PAPER A

HIGH RESOLUTION CROSS-WELL IMAGING OF A WEST TEXAS CARBONATE RESERVOIR

Part 1 - Project Overview and Data Acquisition

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Seismic Tomography Project

ABSTRACT

Cross-well traveltime tomography and reflection imaging were combined to produce high resolution images of a West Texas carbonate reservoir. The cross-well project reported on here represented the geophysical component of a miscible CO_2 flood pilot study. The project objectives were to (1) evaluate the effectiveness of the high frequency piezoelectric source, (2) assess the capability of cross-well seismology to assist with reservoir delineation and characterization prior to CO_2 injection, and (3) monitor movement of CO_2 after injection. Data were acquired using the piezoelectric source and a hydrophone array. Field operations were distinguished by the fact that nearly 80,000 seismic traces were recorded in approximately four days using the technique of recording with the source moving, i.e., on-the-fly. Initial tomography and reflection results illustrate vividly how high frequency cross-well seismology can be used for imaging subtle velocity variations and bed geometry inside a thin reservoir. Moreover, the results demonstrate the great potential of cross-well seismology to meet the needs of high resolution reservoir description. Data from two cross-well profiles are described, one between wells 184 feet apart, the other between wells 600 feet apart. In this paper, Part 1 of 5, we present an overview of the project, review data acquisition, and summarize the results. We discuss the hardware used, data gathering method, then summarize the results to date. The four companion papers present additional details.

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shown in the figure. Profile #1 was uniformly sampled at 2.5 ft. source and receiver spacing, Profile #2 at 5.0 ft.

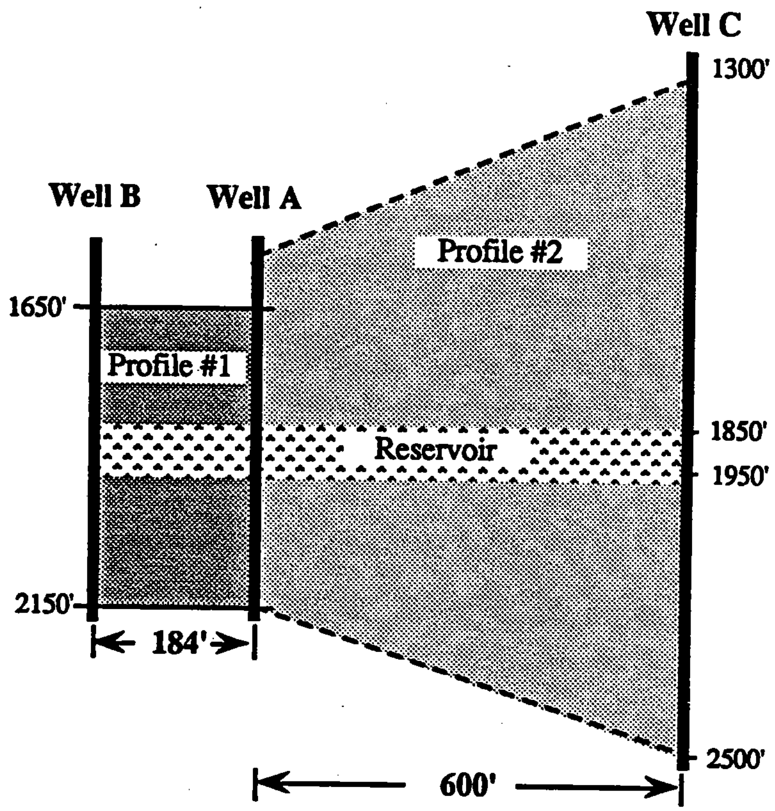


Figure 1. Profile #1 (201 sources x 178 receivers) was recorded between wells A and B. Profile #2 (240 sources x 153 receivers) was recorded between wells A and C. Receivers are in Well A.

Prior to these surveys, high frequency datasets recorded primarily for tomography were not suitable for reflection processing because of severe spatial aliasing of events with low phase velocity, e.g., reflected arrivals and tube waves (Rector, 1992a). Partly in response to our interest to create high resolution reflection images from cross-well data, we focused attention on improving data acquisition, namely finer sampling and faster field operations. The West Texas profiles described here were the first run using the new acquisition method of recording on-the-fly, where the source is continuously moving while being fired. This technique significantly improved both depth control and acquisition speed.

