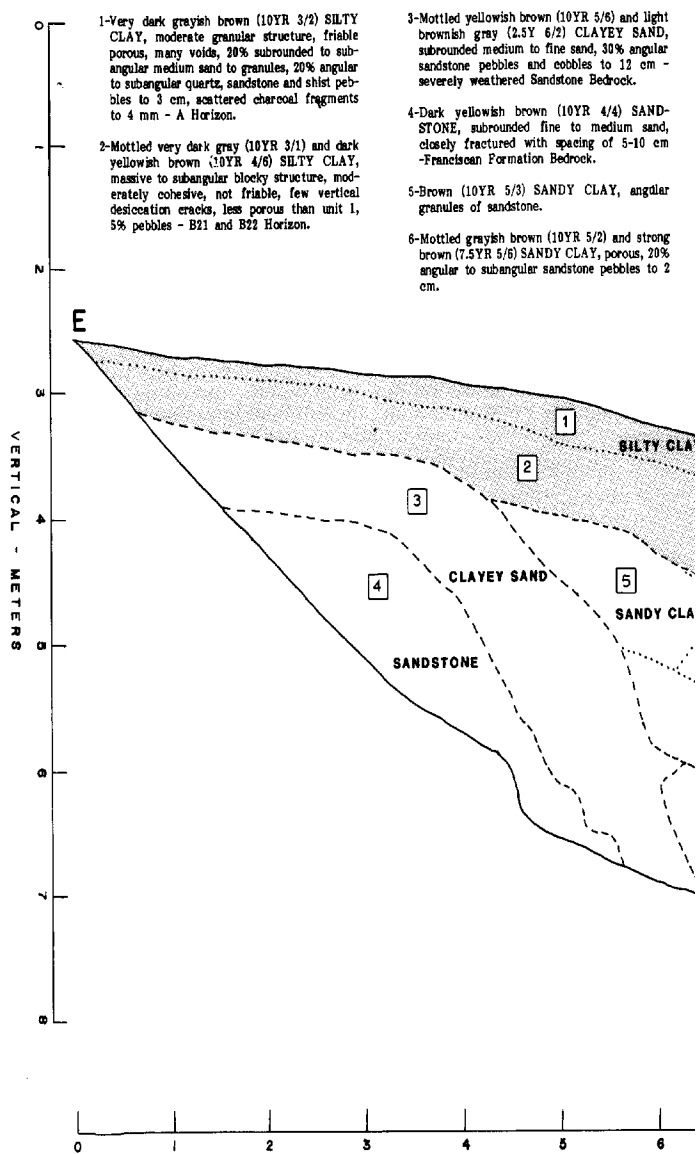


Fig.9. Log of south fault exploration trench (trench 2) at Laughlin Range site. See Fig.

7-Mottled brown (10YR 5/3) and dark yellowish brown (10YR 4/6) SANDY CLAY, less porous than unit 6, 10% angular to subangular sandstone pebbles to 2 cm.

8-Mottled light brownish gray (10YR 6/2) and yellowish brown (10YR 5/8) SILTY CLAY, 20% medium to coarse sand, 20% granules and pebbles to 2 cm, scattered siltstone cobbles to 10 cm.

9-Mottled light yellowish brown (2.5Y 6/4) and yellowish brown (10YR 5/6) SILTY CLAY, 40% coarse sand and granules.

10-Mottled dark yellowish brown (10YR 4/4) and dark brown (7.5YR 4/4) SANDY CLAY, strong columnar structure, scattered subangular quartz and silicified sandstone pebbles - B23 Horizon.

11-Mottled very dark gray (10YR 3/1) and dark yellowish brown (10YR 3/6) SANDY CLAY, moderate coarse subangular blocky structure, 30% subangular sandstone pebbles to 4 cm, rounded chert cobble of 8 cm.

12-Dark grayish brown (10YR 4/2) SANDY CLAY, moderate subangular blocky structure, 25% medium sand to granules, 15% angular to subangular sandstone pebbles.

13-Dark brown (7.5YR 3/4) with streaks of very dark grayish brown (10YR 3/2) SANDY CLAY, massive structure, 15% coarse sand, 15% angular to subangular granules and pebbles to 2 cm.

14-Mottled very dark gray (10YR 3/1) with reddish yellow (7.5YR 6/6) SANDY CLAY, 25% angular to subrounded pebbles.

15-Mottled yellowish brown (10YR 5/6) with brown (7.5YR 5/2) CLAY, 10% subangular sandstone pebbles from 0.5 cm to 2.0 cm, no sand and little silt.

16-Mottled very dark grayish brown (10YR 3/2) with dark brown (7.5YR 3/4) SANDY CLAY, 25% coarse sand and granules, 15% subangular sandstone pebbles to 2 cm.

17-Mottled black (10YR 2/1) and dark yellowish brown (10YR 3/6) SANDY CLAY, 10% angular sandstone pebbles.

18-Very dark gray (10YR 3/1) SANDY CLAY, 25% angular to subangular sandstone granules and pebbles to 3 cm, amount of medium to coarse sand varies and is 40% in some pockets.

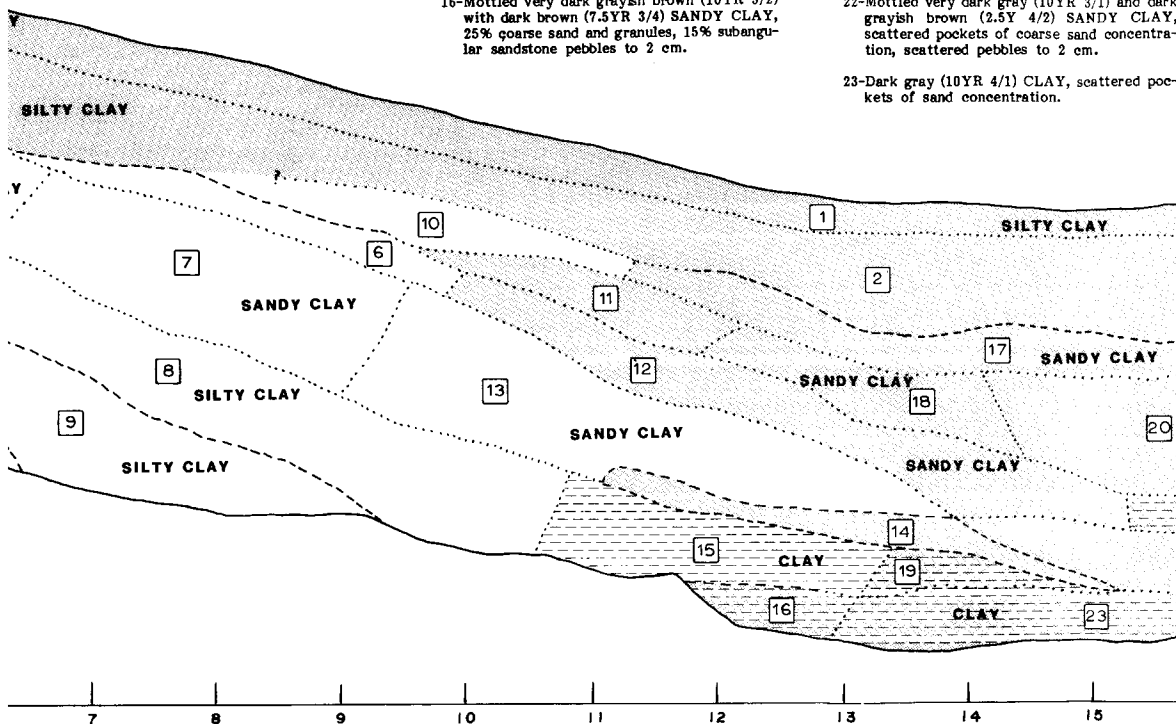
19-Mottled gray (10YR 5/1) and strong brown (7.5YR 5/6) CLAY, scattered pockets of coarse sand concentration.

