Deriving Subset Volumes
With Grid Masks

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Editor's note: *This is the second in a two-part series on modeling ore bodies. The first part, "Modeling Bauxite Thickness and Volumes in ArcGIS" ran in the April–June 2004 issue of ArcUser. Readers who worked this first tutorial can use the final map document as a starting point for this tutorial. However, the sample dataset includes a map document that can be used to start this tutorial.*

The previous exercise used the cut/fill functionality in the ArcGIS Spatial Analyst or ArcGIS 3D Analyst extension to calculate total tonnage for Jamaican bauxite pods. Surface ownership in the bauxite mining areas is complex, and it is often not possible to establish the surface and mineral ownership of an entire pod. The Jamaican bauxite industry is very mature and is characterized by declining reserves, lower grades, and an extensive rural population living in the mining areas. To guide property acquisition and mine planning, engineers and land managers must develop and share resource information that summarizes both owned and nonowned tonnage.
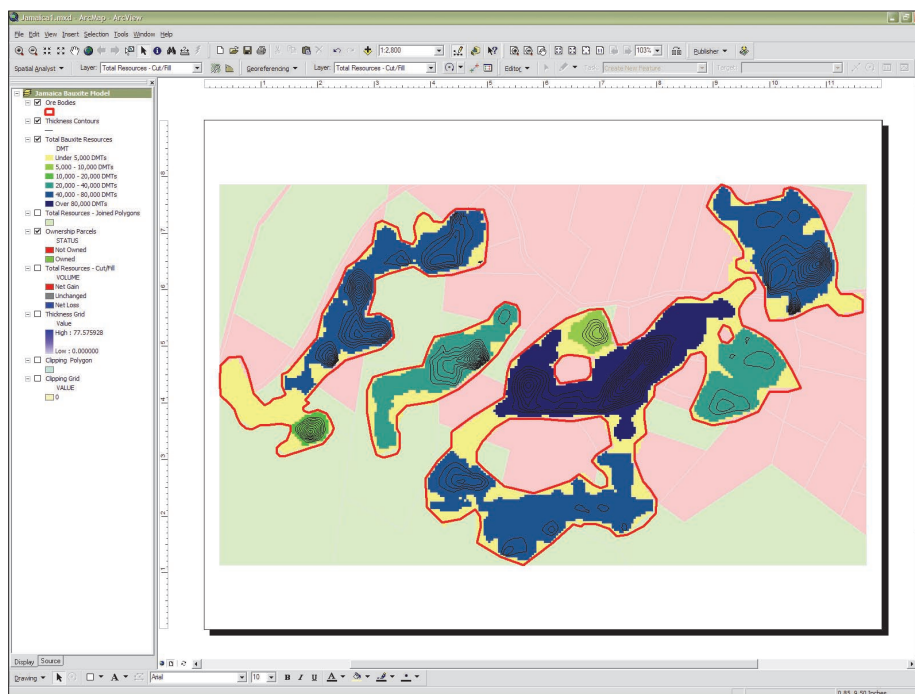
This exercise will continue to assess the thickness and tonnage of a small area of a mining lease using the tonnage calculations developed in the previous exercise. By creating and applying grid masks, resource categories can be defined. The cut/fill volumetric derivatives will be converted to shapefiles, shapefiles will be combined, and bauxite resources will be calculated with respect to ownership.

This exercise teaches techniques for
• Constructing complex grid masks identifying separate ownership
• Deriving multiple volumes by repeated cut/fill
• Converting multiple cut/fill grids to polygon shapefiles
• Joining tabular data to shapefiles
• Coding and merging shapefiles
• Calculating tonnage and average thickness by ownership in a single shapefile table

Getting Started
For readers that completed the "Modeling Bauxite Thickness and Volumes in ArcGIS" tutorial, start ArcMap and reopen jamaica1.mxd, the map document created by the exercise. Alternatively, unzip the sample dataset using WinZip, start ArcMap, and open jamaica1.mxd. In either case, choose File > Save As and save jamaica1.mxd as jamaica2.mxd. Perform some Table of Contents

After opening jamaica1.mxd and renaming it jamaica_2.mxd, rename layers in the TOC.

