A Method for Creating a Three Dimensional Model from Published Geologic Maps and Cross Sections

By Gregory J. Walsh

Prepared in cooperation with

the Moroccan Ministry of Energy, Mines, Water and the Environment (Ministère de l'Énergie, des Mines, de l'Eau et de l'Environnement - MEM)

Google Earth (GE) files:
Please note: These files are for visualizing the geology at a regional scale only, and should not be used in any way for site-specific decisionmaking. The original published maps contain more complete geologic information. In Google Earth it is possible to view the geology at much greater scale than that intended by the authors. This gives an impression of greater accuracy than is actually present in the models shown here.
[Disclaimer modified from the Google Earth version of *Graymer and others (2006)*.]

Open-File Report 2009–1229

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2009

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Suggested citation:
Walsh, G.J., 2009, A method for creating a three dimensional model from published geologic maps and cross sections: U.S. Geological Survey Open-File Report 2009–1229, 16 p., available online only at http://pubs.usgs.gov/of/2009/1229/.

Contact

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Downloadable files that are part of this report:
This report consists of a text, available in PDF format, and a zip file of KML files (KMZ file).

Open the KMZ file in Google Earth and play the tour for a quick flyover of the models.

- **Google Earth ver. 4.3: File, Open**, browse to KMZ file, select **Tools, Play Tour**.
- **Google Earth ver. 5.0: File, Open**, browse to KMZ file, select **Tour in GE 5.0** at the bottom of the **Places** menu; click the **Play Tour** icon in the lower right corner of the **Places** menu.

Key software used in this report:
Google Earth™
Google SketchUp™

Acknowledgments

Gregory Walsh would like to thank Steve Kluge for his applications of the modeling described herein to a map the author completed in western Connecticut. Dave Soller and Rob Stamm provided helpful review comments.

Support for recently published work in Morocco came from the Ministère de l'Énergie, des Mines, de l'Eau et de l'Environnement (MEM) under contract through their National Program of Geologic Mapping (PNCG).

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Abstract

This brief report presents a relatively inexpensive and rapid method for creating a 3D model of geology from published quadrangle-scale maps and cross sections using Google Earth™ and Google SketchUp™ software. An example from the Green Mountains of Vermont, USA, is used to illustrate the step by step methods used to create such a model. A second example is provided from the Jebel Saghro region of the Anti-Atlas Mountains of Morocco. The report was published to help enhance the public's ability to use and visualize geologic map data.

Introduction

The virtual globe Google Earth is widely used for visualization of earth science information because it is free and easy to use. Since the release in 2005, Google Earth (GE) has been used by many authors to publish earth science map data, teach geology by showing the Earth in three dimensions, and create 3D models and virtual field trips (for example, Graymer and others, 2006; Lienkaemper, 2006; De Paor, 2007; De Paor and Sharma, 2007; Kluge, 2007; Kluge and others, 2007; Whitmeyer and others, 2007; Williams and De Paor, 2007; Tewksbury, 2008; McColloch and McColloch, 2008).

Recent uses of the Google SketchUp software have led to the development of 3D earth science models that can be directly incorporated into GE scenes (De Paor and others, 2008; McDonald and De Paor, 2008; Whitmeyer and De Paor, 2008; De Paor, 2007). These models create extremely effective visualization tools that can also be used for analysis of temporal changes in 3D models. Given the proper training, both the novice and advanced GE user can quickly create simple 3D models from scanned quadrangle-scale maps and cross sections. A more comprehensive approach in which many aspects of earth science are incorporated into GE is described by De Paor (2007) and De Paor and others (2008).

The goal of this report is to describe the steps necessary for rapid creation of a 3D model from published geologic maps and cross sections. Admittedly, the methods in this report do not address the problems associated with accurately viewing the subsurface, since current versions of GE do not allow subsurface viewing. Despite this shortcoming, the models presented here can accurately portray the geology on the Earth's surface and the eroded geology aboveground from existing published maps without the need to create complex models. Perhaps in future versions of GE, the viewer will have the ability to toggle off the satellite imagery, or make it semi-transparent as can now be done in GE for water bodies, and see the cross sections below ground with the map still clamped to the surface terrain.

This report provides two contrasting examples of the geology in mountainous regions: one in Vermont, U.S.A., a location that is humid, temperate, and vegetated, and the other in Morocco where it is arid, desert, and unvegetated. The Vermont example shows the bedrock geologic map of the 7.5-minute Rochester, quadrangle (Walsh and Falta, 2001). The area is densely forested and the surface geology is not visible on satellite imagery. The geology consists of complexly deformed Mesoproterozoic to Early Paleozoic metamorphic rocks with a steeply dipping penetrative foliation. The Morocco example shows the geologic map of the 15-minute Timdghas quadrangle (Walsh and others, 2008). The area is underlain by weakly deformed Neoproterozoic hypabyssal plutons and their comagmatic volcanic rocks. The Neoproterozoic rocks are covered by an Early Paleozoic sedimentary sequence that dips gently to the south-southeast. The Anti-Atlas region is largely unvegetated and much of the geology is visible on satellite imagery. The Anti-Atlas Mountains region are is one of the best places on Earth to see well-exposed surface geology from space.

Methods

The 3D models in this report were created with Google Earth (ver. 4.3) and Google SketchUp (ver. 7.0). The model was then tested and saved as a KMZ file in Google Earth (ver. 5.0).

Google Earth and Google SketchUp are relatively easy to learn and use; therefore, extensive user experience is not necessary in order to create 3D models from maps and cross sections. Both software packages have extensive online tutorials and help files, and no attempt to duplicate these training materials is made here. Users who are new to SketchUp should consider viewing some of the short introductory SketchUp Video Tutorials prior to using the methods described in this report. Users will find it useful to have some experience with scanning and image-editing software such as Adobe Photoshop or Corel Photo-Paint. Basic knowledge of GIS principles, map projections and datums, and simple text editing of Keyhole Markup Language (KML) code are also useful.

Step 1: Prepare maps and cross sections.

- Begin by either scanning your paper map or obtaining a scanned copy from the publisher. A useful resolution is 150–200 dpi, but you can change that according to your needs and the size and detail on your map. The final GE model will primarily be for onscreen visualization and it is not intended for publication-quality graphics. The two examples in this report are available in digital format, so scanning was not necessary. The example of the Rochester quadrangle, Vermont, U.S.A. (Walsh and Falta, 2001) was obtained from the *National Geologic Map Database, Geosocience (NGMDB) Map Catalog* in multiresolution seamless image database (MrSID) format and converted to JPEG format in ArcGIS 9.3. The link to the Rochester map in the NGMDB is shown in the "References Cited" section of this report. The map of the Timdghas quadrangle, Morocco (Walsh and others, 2008), was created for the Moroccan Ministry of Energy, Mines, Water and the Environment (*MEM*), through a contract with the Moroccan government. The map was converted from Adobe PDF to JPEG in Adobe Acrobat 9 Pro. The Timdghas map and maps of four adjacent 15-minute quadrangles are available from the *MEM*.
- Save the map in RGB 24-bit JPEG format, or another compatible format. SketchUp is able to import five different 2D image formats *(.jpg, .png, .tif, .tga. .bmp*). The methods described in this report work for RGB 24-bit JPEG format. The 24-bit JPEG format was chosen because it maintains accurate color rendition. An attempt to import a CMYK 32-bit JPEG image produced a grayscale image in SketchUp. A paletted 8-bit TIFF format yielded colors that did not match the original publication. Once the 24-bit JPEG format proved successful, no attempt was made to test the other formats for compatibility with SketchUp.
- Precisely crop the quadrangle-scale map to the limits of the map sheet and save the map to a new file (fig. 1*A*). Precisely crop the cross-sections and save them to separate files (fig. 1*B*). It is not necessary to crop the cross sections to their limits; instead you will want to keep the marginal information so it is visible in the model (fig. 1*B*).

The method described above works well for rectangular maps at scales of 1:50,000 or larger. Smaller scales maps, or maps covering very large areas, will not produce rectangular areas because lines of longitude converge towards the poles and diverge towards the equator. Users of large maps may find it useful to obtain a grid of quadrangle boundaries that can be viewed in GE and used to register the maps graphically in step 2.

Step 2: Create a ground overlay.

From the cropped map, you can create a **Ground Overlay** by either writing some simple KML code or graphically registering the map using **Add** an **Image Overlay** from **Temporary Places** in the **Places** menu in the Google Earth **Sidebar** (**Temporary Places**, right click, **Add**, **Image Overlay**). Users who use the graphical approach for maps covering large areas, and not the KML method, will find it useful to review the Google Earth help on *Image Overlays*. If you choose to use the graphical approach, you will require a reference grid, or some other reference points, to register your map. For example, *MapFinder* for GE is a free tool for identifying USGS 7.5-minute quadrangle boundaries.

