Three-Dimensional Modeling and Visualization of Greens Creek Drill-Hole Data

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Abstract

Three-dimensional modeling and visualization provide powerful tools for evaluating and interpreting chemical and physical properties in space, including subsurface domains. These tools were applied to drill-hole data provided by the Kennecott Greens Creek Mining Company for the Greens Creek mine on Admiralty Island, southeast Alaska. Three-dimensional models of subsurface data from drill-core chemical assays, ore lithology logs, mine workings, digitized faults, and digital terrain were produced and combined to create visual displays that could be manipulated and rendered as images for this report. The validity of the model showing the distribution of orebodies is confirmed by comparisons with plan and cross-section drawings produced by geologists at the mine. The three-dimensional models should therefore be useful to guide mining development efforts and could also be effectively used to revisit previously developed mine areas to determine where additional production might be targeted.

Introduction

This chapter describes methods that were used to render Greens Creek mine drill-hole information into three-dimensional models of the distribution of orebodies and of geochemical concentrations within the orebodies. Geologic structures, mine workings, and a topographic surface were also modeled and were integrated with the other models for purposes of scientific visualization. Data descriptions, coordinate transformation procedures, and modeling techniques are included. Dynamic Graphics, Inc., EarthVision software was used to successfully calculate and display the three-dimensional models, and several graphical images of the modeling results are included in this report.

Description of the Dataset

In 1997, the Kennecott Greens Creek Mining Company provided core log data for 1,895 exploration drill holes in the Greens Creek mine vicinity. There are 12,764 deviated segments in these holes and more than a million observations and analytical determinations at 75,291 locations along the core segments. These data include measured depths, geochemical concentrations, lithologic and ore-type classifications, and inclinations and orientations of drill-hole segments. The spatial coordinates of the drill-hole collars (origins) and the azimuths of the holes were relative to a local surface grid of northings and eastings, measured in feet. The origin of this grid, relative to the Alaska State Plane projection, Zone 1, Clarke 1866 spheroid, NAD 1927 datum, also in units of feet, is 2262748.50N; 2479273.89E. These coordinates correspond to lat 58.0234985°N., long 134.7311267°W.

The spatial reference for the mine workings, however, is a local grid of cross-section (*XS*) and long-section (*LS*) coordinates whose origin is given as northing 12635.93 ft and easting 17438.42 ft in terms of the surface grid coordinates. Therefore, the mine grid origin is at Alaska State Plane Zone 1 coordinates of 2275384.43N and 2496712.31E. The mine grid is rotated 26.5651 degrees counterclockwise from due north. The mine coordinate elevations are 60 ft higher than true above-sea-level elevations (chap. 7).

Data-Processing Procedures

Although the data were provided with spatial coordinates in terms of the local surface grid, it was felt that three-dimensional modeling and visualization of the subsurface data would be most useful if rendered in terms of the mine coordinates. This necessitated the task of mathematically describing the paths of every drill hole in mine-coordinate space. From a computational perspective, there are complicating factors presented by the Greens Creek drill-hole data in addition to the offset and rotation of the mine grid relative to the surface grid. First, the paths of the drill holes are deviated. That is, each hole may be composed of numerous segments with varying azimuths and inclinations. Furthermore, because the origins of most of the drill holes are underground, the inclinations of the many boreholes vary from downward to upward (fig. 1).

Path calculations were performed by first converting the surface grid northing and easting coordinates, given for the collar (origin) locations of the drill holes, into mine cross section and long section coordinates, respectively. After revisiting previous lessons in geometry and trigonometry, the following formulas were derived:

$$XS = \left[(N - N_0) - \left(E - E_0\right)\tan\alpha\right]\cos\alpha\ , \qquad (1)$$

and

$$LS = \frac{(E - E_0)}{\cos\alpha} + \left[(N - N_0) - \left(E - E_0\right)\tan\alpha\right]\sin\alpha\ , \qquad (2)$$

where E_0 is the surface grid easting of the origin of the mine grid,
E is the surface grid easting coordinate of the drill-hole collar (origin),
N_0 is the surface grid northing of the origin of the mine grid,
N is the surface grid northing coordinate of the drill-hole collar (origin),
α is the angle of axis rotation.

The next step was to calculate the three-dimensional location of each deviation in every drill hole, given the measured downhole depth of each inflection and the inclination and azimuth of the drill hole at each of these points. The following calculation framework was derived:

$$LS = LS_0 + \left(MD\cos n\phi\sin\theta\right), \qquad (3)$$

$$XS = XS_0 + \left(MD\cos\phi\cos\theta\right), \qquad (4)$$

$$TVDSS = [Z_0 + (MD\sin\phi)] - 60\ , \qquad (5)$$

where MD is the measured downhole distance from the origin of the core segment,
LS_0 is the long section coordinate of the origin of the core segment,
XS_0 is the cross-section coordinate of the origin of the core segment,
Z_0 is the mine elevation coordinate,
ϕ is the inclination of the drill-hole segment from horizontal, in radians,
θ is the azimuth (relative to *LS*-*XS* axes) of the drill-hole segment, in radians,
TVDSS is true vertical distance above sea level (elevation).

Because the azimuths and inclinations of the boreholes change at inflection points, or deviations, along the paths, the application of these formulas is somewhat involved. Each time a point of inflection is encountered along a hole, the 3-D coordinates must be calculated for the inflection point and then reintroduced into formulas 3–5 as a new origin for the next section of core, until another deviation is encountered, and so on. To apply the required series of successive calculations for each of the drill holes with thousands of deviated segments, Robert McFaul of Dynamic Graphics, Inc. (DGI), wrote and provided programming code to accomplish the task. Bob Belcher of DGI also assisted with subsequent modeling tasks.

The log and assay data were recorded for core segments defined by a top (first) measured downhole depth and a bottom (second) measured depth. It was felt that a reasonable single measured distance to attach to each data point is the midpoint of the core segment from which the data were obtained. This midpoint was calculated for each core segment and was used as the measured downhole depth for each data point.

