

Mapping Bedrock as Shallow as 4 m under Dry Alluvium with Seismic Reflections ENG 2.2

Don W. Steeples, Richard D. Miller, Kansas Geological Survey; and Michael Brannan, Phillips Petroleum Co.

SUMMARY

Shallow seismic-reflection techniques were used successfully to image the bedrock-alluvium interface as shallow as 4 m in the Texas Panhandle. Optimum placement of water-quality monitor wells around an evaporation pond was made possible because the seismic data showed bedrock valleys to within 1 m horizontally and vertically. The normal moveout velocity within the near-surface alluvium varies from 225 m/sec to 400 m/sec. The wavelet reflected from the bedrock-alluvium interface has a dominant frequency of 170 Hz. Low-cut filtering at 24 dB/octave below 220 Hz prior to analog-to-digital conversion was partially responsible for boosting the frequency content of the recorded data.

INTRODUCTION

Detailed knowledge of the bedrock surface is often crucial in the planning of well locations for ground-water quality monitoring. Changes in ground-water quality often first appear in monitor wells located in lows in the bedrock surface. Data possessing the necessary detail for conclusive bedrock surface mapping have generally come from extensive drilling programs, which are both time consuming and expensive. High-resolution seismic-reflection profiling has been used to image surfaces as shallow as 3 m and resolve beds as thin as 1 m in a variety of near-surface geologic settings (Doornenbal and Helbig, 1983; Birkelo et al., 1987; Myers et al., 1987; Treadway et al., in press; Branham and Steeples, 1988). The seismic-reflection technique has the potential to produce the necessary details of a shallow (4-m-deep) bedrock surface to pinpoint optimum locations for monitor wells.

RESOLUTION

Increasing the dominant frequency and broadening the frequency spectrum of recorded reflection energy improves resolution of shallower and thinner beds (Widess, 1973). This increase in the frequency of recorded energy can be obtained by severe low-cut filtering, proper field equipment for conditions, and careful field procedures. Severe low-cut filtering effectively attenuates the lower-frequency information (ground roll), which allows balancing of the spectrum toward higher frequencies. Also, by attenuating much of the high-amplitude, low-frequency information, analog gain of the seismic amplifiers can often be increased in the field to improve the signal-to-noise ratio.

GEOLOGIC SETTING AND FIELD PROCEDURES

The seismic survey included three 12-fold CDP lines around the perimeter of an evaporation pond in Hutchinson County, Texas (Fig. 1). Drill data from around the evaporation pond, prior to the seismic survey, showed a 3 to 15-m-thick layer of dry alluvium overlying a Permian red-bed sequence of limestones, shales, and dolomites. The preliminary bedrock contour map, compiled from drill data only, shows bedrock lows on the north end of the pond. The variations in bedrock elevation are primarily caused by an erosional surface of the Permian-aged red beds beneath the alluvium. The ground-surface topography is a generally subdued version of the major bedrock topography.

The data were acquired using a modified .30-06 hunting rifle, single undamped 100-Hz geophones, and an I/O DHR-2400 seismograph. The .30-06 rifle was modified with a blast-containment device that reduced the amplitude of the air-coupled wave and contained any stray bullet or rock fragments (Miller et al., 1986). The source was centered between two sets of 12 recording channels with a source-to-closest-receiver distance of 3.7 m. The source and receiver interval was 1.2 m. The single 100-Hz geophones attenuate energy below 100 Hz and maintain a flat response to energy up to 1000 Hz. The DHR-2400 is a fixed-gain system with A/D conversion of 11 bits plus sign. The amplifiers possess 72 dB of dynamic range with less than a 120 nanovolts RMS noise level. Pre-A/D low-cut filters with 24 dB/octave rolloff and -3 dB point of 220 Hz were used to maximize resolution and reduce the effects of ground roll. The close attention given to source-and-receiver ground coupling and to the selection of low-cut filters improved frequency response and reduced unwanted noise, which was essential to the quality and success of this survey (Knapp and Steeples, 1986).

DATA PROCESSING

Data processing was done on a 32-bit Data General computer at the Kansas Geological Survey with a proprietary set of algorithms that has been in standard use on TIMAP seismic systems marketed by Texas Instruments. Emphasis and detail was placed on near-surface velocity analysis and in muting refracted arrivals. The coherency of the stacked data was improved by the addition of a surface-consistent statics routine with a 1-msec (equivalent to about 1/6 of a wavelength) maximum

allowable static shift. The statics operation enhanced the subtleties previously suspected on preliminary stacked sections. No processing procedure or step after the detailed velocity analysis altered the general interpretation of the data.

