

3D GPR Interpretation: Step-by-step

prepared by Jeff Daniels 11/24/00

Note: This document has not been edited, or reviewed

C 1.0 Overview

Three dimensional (3D) GPR data interpretation is impossible without good field data and good interactive software. All GPR data must be interpreted. There are no automatic image displays of 3D GPR data. The interpretation begins with the field data, continues through the processing, and is finalized in the three dimensional display. Any disconnect along the way will result in 3D displays that do not accurately represent the field data, or data that is cannot be interpreted.

The approach taken in this document is a hybrid of 2D/3D data collection and interpretation. Measurements are made along 2D profile lines, with the transmitter and receiver antennas very close together and moved in tandem along the line. Lines are spaced very closely together, following the Nyquist sampling rule that no sample (trace, or line) should be farther apart than one-half of the size of the object. In fact, a much closer spacing is recommended. The single most important factor (next to gross incompetence of the field personnel, poor planning, or inappropriate physical property contrasts for the method to be able to detect the target) contributing to the failure of geophysical methods to detect targets is spatial aliasing. In other words, profile lines that are spaced too far apart to detect the target in the subsurface often makes survey data worthless. The general rule-of-thumb for collecting a good 3D data set is that the line spacing should be less than one-half of the most ambitious estimate of spacing. In fact, it is a simple truth that you can never have a line spacing that is too small. The resulting digital data files from a detailed survey are very large, requiring programs that are fast, flexible, and capable of handling and storing large arrays.

The objective of GPHYZGPR is to provide the interpreter with all of the tools necessary to process and interpret GPR field data that are measured along profile lines, and to combine profile lines into a three dimensional block that can be interpreted in terms of subsurface objects. The underlying precepts of interpreting three dimensional data sets are: 1) the data display scale must be appropriate for the targets, and 2) getting a good 3D display “is” the interpretation. Interpretation and display are inextricably combined. In spite of what some GPR hardware and software vendors would like us to believe, there are no “automatic” 3D data displays of complex GPR data sets that will provide an interpretable image of the subsurface anomalies associated with targets. Good 3D displays are the end result of hard work, that often take several days (or in some cases weeks) to achieve. Display interpretation is as much of an “art” as it is a “science”. It is a “science” in the sense that the interpretation tools (processing and display) are developed and implemented along lines of good scientific and engineering principles, and it is an “art” in the sense that the interpreter must make decisions on how to apply the processing and display tools.

This Appendix goes through the interpretation of a complex data set in a step-by-step fashion. It is hoped that this will provide novice interpreters with some insight into one approach to the interpreting a 3D data set, and more advanced interpreters with an example of pushing the envelope of interpretation. This interpretation began without a thorough knowledge of this data set, other than the fact that the data were considered to be too complex to interpret rigorously when they were initially collected back in 1997.

Finally, I would like to add the personal observation that there are numerous approaches to interpreting a data set, and the following discussion represents one of many ways to develop an interpretable 3D image of GPR data. I would never argue that this is the only way to interpret data, but it is the path that I have developed over many years of experience. However, the interpretation tools in GPHYZGPR have been developed to accommodate my approach to interpretation.

C 2.0 About the Data Set

These data were collected in the summer of 1997 at a Brownfield site located along Lake Street in Chicago, Illinois. The site was an open field, with an elevated rail line running along one side of the site. A photograph of the site is shown in Figure C1. Several antennas were run along lines that were spaced 2 ft. apart. There were 60 lines (covering a data width of 118 ft.), and each line was 350 ft. long. The grid and distances are shown in Figure C2. Very little is known about the potential underground site conditions. The objective was to survey the site with several techniques (magnetic gradiometer, GPR, and EM). The methods and the initial interpretation of the data are presented in Holt (1997), and will not be described in detail here.



FIGURE C1. Photograph of Lake Street, Chicago field site.

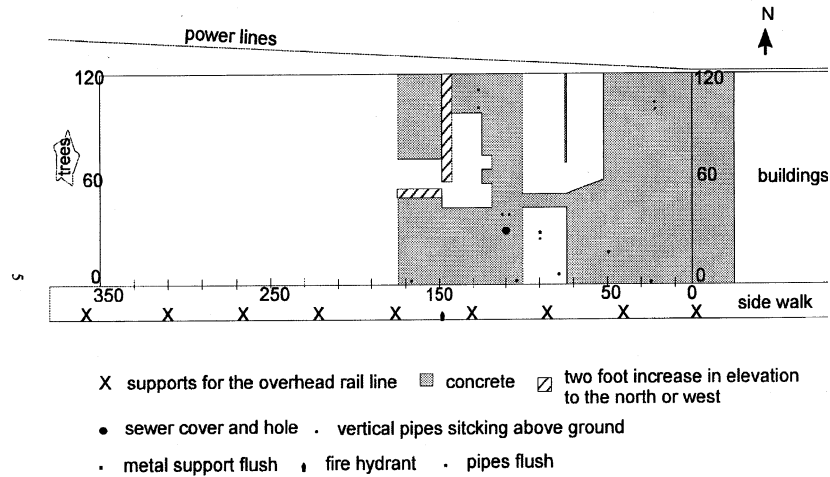


FIGURE C2. Map of the Chicago Lake Street Site (modified from Holt, 1997).

The GPR field data were collected along the lines, with a trace spacing of approximately 0.188 ft. (an average of 1860 traces were recorded over a distance of 350 ft.), and 512 samples per trace over a 50 Ns time-range. In keeping with our rule of applying a minimum amount of filtering, or gain to the data in the field, a simple linear (2 point) gain was applied to each trace, with a simple low-cut filter of 50 Mhz.

