The Application of Low Frequency GPR to Stratigraphic Investigations

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Abstract – **Low frequency radar is an excellent tool for stratigraphic investigations. We perform stratigraphic GPR surveys using GSSI's 100-MHz high-power bi-static and Multiple Low Frequency (80- to 15 MHz) antennas. the MLF in point mode, we have reached depths up to 130 feet in unsaturated sand. However, low frequency GPR data often require significant processing to remove spurious instrument noise and, particularly in urban sites, interference produced by buildings, power lines, and other sources of cultural interference. As the improvements in GPR software have increased data processing capabilities, low-frequency GPR surveys produce more useful information. In this paper, we illustrate the importance of data processing to produce usable data from a number of different sites, each of which presents different challenges.**

***Keywords* – MLF, Low Frequency, Stratigraphy, Bedrock.**

I. INTRODUCTION

We have found low frequency GPR an extremely effective complementary method to other geophysical techniques for mapping stratigraphy and bedrock over large areas [1][2]. If GPR can be used at a site, it has the advantage of increasing data coverage and producing greater data density. It is well known that GPR is site-specific in terms of its penetration and resolution; thus we would expect better results in unsaturated than saturated materials, and in sand rather than clay. However, the conventional wisdom about factors limiting GPR signal penetration does not always apply. In the 10 years that we have been performing stratigraphic investigations using low frequency GPR, we have worked successfully at sites with subsurface conditions ranging from unsaturated sand to fill, organic silt, and clay. In many cases, the key to success has been selecting the highest frequency antenna that reaches the required depth along with careful processing of the raw records.

II. EQUIPMENT

We use Geophysical Survey Systems, Inc.'s (GSSI) SIR System 3000 for data collection. For stratigraphic surveys we use GSSI's 200-MHz mono-static antenna or, more frequently, 100-MHz high-power bi-static (see Figure 1) and multiple low frequency (MLF) antennas (see Figure 2). The MLF is extremely versatile, since it can be configured in the range of 80- to 15-MHz. However, the MLF is unshielded, so it is important to identify spurious reflections introduced by cultural features (fences, buildings, overhead power lines, etc.).

We collect low frequency GPR data in point, continuous, survey wheel mode. The advantages of using a survey wheel is that it increases the amount of areal coverage and controls the signal pulse; the disadvantage is that the signal cannot be stacked as in point mode, which produces better records, especially under conductive soil conditions. For survey wheel mode data collection, the antenna is mounted on a wooden skid (see Figure 2).

Figure 1. 100-MHz high-power antenna being used in bi-static mode to search for deep voids.

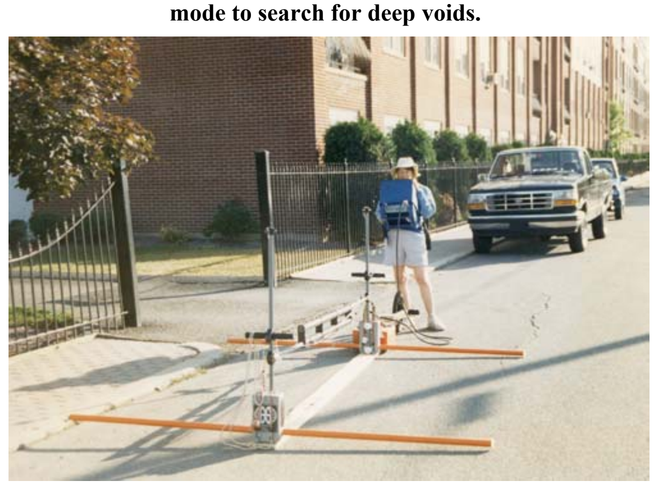

Figure 2. MLF antenna in 40-MHz configuration for urban bedrock mapping project.

Using the 20-MHz MLF antenna in point mode, we have been able to reach depths of 130 feet in unsaturated sand cliffs on Martha's Vineyard.

