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SEISMIC EMISSIONS SURVEYS

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ABSTRACT

With recent improvements in acquiring, processing and interpreting data, seismic groundnoise provides a valuable tool for geothermal exploration. A time domain beam-steering array processing technique is employed. This process eliminates the occurrence of false anomalies caused by local geologic amplification effects. Surveys of this type are used to locate naturally fractured reservoirs. Results from Dixie Valley and Desert Peak, Nevada correlate well with the location of productive wells or known geology.

INTRODUCTION

Since the early 1970's groundnoise surveys have been used in an attempt to locate geothermal reservoirs. Although, controversy on the utility of this technique for locating geothermal reservoirs exists, interest remains high since it is one of the few methods considered as a direct geothermal indicator. Part of the problems in earlier surveys resulted from a lack of understanding of the local geological effects. Initially, amplitude spectra (PSD) were recorded at a number of locations and compared to determine areas of high noise concentration. It was later determined that surface layers of alluvium could also cause ground amplification (Wagner and Katz, 1975; Katz, 1976; Iyer and Hitchcock, 1976) resulting in false anomalies. To alleviate this problem time domain and frequency domain solutions, independent of ground amplification, were developed to locate the seismic noise source. Both of these methods rely on correlation techniques.

Liaw and McEvilly (1979) at Grass Valley, Nevada, Douze and Laster (1979) at Roosevelt Hot Springs, Utah, Oppenheimer and Iyer (1980) at Yellowstone National Park, and Liaw and Suyenaga (1982) at Roosevelt Hot Springs, Utah and Beowawe, Nevada all analyzed their groundnoise data using frequency-wavenumber techniques. In general, the results of all these surveys were mixed and non-conclusive. In some cases the seismic noise source was indicative of a Rayleigh wave characteristic of cultural noise or wind. In other cases during the same survey the groundnoise was characteristic of body (P) waves arriving from a possible geothermal source at depth. However, these results showed the noise arriving from random directions that could not be correlated with known features.

Capon et al. (1967,1968) described a time-domain beam forming array processing method to locate small seismic events lost in noise at the Large Aperture Seismic Array (LASA) in Montana. Page and Sebastian (1975) describe the use of a method similar to Capon's to process seismic noise at Long Valley, California. Utah Geophysical, Inc. (UGI) improving on the methods of Capon et al. has developed new field, processing and analysis techniques that appear to be successful in locating fractured reservoirs. We refer to this method as seismic emissions. Results at Dixie Valley (Sunedco), Desert Peak (Phillips), and Dixie Hot Springs (Chaffee Geothermal) will be discussed. Drilling has confirmed survey results at Dixie Valley and Desert Peak. Surface geology and microearthquake activity appear to support results at Dixie Hot Springs.

THE METHOD

Data is acquired using a six element array usually having a diameter of 2000 to 3000 feet. The array is moved every other day to a new location within the survey area until four different sites are occupied. Data from the six vertical HS-10-(2Hz) seismometers is transmitted via FM telemetry to a central recording site and recorded, along with WWVB timing, on magnetic tape.

Prior to processing, 48 hours of data is stripped out and edited to find quiet sections containing a minimum amount of cultural and wind noise. These quiet sections are then digitized at a rate of 100 samples per second. Processing employs an array processing-beam steering algorithm. To impliment this program, the typical 4 by 4 mile area of interest is divided into a 1000 ft. grid. This results in a 21 by 21 matrix or 441 possible locations to be evaluated. Travel times from each grid point to each receiver are then calculated. Recorded traces are then shifted according to the corresponding travel times for a particular point in the grid and cross correlated to test their coherency. This is repeated for all points in the grid by an iterative process. Areas exhibiting high correlation values indicate that the signal is in phase for that point, and thus, it is the probable location of the noise source.

