MEASUREMENT AND ANALYSIS OF THE NEAR SURFACE STRESS FIELD IN THE VICINITY OF ACTIVE FAULTS IN SOUTHERN CALIFORNIA

Terry Engelder

Lamont-Doherty Geological Observatory of Columbia University
Palisades, New York 10964

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ABSTRACT

The objective of this research project is to successfully measure the regional stress field in a tectonically active area using the near-surface strain relief method, an in-situ technique originally developed by the U. S. Bureau of Mines.

During the summer of 1980, about fifty strain relief measurements were made at two sites near Palmdale, California, one 2 km SW of the San Andreas fault (site L) and the other 20 km to the NE (site I). Previous near-surface data indicated that measurements made within 6 m of the surface might be unreliable for predicting tectonic stress in this region, perhaps due to thermal stresses in the upper few meters associated with large seasonal temperature variations. In an effort to address this question, measurements were made successively to depths of 29 m at both sites.

Results of successful measurements are attached. Both the orientation and magnitude inferred for the maximum horizontal compressive stress (P) are plotted vs. depth (up is also North), and shown for reference are the respective lithostats, or estimates of the vertical stress, at each site. For measurements made below 6 m, a very consistent NNW orientation for P was obtained. The rose diagrams also shown reflect the averages and standard deviations obtained at sites I and L. A N23°W orientation for P is in excellent agreement with tectonic stress orientations inferred by Zoback et al. (1980) from deep hydrofracture measurements to depths of 800 m at sites within 2 km of our site L. It is also in agreement with orientations inferred from strain accumulation on the Palmdale and Pearblossom trilateration nets (Lisowski and Savage, 1979).

INTRODUCTION

Photoelastic models developed by Barber and Sowers (1974) and finite element models currently under development suggest that the accumulation of strain along a strike-slip fault results in a rotation of the tectonic stress field associated with the strained portion. Thus in theory, the measurement of stress near active strike-slip faults may be used to identify areas of high strain accumulation, hence high rupture potential. Based on this idea, stress measurements were made along the 1857 break of the San Andreas fault near Palmdale, California, for the purpose of identifying a rotation in the stress field and the implied presence of strain accumulation. This project was begun in 1977 (Sbar et al., 1979) with additional measurements made during the summer of 1979. In this technical report, our most recent data will be presented along with its interpretation. In addition, the various stress measuring techniques used and the validity of comparing their results will be discussed. Finally, results of finite element modelling of stress will be presented as a tool to aid in the understanding of the regional tectonic stress in the area.

METHODS OF MEASURING STRESS

Principally, two strain relief techniques have been used to measure stress during this project. They are the U. S. Bureau of Mines borehole deformation gauge and C.S.I.R. 'doorstopper' techniques. As strain relief techniques, both indirectly measure stress by directly measuring the strain in a rock associated with its removal from an *in situ* stress field.

The stresses we measured during the summer of 1980 were primarily made with the U. S. Bureau of Mines technique. A detailed description of the gauge and the technique can be found in Hooker (1974). Briefly, the gauge consists of six individual strain gauges mounted on cantilevers oriented in such a way as to record strains along three horizontal axes 120° apart. The cantilevers are inside a cylindrical steel jacket and make contact with the inside of an EX (3.8 cm diameter) borehole by way of a series of buttons at the lower end of the jacket. To make a measurement, the gauge unit is oriented in the EX borehole and overcored, freeing a 15.2 cm diameter core from the local stress field (Figure 1A). The resulting strain is measured as a deformation of the EX borehole.

The second strain relief used during the summer of 1979 and the only one used by Sbar et al. (1979) is the C.S.I.R. 'doorstopper' technique. This method is described in detail by Sbar et al. (1979). The technique involves bonding a three-component foil resistance strain gauge to the flattened bottom of an NX (7.6 cm diameter) borehole (Figure 1B). Upon overcoring, a 5.5 cm diameter core is freed from the local stress field. Strains are measured by the doorstopper as the core relaxes in response to the removal of this stress. With both techniques, strains were measured continuously during the overcoring by running the cable through the drill string to our strain indicator.

