United States Department of Agriculture	**Natural Resources Conservation Service**	**11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Geol – Ground-Penetrating Radar (GPR) Field Assistance **Date:** 13 July 2000

To: Dr Tom Hooyer
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Purpose:
The purpose of this investigation was to explore the potentials of using GPR to detect large boulders and map the subsurface stratigraphy of tunnel valleys.

Participants:
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Paul Cutler, Assistant Scientist, Wisconsin Geological and Natural History Survey, Madison, WI
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Tom Hooyer, Geologist, Wisconsin Geological and Natural History Survey, Madison, WI

Activities:
All activities were completed on 25 January 2000.

Background:
A tunnel valley is a shallow trench cut in drift by a subglacial stream (Bates and Jackson, 1980). These features consist of long linear valleys, oriented perpendicular to the ice margin and were formed by a meltwater river flowing in a subglacial tunnel (T. Hooyer, personal communication). In Wisconsin, many tunnel valleys are several hundred meters wide, several meters to tens of meters deep, and several kilometers long (Clayton et al., 1999). In Wisconsin, there are approximately 80 tunnel valleys located just behind the western margin of the Green Bay lobe of the Laurentide Ice Sheet (T. Hooyer, personal communication). These valleys rise westward, up an adverse slope, in the direction of glacier flow and often breach the outermost moraine (T. Hooyer, personal communication). Large outwash fans are located immediately beyond the terminus of these features. These fans are an important source of sand and gravel in Wisconsin.

Because of the limitations of traditional data collection techniques, the subsurface stratigraphy of these features has not been widely studied. Ground-penetrating radar is a noninvasive geophysical tool that can provide high-resolution information of the shallow subsurface stratigraphy and structure of tunnel valleys. Recently, GPR has been used to map sedimentary units and characterize depositional sequences. Beres and other (1999) used GPR to map coarse-textured glaciofluvial deposits. Rea and Knight (1998), and Jol and Smith (1991) used GPR to map glaciodeltaic sediments. Leclerc and Hickin (1997), Naegeli and others (1996), and Vandenberghe and van Overmeeren (1999) used GPR to study the sedimentology of stream channels.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. A 120 mHz and a 400 mHz antenna were used in this

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

study. Scanning times of 140 and 150 nanoseconds (ns) were used for the surveys in Langlade and Waushara counties, respectively. Hard copies of the radar data were printed in the field on a model T-104 printer.

Study Sites:

Study sites were located in Langlade and Waushara counties along the western margin of the Green Bay lobe. The site in Langlade County was located at a gravel pit near the town of Antigo. The gravel pit was located at the head of an alluvial fan. A large boulder layer was observed in the walls of the gravel pit at a depth of about 2-4 m below the surface. Soils mapped in the area of the gravel pit were members of the Antigo and Langlade series. These soils formed in loess or water laid silty deposits overlying sand and gravel on outwash plains. The very deep, well drained Antigo soil is a member of the coarse-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Haplic Glossudalfs family. Thickness of the silty mantle ranges from 12 to 40 inches. The deep, well drained Langlade is a member of the coarse-loamy, mixed, superactive, frigid Haplic Glossudalfs family. Thickness of the upper silty deposit ranges from 26 to 42 inches.

The Waushara County site was located near the town of Hancock. The radar was towed along several roads, trails, and open areas that cross an alluvial fan. Soils mapped in the area are members of the Coloma and Plainfield series. The very deep, somewhat excessively drained Coloma soils formed in sandy drift on moraines and outwash plains. Coloma soil is a member of the mixed, mesic Lamellic Udipsamments family. The Plainfield series consists of very deep, excessively drained soils formed in sandy drift on outwash plains, stream terraces, and moraines and other upland areas. Plainfield soil is a member of the mixed, mesic Typic Udipsamments family.

Field Procedures:

Traverse lines of variable lengths were established at each site. Along each traverse line survey flags were inserted in the ground at intervals of about 15 m and served as reference points. Radar surveys were completed by pulling the 120 mHz antenna along these traverse lines. As the antenna passed each reference point, the operator impressed a vertical line on the radar profile. These vertical lines identified relative locations along each traverse line.