Mathematically, the highest obtainable correlation value is one. This value is rarely obtainable in seismic processing. However, there are statistical standards that determine if the correlation value obtained is indicative of a coherent signal.Typically, seismic emission correlation values are on the order of 0.05. Using any of the traditional standards, a value this low would be considered non-coherent. However, we have to consider the type of data we are working with and derive a new set of standards to evaluate it. The data set is most likely made up of random background noise (i.e. wind, human or animal movement) which is of much higher amplitude than the signal of interest. This masks the P wave signal of interest resulting in a poor signal to noise ratio. However, the seismic signal derived from the reservoir has three characteristics that make it resolveable. Although, it is of smaller amplitude, it is consistantly being generated from the same location while the cultural noise is random in direction. By using a correlation window that is large enough, the random cultural noise should be averaged out while the signal from the reservoir would be enhanced. Secondly, the seismic signal from the geothermal reservoir appears to be a P-wave (Liaw and Suyenaga, 1982), thus traveling at twice the velocity of the background produced Rayleigh wave. Since, the ray tracing uses a P-wave velocity model, the cultural noise is subjected to a velocity filter. It cannot align itself in phase for the correlation because the P wave velocity does not permit this to occur. Finally, background noise travels across the array along the earth's surface. Whereas, the seismic waves from a geothermal reservoir would arrive from below the array. This causes the apparent velocities from the reservoir to be much higher than those traveling across the array from cultural noise. This effect further adheres to velocity filtering, enhancing the P wave arrivals. Considering the above combination of signals where the cultural noise is being filtered, while the more subtle reservoir signal is being preserved, low correlation values would be expected. Because of this we have chosen to use relative correlation values rather than absolute values. For any data set, values that exceeded 80% of the maximum value were considered anomalous. In addition, at least two and in most cases three arrays had to have their anomalous values occur at the same location for a seismic emissions anomaly to be defined. In this manner there had to be repeatability over a period of several days for an anomaly to occur.

Of importance when interpreting the data is the fact that the array diameter is small compared to the area it is searching. Therefore, seismic sources located more than approximately a half mile from the array result in the array generating a directional vector pointing toward the source rather than defining it uniquely. In this case at least two arrays need to have their vectors intersect to define the source location. In addition, the small diameter of the array causes the location to depend on the velocity below the array rather than the velocity for the entire survey area.

The velocity models are usually obtained from well logs or refraction surveys and may not be representative of the entire survey area. Differences in velocity will cause the directional vector to deviate slightly from the true location. These errors have been observed to be small ($<$500 ft.) at arrays located close to the source. For arrays located a few miles from the source, the error is usually less than 1500 ft. Separate models can be used for each array to account for lateral changes in geology.

RESULTS

Dixie Valley (Sunedco):

A seismic emissions survey was performed in 1977 at Sunedco's Dixie Valley Geothermal Prospect prior to the drilling of the initial test well. This well located in Section 18 proved productive confirming the findings of the seismic emissions survey which had indicated a fractured reservoir in the vicinity of this well.

The seismic emissions survey was used to evaluate a 6 by 6 mile area. Four arrays were processed. Results are shown in Figure 1. Anomalies occur in parts of Sections 18,17,8 and 7. Directional vectors (high correlation regions) from three arrays intersect at these points forming the anomalies. In addition, the fourth array was close enough to the anomalous region to provide a unique solution. A refraction survey (Thomson et al.,1967) indicates a buried normal fault, downthrown toward the east at approximately this same location. A high degree of confidence was placed on these anomalies since the results from all four arrays indicated the same locations for the seismic noise sources. The refraction survey provided additional confirmation of these locations.

Recent drilling appears to have encountered reservoir toward the north beyond the extent of the seismic emissions anomaly. It is assumed that the emitted noise was either localized or stronger toward the southern part of the reservoir where the anomaly occurred. In any case, a drilling program based on the conclusions of this survey would have likely resulted in a commercial discovery. Results of a later microearthquake survey added supporting information to the initial findings. Parchman and Knox (1981) have previously reported on the characteristics of this site.

Desert Peak (Phillips):

During 1983, using improved processing algorithms and field procedures, a 4 by 4 mile area was evaluated at Desert Peak, Nevada for Phillips Petroleum Co. This survey was performed twice, prior to and after a reservoir test that lasted several months. Results of both surveys were almost identical demonstrating the repeatability of the seismic emissions technique. Unlike the Dixie Valley survey, wells had already been drilled defining the reservoir. Results of the survey performed prior to the reservoir test are shown in Figure 2. The anomalous region (A) shown in the NE¼ of section 21 appeared on both surveys and is coincident with the current productive wells. It was formed by the intersection of directional vectors from all 4 arrays providing a high degree of confidence in the results. Single station anomalies (B,C,D,E), being less well defined and possibly caused by array biasing or leakage, are shown dashed. Data were processed using a depth of 4000 ft. Inferred faults were located in part by using the observation from previous work that seismic emissions anomalies usually occur at cross faults. In addition, Phillips (John Maas, personal communication) reprocessed the raw correlation values using different statistical packages to generate a contour map to compare the results with faulting identified by magnetic and self potential surveys. The geology and reservoir characteristics have been described by Benoit et al. (1982).