Modeling

For three-dimensional modeling of the drill-hole data, it was necessary to calculate the coordinates of each of the observation locations in three-dimensional space, in this case *LS*, *XS*, and *TVDSS* (elevation). This task was performed using Dynamic Graphics, Inc., EarthVision software. By incorporating core logs and assay data with the drill-hole paths, the software calculated the three-dimensional coordinates of each data point. The result was a file of data with associated drill-hole identifiers, three-dimensional coordinates, and associated physical and chemical properties. These property data were used as input for three-dimensional EarthVision modeling calculations.

This procedure produces a three-dimensional grid depicting the calculated distribution of the measured property throughout a defined volume. The calculated models are grids in the shape of rectangular prisms containing grid nodes at regularly spaced intervals in each dimension. The calculated value of the property being modeled is stored for each grid node location and used for subsequent display and analysis. The drill-hole data locations (fig. 1) are most densely distributed within a volume bounded by cross-section coordinates of 2000 to 5200, long-section coordinates of 4200 to 7100, and true elevations between –400 and 3,000 feet. The rest of the three-dimensional models produced in this study are confined to the rectangular prism defined by those limits. The displays of these models were also clipped by the two-dimensional topographic surface grid discussed below.

Minimum-Tension Gridding

To produce spatially continuous two- and three-dimensional models that are representative of data associated with scattered points along drill holes, topographic maps, and digitized cross sections, interpolated grid values were calculated using 2-D and 3-D minimum-tension gridding algorithms in the EarthVision software suite. The following discussion is derived from EarthVision documentation by Dynamic Graphics, Inc. (Dynamic Graphics, Inc., 1997).

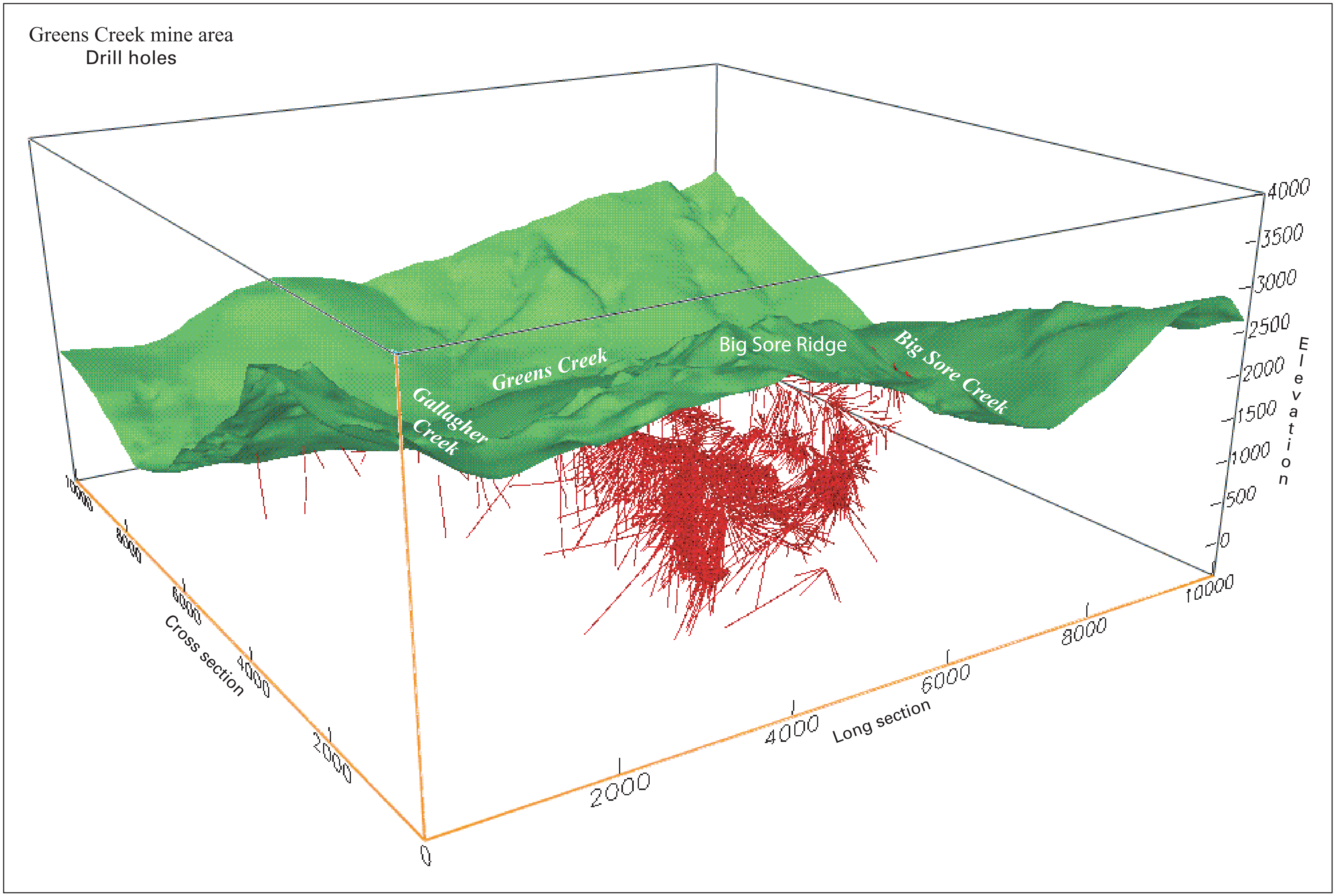

Figure 1. Drill-hole locations, Greens Creek mine area. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

The main goals of representational gridding are to honor the values of the input data as closely as possible and to calculate a reasonable-looking model for grid nodes that are not on or adjacent to input data points. Minimum tension is the distribution of the second derivative or curvature of the property variation among the nodes such that the sum of the squares of the second derivative (tension) is minimized.

