

What You Will Need

- ArcGIS 8.3 (ArcView, ArcEditor, or ArcInfo license)
- ArcGIS Spatial Analyst or ArcGIS 3D Analyst
- Sample data downloaded from *ArcUser Online*
- An unzipping program such as WinZip

Modeling Bauxite Thickness and Volumes in ArcGIS

By Mike Price, *Entrada/San Juan, Inc.*

This tutorial uses techniques for estimating the volume and thickness of an ore that are employed by GIS specialists working in the mining industry. It teaches the basics of constructing a volumetric model, deriving volumes with cut/fill, converting raster data to a shapefile, calculating bauxite tonnage, and average thickness from all available resources using ArcGIS. At the end of the exercise, tonnage and average thickness of all pods will be accessed. The data used has been generalized from real data that describes bauxite in Jamaica. For more information on bauxite mining in Jamaica, see the accompanying article, "Notes on Jamaica's Bauxite Industry."

This exercise works well in a classroom setting or for GIS professionals who want to work independently to enhance their ArcGIS skills. It teaches procedures and techniques for

Acquiring and managing data

Creating thematic legends

Contouring gridded thickness

Determining total volume using cut/fill

Exporting a cut/fill table

Converting cut/fill grid areas to a polygon

shapefile

Joining tabular data and combining grid

volumes with tabular ore body data

Calculating total tonnage and average

thickness in a shapefile table

File	Description
clipgrd1	base grid
thikgrd1	bauxite thickness grid
clippol1	clipping polygon shapefile
orelimit	ore body outlines shapefile
parcels1	landownership polygon shapefile

Table 1: Description of sample data files

File Name	New Name	Line Color	Fill Color	Comments
orelimit.shp	Ore Bodies	Red	None	Increase line width to 2 points.
parcels.shp	Ownership Parcels	Black	Symbolize on Categories using Status Field; Not Owned is red, Owned is green.	Set layer transparency to 80 percent.
thikgrd1	Thickness Grid	NA	Draw raster values ramped along a stretched blue color ramp.	
clippol1.shp	Clipping Polygon	Black	Light green	
clipgrd1	Clipping Grid	None	Yellow	

Table 2: Symbolize data layers.

Getting Started

Visit the *ArcUser Online* Web site (www.esri.com/arcuser) and download the sample data for this tutorial. The zipped file contains three shapefiles and two grids. Create a directory for this project and unzip the data into it. If using WinZip, be sure to check the Use Folder Names box so that appropriate subdirectories will be built as the file is unzipped.

1. Start an ArcCatalog session and preview the sample data. The data contained in the SHPFiles and GRDFiles subdirectories represents slightly modified bauxite modeling data, extracted from an active Jamaican lease that has to be shifted and generalized for use in this exercise.

2. Start an ArcMap session and drag and drop all the sample data files into the Map Document. Because no projection information was included with these files, they can be added in any order.

A description of each file is listed in Table 1. These files are in a modified Jamaican imperial coordinate system, which was derived from the Jamaican Datum of 1938, using a modified Clarke 1880 ellipsoid. Although all dimension

units are imperial system measurements, the final reserves will be reported in dry metric tons (DMTs).

Creating Thematic Legends

Now, let's organize the project a bit by giving the Data Frame and files meaningful names, setting the map units, and thematically mapping the landownership data.

