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A High Resolution Seismic Reflection Profile at the Prince Ranch, South Dakota

by

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INTRODUCTION

This report discusses the results of a seismic-reflection survey conducted by the U.S. Geological Survey on the Prince Ranch approximately 35 km west of Pierre, S. Dak. (fig. 1). Previous workers in this area observed evidence of stream rejuvenation (Jones-Cecil, and others, 1988), and basement faulting in seismic reflection profiles (T.C. Nichols, unpub. data, 1989). We were asked to use high-resolution seismic reflection methods to examine if faulting occurs in formations which overlie basement. The 1.2-km reflection profile was oriented approximately north-south along the east side of a cattle fence running through the middle of sec. 14, T. 5 N., R. 27 E. The southern end of the profile is located 0.8 km (N. 79 E.) from the southwest corner of sec. 14.

The seismic data are of sufficient quality and resolution (100 Hz dominant frequency) to show small-scale structural features, such as faulting and folding, in formations that overlie the basement. However, the 0.5 sec reflection record (equivalent to about 730 m in depth) does not include the basement reflector, which occurs at about 0.65 sec on a commercial seismic-reflection profile located 0.5 km east of the USGS line (T.C. Nichols, unpub. data, 1989); therefore, direct correlation between shallow structures and the basement can not be made.

FIELD METHODS

The seismic-reflection data were recorded using a 24-channel digital seismograph with a 50 Hz low-cut recording filter to help suppress ground roll, air-blast, and refraction energy. Common-depth-point (CDP) techniques (Mayne, 1962) and the Mini-Sosie method (Barbier, 1983) were employed for total profile length. Four modified earth tampers (Wackers) were used as the seismic energy source. The Mini-Sosie method uses seismic signals and time of impact (a combined total of 1500 impacts per station) of the four Wackers in an autocorrelation process. In this process, the time series formed by the impact times of the Wackers, is cross-correlated with the recorded seismic signal. The Wackers operate simultaneously, independently, and at random speeds. Geophone groups consisted of six 28-Hz (natural frequency) geophones clustered together and placed 9.1 m apart for each cable take-out and data channel. Maximum offset between the source and the nearest geophone was 27.4 m. The data were transferred to digital tape during the recording process.

DATA PROCESSING

The recorded digital data were processed on a VAX/780 computer using Digicon's DISCO seismic-processing software at the U.S. Geological Survey, Denver, Colo. Basic data-processing procedures were used in the following sequence:

(1) Trace edit to remove noisy data
(2) CDP trace sorting
(3) Elevation timing correction (datum statics)
(4) Exclusion of refraction energy and surface waves (muting)
(5) Seismic velocity analysis (normal-moveout-correction)
(6) CDP compositing (CDP stack)

(7) Frequency filter
(8) Mild coherency filter
(9) Automatic-gain-control (AGC) scaling

The seismic data are displayed in this report in record-section format (fig. 2) that shows reflection amplitudes in a time-versus-horizontal distance plot.

DISCUSSION

The structural deformations observed in this reflection profile appear to be continuous from the deepest to the shallowest reflector in the profile. However, for a given structure, the amount of deformation in shallow reflectors is less than that observed in deeper reflectors. In some cases, the faults that offset the deepest reflector may not be continuous to the shallower reflectors and instead create small folds in these shallow reflectors.

Five primary semi-continuous reflectors are observed in the section (fig. 2). Four reflectors can be correlated to known formation contacts by using the seismic velocity model derived from the data and the electric log from the Prince No. 23-14 drill hole (R.A. Schoon, written commun., 1988). This drill hole is located approximately 35 m east of station 195. The reflectors, designated R1 thru R5 (fig. 2), are associated with the following formations and the depths are determined from the ground surface (604.7 m).

Reflector Number	Formation	Calculated Depth (m)	Prince 23-14 Depth (m)
R1	Base, Pierre Shale	203.6	213.4
R2	Base, Niobrara Chalk	300.5	307.2
R3	Unknown	428.5	
R4	Top, Dakota Sandstone	527.3	502.9
R5	Top, Inyan Kara Sandstone	669.3	647.7

The zero time line in the reflection profile is equivalent to an elevation of 579.1 m (fig. 2). Discrepancies between the calculated formation depth and well log depth are probably due to errors in the calculated velocity model and the indefinite location of boundaries between formations observed on the well log. These indefinite boundaries may be generating a reflection at a slightly different depth than the depth picked on the well log for the contact between two formations. In general, the profile depths are in relative agreement with the depths observed on the well log.