20-Dark gray (10YR 4/1) SANDY CLAY, massive structure, amount of sand and granules varies from 50% in local pockets to none elsewhere, scattered subangular to subrounded chert and sandstone pebbles to 2 cm, a few sandstone cobbles to 8 cm.

21-Mottled dark grayish brown (10YR 4/2), dark reddish brown (5YR 3/3), and black (N 2/0) CLAY, weak, very fine subangular blocky structure, scattered pebbles to 2 cm.

22-Mottled very dark gray (10YR 3/1) and dark grayish brown (2.5Y 4/2) SANDY CLAY, scattered pockets of coarse sand concentration, scattered pebbles to 2 cm.

23-Dark gray (10YR 4/1) CLAY, scattered pockets of sand concentration.



7 for explanation.

24-Very dark gray (10YR 3/1) SANDY CLAY, 20% sandstone pebbles to 2 cm.

25-Mottled very dark gray (10YR 3/1), grayish brown (2.5Y 5/2), and strong brown (7.5YR 4/6) SANDY CLAY, 20% sandstone pebbles to 2 cm.

26-Mottled grayish brown (2.5Y 5/2) and dark yellowish brown (10YR 4/8) SANDY CLAY, moderate coarse subangular blocky structure with slickensides on ped surfaces, scattered sandstone pebbles to 3 cm.

27-Dark brown (7.5YR 3/2) SANDY CLAY, moderate granular structure, porous, very friable, 20% subrounded pebbles - A1 Horizon.

28-Dark brown (10YR 3/3) SANDY CLAY, massive structure, friable, 30% angular and subangular sandstone and schist pebbles and cobbles, flat shist fragments are parallel to slope - A2 Horizon.

29-Dark yellowish brown (10YR 4/4) SANDY CLAY, massive structure, 20% granules and cobbles.

30-Yellowish brown (10YR 5/6) SANDY CLAY, 50% angular sandstone pebbles and cobbles.

31-Mottled yellowish brown (10YR 5/8) and strong brown (7.5YR 5/8) SANDY CLAY, 10% angular sandstone pebbles to 1 cm.

32-Dark yellowish brown (10YR 4/4) SILTY CLAY, 40% subangular graywacke sandstone pebbles to 2 cm and subrounded pebbles to 0.5 cm, common moderately thick clay films on pebbles.

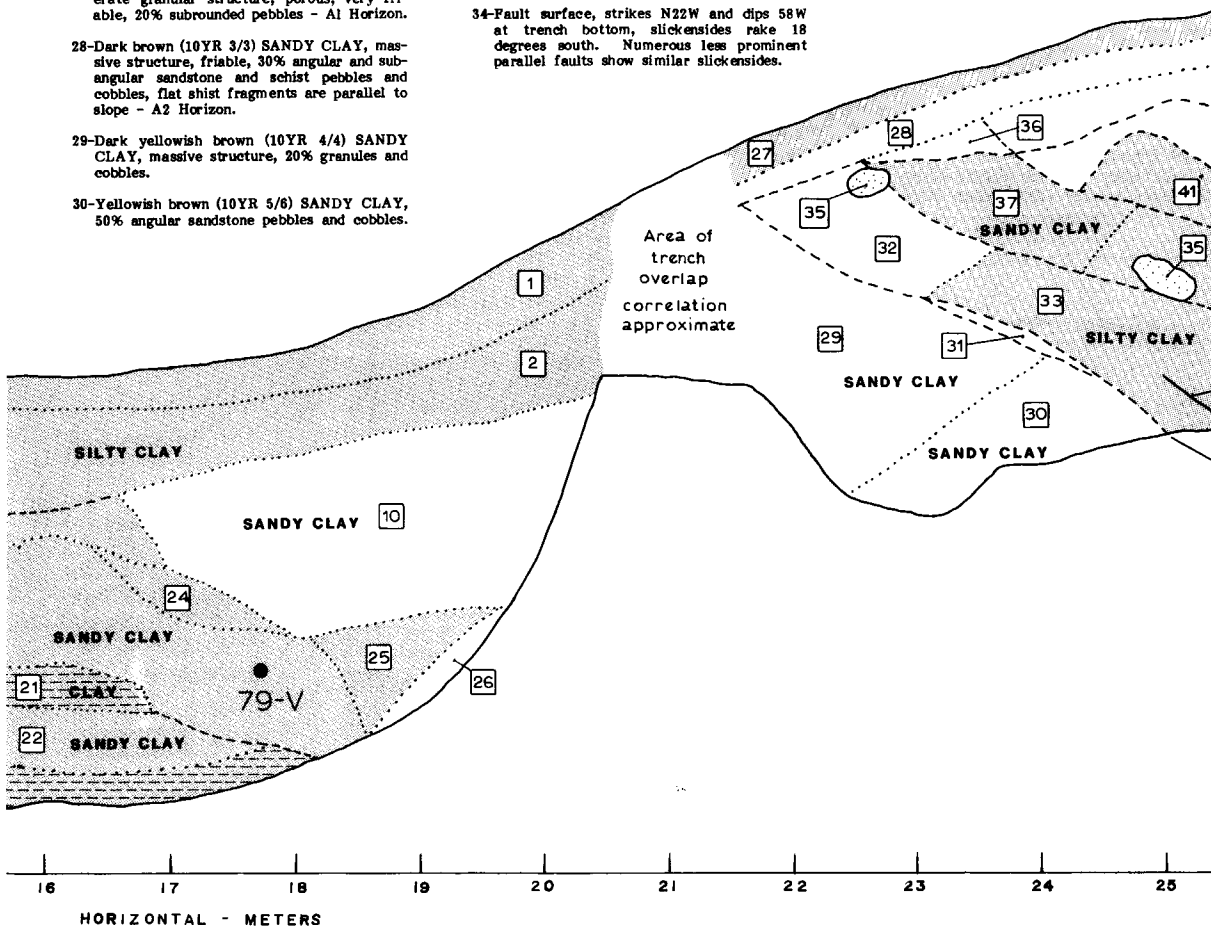
33-Dark gray (5Y 4/1) SILTY CLAY, 30% rounded to subrounded pebbles and cobbles, scattered cobbles to 20 cm, fault near base of exposed wall, fabric parallel to fault - Fault Zone.

