Ground-Water Exploration in Western Yellow Medicine County Using Two-Dimensional Seismic Reflection Methods

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1.0 Introduction

In 1997, the Minnesota Department of Natural Resources, Division of Waters (DNR Waters), began a test hole-drilling project with local water appropriators as part of a regional ground-water exploration effort (Southwestern Minnesota Groundwater Exploration Project 1996-1997, Progress and Final Reports). Figure 1 shows the locations of these test holes as triangles.

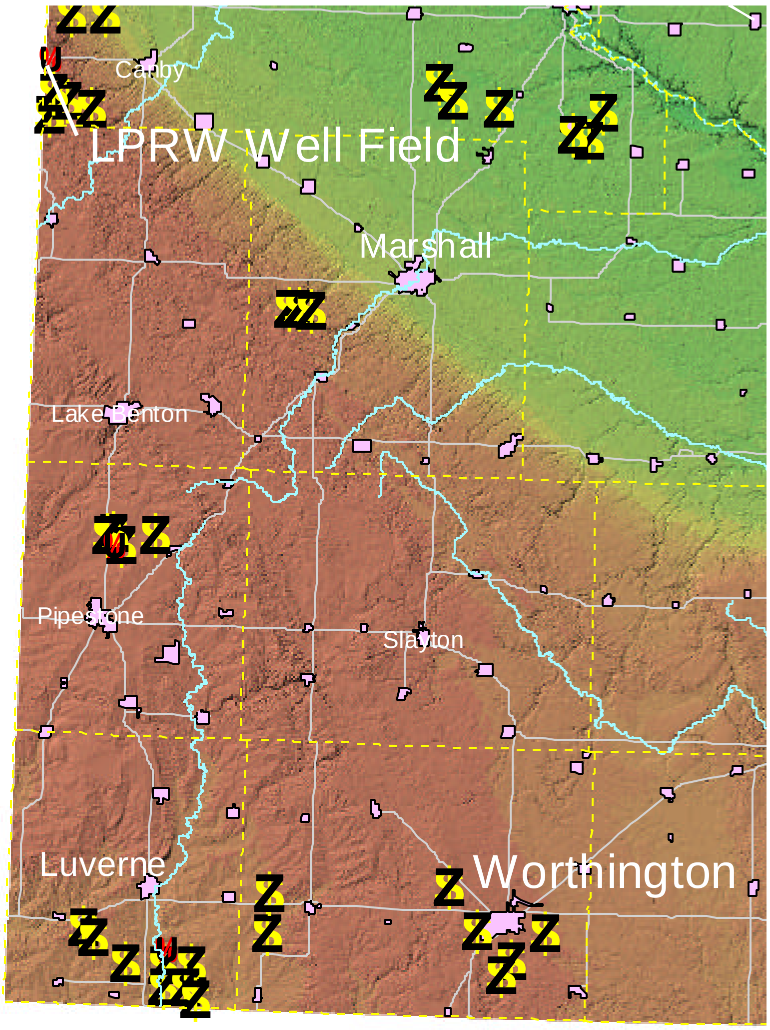

Figure 1. Southwestern Minnesota Shaded Relief Map with Test Hole Locations

The yellow triangles represent DNR Waters test holes that have been drilled since 1997. The higher elevation areas are shown in brownish tones and the lower elevation areas are shown in greenish tones.

Lincoln-Pipestone Rural Water (LPRW) was one of the appropriators in this partnership. Exploratory drilling with LPRW included test holes near the Burr Well Field west of Canby, Minnesota, near the South Dakota border (Figure 2).

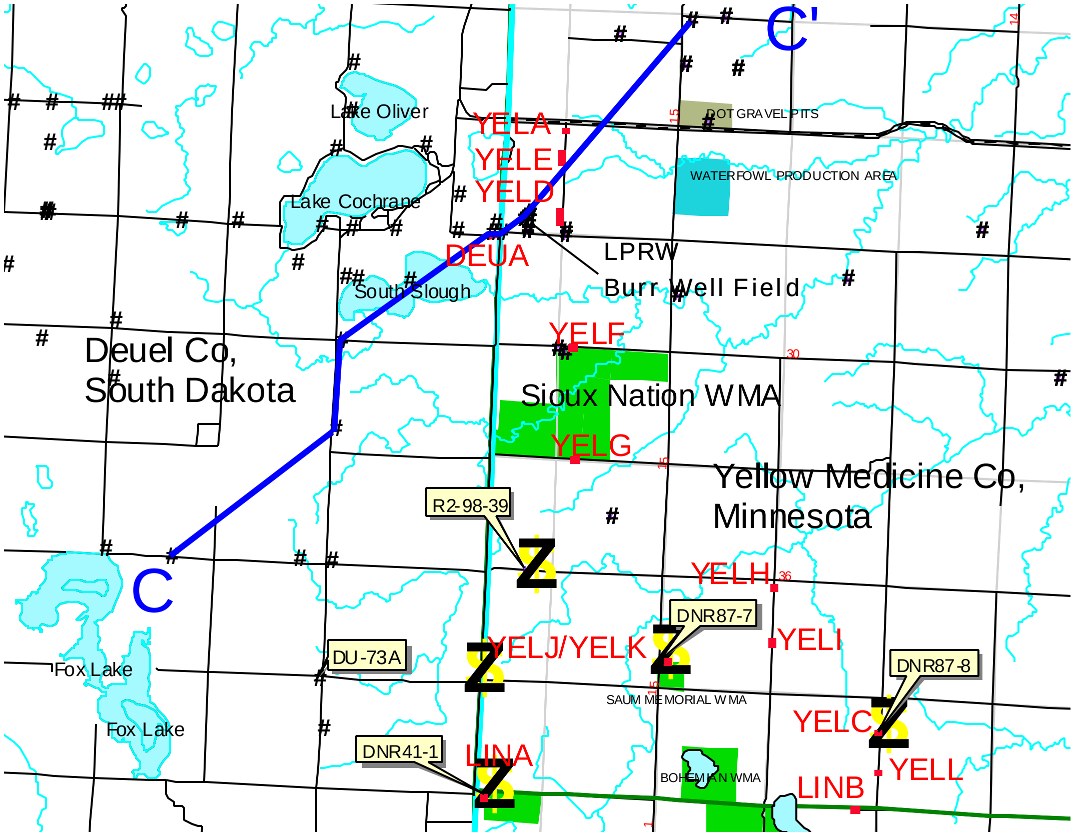

Figure 2. Lincoln-Pipestone Rural Water Burr Well Field Area

DNR Waters test hole locations are shown as yellow triangles. The black dots are other test hole and well locations. Seismic line locations are shown as red bars. The green squares and rectangles are DNR wildlife management areas. The blue line is cross section C-C'.