Four different structures that deform R5 were analyzed, and their changes in appearance and dimensions on the reflectors above R5 were noted. The locations of these structures were identified by their corresponding station location number that is annotated immediately above the zero time line on the reflection profile of figure 2. The apparent regional dip on all reflectors is about 1.5^{o} south. The smaller structures, which are the focus of this report, are imprinted on the overall regional dip.

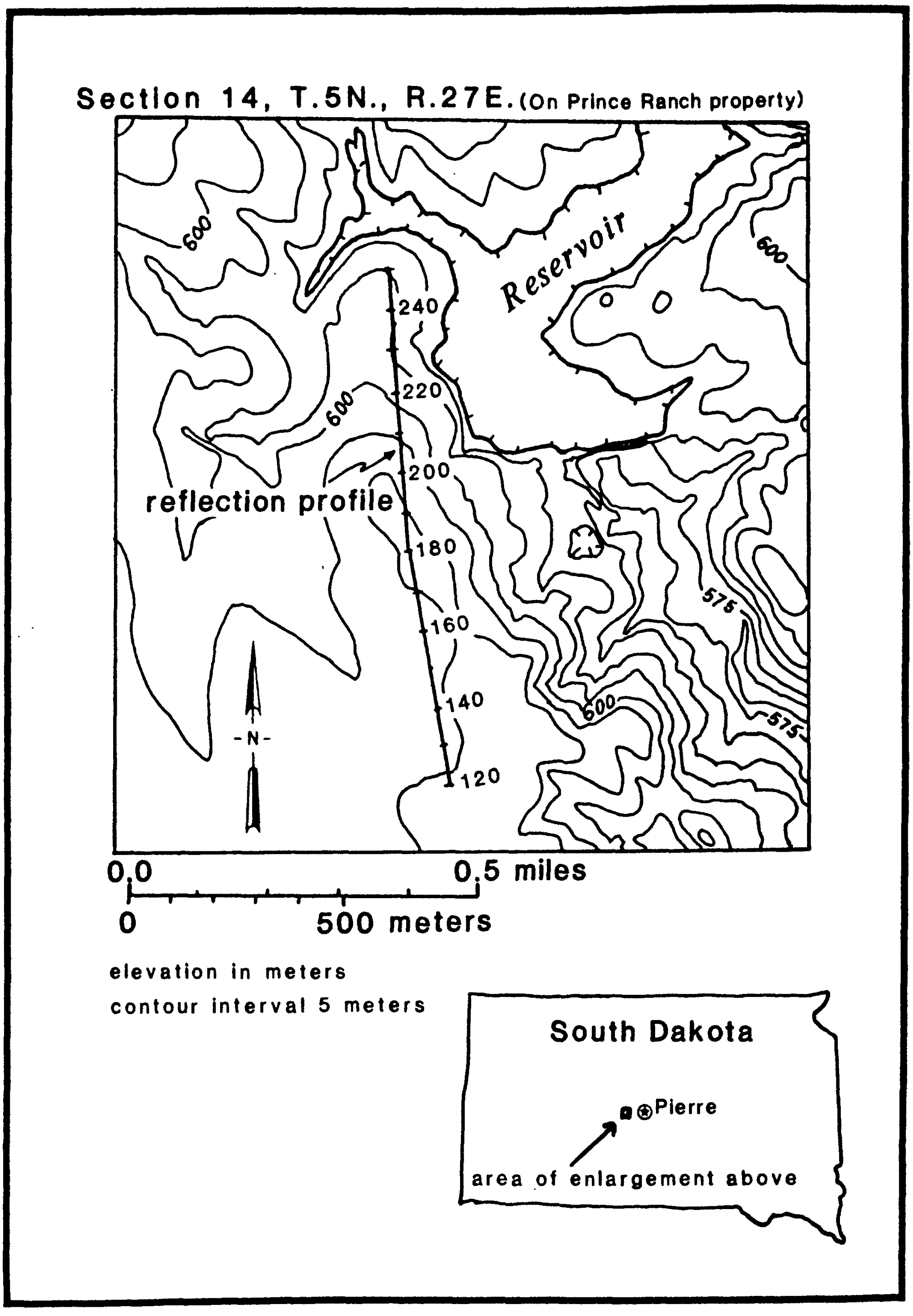

Figure 1. Location of reflection profile in Sec. 14, T. 5 N., R. 27 E., on the Prince Ranch property about 800 m north of S. Dak. Highway 14. Numbers annotated along the profile are station numbers used to identify geophone positions in the field, and to locate structural features in the seismic section shown in figure 2.