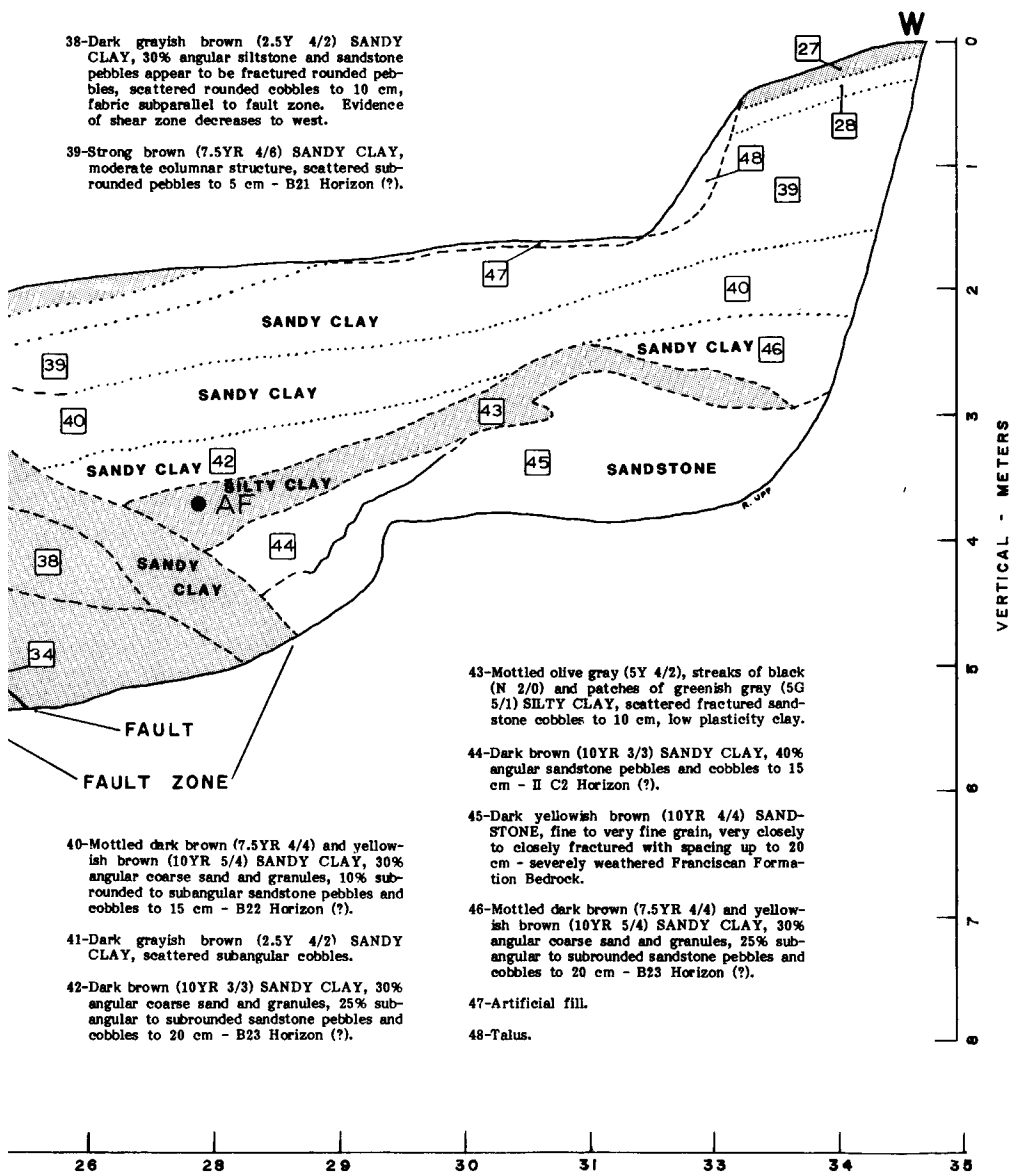
34-Fault surface, strikes N22W and dips 58W at trench bottom, slickensides rake 18 degrees south. Numerous less prominent parallel faults show similar slickensides.

35-Rounded sandstone boulders.

36-Dark yellowish brown (10YR 4/4) SANDY CLAY, moderate columnar structure, firm, plastic clay, 10% angular sandstone and schist pebbles - B Horizon.

37-Dark olive gray (5Y 3/2) SANDY CLAY, moderate columnar structure, very firm, scattered subangular cobbles.





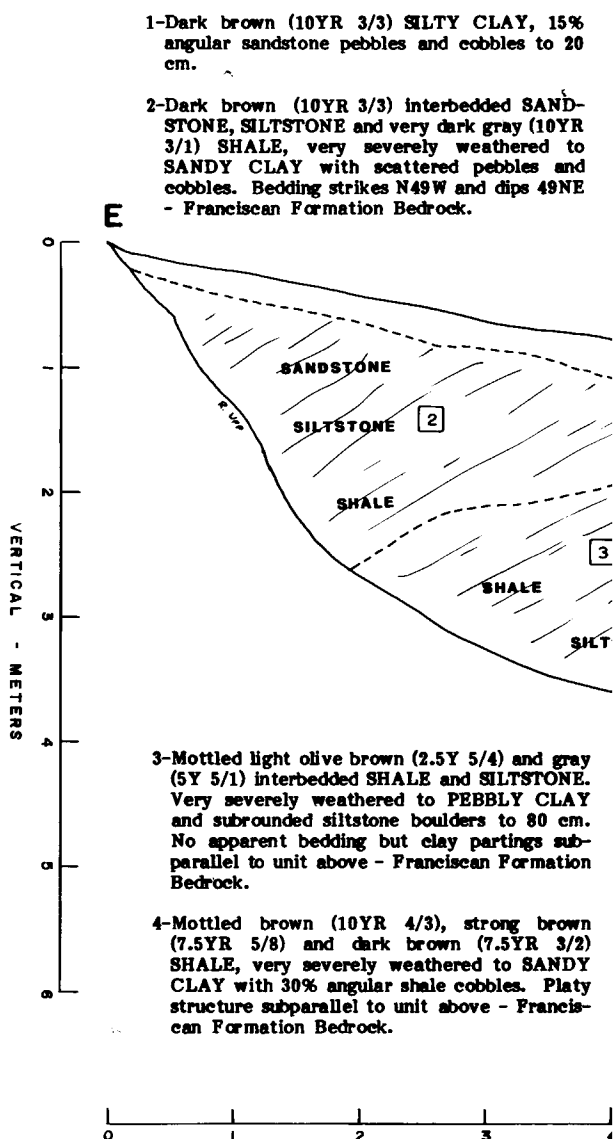
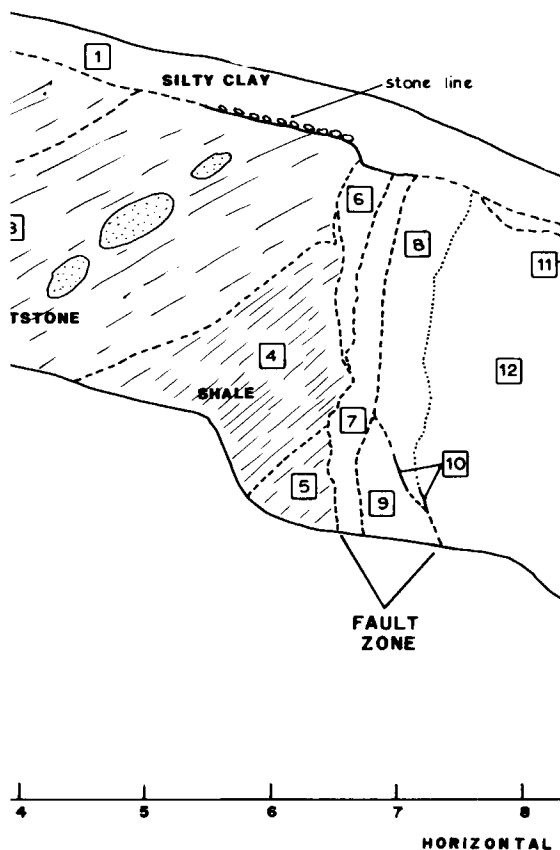


Fig.12. Log of northern fault exploration trench (trench 3B)

5-Mottled dark grayish brown (2.5YR 4/2) and dark yellowish brown (10YR 5/8) SANDSTONE, very severely weathered to SANDY CLAY with 40% angular sandstone pebbles - Franciscan Formation Bedrock.

6-Mottled dark brown (10YR 4/3), strong brown (7.5YR 5/8) and dark brown (7.5YR 3/1) SANDY CLAY, 30% angular granules and pebbles - Fractured Bedrock in Fault Zone.