Figure 3 shows the glacial stratigraphy in the Burr Well Field area. Most of the wells in the Burr Well Field produce ground water from a combination of the 2, 3, and 4a sand layers.

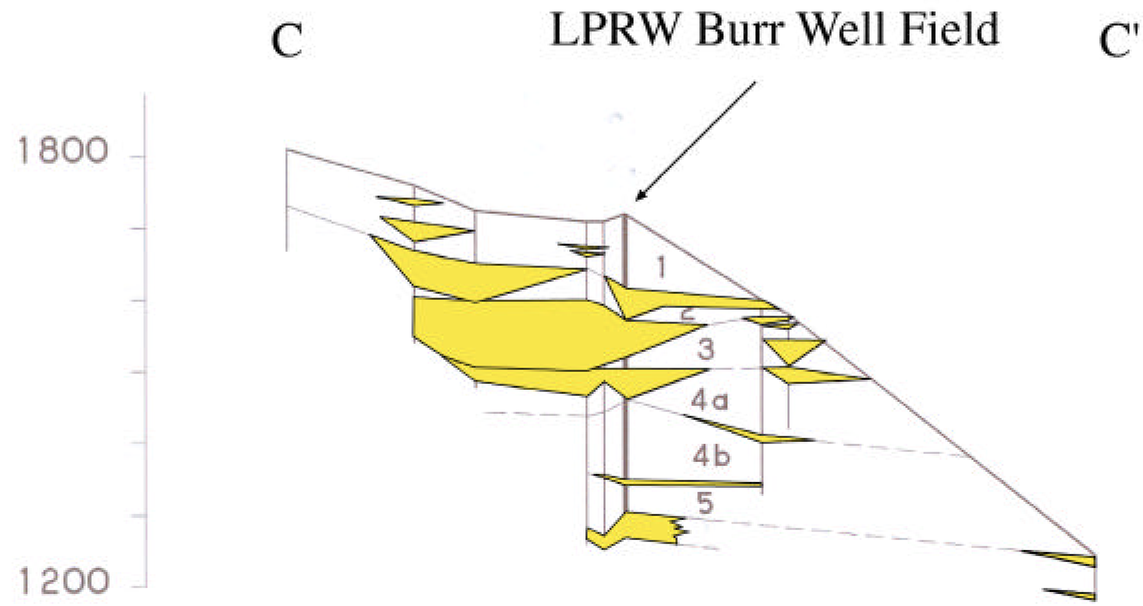

Figure 3. Cross Section C-C'

This diagram represents the stratigraphy of the area as we understood it in 1997. The yellow polygons are buried sand layers that are used as aquifers in this area. The uncolored areas between the sand layers are predominantly clayey glacial till. The vertical scale is elevation above sea level in feet. The vertical exaggeration of this cross section is approximately 50.

LPRW hoped to increase ground water withdrawal rates from this aquifer to meet rising demands for services. However, DNR Waters put limits on the LPRW appropriation permit from this aquifer due to interferences with special wetlands, called calcareous fens, at the Sioux Nation Wildlife Management Area (WMA). LPRW was encouraged to explore for deeper aquifers that might be isolated from the area fens. During the spring and summer of 1998, DNR Waters geophysics personnel acquired seismic reflection data in the Burr Well Field area in an attempt to find deeper aquifers. The purpose of this report is to summarize the results of this study.

2.0 Field Acquisition Methods

The data sets are a combination of walk-away surveys and common depth point (CDP) surveys. A 12-pound sledgehammer was the most commonly used energy source, although explosive Kinepak charges were used on some lines to overcome low signal-to-noise situations. When explosives were required, a half-pound charge was buried in an auger-drilled hole measuring 5 feet deep and 2 inches in diameter. The recording assembly consisted of 100-hertz geophones connected to a 24-channel Bison seismograph.

3.0 Calibration Lines

Before acquiring data in unknown areas in the Burr Well Field area, we collected seismic reflection data at DNR Waters test hole locations. By comparing the stratigraphic information that we collected from the test holes to the seismic data, we were able to match the reflections with their corresponding stratigraphic interfaces.

Figure 2 shows the locations of all the seismic data acquired in 1998. The seismic lines are shown as short lines with four-letter labels starting with Y, L, or D (e.g., YELA, LINA). Seismic lines YELK, LINA, DEUB, and YELC were collected over existing bore holes and were used to calibrate the seismic response to known geology.

Shown in Figure 4 is a comparison of known stratigraphic interfaces (lithostratigraphy) and interpreted seismic stratigraphy at the 87-7 test hole.