The radar profiles were printed and reviewed in the field. All radar profiles were also stored on disc. These profiles were later processed and made into bitmap images. The radar profile shown in this report was processed through the WINRAD software package.[2] Processing was limited to signal stacking, horizontal scaling, color transforms and table customizing. Signal stacking, color transformation and table customization were used to reduce background noise.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (d), two-way pulse travel time (t), and velocity of propagation (v) are described in the following equation (Morey, 1974):

$$v = 2d/t \qquad [1]$$

The velocity of propagation is principally affected by the dielectric permittivity (e) of the profiled material(s) according to the equation:

$$e = (c/v)^2 \qquad [2]$$

Where c is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric constant of a material.

The velocity of propagation and the depth scale were determined by visual correlation of a radar profile with the measured depth (1.8 m) to a boulder layer observed in the face of a gravel pit wall at the Langlade County site. Based on the measured depth and the two-way travel time to this interface, and equation [1], the velocity of propagation was estimated to be about 0.09207 m/ns. Using equation [1], scanning times of 140 and 150 ns, and a propagation velocity of 0.09207 m/ns, the maximum depth of observation was estimated to be about 6.4 m in Langlade County and 7.0 m in Waushara County, respectively.

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[2] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

Results:
In areas of Antigo and Langlade soils, the radiated energy was rapidly attenuated and observation depths restricted by the shallow to moderately deep silt cap. The 400 mHz antenna was more depth restricted than the 120 mHz antenna. Even when operated directly on gravel (dirty) layers, the observation depth of the 400 mHz antenna was severely restricted and mostly limited to the surface layers. As a consequence, only the 120 mHz antenna was used in this study.

Figure 1 is a representative radar profile from the Langlade County site. This profile was collected with the 120 mHz antenna. In Figure 1 the horizontal and vertical scales are in meters. The radar traversed a low ridge that was near the gravel pit. The ridge is located between observation points 30 and 75 m. On the ridge, the silt cap was thinner and the coarse-textured outwash deposits were closer to the soil surface. As a consequence, the depth of observation was greater on the ridge than on lower-lying areas. On the lower-lying areas that adjoined the ridge, the silt cap was thicker and the radar energy was more rapidly attenuated. Silt caps greater than 0.25 to 1 m thick cause severe attenuation of the radar energy that reduces the GPR's observation depth observation. Although maximum observation depths as great as 2 m were sporadically obtained in areas of Antigo and Langlade soils, depths were generally less than 0.5 m. Because of restricted observation depths, GPR is considered an inappropriate tool to investigate tunnel valleys in areas of Antigo and Langlade soils

Figure 2 is a representative radar profile from the Waushara County site. This profile was collected with the 120 mHz antenna. In Figure 2 the horizontal and vertical scales are in meters. In this area of Plainfield and Coloma soils, the depth of observation was assumed to be greater than 6 meters. Compared with data collected in areas of Antigo and Langlade soils, the radar provided deeper and more continuous data in areas of Plainfield and Coloma soils. Plainfield and Coloma soils do not have a silt caps.

In Figure 2, the radar traversed a nearly level outwash fan. Two units or facies are identifiable in Figure 2. Jol and Smith (1991) defined a radar facies as a "mappable, three-dimensional sedimentary unit composed of reflections whose parameters differ from adjacent units." The upper 2 m of the profile contains lower amplitude and diffuse reflectors from soil and fill materials. Below a depth of about 2 to 3 m, the radar profile contains numerous, high-amplitude, continuous parallel or slightly dipping reflectors. These reflectors are believed to represent horizontal bedded and relatively extensive sheets of coarse-textured outwash deposits.

Figure 3 contains similar radar facies to the ones described in Figure 2. Within the upper 3 to 4 m of the radar profile, reflectors appear to be fairly continuous and parallel to slightly dipping. However, between depths of about 3 to 6 m, the reflectors appear to be discontinuous, more steeply dipping, and chaotic. Radar reflectors within the area enclosed in the box are noticeably disordered. These reflectors may represent a concentration of large boulders or an area of sediments deposited in more turbulent flow.