III. DATA PROCESSING

One of the stumbling blocks to low-frequency GPR surveys is the amount of processing the often required to "clean up" the raw data. We process GPR data using GSSI's RADAN for Windows NT™ with Interactive Structural and Stratigraphic Module™. Processing may include high- and low-pass filters, background removal, stacking, spatial FFT, deconvolution, and migration.

IV EXAMPLES

Processing of low frequency GPR data requires patience and ofttimes a trial-and-error approach to determine the best procedure. The examples that follow illustrate three different survey environments. In each case, the final product was acceptable, but sometimes only after considerable effort.

4.1 Survey over Water

Figures 3a and 3b show examples of processed and unprocessed records for data collected during a freshwater lake survey with a 100-MHz bi-static antenna. The purpose of this survey was to determine relative percentages of sand and cobbles beneath the lake bottom. The antenna was placed in a plastic boat powered by a small trolling motor, with survey lines marked by floats to keep the boat on track. Data were collected along traverses in continuous mode, with the record marked every 25 feet (see Figure 3a).

When the raw records were filtered and background removal applied, multiple layers were clearly visible below the lake-bottom (see Figure 3b). We were able to reach an estimated depth of over 40 feet and map up to seven stratigraphic units--from glacial till and outwash to recent lake-bottom mud and peat.

4.2 Survey over Urban Fill

Figures 4a and 4b show a raw and processed GPR record for a survey along urban streets using an 80-MHz antenna. The survey, to determine bedrock depths along a proposed sewer alignment, was conducted under difficult site conditions: Data had to be collected at night along an otherwise