Two antennas were utilized: 1) a GSSI multi-component antenna, and 2) a GSSI 300 Mhz antenna system. Data sets with two polarizations were run with the multi-component antenna system (co-poles orientated perpendicular to the direction of the profile lines, and cross-pole). In addition, data were measured along lines running North-South at a 2 ft. spacing for the multi-component antenna system. The co-pole data from the multi-component antenna are used for the following example.

C 3.0 Two Dimensional Data Processing using GPHYZGPR

The two dimensional processing proceeded initially along a very simple processing sequence, as follows:

1. Read in the data and create a list of all files. GPHYZGPR automatically reads in the header information from Sensors & Software and GSSI systems. The list is created for all of the data files in the survey. This incorporation of all files into a single list insures that all of the data will be processed in a uniform manner.
2. Apply a bandpass frequency domain filter to the data to eliminate the “wow” from the data. Otherwise, the filtering was minimal.

3. Standardize the data, including adjusting the line direction and making all of the line lengths equal.

A raw field data file and a reversed and filtered data file are shown in Figure C3.

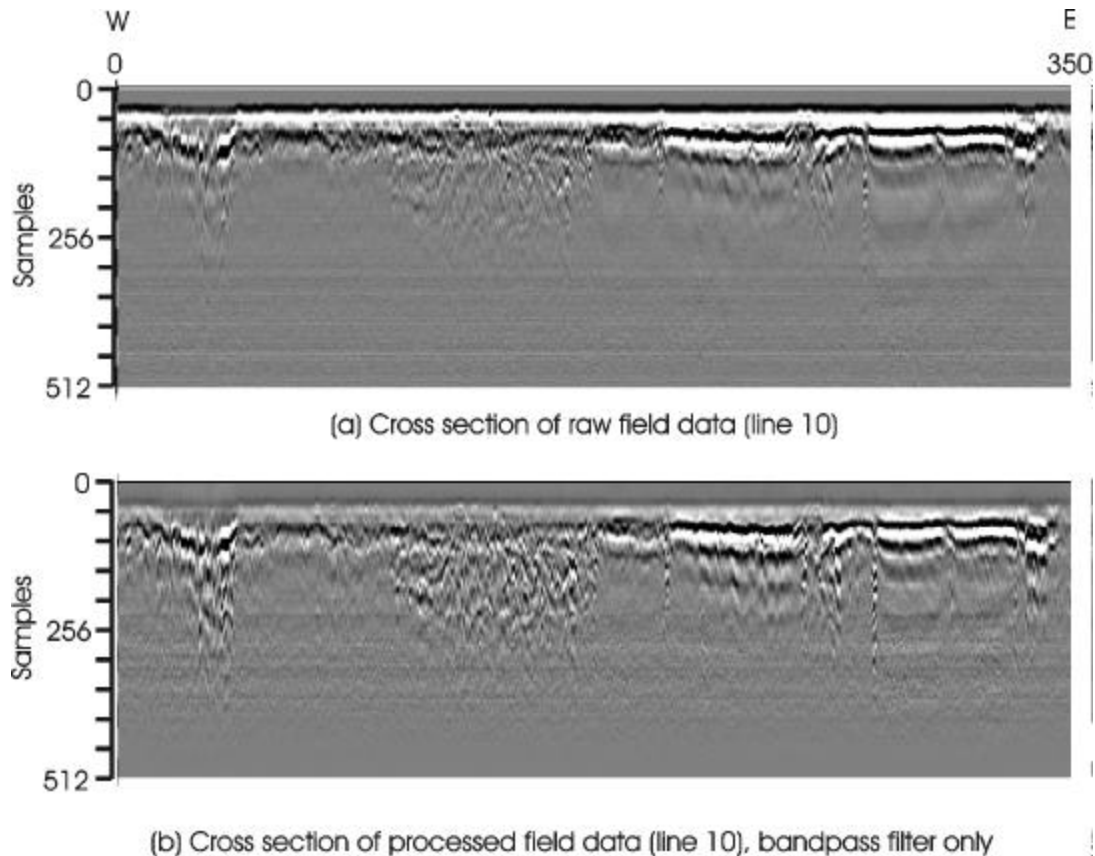


FIGURE C3. Raw field data cross section, and filtered and reversed field data file for the Lake Street data set.

A comparison of a sample of three lines are set aside for reference when the 3D data set is interpreted. This concludes the initial 2D analysis of the data. The *TWO DIMENSIONAL* analysis menu may be revisited if more advanced interpretive processing is required (migration, trace subtraction, or amplitude isolation analysis), and for determining the velocity of the medium to calculate the depths to objects.