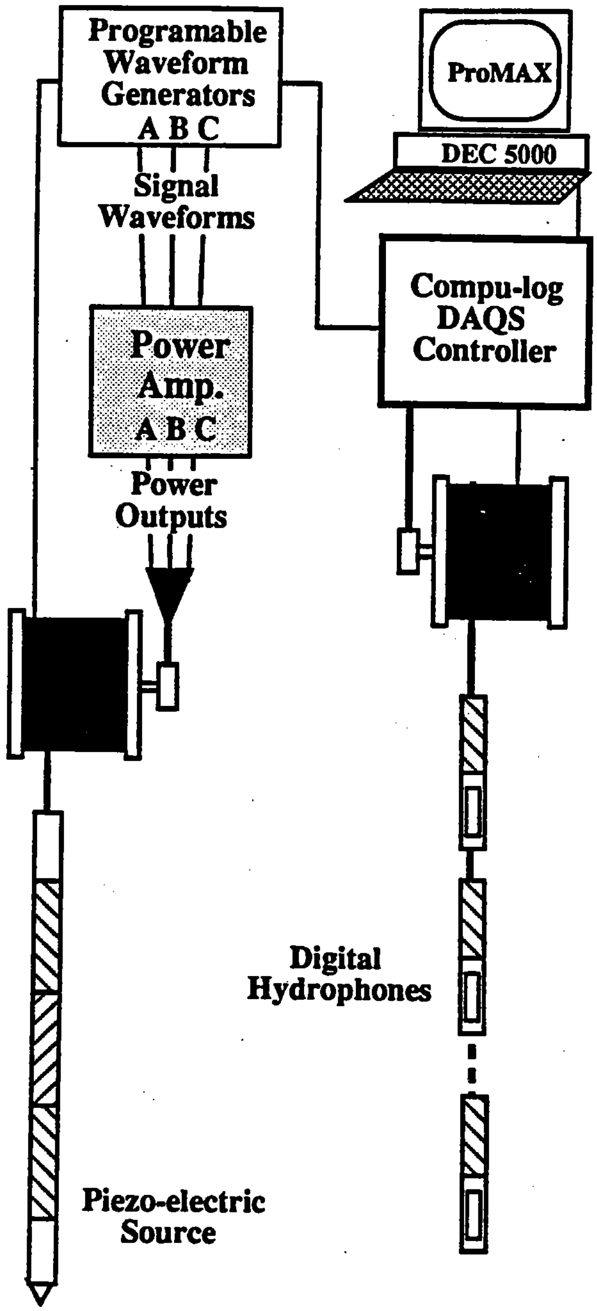
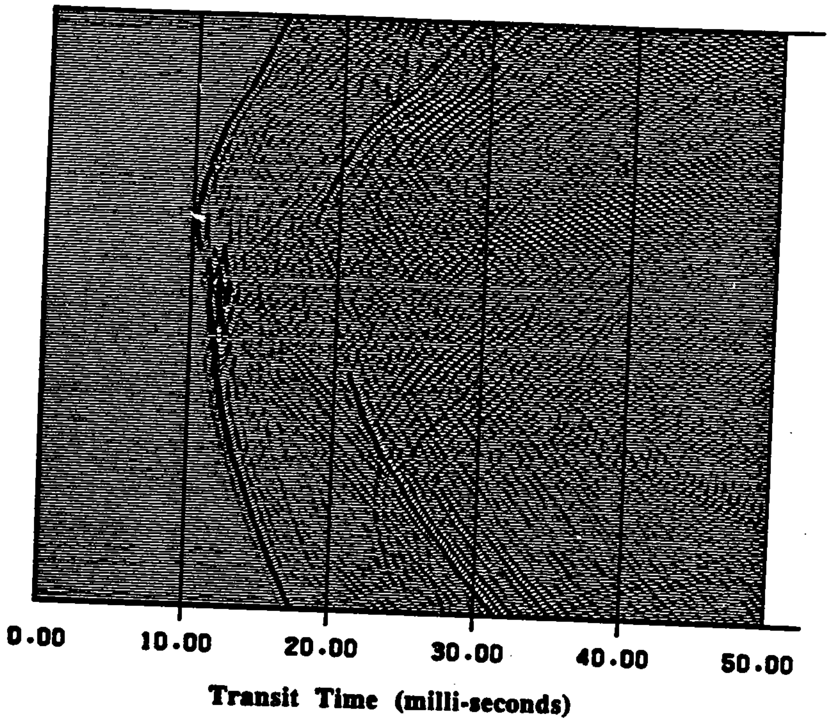
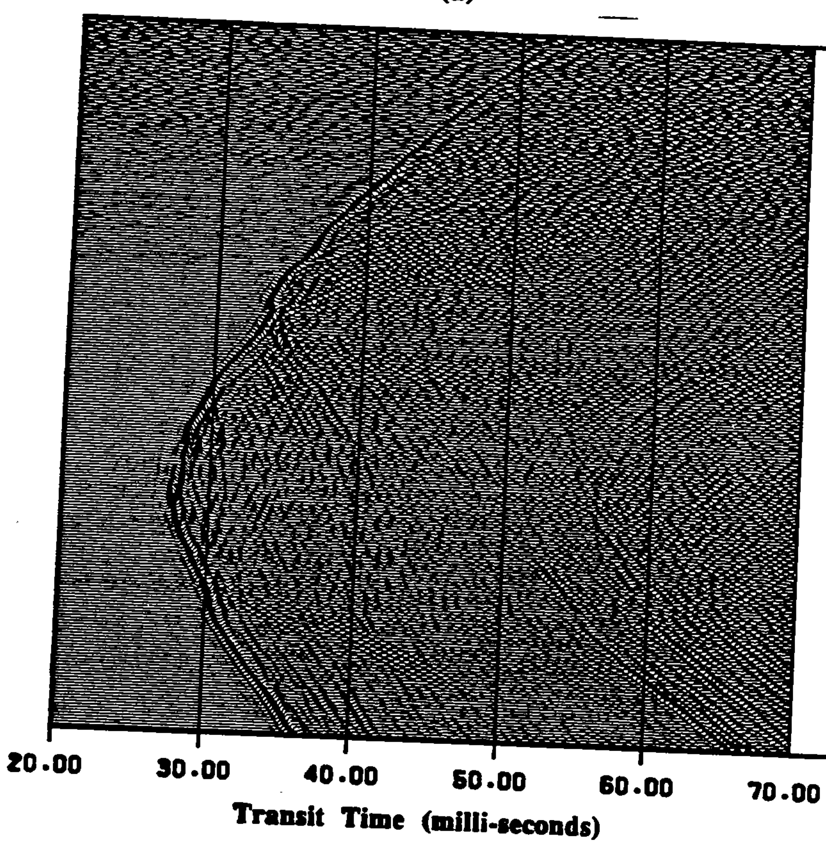


