Precision Raised-Relief Maps – Adding the Third Dimension

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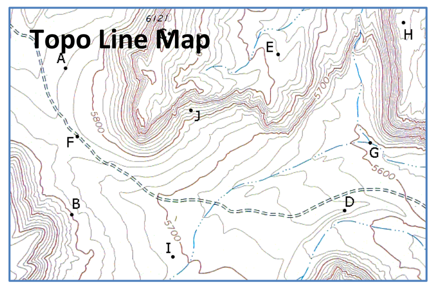
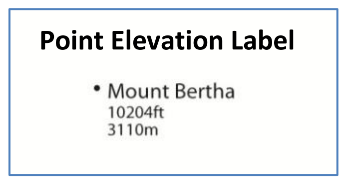
Why 3D Maps?

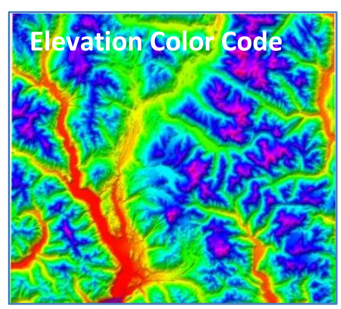
The shape and elevation of the terrain is of critical interest to many map users. When dealing with high hills or mountainous terrain, the elevation and slope is a major concern for hikers, backpackers, mountain bikers, pilots, land developers, utility/municipal planners, fire fighters, law enforcement officers, and many other map users. When planning a route through a complex and challenging topographic terrain, accurate and easy to understand elevation and slope data is key to a successful trip, mission, or project. This paper explores ways to create maps that effectively present the third dimension.

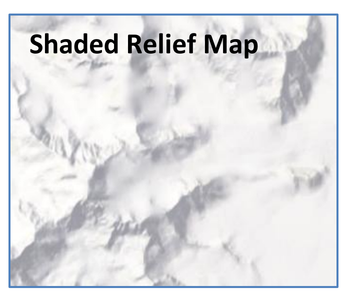
How Maps Convey Elevation

When the terrain elevation and shape information is needed on a map or chart, there are several ways to present it with two-dimensional media:









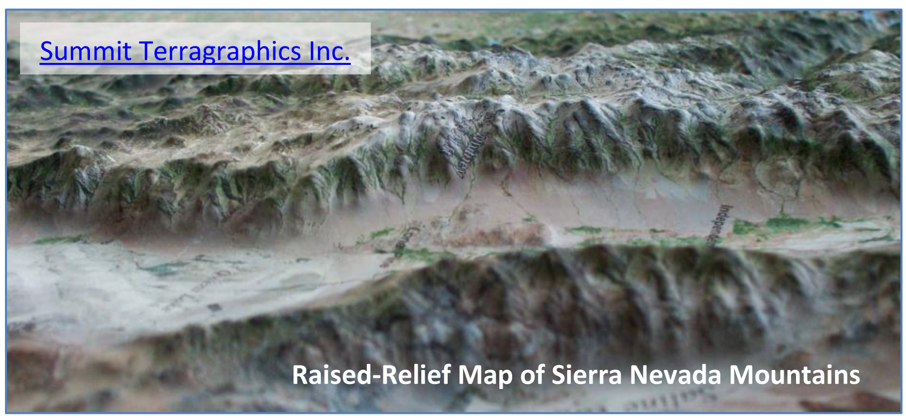
- **Topographic contour lines** -- Topo contour line maps are accurate, but it can be difficult to visualize a terrain shape, especially for the novice map user. These lines of constant elevation accurately display terrain elevation and slope (by line spacing), but are confusing to most casual map users. Even for experienced map users, quickly understanding complex terrain from contour lines is not easy. Areas of steep slope can be seen (from dense line spacing), but relative and absolute elevation is difficult to understand spatially.
- **Point elevation labels** – The elevation of peaks, passes, lakes, valley floors, etc. can simply be labeled on a map. This is effective for showing terrain elevation for selected point locations, but is not effective at conveying complex slope and elevation information.
- **Color elevation coding** – Elevation can be shown by colored zones or a color gradient. Such displays do allow a quick understanding of elevation, but it can be difficult to resolve precise elevation and slope. The human eye doesn't naturally associate elevation with a false color. These maps can be more effective if logical and natural colors are used for elevation (green for lowlands, brown for mid elevation, and white or gray for peaks).
- **Shaded relief** – Shaded-relief maps have become very good at illustrating slope, and the position of peaks and ridgelines, but the relative and absolute elevation information is difficult of convey.