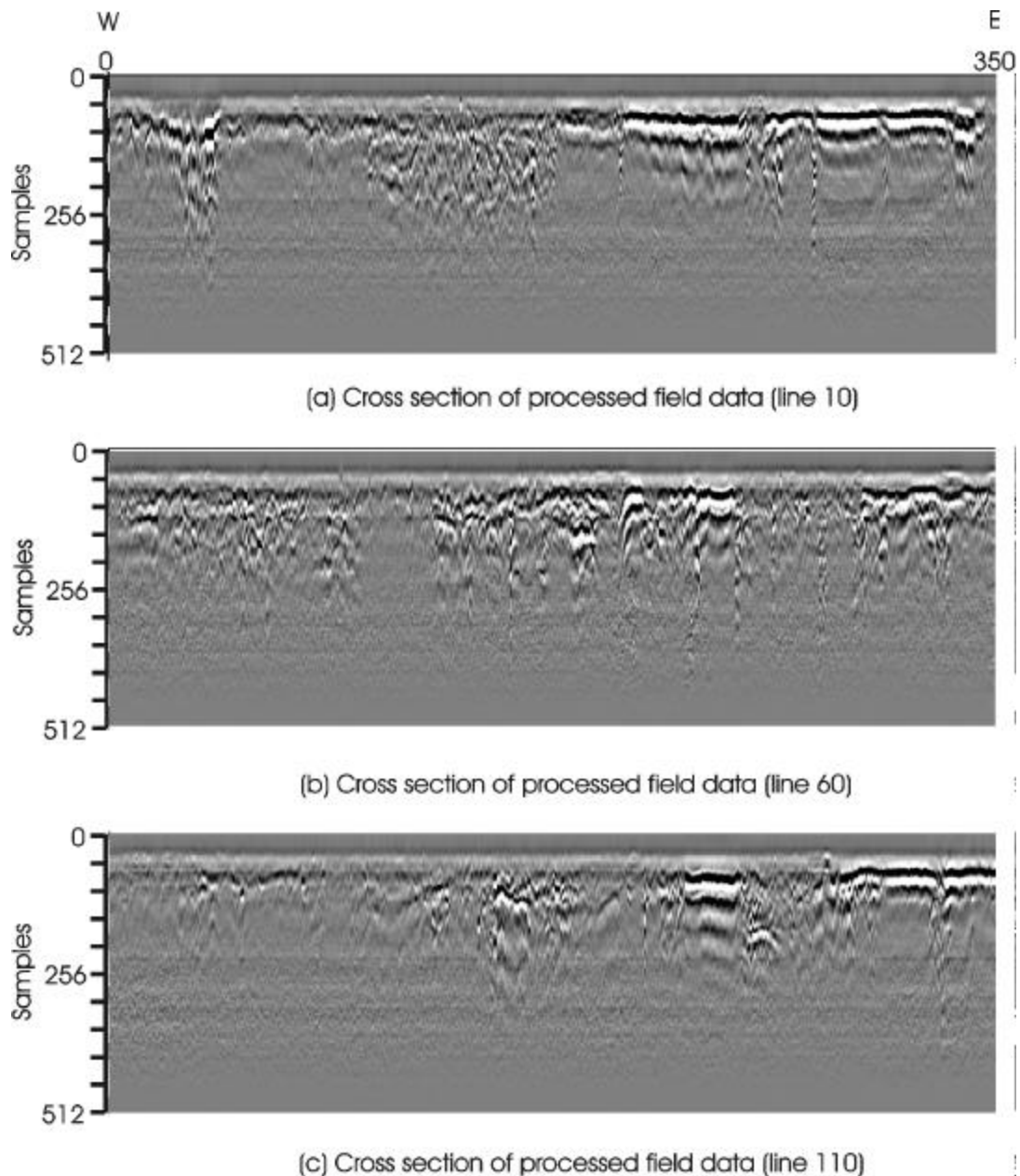


FIGURE C4. Processed 2D GPR data along the 8 ft., 60 ft., and 110 ft. profile lines.

C 4.0 Formation of 3D Data Subsets

The map in Figure 2 and the cross sections in Figure 4 indicate the following about the area: 1) the area is divided into two areas based on the surface material, 2) the surface material does affect the GPR data, and 3) the GPR data show that the subsurface is very complex, containing numerous objects and debris. The depth of penetration of the GPR data is moderate (approximately 300 samples, or 30 Ns), but the lateral resolution down to that depth appears to be excellent. The fact that the subsurface debris is extensive means

that it is necessary to subdivide the data set into subsets in order to view the data properly in three dimensions.

It is important to have an objective in-mind concerning the targets that are of interest to image. In this case, we can anticipate that there are a lot of scattered objects in the subsurface that will give very localized anomalies, and these objects will simply cause clutter on the records unless we use very small subsets. Therefore, our initial targets in this case will be the larger features that might be expected in this case, including: 1) waste pits and trenches, 2) pipes, 3) tanks, and 4) foundations. It would be convenient to subdivide the area into two blocks, with one block covering the grassy area on the west side of the field, and the other block covering the paved area on the east side of the field. However, it is anticipated that these two areas would still be too large to produce manageable 3D views of the data, and therefore the data will be subdivided into four blocks. The four blocks will be defined as follows: 1) grassw, consisting of all of the traces from 0-95' (traces 0-504) on the west side of the area, 2) grasse, consisting of all of the traces from 90'-185' (traces 478-983) in the middle of the area, 3) pavedw, consisting of all of the traces from 170'-265' (traces 903-1408) on the west side of the paved region, and 4) pavede, consisting of all of the traces from 260'-350' (traces 1382-1860) on the east side of the paved region. This block size creates blocks that are approximately the same size (note that there are 61 lines spaced 2 ft. apart), and allows some overlap of the blocks. Smaller subsets can be taken later, if these blocks prove uninterpretable due to clutter.

C 5.0 Establishing the View Parameters

C 5.0.1 Preliminary Steps of Forming a 3D View

A block of data can be quickly formed through the *Three Dimensional* menu. The only difficult decision is establishing the vertical trace gain, and overall maximum cutoff amplitude for the block. The amplitude cutoff is important, since the amplitude range determines the color scale assignment range, which determines the amplitude resolution (discrimination) of the display. The gain is also important, since it determines the relative amplitude as a function of time (vertical dimension of the block). This is the first true subjective decision in the interpretation process, and there are no fixed rules for making this decision. Generally, it is best to decrease the amplitude slightly with respect to time. However, be fore-warned that this amplitude variation will affect the interpretation.

The initial block is displayed as a gaudy color variation with a single cross section. You will want to change this display. However, it is almost always fruitless to try to form an alpha-rendered image at this point by adjusting the colors and opacities. The next step should be to simply get your bearings, and establish a reasonable initial color display. This is best done by viewing the slices, rather than going immediately to the 3D rendered image.

