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SUMMARY OF TECTONIC AND STRUCTURAL EVIDENCE FOR STRESS ORIENTATION AT THE NEVADA TEST SITE

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SUMMARY OF TECTONIC AND STRUCTURAL EVIDENCE FOR

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SUMMARY OF TECTONIC AND STRUCTURAL EVIDENCE FOR STRESS ORIENTATION AT THE NEVADA TEST SITE

By

W. J. Carr

ABSTRACT

A tectonic synthesis of the NTS (Nevada Test Site) region, when combined with seismic data and a few stress and strain measurements, suggests a tentative model for stress orientation. This model proposes that the NTS is undergoing extension in a N. 50° W.-S. 50° E. direction coincident with the minimum principal stress direction. The model is supported by (1) a tectonic similarity between a belt of NTS Quaternary faulting and part of the Nevada-California seismic belt, for which northwest-southeast extension has been suggested; (2) historic northeast-trending natural- and explosion-produced fractures in the NTS; (3) the virtual absence in the NTS of northwest-trending Quaternary faults; (4) the character of north-trending faults and basin configuration in the Yucca Flat area, which suggest a component of right-lateral displacement and post-10 m.y. (million year) oblique separation of the sides of the north-trending depression; (5) seismic evidence suggesting a north- to northwest-trending tension axis; (6) strain measurements, which indicate episodes of northwest-southeast extension within a net northeast-southwest compression; (7) a stress estimate based on tectonic cracking that indicates near-surface northwest-southeast-directed tension, and two stress measurements indicating an excess (tectonic) maximum principal compressive stress in a northeast-southwest direction at depths of about 1,000 feet (305 m); and (8) enlargement of some drill holes in Yucca Flat in a northwest-southeast direction.

It is inferred that the stress episode resulting in the formation of deep alluvium-filled trenches began somewhere between 10 and possibly less than 4 m.y. ago in the NTS and is currently active. In the Walker Lane of western Nevada, crystallization of plutons associated with Miocene volcanism may have increased the competency and thickness of the crust and its ability to propagate stress, thereby modulating the frequency (spacing) of basin-range faults.

INTRODUCTION

In 1972 the U.S. Geological Survey began a review and synthesis of the tectonics and structure of the Nevada Test Site region in order to estimate the present orientation of the regional stress field. This

because older structures profoundly influence the young ones, the older structural framework must also be well understood. For these reasons this report also presents a brief review of the tectonic setting of the Nevada Test Site region.

I appreciate the valuable assistance given in discussions and the background material provided for this report by colleagues, especially R. C. Bucknam, R. E. Anderson, W. D. Quinlivan, and G. E. Brethauer.

GENERAL TECTONIC SETTING OF NEVADA TEST SITE REGION

The Nevada Test Site lies within the Great Basin, a structural and physiographic region that consists of generally linear mountain ranges and valleys lying between the Colorado Plateau on the east and the

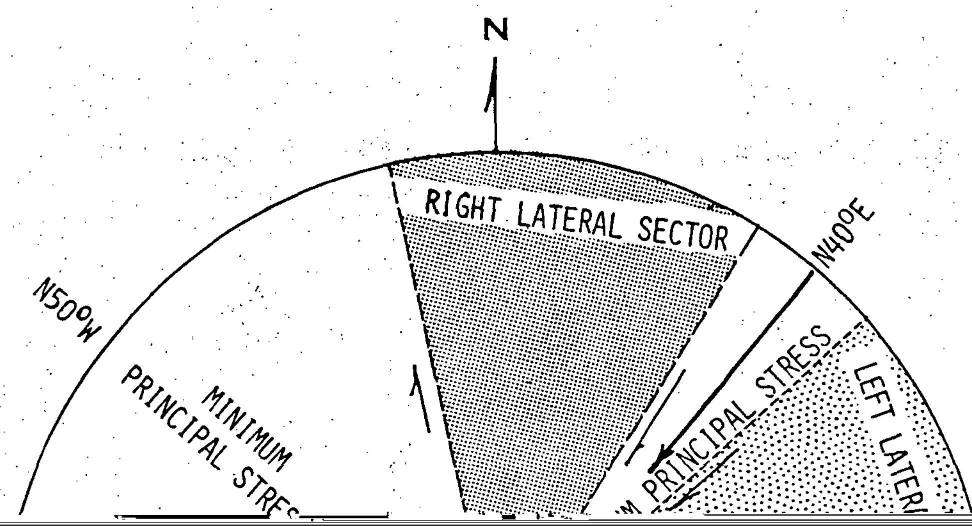
crust. Detailed mapping and modern dating techniques have shown that much of the middle and late Tertiary structural movement is spatially and temporally associated with volcanism, particularly in the western Great Basin (Christiansen and others, 1965).

The generally linear mountain ranges of central Nevada are interrupted in the western Great Basin by several major northwest-striking lineaments (fig. 1), which together form a zone of disrupted topography called the Walker Lane (Locke and others, 1940). These lineaments mark shear zones locally demonstrated to have as much as 30 miles (50 km) of right-lateral offset (Stewart, 1967; Longwell, 1960). These structures are associated with complementary northeast-trending faults, commonly having relatively small left-lateral displacement and large-scale drag folds or oroclinal bends (Albers, 1967) that strike east to northeast. In some areas the Walker Lane shear zones are buried under upper Miocene and Pliocene volcanic rocks; at other places the shear zones may be present at depth but expressed at the surface only by oroclinal bending or low-angle faulting.