Original Layer Name	New Layer Name
cf01a	Total Bauxite Resources
totalres	TotalResources-Joined Polygons
cf01	TotalResources-Cut/Fill
clipgrd1	ClippingGrid

Figure 1: Rename layers

(TOC) cleanup by renaming layers as suggested in Figure 1. Color ramps can also be modified if desired.

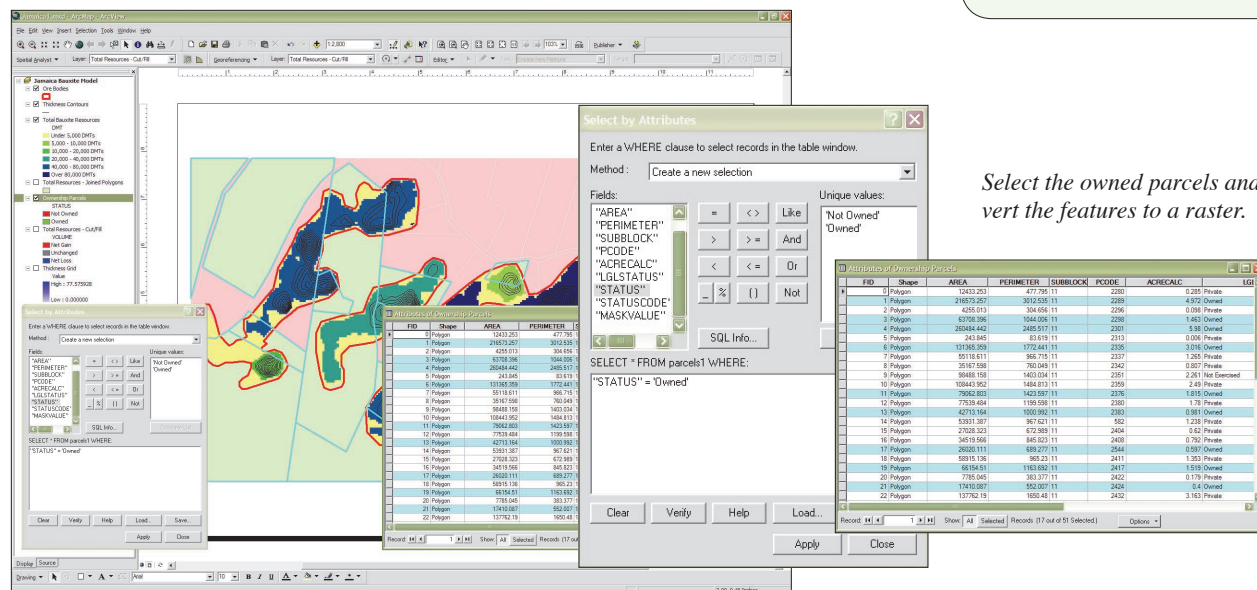### Determining Bauxite Tonnage by Owner
The Ownership Parcels layer will play a key role in this new analysis. Two mask grids, created in this step, will constrain volumetric calculations to owned and nonowned resources. These grids use a cell value of zero to mark off locations by ownership. Before building these grids, choose Spatial Analyst > Options in the Spatial Analyst toolbar and verify that the Working directory has been set to \Jamaica\GRDFiles\JA_1880\ and the Analysis extent and Cell size are Same as Layer Clipping Grid. If not, apply these parameters and save the project.

There are several different ways to create masks for owned and nonowned areas, but one of the easiest methods is to select parcels of one type and convert the selected parcels to a grid with a value of zero. Next, select nonowned parcels and convert this selection to another grid also with a value of zero. Follow these steps to create these masks.
1. After creating both masks, right-click on the Ownership Parcels layer in the TOC and choose Open Attribute Table from the context menu. Observe the Status, StatusCode, and MaskValue fields. Notice that the MaskValue field contains a value of zero for all records.
2. In the attribute table, choose Options > Select by Attributes. In the dialog box, choose Create a New Selection as Method and create the expres-

Select the owned parcels and convert the features to a raster.