An initial view of the entire example data set (0-300 samples) is shown in Figure C 5. The first view (Figure C5-b) is the view on opening the file, a cross-sectional corner view is seen in Figure C 5-b, while a cross section along line 10, which corresponds to the 2D section in Figure 4, is shown in Figure C5-c. This initial block of data may be too large to interpret, or to image in three dimensions. The appropriate scale of the data set that is being viewed is a function of the number of traces, lines, and samples. However, the only way to determine the optimum number of samples, traces, and lines to display is to experiment with different subsets of the data. A subset of the data consisting of 504 traces is shown in Figure C 6. These data are much easier to interpret than the entire data set in Figure C 5. It may be decided later to further subdivided the data shown in Figure C6 in order to isolate a particular anomaly. However, we will proceed to develop the image for the data shown in Figure C 6.

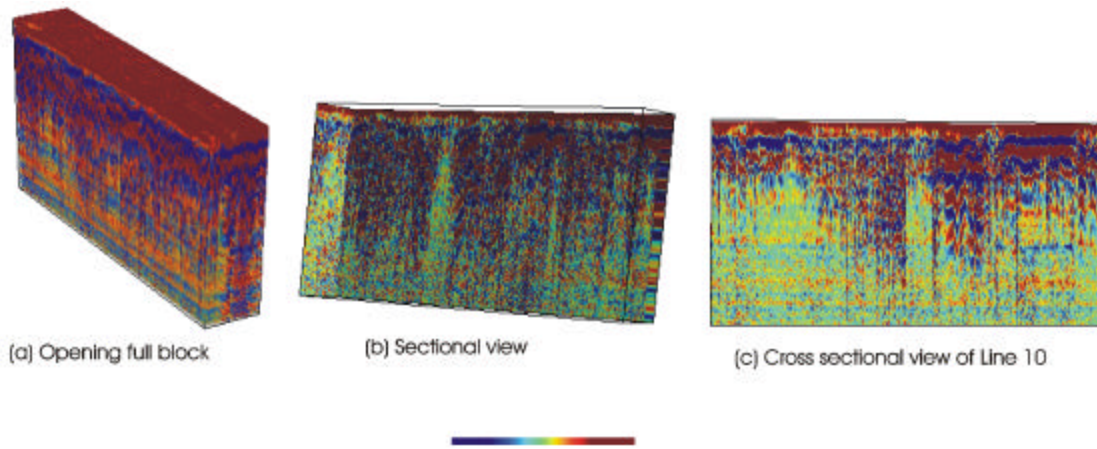


FIGURE C5. Opening views showing the entire data (1860 traces) set down to 300 samples. Note overlap and complexity of data display.

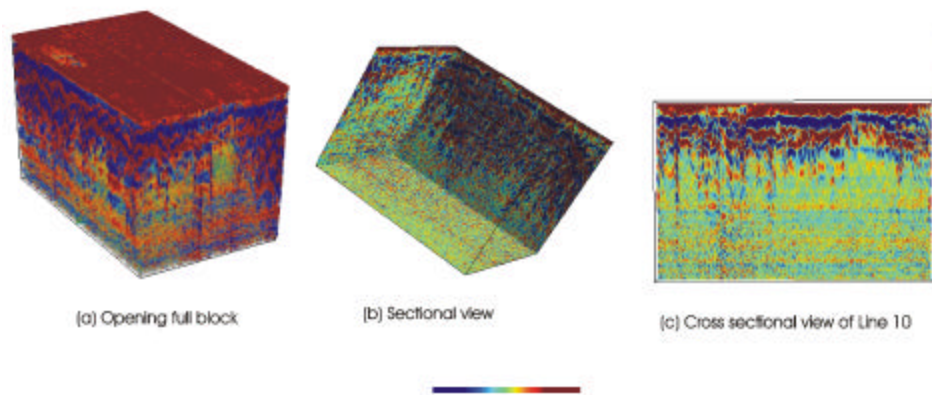


FIGURE C6. Opening views of a subset of whole data set from 0-503 traces on the west side of the study area.

The choice of color is primarily a question of personal preference. However, colors that cannot readily be copied (e.g. light yellow, or light blue) should generally be avoided. A rainbow of colors can also be difficult to decipher, and tends to make the final image very cluttered. The best choice is usually a simple blend of a single color. The color range of white-red-black is chosen for the following examples.

It is best to work back-and-forth between the color and opacity adjustment to achieve the optimum image. If there are too many objects in the image, then no color/opacity combination will enable the interpreter to see the anomalies. In this case, the interpreter should work with a smaller block, or work with sub-blocks within the current working block.

The initial color assignment chosen in our example is shown in Figure C 8-a, and the linear function plot for these colors is shown in Figure C8-c. The opacity is a simple linear ramp that is shown in Figure C8-e. The single polarity plot is shown in Figure C8-b, and the corresponding function plot is shown in Figure C8-d. The contrast in detail is most obvious by comparing the 3D block views (Figures C8-f and C8-g). The figures speak for themselves.

The next step in interpretation is to get a handle on the data set. (My curiosity at this stage forces me to browse through the block. I want to see what I have!) The “pillow” time slices (Figure C9) are generally a good way to get an quick look at the interior of the block. These finite-thickness blocks give a textured view of the data, which tends to reveal more trends in the data than simple slices. Sometimes (rarely) the interpretation is complete at this stage, and it is not necessary to go into more color/opacity “filtering”. However, for this example we will proceed to try to obtain an optimum pseudo-image, with colors and opacity adjusted to reveal anomalies on the interior of the block.