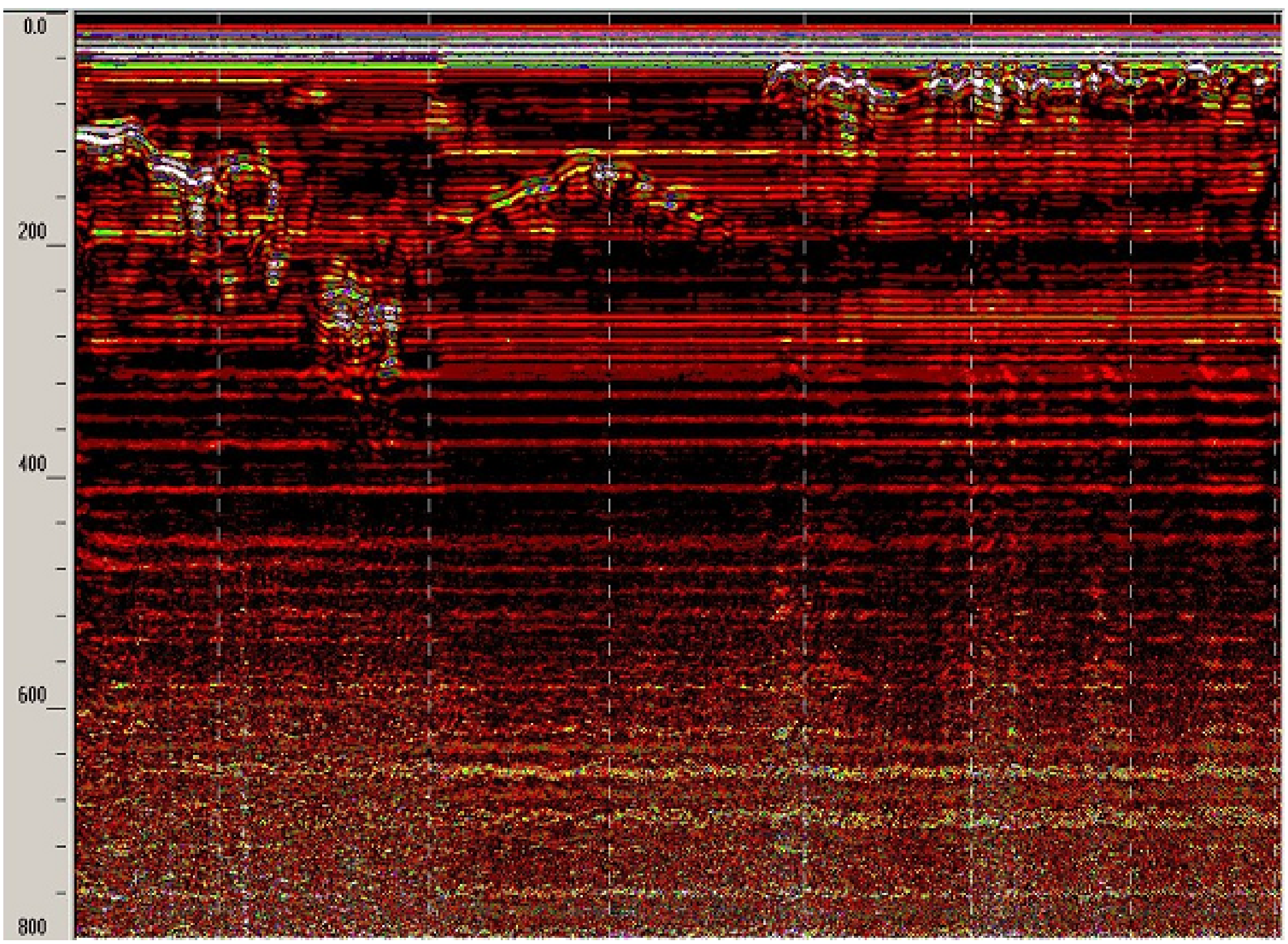

Figure 3a. Raw record for a freshwater lake survey using a 100-MHz bi-static antenna. Data were collected in continuous mode, with the record marked at 25-foot intervals.