After generating cut/fill rasters for owned and nonowned parcels, sort and inspect the attribute tables for both layers.
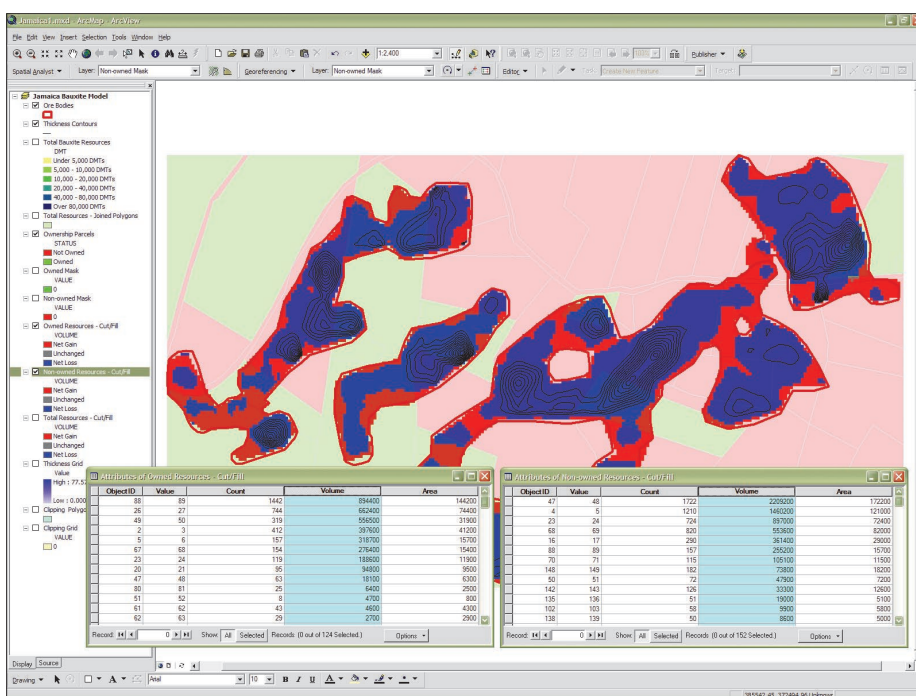
sion "STATUS" = "Owned". Close the table and retain the selection set.

3. In the Spatial Analyst toolbar, click the drop-down and choose Convert > Features to Raster. In the Features to Raster dialog box, verify that Input Features has been set to Ownership Parcels, the Mask Value is set to Field, and save the Output Raster to \Jamaica\GRDFiles\JA_1880\. Name the output raster ownmask1 and click OK. Watch the mask build and load into the project.

4. To create a nonowned mask, reopen the Ownership Parcels table, click Options in the table, and choose Switch Selection. Follow the same steps described for creating the owned mask with one exception. Use the expression "STATUS" = "Not Owned." Name the second mask grid nonmask1.

5. Compare each mask to the Ownership Parcels and confirm that each mask contains only cell values of zero and that the cells correspond with the proper ownership status. In the Layer Properties dialog box, rename ownmask1 to Owned Mask and nonmask1 to Non-owned Mask. If problems occur, remove the suspect mask from the project and build it again. Save the project.

Determining Volume Subsets by Cut/Fill

Next calculate volume subsets. The first tutorial developed a naming convention for cut/fill grids, DBF output tables, and the polygon shapefile converted from the cut/fill grid. The Total Resources cut/fill grid was named cf01, the DBF output file was named cf01.dbf, and the converted shapefile was named cf01a.shp.

In processing two ownership types, the same procedure will be performed twice. The new Owned Resource Cut/Fill grid will be named cf02, its output table cf02.dbf, and its converted shapefile cf02a.shp. The Nonowned Resource

grid will be called cf03, the DBF file called cf03.dbf, and the converted shapefile called cf03a.shp. Store the grids in \Jamaica\GRDFiles\JA_1880. Create a new directory, \Jamaica\DBFFiles, and place the DBF tables in it. Save the shapefiles to \Jamaica\SHPFiles\JA_1880.

The 10-foot thickness grid created in the last tutorial contains values in feet for bauxite in the mapped ore bodies. Cells outside of ore bodies contain No Data. Each mask grid contains zero values over owned and nonowned polygons. This step will calculate two volumes using the cut/fill

function.