The EarthVision two-stage minimum-tension gridding method reconciles these two, sometimes conflicting, goals. The two stages of minimum-tension gridding are (1) the initial estimate, and (2) cubic iteration functions with scattered data feedback.

The initial grid estimation process calculates a property value for every grid node in an extremely coarse grid that is used in the initial stages of gridding. Next, iterations begin, each a calculation of a new property value for each grid node with neighboring grid nodes providing input values to a cubic function that determines the new value. Once the new value is calculated for a node, the scattered data are used for the feedback process. Each set of iterations produces a finer grid, and this process is repeated until the desired grid size is produced.

To ensure that the original data values are honored, each iterative reevaluation of grid nodes is followed by a feedback process that compares the calculated property values to the input scattered data values that fall within a one-cell zone around the grid nodes. If the difference is less than with the preceding iteration, the program accepts the new function-derived grid node value and proceeds to recalculate the next grid node. If, however, the difference has increased, the node is reset to a value closer to the input scattered data point. Through this process, the scattered data feedback keeps grid nodes tied to neighboring scattered data while allowing the cubic function to distribute tension in a reasonable fashion. The result of these operations is a continuous data distribution that honors the values of the original scattered points and that can be displayed and manipulated in 2- and 3-D visualizations.

Topographic Model

Terrain data were digitized from topographic contour maps by the Kennecott Greens Creek Mining Company and were made available in Alaska State Plane Zone 1 coordinates by Andy West. The State Plane coordinates were first translated to the Greens Creek mine local surface grid reference system by subtracting the 2262748.50N, 2479273.89E grid origin offsets described earlier. The resulting local surface grid coordinates were then transformed to mine grid long-section and cross-section coordinates by applying equations 1 and 2, so that a terrain model calculated from the data would be correctly geographically referenced with respect to the subsurface ore, geochemical, and structural models. EarthVision two-dimensional minimum-tension gridding was applied to the transformed data to produce the topographic surface model that is included in figures 1–4. It can be seen that this model, when rendered in three-dimensional space, appears as a thin floating wafer, similar to the fault planes in this respect.

The topographic surface was also used to constrain, or clip, the ore, geochemical, and fault models at the ground surface. Otherwise, the models would be unrealistically extrapolated to fill the entire extent of the volume defined by the model limits of *LS*, *XS*, and *TVDSS*.

Ore Model

The core log data include lithologic codes that permit the identification of five types of ore in the Greens Creek mine. Because goals of the three-dimensional modeling in this study were not only to model and visualize the distribution of orebodies, but also to depict geochemical distributions within those orebodies, it was necessary to derive a numeric variable to designate each lithologic log observation as ore or “non-ore.” The samples designated as ore were given an ore value of 1; non-ore samples were assigned an ore value of 0. A three-dimensional minimum-distance gridding algorithm was first applied to the derived ore value variable, by which grid cells within a prescribed distance from data points were assigned the value of the nearest data point. The appearance of this ore model, however, was found to be somewhat unsatisfactory because the display routine imposed continuously varying ore values to the desired binary distribution. Instead, although minimum-tension gridding is more typically used for continuously varying properties, a somewhat unconventional application of the technique was used in this study to create 3-D models of ore distribution (fig. 2).

Minimum-tension gridding calculations were applied to the ore value variable, and the resulting continuously varying model values were converted to binary form. All model values of 0.5 or greater were converted to 1. All model values less than 0.5 were converted to 0.

The validity of the results was tested by comparing this binary ore model with views of various cross sections and plan views of ore distributions as shown by Proffett (chap. 7) and other maps created and provided by the Kennecott Greens Creek Mining Company. Close agreement was noted between the results of the three-dimensional ore model and geologist-drawn cross sections showing ore delineation. Although the cross-section profiles of orebodies mapped by geologists were rendered in greater detail, the 3-D model shows similar orebody shapes and precise spatial concordance at locations where comparative drawings are available to be examined.

Geochemical Models

EarthVision minimum-tension 3-D gridding was applied to geochemical variables in the scattered point data of the drill-core assays, and to derived variables such as element concentration ratios. To produce models that could readily be related to modeled orebody distributions derived from geologic interpretations rendered by mine geologists, the three-dimensional geochemical grids were constrained by the interpreted orebodies (fig. 2). To do so, each of the