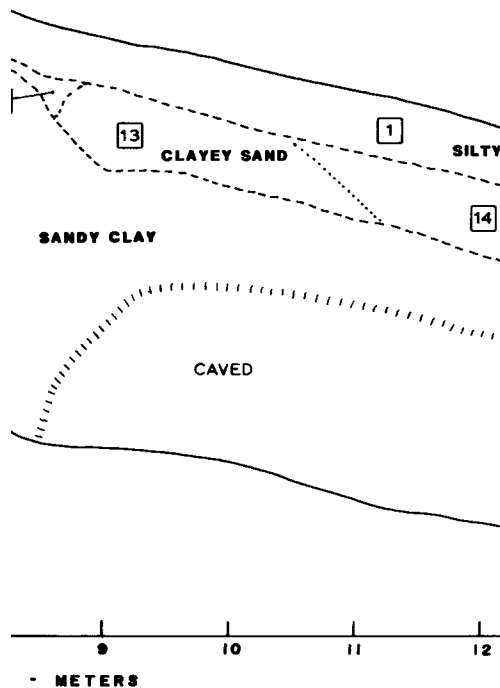


at Upp Creek site. See Fig.7 for explanation.

7-Mottled dark yellowish brown (10YR 4/4), yellowish red (5YR 6/8), grayish brown (5YR 5/8), and very dark grayish brown (10YR 3/2) SANDY CLAY, 40% angular to subangular coarse sand and pebbles to 1 cm - Crushed Bedrock in Sheared Zone.

8-Mottled dark yellowish brown (10YR 4/4) with specks of reddish yellow (7.5YR 6/8) and dark brown (7.5YR 3/2) SANDY CLAY, moderate columnar structure to about 2 meter depth, hard consistency, 30% angular coarse sand and pebbles - Weathered Zone adjacent to Sheared Zone.

9-Mottled dark yellowish brown (10YR 4/6) and brown (10YR 5/3) SANDY CLAY, vertical platy partings, 30% fine to medium sand, no pebbles.



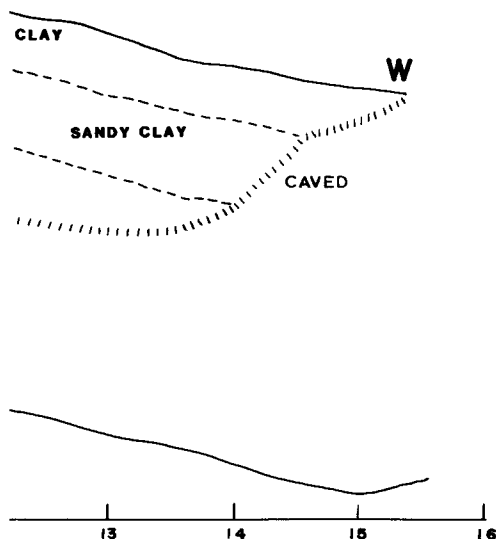
10-Cracks open 1 to 2 mm, no slickensides.

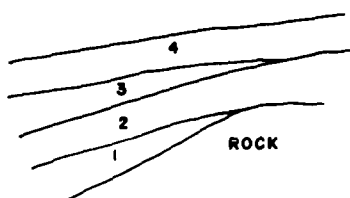
11-Mottled dark yellowish brown (10YR 4/4) with specks of very dark brown (10YR 2/2) SANDY CLAY, 20% subrounded to subangular pebbles to 0.5 cm -Alluvial Deposit.

12-Mottled dark yellowish brown (10YR 4/4) with specks of yellowish red (5YR 5/8) and dark reddish brown (5YR 2.5/2) SANDY CLAY, hard consistency, 30% coarse sand and granules, many vertical fissures both parallel and perpendicular to trench walls, slabs tend to collapse along fissures - Colluvium.

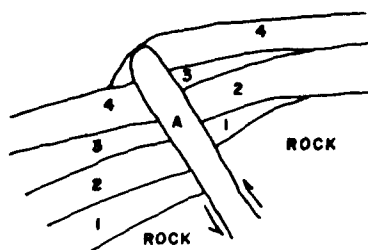
13-Mottled dark yellowish brown (10YR 4/6), yellowish red (5YR 5/6) and black (5YR 2.5/1) CLAYEY SAND, medium sand, scattered subangular pebbles to 5 cm - Colluvium.

14-Mottled yellowish brown (10YR 5/8) with specks of very dark brown (10YR 3/2) SANDY CLAY, medium sand, 20% granules - Colluvium.

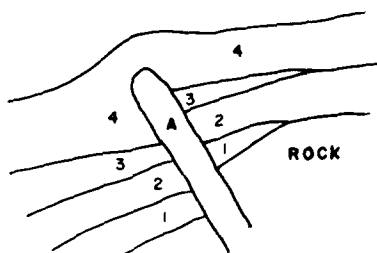




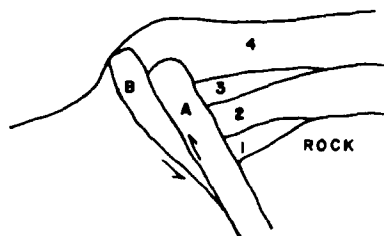
STAGE 1: Colluvial Units 1 through 4 deposited on Franciscan sandstone bedrock during a period of fault inactivity.



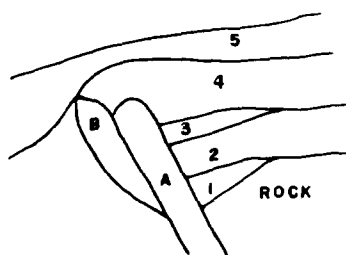
STAGE 2: Period of fault movement, west-side-up. Movement created Fault Zone A which cut and offset colluvial Units 1 through 4.



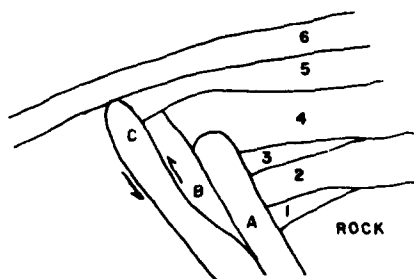
STAGE 3: Continued deposition of colluvial Unit 4 covered top of Fault Zone A.



STAGE 4: Fault movement created Fault Zone B and offset all of Unit 4. Units east of fault became indistinguishable because of increased accumulation of debris and horizontal fault displacement.



STAGE 5: Period of deposition of colluvial Unit 5 which covered Unit 4 and top of Fault Zone B.



STAGE 6: Fault movement created Fault Zone C which cut Unit 5, followed by deposition of colluvial Unit 6 which covered Unit 5 and Fault Zone C.

Fig.10. Sequence of fault movements as inferred from relationships exposed in the south trench at the Laughlin Range site.