1. Click the Spatial Analyst toolbar drop-down and choose Surface Analysis > Cut/Fill. In the Cut/Fill dialog box, specify Thickness Grid as the Before Surface and Owned Mask as the After Surface. Leave Z Factor and Output Cell Size unchanged. Save the output raster to \Jamaica\GRDFiles\JA_1880\, name it cf02, and click OK. The cut/fill grid will be calculated and loaded into the Data Frame. Rename this layer Owned Resources.

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2. Repeat the process for Non-owned Resources using Non-owned Mask as the After Surface. Name the output raster cf03 and rename the layer Non-owned Resources-Cut/Fill.

3. Inspect both cut/fill attribute tables. Right-click the Volume field and select Sort Descending from the context menu. The blue features represent Net Loss, reported in positive values, and the red features show zero volume. The Net Loss values, reported in cubic feet, represent the volume of bauxite resource contained in each pod, subdivided by ownership.

Exporting and Editing Cut/Fill Tables

The next step will export the cut/fill tables, code the records by ownership, convert grid areas to shapefiles, and join volume and area data to the shapefiles. After merging the owned and non-owned shapes, the tonnage and average thickness will be calculated. Although this sounds like a lot of work, it follows a logical work flow.

1. Open the Attribute Table for Owned Resources-Cut/Fill, click Options, and select Export. Export All Records to \Jamaica\SHPFiles\JA_1880\cf02.dbf. Add the new table to the current map.

2. Repeat the procedure for Non-owned Resources-Cut/Fill, exporting all records to \Jamaica\SHPFiles\JA_1880\cf02.dbf.

3. Open each DBF table. In the table, click Options and choose Add Field. Add a new field called Status and set the field Type to Text and the Precision to 20. Right-click the Status field and choose Calculate Values. Use the field calculator to populate the Status field in cf02.dbf with Owned and the same field in cf03.dbf with Not Owned.
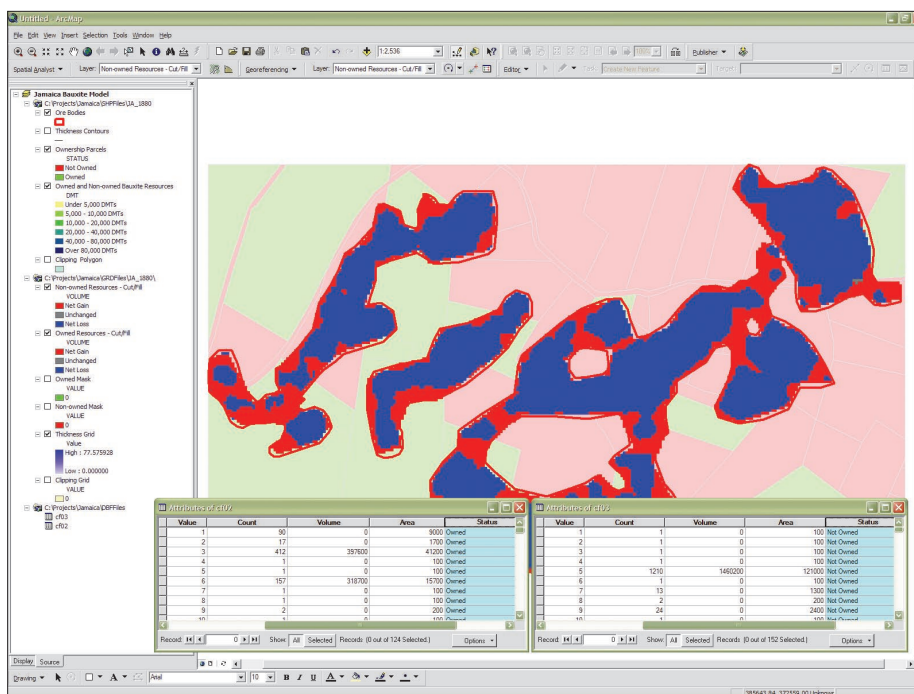
Converting Cut/Fill Grid Areas to Polygon Shapefiles

Now the cut/fill grids can be converted to shapefiles.

1. In the Spatial Analyst toolbar, click the dropdown and choose Convert > Raster to Features. Select Owned Resources-Cut/Fill as the Input Raster, Value as Field, and \Jamaica\SHPFiles\JA_1880\cf02a.shp for Output Features. Remember to include the letter *a* in the output shapefile's name and save it in the SHPFiles directory. Do not mix shapefiles and grids in the same folder, and remember to **uncheck** the Generalize Lines box! By *not* generalizing, the exact cut/fill grid boundaries will be respected by the process. Click OK.