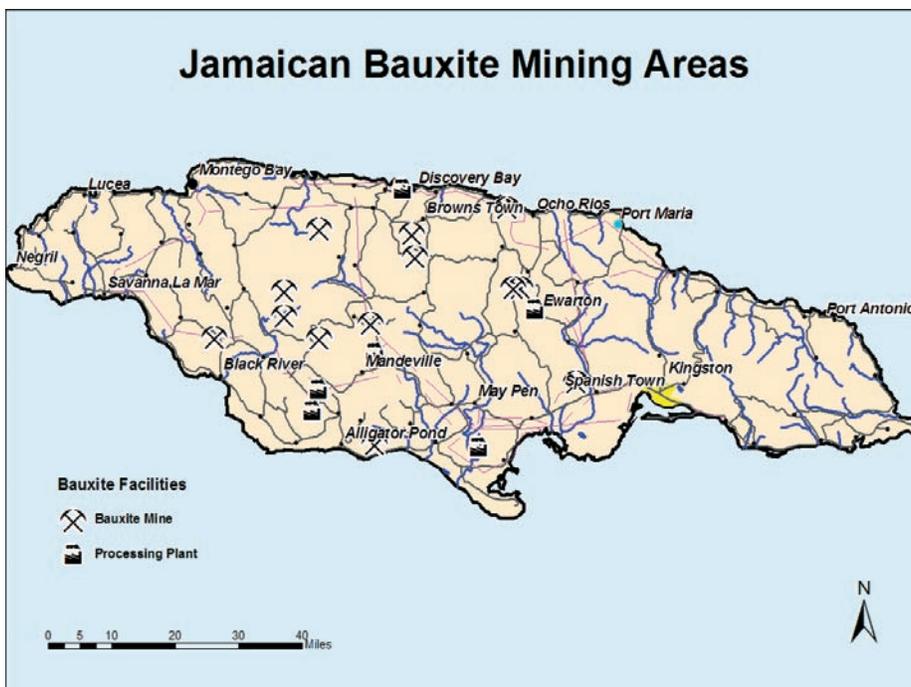
1. Right-click on the Data Frame and choose Properties. Change the name to Jamaica Bauxite Model. Set the Map Units to Feet.

2. Right-click on each layer in the Table of Contents (TOC) and modify the display of the data layers by reordering them and changing the symbology as suggested in Table 2.

3. Finally, set the base project scale to a standard value of 1:2,400. Save the project as Jamaica1.

Determining Total Bauxite Tonnage

Before any calculations can be made, the data should be validated. Contours generated using the ArcGIS Spatial Analyst extension will show if this is typical karst terrain. Using thikgrd1, the grid showing the bauxite thick-



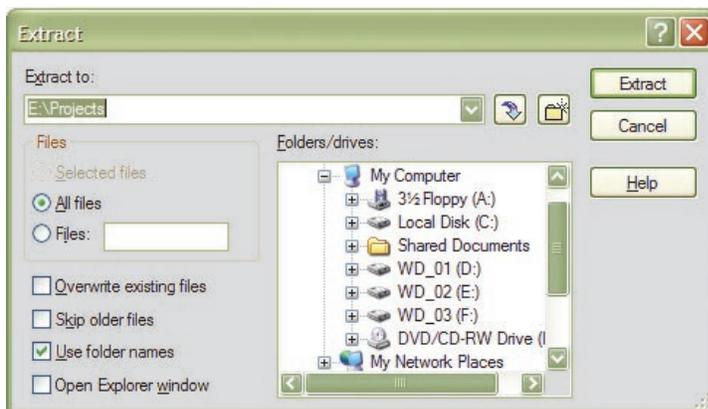
Jamaica produces nearly one-third of the primary aluminum ore bauxite consumed in the United States.

ness, a base grid called clipgrd1, and the Cut/Fill choice in the Surface Analysis submenu, a cut/fill grid will be generated. The attribute table for the output grid will be exported as a dBASE file, and the grid will be converted to a shapefile. Combining the grid volumes with the table containing the ore body data will allow calculation of the total tonnage and the average thickness for this mineral resource.

Contouring Gridded Thickness

Before performing any calculations, study the thickness data to verify that it is reasonable and accurate. At Alpart Mining Venture, one of the companies that mines bauxite in Jamaica, thickness data originates in Vulcan mine modeling software developed by ESRI Business Partner Maptek/KRJA Systems Inc. Maptek's Vulcan mine modeling program produces thickness grids through careful modeling of field mapping, auger borings, and ground penetrating profiles, guided by engineering geologists. Thickness grids export from Vulcan in ESRI Grid format, using a conversion algorithm written by Maptek and available to all Vulcan/ESRI users. Since 2000, ESRI and Maptek have pioneered GIS/mine modeling integration in Jamaica. For more information, check out Vulcan on the Web at www.vulcan3d.com.