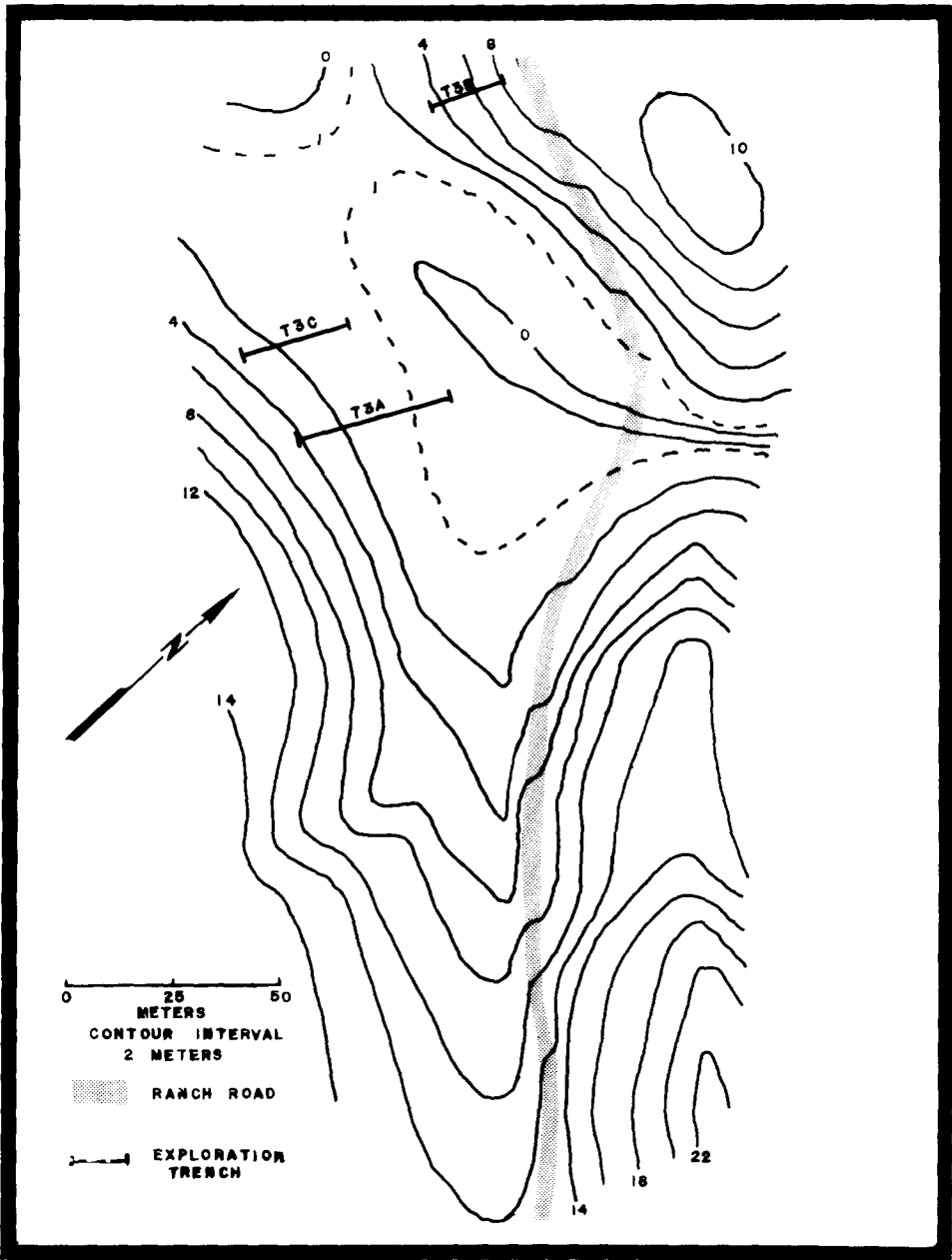


Fig.11. Locations of exploratory trenches at Upp Creek site.

A distinct step of about 30 cm in the contact between the younger colluvial deposits and the underlying units, which appears on the southwest side of the fault zone, may represent fault offset. A reasonable explanation of this step is that eastside-up faulting occurred prior to deposition of the younger collu-

vium. Supporting this interpretation is an outcrop of sandstone that lies about 2 m south of the trench and in line with the step. This outcrop is probably an exposed part of the eastside-up-faulted block that has not yet been covered with colluvium. Another, but less likely explanation is that the fault movement occurred after deposition of the younger colluvium and that subsequent weathering has obscured all near-surface evidence of faulting, except the resistant sandstone outcrop.

No organic materials suitable for age-dating were found in the trenches at Upp Creek, hence it was impossible to obtain radiocarbon dates that might indicate the age of faulting. Radiocarbon-dating of a bulk sample of the undisturbed soil overlying the fault gave a mean residence time of 2000 ± 60 years before present, which suggests that there has been no fault movement in at least that time period.

PARSONS CREEK THRUST FAULT

A prominent thrust fault is exposed on the south bank of Parsons Creek near the Hopland Field Station of University of California (Fig.19). The eroded creek bank at this locality is about 4 m high and exposes beds of moderately cemented clay, sand, and fine gravel of older alluvial deposits, overlain by poorly consolidated coarse sand, gravel, and small boulders of younger terrace deposits (Fig.13). The older alluvium has a northward apparent dip of about 10 degrees; the terrace deposits are essentially horizontal. A soil profile about 0.5 m deep has been developed on the terrace surface.

The fault strikes N88W and dips 35 degrees to the north. The north side has moved up, relative to the south, indicating a component of reverse or thrust movement with an apparent vertical separation of about 2 m. Both the older and younger deposits are offset, but the soil horizon has not been disturbed by faulting.

A charcoal fragment was obtained from the older alluvial deposits about 2 m north of the fault. This charcoal has a radiocarbon age of $16,500 \pm 160$ years before present. Since deposition of the charcoal, the following events have occurred.

- (1) Deposition of the older alluvial deposits that overlie the charcoal fragment, about 16,500 years ago.
- (2) Northward tilting of older alluvium, possibly in conjunction with movement on the nearby Hopland segment of the Maacama fault zone.
- (3) Erosion of the older alluvium and deposition of younger terrace deposits.
- (4) Northside-up thrust faulting, probably sympathetic with strike slip on the Maacama fault zone. The number of faulting events cannot be estimated from the evidence on hand.
- (5) Erosion of the upper terrace surface to near its present elevation.
- (6) Downcutting of the creek channel and development of a soil profile on the terrace surface.

The age of the charcoal sample indicates that fault movements have occurred during the past 16,500 years. Deposition and tilting of the older

alluvium and deposition of the terrace deposits occurred between 16,500 years ago and the time of the first thrust fault movement. The number of post-charcoal pre-faulting geologic events suggests that the faulting was significantly younger than the charcoal sample. It could well have occurred within the past 10,000 years.

EVIDENCE THAT MAACAMA FAULT ZONE IS RIGHT-LATERAL

The fault-produced topographic features along the Maacama fault zone, as observed on aerial photographs, from the air and on the ground, are interpreted to be results of strike-slip displacements.

The fault surfaces exposed in the two exploratory trenches at Laughlin Range (Fig.6) are marked by predominantly horizontal slickenlines, indicating a major strike-slip component of most recent displacement. The 18-degree rake of slickenlines exposed in Trench 2 at Laughlin Range, however, indicates a significant vertical component of movement at that location, with the westside up relative to the east.

Evidence for sense of displacement, however, is unclear. Some features, such as streams and ridges, are apparently offset in a right-lateral sense, but other offsets can be attributed to non-tectonic causes such as landsliding and normal stream meanderings. In addition, nearly one fifth of apparent stream offsets along active fault segments would represent left-lateral displacement if they were indeed expressions of faulting.

Evidence of creep along the fault zone includes right-laterally offset curbs, sidewalks, and other reference features, as well as distinctive left-stepping en-echelon pavement cracks that clearly are results of right-lateral movement (Upp, 1982).

Studies of microseismic activity on the Maacama fault zone (Dames and Moore, 1977; Cockerham and Herd, 1982) have shown that small-scale rupture has been recurring at depth and the first-motion, P-wave direction for two seismic events (Dames and Moore, 1977) has suggested right-lateral strike-slip.

COMPARISON OF FAULT TRACES IN MAACAMA FAULT ZONE WITH FAULT TRACES IN EXPERIMENTAL MODELS

The Maacama fault zone can be compared with wrench faults, which are high-angle strike-slip faults of great linear extent. Model studies (Wilcox et al., 1973; Freund, 1974) and field investigations (Tchalenko and Ambraseys, 1970) have shown that, in the initial phase of development, simple wrench faults produce a complex of structures.