To create a KML file, you can use a text editor like Microsoft Notepad. Simply copy and paste the text below, and save the file as **mapname.kml**, where **mapname** is a name you choose (**RO_map.kml**, in the following example).

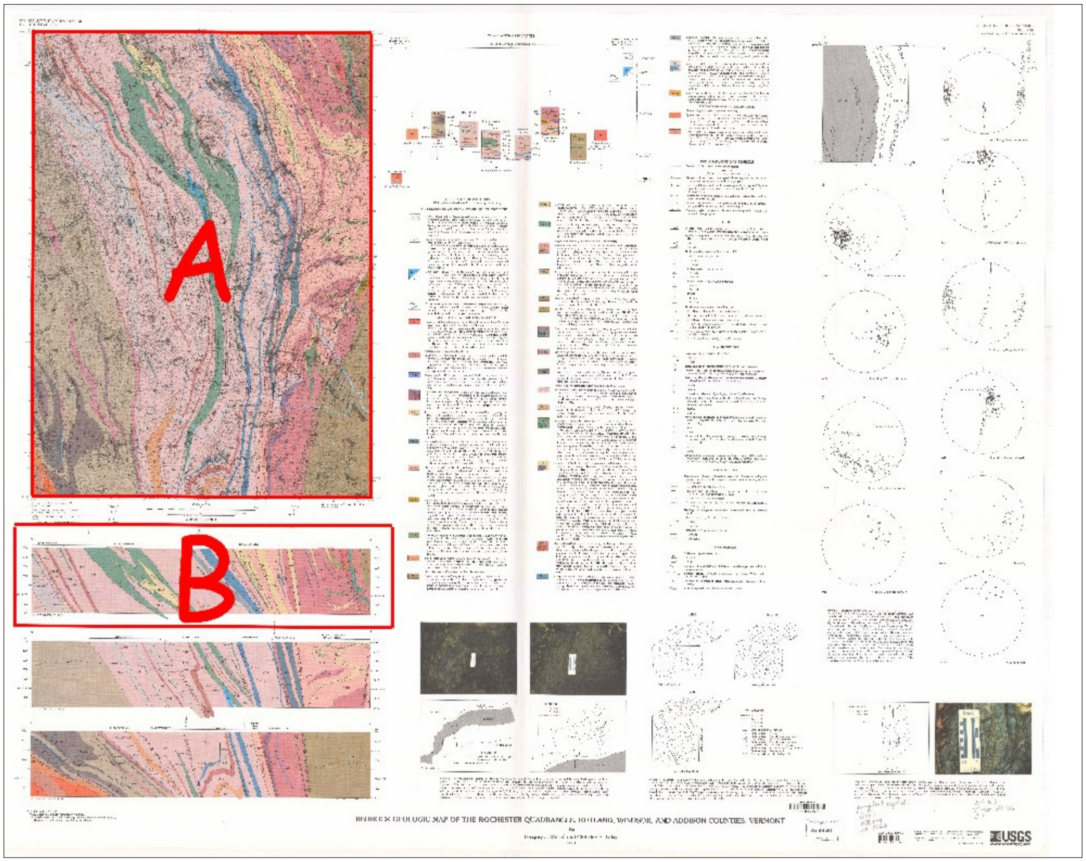

Figure 1. Example of a scanned map of the bedrock geology of the Rochester quadrangle, Vermont (Walsh and Falta, 2001). *A*, Areas outlined in red show the cropped map; *B*, shows an example for cross section A-A′.

Example from Rochester quadrangle, Vermont (**RO_map.kml**):

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.0">
<Document>
<GroundOverlay>
 <name>Bedrock geologic map of the Rochester quadrangle</name>
 <Icon>
 <href>RO_map.jpg</href>
 </Icon>
 <LatLonBox>
 <north>43.875</north>
 <south>43.75</south>
 <east>-72.75</east>
 <west>-72.875</west>
 </LatLonBox>
</GroundOverlay>
</Document>
</kml>
```

The blue text in the example above is standard KML code. The red text needs to be modified according to your specific map:

- The <name> reference can be anything you want. In the example above, a part of the full title of the map was used.
- The <Icon> <href> reference should be the filename of your map.
- Note in <LatLonBox>that west longitude coordinates are considered negative.

You will need the bounding limits of your quadrangle in decimal degrees (shown in red in the KML example above). In this example, the coordinates of the published map use the NAD27 horizontal datum; however, GE uses a datum of WGS84. In the United States, maps will have a slight offset in coordinates due to the datum change. To portray your map precisely, you will need to convert the coordinates from NAD27 to WGS84. If you do not adjust the coordinates, your map will not be accurately registered but may still be useful for 3D viewing in GE. In the Vermont example, the coordinate shift is stated on the published topographic map and indicates that the shift from NAD27 to NAD83 is 36 meters west and 3 meters south. Relative to other datum shifts, this shift is not too large. Outside the United States or Canada, your source map will not use the NAD27 datum, but some other datum, and the transformation of coordinates to the WGS84 datum may be much larger. For example, the datum shift in the Morocco map is 143 meters west and 274 meters north. The Morocco example uses the Merchich datum, and the precise map coordinates were obtained from the published GIS database (Walsh and others, 2008). Accurate transformation in such cases will require some knowledge of map projections, datums, and GIS.

In the KML example above, the map limit coordinates are based on the NAD27 datum, and they need to be converted to WGS84 datum. This is easily accomplished with an online tool. (Note: WGS84 and NAD83 are essentially the same, since WGS84 was derived from NAD83). For example, see *http://www.ngs.noaa.gov/cgi-bin/nadcon.prl*, where

	Latitude	Longitude
NAD 27 datum values:	43° 52’ 30.00000”	72° 52’ 30.00000”
NAD 83 datum values:	43° 52’ 30.32357”	72° 52’ 28.39185”
NAD 27 datum values:	43° 45’ 00.00000”	72° 45’ 00.00000”
NAD 83 datum values:	43° 45’ 00.24034”	72° 44’ 58.37061”

Now convert degrees minutes seconds to decimal degrees. For example, see *http://www.fcc.gov/mb/audio/bickel/DDDMMSS-decimal.html*, where

43° 52’ 30.32357” = 43.875090°
72° 52’ 28.39185” = 72.874553°
43° 45’ 00.24034” = 43.750067°
72° 44’ 58.37061” = 72.749547°

Revised KML file:

```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.0">
<Document>
<GroundOverlay>
 <name>Bedrock geologic map of the Rochester quadrangle</name>
 <Icon>
 <href>RO_map.jpg</href>
 </Icon>
 <LatLonBox>
 <north>43.875090</north>
 <south>43.750067</south>
 <east>-72.74957</east>
 <west>-72.874553</west>
 </LatLonBox>
</GroundOverlay>
</Document>
</kml>
```

Next, open the KML file in GE:

Go to **File**, **Open**, then **Browse** to the KML. The map should be accurately registered and will be draped over the terrain model.

It is also useful to view the map without the terrain, or in 2D, by “floating” a copy of the flat map in the air, as follows:

- Go to **Places**.
- Go to **Temporary Places**.

- Go to **RO_map.kml**.
- If there is a "+" sign next to **RO_map.kml**, click on it to expand the folder.
- Right click on the name of the map, and **Copy**.
- Right click, and **Paste**.
- Right click on the new copy of the map.
- Right click, **Properties** (named **Get Info** on the Mac), click the **Altitude** tab, and change the Altitude to some value aboveground (fig. 2).

Next, add some descriptive text information about the map you just created, such as its source, scale, and type:

- Right click on **RO_map.KML** folder.
- Click **Properties** (named **Get Info** on the Mac).
- Click the **Description** tab in the **Edit Folder** window.

See the following example (fig. 3):

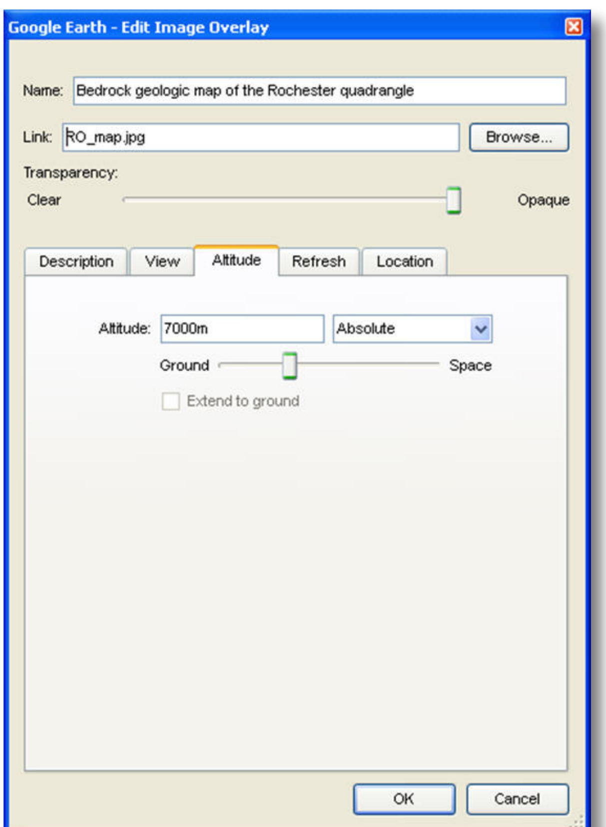

Figure 2. The **Edit Image Overlay** window showing the **Altitude** tab. The value of 7000m is added here to make the second copy of the map "float" above the ground, allowing you to see how the geology is portrayed on the flat 2D map.

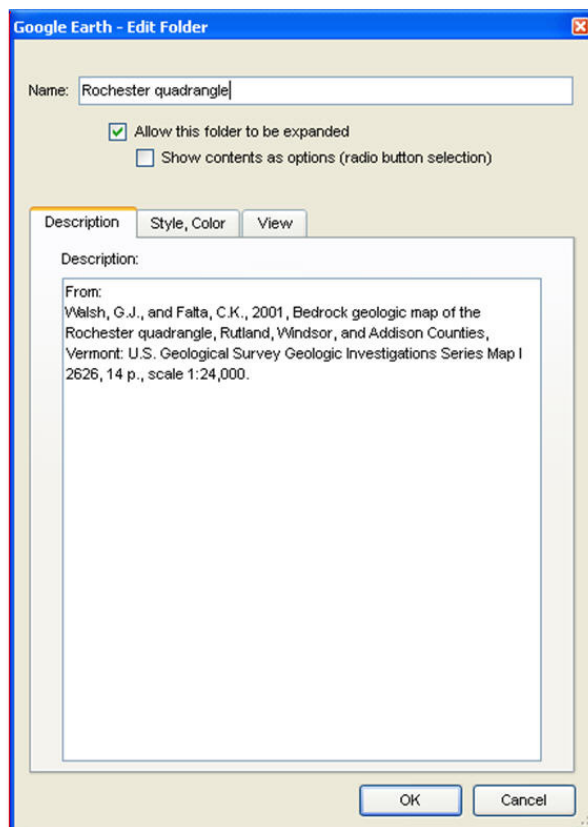

Figure 3. The **Edit Folder** window showing the **Description** tab where the reference to the map can be added.

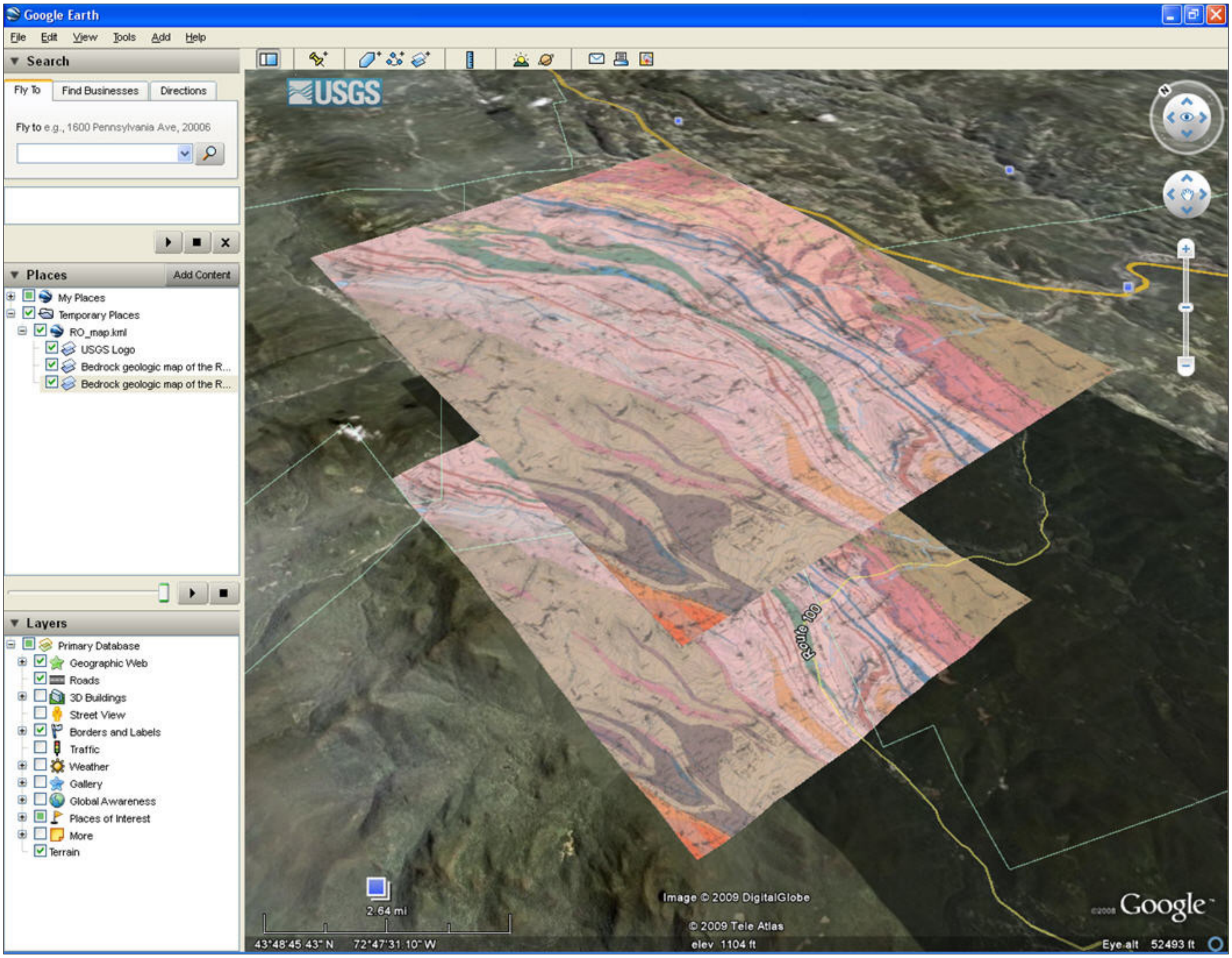

Figure 4. The GE window showing the two maps as viewed from a starting location in the air to the southwest. The lower map is at the ground surface and is linked to the terrain, and the upper map is flat and floating 7000m above the ground.

Click **OK**.

Next, you may want to navigate the view in GE to a suitable starting location (fig. 4). To do this, move the view in GE to a place of your choice, then:

- Right click on **RO_map.kml**, click **Properties**.
- Select the **View** tab, **Snapshot current view**, **OK**.

Finally, you will want to save the files to a KMZ file. The KMZ file is a single compressed or “zipped” file:

- Go to **File**, **Save**, **Save Place As**, and name the **KMZ** file.

Step 3: Create the model in Google SketchUp.

Launch SketchUp:

- Choose “Google Earth Modeling – Meters” as the default template.