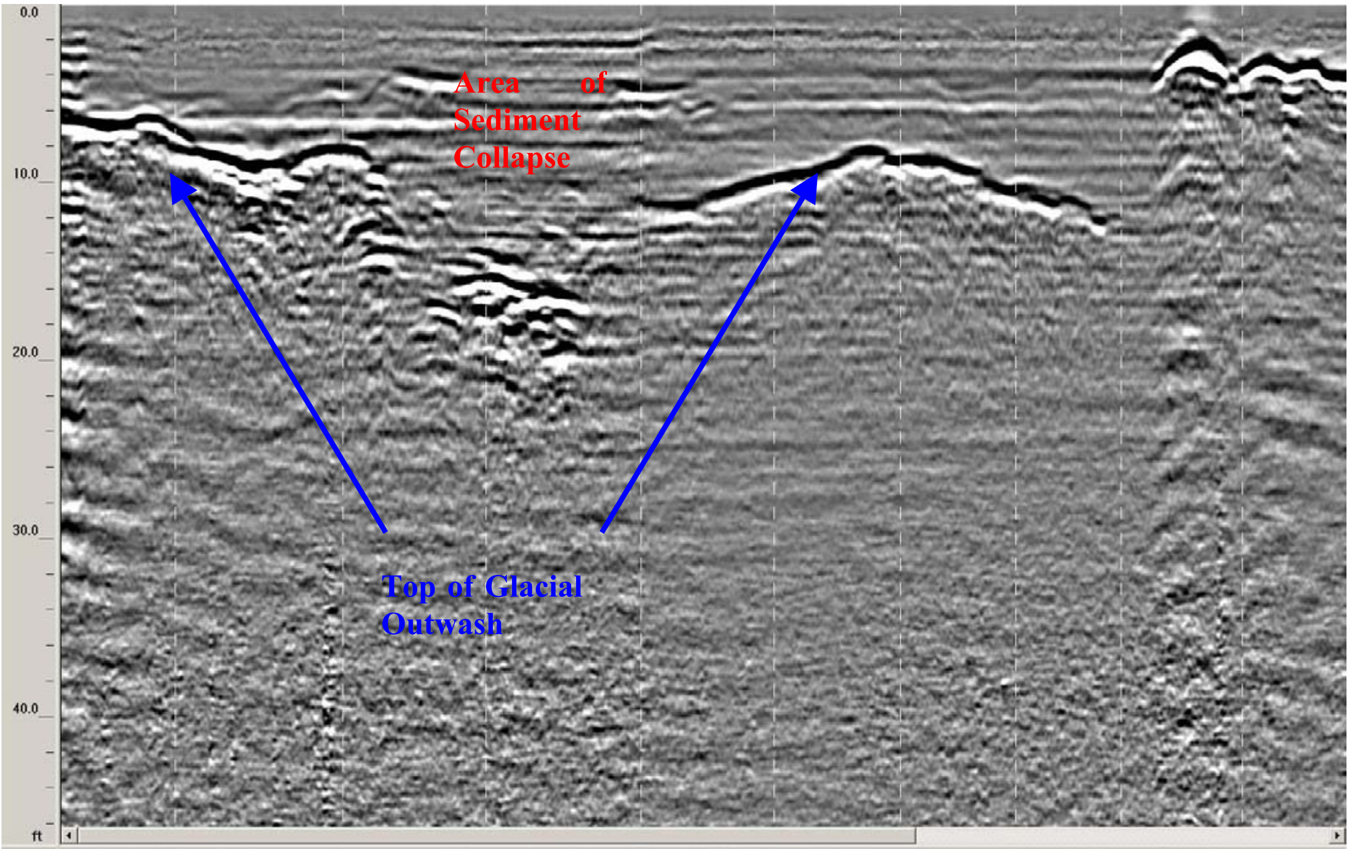

Figure 3b. Processed record for Figure 3a (gray scale). Background removal and filtering reveals area of collapsed sediment and glacial outwash beneath recent lake-bottom sediments. Vertical scale is depth in feet.

active road in downtown Boston, Massachusetts. The rock was shallow at some locations (<5 feet), and situated directly beneath trolley tracks that had been paved over with bituminous concrete. At some sections, cobblestones were also present beneath the pavement. Further, the subsurface above the rock consisted of urban fill. Normally, a