Since both the Bureau of Mines and doorstopper techniques are strain relief methods, the elastic moduli of the rock must be known in order to transform strain to stress. To determine the elastic moduli, a radial compression chamber was used to apply a uniform radial stress to each 15 cm

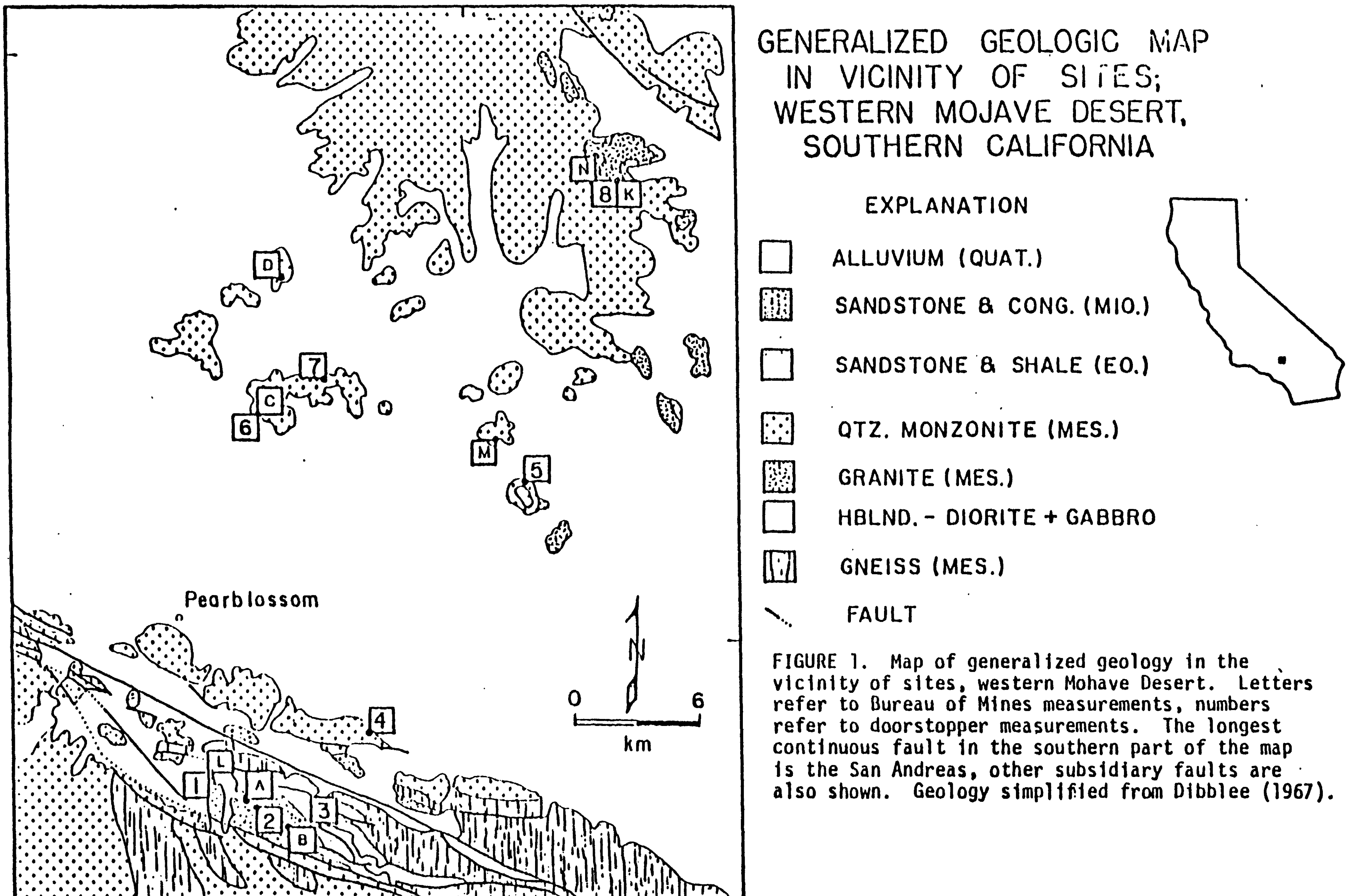


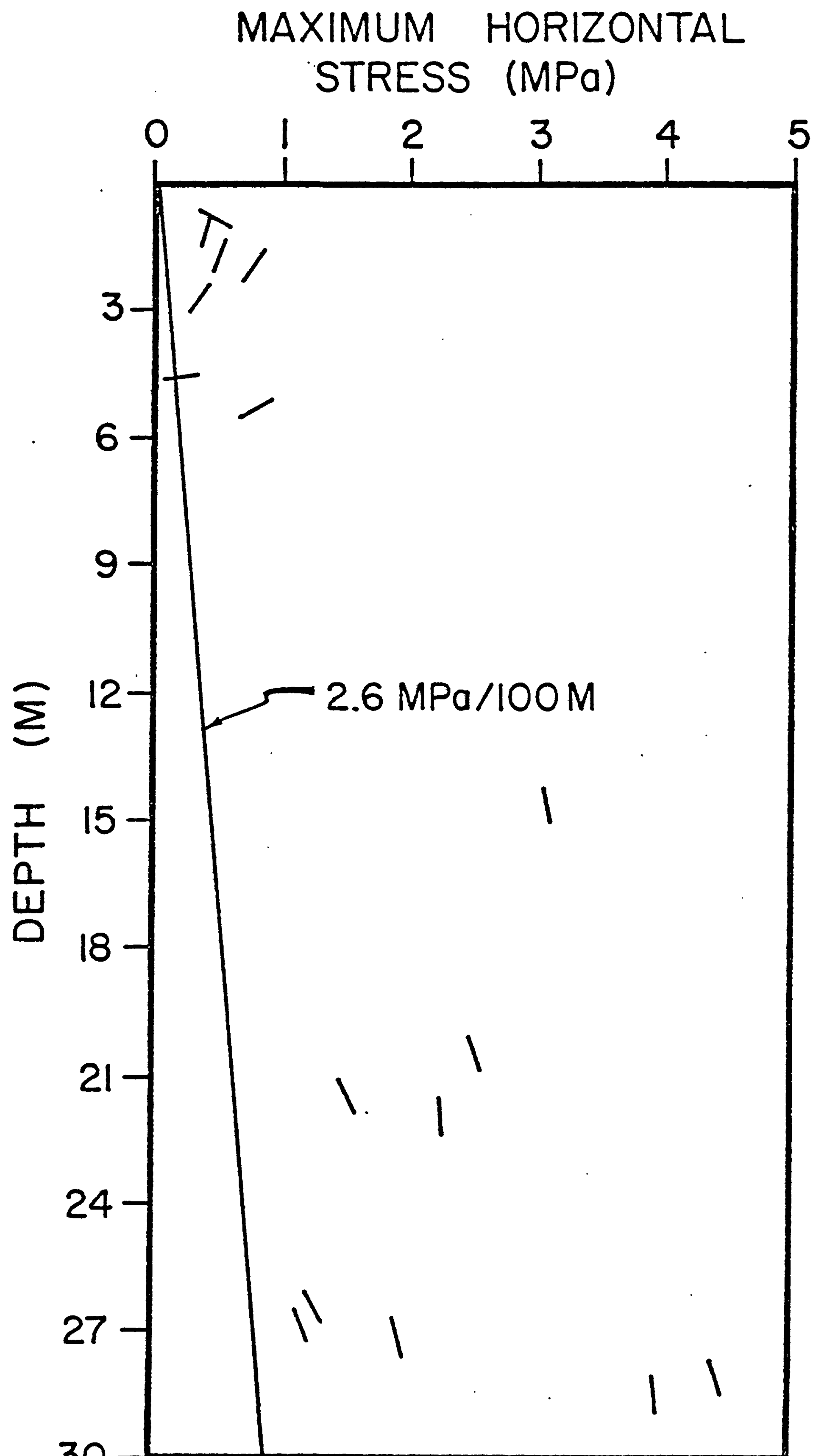
FIGURE 1. Map of generalized geology in the vicinity of sites, western Mohave Desert. Letters refer to Bureau of Mines measurements, numbers refer to doorstopper measurements. The longest continuous fault in the southern part of the map is the San Andreas, other subsidiary faults are also shown. Geology simplified from Dibblee (1967).