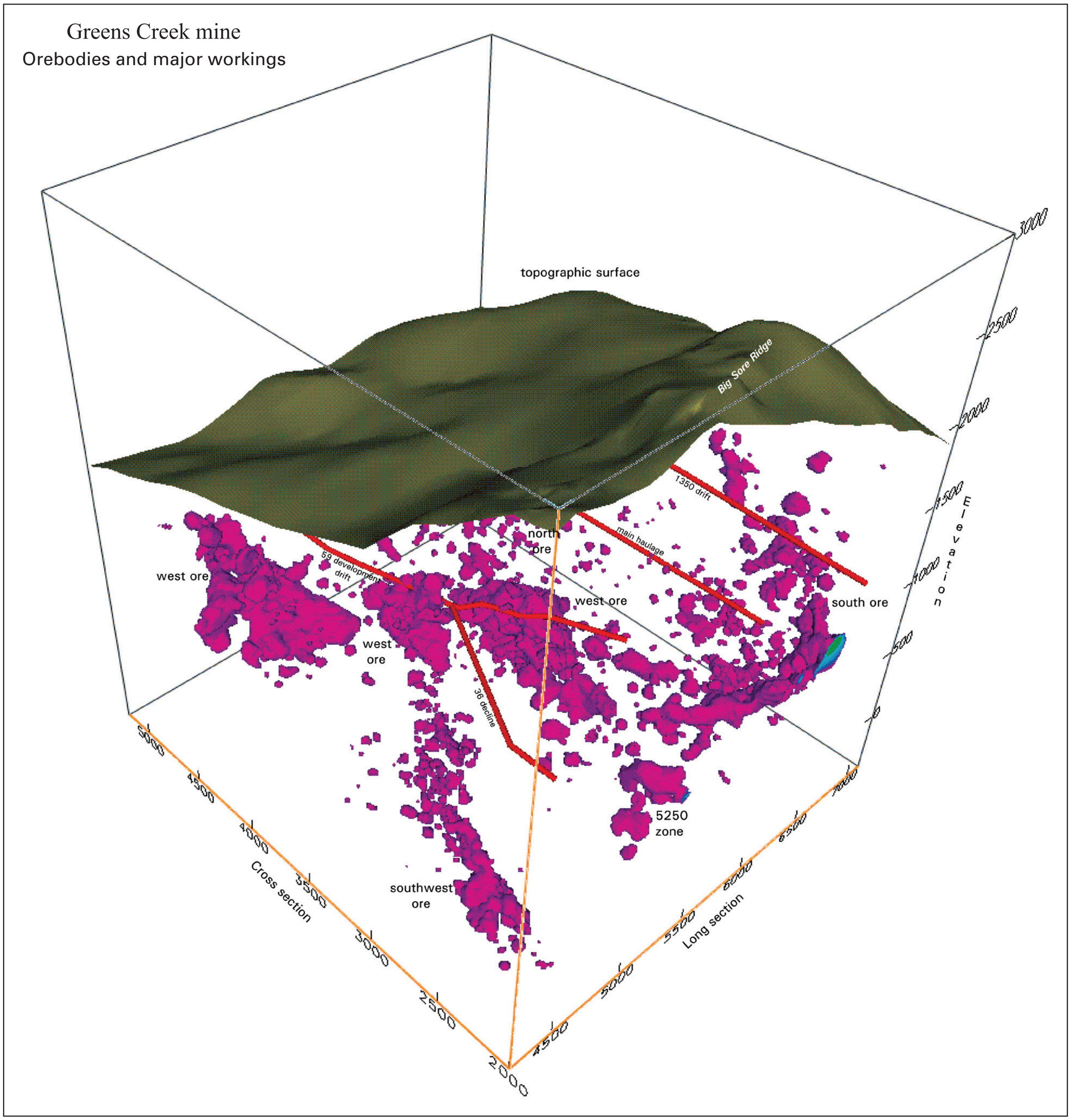

Figure 2. Greens Creek mine orebodies, showing major workings. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

three-dimensional geochemical grids was multiplied by the binary ore grid to produce models of geochemical variables within interpreted orebodies. The multiplication operation left the geochemical distributions unchanged in the presence of ore (ore value=1) but changed the geochemical grid values to 0 in the presence of non-ore (ore value=0). Some of the resulting geochemical models are shown in figures 3–8.

It had also been intended to model the lithologic horizons of the mine and to conformably model geochemical distributions among these units as well, but intractable difficulties were encountered in the form of numerous discontinuous repetitions of lithologies down the same drill holes. Additional information pertaining to dip and azimuth of the bedding planes would have been required to successfully create lithologic horizon models.

Geologic Structure Models

Several of the most important geologic structures in the area were modeled to provide three-dimensional visualization of these features. Cross sections and surface maps produced by Proffett (chap. 7) were used to digitize locations along the Klaus shear, the Maki and Little Maki faults, and the Upper Shear Zone. The *LS*, *XS*, and *TVDSS* coordinates of plan and cross-section traces of these structures were recorded and used as input to EarthVision's fault-modeling program. The modeled structures appear as thin wafers, floating in space, and can be combined with geochemical and ore models as shown in fig. 3.

Visualization

A significant advantage of three-dimensional modeling is that it makes available practically unlimited perspectives from which to view or visualize the results. The models may be sliced, rotated, panned, and zoomed in countless ways. Isovalue shells, equivalent to three-dimensional contour surfaces and analogous to two-dimensional contour lines, may be chosen for display, and volumetric statistics can be readily calculated and displayed for each variation of the property models. In addition, various 3-D models may be combined for simultaneous display and visualization.