Volcanism in the Walker Lane mobile belt is predominantly Miocene in age and tends to be concentrated where the major right-lateral faults die out or display multiple branches and en echelon arrangement. An especially favorable locus appears to be wherever the large right-lateral fault zones step to the right several miles and where their ends are connected by northeast-trending faults, most of which have a small component of left-lateral offset. The northeast-trending faults can be regarded as rifts or spreading centers; commonly they are

of earlier activity having developed a structural grain by the time of basin-range faulting.

A variety of Tertiary structural styles occurs in the large area of the Nevada Test Site (fig. 2). The structures seem to be influenced by rock type as well as by preexisting structural grain. On the west a dissected volcanic tableland contains three major caldera complexes; caldera structure is closely associated in time with local north-trending basin-range faulting (Christiansen and others, 1965), and with northeast-trending faults having a small component of left-lateral slip. East of along the Las Vegas Valley shear zone within and beyond the area of the Timber Mountain caldera complex, where it is expressed largely by gravity and topographic trends. Paleozoic rocks appear to be bent around the southeastern edge of the volcanic field, and the thrust zone (Barnes and Poole, 1968) along the Belted and Eleana Ranges probably extends westward in an arc to Bare Mountain. Complicated structures associated with the zone of oroclinal bending and basin-range faulting in the southeastern part of the test site consist of two important structural elements--northeast-trending fault zones of small-scale left-lateral offset, such as the Cane Spring and Mine Mountain systems, and northwest-trending fault and flexure zones displaying right-lateral offset or bending. Detailed mapping (W. J. Carr and others, unpub. data, 1967) and seismic records described later show that these two systems mutually offset one another and that they are both locally active. Significantly, the current structural and seismic activity within these fault zones is concentrated near areas of deep-

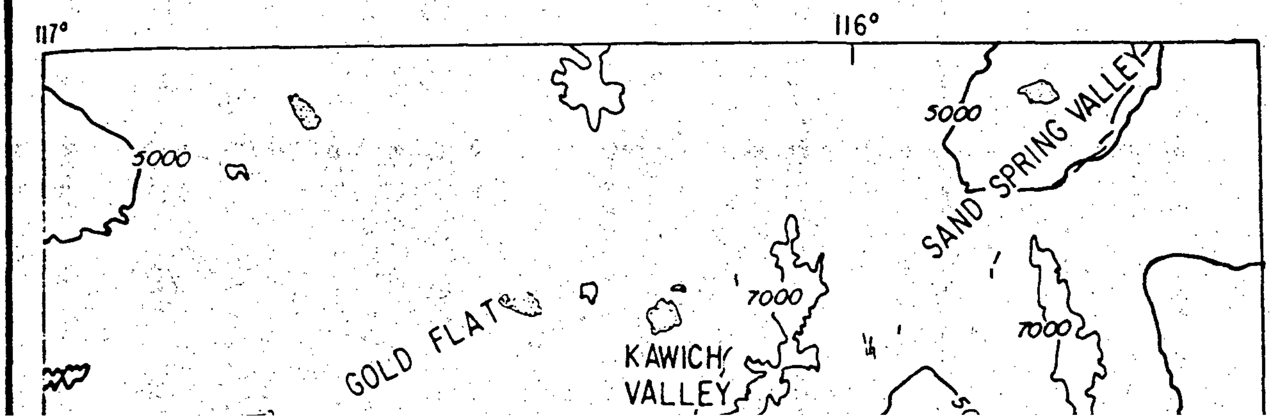

N
RIGHT LATERAL SECTOR
N40°E
N50°W
MINIMUM
PRINCIPAL STRESS

FAULTS AND FRACTURES OF QUATERNARY AGE

Faults in alluvium

Faults of Quaternary age having a northwest trend are not present in the test site area or along the Las Vegas Valley shear zone, but are common to the west and northwest along the Furnace Creek, Owens Valley, and Soda Spring Valley fault zones. Parts of these areas to the northwest are also the loci of much current seismic activity and of historic large earthquakes that caused surface displacements. However, available information (Papanek and Hamilton, 1972; Fischer and others, 1972), suggests to me that much of the stress relief is occurring not on the major faults of northwest trend but near them on northeast-trending faults, particularly where these faults are striking nearly east-west as they approach the main northwest-trending zones (figs. 1 and 2). Additional evidence will be given in the section on seismicity.

In the test site region, faults and fractures of Quaternary age form a zone (fig. 4) flanked on the east and west by areas having very little Quaternary faulting. Few, if any, of the fault scarps within this zone are fresh enough to suggest large earthquakes within the last few thousand years. The scarps nearly all lie in depressed areas that are mainly below 5,000 feet (1,524 m) in elevation. I suggest that the scarps are the surface expression of a seismic belt which currently is relieving stress by fairly numerous small earthquakes but which had been the site of larger earthquakes prior to the last few thousand years. The NTS zone of faulted alluvium is strikingly similar in trend and relative location to part of the Nevada-California seismic belt--a zone