- Go to **File**, **Import**, choose the .jpg format with the option “Use As Image,” and **Open**. Click two points to define a box with the map in the horizontal plane (fig. 5*A*).
- Select the **Rectangle** tool (fig. 5) and draw a horizontal rectangle on top of the map that is about the same size of the map.

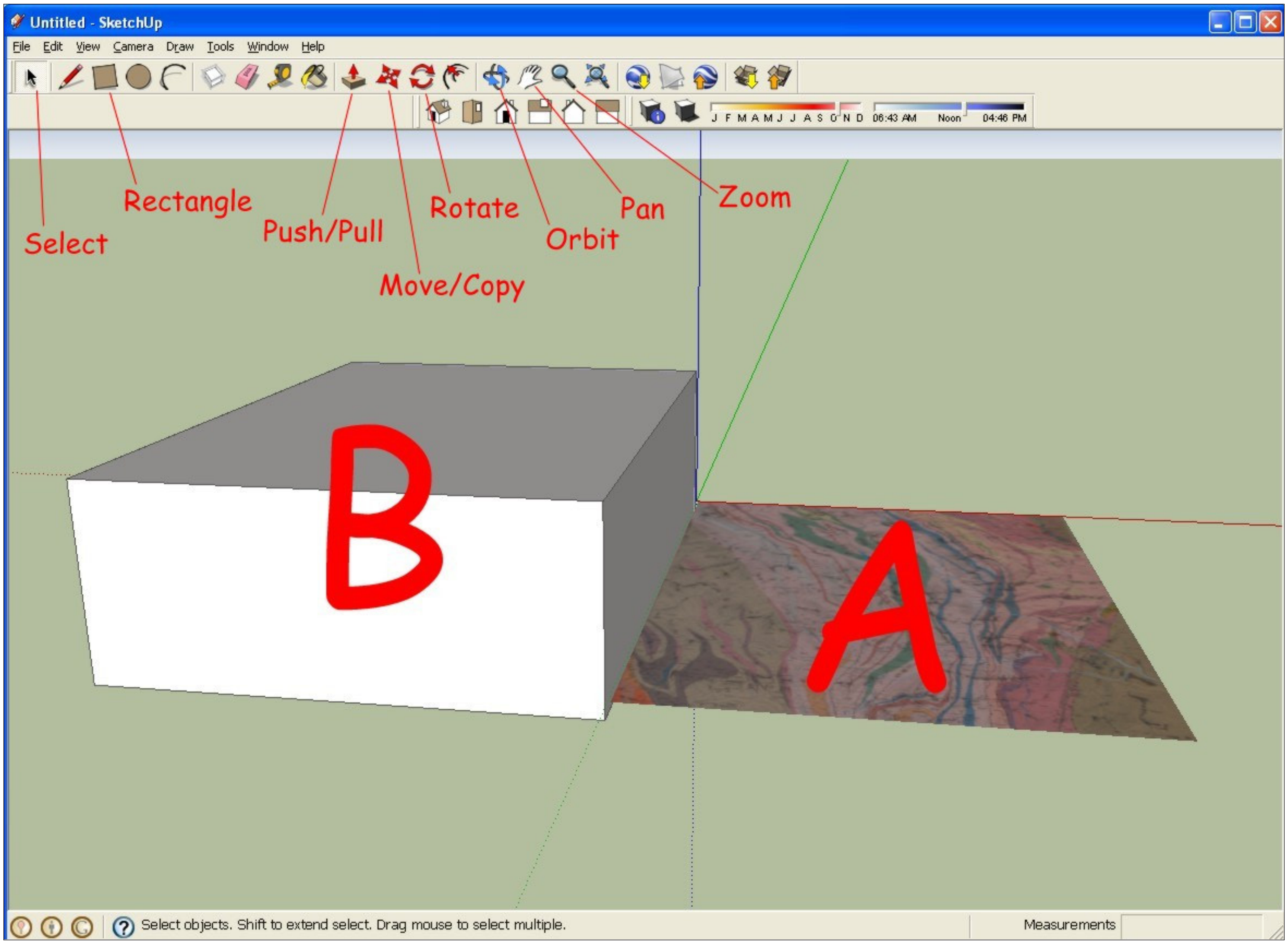

Figure 5. The Google SketchUp window showing the map (*A*) and the temporary cube (*B*) as viewed from in the air to the south-southeast. The white face of the cube will be used in the following procedures and is shown as the gray vertical plane in figure 6*A*. The common tools are labeled on the toolbar.

- Next, use the **Move/Copy** tool (fig. 5) to move the rectangle to the side of the map, so that the two objects are now adjacent (fig. 5).
- Next, use the **Push/Pull** tool (fig. 5) to pull the horizontal rectangle upwards to make a temporary cube with vertical sides (fig. 5*B*).

Save the file as a SketchUp SKP file. Remember to save periodically after creating new elements.

- Now, select and delete all but one vertical face (the white vertical rectangle in fig. 5*B*), and all the lines associated with the deleted faces. You simply click on the face or line with the arrow **Select** tool (fig. 5) until it is highlighted, and then press delete on your keyboard.
- **Move** the remaining face into an approximate position of the cross section, but slightly off the map (fig. 6*A*). You can save some steps later by creating a number of temporary vertical planes equal to the number of cross sections. Do this by copying the vertical plane, pasting it, and then moving it off to the side until you need it for subsequent cross sections. Create as many planes as you need.
- Import one of the cross section JPEG files onto the vertical face (fig. 6*B*). To do this, go to **File**, **Import**, and browse to the JPEG; and then pick two points on the vertical plane to fit the cross section. The cross section will snap to the vertical plane.

  The plane used to place the image into SketchUp is only temporary (fig. 6*A*). It can now be deleted. To do this, select the vertical plane and its four outlined sides, and then press **Delete** on the keyboard.

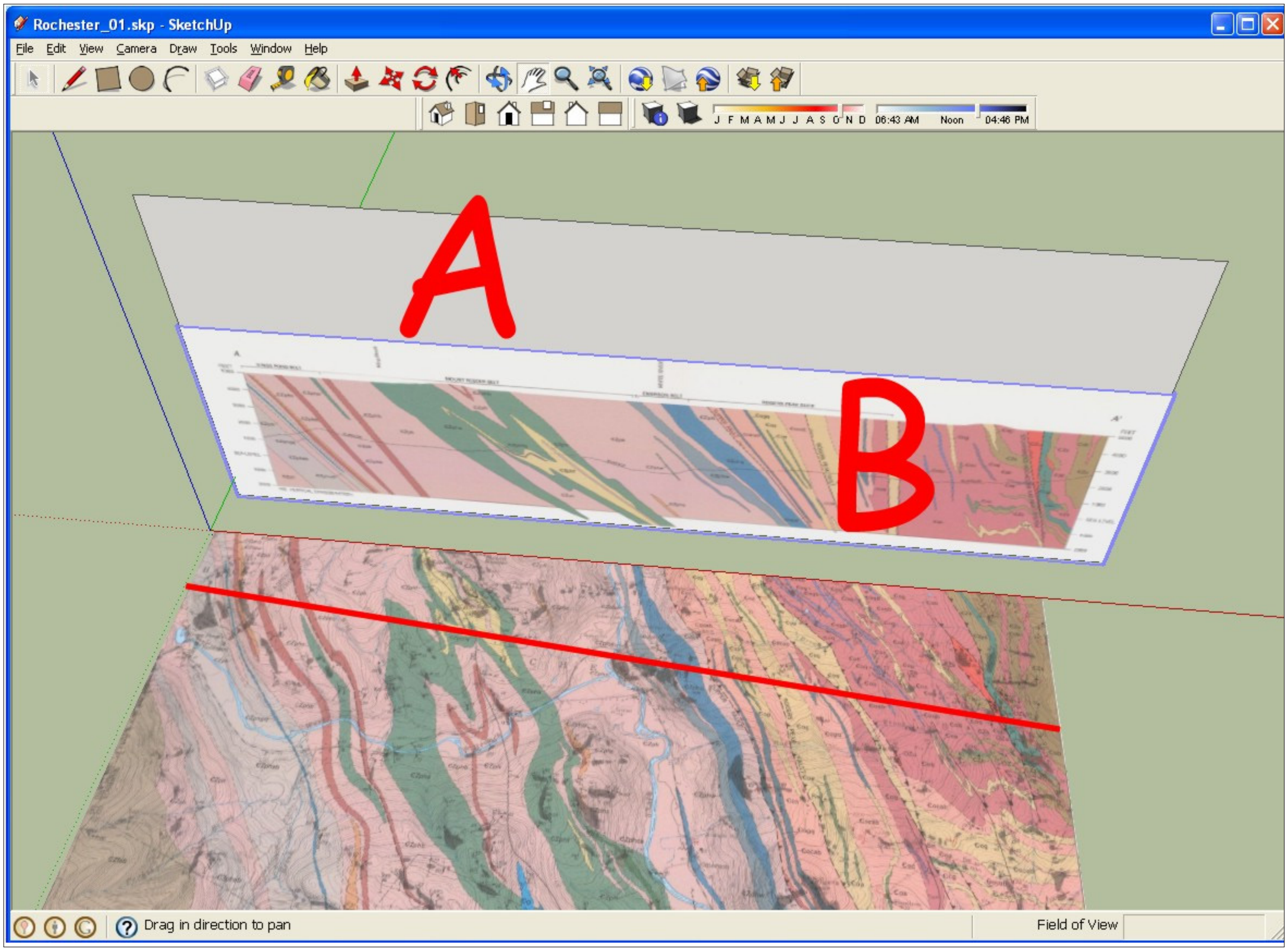

Figure 6. The Google SketchUp window showing *A*, the vertical plane with the cross section; *B*, imported onto the plane. The line of section on the map is shown in red.

Now **Scale**, **Rotate**, and **Move** the cross section until the two ends match the line of section on the map.

- Select, Tools, and Rotate (**Rotate** on toolbar, fig. 5).
- Select, Tools, and Scale.
- Select, Tools, and Move (**Move/Copy** on toolbar, fig. 5).