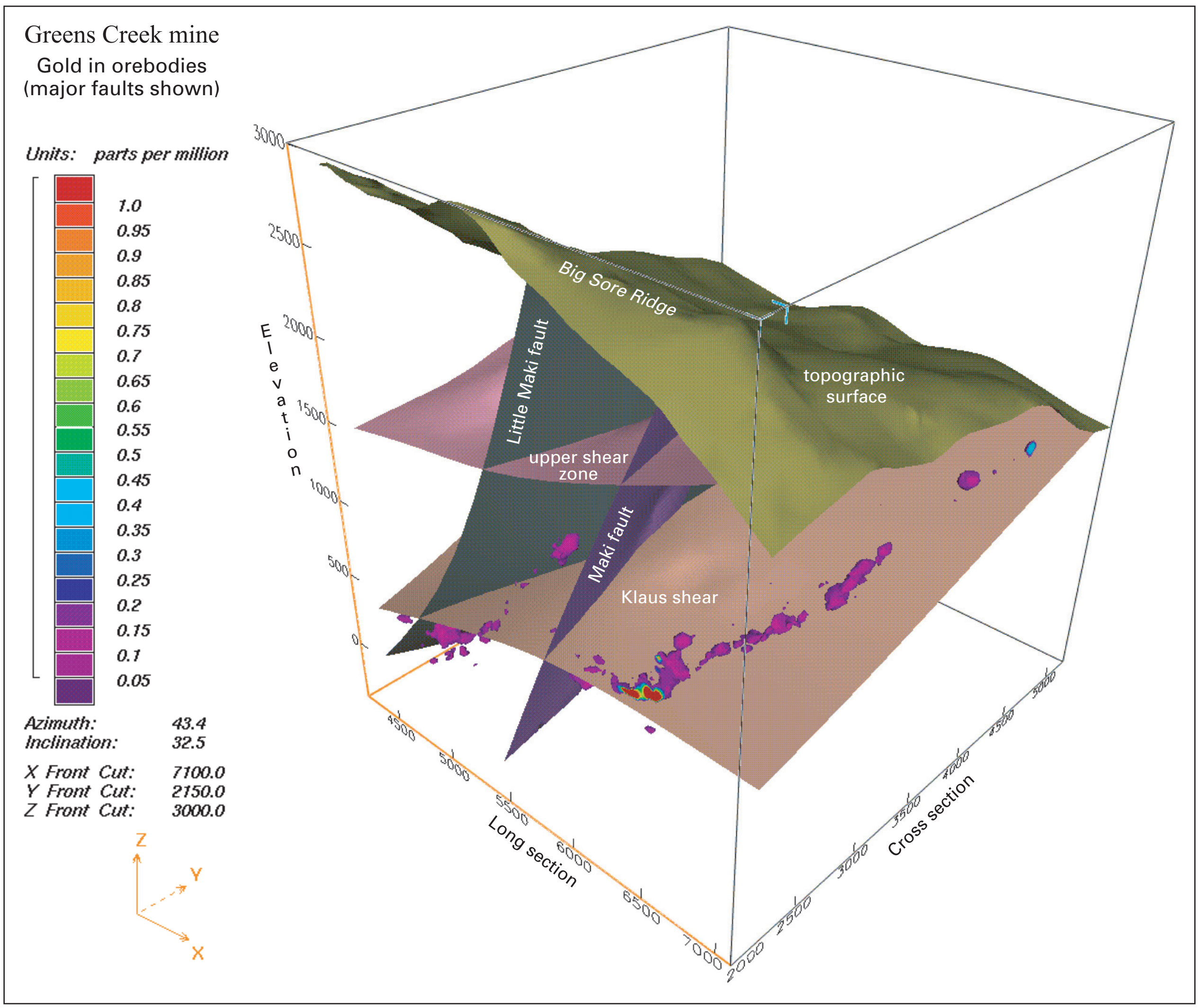

Figure 3. Faults, shear zones, and gold distribution within orebodies, Greens Creek mine. Only gold concentrations greater than 0.05 part per million are shown. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

A few of the myriad visualization possibilities for the three-dimensional models produced for the Greens Creek mine are included here. Figure 4 shows a chair cut display of the three-dimensional distribution of silver within ore bodies, clipped by the topographic surface above. It can be seen that parts of five different cross sections are shown in the same image, and that a sixth is possible if the top slice of the model were lowered to be below the topography. Figures 5–7 show isovalue shells of silver, zinc, and antimony, and figure 8 shows isovalue shells of the arsenic:antimony ratios.

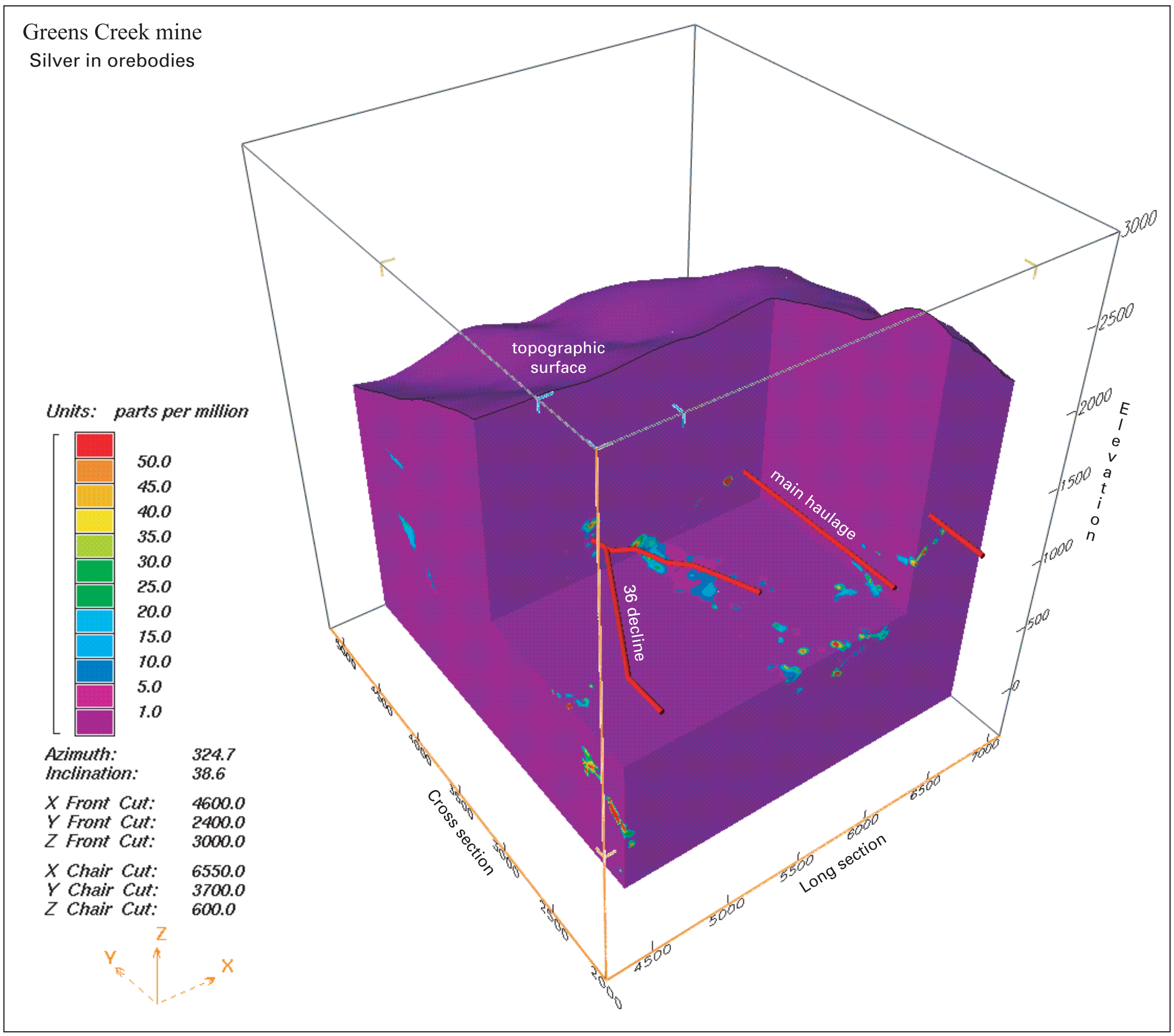

Figure 4. Chair cut display of silver in orebodies, Greens Creek mine. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