The results of this survey were quite similar to that at Sunedco's Dixie Valley Prospect. In both surveys, all four arrays pointed to the same location forming the anomalous region where the fractured commercial reservoir appears to occur.

Dixie Hot Springs (Chaffee Geothermal):

In 1983, both seismic emissions and microearthquake surveys were performed for Chaffee Geothermal at their Dixie Hot Springs, Nevada Prospect. Results from the seismic emissions survey are shown in Figure 3. Unlike the previous two surveys that had one prominent noise source, this prospect appears to have several different sources. Anomalies A and B are seen on both Arrays 3 and 4, whereas, Anomalies C, D and E are seen only on one array. The reason for the one-array anomalies in this survey is likely caused by the array's close proximity to the noise source. Array 1 is close to Anomaly D and Array 2 is close to Anomaly C. Because the seismic noise is so close, it masks the noise arriving at these arrays from the more distant sources (Anomalies A & B). Anomalies A, C and D align themselves with the Dixie Meadows Fault which is associated with a series of springs. Anomaly B, lies along the 1954 scarp of the Stillwater Fault. As mentioned previously, the seismic emissions anomalies usually occur at cross faults. Reports by Koenig et. al. (1976) and Denton et. al. (1980) show the Whiterock and Mississippian Canyons, just north of the survey, to be fault controlled and extending into the valley. Assuming this is also the case for Cottonwood Canyon, an inferred fault can be placed through Anomalies A and B. These anomalies would then appear at cross faults.

Additional evidence suggesting the existence of a cross fault was supported by the location of microearthquakes. Following the seismic emissions survey, a microearthquake survey was conducted for a two week period. Sixty-three events were located, of these about one-third were found to occur within the region defined by the previous seismic emissions Anomalies A and B. Spectral analysis of the microearthquakes indicated low Q (high attenuation) values along the previously mapped areas of faulting. These low Q values coincided with the seismic emissions anomalies confirming the possible existence of a fractured zone.

CONCLUSIONS

The three seismic emissions surveys described within this report are typical of the results found at several other locations. The results of other surveys are either proprietary or have been reported elsewhere (i.e. Swift, 1979). Results appear to correlate well with drilling and other geological and geophysical methods. Although surveys of this type have been controversial in the past, as perhaps with any geophysical method, the consistency and reliability of current results are encouraging. This would indicate that with careful data acquisition and improved processing techniques, seismic emissions could be a meaningful and reliable geophysical tool.