Most important is the precise matching between the X, Y positions of the ends of the vertical cross-section plane to that of its associated line of section on the map. Later, when you generate the 3D model in GE, the Z-value (elevation) can be edited to make the surface profile of the cross section match the terrain model. Until you become proficient, the **Scale**-**Rotate**-**Move** process will take some trial and error. Here, it is helpful to use the online SketchUp tutorials, especially for *Rotate*. During this process, it is useful to change your viewing perspective of the cross section in order to achieve a more accurate placement and proper angle of rotation. Viewing the map from directly above is a useful way to align the section.

When using the **Scale** tool, be sure that you only select the green-cube handles on the corners of the cross section so you change the scale using a locked aspect ratio. Alternatively, after selecting a green corner box, you can type in a scale factor on the gray box at the lower right of the SketchUp window.

If you are having trouble rotating the section to the proper angle, you may want to turn off angle snapping. To do this, go to **Window**, **Model Info**, and **Units**. In the **Model Info** window (fig. 7), uncheck **Enable angle snapping** and adjusting the **Precision** of the **Angle Units** to a very low number.

You may also want to adjust the **Precision** of the **Length Units** and uncheck **Enable length snapping** in this window, in order to more precisely scale your cross section.

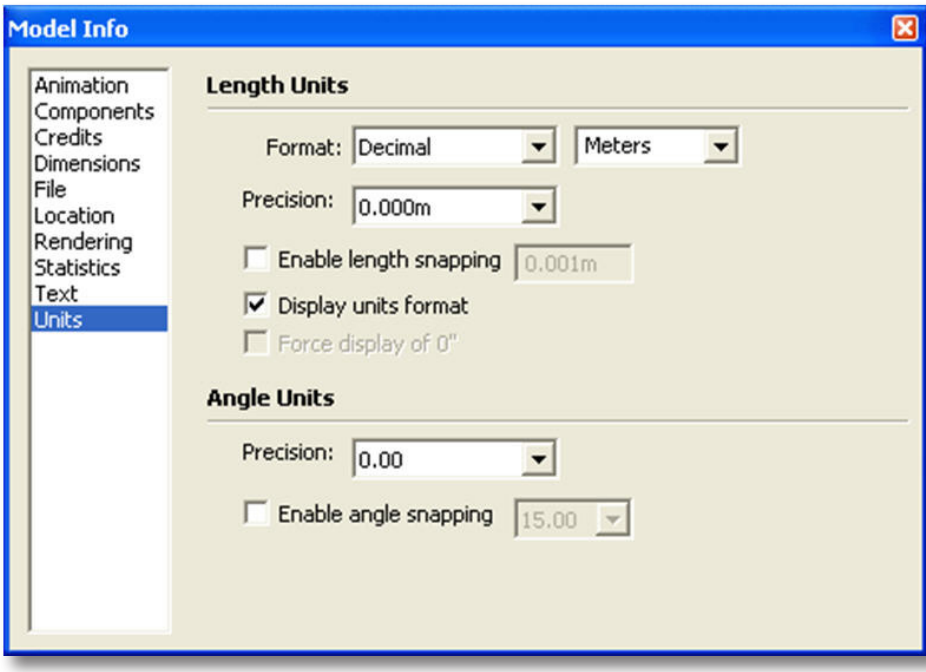

Figure 7. To more precisely scale and rotate your cross section, adjust the **Precision** of the angle and length units and uncheck the boxes that enable snapping in the Google SketchUp **Model Info** window. The boxes are checked by default.

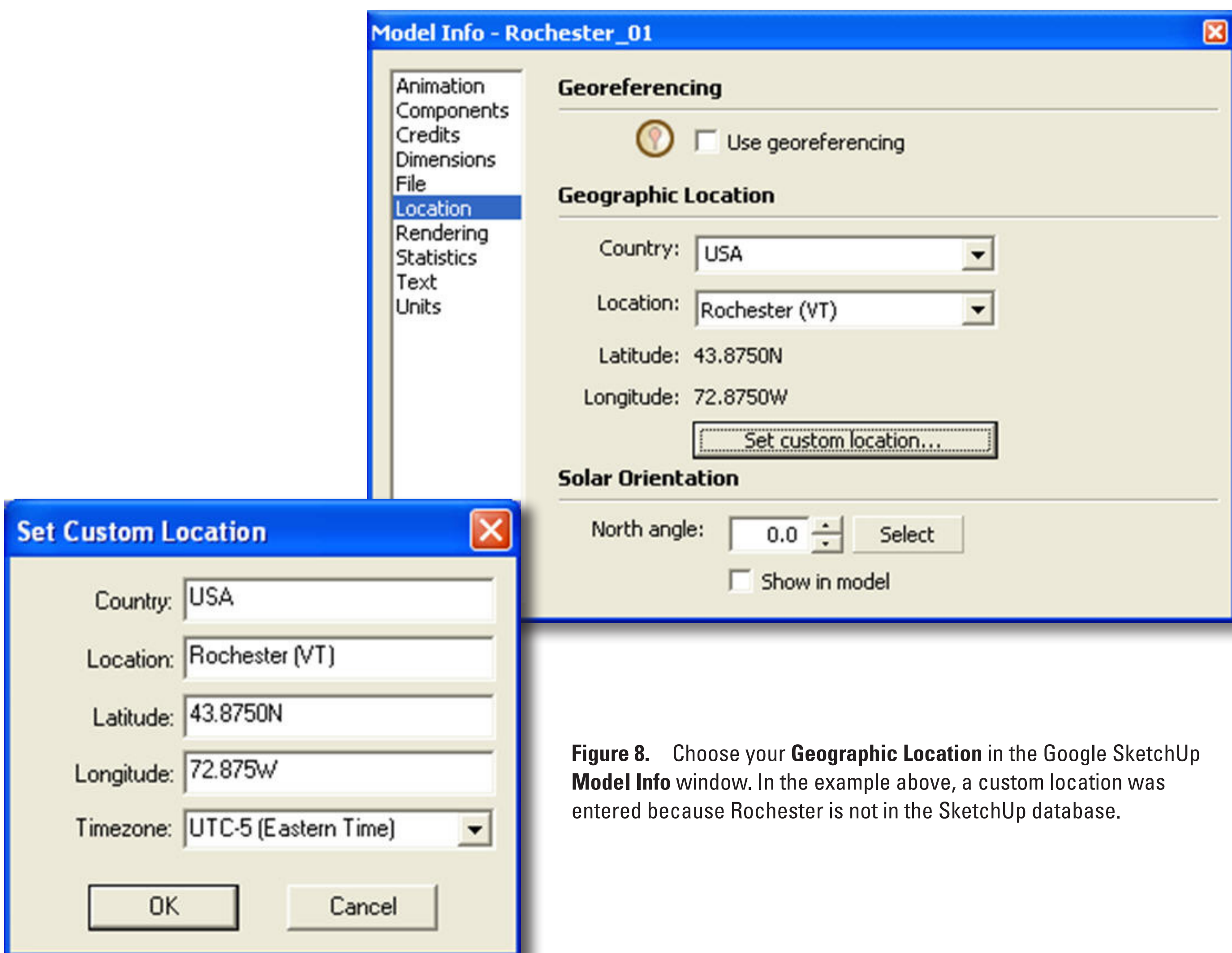

Figure 8. Choose your **Geographic Location** in the Google SketchUp **Model Info** window. In the example above, a custom location was entered because Rochester is not in the SketchUp database.

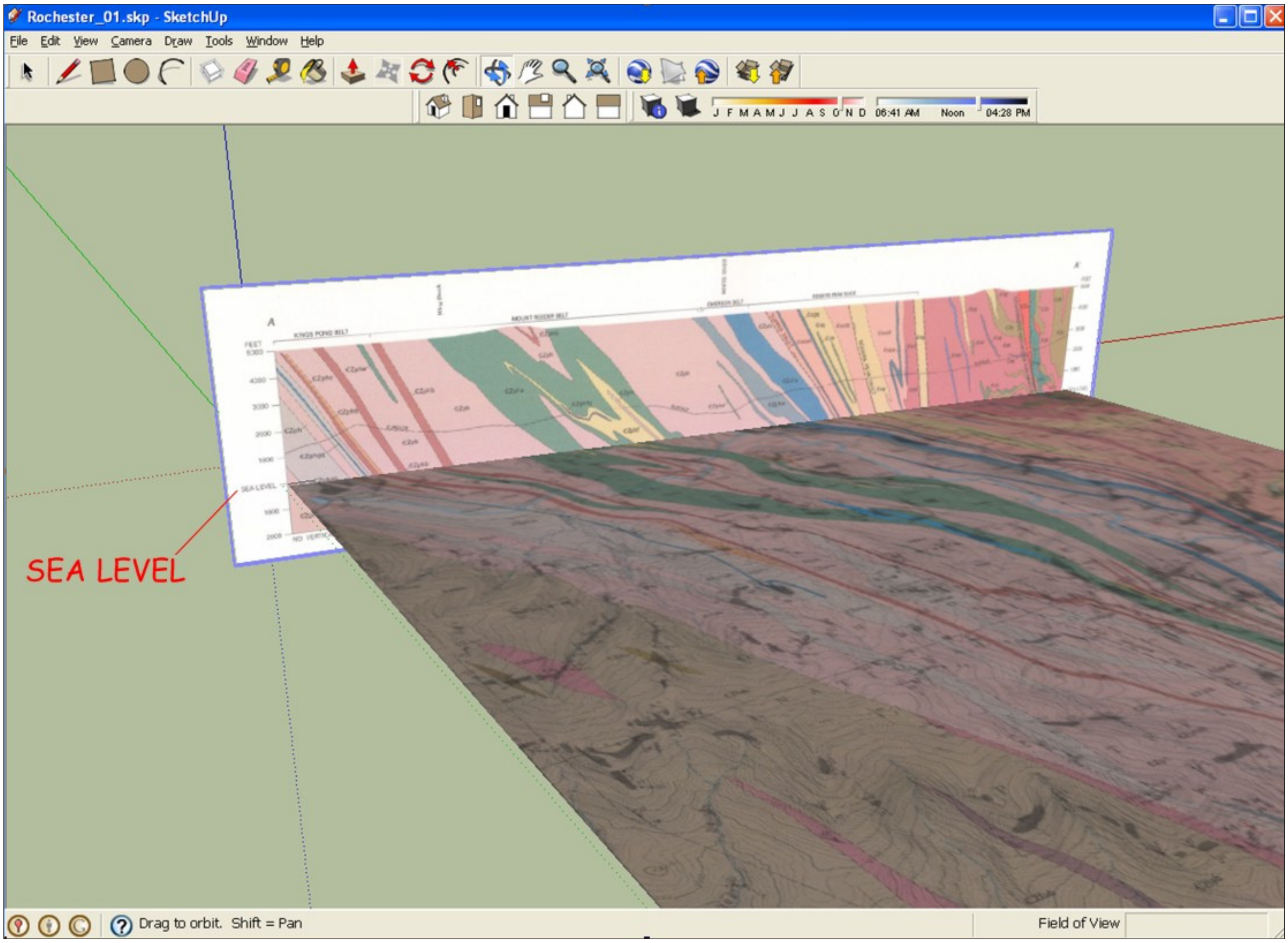

Figure 9. The Google SketchUp window showing the map with the cross section properly located. In this example, the "SEA LEVEL" mark on the cross section is aligned with the horizontal reference plane formed by the green and red axes (Z=0). The light blue outline around the cross section shows that it is currently selected.

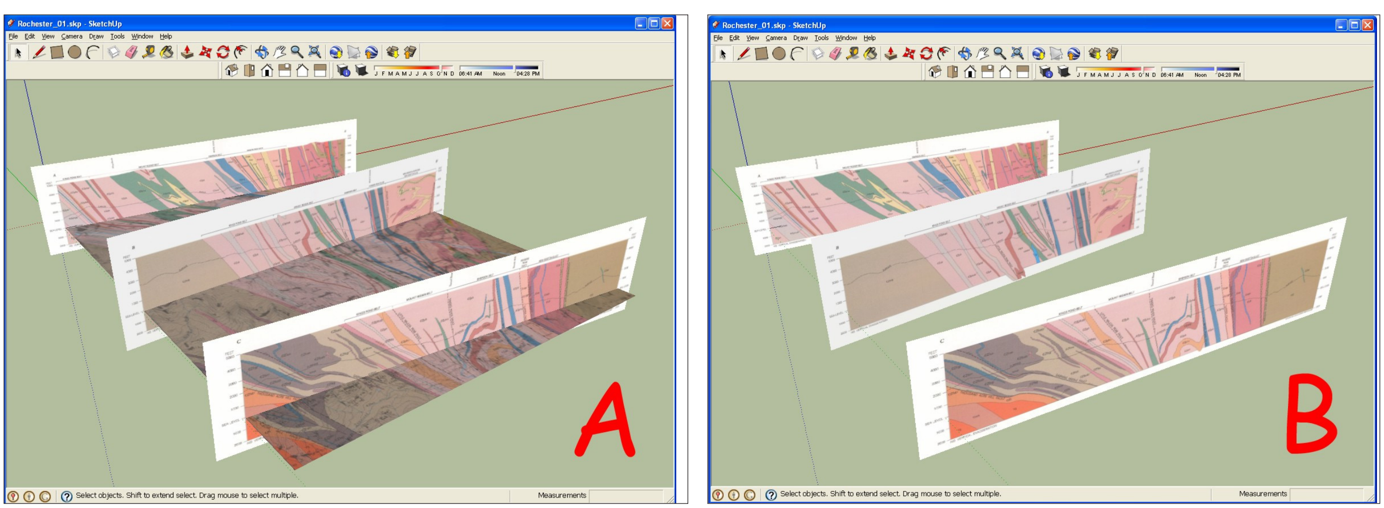

Figure 10. Google SketchUp windows showing *A*, the final appearance of the three cross sections with the map. *B*, prior to exporting the cross sections to GE, the map was deleted from the SketchUp model.