1. To begin the analysis, validate the thickness data by contouring it in ArcGIS Spatial Analyst or ArcGIS 3D Analyst and inspecting the con-

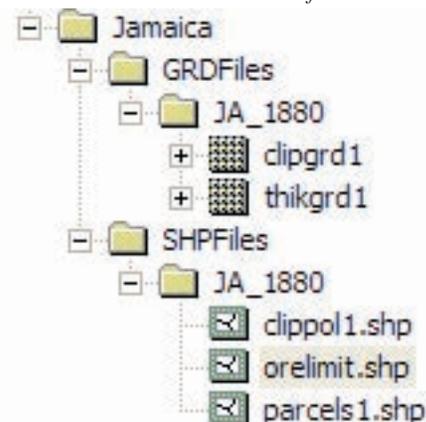


When unzipping the sample data archive, be sure to check the Use Folder Names box so the subdirectories will be generated and populated with the appropriate files.

tours to confirm that they represent a typical karst terrain. Load either the ArcGIS Spatial Analyst or the ArcGIS 3D Analyst extension and open the extension's toolbar. The exercise and illustrations show ArcGIS Spatial Analyst, but ArcGIS 3D Analyst can be used for the same operations.

2. In the ArcGIS Spatial Analyst toolbar, click the drop-down menu and choose Options. Click on the General tab, set the Working directory to \Projects\Jamaica\GRDFiles\JA_1880, and click the Extent and Cell Size tabs and set them to Same as Layer Clipping Grid. Click OK to set Options. Select Thickness Grid as the active ArcGIS Spatial Analyst layer and save the project.

3. Click on the drop-down menu again and



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choose Surface Analysis > Contour. In the Contour dialog box, select Thickness Grid as Input surface, set Contour Interval to 5, and leave Base Contour set to 0 and Z Factor set to 1. Finally, set Output Features to \Projects\Jamaica\SHPFiles\JA_1880\ and rename the output file thikcon1.shp. Click OK. Watch as the contours load into the Data Frame.

Jamaican bauxite forms by tropical weathering of aluminum-rich soils. The soils are probably derived from volcanic ash that fell on the island, possibly 30 million years ago. Bedrock in western Jamaica is a soft, easily eroded limestone, and millions of years of weathering and erosion have formed a complex terrain of high limestone knobs separated by tight valleys and collapsed cave systems. The ore pod contours suggest a northeast–southwest trending stream system including deep sinkholes, shallow terraces, and steep-sided canyons. A single major sinkhole in Ore Body 458 is more than 70 feet deep with limestone at the surface just 35 feet from its bottom. That represents a very steep slope of 2:1. Yes, this data is valid—it's a classic karst!