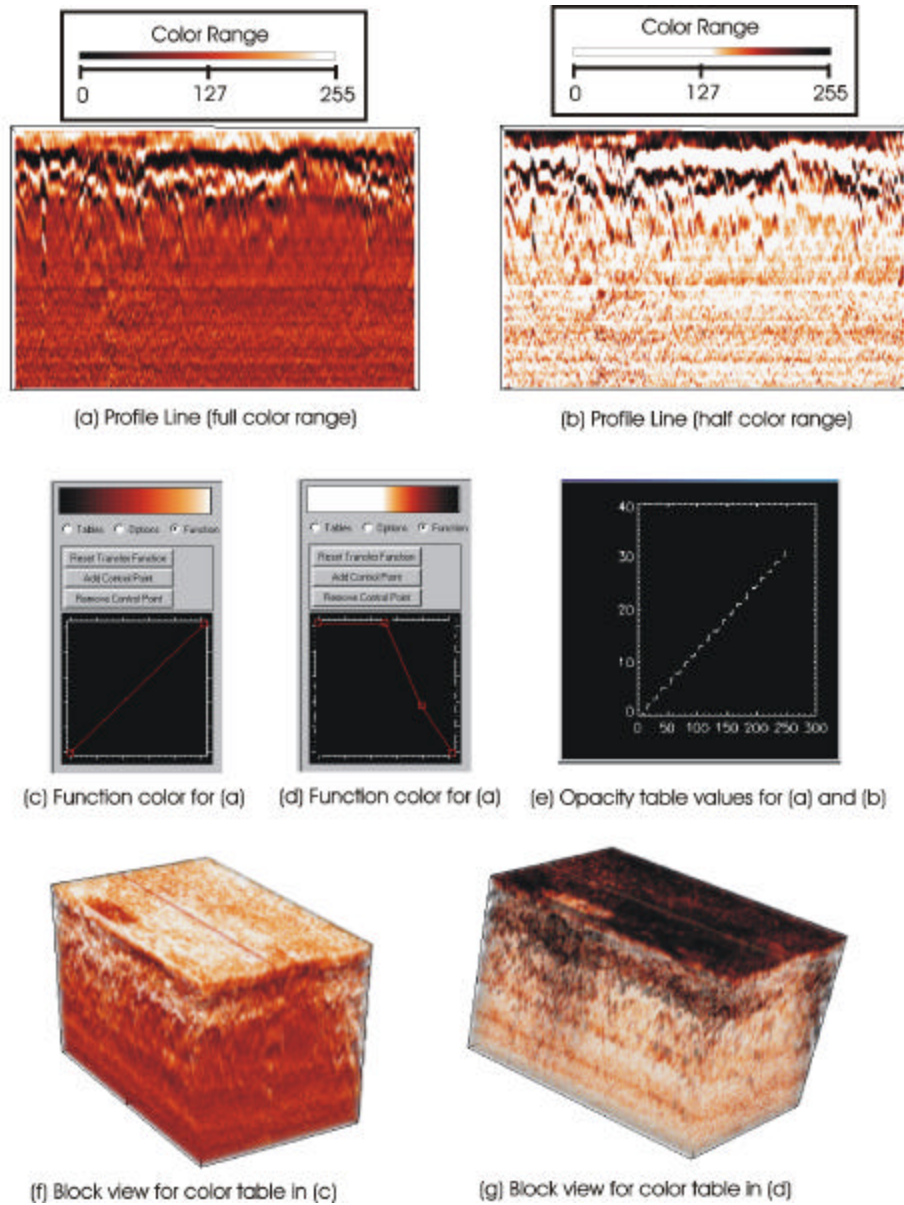


FIGURE C8. Color selection, showing the original block with a linear range of colors applied to both polarities, and a single polarity. The 3D blocks corresponding to these polarities are shown in (f) and (g).

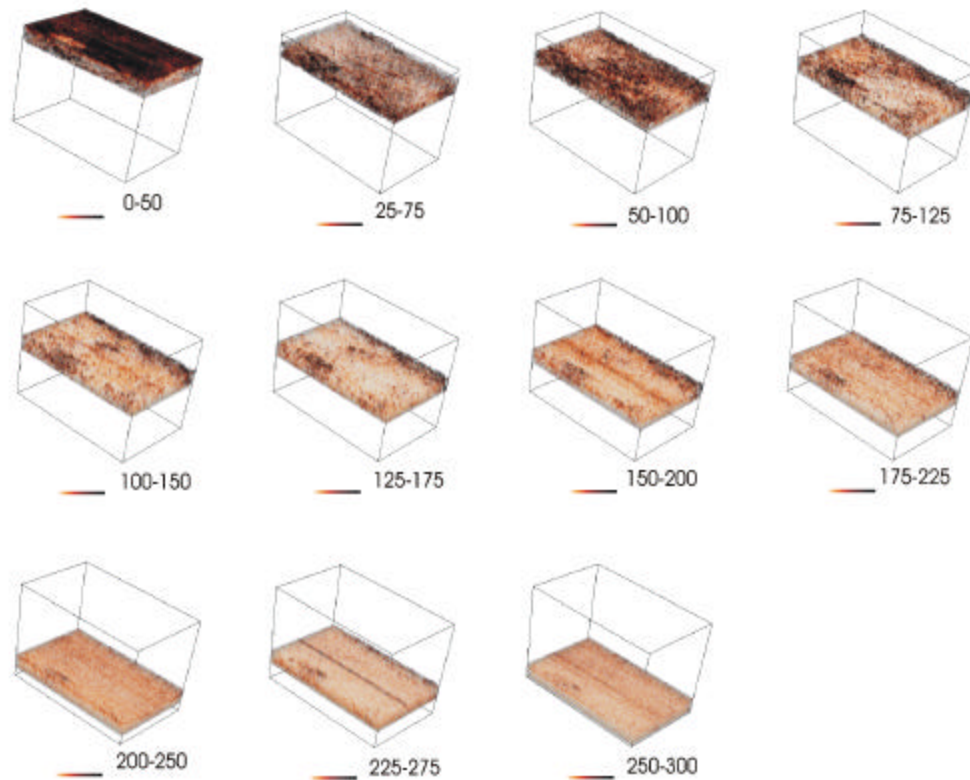


FIGURE C9. Pillow slices for the color assignment shown in Figure C 8-b.

