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TITLE A NEW METHOD FOR DETERMINING FLUID FLOW PATHS DURING HYDRAULIC FRACTURING

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SUMMARY

Although hydraulic fracturing is a popular method for increasing the productivity of oil and gas wells, there is no direct way other than drilling additional boreholes to determine where the injected fluid has gone and thus what direction a fracture has propagated. Information about fluid flow paths is important for designing subsequent fracturing operations for nearby wells. Determining the locations and orientations of permeable fractures is also important in studies of potential toxic waste repositories where it is critical to understand fluid flow paths. We have developed a method for determining the orientations and locations of fractures along which fluid flows during hydraulic fracturing. The method is based on accurate determination of the locations of microseismic events, or microearthquakes, that accompany the hydraulic injection. By applying a pattern recognition technique to the locations of events from one hydraulic fracturing operation we find planes in the data along which we presume that the fluid has traveled. The planes determined using our method intersect the injection borehole and a second, nearby borehole, in regions where other data indicate that fractures are present.

INTRODUCTION

During the past 12 years we have been monitoring seismicity associated with hydraulic fracturing in granitic rock (Albright and Hanold, 1976). This work has been carried out with the implicit assumption that the seismicity is a direct result of the fluid pressure on the rock and thus is an indication of where the fluid has penetrated in the formation (Murphy and Fehler, 1986). We have reported that the fluid penetrates the formation along pre-existing fractures in the rock that open in response to the fluid pressure interacting with the in situ stress field (Murphy and Fehler, 1986). We have justified our assertion with the observation that the zone in which seismicity occurs is diffuse, that this observation cannot be explained by systematic errors in locations of the microearthquakes, and hence cannot be explained by a single tensile fracture. Until now we have had no method for determining where individual fractures exist in the formation. We now present results of applying a method, called the three point method, for determining orientations and locations of planes defined by locations of microearthquakes in a reservoir.

METHOD

The method is based on the observation that every combination of three microearthquake locations defines a plane. We begin by calculating the strike and dip of the plane made out of every possible combination of three microearthquake locations within a data set from a single hydraulic fracturing experiment. One intuitive way to find the orientation of any plane along which the microearthquakes may have occurred would be to separate all of the planes defined by combinations of three locations into bins corresponding to ranges of similar orientations, and to then identify which bin has the largest number of planes. However, this technique would produce a biased result due to the shape of the region in which the microearthquakes occur. This bias was discussed for the two dimension case by Lutz (1986). The bias caused by the shape of the region in which the microearthquakes fall can be eliminated by normalizing the number of combinations in each bin by the number of combinations in each bin found for synthetic sets of location data. These synthetic locations are uniformly but randomly distributed throughout the zone in which the actual microearthquakes were found to occur. In this way, we obtain an unbiased estimate of the orientation of planes along which microearthquakes fall and, by comparison with many sets of synthetic locations, can also obtain a statistical estimate of the reliability of the result.

To determine the location of the plane, we count how many times, T_j, that a given microearthquake, j, combines with other microearthquakes to form planes with the preferred orientation. The earthquakes that have the largest value of T_j are those that fall along the plane. By plotting the locations of these events, we find the location of the plane defined by the data.

The method can be successively applied to a given dataset to find planes of differing orientations. By removing those earthquakes that were found to define the primary plane, we eliminate the preference for that orientation in a subsequent application. In this manner further planes can be obtained from the data.

Figure 1 shows the application of the three point method to test data consisting of 200 synthetic locations that fall inside a box of dimensions 200 by 200 by 400 m, with the long axis oriented north-south. Twenty five of the locations were placed along a plane and subsequently perturbed off the plane by 20 m to represent errors in locations. The locations are drawn in vertical cross section oriented perpendicular to the strike of the plane so that the line represents the location of the plane defined by the unperturbed data. The method was successful in determining the location of the plane in these data.

RESULTS

We have applied the three point method to a suite of microearthquakes that accompanied a massive hydraulic fracturing operation in granitic rock. During the operation, 21,600 m³ of water were injected into a 20 m long section of wellbore at an average rate of .1 m3/sec. A total of 844 microearthquakes were located and used in the analysis. The events were located using travel times to several subsurface seismic stations located in boreholes surrounding the injection borehole (House, 1987). The precision in the locations is estimated to be 20 m. A total of five planar orientations along which seismic events occurred were found by the method. The first plane found, shown in Figure 2, contains 140 microearthquakes. This plane intersects the injection wellbore, labeled EE-2, in a location where several major fluid flow exits were identified during the hydraulic fracturing operation. The second plane, shown in Figure 3, intersects a borehole that was drilled after the hydraulic fracturing. The point where this fracture intersects the wellbore was identified as a fracture zone by analysis of drill cuttings (Levy, written communication).