It was hoped that GPR would clearly distinguish layers of large boulders from layers of cobbles, coarse sands and gravels. While some large boulders may have been distinguished by GPR, more fieldwork is necessary to verify this interpretation. Individual boulders and the microstructure of tunnel valleys may be difficult to distinguishable with GPR. Ground-penetrating radar is sensitive to variations in grain size that cause significant differences in electrical conductivity (Greenhouse et al., 1987). Differences in electrical conductivity are principally attributed to changes in moisture content, which are related to variations in grain size, porosity, and composition. However, some strata and point anomalies (such as boulders), because of their similarity dielectric properties with the bounding matrix, may be difficult to distinguish with GPR. Leclerc and Hickin (1997), working on floodplain deposits, reported that the interface separating medium sands and gravel did not produce a distinct reflection on radar profiles. These researchers noted that contacts between individual strata within sedimentalogical units are generally weaker than boundaries separating major geologic or stratigraphic units and the water table. Beres and other (1999) conducted radar survey along open pits having exposures of massive gravel sheets with cobbles and small boulders. They noted that the appearance of radar reflections from these sheet was "vague" because of variations in grain sizes and thin interlayer of sands, pebbles, and/or coarse lag.

The size, depth, and dielectric properties (in contrast to the dielectric properties of encompassing or adjoining matrix) as well as operating frequency will establish whether or not boulders can be detected with GPR.

Conclusions:
Areas with shallow to moderately deep silt caps are inhospitable to GPR. In areas of Antigo, Langlade, and similar soils, the use of GPR for the detection of large boulders and the delineation of the subsurface stratigraphy of tunnel valleys is considered inappropriate. In areas of coarse-texture soils that lack silt caps (Plainfield and Coloma soils), GPR can be used to map major subsurface stratigraphic units or "radar facies."

Results from this study do not justify conclusions on the ability of GPR to detect large boulders. Additional GPR studies at suitable gravel pits are recommended. Without exposures or borings, it is impracticable to attempt to correlate radar imagery with large boulders or stratigraphic layers. More work is needed to characterize the *graphic signature* of large boulders and tunnel valleys. With low frequency antennas, small-scale features such as individual boulders may be difficult to distinguish on radar profiles. Higher frequency antennas (greater than 400 mHz) may be used in areas of coarse-textured soils. Though high frequency antennas provide shallower depths of observation, these antennas provide more highly resolved images of the glaciofluvial fabric (individual boulders and large cobbles) of sediments than lower frequency antennas.

A complete file of the radar profiles in bitmap format is enclosed for your review.

It was my pleasure to work with again with you in Wisconsin.

With kind regards,

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Research Soil Scientist

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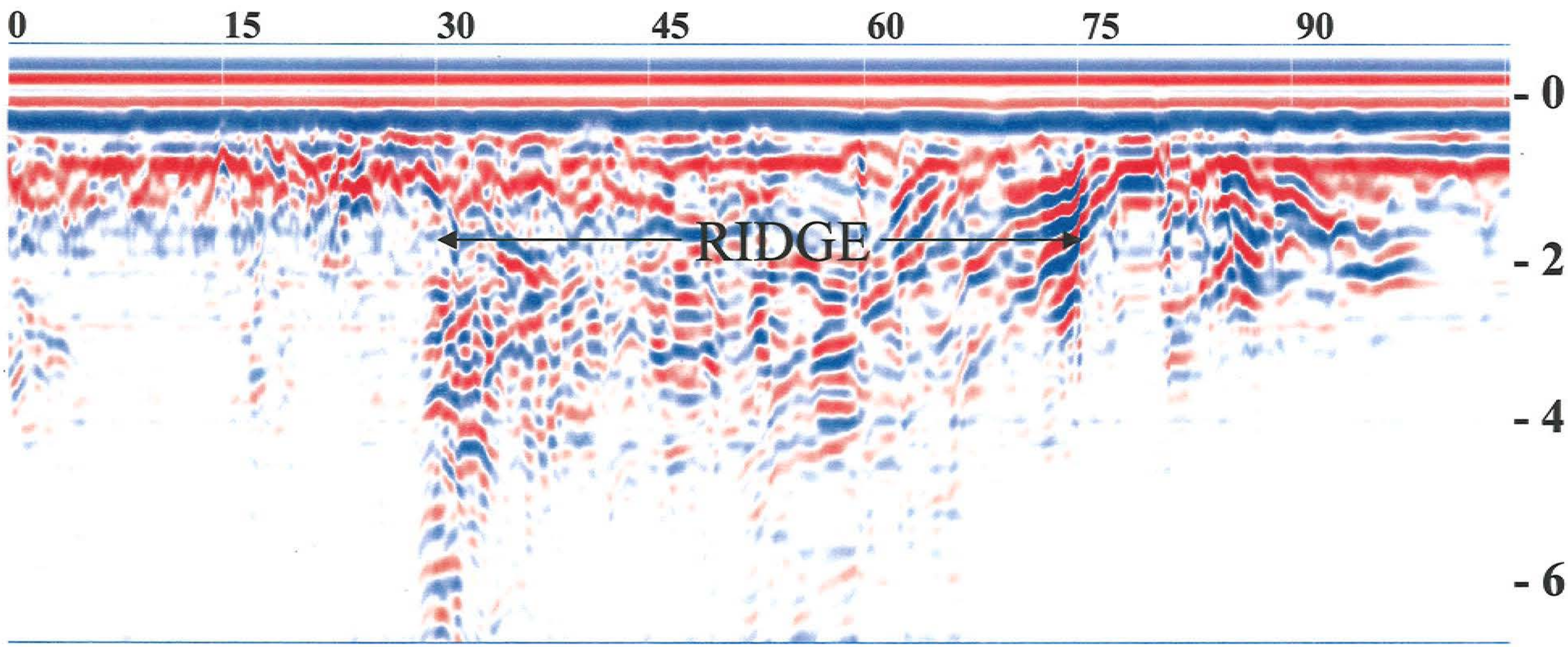