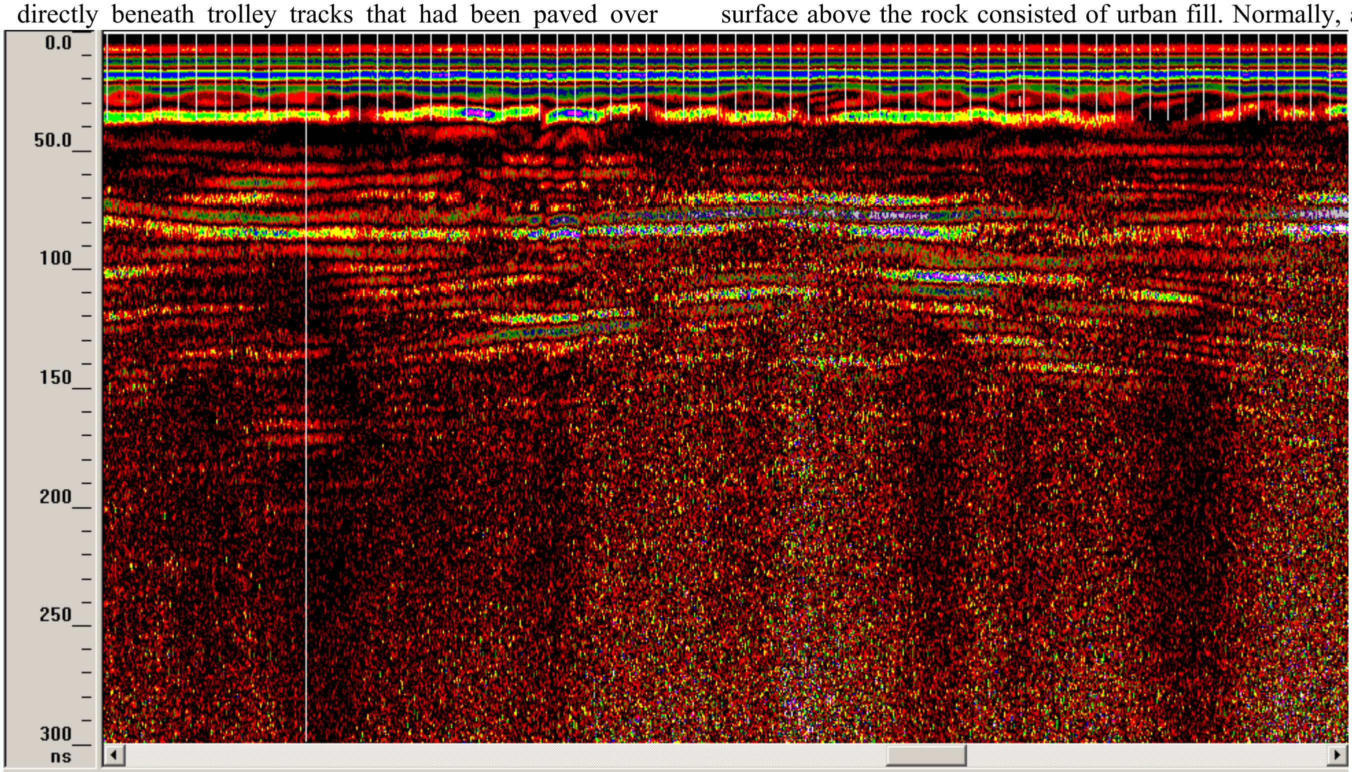

Figure 4a. Raw record from urban street survey using 80-MHz antenna. Data collected in survey wheel mode.