Unfortunately, there are no “rules” on how to obtain a good semi-transparent block image. This is where the interpretation “art” controls the process. It is somewhat a process of trial-and-error. However, every interpreter will eventually develop their own approach to developing an image. My personal approach is to start with the whole data set, and simplify it step-by-step, a typical sequence of simplification steps is as follows:

- 1.) Simplify the color range to two colors, or gray scale. (Figure C10-b)
- 2.) Eliminate one of the polarities of the signal from the block. This is done in two steps:
 - (a) Compress the color chart to half the range. For example, make the color white for the color indices in the range of 0-127 on a gray scale chart. (Figure C10-c.)
 - (b) Assign a value of zero opacity for the color indices in the range of 0-127. This effectively makes any voxel with an index in this range transparent. (Figure C 10-d). Note that if you have the grid turned-on, you must reset the opacity of Index 127 to an opacity of 255 (opaque) to see the vertical, and/or horizontal, grid lines.

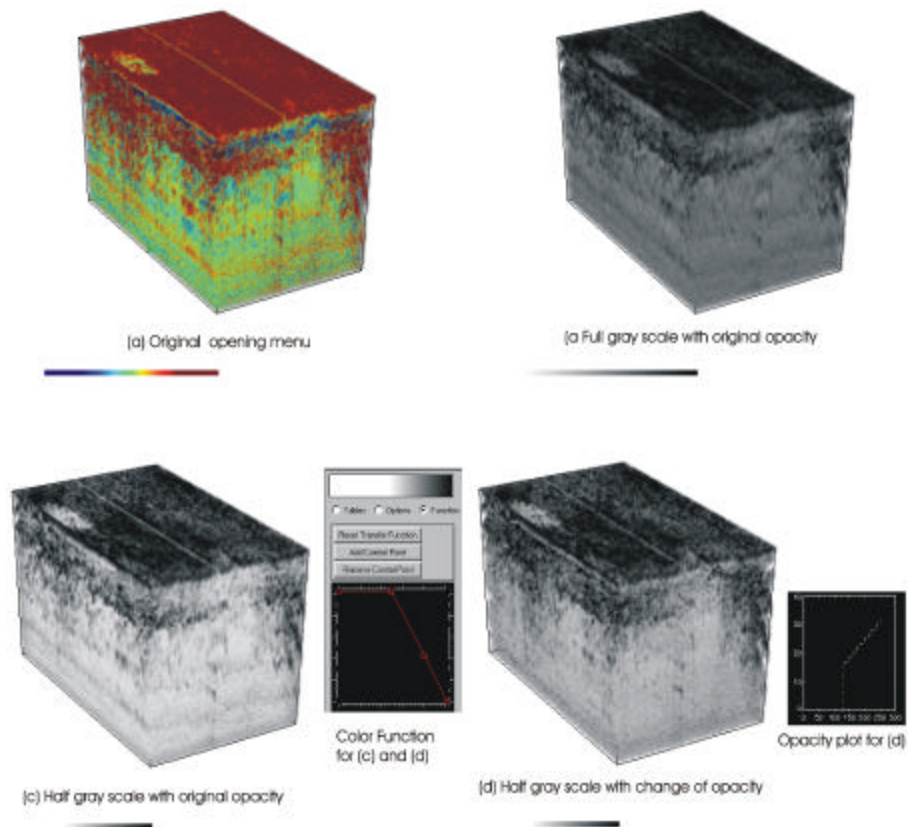


FIGURE C10. Initial simplification of colors and color assignment.

3.) Turn-on the Color Function menu, and fine tune the color. After slowly changing the color range, I obtained the result shown in Figure C11. The Color Function Table and a plot of the Opacity Table values are also shown. (The Opacity Table plot can be obtained at any time by simply clicking on the Stats Button.) Note that I made more of the image transparent by setting the opacity to zero up to Color Index value 175, and flattened the opacity values from 175-255 to a value of 10. This may seem extreme, but I have found that I rarely assign an opacity value higher than 30 for block views, even though the range is from 0-255.

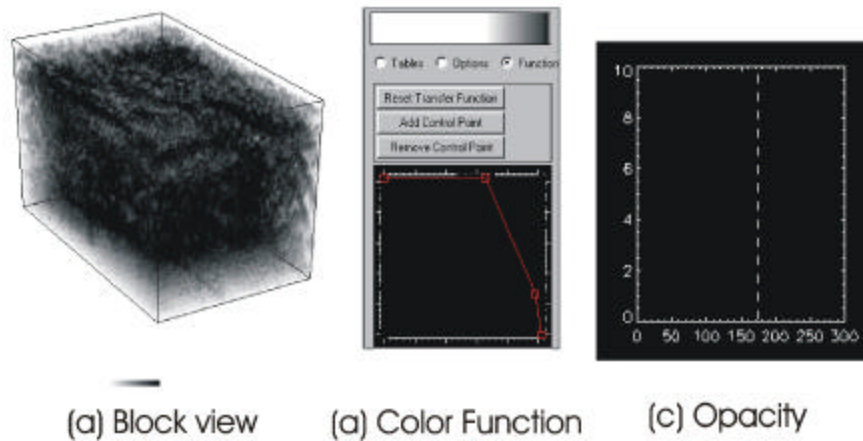


FIGURE C11. Block view with refined color and opacity.

4.) Next, I continue to change the opacity and color values. I also eliminate the direct arrival and some of the surface ringing effect from my image by only showing samples that are greater than the value of 15. If a clear image cannot be obtained with the entire block, then you must work with smaller blocks. This is the case with our sample data set. Figure C12-a shows the result of a rather extreme set of color/opacity values. Plots of the opacity and color values are shown in Figure C12-b and C12-c. This view shows nothing but a single black glob. However, dividing the block up into sub-blocks of 100 traces (~20' of distance), yields the group of blocks shown in Figure C13-1 through C13-e. Note the effectiveness of the transparency in these smaller blocks. Other pillow and slices perpendicular to those in Figure C13 could be produced that would help to view the anomalies, but now lets try to improve the color contrast and “jazz up” the display a little. This final step will probably do nothing to improve the interpretability of the data, but lets give it a try.