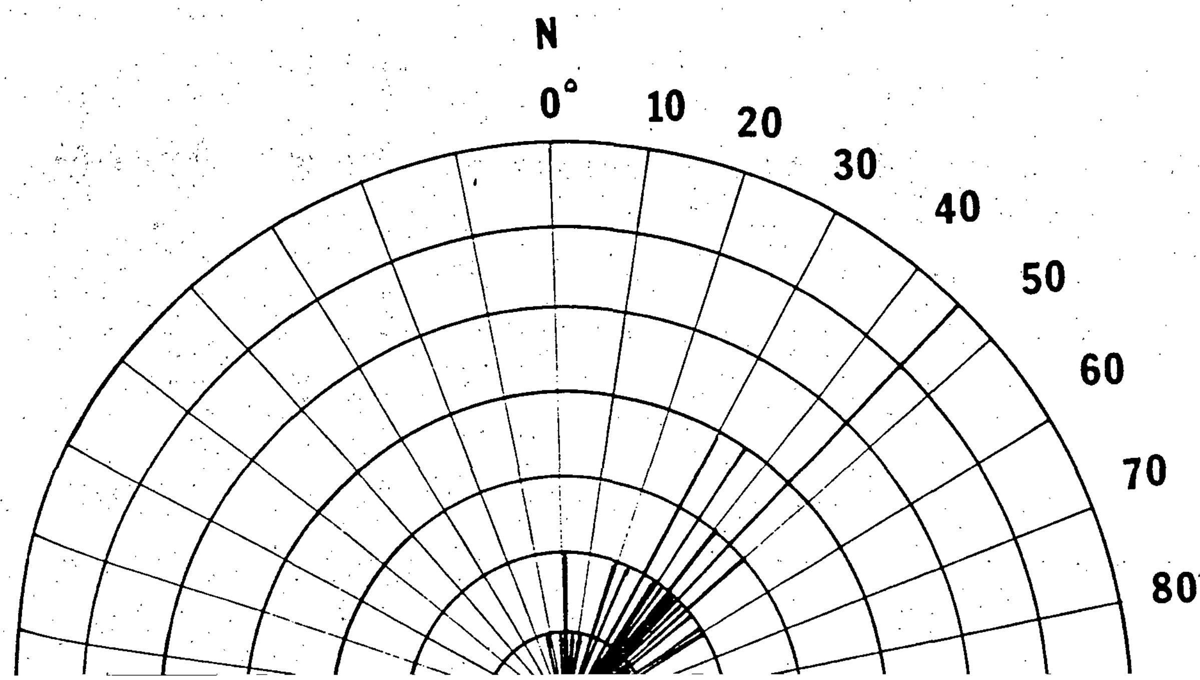

117°
116°
5000
5000
SAND SPRING VALLEY
7000
7000
GOLD FLAT
KAWICH
VALLEY

of historic large earthquakes that caused surface breakage (fig. 1). Both belts bend to a northeast trend as they cross the Walker Lane, and both appear to show right-lateral oblique slip in their northerly trending portions and left-lateral oblique slip in their northeasterly trending portions. However, at the test site the evidence for left-lateral slip on the northeast-trending faults is mostly in rocks of pre-Quaternary age, even though the faults cut Quaternary deposits. En echelon patterns characteristic of lateral slip seem to be absent from the younger of these northeast-trending faults, but the scarps are old and poorly defined.

The Yucca fault is the only youthful-appearing prenuclear testing fault scarp in the test site area. It will be discussed in detail in the section on page 23.

Fractures in alluvium

Underground explosions at the test site have produced many fractures in the alluvium. The average trend of shot-induced fractures in Yucca Flat is N. 40° E. (fig. 5). This direction is based on 70 occurrences, including prominent long fractures; fractures that are closely spaced in a zone were counted as a single occurrence. If individual fractures had been counted, the frequency of this trend would have been tremendously reinforced because fracture swarms having this trend are much more numerous than those exhibiting other trends. No great difference in fracture trends seems to exist from one part of Yucca Flat to another, although there is a tendency for fractures in Area 3 to trend slightly


N
0°
10
20
30
40
50
60
70
80

more northerly than those in the northern part of Yucca Flat. Fractures probably lying along faults were excluded from the count as were fractures that are clearly radial or concentric to shots. There is a minor maximum-of-fracture-trend frequency near north; it is possible that fractures having this trend are fault related. Horizontal separation of an inch or less, normal to the crack, is the usual displacement associated with these fractures. Significantly, the swarm of northeast-trending explosion-related cracks in north-central Yucca Flat crosses the major Yucca fault zone without being obviously affected by it.

Barosh (1968, p. 204-207) showed that in some areas of Paleozoic bedrock around Yucca Flat a well-developed system of northeast-trending joints and very small faults is present, nearly paralleling the trend of shot-induced fractures in alluvium. These joints in Paleozoic rocks are not explosion related. Analysis of the geologic mapping east of Yucca Flat also shows an east-northeast-trending system of small faults in the Paleozoic rocks. No joints or faults of this trend are known in the tuff outcrops adjacent to the fractured alluvium, but outcrops of tuff are sparse and irregularly distributed in these areas and no large underground explosions have been detonated near them. On Banded Mountain, however, a few basalt dikes of late Tertiary or Quaternary age intrude the northeast-trending faults, suggesting that northwest-southeast tensile stress was present at the time of basalt intrusion.

I believe that the described relations indicate that most of the randomly distributed northeast-trending explosion-produced cracks in Yucca Flat are basically unrelated to underlying faults and thus


WELL B

alluvium, which in turn trends toward a bedrock fault; (5) topographic data at hand for Yucca playa indicate no subsidence has occurred in the immediate area of cracking; (6) water levels (William Thordarson, oral commun., 1973) in wells B and C (fig. 6) at the edges of the playa indicate no significant lowering of the water table during the last 10 years; and (7) large quantities of water flow into the cracks when they are new, indicating that they go to considerable depth, probably into rocks beneath the alluvium.