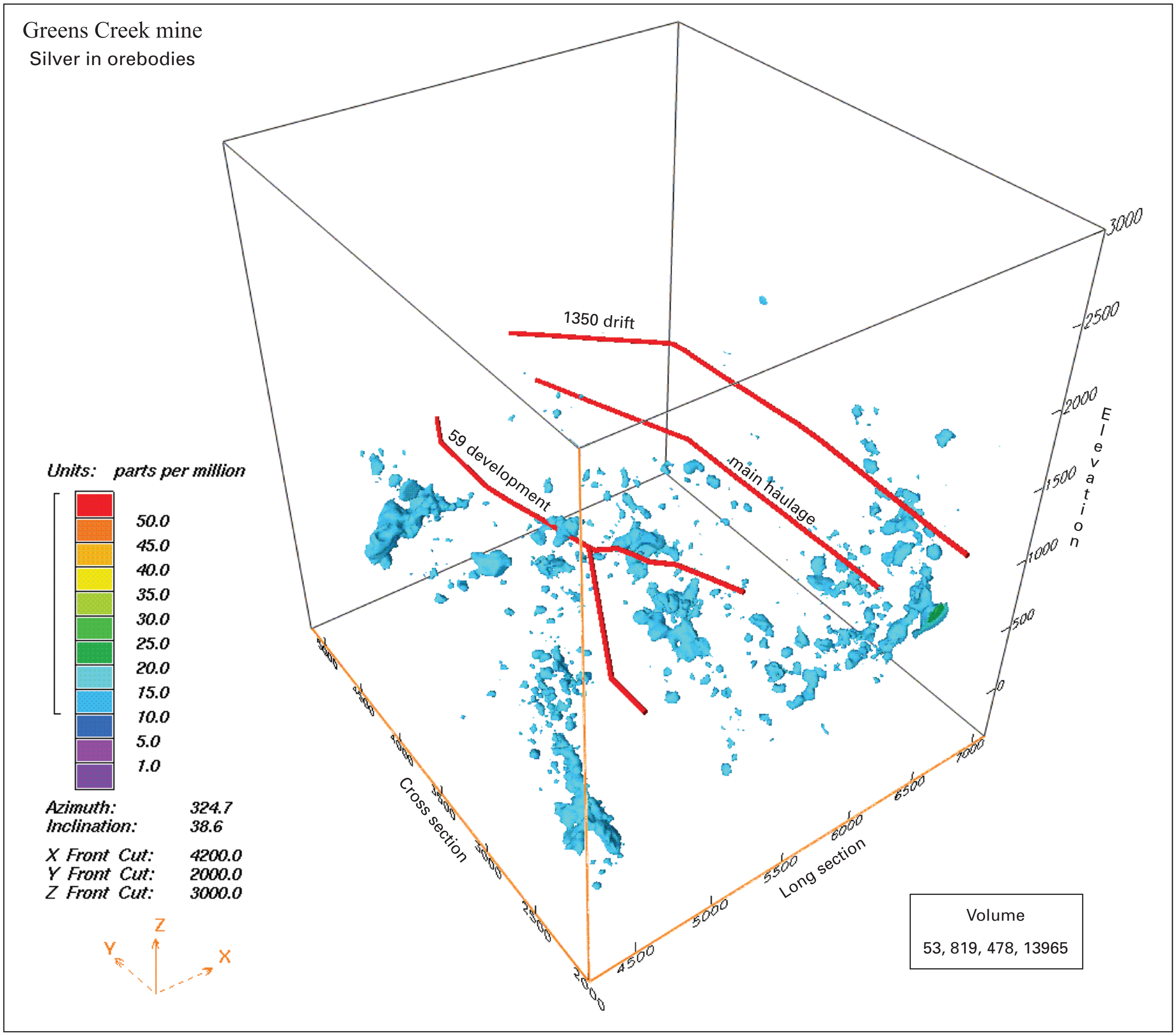

Figure 5. Isovalue shell display of silver greater than 10 parts per million in orebodies, Greens Creek mine. Volume calculated in cubic feet. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