RESULTS

The reflector identified as the bedrock-alluvium interface dominates the recorded data. The bedrock reflector is the largest amplitude and highest frequency coherent event on the field plots (Fig. 2). By collecting seismic data only within the optimum window (Hunter et al., 1984) and with relatively severe low-cut filters, energy reflected off anything deeper than the bedrock surface is attenuated to a level not observable on field data. The airblast energy and the reflected energy can be identified on the majority of the field plots. Clearly identifiable surface-wave energy is absent from the field plots. This can be attributed mainly to the severe low-cut filters and high-frequency projectile source.

The bedrock reflector can be clearly identified on the CDP gathers (Fig. 3). Due to the continuous and smooth nature of the reflection on the gathers, a unique normal-moveout velocity can be calculated and applied with a high degree of confidence. A lack of velocity control can easily decrease the dominant frequency and bandwidth of the final stacked section. With the application of an NMO velocity that is incorrect, the apparent relative bedrock depth could be erroneous.

Line 1 traversed the east side of the pond intersecting line 2, line 3, and the test boring well MW-7 (Fig. 4). Data quality is quite good with a discernible bedrock reflection prominent across the entire line. After removal of the refracted arrival by muting, the lone event on the CDP stack is the bedrock reflector. As expected, the bedrock surface has a local slope similar to the ground surface. The test-well data confirmed the identification of the reflection as bedrock surface. The undulation of the seismically defined bedrock surface, as shown on the bedrock-contour map (Fig. 5), is indicative of paleo-drainage patterns and was not expected to be so dramatically different than present-day topography.

The two bedrock contour maps, one derived from drill data (Fig. 1), the other from drill data and seismic data (Fig. 5), show the general bedrock surface trend of the area. The contour map developed from the combined seismic and drill data, however, shows much more detail. The subsurface sampling interval is 0.6 m for the seismic profile, whereas the drill-data subsurface spacing is approximately 60-100

m. The increased subsurface resolution obtained with seismic-reflection data allows accurate placement of a minimum number of wells to monitor fluid levels and water quality. The bedrock valley most likely to channel subsurface fluids from the pond is located at CDP 1018 on line 2 and 2016 on line 3 (accuracy 1 m). A second potential channel for subsurface flow along the bedrock-alluvial interface is at CDP 937 on line 2. If well placement were determined from drill data alone, the accuracy would be no better than 40 m.

CONCLUSIONS

Shallow reflections recorded from the bedrock surface at this site in Hutchinson County, Texas, possessed sufficient resolution to confidently identify the major paleo-drainage and bedrock lows near an evaporation pond. The dominant recorded frequency of the data was about 170 Hz. The seismic data improved the accuracy and precision of the bedrock-structure map by more than an order of magnitude. Shot-point-by-shotpoint velocity analysis was necessary to properly correct for the normal-moveout alignment of the bedrock reflector. Without the detailed lateral-velocity analysis, extreme velocity variations over short segments of the line could have resulted in decreased frequency and coherency of the stacked data and erroneous calculations of depth-to-bedrock. The bedrock reflector varies in two-way travel time between about 30 msec and 80 msec (after elevation correction), which equates to a bedrock depth from about 4 m to 10 m. This much depth fluctuation and velocity variability in the near-surface material would cause severe statics problems for deeper reflection surveys. The coherency and ease of a confident interpretation was greatly enhanced by the application of a detailed surface-consistent statics routine. The optimum location for a single monitor well is at CDP 2016 on line 3.

ACKNOWLEDGEMENTS

We appreciate the release of this work for publication by Phillips Petroleum Company and Great Plains Geophysical. We would also like to thank Esther Price for her work in manuscript preparation, Rex Buchanan for his editorial suggestions, and Pat Acker for the quality graphics.

REFERENCES

- Birkelo, B. A., Steeples, D. W., Miller, R.D., and Sophocleous, M.S., 1987, Seismic reflection study of a shallow aquifer during a pumping test: *Ground Water*, 25, 703-709.
- Branham, K. I., and Steeples, D. W., 1988, Cavity detection using high-resolution

seismic reflection methods: AIME Transactions, in press.

Doornenbal, J. C., and Helbig, K., 1983, High-resolution reflection seismics on a tidal flat in the Dutch Delta-acquisition, processing, and interpretation: First Break, 9-20.

Hunter, J. A., Pullan S. E., Burns, R. A., Gagne, R. M., and Good, R. L., 1984, Shallow seismic reflection mapping of the overburden-bedrock interface with the engineering seismograph--some simple techniques: Geophysics, 49, 1381-1385.

Knapp, R. W., Steeples, D. W., 1986, High-resolution common depth point seismic-reflection profiling, field acquisition parameter design: Geophysics, 51, No. 2, 283-294.

Miller, R. D., Pullan, S. E., Waldner, J. S., and Haeni, F. P., 1986, Field comparison of shallow seismic sources: Geophysics, 51, 1067-1092.

Myers, P. B., Miller, R. D, and Steeples, D. W., 1987, Shallow seismic reflection profile of the Meers fault, Comanche County, Oklahoma: Geophysical Research Letters, 15, 749-752.