For small displacements in experiments, synthetic, or Riedel (R), shears develop as small en-echelon strike-slip faults inclined at a low angle of about $\phi/2$ to the wrench zone and with the same sense of movement (Fig.14). Here, ϕ is the angle of internal friction, which generally is approximated as 30° (Freund, 1974).

Antithetic, or conjugate Riedel (R'), shears develop nearly perpendicular to the wrench zone, at an angle of about $90^\circ - \phi/2$, and with the opposite sense of

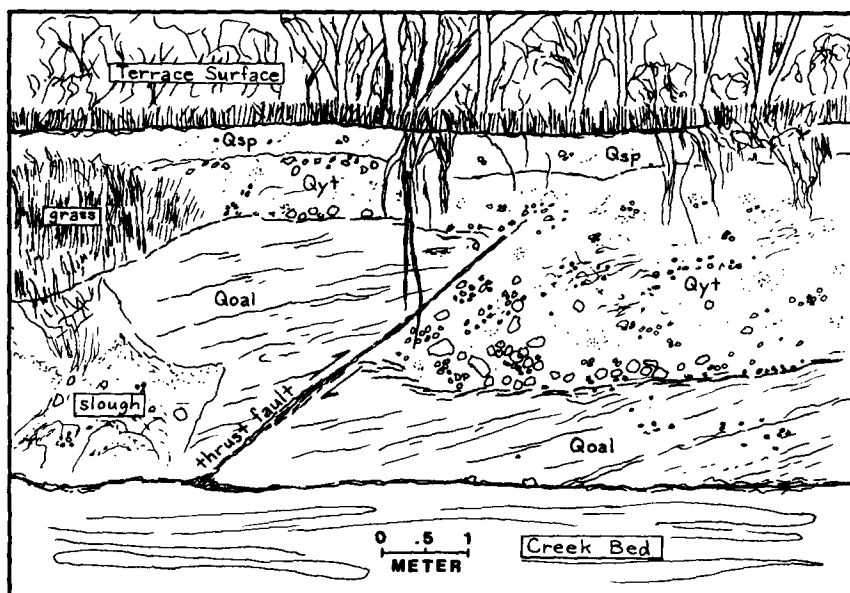


Fig.13. Parsons Creek thrust fault: *Qal*=older alluvial deposits of moderately cemented clay, sand, and fine gravel; *Qyt*=younger terrace deposits of uncemented coarse sand, gravel, and small boulders; *Qsp*=soil profile.

movement. En-echelon folds also develop at about 45° to the wrench zone, but in an orientation opposite to that of the synthetic shears. Local tension fractures or normal faults, oriented perpendicular to the direction of maximum extension, develop at about 45° to the direction of shear movement.

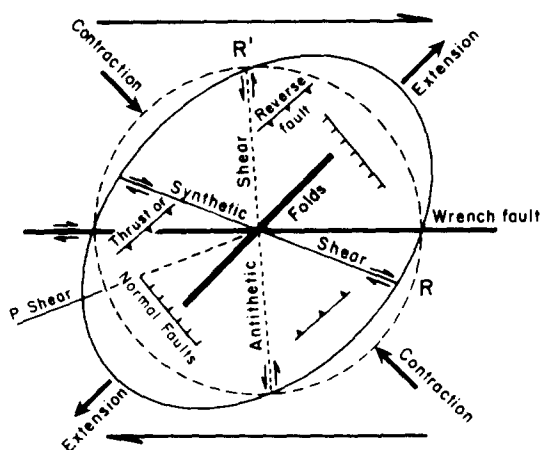


Fig.14. Simple shear strain ellipse. Geometric relations of structural features to right-slip wrench fault combined schematically with strain ellipse and principal strain directions (Keller et al., 1982).

As deformation increases in experiments, displacement along synthetic shears increases and along antithetic shears decreases. The synthetic shears tend to bend, but the average orientation remains nearly constant. Larger displacements occur along parts of the fault which bend opposite to the sense of shear, whereas smaller displacements occur on parts that bend toward the shear (Freund, 1974).

For large deformations that tend toward direct shear conditions, new shear planes (P-shear) are formed in a direction approximately opposite to the synthetic shears (Tchalenko and Ambraseys, 1970). The orientations of P-shears are about 10° to 15° from the shear direction of the wrench zone (Aydin and Page, 1984).

As deformation proceeds, displacement along the wrench zone increases and the zone of en-echelon shears narrows. Eventually all slip occurs along a few closely spaced faults or along one throughgoing wrench fault (the D-fault of Skempton, 1966) parallel with the direction of applied shear, thus marking the last stage in the early phase of wrench zone deformation (Wilcox et al., 1973).

Field mapping has shown that the Maacama fault zone in Mendocino County is expressed as one throughgoing wrench fault, or in detail as a few closely spaced strike-slip faults (Fig.19). The trends of most individual active segments diverge by only a few degrees from the trend of the main fault zone (Fig.4). This fault geometry suggests that, if the observations of experimental models are relevant, deformation along the Maacama fault zone has progressed beyond the early stage of wrench fault development and that further deformation cannot be explained by a simple model.

The crustal blocks opposed across a wrench fault ordinarily do not move parallel to the fault, but instead tend to converge or diverge as wrenching proceeds. Convergent wrenching tends to enhance compressive features such as pressure ridges, en-echelon anticlines, subsidiary reverse faults, and low-angle thrusts (Sylvester and Smith, 1976; Aydin and Page, 1984).

Crowell (1974) and Dibblee (1977) show that such structural features typically are in the vicinity of bent or braided parts of wrench faults, where the slip of two blocks is both lateral and convergent (Fig.15, A-C).

The thrust fault exposed on the bank of Parsons Creek near Hopland may be an excellent example of a wrench fault compressive structure. The thrust is about 600 m northwest of a 30-degree westerly bend in the trend of the main Hopland fault segment (Fig.16). Such a bend would produce compression on each side of a northwest-trending right-lateral wrench fault zone (Fig.15A). The thrust fault trends at an angle of about 40 degrees to the main fault (Segall and Pollard, 1980; Fig.14).

Divergent wrenching also forms extension structures, such as normal faults or pull-apart basins (Fig.15, D-F). A northerly bend in a northwest trending right-lateral wrench fault zone (Fig.15D) therefore should cause extension.

The northern end of the Calpella fault segment north of Ukiah bends about 10° toward the north, as shown schematically in Fig.17, and a prominent normal fault (the Mill Creek normal fault) is exposed in the 12 m high western bank of Mill Creek about 1 km northwest of the bend (Fig.19). Ukiah Beds or

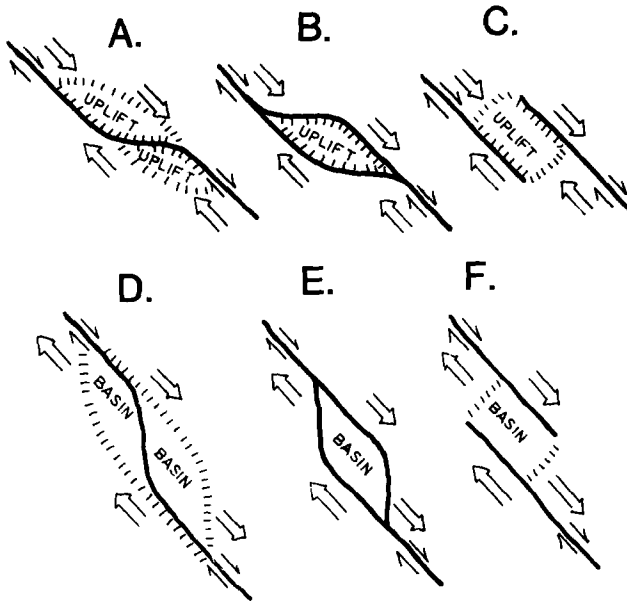


Fig.15. Areas of compressive and tensile stress in right-lateral wrench fault zone. Compression and uplift develop on both sides of curving fault (A), braided fault (B), or left-stepping fault (C); tension and basins develop on both sides of curving fault (D), braided fault (E), or right-stepping fault (F). Modified from Dibblee, 1977.