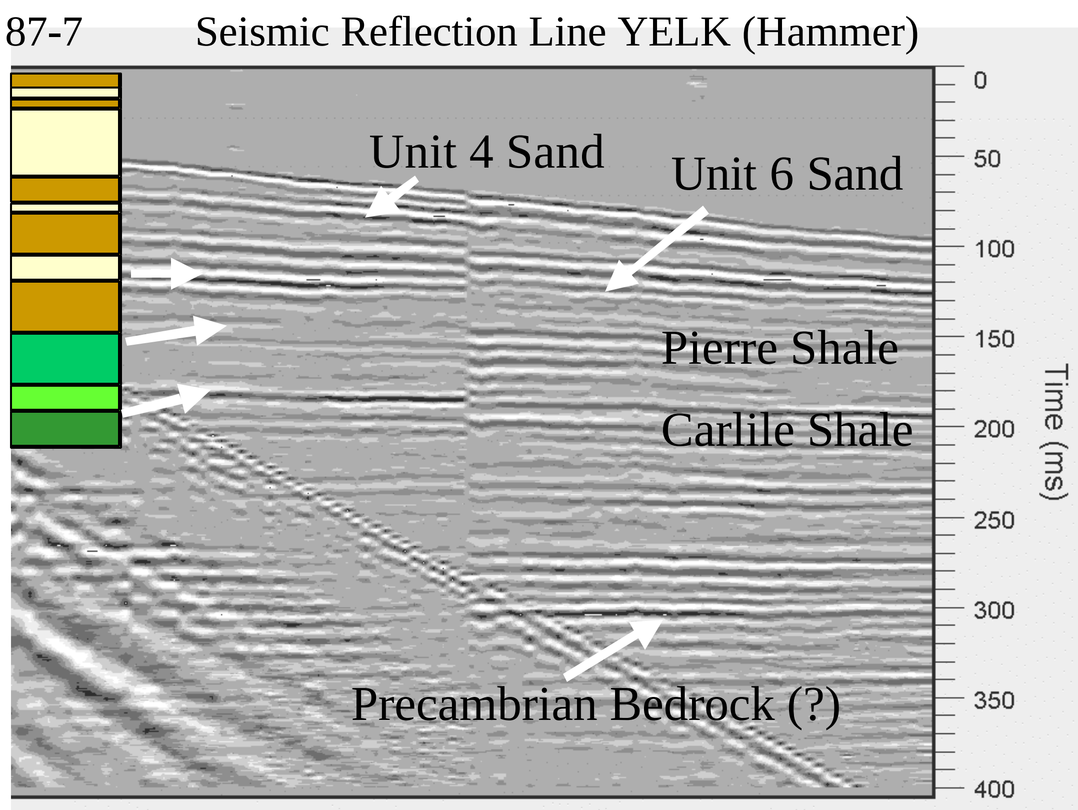

Figure 4. Test Hole 87-7 and Seismic Line YELK

The lithology recorded during the drilling of test hole 87-7 is compared to the strong seismic reflections of line YELK. The light yellow areas of the 87-7 log represent sand, the brown areas are clayey till, and the green areas are Cretaceous shale.

Strong reflections are associated with the Unit 4 and Unit 6 sand layers, the top of the Cretaceous Shale (Pierre Shale), and the Cretaceous Carlile Shale. The well stratigraphy is represented by depth, which is linear, but the seismic section shows two-way time, which is not linear. The seismic velocities are higher in the Cretaceous shale than in the Quaternary sediments; therefore, time events in the Cretaceous formations seem to arrive before the various layers shown on the log. The correlations shown in Figure 4, however, are accurate.

Figure 5 shows a comparison of test hole 41-1 and line LINA. Strong reflections are associated with the Unit 4 and Unit 6 sand layers and the Pierre Shale.

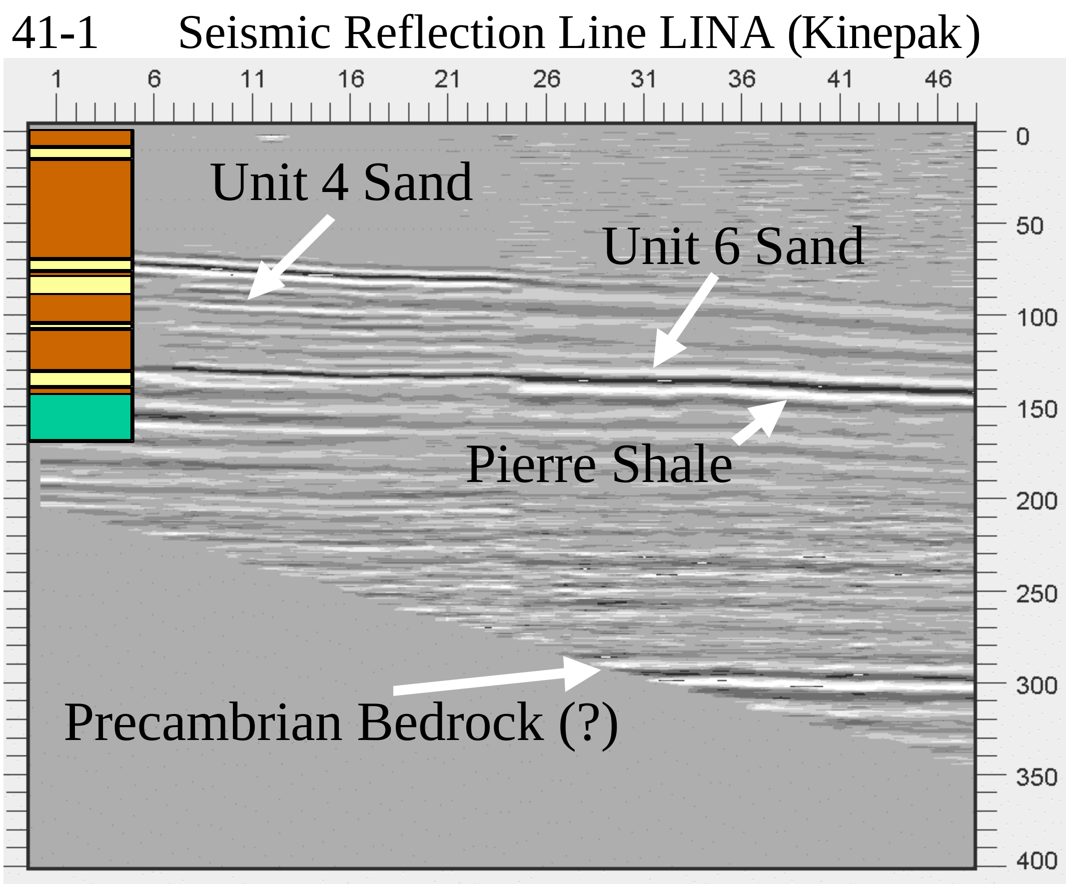

Figure 5. Test Hole 41-1 and Seismic Line LINA

The lithology at Test Hole 41-1 is compared to the strong reflections of line LINA.

In both of these calibration lines, we have marked a possible Precambrian bedrock reflection. No test holes or wells in the area were deep enough to allow us to positively define the Precambrian bedrock from seismic data.