Treadway, J. A., Steeples, D. W., and Miller, R. D., 1988, Shallow seismic study of a fault scarp near Borah Peak, Idaho: Journal of Geophysical Research, in press.

Widess, W. B., 1973, How thin is a thin bed?: Geophysics, 38, No. 6, 1176-1180.

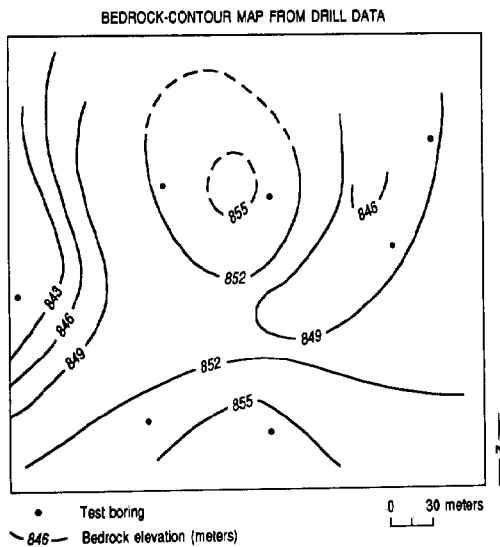


FIG. 1. Bedrock surface topography defined by drill data.

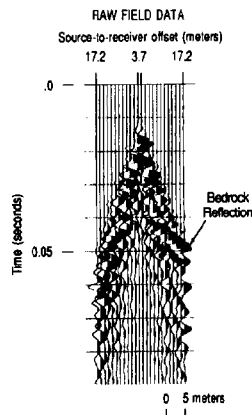


FIG. 2. Field plot identifying bedrock reflector.

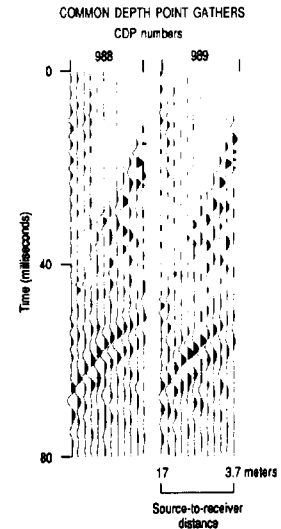


FIG. 3. CDP gathers.

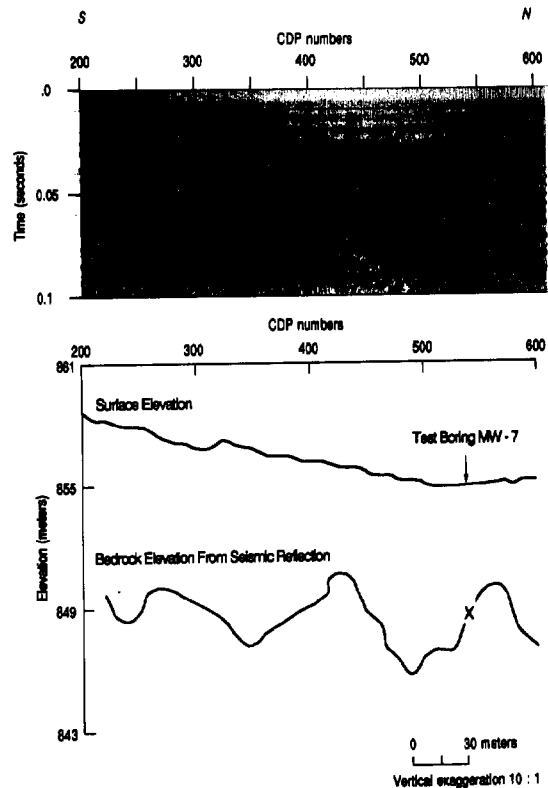


FIG. 4. 12-fold stack and interpreted bedrock surface.

Mapping bedrock with reflections

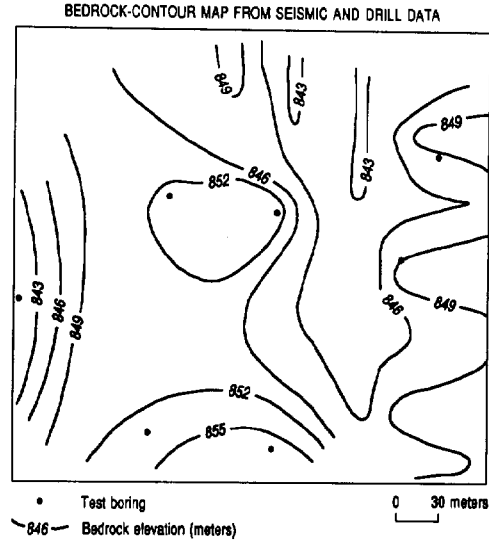


FIG. 5. Bedrock surface using seismic profiles.