USING HIGH RESOLUTION SEISMIC REFLECTION TO STUDY THE CONVERGENCE OF THE HUMBOLDT FAULT ZONE AND THE NEMAHA RIDGE NEAR BELLEVUE, NE

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Abstract

High-resolution seismic reflection was used in association with borings to delineate the structural complexities of the Humboldt Fault/Nemaha Ridge near their convergence and intersection with the Midcontinent Rift (Midcontinent Geophysical Anomaly, MGA) in east-central Nebraska. A drilling program intended to explore for high quality limestone necessary for milling cement encountered an unexpected inconsistency in the depth of the top of the Mississippian. A limestone locally marking for the Mississippian-Pennsylvanian boundary appeared to be offset over 125m between two boreholes separated by less than a kilometer. High-resolution seismic profiles were acquired at near right angles to the axis of these three major mid-continent structures to map the upper 300m and define the nature of the structural discrepancy between the two boreholes. Using a high frequency vibrator and a 240-channel recording system. Seismic reflections were recorded from depths over 300m and with dominant frequencies above 120 Hz. A common mid-point stacked section depicts two complex fault zones separated by an uplift structure almost 800m wide. Seismic interpretations suggest this drill-discovered anomaly is related to faulting and associated uplift along a narrow section of the northernmost extension of the Nemaha Ridge. Borehole 02-18D penetrates the a portion of the Humboldt Fault Zone and 02-17D is situated in a basin immediately west of the Nemaha Ridge. The missing Mississippian rocks were uplifted on the top of the anticline, eroded and been replaced by at least 120m of cyclic Pennsylvanian strata. Seismic reflection data provide insight into the processes and timing of this major mid-continent structural feature. Based on drill data alone, the discrepancy between these two boreholes could be interpreted to have the result from faulting, structural unconformity, or erosion.

Introduction

Shallow, high-resolution seismic reflection techniques have been successful at delineating structural and stratigraphic features associated with tectonic and depositional features within the mid-continent, especially in Kansas and Oklahoma (Miller et. al., 1990b; Geier, 1999; Miller et al., 1995b). This technique was used to define the structural complexities associated with a 120m discrepancy in the uppermost part of the Mississippian contact between two boreholes separated by less than a kilometer outside of Bellevue, NE. The site is situated immediately north of the Nemaha Uplift (Ridge) within a zone defined as part of the Midcontinent Geophysical Anomaly (MGA) (Steeples, 1995).

Geophysical Setting

The two main geological features of eastern Nebraska are the Nemaha Uplift defined on the east by the generally north/south Humboldt Fault Zone identified or inferred to be present within the Paleozoic or upper Pre-Cambrian, and the Midcontinent Geophysical Anomaly (MGA) bounded on the south by the Union Fault running northeast-southwest (Burchett et. al., 1985). This survey was conducted north of the Nemaha Ridge within an area that was predominantly influenced by past tectonic activity linked to the Precambrian Midcontinent Rift System (see **Figure 1**).