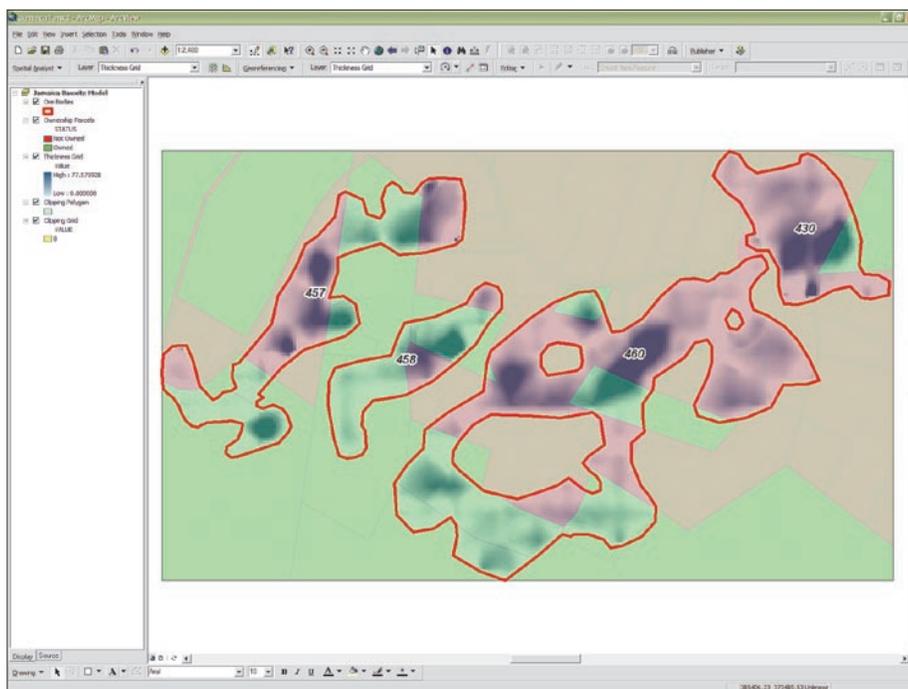
Determining Total Volume by Cut/Fill

The October–December 2002 issue of *ArcUser* included an article by this author describing a procedure for calculating volumes by applying a cut/fill analysis to a thickness grid against a zero value clipping grid. The method derives volume as a first derivative of thickness. This article is available online at www.esri.com/news/arcuser/1002/files/volumes.pdf. Since writing that article, the author has found many uses for the cut/fill derivative, and determining volume and tonnage of bauxite in a karst terrain is one of the best.

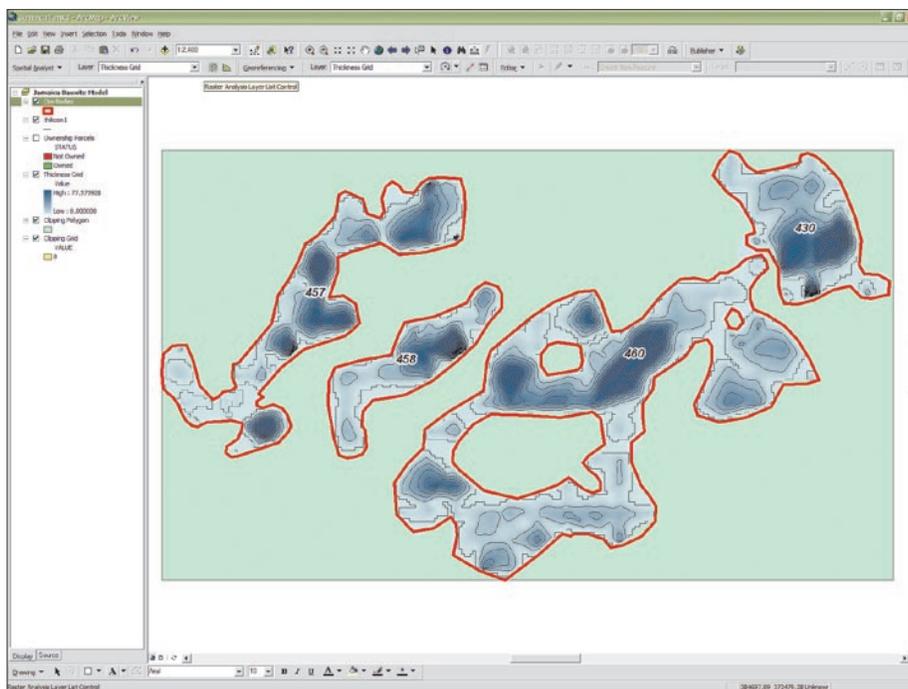
Thickness Grid (thikgrd1) contains values in feet for 10-foot cells within mapped ore bodies. Cells outside of ore bodies contain No Data. Since cells outside of ore bodies contain No Data, a single cut/fill calculation of the thickness grid against the clipping grid, which has all cells with a zero value, calculates the total area and volume for all ore pods.

1. Click on the ArcGIS Spatial Analyst dropdown menu, and choose Surface Analysis > Cut/Fill. In the Cut/Fill dialog box, specify Thickness Grid as the Before Surface and Clipping Grid as the After Surface. Leave Z Factor and Output Cell Size unchanged and name the Output Raster cf01. Click OK to calculate the new surface. The cut/fill grid will load into the Data Frame.

2. Right-click cf01 in the TOC and choose Open Attribute Table. Right-click on the Volume field and select Sort Descending. Blue colors represent Net Loss, reported in positive values, and red colors show zero volume.



Thematically map the layers in the project based on the suggestions in Table 2.