2. Repeat this procedure for Non-owned Resources-Cut/Fill and save the resulting shapefile as cf03.shp.

3. These shapefiles will be merged into a master set and removed from the project. Open each shapefile's Attribute Table and observe the GRIDCODE field. These values correspond with records coded by VALUE in cf02.dbf and cf03.dbf.

Use the Field Calculator to populate the new STATUS field in both cut/fill raster attribute tables.

These fields will be used to join cf02.dbf to cf02a.shp and cf03.dbf to cf03a.shp.

Joining Tabular Data, Merging Shapefile Subsets

In the TOC, right-click cf02a.shp and choose Joins and Relates > Join. In the Join Table dialog box, base the join on the GRIDCODE field. The table to join from is cf02.dbf, and the field in the table to base the join on is VALUE. Repeat this procedure for cf03a.shp and cf03.dbf. For more information on joins, see the ArcGIS Desktop online help.
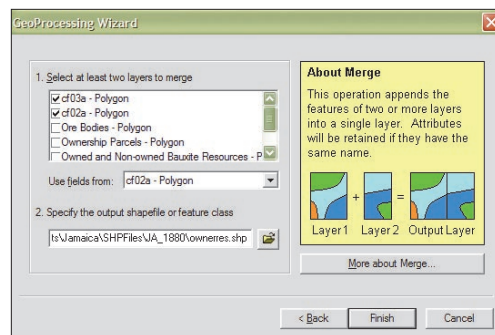
The two bauxite resource subsets, Owned Resources and Non-owned Resources, could be kept separate, but since they have been coded by ownership status and both have the same table structure, they can be merged into one master set before calculating tonnage and average thickness.

1. From the ArcMap menu, choose Tools > Geo-Processing Wizard. Click the radio button next to Merge layers together and click Next. Select cf02a-Polygon and cf03a-Polygon as the layers to merge, use the fields from either set, and specify \Jamaica\SHPFiles\JA_1880\ownerres.shp as the output shapefile. Click Finish and watch the merged shapefile load into the TOC.

2. Rename the shapefile Owned and Non-owned Bauxite Resources. Remove cf02a.shp and cf03a.shp from the TOC and save the project.

Calculating Total Tonnage and Average Thickness

Before calculating tonnage and average thickness

Use the GeoProcessing Wizard to merge the owned and nonowned parcel layers.

for owned and nonowned bauxite, add fields for these calculations.

1. Open the Owned Bauxite Resources attribute table, click the Options menu, and use Add Field to add two fields, DMT and Avgthick. In the dialog box, apply the parameters listed in Figures 2 and 3. Repeat this process with the Non-owned Bauxite Resources attribute table. Note that bauxite tonnage is reported in Dry Metric Tons (DMT) and that one cubic foot of bauxite weighs 0.0410 DMT.

2. When all fields have been added, right-click the name of each field, choose Calculate Values from the context menu, and use the formulas in Figure 4 to calculate DMT and average thickness.

3. To verify the work done thus far, compare the new ownership tonnage with the original resources calculated in the first exercise. Right-click the DMT field and choose Statistics. Com-

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

Figure 2: Dry Metric Tons field

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

Figure 3: Average Thickness field

pare the numbers just calculated with the original statistical summary of DMTs in Total Bauxite Resources.

In the first exercise, 388,909.60 DMTs were derived. The new calculations should show 388,860.40 for Owned and Non-owned bauxite. This difference of less than 50 DMT is insignificant. If the numbers are correct, save the project. If not, check the naming conventions and calculations and tabular joins performed.

```
Dry Metric Tons
DMT = [Volume] * 0.0410

Average Thickness
AvgThick = [Volume] / [Area]
```

Figure 4: Formulas for field calculations

Some Tests

Now the property department, mine planners, and equipment schedulers for the fictional mining company in this exercise have some useful data to work with. The owned and nonowned total bauxite resource is slightly under 400,000 DMTs, and it closely agrees with the original estimate.