4.0 Prospect Lines and Test Drilling

Having familiarized ourselves with the seismic stratigraphy of area, we acquired data at locations where we hoped to identify deeper aquifers. The prospect lines include the lines shown on Figure 6 that are not associated with test hole locations.

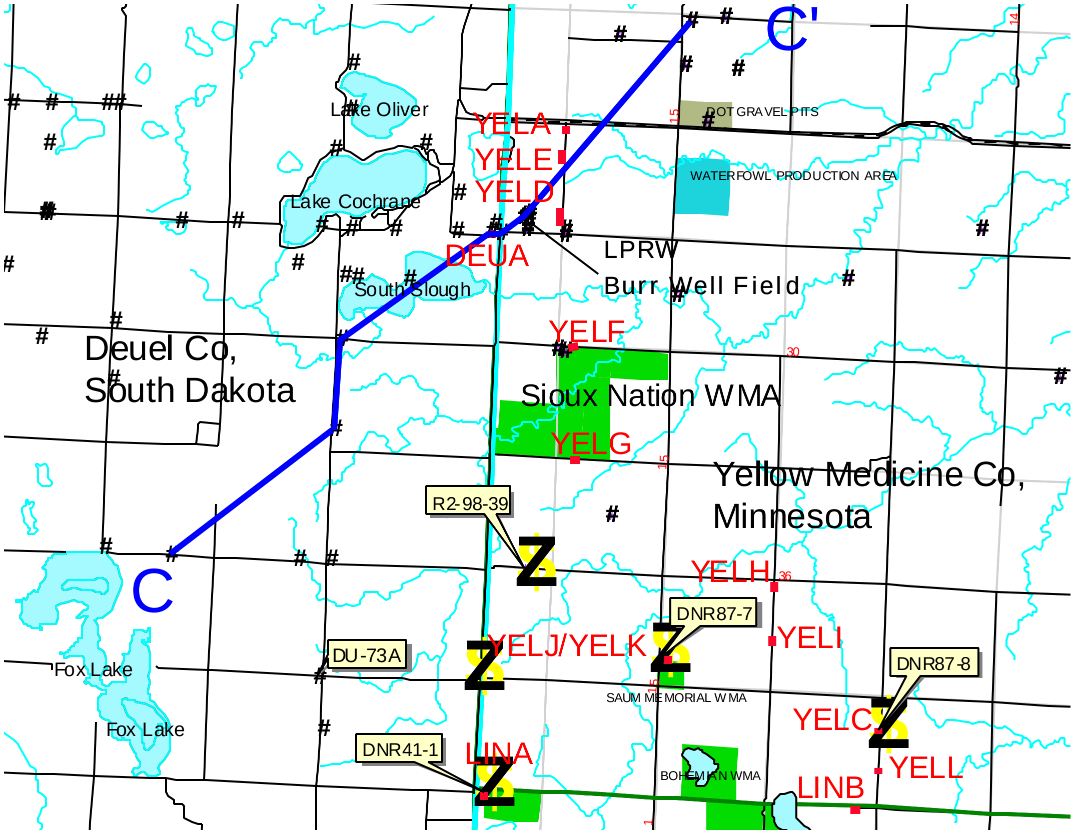

Figure 6. Burr Well Field Area Seismic Line Locations

The lines nearest the Burr Well Field appeared to have the deeper reflections we were looking for. Their reflection suggested that a deeper aquifer was present. Lines YELA and YELE are shown in Figures 7 and 8, respectively, with preliminary interpretations of the strong reflections.