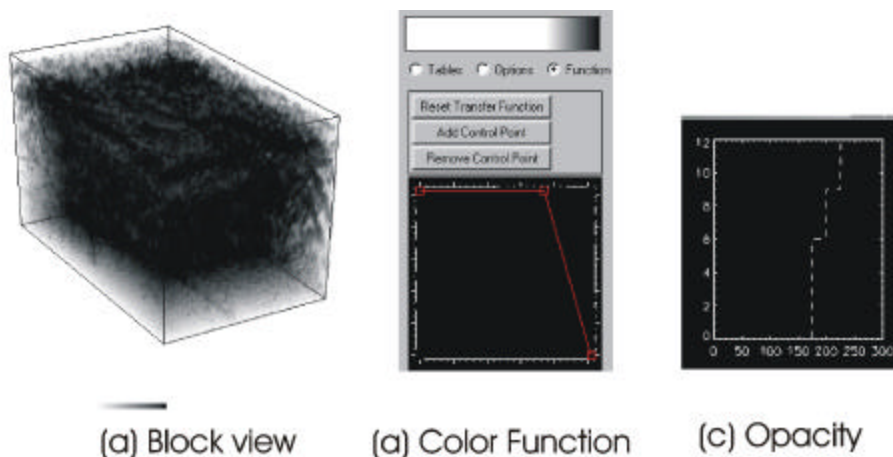


FIGURE C12. Next step in process of refining the “color” and the opacity. The opacity is the most important parameter at this stage.

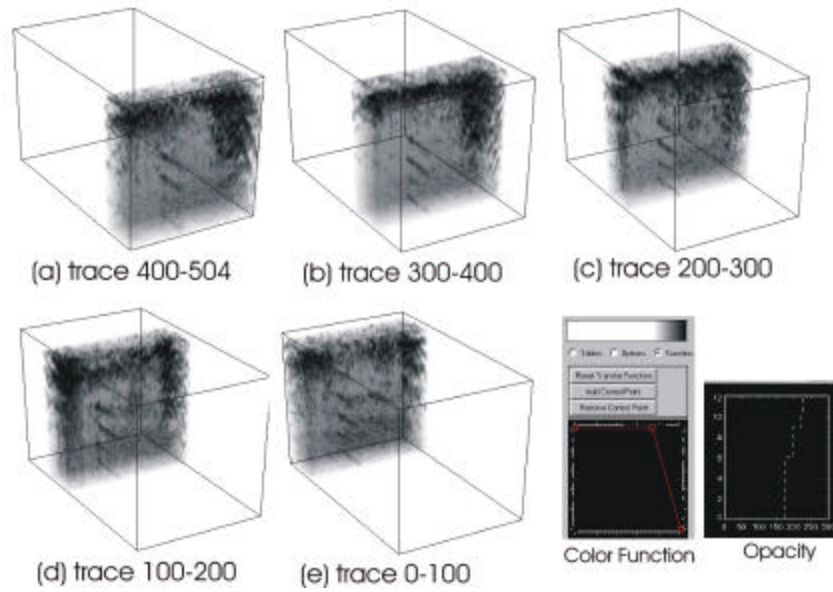


FIGURE C13. Vertical slices of the block view in Figure C12.

5.) The effect of adding some color to the interpretation are shown in Figure C14. Line and time slices are shown in Figure C15. This does improve the visual appeal of the data set, and tends to show some details that are not seen in the gray scale display.

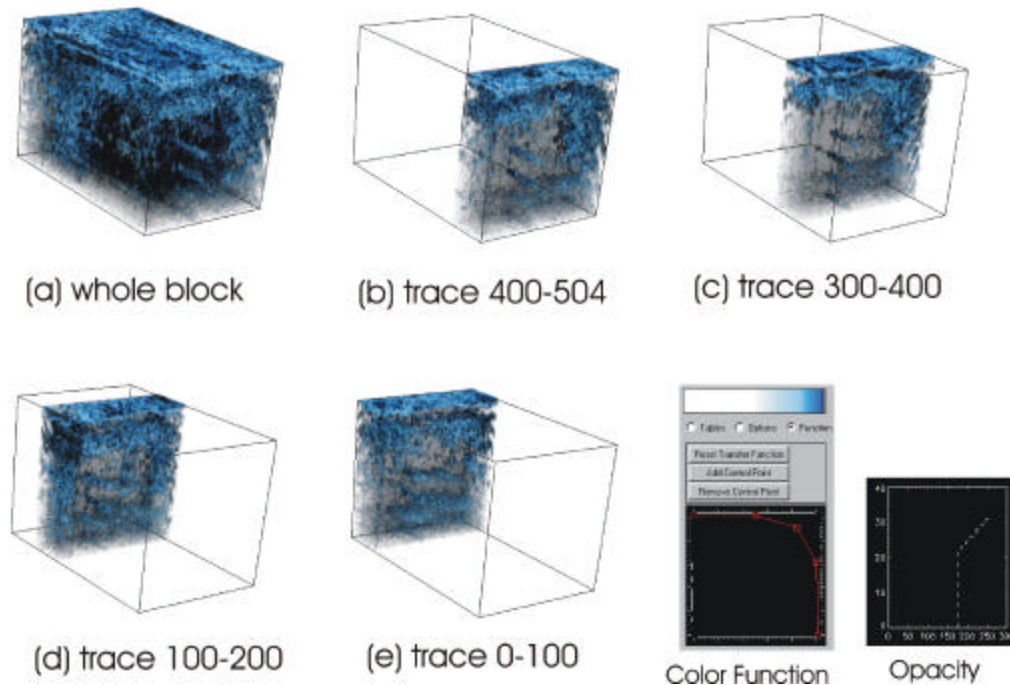


FIGURE C14. Color trace slices and whole block for the example data set.