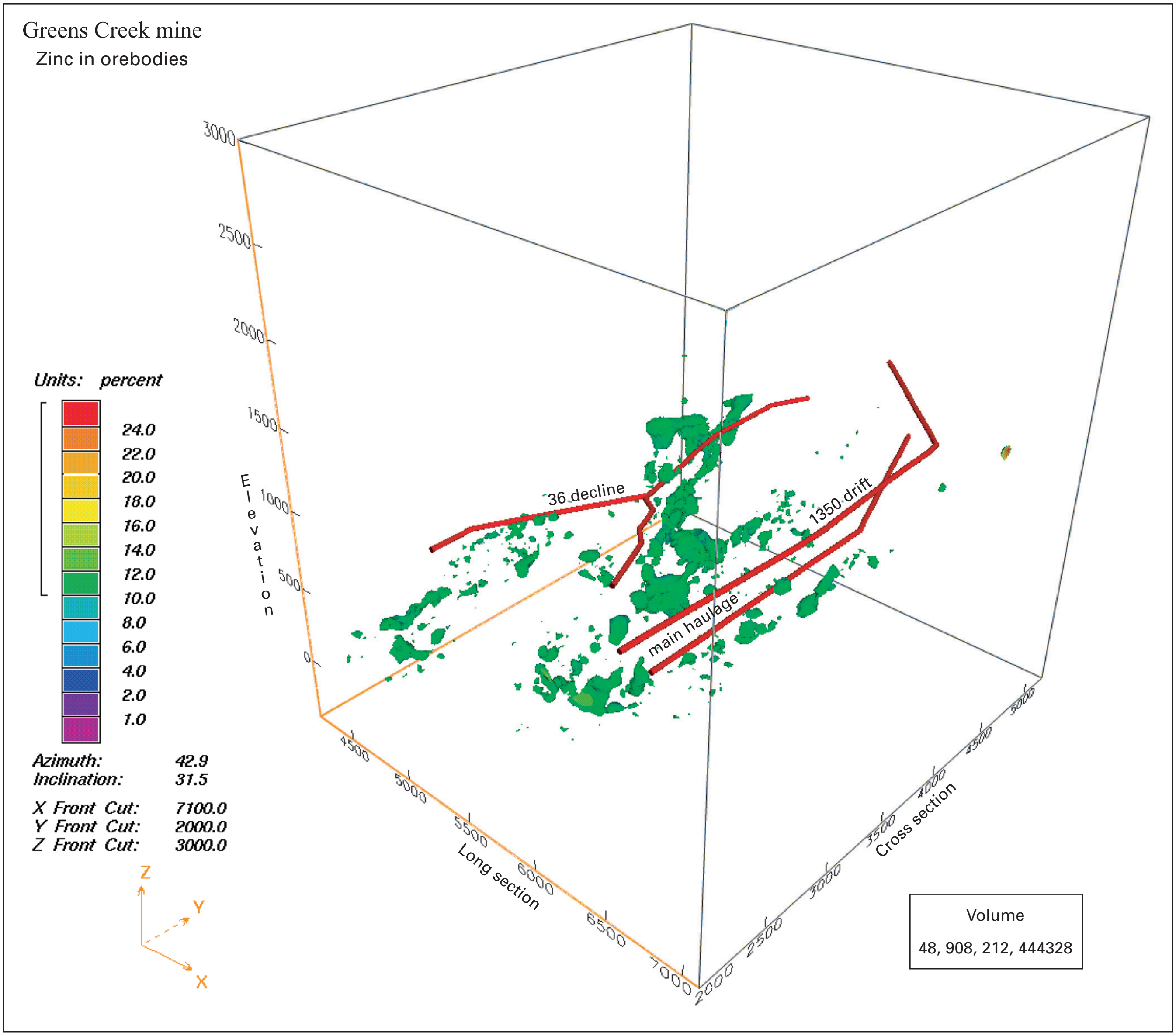

Figure 6. Isovalue shell display of zinc greater than 10 percent in orebodies, Greens Creek mine. Volume calculated in cubic feet. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

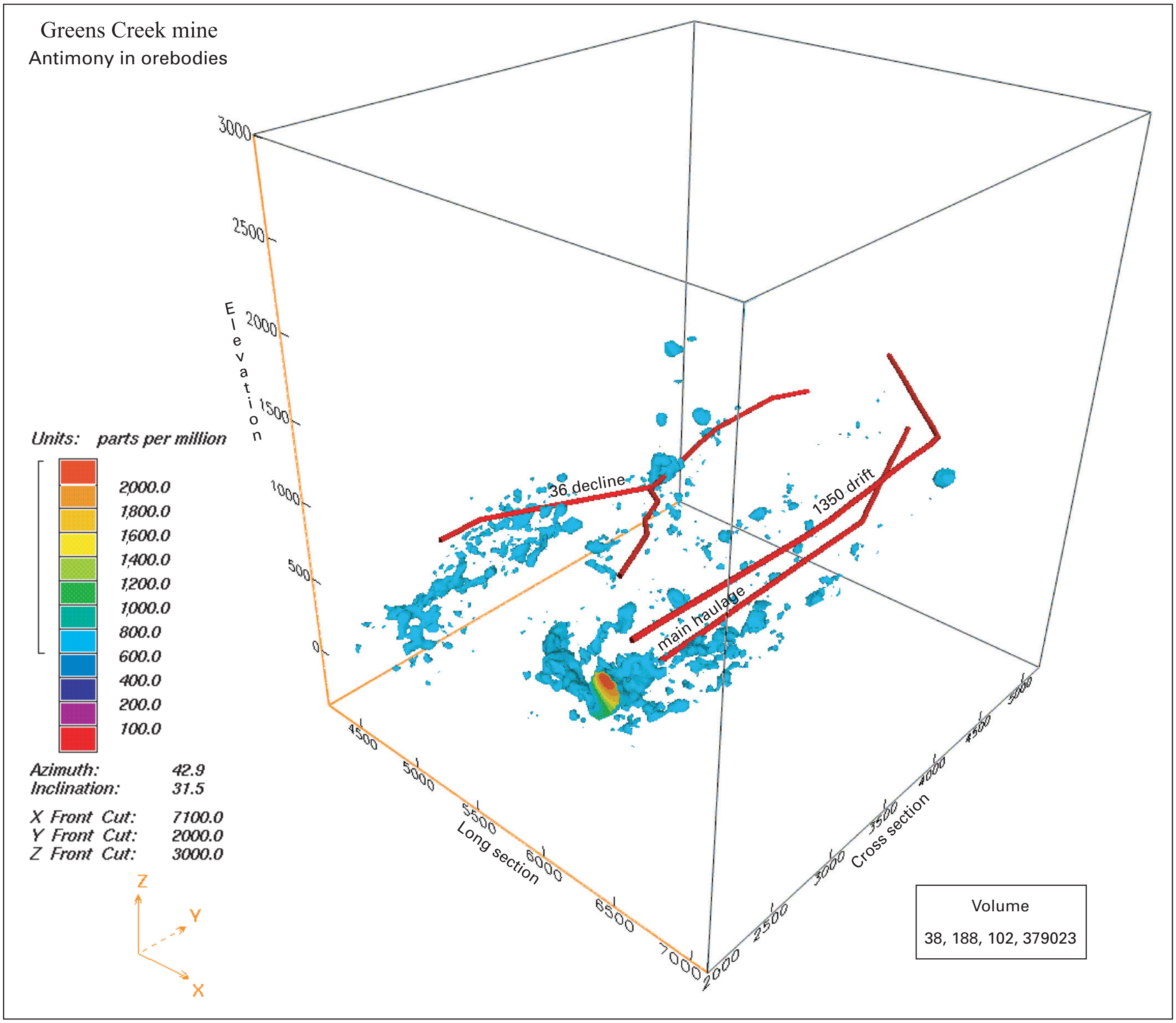

Figure 7. Isovalue shell display of antimony greater than 600 parts per million in orebodies, Greens Creek mine. Volume calculated in cubic feet. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