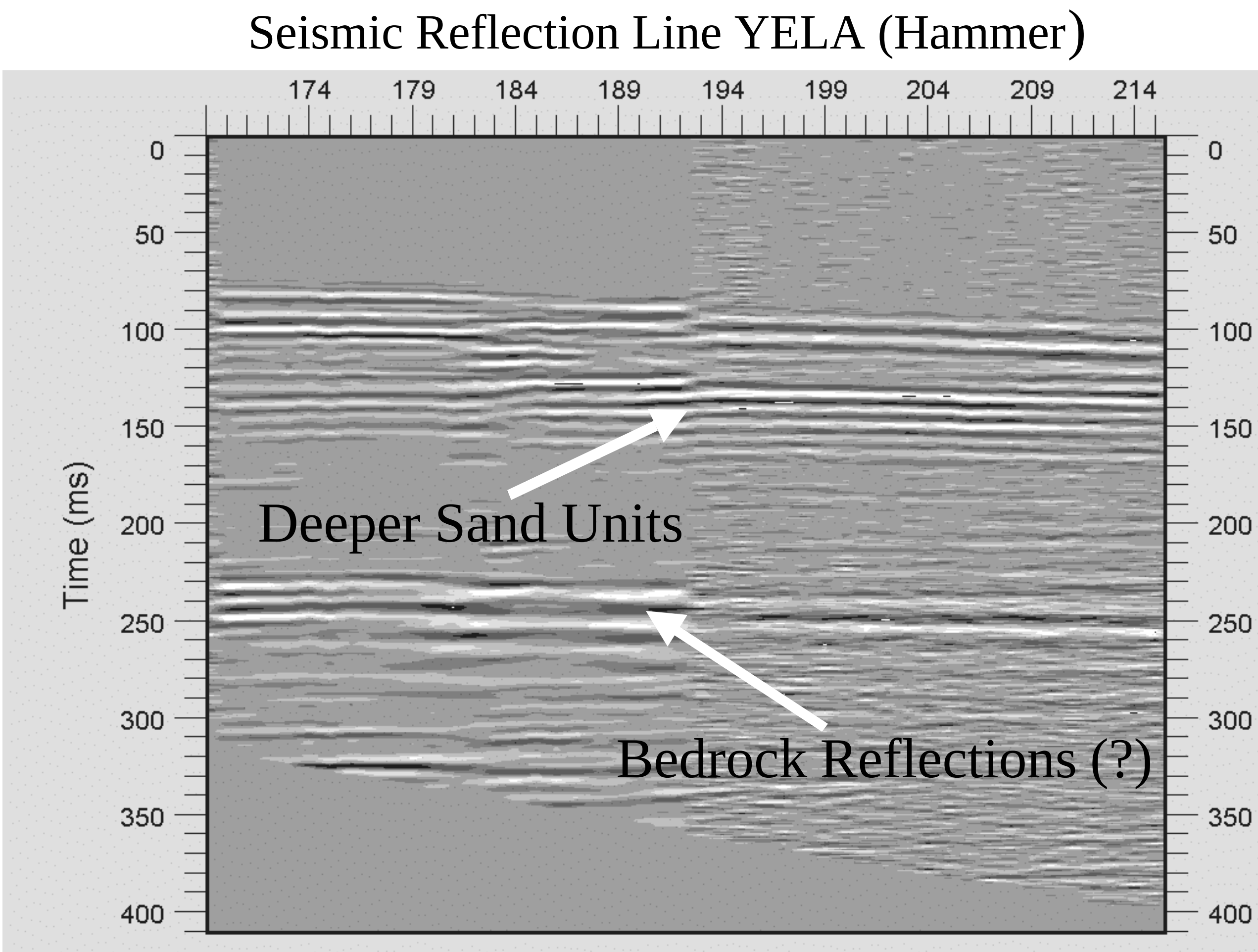

Figure 7. First Interpretation of Seismic Line YELA

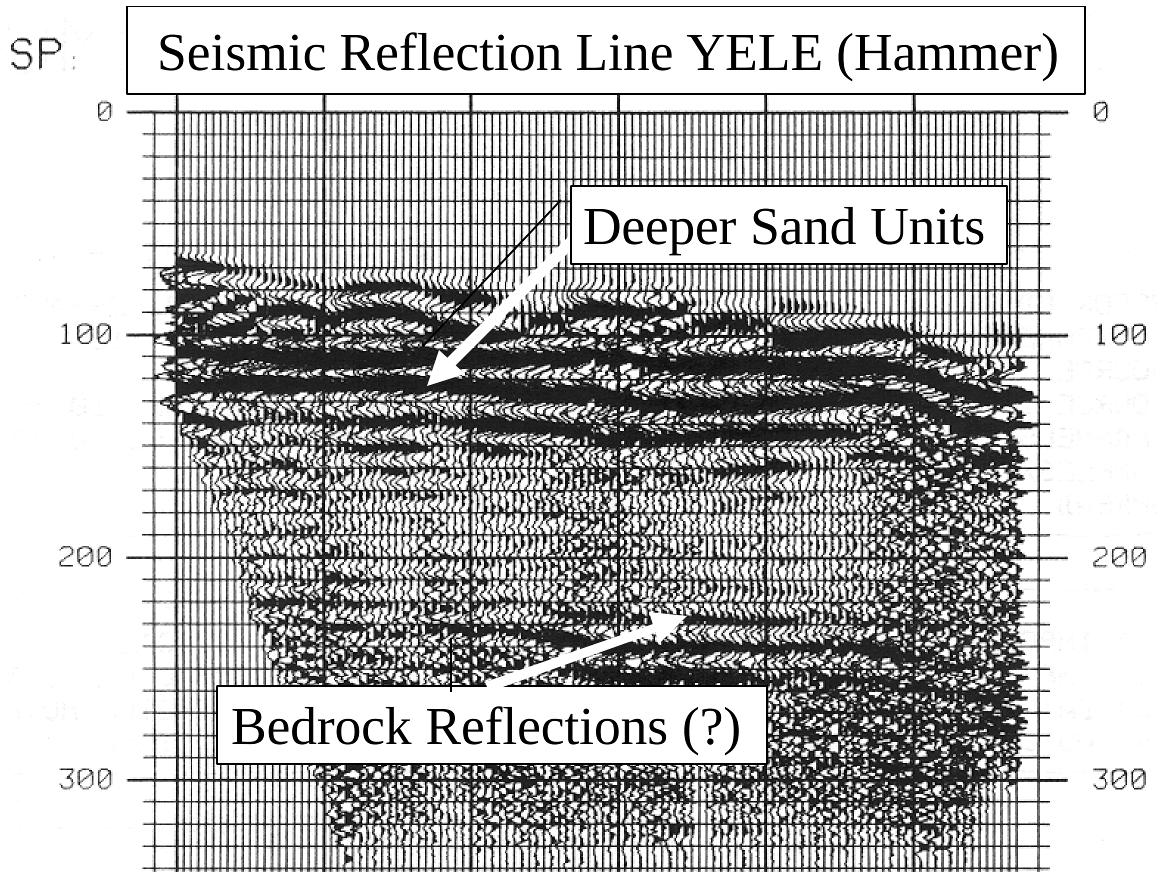

Figure 8. First Interpretation of Seismic Line YELE

The relative depth of the "Deep Q Sand" of line YELA is shown in Figure 9 next to the "Shallow Q Sand" of line DEUB. The thick sand layer at the DEUB location (confirmed by mud log information from South Dakota test hole R2-96-02) correlates with the shallow aquifer at the Burr Well Field, indicating that this sand layer provides most of the water supply.