INTERPRETATION

We interpret the planes found by the three point method to be flow paths along which the water flowed into the rock. These fractures are most likely preexisting joints which open in response to fluid pressure acting against the present in situ stress field. The above method of locating fractures during hydraulic fracturing thus locates those fractures which are most likely to be flow paths given the current state of stress. The method could readily be applied to assessment of hazardous waste sites where such fractures must be characterized and to oil and gas wells where knowledge of fracture orientation is desirable. It should be noted that not all of the planes found are directly connected to the injection wellbore. Presumably some of these planes are fractures that have connections to the injection wellbore through fractures which are too small to be detected seismically.

CONCLUSIONS

The three point method has been successfully applied to a microearthquake location data set collected during a massive hydraulic fracturing operation. Planes with five differing orientations were found by the method. The first two planes were found to intersect wellbores in locations where other data indicate the presence of fracture zones. This method thus provides a powerful framework for interpretation of microearthquake data collected during hydraulic fracturing operations, and provides locations of flow paths along which water flowed during the injection.

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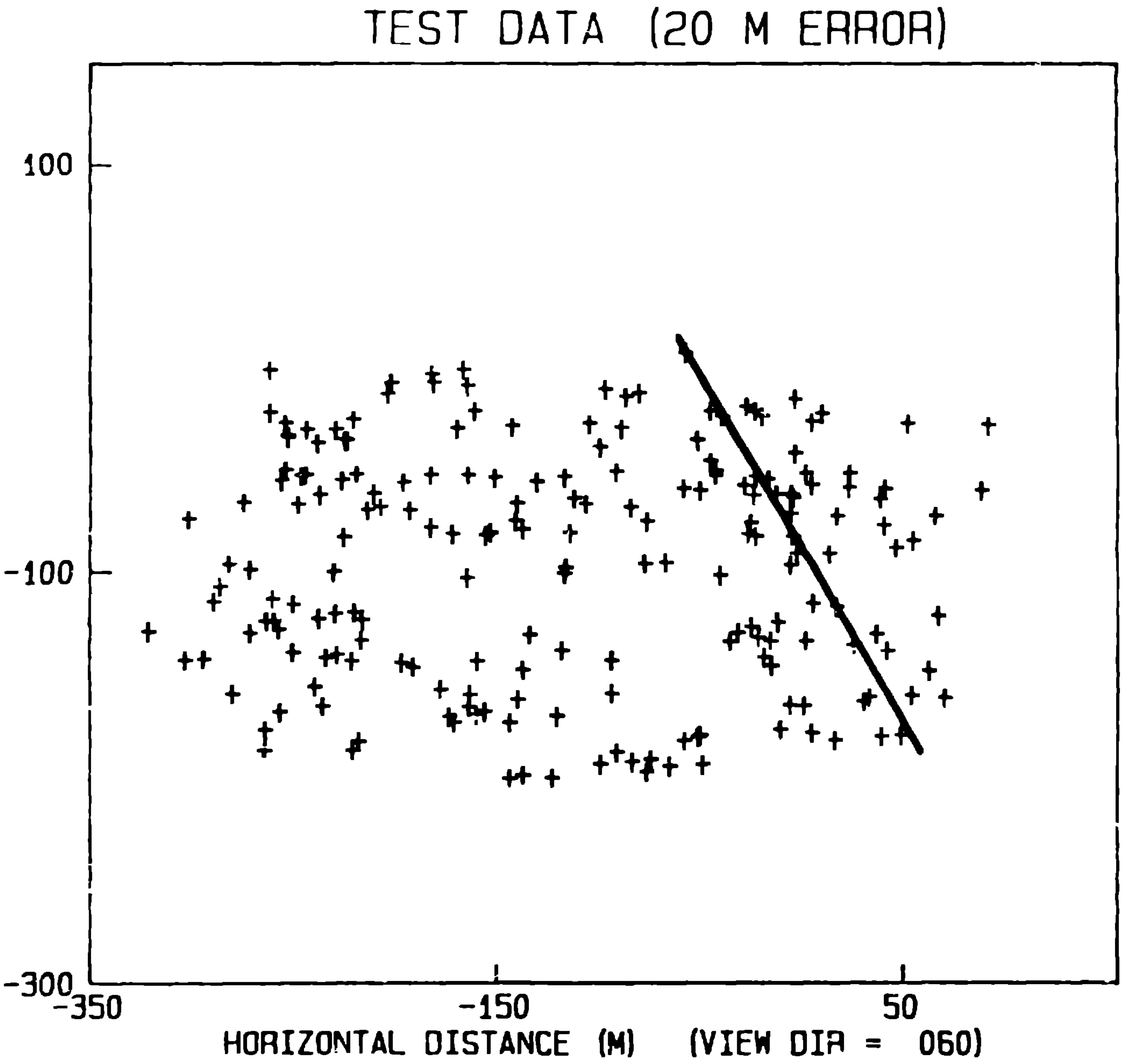