Of course these four mapping techniques can be combined to make a composite elevation map display. However, this may lead to a cluttered and confusing map with excessive color, shades, and lines. For quickly interpreting complex terrain shape, 2D maps often fall short.

Very recently, the representation of terrain shape using 3D digital modeling and visualization technology has been very popular and widespread. Google Earth, Bing Maps, and other applications are well-known examples. The ability for the casual web map user to pan, zoom, and adjust perspective has proven to be a very powerful tool. Few people today haven't been exposed to the value of these 3D web mapping and terrain visualization applications. The only drawbacks to this approach are that it is tied to a computer or mobile device (which, or course, is also its strength) and the limitations of digital displays.

Google Earth™ Map

Sometimes, however, map users just don't want to use a digital display, and prefer a good old-fashioned printed map or wall map for understanding challenging terrain areas. Wall or table-top maps, in particular, are still desired as much for their artistic value, as for their functional use. In this case, raised-relief maps are the clear solution. Raised-relief maps take any normal 2D map a step farther, by physically modeling the third dimension (elevation). The resulting 3D earth model has a key advantage in that the average user can very quickly and completely understand the terrain shape and features, and how that terrain shape relates to other details of the map (roads, trails, airspace, borders,…). No complexity is introduced by having to decipher contour liners or elevation color coding. It's like looking down on the earth from high above with enhanced stereoscopic vision. Furthermore, by not introducing contour lines, false shading, or color coding, the map is uncluttered and the printed map information is easier to see and relate to the terrain. This is especially true when looking at high-resolution satellite imagery, which combines very well with the raised-relief 3D approach to create impressive earth models.



Raised-Relief Map of Sierra Nevada Mountains

A Brief History of Raised-Relief Maps

Raised-relief map and earth/terrain models have been used for a long, long time – dating back hundreds and even thousands of years. The early hand-made maps were constructed of whatever materials were available and based on the local geographic knowledge of the map craftsman.

Accurate raised-relief maps and models first started appearing 400 to500 years ago in the form of models made from wax and other formable materials, often driven by military or defense applications. As materials and manufacturing processes improved, raised-relief maps became reproducible and portable. During World War II, the US Defense Department had rubber raised-relief maps made of the Normandy Beaches in preparation for the D-Day amphibious assault. These 47" x 47" rubber raised-relief maps had the surface features precisely painted showing the roads, houses, hedgerows, forests, and fields. The maps were rolled up and carried on board the invasion ships by intelligence officers for briefing the troops.

After WWII, the US Defense Department funded significant other production of raised-relief maps for strategic and tactical planning and training. This included the production of thermoformed plastic maps of many regions of both the US and the world. The Soviet Union produced similar raised-relief maps of areas of interest. Today, the defense interest has largely evolved into digital-graphic display of 3D map information, but some raised-relief models are still produced and used.

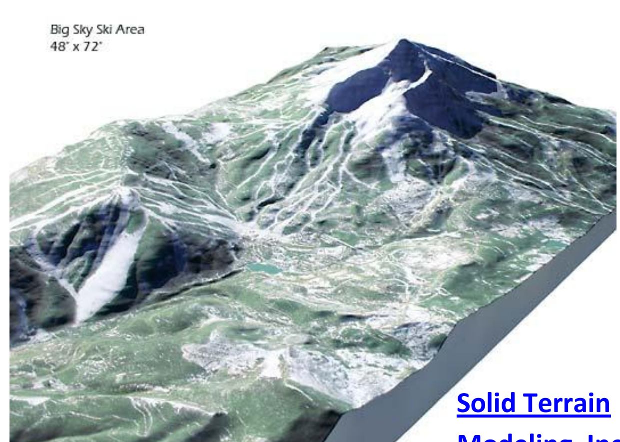
Making Raised-Relief Maps by Direct Model Building

Building 3D physical earth models is now done using one of two common methods: direct model-building or vacuum-thermoforming of printed sheets.