diameter core with the Bureau of Mines gauge in the position occupied during the initial overcoring. The magnitude of the applied radial stress was then plotted against the resulting strain along each of the three strain gauge component directions. From this plot the in situ strain relief is interpreted in terms of stress. In addition, by determining the moduli along three directions for each core, a first order correction for the effects of rock anisotropy is made.

THE DATA

During the summer of 1980 about fifty strain relief measurements were made at two sites near Palmdale, California (Figure 1). One site, 2 km SW of the San Andreas fault, consists of Miocene sandstone and conglomerate (site L). The other site, 20 km to the NE of site L, consists of a Mesozoic quartz monzonite. Previous near surface data indicated that measurements made within 6 m of the surface might be unreliable for predicting tectonic stress in this region, perhaps due to thermal stresses in the upper few meters associated with large seasonal temperature variations. In an effort to address this question, measurements were made successively to depths of 29 m at both sites.

Site I - The Mesozoic Quartz Monzonite. Several overcoring measurements within the top six meters of the quartz monzonite show a scatter in the orientation of maximum horizontal stress. Figure 2 shows the orientation of the maximum horizontal stress plotted as if in map view with north



SITE I

Figure 2

toward the top of the page. Each data point shows maximum horizontal stress versus depth as well as the orientation of maximum horizontal stress. Between the depth of 6 and 15 meters, many fractures were encountered and no data were collected. Below 15 m, nine measurements were attempted and all measurements show the maximum horizontal stress oriented about 15° west of north. The differential stress (P-Q) at site I is less than 1 MPa at less than 6 meters depth but is between 0.8 MPa and 1.8 MPa at depths greater than 15 m (Figure 3).

Site L - The Miocene Sandstone and Conglomerate. 40 overcoring measurements were completed in a 29 m deep hole in Miocene sandstone within 2 km of the San Andreas fault (Figure 1). The hole for these 1980 measurements was drilled within 10 meters of a 13 meter deep hole for measurements made during 1979. The 1979 measurements showed an average maximum horizontal stress oriented at 20° west of north. The orientation of maximum horizontal stress for the forty 1980 measurements shows a scatter with two groups of measurements showing a west of north trend for maximum horizontal stress. Those groups come from depths of 4 to 9 m and 21 to 27 m. Near-surface measurements show the highest stress and are interpreted to be high because of thermal stresses. At site L the stress difference is uniformly less than 1 MPa for the entire depth of the hole (Figure 5).