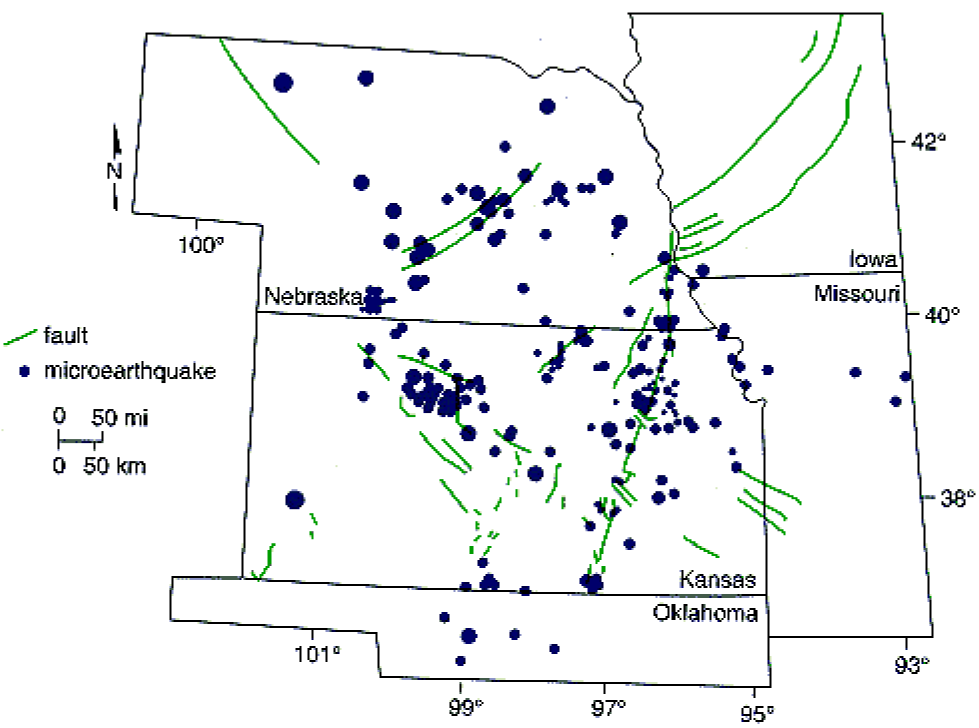

Figure 1.: Micro-earthquakes recorded by the Kansas Geological Survey between August 1977 and August 1989 are size-coded by local magnitude (Steeples, 1995).

The Nemaha Uplift consists of a buried mountain range composing of granite that began formation 300 million years ago around the end of the Mississippian period and the beginning of the Pennsylvanian. Its extent ranges from Omaha to Oklahoma City (**Figure 2**). Parts of the eastern front of the mountain range vary in elevation and change from over 600m in less than 5km, to several hundreds of meters across, as large as entire counties (Cole, 1976; Geier, 1999). Faults that bound the Humboldt Fault Zone suggest from micro-earthquake activity to still be slightly active today. The proximity of this survey to the MGA and Nemaha Ridge suggests regional faulting and folding of the mid-Pennsylvanian and early rock layers should be expected. Two coreholes located within a half-mile of each other and about two miles from a basement granitic intrusion were drilled to explore for high grade limestone used in the production of cement provided the ground truth for the study. Rocks encountered in the two boreholes possess dramatic differences in layer thickness and composition below 120m. Borehole 02-17D shows Pennsylvanian shale resting unconformitably on Mississippian Limestone at a depth of 170m, whereas at borehole 02-18D, the limestone has been replaced with 120m of cyclic Pennsylvanian sequences.

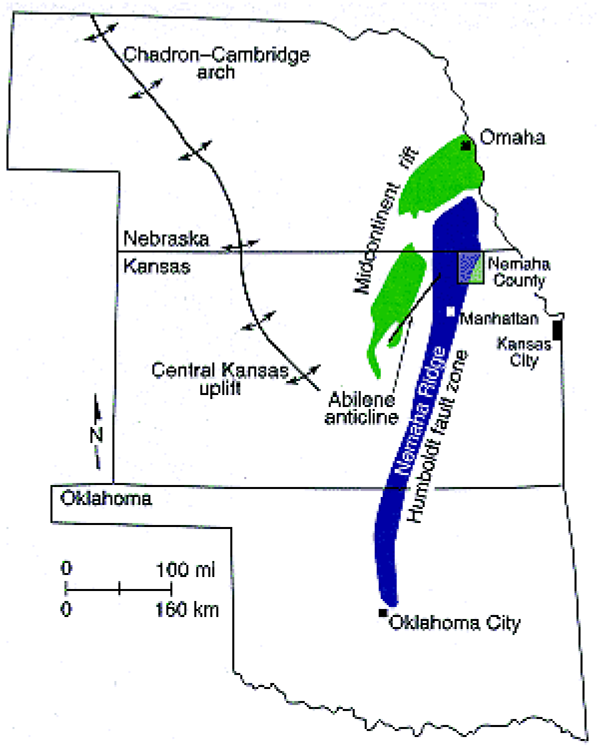

Figure 2.: Regional tectonic features that are apparently related to earthquake activity. Nemaha County is the location where the Nemaha Ridge was discovered in the early 1900's (Kansas Geological Survey, 1989, Bulletin 226).