Now experiment with this new data and create queries that a mining engineer or a land agent might perform. First, identify the owned large tonnage resource and summarize those tons. Assume that 5,000 DMTs, and an average thickness of 10 feet or more, is the minimum body that will be mined. This query will include three items—parcel ownership, DMT greater than 5,000, and average thickness that is greater than 10 feet.
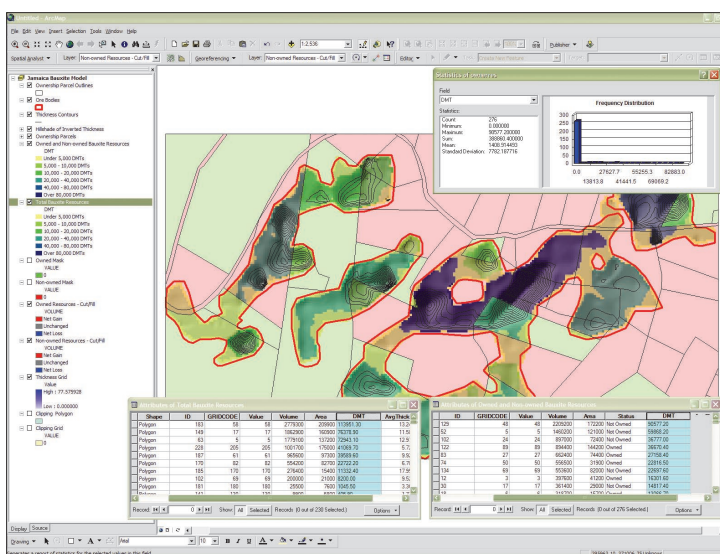
1. Open the attribute table for Owned and Non-owned Bauxite Resources, click Options, and choose Select by Attributes. Create the query in Figure 5 and click Apply. In the table frame, click the Selected Records button. Four owned regions should be identified. Right-click the DMT field and choose Statistics. This will list total economic ton-

```
"Status" = "Owned" AND "DMT" >=5000 AND "AvgThick" >=10
```
Figure 5: Identify owned resource tonnage

```
"Status" = 'Not Owned' AND "DMT" >=5000 AND "AvgThick" >=10
```
Figure 6: Summarize nonowned but mineable resources

After calculating tonnage, view the statistics for Total Bauxite Resources.

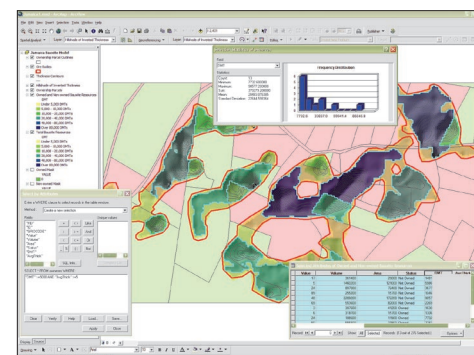nage. This should identify less than 55,000 DMTs, and each region will be part of a larger pod.

2. The next step will calculate high tonnage resources that are not presently owned, especially resources that are part of a larger partially owned pod. Using a similar query, shown in Figure 6, summarize the nonowned resources that can be mined. If enough nonowned bauxite near owned bauxite is located, the land department might want to negotiate with the surface owners. The query in Figure 6 returns five areas, totaling over 212,500 DMTs. This is encouraging!

3. Finally, modify the query to select all areas that contain at least 5,000 DMTs and average at least 10 feet thick. This query returns nine regions, containing more than 267,000 DMTs. Lowering the average thickness to five feet and running this modified version of the query in Figure 5 identifies economically break-even areas. This query returns 13 areas that contain more than 370,000 DMTs.

Remember that the total resource includes some 390,000 DMTs. If the rights to mine all parcels were acquired and worked carefully, more than 90 percent of the bauxite could be recovered. In truth, mining decisions are a bit more complicated than this, but these queries demonstrate how ownership subsets might be used by planners and engineers.

Summary

Though most readers are not bauxite miners, this cut/fill procedure can be used in many areas of study. This method has been used to calculate wildland fuel loads, rainfall amounts by water-

The final query identifies the economically break-even areas.

shed, and volumes of sediment retention ponds. Readers who develop other uses for this technique are invited to e-mail the author and share them. Contact

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