Direct earth-model building was done years ago by manually cutting contour line sheets, positioning and stacking them together, and then topping the model with clay or plaster and hand-painting the surface details – clearly a very labor intensive technique with limited resolution and accuracy. Today, much more accurate earth models and 3D maps can be built using either of two digital direct-build manufacturing methods:

- **Computer-Controlled Milling** (a removal process). With this method, a 3D terrain model is constructed by milling or routing the terrain shape from a block of foam, plastic, or wood, and then printing the map data on the modeled terrain surface. Large one-off 3D maps are formed this way, often for use as public displays. National park visitor centers and museums often have these large 3D maps in their lobbies or other display areas. The large size makes for an impressive raised-relief map.

Milled-Printed Raised-Relief Map



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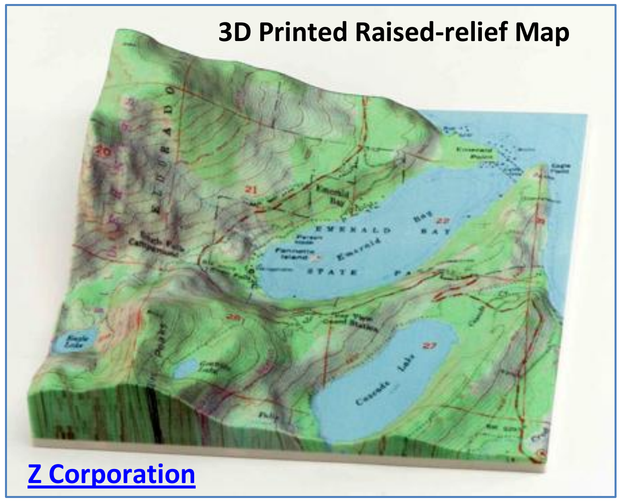
- **3D Printing or Rapid Prototyping** (a constructive/additive process). This is a new technology that has evolved out of the rapid prototyping (RP) industry. With RP machines, earth models can be built by replicating a digital solid model or terrain surface. 3D printing, in particular, has been used to create full-color 3D earth models, incorporating satellite earth imagery or illustrated maps draped over the terrain surface. To build a large earth model map using this approach, the model must be divided into individual tiles, built separately, and then reassembled into the full terrain model/map.



3D Printed Raised-relief Map

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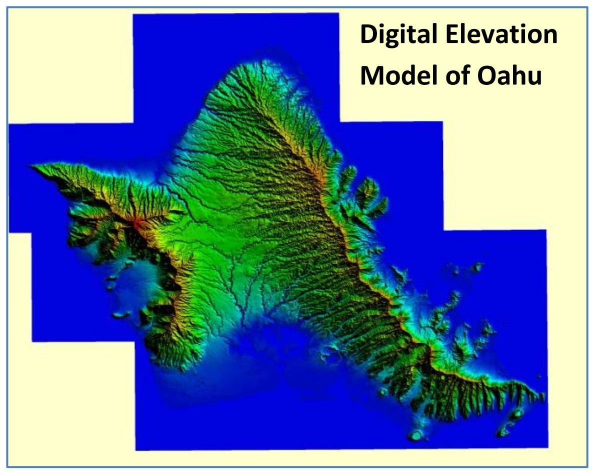
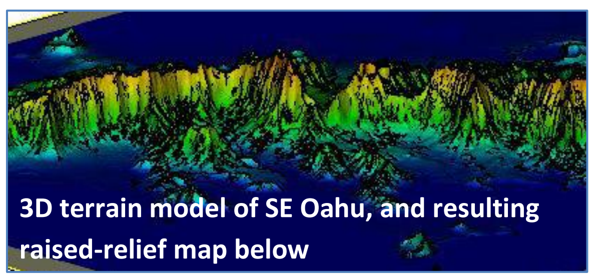
Both methods above are effective for creating large 3D earth models.