While the **Model Info** window is displayed, click on **Location** and change the **Geographic Location** to match your map (fig. 8). If you do not do this, your imported model will be placed into GE in the default location of Boulder, Colo. It is important to understand that the model you are creating here in SketchUp is separate and independent from the **Image Overlay** you created in step 2. The location information from step 2 is not stored in SketchUp, so you need to specify it in general terms here. The location you enter here is only approximate, so a town or city within your map will work fine. You will precisely locate and place the model in step 4B later. Close the **Model Info** window when you are finished.

The aligned cross section and map are shown in figure 9. Save your work and repeat the procedures in step 3 starting with creation of the temporary cube (fig. 6*B*) for any remaining cross sections. Alternatively, you can use the temporary vertical planes you created earlier. Once all the cross sections are added to the SketchUp model, select and delete the horizontal map (fig. 10). You will display the map in GE with the **Grid Overlay** created in step 1, not the horizontal map in SketchUp.

Next, Save the SketchUp model, and then export it to GE:

- Go to **File**, **Export**, and **3D Model**.
- Choose a filename with a KMZ extension (for example, **RO_model.kmz**).

Step 4: Put the Google SketchUp model into Google Earth.

Step 4A: Edit the emission line in the DAE file.

When you export the model as a KMZ file, SketchUp creates a zipped file (**RO_model.kmz**) that contains a number of files, including a file called **RO_model.dae** in Digital Asset Exchange (DAE) format. The DAE format is used for 3D rendering in XML language using the COLLAborative Design Activity schema or COLLADA (*Barnes and Finch, 2008*). In the code, the DAE file contains instructions for 3D rendering and shading of the model using a Lambertian diffuse material, which produces a diffuse shaded surface that is independent of lighting (*Barnes and Finch, 2008*). The code contains a line for controlling **emission**, which declares the amount of light emitted from the surface. In the version of SketchUp (7.0.8657) used in the report, the default **emission** code creates a model with undesirable gray, washed-out colors. Through trial and error, the **emission** code was modified in order to retain the original color of the cross sections. The compression software WinZip was used to access the DAE file without compromising the integrity of the KMZ file. In order to change the code in the DAE file, a text editor was used as follows:

- Right click on the **RO_model.dae** file, and choose **Open With**.
- Choose **Winzip**.
- From the Winzip window, Right click on the DAE file and choose **Open With**.
- Choose **Notepad** or **Wordpad**.
- Edit the **emission** line for each cross section (in this example, they are texture1.jpg, texture2.jpg and texture3.jpq) created by SketchUp when the model was exported to KMZ format.

See the following example:

```
<lambert>
<emission>
   <color>0.000000 0.000000 0.000000 1</color>
   </emission>
</lambert>
```

The color line was changed to:

```
<color>1.000000 1.000000 1.000000 1</color>.
```

Finally, save the file in Notepad, and say **Yes** when Winzip asks if you want to update the archive file. Future versions of SketchUp may make this step obsolete, but at the time of writing this report, this procedure was considered necessary.

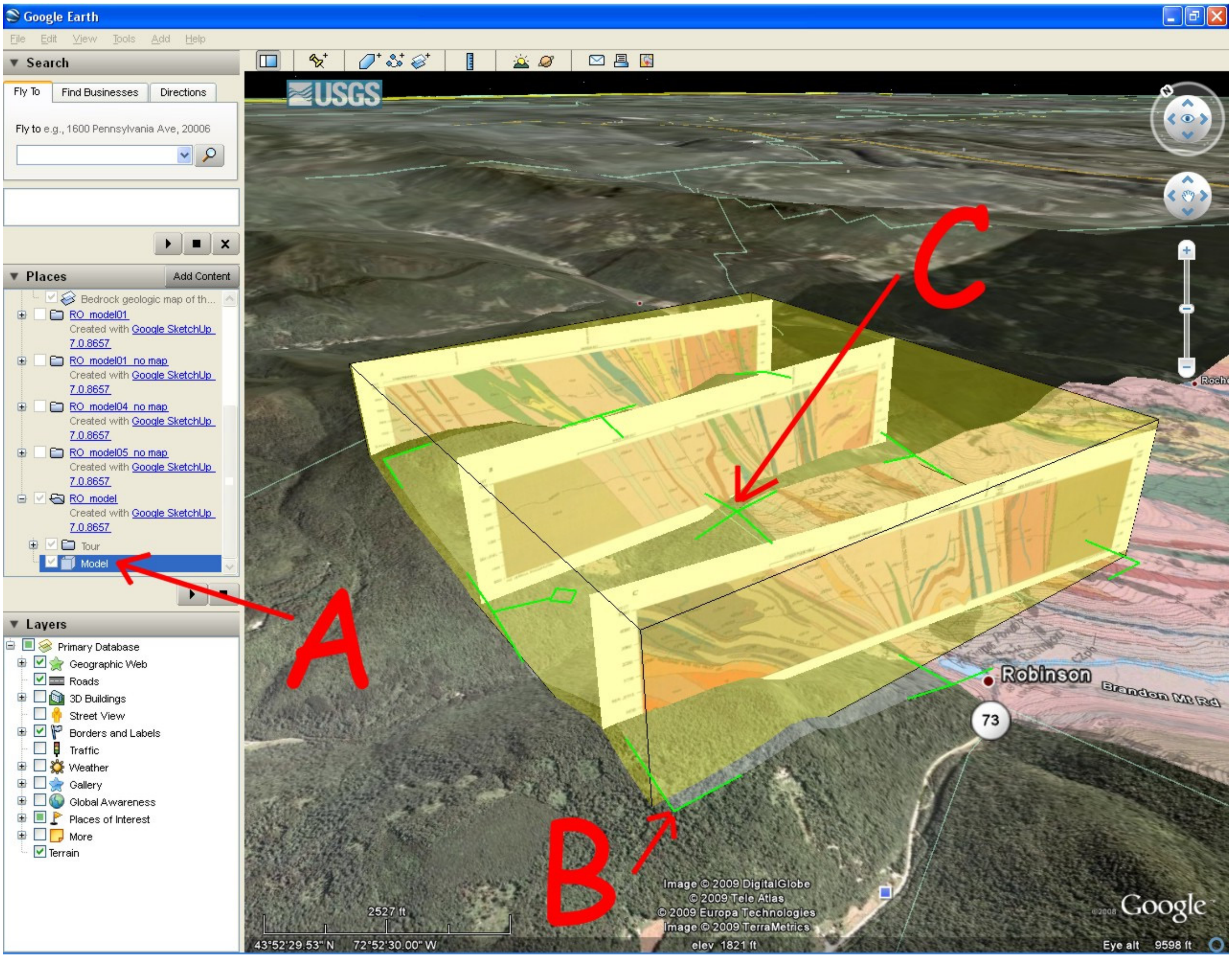

Figure 11. Google Earth window showing *A,* the location of the **Model** in the **Places** window and the green handles used for resizing the model within its green transparent cube. *B,* Use the corner handles to resize the model. *C,* Use the center handle to move the model.

Step 4B: Place and edit the model in Google Earth.

Now you can open GE and move to the location of your **Ground Overlay** map created in step 2.

Next, choose **File**, **Open**, and browse to the KMZ file (for example, **RO_model.kmz**).

The GE viewer will change when the model is open. Although the view will be centered on the model, the model will not be properly located or sized. The model will be in the **Geographic Location** specified in step 3. At this point you need to reposition and resize the model. To do this:

- Click on the "+" sign next to the model name in the **Places** window (fig. 11*A*).
- Right click on the Model (fig. 11*A*), and choose **Properties**.

A transparent green cube with green positioning handles will appear around the model (fig. 11*B*, *C*). The model will be too small at this stage, so to resize the model, click and drag any corner handle and expand the model. Progressively zoom out and interactively expand the model until it is approximately the right size.

Once the model is approximately the right size, click and drag the center handle (fig. 11*C*) to reposition it. Continue this iterative process until the model is accurately located. It is useful to change your viewing perspective during this process, especially from straight overhead, which allows you to evaluate how the ends of the sections match the map.

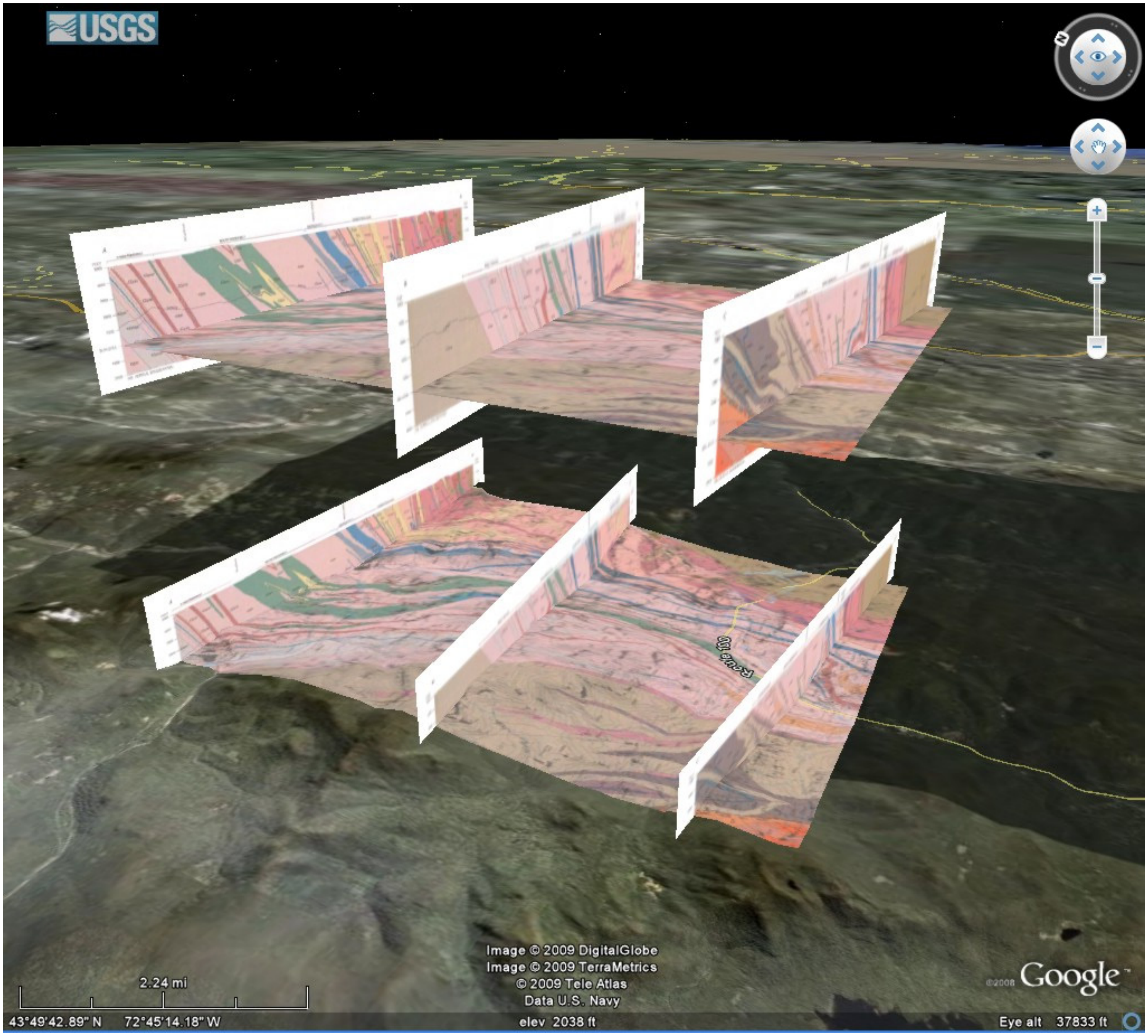

Figure 12. Google Earth window showing the final model with four elements, including two maps and two sets of cross sections. The lower map and sections are linked to the surface and the terrain, while the upper floating map and sections are 7000m aboveground. Both the surface and floating elements utilize the same base map with its three linked cross sections.

Once you are satisfied with the X, Y position of the map, you will need to adjust the Z-value, or **Altitude**, to get the line of the topographic profile to match the terrain model in GE. It is unlikely that the topographic profile shown on the cross sections will precisely match the GE terrain model. For visualization purposes, however, you should be able to achieve a close fit.

To change the **Altitude** of the model:

- Right click on the Model (fig. 11*A*) in the **Places** menu, and choose **Properties**.
- Click the **Altitude** tab.
- Adjust the **Altitude** value and setting to **Absolute** until the profile matches the terrain model.
- Click **OK**.

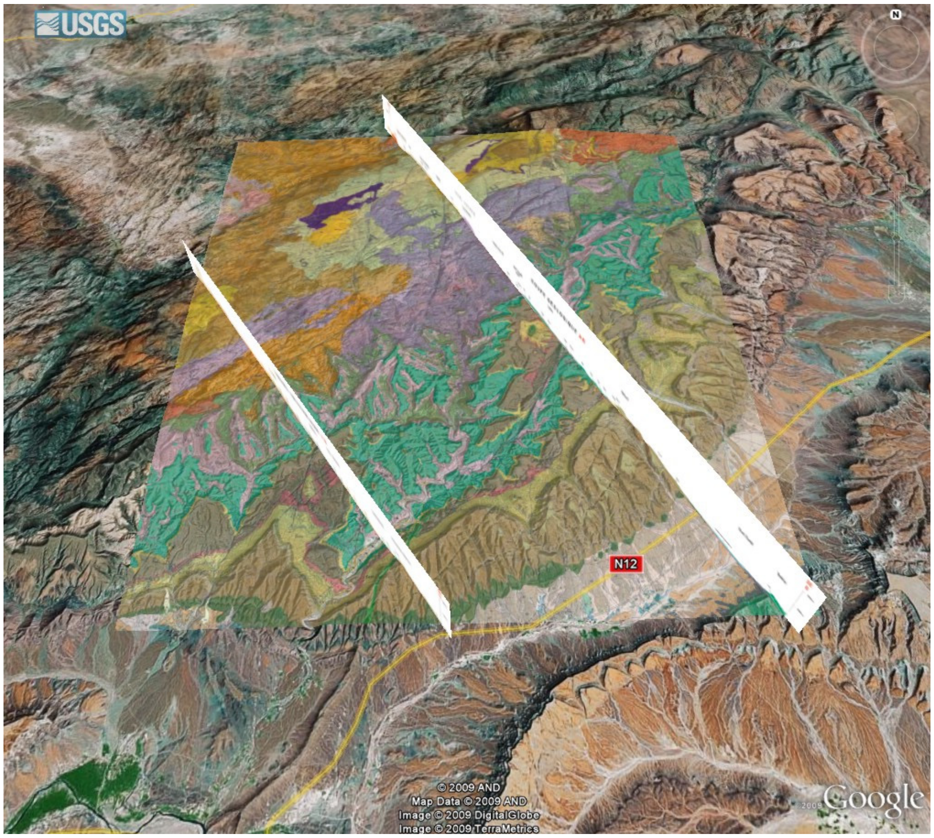

Figure 13. Cropped Google Earth window showing the Timdghas quadrangle in Morocco. Here the map is made transparent so the geology is visible in shaded relief. Note the cross sections do not show the geology aboveground.

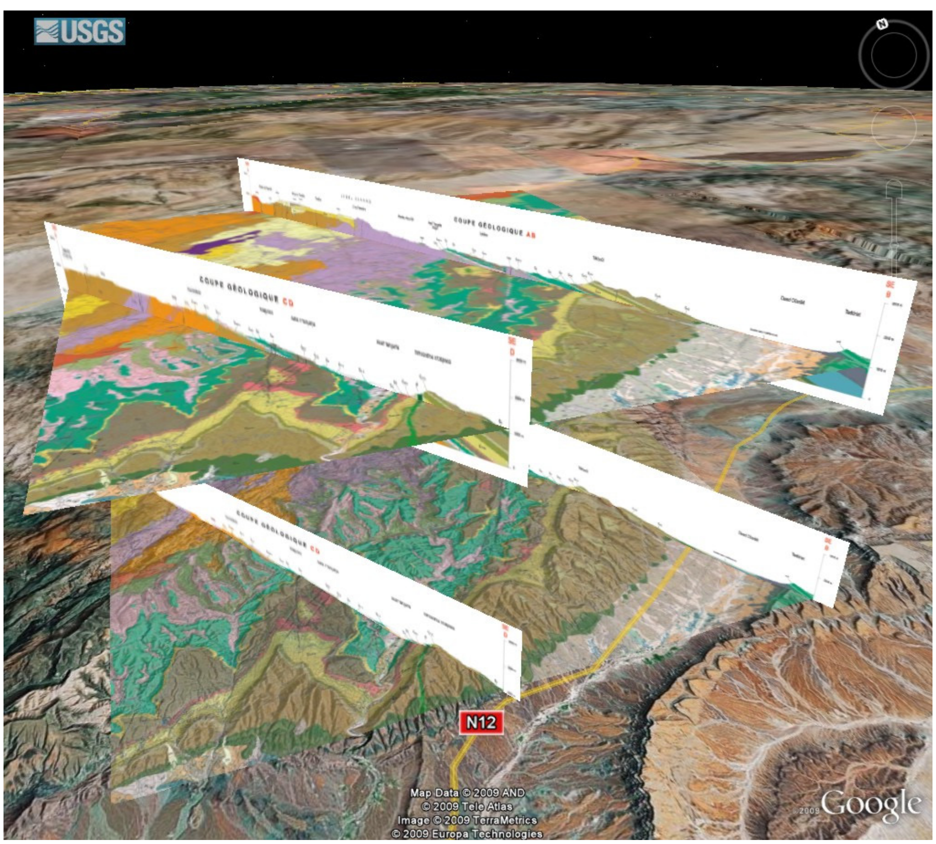

Figure 14. Cropped Google Earth window showing the Timdghas quadrangle with the surface map and cross sections, plus the floating map and sections at 8800m altitude. Note the floating sections show the geology below ground.