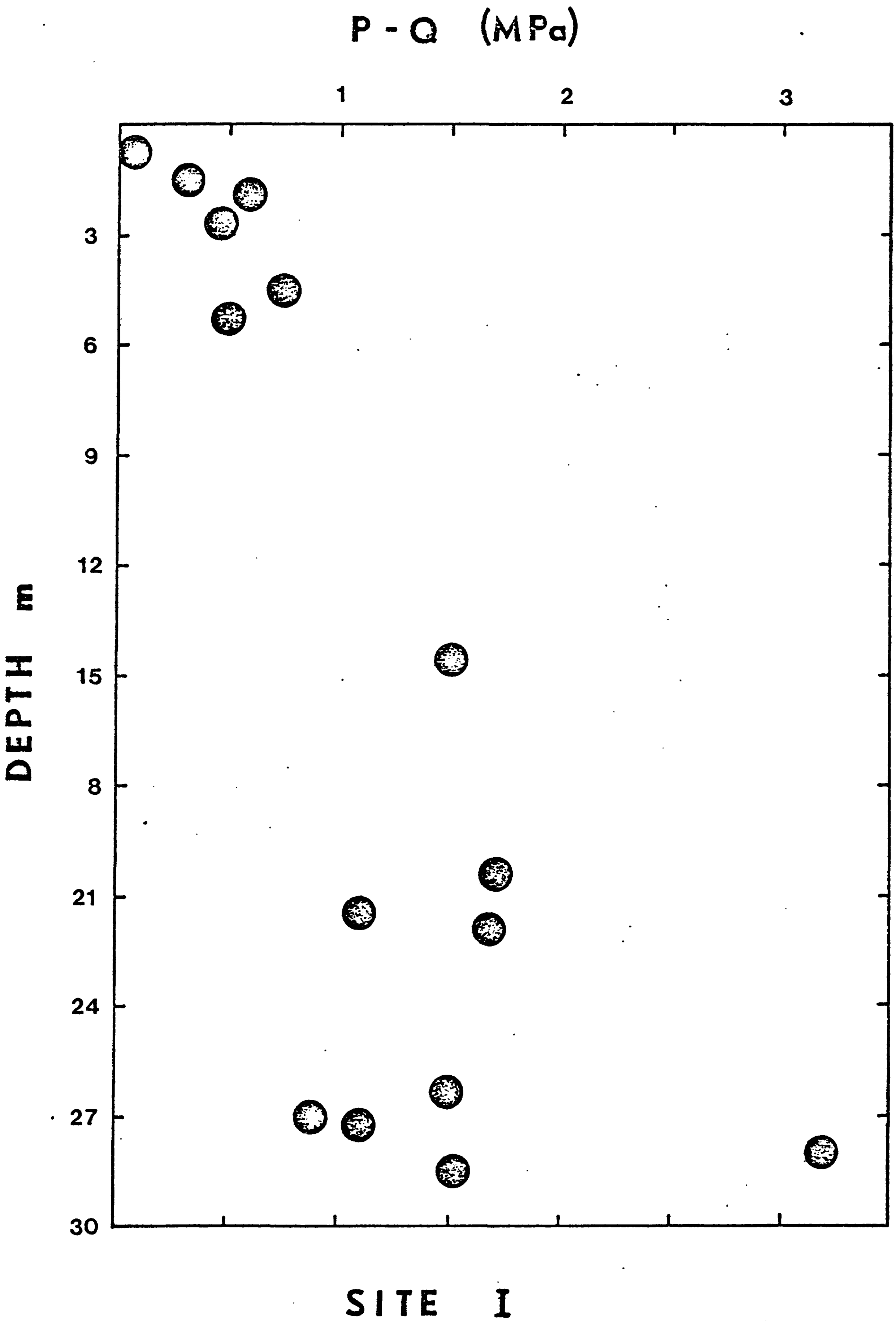


Figure 3

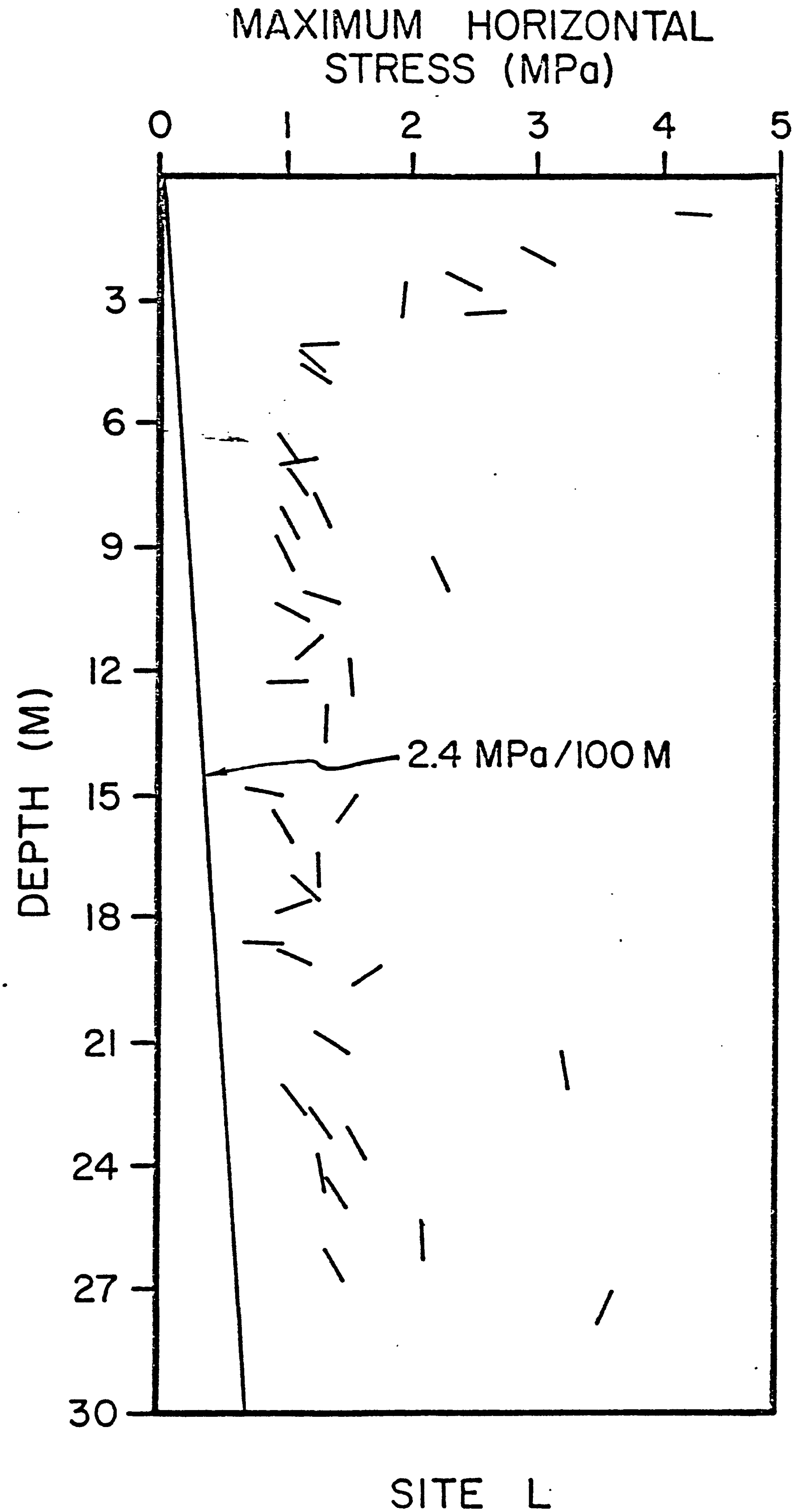

MAXIMUM HORIZONTAL STRESS (MPa)
0
1
2
3
4
5
DEPTH (M)
3
6
9
12
15
18
21
24
27
30
2.4 MPa/100 M
SITE L

Figure 4

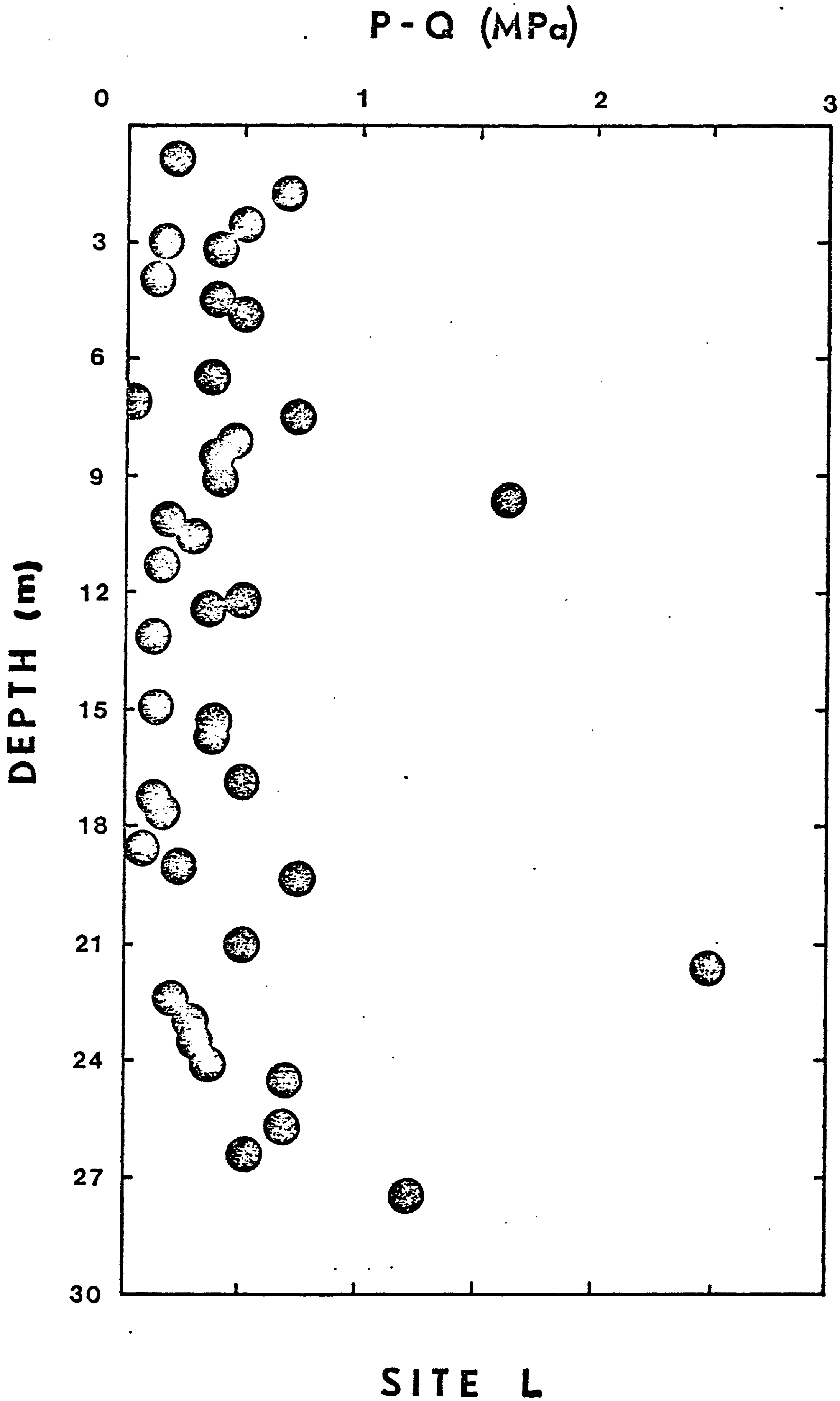


Figure 5

DISCUSSION

The average orientation of maximum horizontal stress of N14°W at site I and N23°W at site L is in excellent agreement with tectonic stress orientations inferred by Zoback _et al_. (1980) from deep hydrofracture measurements to depths of 800 m at sites within 2 km of our site L (Figure 6). It is also in agreement with orientations inferred from strain accumulation on the Palmdale and Pearblossom trilateration nets (Lisowski and Savage, 1979). The excellent agreement between our near-surface results and the results of others, particularly those sensing to much greater depths, leads us to conclude that we are indeed measuring tectonic stress with this relatively inexpensive technique.