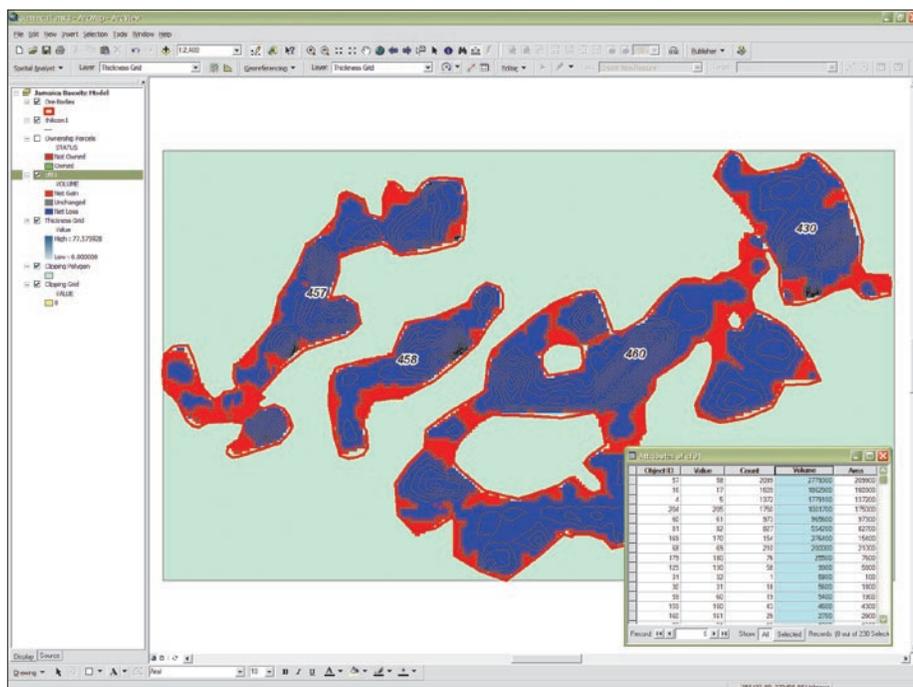


Contouring is performed to validate the bauxite thickness grid data.

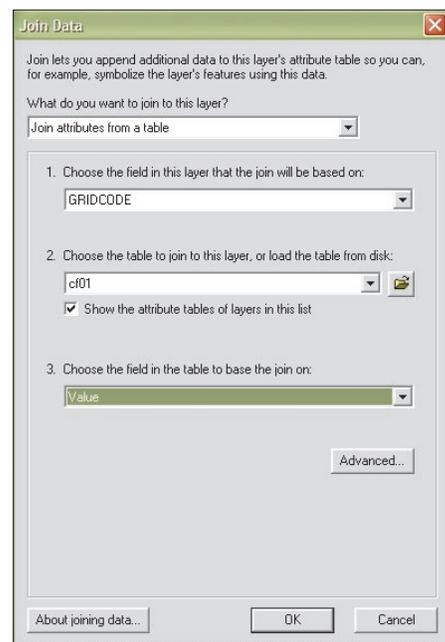
The Net Loss values are the interesting values, and they are reported in cubic feet. They represent the volume of bauxite resource contained in each pod. Calculating the total resources requires knowing how many cubic feet of bauxite are in a DMT. On this project, engineers have determined that one DMT of bauxite ore contains 23.39 cubic feet of ma-

terial, or one cubic foot of bauxite represents 0.041 DMT, so multiplying the volume by 0.041 will yield the answer. In addition, dividing volume by area will calculate the average thickness for each pod.

However, it is not quite that simple. It will require data conversion steps. Before calculating the DMT and average thickness, the cut/fill



Using the cut/fill functionality in ArcGIS Spatial Analyst, the volume of bauxite resource contained in each pod is calculated and reported in cubic feet.



The join will be based on the GRIDCODE field, the table to join to is cf01, and the field in the table to base the join on is Value.

attributes must be exported to a dBASE (DBF) table and the cut/fill raster converted to a shapefile, and the DBF table must be joined to the shapefile.

Exporting a Cut/Fill Table

In the Cut/Fill table, click Options and select Export. Export All Records to \Projects\Jamaica\SHPFiles\JA_1880\cf01.dbf. Note that this data will reside in the SHPFiles directory. Add the new table to the current map. In the Table of Contents, click the Source tab and open the table. Study the fields, especially the Value field. This field will be used to join the tabular data to the shapefile of the cut/fill geometries.