Data Acquisition

Three sub-parallel east-west profiles ranging from 2km to over 3km and separated by less than 8km were recorded in hopes of intersecting the major structures responsible for the discrepancy between the two boreholes. A IVI Minivib, 40Hz geophones with a receiver spacing of 5m and a source spacing of 2.5m were used to record seismic reflections with dominant frequencies over 125Hz to depths greater than 300m, and were recorded on a 24-bit, 240-channel Geometrics StrataView seismograph. The profiles were approximately two miles long with the boreholes located between the survey lines (**Figure 3**).

Data processing focused on enhancing the signal-to noise ratio. Processing steps were similar to conventional petroleum exploration flows (Yilmaz, 1987). Specific distinctions are related to the emphasis placed on velocity analysis (Miller, 1992), lack of extensive wavelet processing, care and precision placed on muting, step-by-step analysis of effects of each operation on reflected energy, limiting statics operations to maximum shifts no greater than one-quarter wavelength of the dominant reflection energy with large correlation window, and coincident iterative velocity and statics analysis. Data suffered from significant attenuation, which was likely related to this extremely young alluvial setting and significant cultural noise associated with gravel mining operations.

Special emphasis was placed on the analysis portions of the processing flow. Velocity, spectral and deconvolution analysis benefited greatly from study of every CMP (Steeples and Miller, 1990). Differentiating between reflections from the direct wave, refractions, air wave and ground roll proved to be a difficult task and on that proved key to producing and interpretable CMP stacked section.

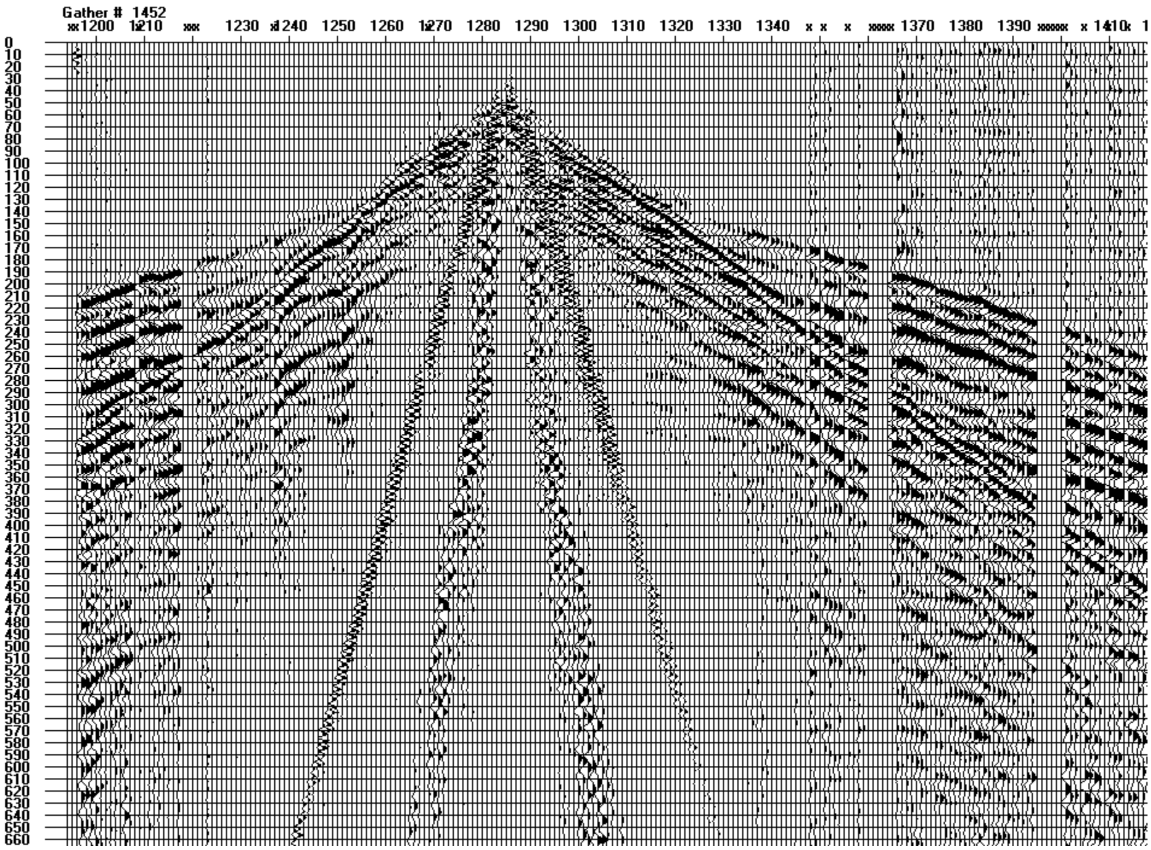

Figure 3.: Shot gather #1452 recorded on northern border of the site.