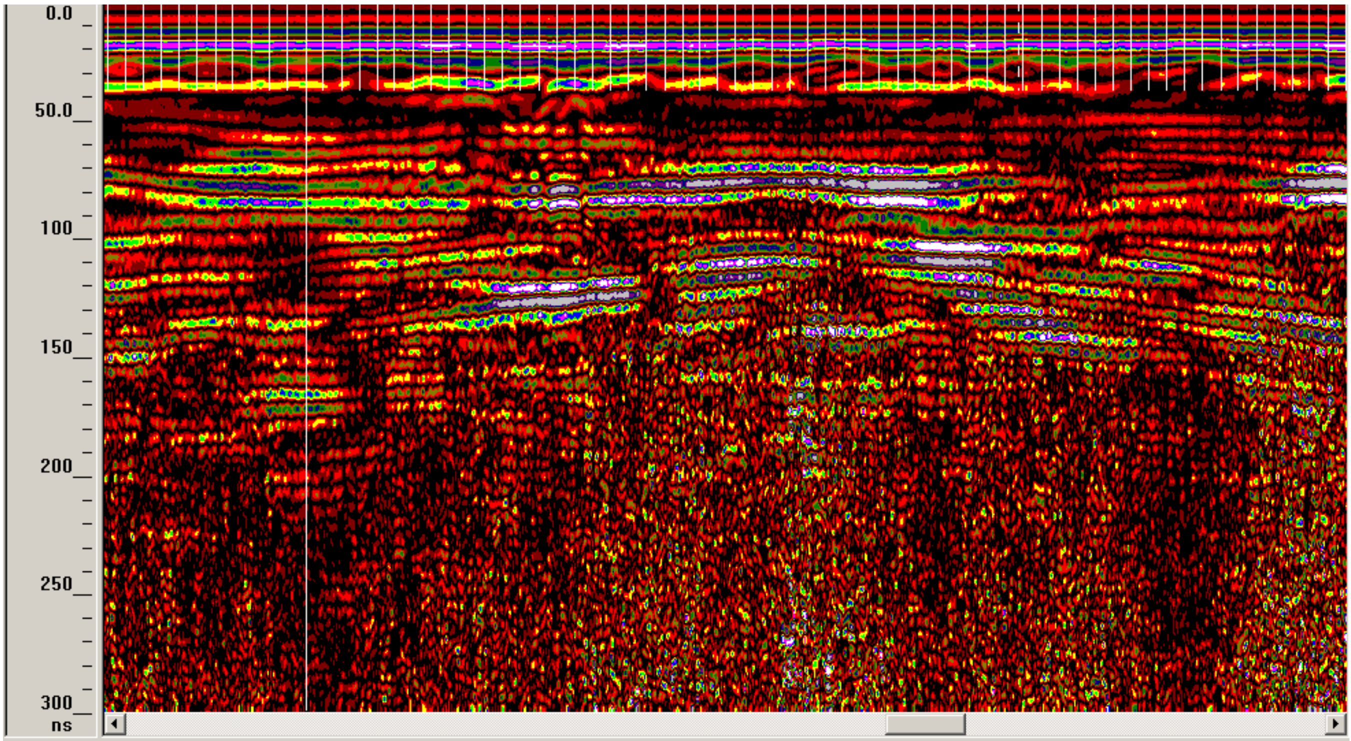

Figure 4b. Record in Figure 4a after processing. Note that significant amount of noise is still present.

200-MHz antenna would have been appropriate for the rock depths anticipated (5 to 25 feet). However, a lower frequency antenna (in this case, 80-MHz) was required to overcome the interference produced by the trolley tracks. The tradeoff was that shallow rock, where present, was within the pulse width of the antenna and could therefore not be resolved.

As Figures 4a and b show, the record still shows the effects of the noisy survey conditions, even after processing.