Fractures inferred to be of tectonic origin are present in several playas of the region. Six fractures of this type are present on or near the surface of Yucca playa (fig. 6). Four of these (fig. 6, A-D) are subparallel and concave to the northwest; their trend varies from about N. 30° E. to N. 50° E. Two older cracks (fig. 6, E and F) beyond the northwest corner of the playa trend more northerly. The four parallel cracks in the southern part of the playa are about equally spaced and are younger from north to south. The youngest crack (D), still a prominent feature but filling rapidly, formed in 1969; the next crack to the north (C) formed in 1960 and was extended northeastward in 1966. On the basis of aerial photos and degree of obliteration, the third crack (B) probably formed prior to 1950. The fourth and northwesternmost crack (A) is older but of unknown age. None of these cracks shows obvious vertical offset, although the pattern of water distribution on the playa surface suggests that the area surrounding the younger cracks has been elevated slightly with respect to adjoining parts of the playa (fig. 6).

1. Groom Lake playa, northeast corner. About 5,900 feet (1,800 m) long, trends N. 47° E.; pre-1952 in age.

2. Small unnamed playa just northwest of Papoose Range, about 4 miles (6.5 km) east of gate 700. Two very faint cracks about 1,000 feet (300 m) and 500 feet (150 m) long, both trending about N. 50° E.

3. North end of playa in Indian Springs Valley, about 18 miles (30 km) north of Indian Springs, 17 miles (27 km) east of Frenchman Lake. Two cracks about 3,000 feet (900 m) long, trending about N. 20° E. and N. 10° E., appear to be at least 20 years old.

4. Frenchman Flat, northeast corner. Two curving cracks, one about 7,000 feet (2,130 m) long, trending N. 5° W. to N. 60° E., the other 2,000 feet (600 m) long trending north to N. 20° E.; both cracks concave to southeast. The easternmost crack is distinctly younger than the western, and looks fresh on photos taken in 1951.

Several other playas in the region were examined on aerial photos and no cracks of this type were detected. None of the photos were low adjacent bedrock are available only for the cracks on Yucca and Frenchman playas. On Yucca playa the major cracks have two distinctively different rocks to increase from east to west across a particular fault block (fig. 8); dips of as much as 60° are present along the east edge of Yucca Flat.

In general, the Tertiary tuffs dip less steeply (the average dip in the hills around Yucca and Frenchman Flats is about 20°) but more erratically than the Paleozoic rocks, because the tuffs tend to drape across uneven surfaces and fault scarps on the Paleozoic rocks. The tuffs are commonly less offset by the basin-range faults than are the Paleozoic rocks. Although there are local exceptions, the tuff units, particularly ash-flow tuffs, do not thicken appreciably in the deeper parts of the Yucca Flat basin. The larger exposed faults of the group are spaced from about 1,500 to 3,000 feet (500-1,000 m) apart, but subsurface dips in the tuff beneath Yucca Flat range from 10° to about 35°, indicating that faults are probably more closely spaced in those areas where the dips in the tuff are steep. For dips of about 30° maintained across fault blocks, small faults spaced only about 200 feet (60 m) apart seem required. If, however, dips in the tuffs steepen into the main faults, as seems likely, fewer faults are required. A good case for this phenomenon, called "reverse drag flexing," has been made by Hamblin (1965) and supported by Anderson (1971). It is a mechanism for achieving horizontal extension and implies curving or flattening of the faults with depth. Little evidence of this flattening exists at the test site because of the lack of deep erosion, but the Baneberry fault in northwestern Yucca Flat appears to flatten slightly with depth; at the surface it dips about 65°, and 1,000 feet (300 m)

lower drill-hole information indicates that it is dipping about 58°. Likewise, the Yucca fault, which at the surface generally dips about 75°-80°, must flatten to 55°-65° in order to fit subsurface geology in some areas. In southwestern Yucca Flat the Carpetbag fault zone may have a low dip, possibly approaching the 40° dip of the Paleozoic surface (fig. 8). Evidence for this will be discussed in a following section.

The Yucca fault is the youngest natural fault scarp in the test site region. It was studied carefully for clues to the present stress field. A large earthquake must have produced the Yucca fault scarp, which extends in a very narrow zone for a distance of at least 15 miles (24 km) and probably as much as 20 miles (32 km) (fig. 7). At least the southern 10 miles (16 km) of the fault scarp shows no evidence of multiple displacements. Magnetic evidence and surface fracturing show that in places the present scarp lies several hundred feet east of older buried parts of the fault zone. No reliable way has been found direction and should display a component of right-lateral slip. Evidence for this is summarized in the following discussions.

The main Yucca fault scarp, though nearly continuous, consists in detail of numerous close-spaced en echelon breaks that consistently step to the left (fig. 9), consistent with a component of right-lateral slip. Much of the en echelon pattern is a result of movement caused by underground tests, thus providing a general measure of present stress orientation. Minor departures from the nearly vertical displacements caused by explosions are, in my opinion, due to shoving and jostling of the alluvium by ground motion. However, fairly consistent minor right-lateral offset resulting from testing has been described for at least one underground test (R. E. Anderson and W. D. Quinlivan, written commun., 1966). Barosh (1968, p. 215) concluded that fracturing from another test indicated a slight right-lateral component.