Figure 1

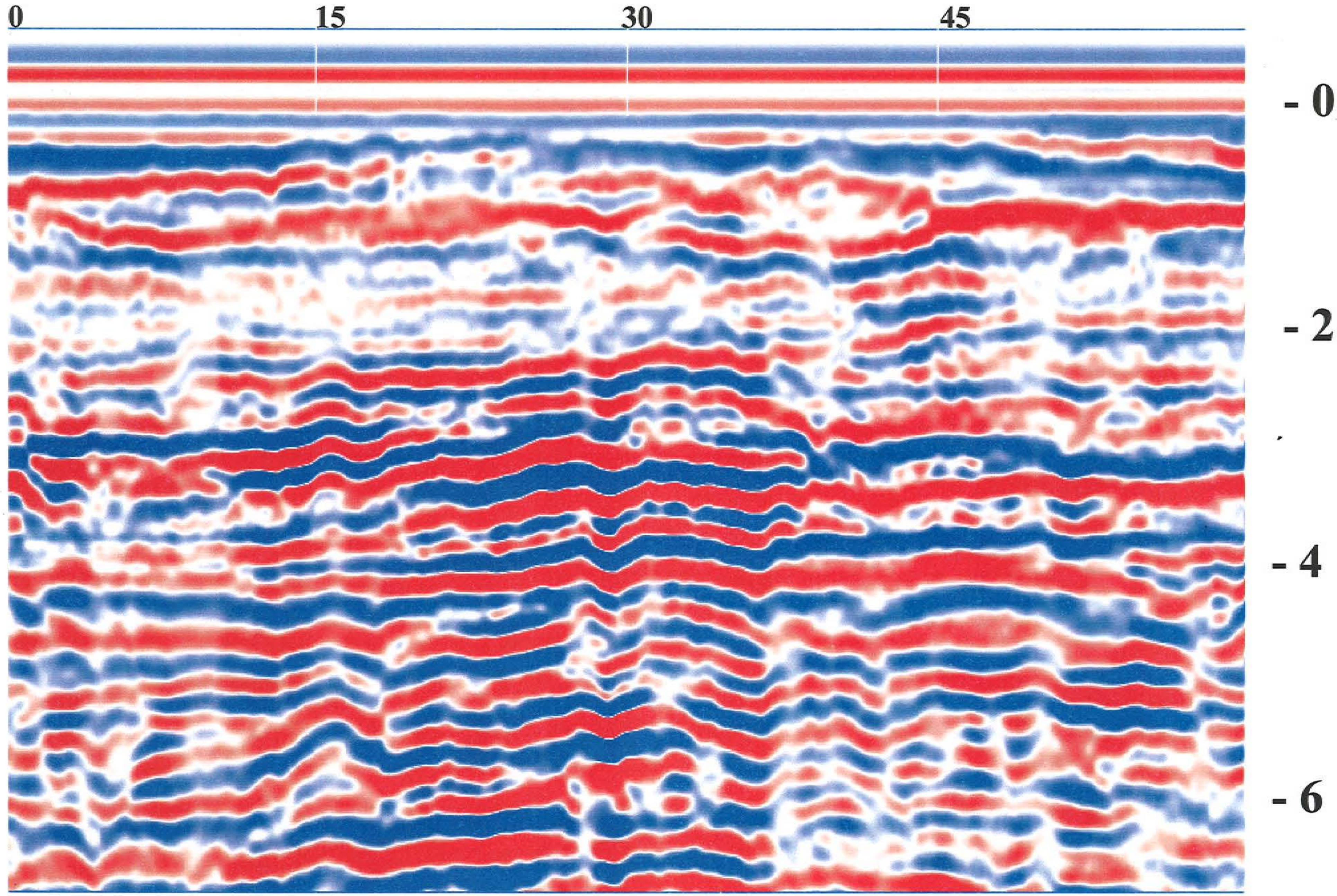