4.3 Survey over Natural Soils

Figures 5a and 5b show the raw and processed GPR re-

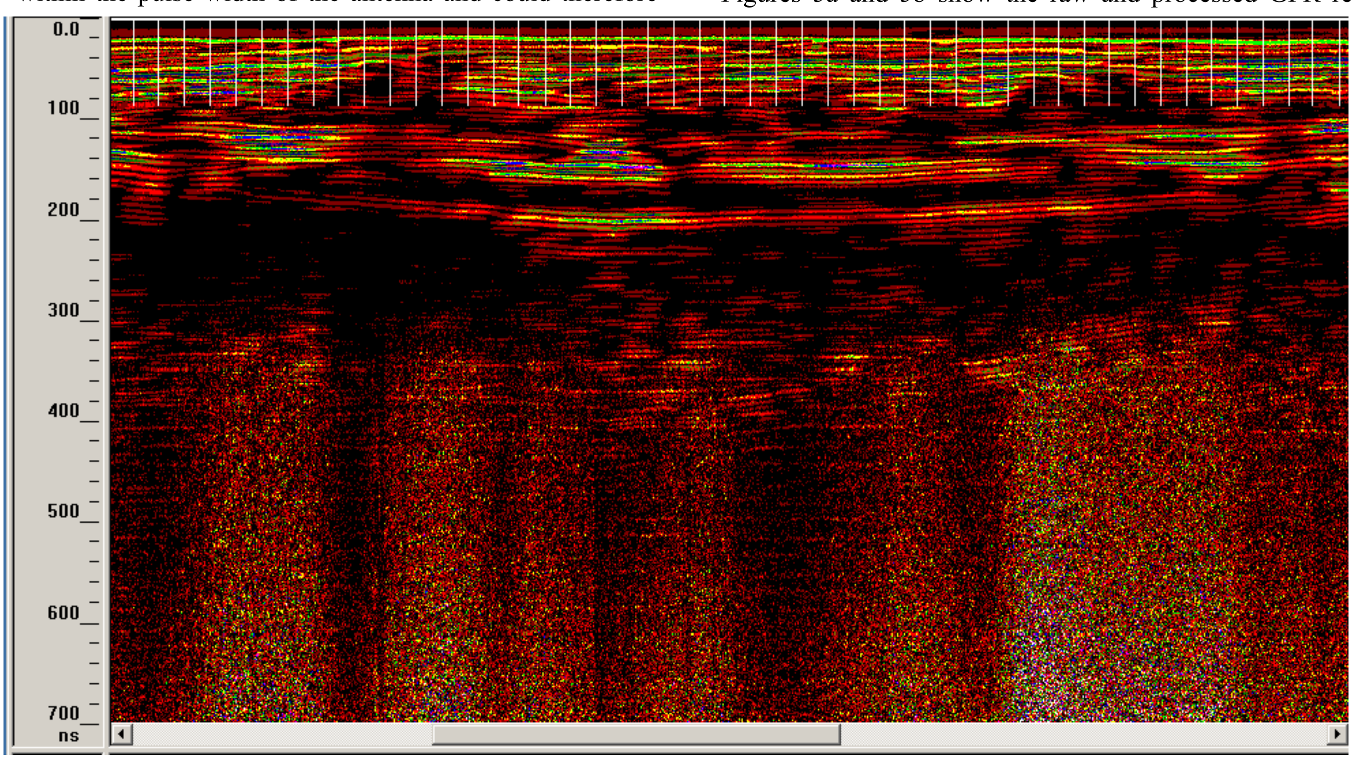

Figure 5a. Raw 100-MHz record for survey over natural soils. Some stratigraphy is evident.

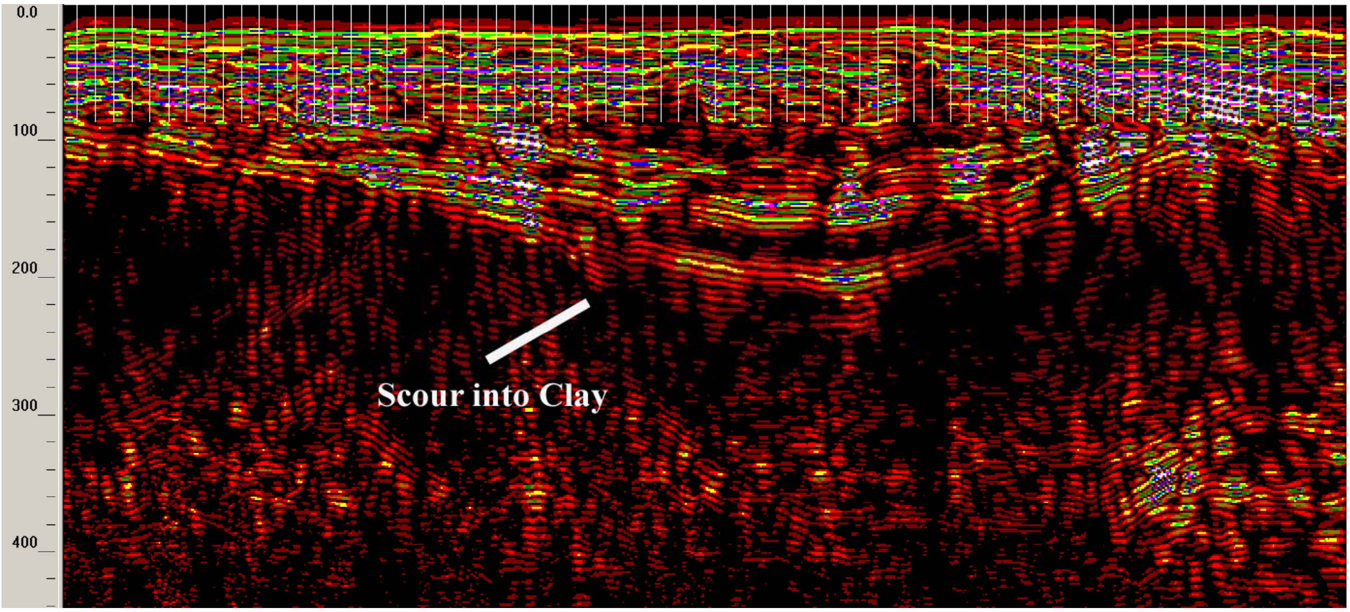

Figure 5b. 100-MHz record in Figure 5a after processing, including background removal and horizontal stacking.

cords for a survey in wooded terrain of northern New England. At this site the goal was to map both stratigraphy (including a thick clay aquitard) and bedrock topography, because of concern that a contaminant introduced into the upper sandy outwash might be making its way into bedrock fractures in areas where the clay horizon was thin or absent.