Next, you will put the cross-section model into the air with the flat, “floating” geologic map. This is useful and allows you to see the map and cross sections from both above and below. We do this because, as mentioned previously, in the current version of GE, the satellite imagery that drapes the terrain does not allow you to look below the surface of the Earth, such that it obscures the cross-section model. Currently, the model linked to the terrain shows the geology projected into the air above the surface, as it used to be before it was eroded; however, the cross sections can also depict the subsurface geology. One way to do this is to simply turn off the **Terrain**. This will allow you to view some of the subsurface geology on the cross sections. To show the full extent of the cross sections, both the portion below present-day land surface and any section extrapolated above, you can link the model to the floating horizontal map created in step 2 (fig. 12). Proceed as follows:

- Right click the model in the **Places** menu (fig. 11*A*), and choose **Copy**.
- Right click the model in the **Places** menu (fig. 11*A*), and choose **Paste**.
- You now have two models in the **Places** menu, so right click one of them (fig. 11*A*), and choose **Properties**.
- Click the **Altitude** tab.
- Adjust the **Altitude** value and setting to **Absolute** until the profile matches the terrain model. In the Vermont example, the sea level on the cross sections will align with the horizontal plane of the map, albeit at 7000m above the ground.
- Click **OK**.

Finally, save everything to a new KMZ file:

- Right click **Temporary Places** in **Places**, **Save Place As**, and filename.

Discussion

Notice in figure 12 how the geologic contacts on the floating map do not match the geologic contacts on the floating cross sections. This occurs because the map is a two-dimensional depiction of the three-dimensional surface, while the cross sections are two dimensional. The only place the map and cross sections will match is along the line of the topographic profile (for example, see the bottom map and model in fig. 12). In mountainous areas, the mismatch seen in the floating map and model will always occur. Only if the terrain is completely flat and horizontal will the map and cross sections match in the floating example. Despite this problem, the floating model still provides a valuable visualization tool. Should future versions of GE allow the viewer to see through the satellite imagery, then the subsurface cross sections will be visible within the terrain-linked map model, and this problem will be moot. This issue is more apparent in the example from Morocco.

In the GE model of the Timdghas map (fig. 13), the surface geologic map was made transparent (go to **Properties** window and modify transparency). This technique allows the viewer to see the effect of natural shadows, or shaded terrain relief, in the underlying satellite imagery. Cross sections on the Moroccan map were prepared according to cartographic standards in use at the *MEM*, and do not show the geology projected into the air (fig. 13). For this reason, the usefulness of projecting the cross-section model onto the terrain model is questioned. In order to visualize the cross sections and the map together, they are placed in the air (fig. 14). Unlike the Vermont example where the cross sections are tied to sea level, the Moroccan example shows the cross sections floating at an arbitrary distance within the map. This is somewhat useful for visualizing the geology, and can be adjusted by modifying the **Altitude** values in the **Properties** menu.

The combination of Google Earth and Google SketchUp provides a powerful tool to facilitate 3D visualization models of published geologic maps and cross sections, despite the inability to view the subsurface in GE. The software and the methods described in this report are fast, free, and easy to use and should enhance the public’s ability to use and visualize geologic map data.

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