Figure 1. Test data for three point method. Line connects points along plane.

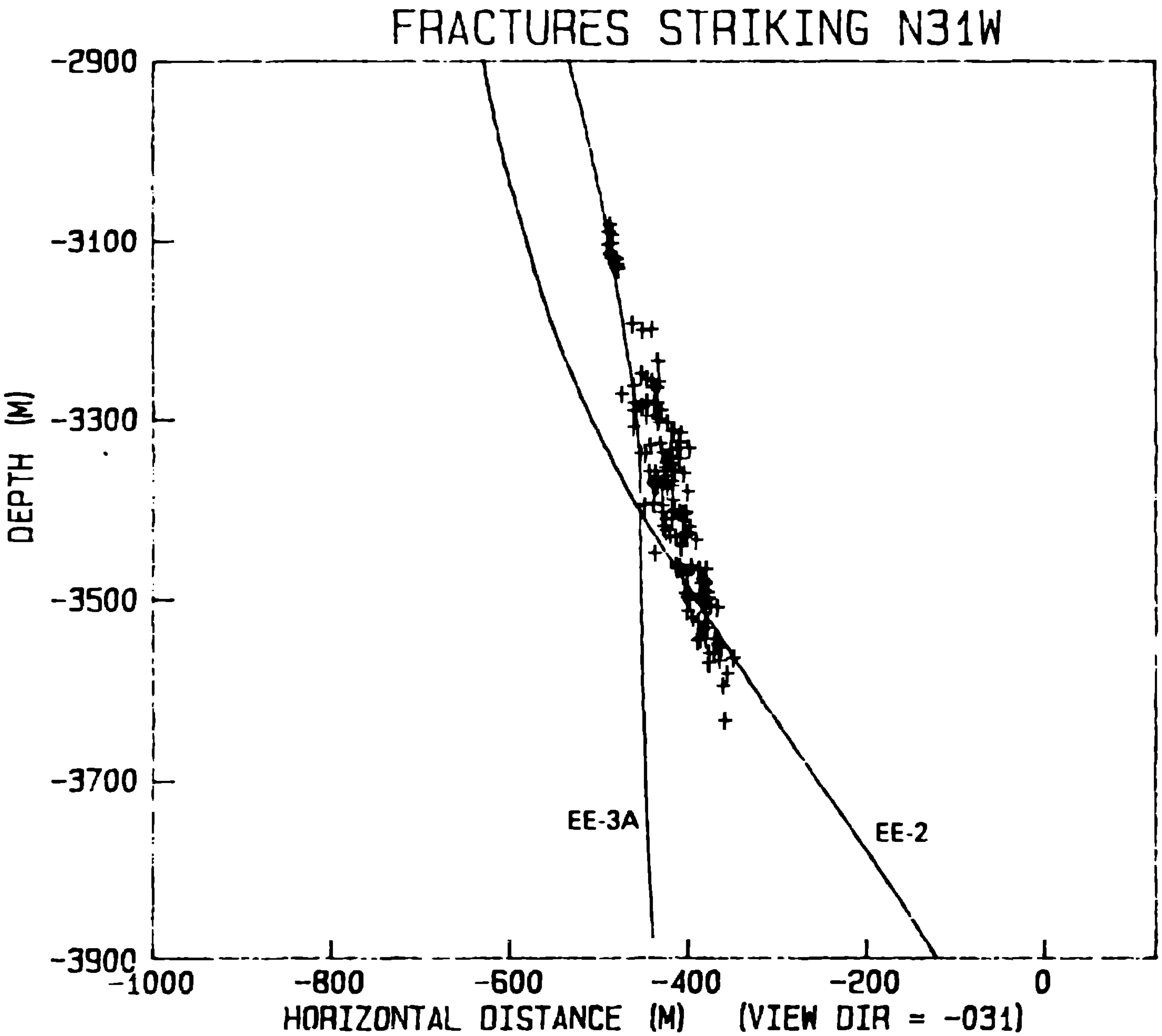

Figure 2. Vertical cross section showing points found along primary plane.