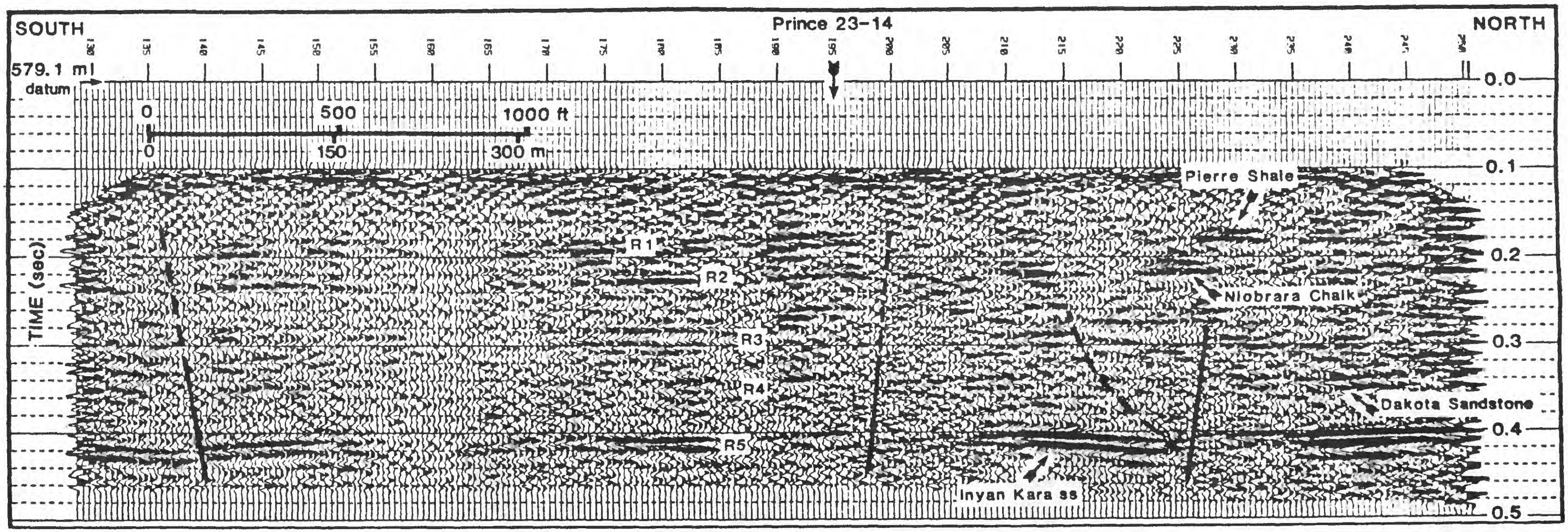

Figure 2. Seismic-reflection profile showing the position of five main reflectors (R1-R5), and location of Prince 23-14 drill hole. Numbers annotated across the top of the profile are the station numbers referred to in the text. Calculated depth to R5 is 669.3 m from the ground surface at station 195. Heavy lines (dashed where there is less certainty) denote the location of faults

Structure 1

Structure 1, below station 225 (fig. 2), appears to be a fault vertically offsetting R5 by approximately 55 ft (down to the south relative to the north). The discontinuity seems to continue vertically up into R4 and R3. The coherency of reflectors in the region of the apparent offset in R4 and shallower reflectors is degraded, possibly as a result of faulting. It is less certain that R4 and R3 are faulted. Apparently R4 and R3 are deformed similarly to R5, that is, they are down-dropped to the south. If R4 and R3 are faulted, the offset is approximately the same as R5. Above R3 the discontinuity seems to fade or disappear. Evidence of the discontinuity is not present at an unidentified reflector at .275 sec, and reflectors R2 and R1 do not appear to be affected by this discontinuity as both display relatively flat horizons in this zone.

