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MICROSEISMIC MONITORING AS A TOOL FOR MAPPING FRACTURES IN THE SAN ANDRES DOLOMITE

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INTRODUCTION

The San Andres dolomite is a prolific oil producing formation extending over a large area of the Permian basin of west Texas and eastern New Mexico. Waterflooding is typically used as a means of secondary recovery in the San Andres dolomite. One problem with waterflooding in some oil fields producing from the San Andres formation is flow anisotropy in reservoirs due to preferred flow along fractures. If the locations and orientations of major fractures in reservoirs were known, waterfloods could be better designed to use well configurations that would delay water breakthroughs and improve recovery. Oil fields of the San Andres dolomite typically have wells spaced uniformly at 400 m in a grid pattern parallel with section boundaries. Pressure interference testing is often not successful because of the large well separation, and the density of wells is insufficient to accurately infer flow direction from breakthrough patterns alone. Microseismic monitoring is an alternative method for determining the location and prevalent orientations of fractures. Los Alamos has successfully used the method in crystalline rock for mapping hydraulic fractures (Fehler et al., 1987). The method relies on the observation that microearthquakes occur along fractures when stress is changed along the fractures by increased fluid pressure. By determining the locations of the induced microearthquakes, some knowledge of the locations and orientations of the dominant fluid paths can be obtained. If the method can be shown to be successful in the San Andres dolomite, it could be a useful tool for optimizing waterfloods in the many fields throughout the Permian basin producing from the formation.

The focus of this study was to determine if microseismicity was detectable in the San Andres formation at rates high enough to be practical for mapping fractures. Microseismicity was monitored within the Chaveroo oil field during a pressurized stimulation of a well and intermittently over the following 5-week period while a pilot waterflood operation was underway. Figure 1 shows the well configuration in the square-mile section of the Chaveroo oil field where the experiment took place. During the pressurized stimulation three thousand barrels of water were injected into well 34-10 over a 5.5-hour period. Subsequently the 4 pilot waterflood injection wells each took about 200 to 250 barrels of water per day under hydrostatic pressure (Figure 1). A single, 3-component, downhole seismometer was placed at the reservoir depth of 1280 m in well 34-7, located 400 m north of the stimulation well 34-10.

MONITORING AND EVENT OCCURRENCE

Monitoring was intermittent over the total 5-week period, however, microseismicity was detected during each monitoring period. Figure 2 shows the monitoring time intervals and the number of events detected during each monitoring period. Data were recorded on both analog tape and digital field recorders. The field digital records provided an event-occurrence count, but their frequency bandwidth was too narrow for determining locations. Digitized analog records represented the signals' full frequency bandwidth because a higher sample rate was used. A more sensitive triggering algorithm was also used when digitizing the analog records, resulting in the detection of more microearthquakes over a given interval of time.

Little microseismicity was detected during the pressurized stimulation. Most of the microearthquakes were detected during normal waterflood production. The histograms in Figure 2 show the number of events detected for which both the compressional- (P-wave) and shear-wave (S-wave) phases could be identified.

Identification of both phases is required for locating events with a single seismometer. For each event identified with both the P- and S-wave phases, there were 4 to 5 events showing only a P-wave phase. Therefore, during normal waterflood production, hundreds of events were sometimes detected within as little as a 12-hour period. In principle, all events could be located if detected on a multi-station network of seismometers.

MICROEARTHQUAKE LOCATIONS

Microearthquake locations were determined using the hodogram technique where the direction to an event is taken as the orientation of the major axis of the best fitting ellipsoid to the particle motion (Matsumura, 1981). The distance to the event is determined from the time difference between the P- and S-wave arrivals. From the analog records 73 events could be reliably located, all of which occurred on the 19th and 23rd of June during waterflood production. Particle motions of the 3-component data indicated that microseismicity was occurring at or near the depth of production (1300 m). The location map shown in Figure 3, therefore, represents a plan view of microearthquake locations at production depth. Events were detected up to 1700 m from the monitor well, but most were within 900 m. A distance of 900 m implies, in principle, that a 2.5 square-km area could be monitored from a single downhole seismometer station. Linear features indicative of fracture patterns are not apparent from the microearthquake locations.