FID	Shape	ID	GRIDCODE	OID	Object	Value	Count	Volume	Area
182	Polygon	183	58	57	57	58	2099	2779300	209900
148	Polygon	149	17	16	16	17	1609	1862900	160900
62	Polygon	63	5	4	4	5	1372	1779100	137200
227	Polygon	228	205	204	204	205	1750	1001700	175000
186	Polygon	187	61	60	60	61	973	965600	97300
169	Polygon	170	82	81	81	82	827	554200	82700
184	Polygon	185	170	169	169	170	154	276400	15400
101	Polygon	102	69	68	68	69	210	200000	21000
180	Polygon	181	180	179	179	180	76	25500	7600
140	Polygon	141	130	129	129	130	58	9900	5800
26	Polygon	27	32	31	31	32	1	5800	100
38	Polygon	39	31	30	30	31	18	5600	1800
60	Polygon	61	60	59	59	60	19	5400	1900
159	Polygon	160	160	159	159	160	43	4600	4300

Export the joined shapefile to a new shapefile called totalres.

Converting Cut/Fill Grid Areas to a Polygon Shapefile

Click on the ArcGIS Spatial Analyst toolbar drop-down menu and choose Convert > Raster to Features. Select cf01 as the Input Raster and Value as Field; choose Polygon as the Output Geometry; and for Output Features, save the file to \Projects\Jamaica\SHPFiles\JA_1880\ as cf01a.shp. Pay special attention to paths and naming conventions.

In the Raster to Features dialog box, make sure to

- Uncheck the Generalize Lines box.
- Include the *a* in the output shapefile's name (i.e., cf01a.shp).
- Save the output file to the SHPFiles directory.

By not generalizing, the conversion process will respect the exact cut/fill grid boundaries. Click OK. Watch the shapefile load into the Data Frame. Open the shapefile's attribute table and note the GRIDCODE field. These values represent the same records coded by Value in cf01.dbf, and they will be used to add the attributes of cf01.dbf to cf01a.shp.

Combining Grid Volumes With Tabular Ore Body Data

In the TOC, right-click on cf01a.shp and choose Joins and Relates > Join. The join will be based on the GRIDCODE field, the table to join to is cf01, and the field in the table to base the join on is Value. Click OK to join the data.

Open the attribute table for cf01a.shp, which now contains data from cf01.dbf, and inspect the data. Sort the data using the Volume and Area fields. Close the table and save the project.