Making Raised-Relief maps by Vacuum-Thermoforming Plastic Sheets

For creating lower cost, lightweight, and easily portable raised-relief maps, vacuum thermoforming of printed plastic sheets is very cost effective, and now is very accurate and precise. Using this technique, a 2D map is first printed on a rigid thin sheet of plastic (usually vinyl). The sheet can be printed with any map image (road map, physical map, thematic map, satellite image map, aviation chart,…). The sheet is then placed in a vacuum thermoforming machine and carefully registered above a 3D terrain mold and then heated to the point of being formable. Vacuum is applied through and around the terrain mold, resulting in the hot plastic sheet being pressed down by atmospheric pressure against the 3D mold surface. The sheet quickly cools and retains the shape of the terrain mold. Compressed air is used to separate the sheet from the mold and the molding process is then repeated, allowing for rapid and cost-effective production of multiple raised-relief maps.



Digital Elevation Model of Oahu



3D terrain model of SE Oahu, and resulting raised-relief map below

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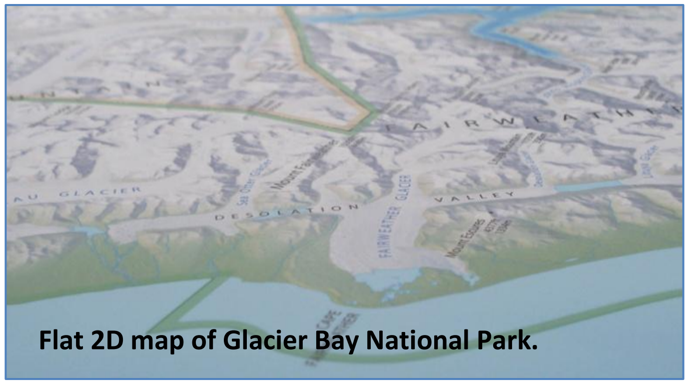
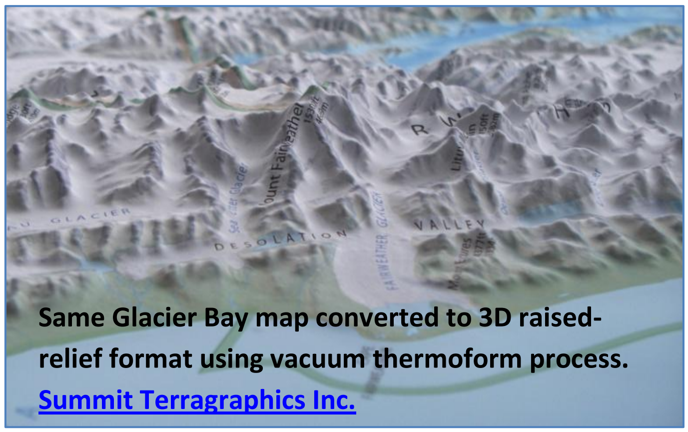
Creating an accurate terrain mold is the key challenge of thermoformed raised-relief maps. The quality of the finished product is only as good as the precision and accuracy of the terrain mold and the process control of the molding operation. Fortunately, today digital elevation models are widely available for much of the world. (The USGS National Map Seamless Data Server is a convenient source for elevation data sets.)

Once the digital elevation model dataset is in hand, several methods can be used to create the terrain molds. The traditional approach is to computer-control-mill the terrain surface from a block of metal, plastic, or wood. This is effective but is a long and tedious machining operation. The second tooling method is to use a Rapid Prototyping machine (the same technology as described above for the Direct-Build technique) to build up the physical tool to match a digital elevation solid model. The RP approach is very accurate, allowing terrain model resolution and tolerance to be near .010" in all three dimensions.



Flat 2D map of Glacier Bay National Park.



Same Glacier Bay map converted to 3D raised-relief format using vacuum thermoform process. [Summit Terragraphics Inc.]

When a high-resolution digital printing process is combined with a precision terrain mold and a tightly controlled molding process, the thermoformed raised-relief maps are extremely accurate, and at the same time relatively low cost. The process allows any orthographic 2D map to be converted to a true 3D raised-relief product, giving the end user a much easier and faster way to understand terrain shape, elevation, and slope.

Summary

Many map users value having an easy and quick way to understand terrain elevation and slope. Modern digital computer/web approaches (Google Earth and others) are powerful and widely accepted. But sometimes a using a computer/digital display is not possible or desired. In this case, raised-relief maps are a clearly advantageous way to present terrain elevation/slope information. Both direct-build and vacuum-thermoformed raised-relief maps are available today for a variety of map applications. And when generated using accurate digital elevation models, raised-relief maps are extremely accurate and precise.