The fault cutting reflector R5 at station 225 appears to have a southward splay that causes an approximate 7.6 m offset in reflectors R4 and R3. The locations of the offsets in R4 and R3 indicate that this portion of the fault bends toward a vertical orientation. Reflector R2 and R1 do not appear to be affected by this splay as they remain relatively flat on each side of the fault zone.

Structure 2

Structure 2 appears to be a low-amplitude anticline (expressed on R5) that stretches from about station 195 to station 225 (fig. 2). The formation of this fold may be related to the faulting that occurrs at station 225 because the fold seems to terminate at the fault. The maximum height of this fold on R5 is about 24.7 m. The anticline is also observed on R4 and R3, with a fold height of about 19.8 m, and has the same axis position as seen on R5. R2 and R1 are not well imaged in this region; therefore, folding is unclear. They appear to be structurally higher by about 12.2 m in the region of the fold compared to the depth of R2 and R1 at station 190.

Structure 3

Structure 3 is a fault located on the south side of the fold described above at station 195 (fig. 2). Here, R5 appears to overlap itself as if in a south over north thrust position. The overlap is probably created by a discontinuity in R5 which causes the processing methods to improperly position the seismic data points. The overlap zone represents an approximate 24.4 m vertical offset fault in R5 and R4. In this case, fault displacement places R5 and R4 up on the south side of the offset, which is opposite to the displacement on the fault at station 225. This particular discontinuity is not evident in R3 due to the lack of reflector coherency. R2 and R1 do not appear to be offset by this fault if the fault is nearly vertical. Instead, R2 and R1 appear to have a slight up-warp that may represent how these horizons reacted to faulting occurring beneath them.

Structure 4

Structure 4 is observed in the area beneath station 140 (fig. 2), and its shape is similar to that seen in structure 1. An apparent discontinuity at station 140 drops R5 down to the south about 12.2 m. Then, south of the discontinuity, R5 arches upward toward station 130 until the reflector is approximately 9.1 m higher than the discontinuous reflector at station 140. It is unclear if the discontinuity at R5 cuts any shallower reflectors. Reflectors R4 and R3 appear to have a similar down-warping structure. If this discontinuity is a fault and it does cut reflectors above R5, the exact location is obscured by poor coherency of reflectors in this zone: an effect that is possibly due to rock fracturing by fault movement.

Zones Void of Reflections

Two explanations for the regions of the reflection profile that are nearly void of reflectors appear to be: (1) the zone represents a region where the reflectors are physically disrupted by faulting and, therefore, presents an irregular reflecting surface to the incident seismic waves, and (2) conditions in the near surface, the upper 10 to 20 ft, cause scattering or absorption of the seismic energy so that it never reaches the reflectors at depth.

The region between stations 158 to 165 is the most prominent of the barren zones. The lack of reflectors in this zone is not caused by faulting because R1 and R5 show faint indications that they may be folded but not faulted in this zone. There is unclear continuity of the other reflectors across this zone. The main cause of this barren zone may be due to the near-surface effects mentioned above when comparing this zone to structure 1, where a prominent fault is observed and there is no widespread degradation of the reflectivity.

SUMMARY

The high-resolution seismic-reflection methods revealed previously unknown structural features in the sedimentary section (180 to 640 m-depth range) overlying the basement in the study area. The sedimentary section, profiled in this study, includes the base of the Pierre Shale (R1) to the top of the Inyan Kara Group (R5). Four possible faults and a small anticline (that may be related to the faulting) offset the Inyan Kara Group Sandstone. These faults may have caused folding and possible faulting in the horizons above R5, though the amount of deformation decreases toward the surface. Regions of the reflection profile, where reflectors are discontinuous, may be the result of fracturing created by faulting, near-surface absorption, scattering of the seismic signal, or a combination of these phenomena.

REFERENCES

Barbier, Maurice G, 1983, The Mini-Sosie Method: Boston, International Human Resources Development Corporation, 90 p.

Jones-Cecil, Meridee, Collins, Donley S., and Nichols, Thomas C., 1988, Stream Analysis--evidence for rejuvenation near Pierre, South Dakota: EOS [Transactions of the American Geophysical Union], vol. 69, no. 18, p. 567-568.

Mayne, W.H., 1962, Common Reflection Point Horizontal Data Stacking Techniques: Geophysics, v. 27, p. 952-965.