Data Analysis

Faults and folds define a plunging anticline with more that 150m of vertical displacement. A 2-D CMP stacked section located in the center of the study area suggests the west portion of the site up to CMP #4180 includes the full undisturbed section of Pennsylvanian strata overlying a thick Mississippian section, which starts at about 180m below ground surface. To the east of the undisturbed segment is a series of normal faults and folds. Borehole 02-17D is located within this region. By combining the seismic and borehole data, it is clear that the predominant Pennsylvanian shales present in the upper 180m in the borehole rest on a thick Mississippian limestone.

Between borehole 02-17D and 02-18D is a seismically defined anticline with the thick Mississippian limestone identified in 02-17D missing, leaving lower Mississippian or Devonic rocks in contact with the shallower Pennsylvanian sediments (**Figure 4**).

Borehole 02-18D is immediately east of the anticline in an area with gradational increase in the upper Mississippian. Towards the east end of the seismic profile, the Mississippian Limestone returns to a full thickness.

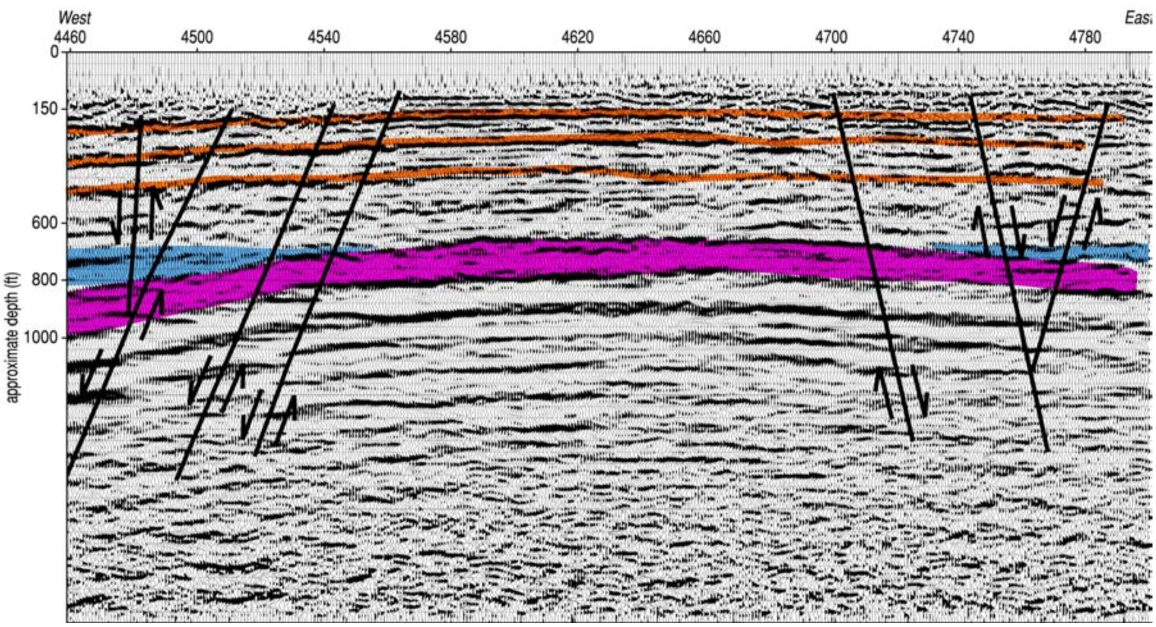

Figure 4.: Processed section of line #2 located on northern border of the site. The image depicts an anticline where the top of the Mississippian limestone (blue) has eroded away. Pennsylvanian sediments (orange) rest on lower Mississippian or Devonic rock (purple).

Conclusion

High-resolution seismic interpretation proved critical in delineating the subsurface in this area and avoiding a potential problem in developing an underground mining operation in this area. This area consists of faults that are consequent of the Midcontinent Geophysical Anomaly and its intersection with the northern segment of the Nemaha Ridge.

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