Calculating Total Tonnage and Average Thickness

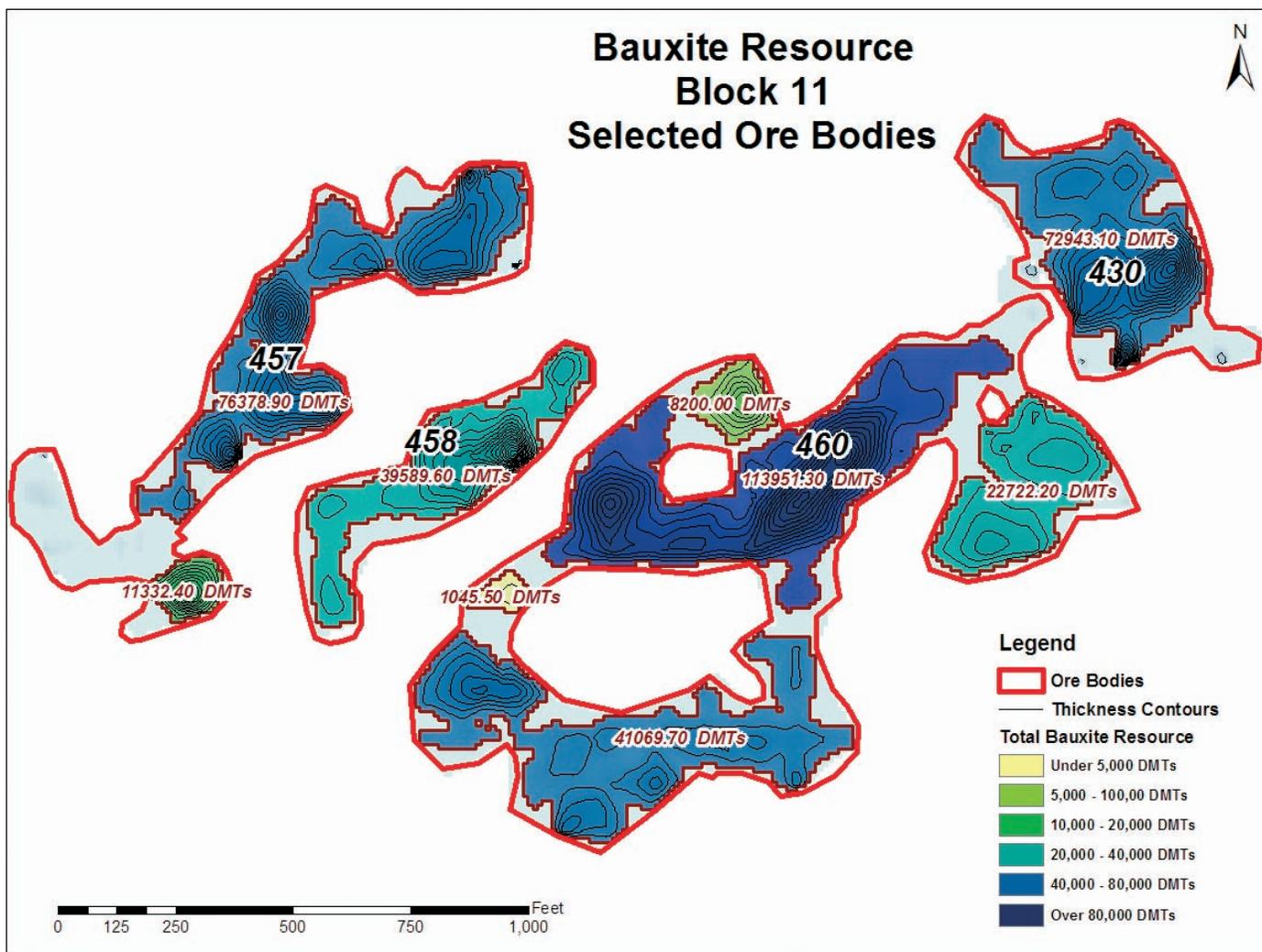
Now the tonnage and average thickness can be calculated.

1. To work with a single unjoined shapefile, right-click on cf01a.shp in the TOC and choose Data > Export Data. For the destination of the Output Shapefile or Feature Class, specify \Projects\Jamaica\SHPFiles\JA_1880\ as the

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The completed exercise yields a map showing bauxite resources. Engineering and economic rules will still need to be applied to the data to define a reserve.

directory and totals.shp as the file name. Click OK and add the shapefile to the project.

2. Drag it just below the Ore Bodies layer. Open the attribute table for totals and sort on the Volume field in descending order. Save the project.

3. The next step is to add two new fields for DMT and average thickness. In the attribute table for totals, click on the Options drop-down menu and choose Add Field. In the dialog box, apply the parameters listed in Table 3 to add the Dry Metric Tons field.

Name	DMT
Type	Float
Field Properties, Precision	12
Field Properties, Scale	2

Table 3: Dry Metric Tons field

4. Repeat the process to add the Average Thickness field using the parameters in Table 4.

Name	AvgThick
Type	Float
Field Properties, Precision	6
Field Properties, Scale	2

Table 4: Average Thickness field

5. Next calculate values for these new fields. If the Editor toolbar is not visible, choose View > Toolbars > Editor. Click on the Editor drop-down menu and choose Start Editing. Right-click on the DMT field, choose Calculate Values, and use the Field Calculator to create the formula below. Click OK.

$$DMT = [Volume] * 0.0410$$

6. Right-click on the Average Thickness field, choose Calculate Values, and use the following

formula. Click OK.

$$AvgThick = [Volume] / [Area]$$

Click on the Editor drop-down menu, and choose Stop Editing and Yes to save the edits.

7. Perform one more validity test. Right-click on the DMT field and choose Statistics. This should show a resource of nearly 389,000 DMTs. If it does, save the project once more. If not, review the steps in the previous section.