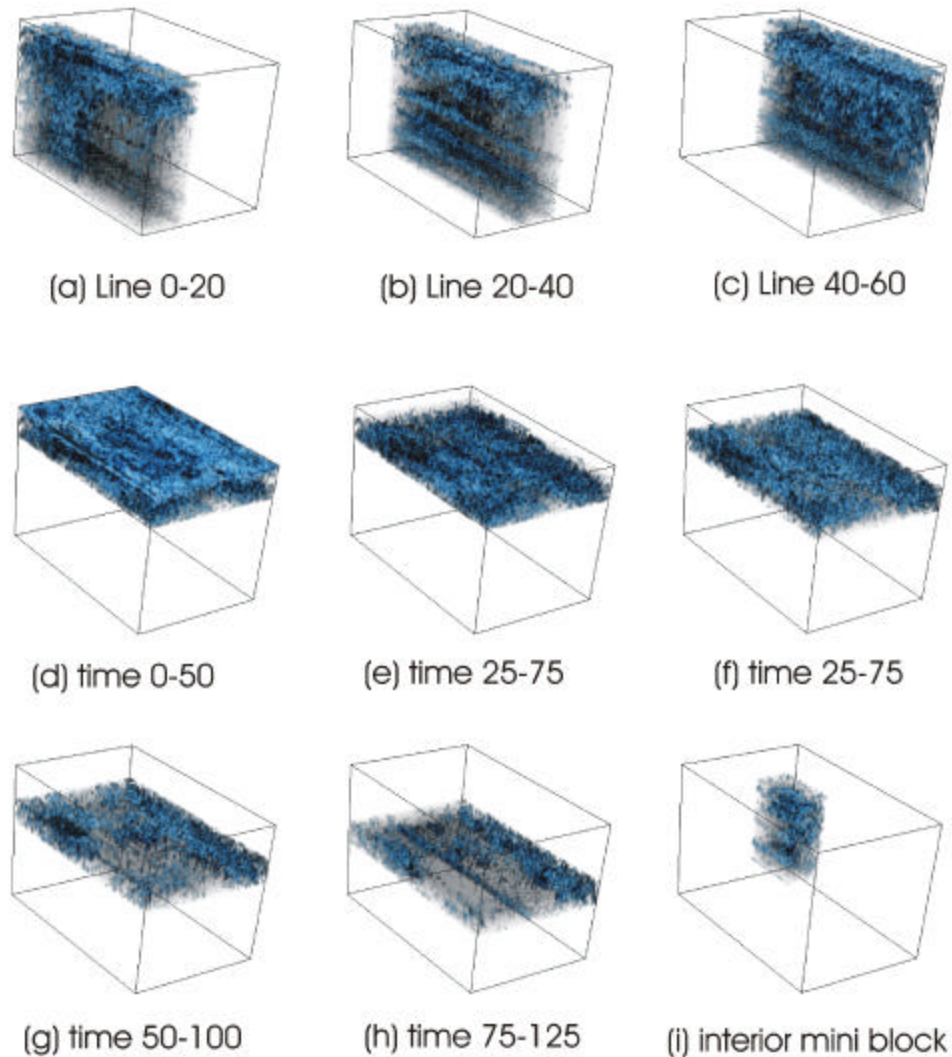


FIGURE C15. Line and trace slices for the example data set. Note interior mini-block.

6.) Remember that this data set is only 1/3 of the entire data set. We save the opacity and color tables (using `C>` and `O>`), and proceed to interpret the other two subsets of our Brownfield GPR data set. The settings should be the same as they were for the first data set, and it should be a simple job of applying the Color and Opacity Tables that we have developed from the first subset of data to the other two data sets. However, this final phase of the interpretation will not be included in this example, since the primary purpose of this exercise is to demonstrate an approach to interpreting a 3D data block, and that task has been accomplished at this point.

Summary Comments

The 3D plots in Figures C14 and C15 are only part of the interpretation. The next step is to go to the other two sub-sets and interpret them, using the colors and opacities that were developed for the first data sub-set. However, in all probability the whole process will be

repeated at least one more time before I will be satisfied with the final result. For example I am not pleased with the fact that the color scale is so compressed. This color compression is caused by the fact that the range of values that were selected for generating the main data block was too narrow. In fact, some of the peaks in the near surface were clipped. Also, I will probably boost the gain a little bit for the later time samples, which effectively cause the data to be nearly constant gain from top-to-bottom. Generally, I object to using this type of gain, since it is not close to the amplitudes that are recorded in the field. Finally, before I am satisfied that I have an optimized interpretation, I will apply some of the two-dimensional filtering routines to the cross sections (e.g., *trace subtraction* and/or *trace max/min cutoff*), generate a 3D block and decide if it is worthwhile to interpret the heavily processed data. In the end, I want to exhaust all of the interpretation tools that I have at my disposal to produce the best possible interpretation of the data.

Obviously, the final and most important step is to take the displays and interpret the source of the anomalies. It is easier to do this with 3D data sets than with 2D data. However, in order to do this properly, we should interpret the GPR data in light of all of the other available data. In the case of this site, we have EM (GEM, EM-31, and EM-61 data), and a cesium magnetometer survey. We also have two other GPR data sets to integrate with this data set. There is a lot of work to be done before we can provide a solid subsurface evaluation of the site, but utilizing GPHYZ will make it a lot easier to incorporate the GPR data in the final geophysical appraisal of the site. The final integrated geophysical interpretation will be left for another day.

I have shown one path to interpreting a data set using GPHYZGPR. Obviously, there are as many paths as there are interpreters. The fact that geophysics is an interpretive science is one of the most challenging aspects of our craft. In my opinion, interpretation is the fun part of geophysics, and 3D interpretation makes interpretation even more fun.