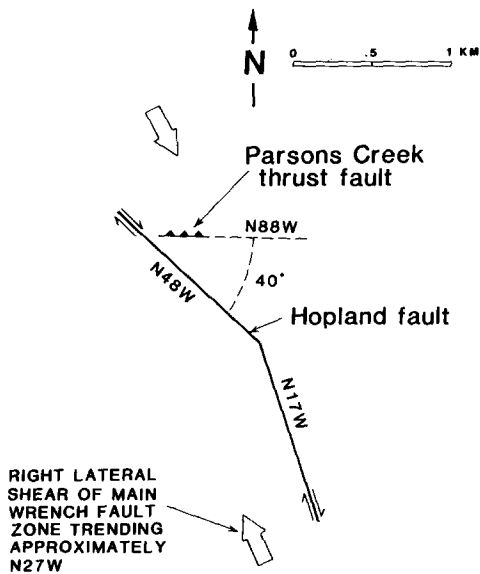


Fig.16. Relation of Parsons Creek thrust fault to the Hopland segment of the Maacama fault zone. Westerly bend in the Hopland fault segment develops compressive stress in right-lateral wrench fault zone. Angle between thrust fault and wrench fault is as predicted from theoretical strain ellipse (see Fig.14).

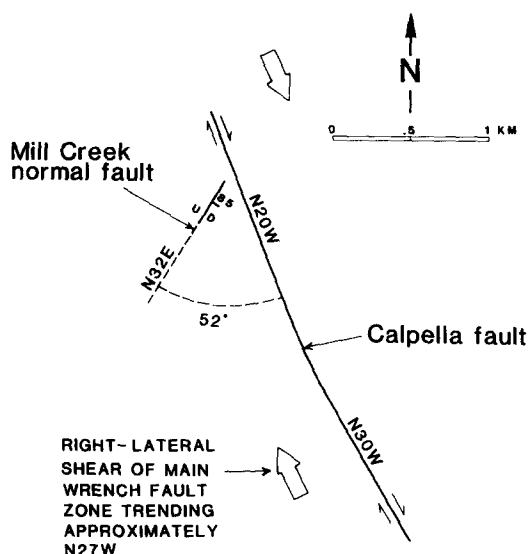


Fig.17. Relation of Mill Creek normal fault to the Calpella segment of the Maacama fault zone. Northerly bend in Calpella fault segment develops tensile stress in right-lateral wrench fault zone. Angle between normal fault and wrench fault is as predicted from theoretical strain ellipse (see Fig.14).

older terrace deposits have been offset along this fault with about 2 m of vertical separation, northwestside-up. Evidence of Holocene displacement is lacking, however. The normal fault trends at an angle of about 50° to the main fault segment, as observed in experimental models (Fig.14).

Divergent extension between en-echelon and branching segments of major wrench-fault zones also can develop pull-apart depressions (for example, Quennell, 1958; Mann et al., 1983; Aydin and Page, 1984). Major pre-Holocene displacements along the Maacama fault zone evidently have created the large pull-apart depressions of Ukiah Valley and Little Lake Valley (McLaughlin and Nilsen, 1982), as well as a smaller depression between the Maacama fault zone and the Rodgers Creek fault zone at Santa Rosa (D.G. Herd, pers. commun., 1982). These basins are now filled with non-marine deposits of Pliocene and Pleistocene age.

Many of the closed depressions and sag ponds along the Maacama fault zone may be smaller-scale examples of pull-apart basins. Exploratory trenches were excavated across two northwesterly aligned topographic sags in the Laughlin Range. The trenches revealed that active fault segments extend along the east side of the northernmost topographic sag and along the west side of the southernmost (Fig.18). This geometry could reflect a right-step in the fault trace (Fig.18, solid line, and Fig.15F), or a bend in the trace (Fig.18, dashed line, and Fig.15D). Either relationship would produce extension and possibly pull-aparts under right-lateral wrench-faulting.

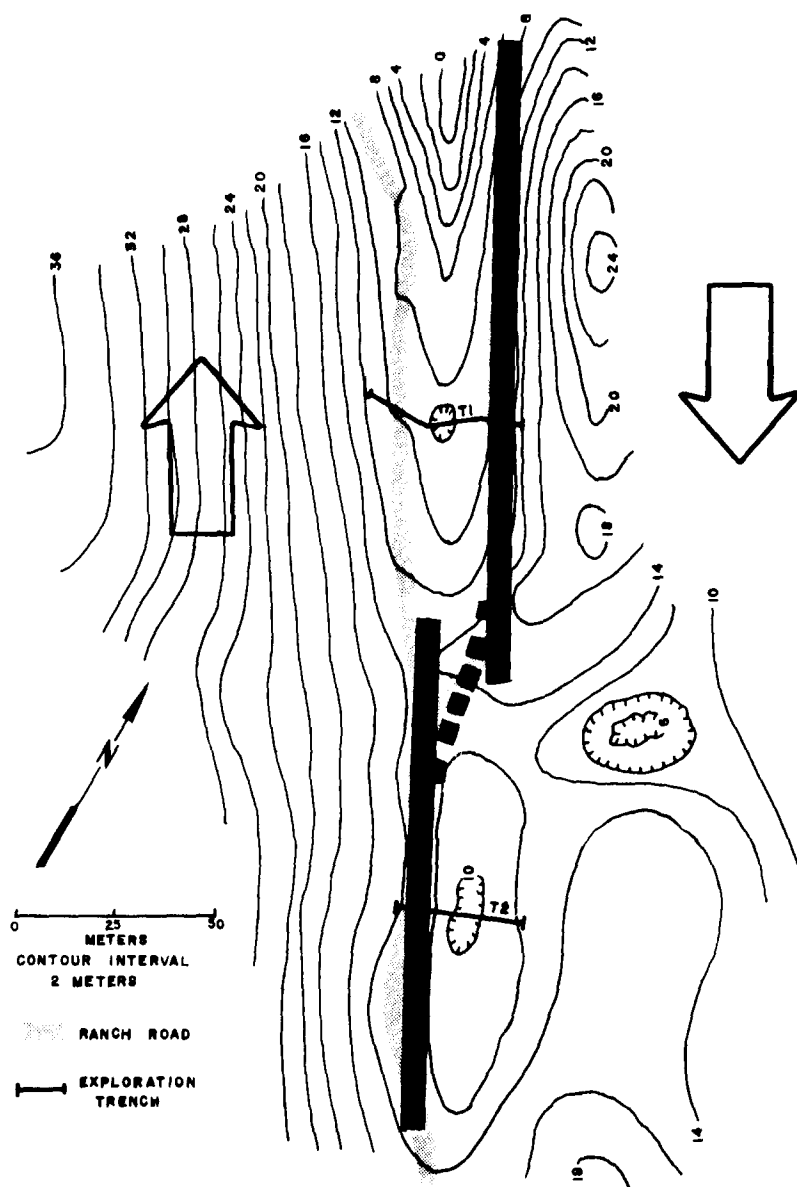


Fig.18. Possible pull-apart sags at Laughlin Range trench sites (schematic diagram). The fault lies on the east side of northern sag and the west side of southern sag. Faults may have bend or right-step relationship. Either case could produce tension and pull-apart under right lateral shearing.