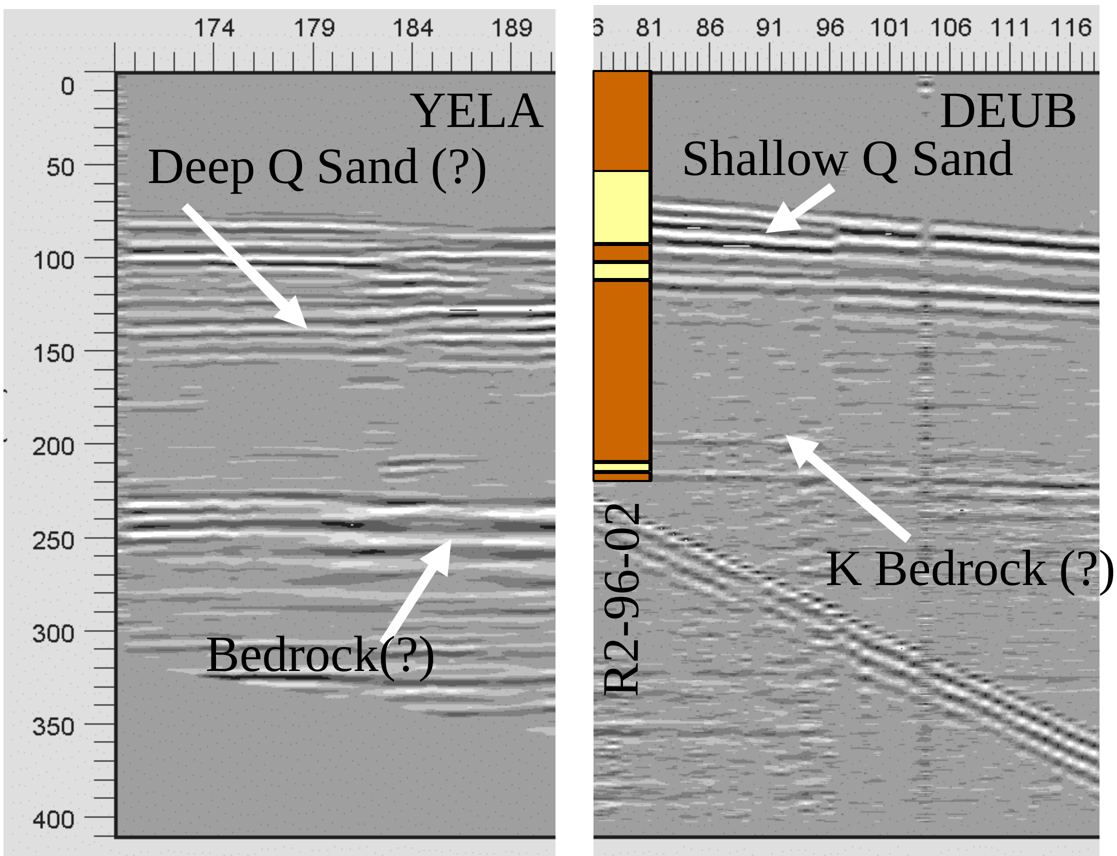

Figure 9. Comparison of Seismic Lines YELA and DEUB

Note that line YELA's strong reflections between 120 and 150 milliseconds do not exist on line DEUB.

Based on these comparisons, we anticipated finding the deep aquifers that we were looking for at the YELA location. In 1999, LPRW drilled three test holes at the locations shown in Figure 10. One of the test holes (633505) was drilled, based on our recommendation, directly across the road from line YELA. Cross section D-D' (Figure 11) includes the test hole drilled at the line YELA location. The location of cross section D-D' is shown in Figure 10.

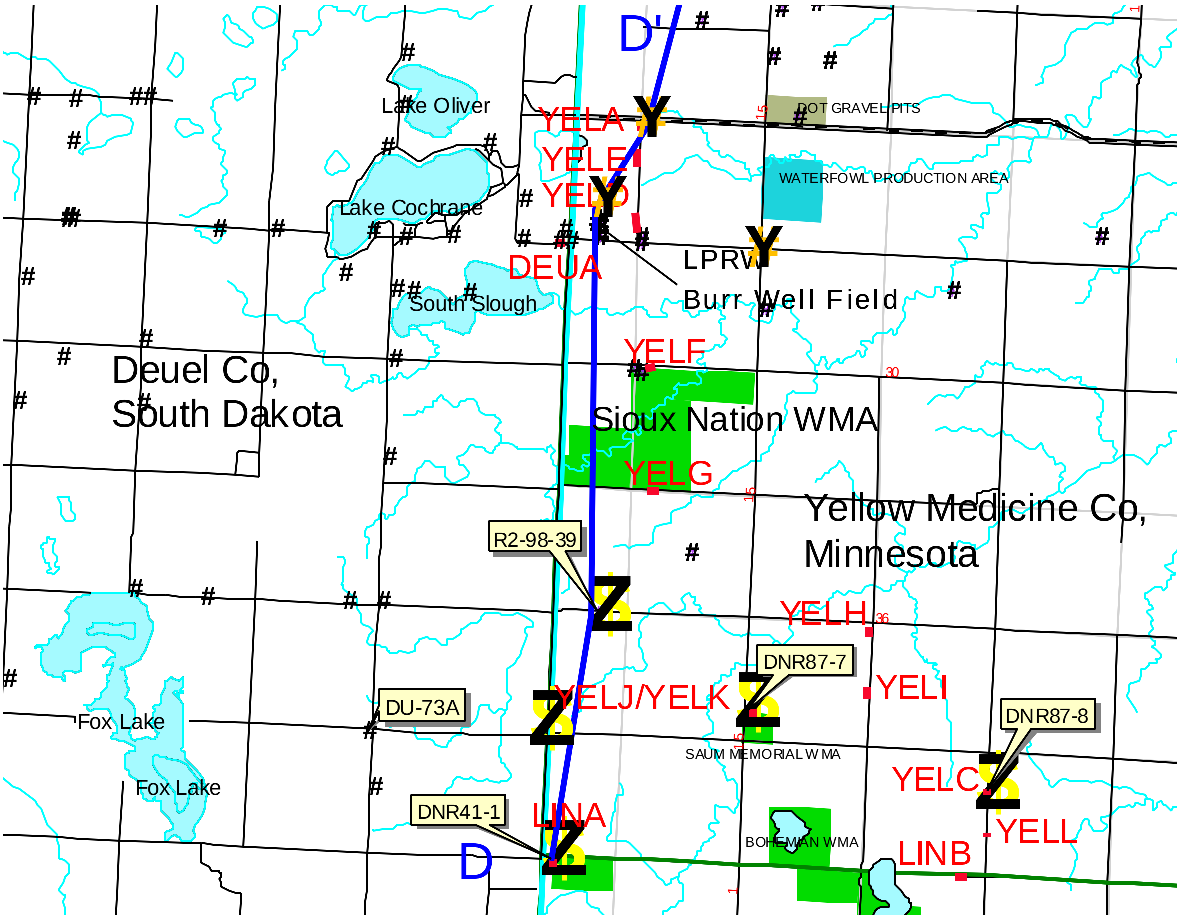

Figure 10. 1999 LPRW Test Hole Locations

The orange circles indicate the locations of test holes drilled by LPRW in 1999. The blue line is cross section D-D'.