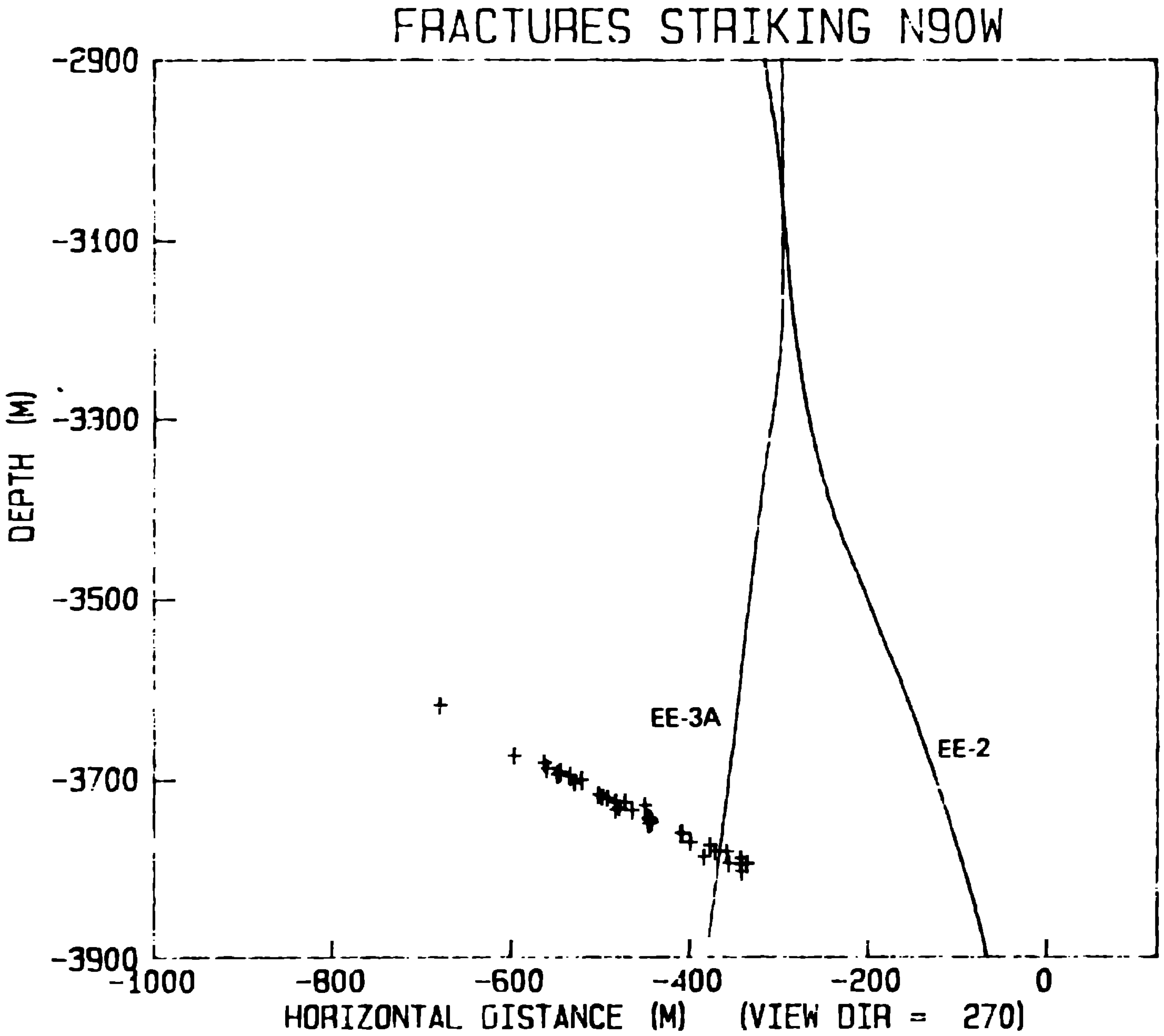

Figure 3. Vertical cross section showing points along secondary plane.