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SEISMIC EMISSIONS MAP

DIXIE VALLEY, NEVADA

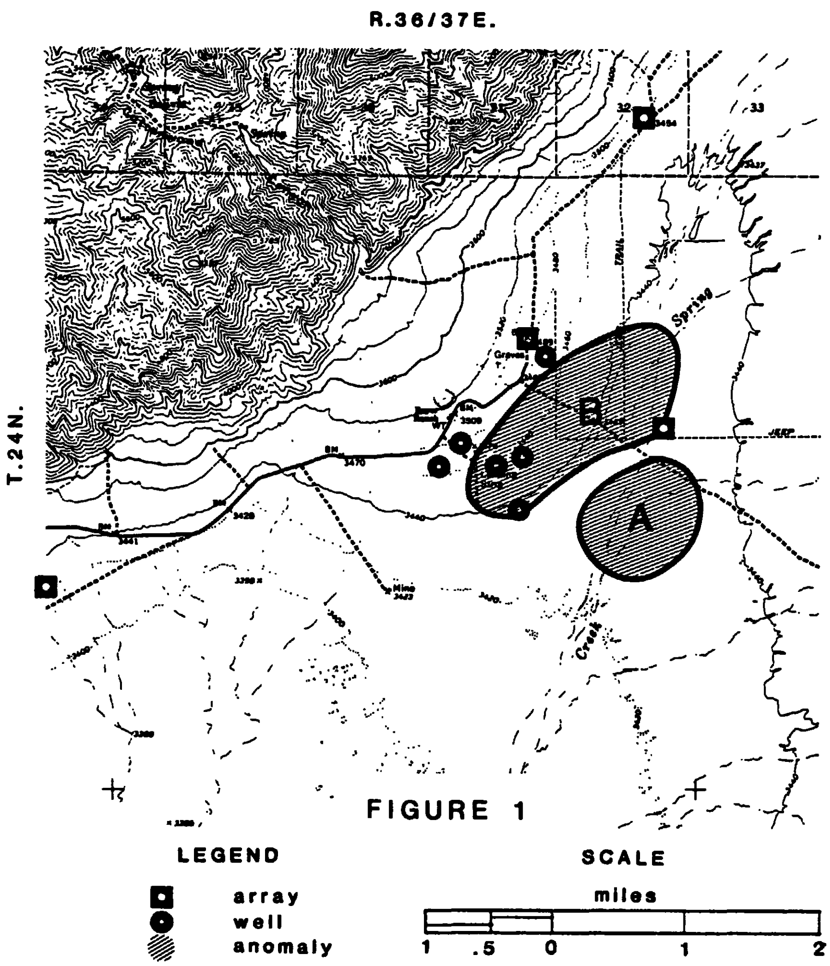

FIGURE 1

SEISMIC EMISSIONS MAP