North-trending surface faulting produced by the Carpetbag event (near UE2b, fig. 7) also shows evidence of right-lateral displacement; a road northwest of the shot was dextrally offset about 6 inches (15 cm) across a 4-foot (1.2-m) -high scarp, and en echelon cracking along the scarp steps to the left in a manner similar to that along the parallel Yucca fault scarp. The total amount of right-lateral slip on the Yucca and Carpetbag fault zones is difficult to estimate, but it could easily equal or exceed the average post-tuff vertical

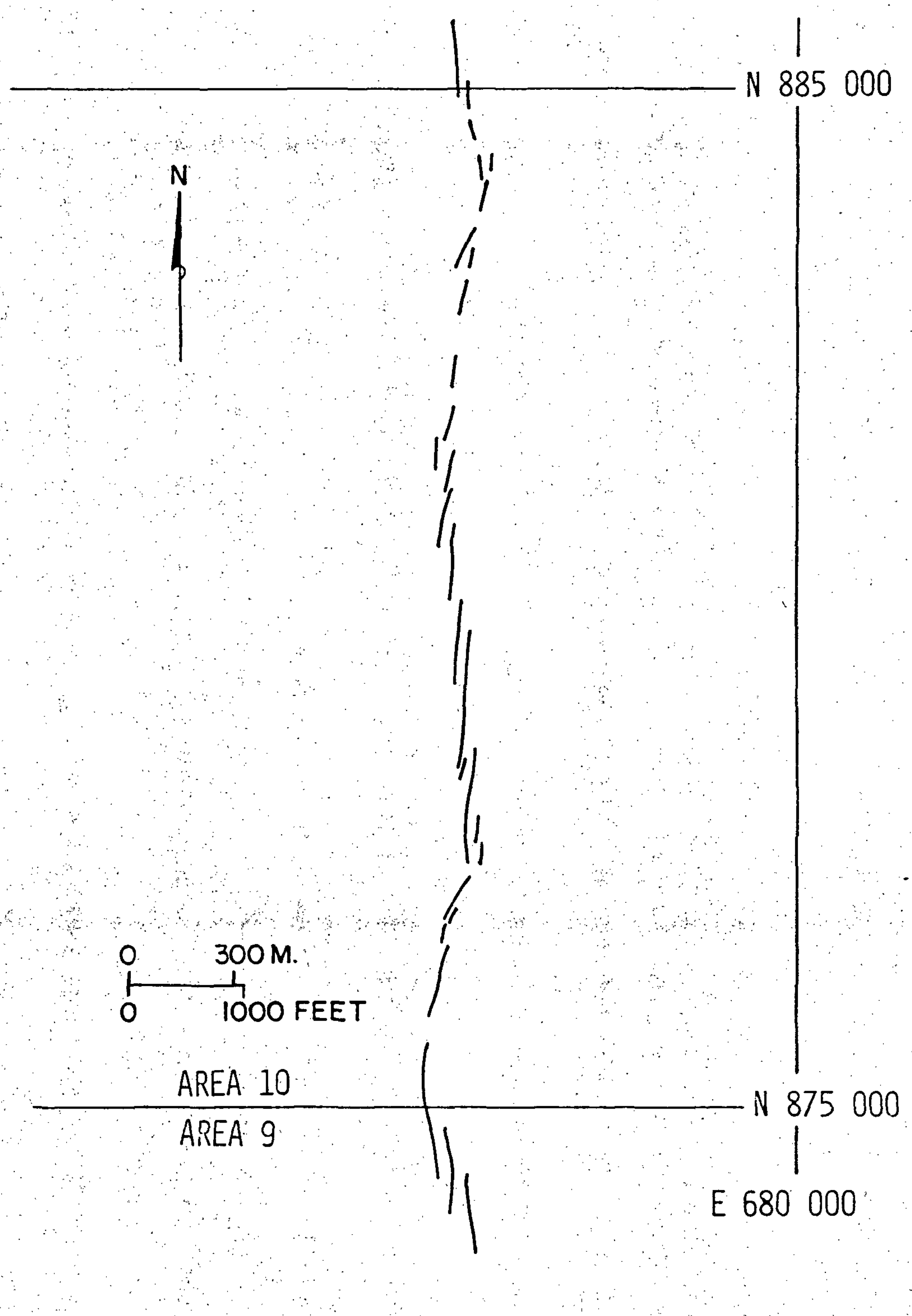
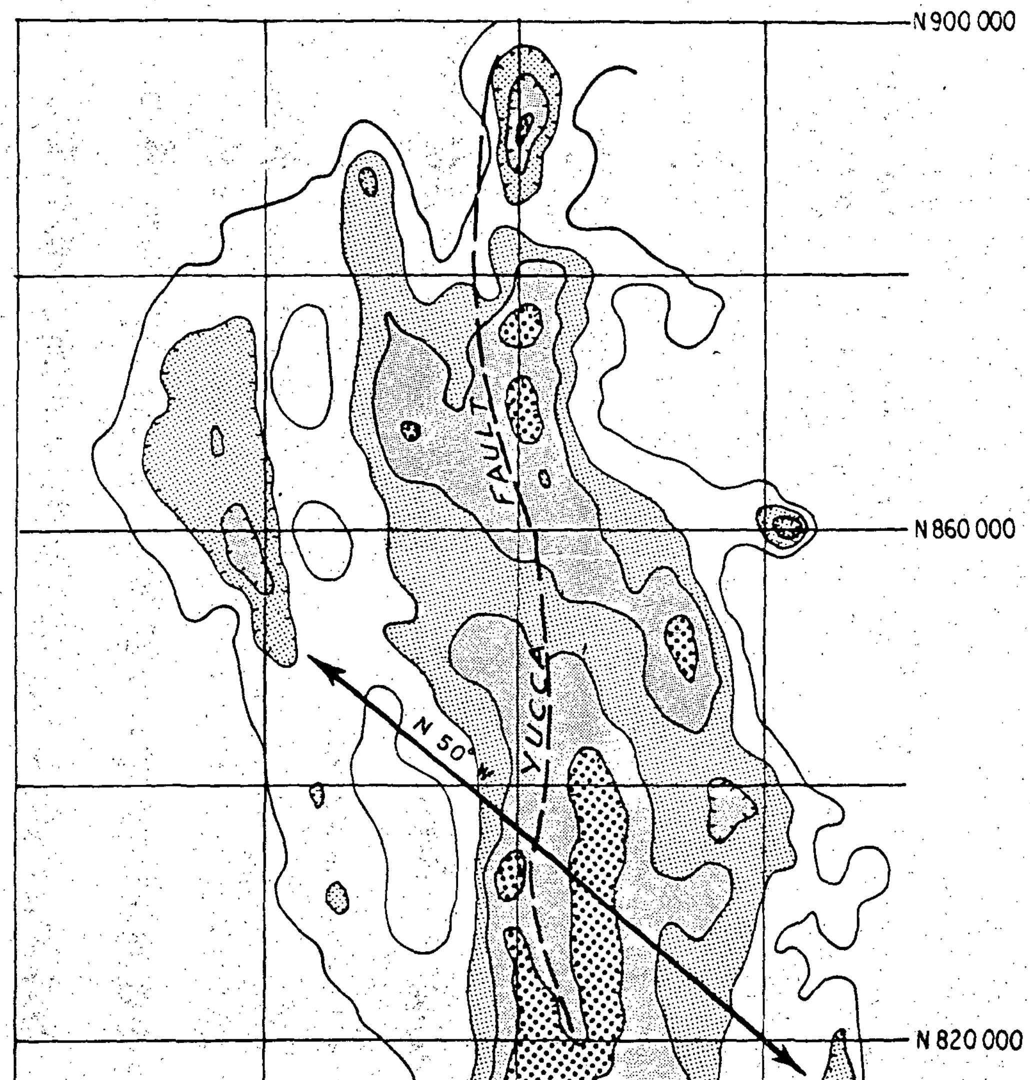