CONCLUSIONS

Microseismic monitoring shows promise of being a practical tool for mapping fractures in the San Andres dolomite in terms of the rate of microearthquake occurrence and the areal coverage possible from a single downhole seismometer. Microearthquakes were detected during normal waterflood production but monitoring was not complete enough to correlate injection/production activity with microseimic event recurrence. Constant monitoring time capability with at least 3 downhole seismometers is needed to more accurately locate events, and to reliably characterize seismic recurrence in the field. In addition, modeling pressure variations in the reservoir may help explain the mechanism that produces the microearthquakes. Data useful in modeling the pressure variations could be from tracer experiments, pressure interference tests and individual well production-injection volumes. Understanding the mechanism of producing the microearthquakes should, in turn, allow the correlation of the microseismicity with fluid flow within the reservoir.

ACKNOWLEDGMENTS

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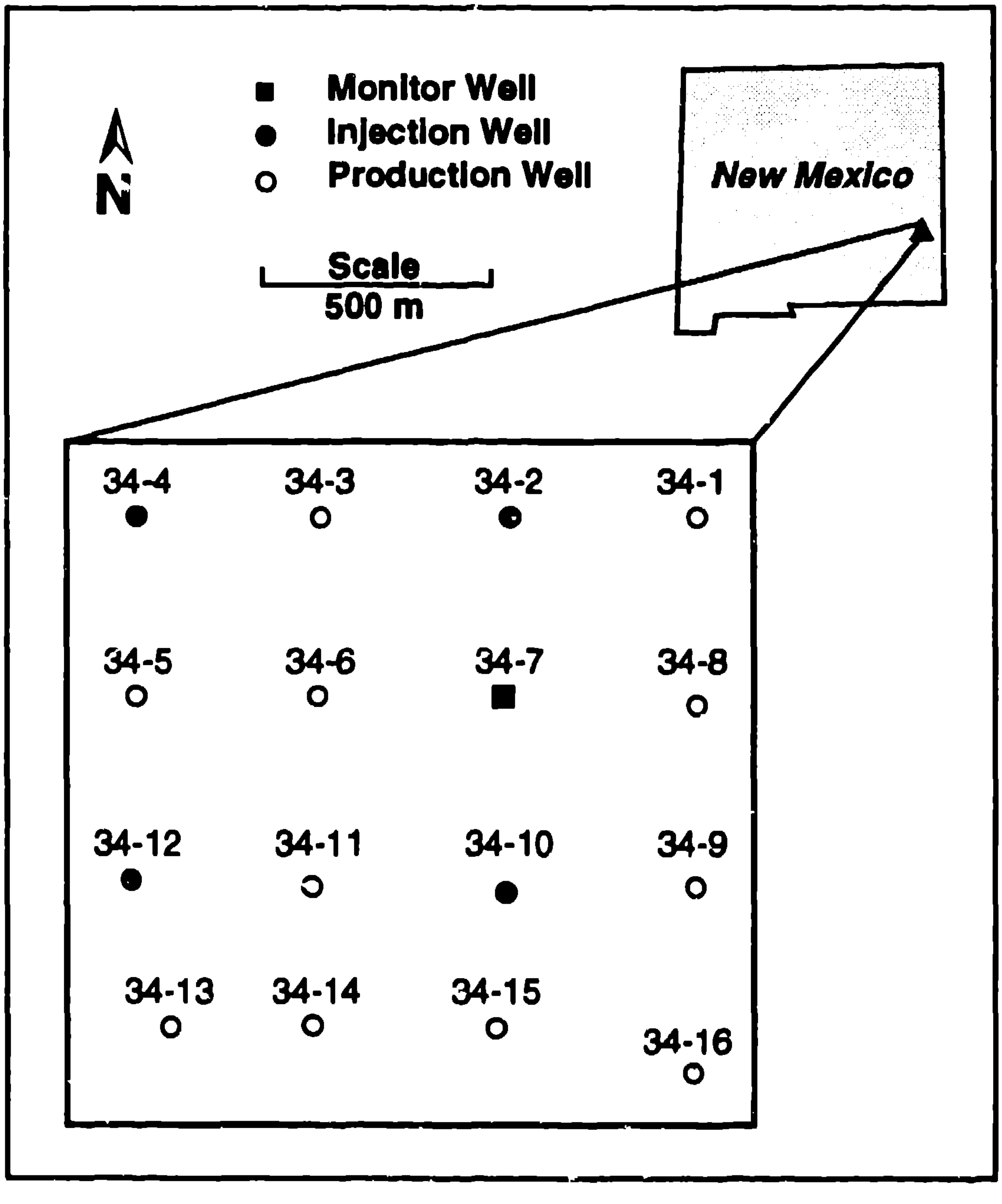
Matsumura, S., 1981, Three-dimensional expression of seismic particle motions by the trajectory ellipsoid and its application to the seismic data observed in the Kanto District, Japan: Journal of the Physics of the Earth, v. 29, p. 221-239.