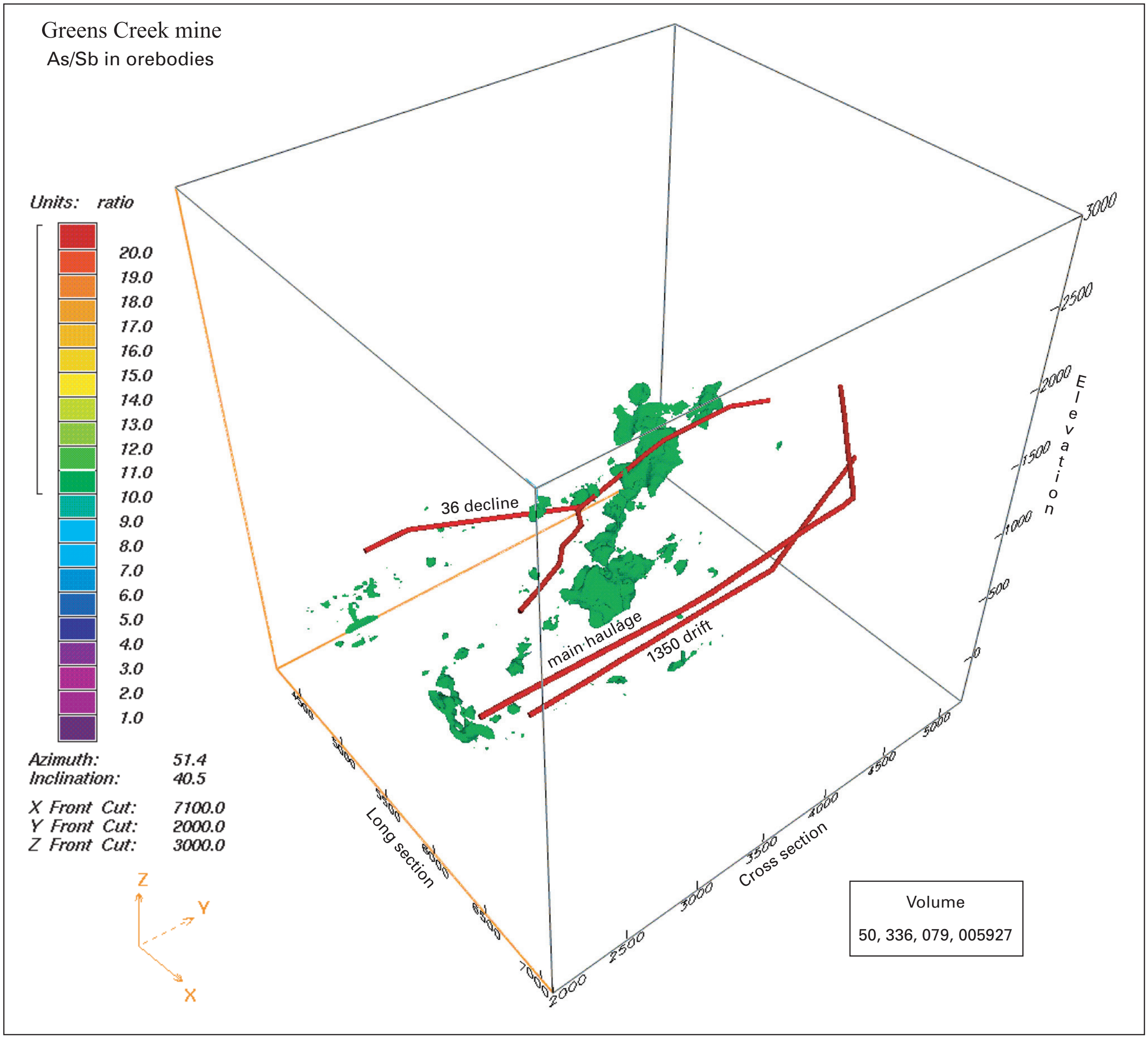

Figure 8. Isovalue shell display of arsenic: antimony ratios greater than 10 in orebodies, Greens Creek mine. Volume calculated in cubic feet. The bearing of the cross-section axis is N. 26.5651° W. Cross-section and long-section coordinates and elevation shown in feet.

Conclusions

The modeling efforts have been successful in producing reasonable three-dimensional renderings of the ore and geochemical information included in the drill-hole data. Verification has been obtained from geologist-drawn plan and cross-section views of the mine. Although the drawn cross sections may provide greater detail in delineating the shapes of the orebodies, the 3-D models provide great flexibility in readily displaying and manipulating unlimited perspectives of the locations, shapes, and volumes of orebodies along with their associated metal content throughout the region of data. These capabilities are potentially valuable tools for examining issues of not only scientific interest, but also of mining development and redevelopment strategies. The three-dimensional models and visualization can be used to guide development as it progresses but might also be used to consider and devise effective strategies for revisiting previously explored areas for the purpose of ancillary production efforts if warranted by changing economic conditions.

Reference Cited

Dynamic Graphics, Inc., 1997, EarthVision user's guide 5.1: Alameda, Calif., Dynamic Graphics, Inc.