Figure 9.--Diagram of shot-induced scarplets along part of the Yucca fault

(fig. 7), which trends about N. 20° E. The evidence consists of the left-stepping of surface fractures along the scarp, northeast-trending tension cracks near the fault, and mismatch in tuff stratigraphy on opposite sides of the fault.

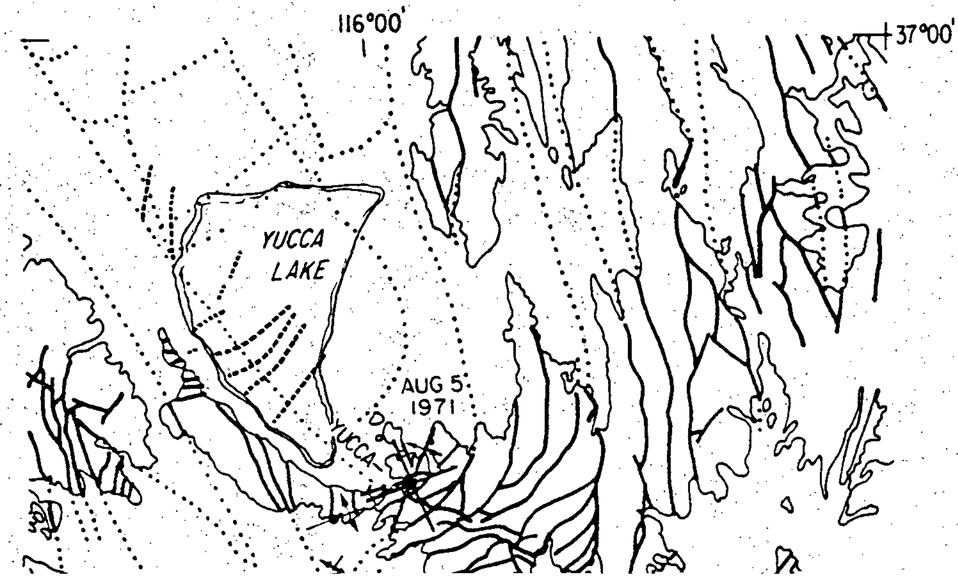
Additional observations may be cited in support of right-lateral slip on north-trending faults in the Yucca Flat area: (1) scattered subsurface data suggest that Paleozoic formations may be displaced several thousand feet laterally across the northern Yucca and Carpetbag faults (fig. 7); (2) slickensides on a few fault surfaces of north-northwest trend in the hills northeast of Yucca Flat show that oblique right-lateral movement has occurred at some point in the fault's history, but most of the strike faults east of Yucca Flat seem to have had principally dip-slip displacement in the geologic past; and (3) the sides of the medial Yucca Flat depression, as outlined by the buried Paleozoic surface determined from gravity (fig. 10), fit fairly well if shoved back together along a line trending about N. 50° W.