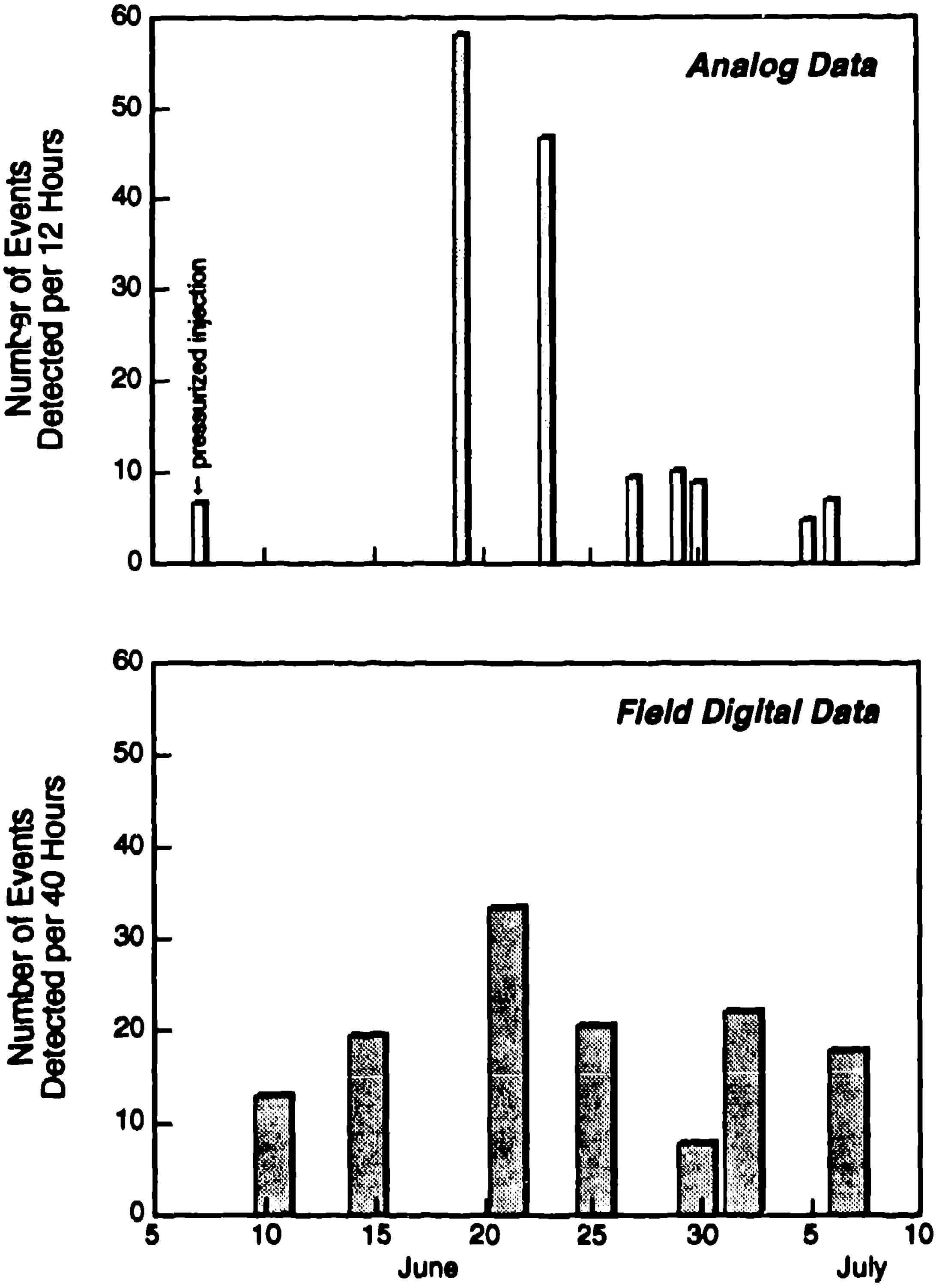
FIGURE CAPTIONS

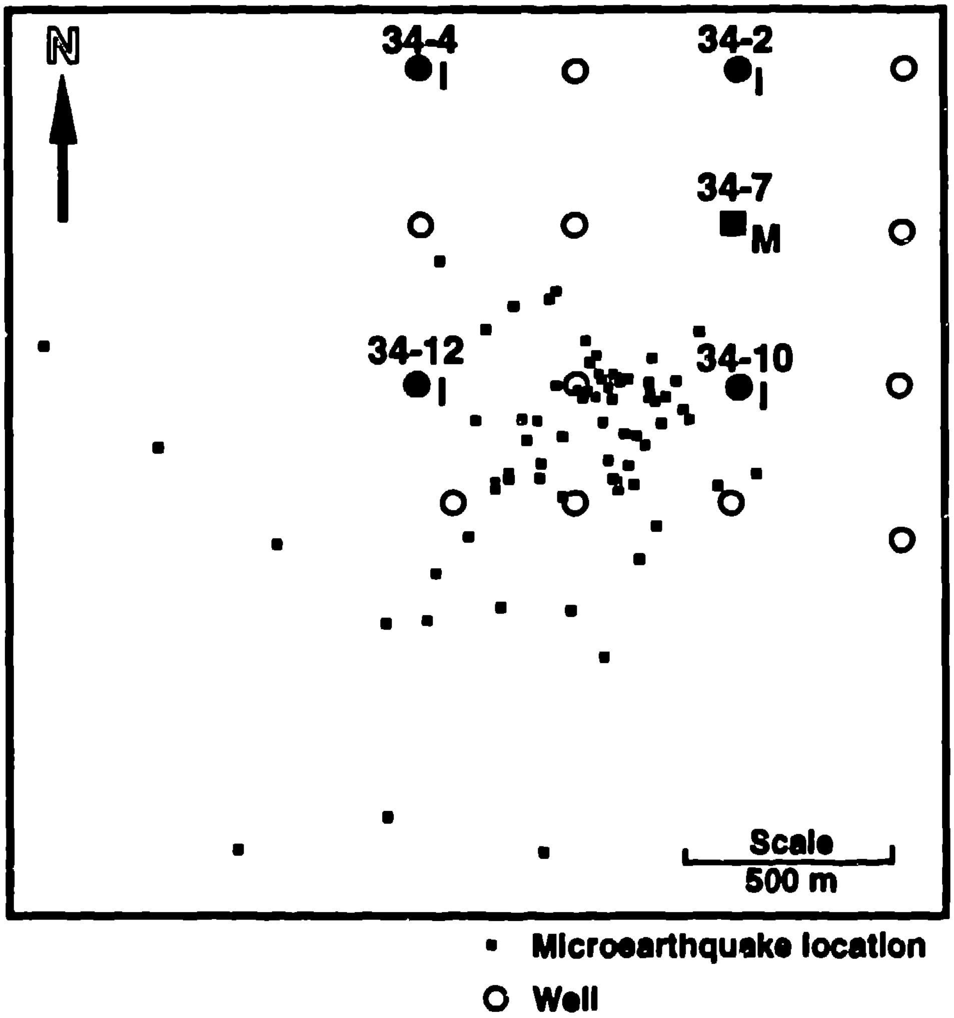
Figure 1. General location map and well configuration of Section 34 of Murphy Operating Corporation's Haley Unit, Chaveroo oil field, New Mexico.

Figure 2. Number of microearthquakes detected from the analog tape per 12 hour recording session (above), and the number of microearthquakes detected by the digital field recorder per 40 hour recording session (below). Monitoring was intermittent. Gaps between bars are when no data were recorded.

Figure 3. Microearthquake location map for events detected on June 19 and 23 shown with the wells of section 34. The map represents a plan view of event locations at production depth (1300 m). I=injector well, M=monitor well.


N
■ Monitor Well
● Injection Well
○ Production Well
Scale
500 m
New Mexico
34-4
34-3
34-2
34-1
34-5
34-6
34-7
34-8
34-12
34-11
34-10
34-9
34-13
34-14
34-15
34-16


Analog Data
Number of Events Detected per 12 Hours
← pressurized injection
60
50
40
30
20
10
0
Field Digital Data
Number of Events Detected per 40 Hours
60
50
40
30
20
10
0
5
10
15
20
25
30
5
10
June
July

N
34-4
I
34-2
I
34-7
M
34-12
I
34-10
I
Scale
500 m
▪ Microearthquake location
○ Well