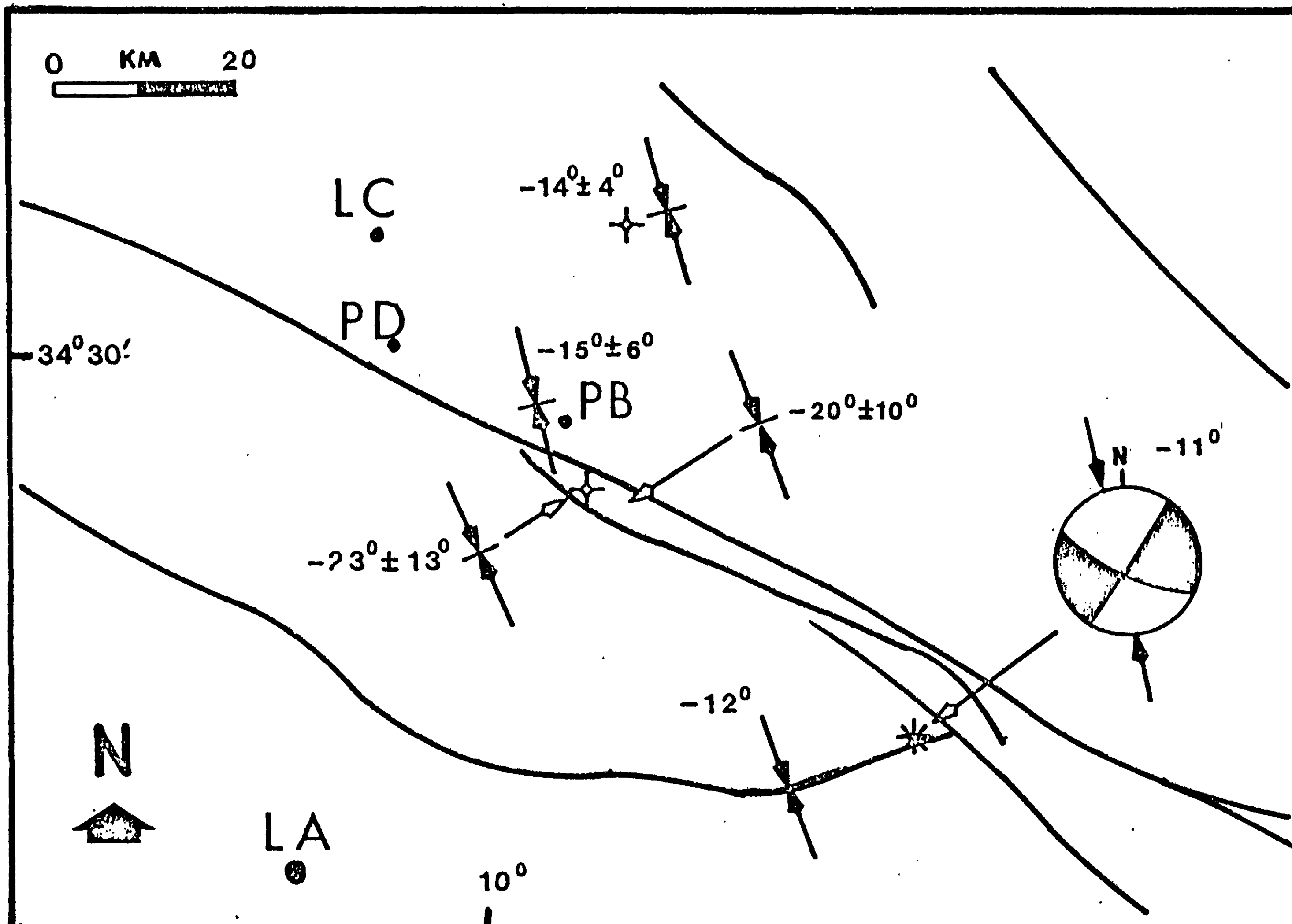


Figure 6

6a

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