DISCUSSION

Tectonic role of the Maacama fault zone

Two north-northwest trending zones of right-lateral faulting diverge as major branches from the easterly side of the San Andreas fault zone north of

Hollister (Fig.1). The more westerly of these two branches, which has been mapped in detail from Hollister to points as far north as Laytonville, includes the Paicines, southern Calaveras, Hayward, Rodgers Creek, and Maacama fault zones (Herd and Helley, 1977). The more easterly branch includes the Calaveras, Concord, Green Valley, and Bartlett Springs fault zones (Herd, 1978; McLaughlin and Nilsen, 1982). Northward from about 40° latitude, evidence for only one major northwest trending fault zone has been detected. This zone, the Lake Mountain fault, may be a left-stepping continuation of the Calaveras–Bartlett Springs branch or a right-stepping continuation of the Hayward–Maacama branch (D.G. Herd, pers. commun., 1982).

Microseismicity in coastal northern California between the latitudes of San Francisco and Eureka was continuously monitored by the U.S. Geological Survey during 1980 and 1981 (Cockerham and Herd, 1982). The recordings showed that epicenters in general were randomly distributed in the region north of latitude 40. To the south between latitudes 40 and 38, however, the seismicity was concentrated in two northwest-trending zones coinciding respectively with the Rodgers Creek–Maacama fault zone on the west, and the Green Valley–Bartlett Springs fault zone on the east. The San Andreas fault in the same latitude range was essentially aseismic during the period of observation. The regional seismicity thus suggests that two lines of wrench-faulting east of the San Andreas fault are currently active at depth. It has also been suggested that these two lines of faults, along with the apparently aseismic Lake Mountain fault zone, may mark the eastern boundaries of slivers of a separate tectonic plate, the Humboldt Plate (Fig.1) (D.G. Herd, pers. commun., 1978).

The time of inception of the Hayward–Maacama fault zone and the Calaveras–Bartlett Springs fault zone have not been determined. The step between major en-echelon segments of these two zones, however, suggests that there has been insufficient displacement to integrate the individual segments into a single throughgoing surface break.

The development of a main throughgoing fault by the integration of shorter en-echelon segments marks the end of the early phase of wrench-zone deformation (Wilcox et al., 1973). It is speculated, therefore, that these two zones are in the early phase of development.

In addition, surface expressions of these fault zones appear to be geomorphically younger than most of the surrounding Coast Ranges landscape, as they cross and indent rather than control the topography.

The Maacama fault zone thus appears to be a major segment in a series of relatively young faults that could develop at some future time into a dominant, throughgoing wrench fault that would replace the San Andreas fault as the western boundary of the North American tectonic plate.

Magnitude of fault offset

This investigation revealed no topographic or stratigraphic evidence from which the amount of Holocene displacement along the Maacama fault zone could be determined. In more arid parts of California, topographic features

offset by faulting have persisted for thousands of years, some of them providing a clear history of fault movements (for example, Sieh, 1977). But in northwestern California, with its much greater rainfall and higher rates of erosion, similar topographic features rarely are preserved for comparable periods of time. Although topographic expressions of the Maacama fault zone were carefully examined as part of this investigation, none was found to clearly have been accentuated or offset by Holocene faulting.

In general, the distribution of bedrock units has not proved to be useful for estimating the amount of offset on the Maacama fault. Much of the fault extends through ground in which lithologically contrasting parts of the Franciscan Assemblage are structurally juxtaposed in complex ways. Moreover, rock types are similar on both sides of the fault throughout most of its extent (Bailey et al., 1964). The Franciscan Assemblage thus serves poorly as a means for estimating fault offset in the study area. In Sonoma County to the south, however, the Maacama fault zone apparently has offset a belt of Sonoma volcanics right-laterally by approximately 20 km (McLaughlin, 1981).

Where displaced reference features are exposed in exploratory trenches, they generally provide evidence of faulting events, as well as a basis for estimating fault separation but rarely for fault slip. Thus, trenches across the San Andreas fault in southern California have revealed progressively displaced sequences of stratified stream and bog deposits, so that offsetting events could be inferred and their numbers estimated. The directions and amounts of net slip for these events could not be determined, however (K.E. Sieh, pers. commun., 1978). The trenches excavated as part of the present investigation (Figs. 8, 9, and 12) exposed essentially unstratified colluvium with no offset reference features that could be used for estimating the amount of horizontal or vertical fault movement.

Rate of fault movement

Average long-term slip rate on the San Andreas fault south of Hollister is about 37 mm/yr. as determined by right-lateral offset of a 3000-year-old stream channel in the Carrizo Plain (Hall and Sieh, 1977). Along the San Francisco peninsula, however, only 20 mm/yr. of long-term slip have been documented for the fault based on offset Pliocene and Pleistocene deposits (Cummings, 1968; Addicott, 1969).

Most of the slip not accounted for north of Hollister generally is assumed to be transferred to the Calaveras and Hayward fault systems (Herd, 1979), and long-term slip rate for these two faults has been assumed to be about 15 mm/yr. (Prescott et al., 1981). Rates of fault creep of about 7 mm/yr. have been measured on both the Hayward and Calaveras faults (Herd, 1979). These rates presumably are equal to or less than the long-term slip rates on each of the two faults, and suggest that the 15 mm/yr. of long-term slip may be about equally divided between the two fault zones (Herd, 1979).

Seismic data suggest that the Hayward fault zone and the Rodgers Creek fault zone may be parts of the same regional structure (Ellsworth et al., 1982). The two faults presumably should have essentially equal slip rates.

The pull-apart basin that has been developed near Santa Rosa between the north end of the Rodgers Creek fault zone and the south end of the Maacama fault zone suggests that these faults may be expressions of a common fault zone at depth. They also should have essentially the same slip rates.

Therefore, I would assume that the average slip rate for the Maacama fault zone should be on the order of 7 mm/yr., the same as that for the Hayward fault zone. This rate is compatible with the slip rate of 3 to 7 mm per year indicated for the Maacama fault zone by the 20 km of right-lateral offset of Sonoma Volcanics dated as 2.9–6.0 million years old (McLaughlin and Nilsen, 1982).

The creep rate along the Maacama fault segment in Willits is about 2 mm/yr. (Simon et al., 1978), based on the maximum amount of reference curb offset since the curb was installed. The apparent difference between creep rate and slip rate along the Maacama fault zone has not yet been reconciled.

Activity of the Maacama fault

Freshness is one indication of the relative age of fault-related geomorphic features, and in northwestern California young-appearing features are assumed to represent Holocene activity.

The topographic features delineating active segments of the Maacama fault are similar to those along the historically active Hayward and Calaveras faults. On the basis of this similarity, I consider the Maacama fault to be an active zone with Holocene displacements. Ongoing aseismic fault creep (Simon et al., 1978) and recorded microseismicity (Dames and Moore, 1977; Cockerham and Herd, 1982) are further indications of current fault activity.

Radiocarbon dating of charcoal fragments in trench 2, extending across the fault segment in the Laughlin Range, indicates at least two and possibly three episodes of faulting within the past $16,200 \pm 150$ years, and probably at least one episode within the past $8,310 \pm 95$ years.

Radiocarbon dating of a charcoal fragment and analysis of an exposure of the Parsons Creek thrust fault, a sympathetic break in the general Maacama zone, suggest that it also has been active during the past 10,000 years.

Radiocarbon dating of mean residence time for the undisturbed surface colluvium mantling the fault segment in the Laughlin Range suggests that no surface rupture has occurred during the past 1140 ± 70 years. The undisturbed colluvium overlying the fault segment near Twin Lakes suggests that it has not ruptured during the past 2000 ± 60 years.

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