Antenna frequencies from 100- to 20-MHz were used for the survey, since both shallow and deep stratigraphic information was required. Processing included vertical high- and low-pass filters, horizontal and vertical stacking, and spatial FFT.

The 100-MHz high-power bi-static antenna identified stratigraphic features such as cross bedding and scours (see Figures 5a and 5b) as well as stratigraphic boundaries and internal bedrock fractures (see Figure 6). At this site the 20-MHz antenna reached depths of over 80 feet.

V. CONCLUSIONS

Low frequency GPR surveys can produce useful data under a

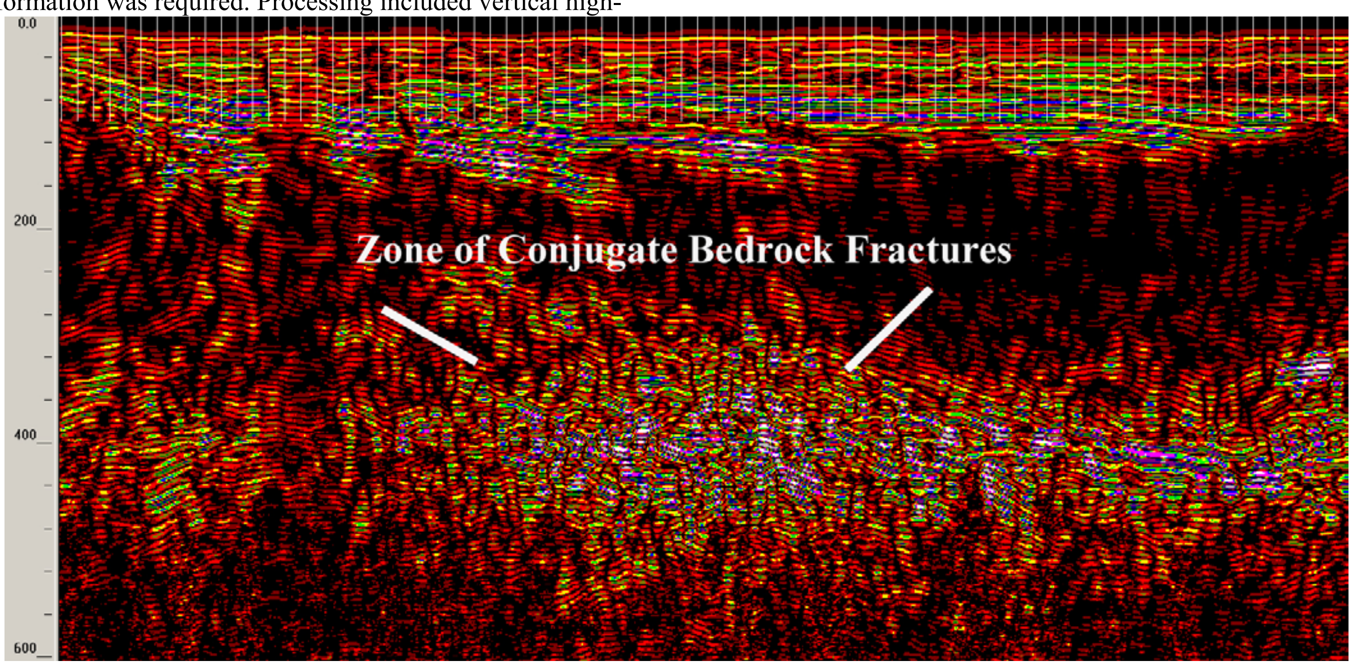

Figure 6. 100-MHz processed record showing upper cross-bedded sands over clay, with conjugate bedrock fracture zone.

variety of site conditions, but in general the raw records require significant processing. While advances in software enhance the data processing, it is unlikely that processing low-frequency data will ever be completely cut-and-dried.

ACKNOWLEDGMENTS

We wish to thank our staff geophysicists, who maneuver our low frequency antennas through fields and woods as well as along urban streets to collect necessary GPR data. We also thank GSSI for ongoing repair and maintenance of our aging systems, which we will be unable to replace for use in the US because of the FCC regulations.

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