Summary

With calculations showing a total resource of slightly less than 400,000 DMTs, it seems as though this information could now be passed off to equipment schedulers and mine planners. At a nominal mining rate of 6,000 tons per day, one mining unit could mine in this area for more than two months. Unfortunately, it's not quite that easy.

Ownership issues haven't yet been addressed by the model. In addition, certain areas

may be too thin and too discontinuous to be mined economically. The model, in its current state, identifies what mining engineers might call a resource, but engineering and economic rules will be needed to define it as a reserve. Those modifications will be addressed in a future tutorial.

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Notes on Jamaica's Bauxite Industry

The island nation of Jamaica produces nearly one-third of the primary aluminum ore bauxite consumed in the United States. Bauxite forms in shallow deposits of tropical soil. In Jamaica, it occurs in irregular, shallow pockets in a highly eroded limestone karst. Kaiser Aluminum Corporation, operating through its wholly owned subsidiary Kaiser Aluminum and Chemical Corporation, has mined bauxite in Jamaica for more than 50 years. Major operations are in the Western Highlands, from 30 to 60 miles northwest of Kingston, Jamaica's capital.

The Jamaican bauxite industry is very mature; reserves are declining, and mined material is often lower grade and thinner than ore mined in the 1950s. Mining areas are surrounded by rural population so it is important to carefully plan and conduct mining activities. After mining, reclamation crews return the land to a state suitable for productive agricultural use or resettlement. Kaiser employs ArcGIS and Maptek/KRJA's Vulcan mining software to plan, mine, and reclaim bauxite ore bodies in the best possible way. Location, tonnage, and quality are three major factors addressed by Jamaican bauxite miners. The spatial analysis capabilities in GIS enable mine operators to effectively locate, plan, mine, and ship bauxite. An overview of GIS use in the Jamaican bauxite industry, written by ESRI writer Jim Baumann, was published in the September 2002 issue of *Mining Engineering Magazine* and is available online at me.smenet.org/200209/pdf/min0209_31.pdf.

Glossary

Average Thickness—This is a calculated value that represents the mean thickness of an ore body or stratum. Average thickness is calculated by dividing volume by area.

Bauxite—Composed of aluminum oxides and aluminum hydroxides, it is a primary ore of aluminum. The principal aluminum hydroxide minerals found in bauxite are gibbsite $Al(OH)_3$, boehmite $AlO(OH)$, and diaspore ($HAIO_2$). Bauxite is largely used in the preparation of alumina (Al_2O_3) and elemental aluminum.

Cut/Fill—The additive or subtractive process, using grids or triangulated irregular networks (TINs), of measuring variation in vertical space. Cut/fill is often applied to concurrent surfaces of differing age to show regions of volumetric gain and loss.

Dry Metric Ton (DMT)—A unit used in earth materials and forest products industries to measure bulk products such as soils or wood chips. One dry metric ton is a volume of material that would weigh one ton (2,204.623 pounds) if all volatile moisture were removed.

Karst—The term karst applies to distinctive landforms found on limestone and dolomite bedrock. A karst terrain includes caves, disappearing streams, sinkholes, and sculpted bedrock. A karst surface is often underlain by a karst aquifer. Karst is derived from the Slovenian word *kras*, the name of a mountain range on the border of Slovenia and Italy.

Mineral Reserve—This term refers to the economically minable part of a measured or indicated mineral resource demonstrated by at least a preliminary feasibility study. This study must include adequate information on mining, processing, metallurgical, economic, and other relevant factors that show, at the time of reporting, that economic extraction can be justified. A mineral reserve includes diluting materials and allowances for losses that may occur when the material is mined.

Mineral Resource—A mineral resource is a concentration or occurrence of natural, solid, inorganic or fossilized organic material in or on the earth's crust in such form and quantity and of such grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics, and continuity of a mineral resource are known, estimated, or interpreted from specific geological evidence and knowledge.

— Definitions courtesy of the *CIM Standards on Mineral Resources and Reserves—Definitions and Guidelines* by the Canadian Institute of Mining, Metallurgy and Petroleum, 2000

Also in This Issue...

Another article in this issue, "Exploring the Karst Landscape of Cockpit Country," describes research on cockpit karst formations being performed in Jamaica with the help of GIS.