Figure 2

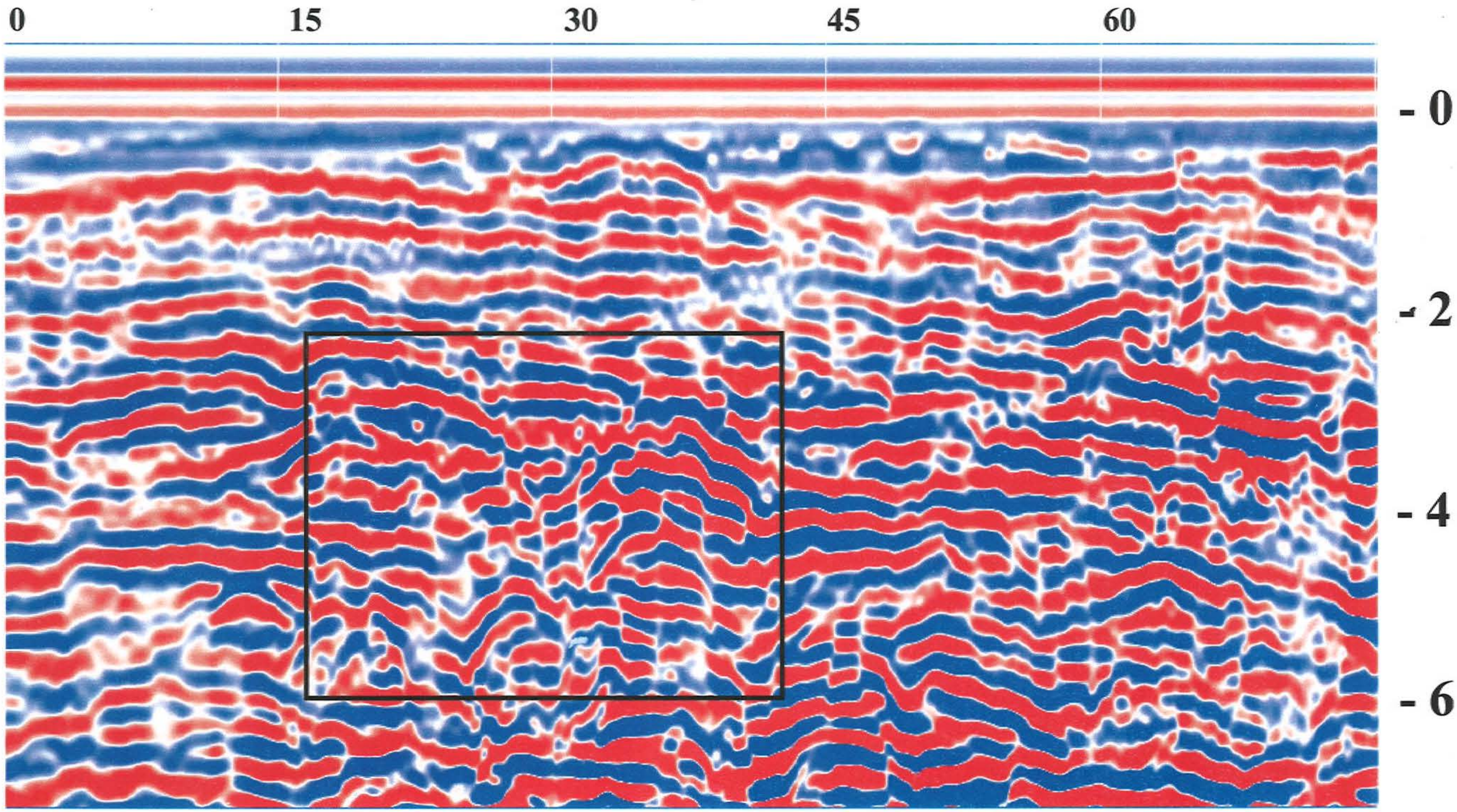

Figure 3