DESERT PEAK, NEVADA

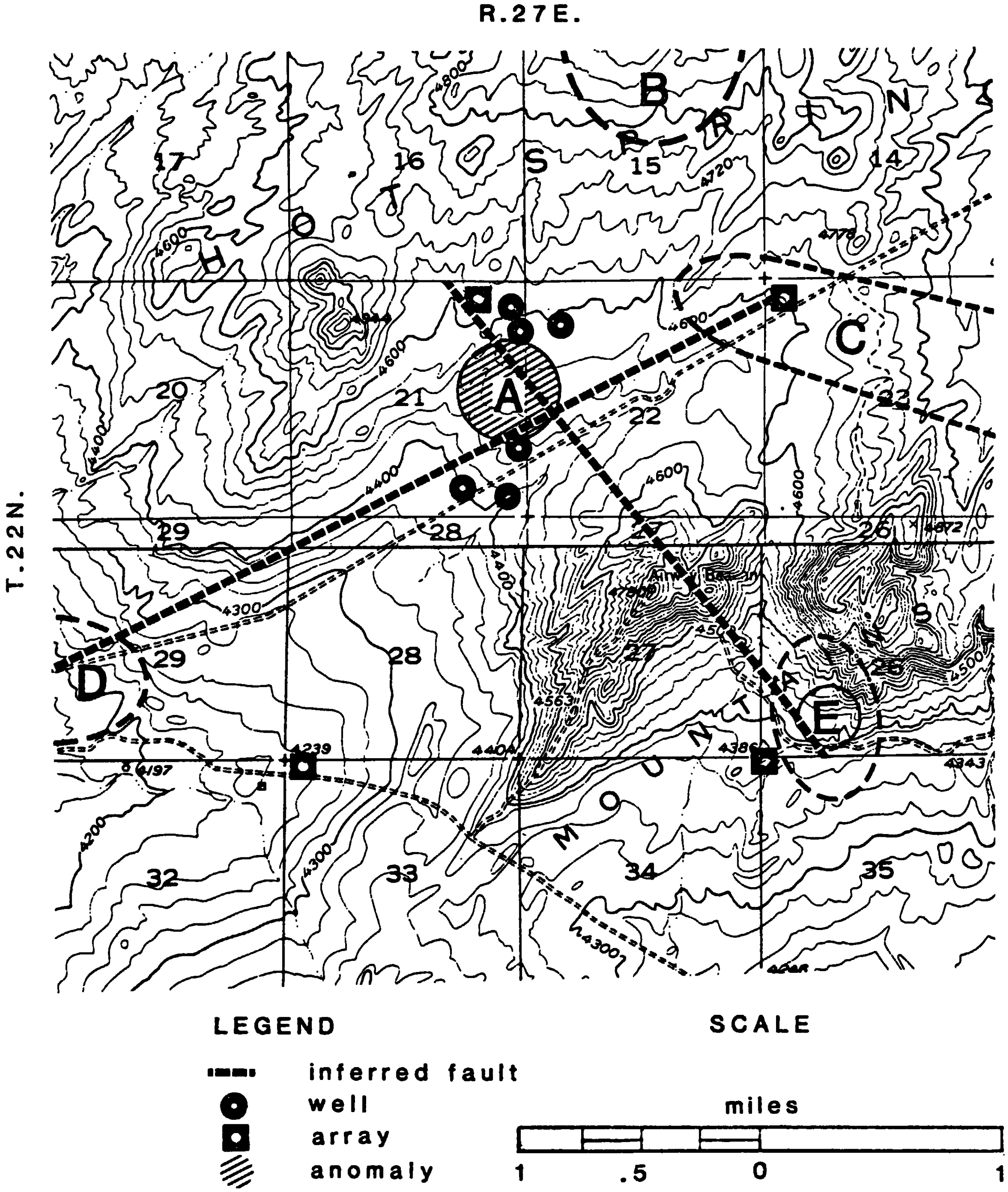

Figure 2

SEISMIC EMISSIONS MAP

DIXIE HOT SPRINGS, NEVADA

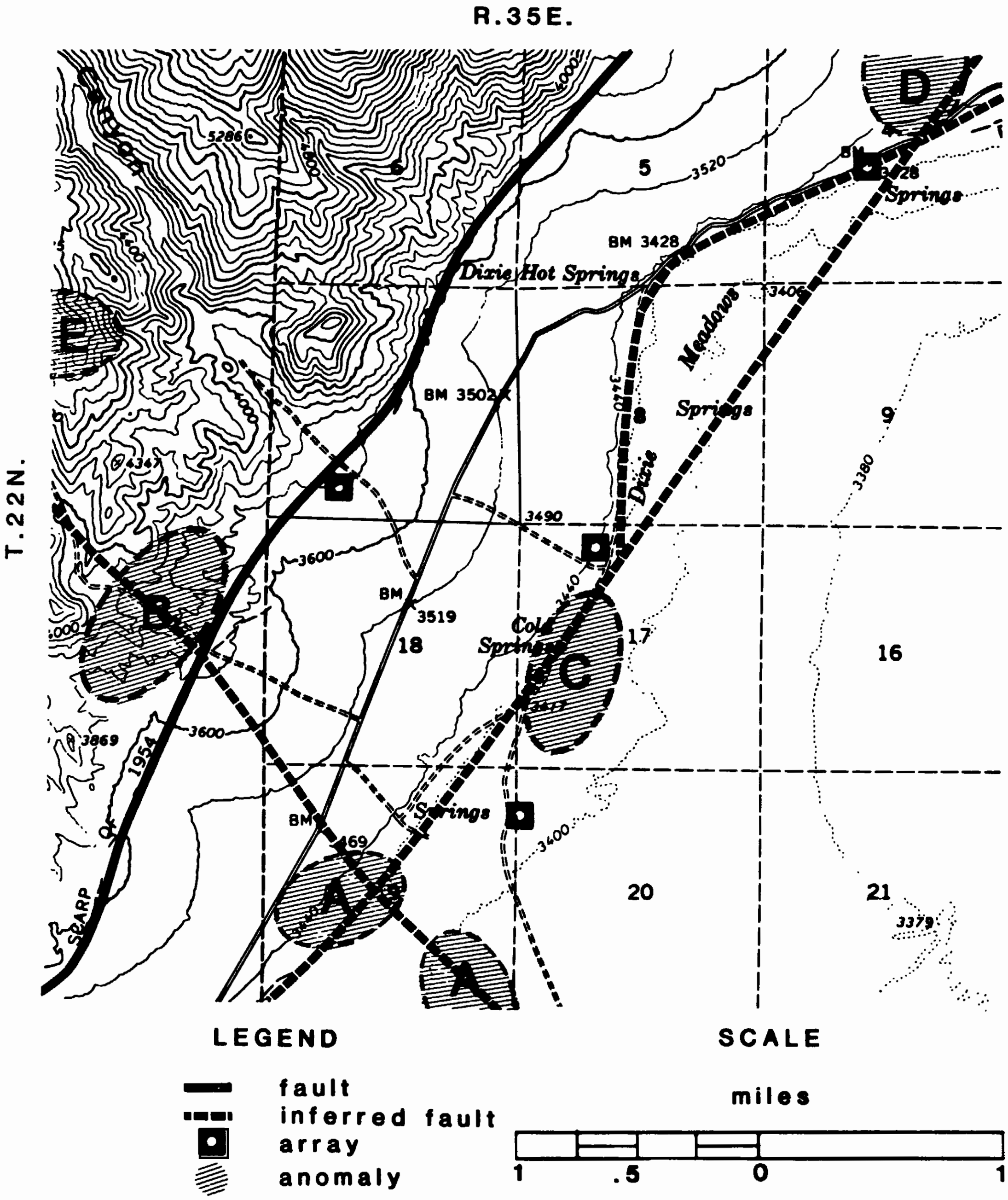

Figure 3