Figure 2. Diagram of the STP data acquisition system.



(a)



(b)

Figure 3. Common-receiver gathers: (a) Profile #1, 2.5 ft. source spacing; Wells A-B. (b) Profile #2, 5.0 ft. source spacing; Wells A-C.

The reflection image general from data for Profile #1, shown in Figure 5b, was generated by a pre-stack XSP-CDP mapping algorithm (Lazaratos, et al, 1992). Though the reflection image is qualitative in nature, it gives 2-3 times better resolution than the tomography. Wavefield separation (Rector, 1992b) played an important part in data preparation before imaging. The volume of data and sorts available from the cross-well geometry provide more opportunity for reflection enhancement. Although the imaging method is similar to offset VSP imaging, the XSP-CDP transform uses many more gathers of data and combines upgoing and downgoing reflections, in this case over 750 gathers. The image shown here is a "brute stack." Each common-source and common-receiver gather was mapped, then the independent images stacked. Reflectors imaged *inside* the reservoir (1850 ft - 1950 ft) provide an unambiguous measure of bed continuity, at a vertical resolution better than 5 feet. Aside from this excellent resolution, the image also provides other remarkable ties to the logs. See, for example, the twin features marked near 2100 feet in well A to the single feature marked in Well B. The reflection image may be used to guide connecting these features, thus delineating the geological framework of the interwell region.

For comparison, we show a typical surface seismic section from the West Texas study area (Figure 5c). (Absolute times and parts of the overburden have been removed.) These data were recorded with 250-foot shot-point spacing with about 50 Hz of bandwidth (e.g., 5-55 Hz). At reservoir depth, the wavelength approaches 300 feet; therefore, the entire 100-foot thick reservoir is visible only as a single event. Reservoir structure is unresolved. That is, no separate identification of the top, bottom, or internal structure is possible. Also, the entire lateral section imaged by cross-well is less than two surface seismic CDP points wide - as illustrated. Clearly, cross-well seismology, whether tomography or reflections, offers complementary high resolution advantages to surface seismic. And, unlike surface seismic, which is often presented as a time section, cross-well reflection images are true depth images with higher spatial resolution.

CONCLUSIONS

We have shown how cross-well direct wave traveltimes and reflections are combined to image the internal structure of a West Texas carbonate reservoir. The high resolution images result from the cooperation of new data acquisition and data processing techniques. Though at small scale, only 184 feet between wells for Profile #1, we believe our results illustrate the enormous potential of cross-well seismology to usefully address reservoir delineation and characterization problems. As illustrated in Figure 5, one role for cross-well imaging is to complement the low resolution but large coverage already available from surface reflection seismology. Although Profile #2 has yet to be processed, the initial results discussed for Profile #1 are only the beginning of a new high resolution technology. Also, much work remains to be done for this particularly study, including processing S-wave tomograms and S-to-S reflection images from both profiles. In addition, our plans include using logs, cores, and an anticipated 3D surface survey to make quantitative estimates of reservoir properties throughout the field. We believe that these results will be extremely useful in reservoir characterization for the CO_2 injection study. A post CO_2 injection survey is planned for late 1992 to attempt monitoring.

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