The deep troughs under Yucca Flat (fig. 10) are significant, relatively young structural features, although they are probably controlled in trend by older faults. Their youthfulness is supported by a general lack of thickening of the Pliocene Timber Mountain Tuff but abrupt thickening of the alluvial deposits in the troughs. The vertical and horizontal displacements involved are in general much greater than those recorded by faulting in the tuffs around the edges of the Yucca basin. Thus, these medial troughs seem to represent a relatively young episode of localized deep basin formation, possibly


N 900 000
N 860 000
N 820 000
FAULT
YUCCA
N 50° W

involving a change in stress orientation and mechanism. This period of tectonic activity may correspond to one in the western Great Basin described by Gilbert and Reynolds (1973, p. 2507), which they were just west of the Carpetbag fault zone. Dips in the Timber Mountain Tuff in drill hole U3ge immediately west of the Yucca fault are also unusually steep, averaging about 32° to the west. These structural attitudes, in conjunction with the deepest part of the Yucca basin, suggest structural rotation into a relatively low-angle east-dipping fault zone having the appearance of a landslide fault. The strong tendency for large range-front faults in the Basin and Range to be landslidelike or doubly concave, both upwards and toward the downthrown side, has been pointed out by Moore

The troughs under Yucca Flat range from 2,000 feet (600 m) to 5,000 feet (1,500 m) across, and the whole group of depressions has a rather constant total width of about 10,000 feet (3,000 m) under



[redacted]

of the southern tip of Yucca playa at a depth of 3 miles (4.6 km) (Fischer and others, 1972). Aftershocks had somewhat deeper hypocenters and were nearly all located in a northwesterly trending zone about a mile and a half (3.2 km) southwest of the main shock. According to Fischer (1972, p. 13) "the axis that bisects the quadrant of compressional first motions, the tension axis, has a near-horizontal, west-northwest orientation for both the main shock and the aftershocks" of the Massachusetts Mountain earthquake. In the main shock the strike of the pressure axis was N. 23° E., and the strike of the tension axis was N. 67° W. For the belt of northwest-trending aftershocks, the pressure axis varied from about N. 30° E. to N. 70° E., the average being about N. 45° E. Of the two fault-plane solutions, one trending N. 22° W. having right-lateral motion, the other trending N. 68° E. showing left-lateral motion, the plane striking northeast seems the most logical choice, as it coincides very closely with a prominent set of faults in the vicinity, many of which have slickensides indicating that the last movement was left-lateral slip. The trend and fault solutions for the aftershocks along a northwest-trending belt at depths of 4-6 miles (6-10 km) fit best with north-northwest-trending faults that cut the nearby CP hogback, but, significantly, the zone of aftershocks parallels a feature called the Yucca-Frenchman flexure (fig. 11 and W. J. Carr and others, unpub. data, 1967). The main shock and a few aftershocks were located very near the flexure at its intersection with the Cane Spring fault zone. The flexure is a right-lateral bend having a probable offset of about a mile (1.6 km). The flexure does not involve

Stress measurements and estimates

The relatively uniform spacing of the four cracks in Yucca playa provides a means for estimating the amount of stress causing them. According to Lachenbruch (1961), a relation exists between crack spacing, crack depth, and amount of stress. Lachenbruch's equations were rearranged by G. E. Brethauer (written commun., 1973) and used to calculate horizontal tectonic tensile stress. The gravitational stress is assumed to be hydrostatic and equal to the weight of the overlying rock. All stress components of a hydrostatic stress field are equal. The formula used by Brethauer is:

$$p = \frac{b\delta}{3.8}$$

where p is the tensile stress in psi, b is the depth of cracking in

Table 2.--Horizontal gravitational (Poisson) and tectonic stress for assumed crack depths

[- indicates tension]

The spacing between cracks A and B (fig. 6) ranges from 600 feet (180 m) to 2,000 feet (610 m), averaging about 1,300 feet (400 m); between cracks B and C from 1,000 to 1,400 feet (305 m to 425 m), averaging about 1,200 feet (365 m); and between cracks C and D from 1,900 feet (580 m) to 2,500 feet (760 m), averaging about 2,200 feet (670 m).

If it is assumed from Lachenbruch's study that the crack spacing is approximately equal to crack depth, an estimate of stress is possible from the figures in tables 1 and 2. The tectonic tensile stress would range from about 42 kg/cm^2 (600 psi) to about 77 kg/cm^2 (1,100 psi) in the hydrostatic condition, and from about 9.1 kg/cm^2 (130 psi) to about 15.8 kg/cm^2 (225 psi) if the Poisson loading criterion is used. The latter method gives distinctly lower values but is considered more realistic in terms of the physical properties of the medium.

Stress measurements have been made by the USGS and U.S. Bureau of Mines in two tunnels under Rainier Mesa. In U12t.02 at a depth of 1,175 feet (360 m) the principal compressional stress direction is N. 28° E. and the maximum excess (tectonic) horizontal stress is 41 kg/cm^2 (586 psi) (H. W. Dodge, Jr., oral commun., 1973). The axis of maximum principal stress is inclined about 3° from the horizontal. In U12n.07 bypass drift, at a depth of 1,250 feet (380 m) the direction of maximum principal stress is N. 47° E. and the excess horizontal stress is 68 kg/cm^2 (972 psi) (V. E. Hooker and others, written commun.