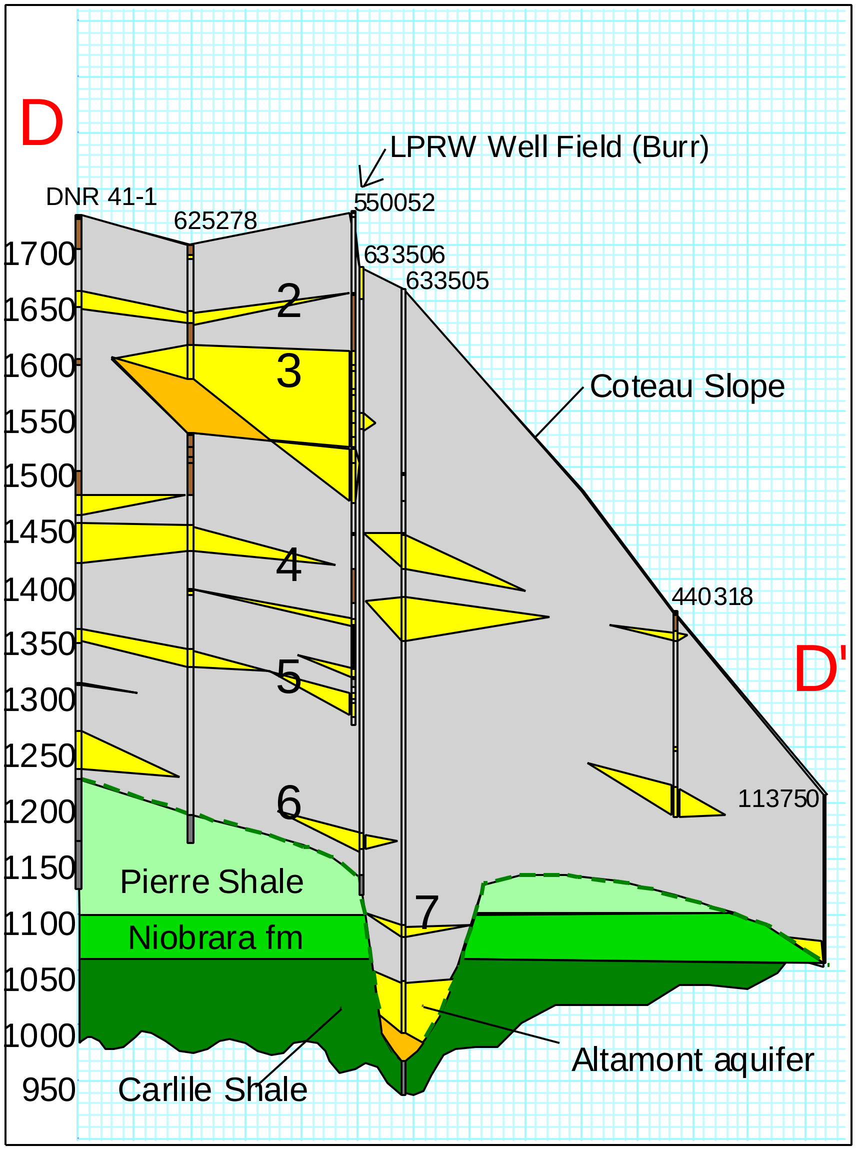

Figure 11. Cross Section D-D'

This cross section places the information learned from test hole 633505 in a larger context.

Sand aquifers below the main producing unit at the Burr Well Field were found as predicted. In addition, a sand-and-gravel-filled buried valley was found at an elevation of approximately 1,050 feet. This unit is the Altamont Aquifer described by the U.S. Geological Survey (Kame, 1985).

5.0 Velocity Profile of LPRW Test Hole 633505

To better understand the nature of reflections observed at the YELA location, we logged the LPRW hole with two downhole geophysical devices: a gamma log tool and a sonic log tool. The gamma tool measures the natural gamma radiation of the formation. The quartz grains of sand layers produce very little gamma radiation; clay minerals produce relatively higher amounts of gamma radiation. Therefore, a gamma log of glacial sediments has low values through the sandy sections and higher values through the clayey sections. The log on the left portion of Figure 12 is a gamma log of LPRW test hole. The arrows indicate low gamma responses that correspond with sand layers.