It has been suggested (V. E. Hooker and others, written commun., 1971) that the stress directions are influenced by the free face of Rainier Mesa, to which the maximum principal stress direction is roughly parallel. Such an influence is possible, but perhaps not very likely, because the measurements were taken more than 2,000 feet (600 m) from the nearest point on the face of the mesa.

Other stress-measurement data were reported by Obert (1963, 1964) from tunnels at Rainier Mesa and in the granitic rock of the Climax stock near the northwest corner of Yucca Flat. These data are being analyzed by G. E. Brethauer, who reports (oral commun., 1974) variations

In addition, caliper logs show that many other, but not all, holes in Yucca Flat are enlarged in an unknown direction. Of 96 holes having six-arm caliper logs, about 40 percent show no preferential enlargement.

The average direction of enlargement for the six holes that have been determined is roughly N. 60° W., a direction very compatible with other information assuming that the direction of enlargement represents the direction of minimum principal stress. In the few cases where the enlarged hole has been photographed or viewed by downhole television, the enlargement takes the form of planes of spalling in the northwest and southeast quadrants of the hole, leaving the northeast and southwest quadrants virtually undisturbed.

Other geologic evidence of extension

Two additional pieces of evidence may be cited in support of northwest-southeast extension. W. D. Quinlivan has pointed out an interesting possible analogy to the enlarged drill-hole phenomenon: the Timber Mountain caldera complex, which might be comparable to a huge drill hole in a stress field, has a northwest elongation (fig. 2), the direction being about N. 55° W. The Timber Mountain caldera formed about 11 m.y. ago.

A large Tertiary pluton, which probably underlies much of the northwestern part of the test site area as magnetically defined, has a very distinct northwest-southeast elongation (fig. 2). Interestingly, the Cretaceous plutonic rocks, including the connected Climax and Gold Meadows stocks, trend more nearly east-west, a direction that could have been related to the general development of a Mesozoic structural north-northeast-trending basin as a whole has a slight right-lateral component of displacement within it. They commented that this direction appears to be fairly consistent over a wide region of the Basin and Range province. Evidence presented in this report strongly supports this general statement, but it should be remembered that the area being considered is not the entire Basin and Range, but rather the Walker Lane and adjacent part of the Great Basin.

There is evidence suggesting that the structural style that probably began to develop in Pliocene time in the test site area with the formation of relatively narrow deep troughs is continuing at present, which, if correct, suggests that the present general stress configuration has existed for several million years. There is a strong hint that present seismic activity in the southwestern Great Basin is generally avoiding Paleozoic and older rocks and is concentrated in areas currently receiving alluvium. In some areas seismic activity is occurring in areas of volcanic rocks of Miocene and Pliocene age, in particular, in areas of volcanic centers or calderas.

Alluvial deposits are very rare, but unconformities are present within the volcanic section in Yucca Flat and elsewhere in the test site region, indicating a period of from roughly 17 to 7 m.y. ago, in which there were few, if any, deep closed basins of the type that now exist. Conglomerates intertongue with mainly the lower parts of the volcanic section near the edges of the volcanic fields, but these gravels are typically fluviatile in appearance and are locally associated with lacustrine limestones. These sediments are unlike the detritus now accumulating in the basins. In the subsurface in Yucca and Frenchman Flats is a widespread deposit of very tuffaceous alluvium postdating the Ammonia Tanks Member of the Timber Mountain Tuff. This unit is present nearly everywhere in the deeper parts of the basins. It contains very few Paleozoic clasts and represents a period of stripping of the tuff from the Paleozoic rocks. In northern Frenchman Flat on the flanks of the Frenchman basin, part of this alluvium underlies the Thirsty Canyon Tuff which is about 7.5 m.y. old. It can along and adjacent to the Walker Lane, and with the idea of the formation of deep basins, within the last 10 m.y. and locally within the last 4 m.y. The localization of basin development implies a fundamental change either in the mechanisms generating the stress or in the physical character of the crust. Locally these basins are undergoing extension and subsidence at the present time. The lack of young faults having a northwest trend in the test site region suggests that the minimum principal stress lies in the northwest-southeast direction, and that stress relief is occurring by bending or in small increments. It is suggested that postvolcanism crystallization of large plutons of granitic rocks beneath and adjacent to the many volcanic centers of the central Walker Lane may have played a part in the initiation of this phase of basin-range development by increasing the capability of the crust to transmit stress and by "spot-welding" the upper crust to the infrastructure, thereby better translating the deep lateral stresses to the surface rocks. The spacing of active basin-range faults may thus be related to the effective thickness of competent crust, the effect of the crystalline rocks being to modulate the spacing of basin-range faults and, hence, basin formation.

None of the very general conclusions of this report should be taken as obviating the need for stress measurements at the test site and elsewhere in the Great Basin. Ideally, quantitative stress measurements should be made in alluvium, tuff, and Paleozoic rocks at several places in the test site so as to determine what local variations may exist. Measurements should be made in highly faulted areas, such as along the east side of Yucca Flat, and in areas of minor faulting, such as the northern Eleana Range and in the southwestern Frenchman Flat area where the structural grain is different from that farther north. Measurements should also be made in zones having a history of right-lateral and left-lateral faulting, such as the Yucca-Frenchman flexure and Cane Spring fault zone.

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