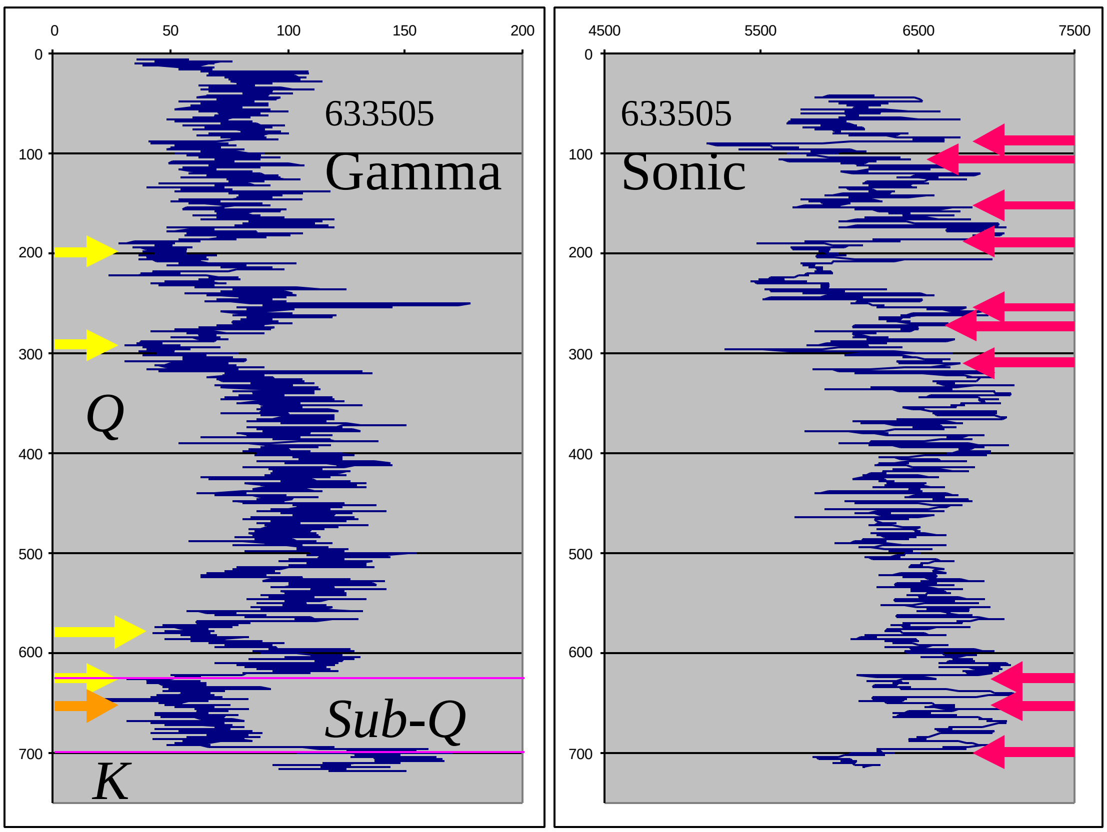

Figure 12. Gamma and Sonic Logs from LPRW Test Hole 633505

The yellow and orange arrows next to the gamma log indicate significant sand and gravel layers. The red arrows next to the sonic log indicate significant velocity contrasts and are, therefore, likely reflectors. These reflectors correlate well with the significant sand layers.

The log on the right portion of Figure 12 is a sonic log of the LPRW test hole. The sonic log measures the travel time or delta T of a sonic impulse produced by the tool to refract through the formation to a receiver at the other end of the tool. The travel time is measured in microseconds per foot. The data have been converted to seismic velocity (feet per second) and plotted versus depth on Figure 11.

The major velocity contrasts on this log are indicated with arrows to suggest horizons that are likely to appear as reflections in a seismic survey. This analysis predicts that the Unit 4 sand layers at approximately 200 and 300 feet, and the Altamont sand at approximately 630 feet should appear on line YELA as bundles of strong reflections. Figure 13 shows a comparison of YELA seismic reflection data with LPRW test hole 633505. The data appear to match very well, indicating that seismic reflection methods can be very successful for finding buried sand aquifers in this area.

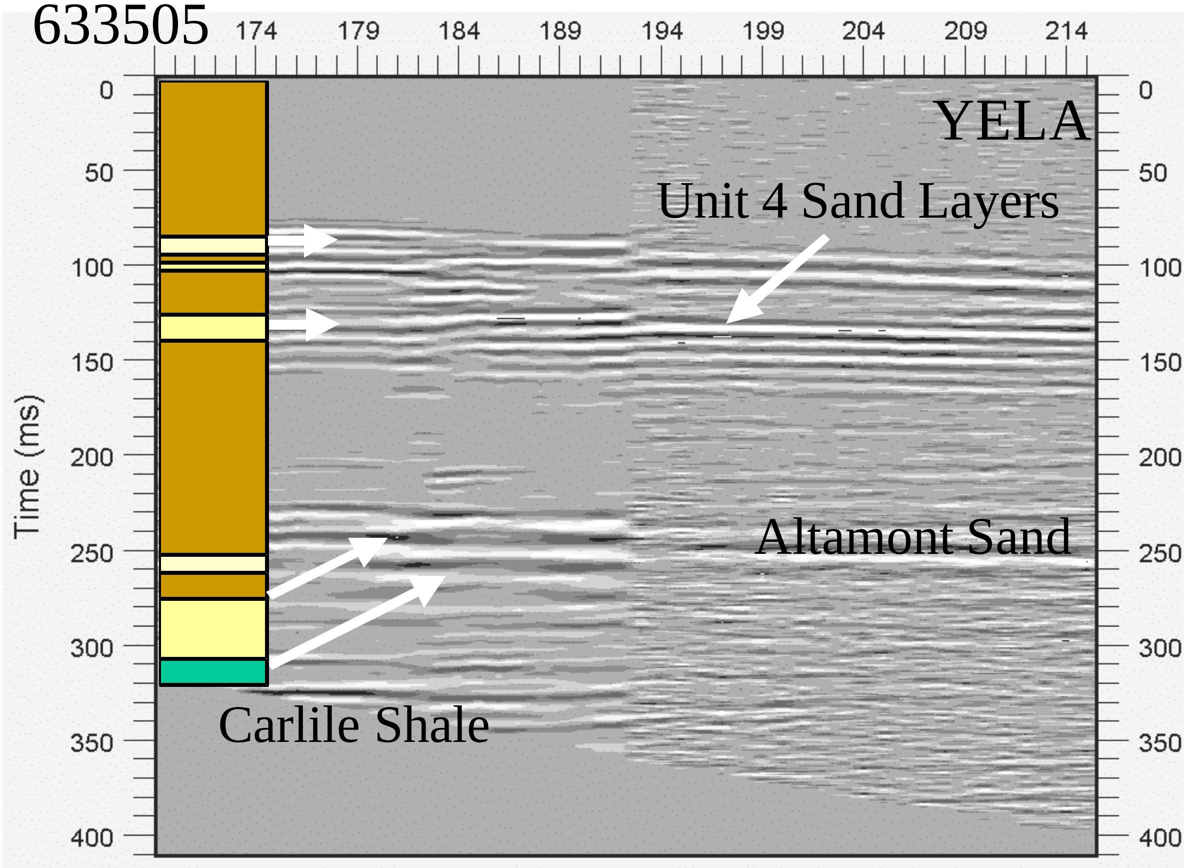

Figure 13. LPRW Test Hole 633505 and Seismic Line YELA (Final Interpretation)

Potentially important sand aquifers encountered during the drilling of test hole 633505 appear as strong reflections on line YELA.

6.0 Summary and Conclusions

The purpose of this project was to determine whether seismic reflection methods and technology could be used to locate buried sand aquifers. Several comparisons of seismic reflection data and test hole data at specific locations indicate significant sand aquifers do appear as strong reflections on the seismic sections. Furthermore, an analysis of the seismic velocity profile from a 1999 LPRW test hole (633505) shows significant velocity contrasts associated with the significant sand layers. Therefore, seismic reflection methods appear to be a useful tool for finding buried aquifers in this area of Minnesota.

7.0 References

Kame, Jack, 1985. Water Resources of Deuel and Hamlin Counties, South Dakota. U.S. Geological Survey Water Resources Investigations Report 84-4069.