Designing 3D Terrain Maps

Tom PATTERSON
US National Park Service

Abstract. Nowadays, despite the ubiquity of automated 3D maps provided by technology companies such as Apple and Google, knowledge about designing 3D terrain maps is still generally lacking in the cartographic community. My talk will provide practical advice about designing obliquely-viewed 3D terrain maps for use on static computer displays or in print. The emphasis is on small-scale views of mountainous landscapes without buildings and other cultural minutiae. I will start with cautionary advice on whether to attempt 3D terrain mapping, which requires considerably more time and expense than planimetric mapping of the same area. The availability of good data, terrain that is suitable for 3D depiction, and the map purpose are all factors in this decision. Next, I will discuss scene setup. Once a digital elevation model is loaded in your 3D software, adjusting the virtual camera for direction of view, pitch, and lens focal length are key considerations. Another critical decision is whether the 3D map should include a horizon and sky, elements that take up precious space on the page and that may not be necessary. Illumination must take into account the dominant terrain structures and whether the terrain is draped with imagery containing embedded cast shadows. The amount of vertical exaggeration affects how dramatic the terrain will appear, and realistic. I will wrap up with a discussion of graphic embellishments to 3D terrain maps, all of which are performed in Adobe Photoshop. Topics include background haze and foreground shadows, sun glints on water surfaces, clouds, and horizon curvature.

Keywords: *3D, terrain, scene setup, camera settings, illumination, horizon and sky, sun glints*

1 Introduction

This article offers ideas and advice about creating obliquely viewed 3D terrain maps for use on static computer displays or as hard-copy output. I emphasize small-scale views of wide geographic areas (i.e. maps) without buildings and other minutiae of the cultural landscape. The basis for my advice is over three decades of hands-on experience making these kinds of maps.

I make custom 3D maps for a variety of media types ranging from printed brochures to trailhead signs to visitor center exhibits. No two of my maps look alike. Nor do I use standardized production techniques; audience needs vary widely from project to project and the availability of good geospatial data is hit or miss. Making 3D terrain maps requires flexibility and opportunism. Accordingly, my workflow entails a general approach rather than prescriptive procedures.

You will need multiple applications to make professional-quality 3D terrain maps. My indispensable software includes Natural Scene Designer Pro for rendering 3D scenes and Adobe Photoshop for raster compositing (and much more). I also use Adobe Illustrator in conjunction with the MAPublisher GIS plugin for vector cartography, and the Geographic Imager GIS plugin for Adobe Photoshop. Taken together these applications are expensive, but with them I can efficiently produce most types of 3D terrain maps. Although your preferred software may be different than mine, the ideas and advice that follow should be generally applicable to your workflow.

What follows are five of the ten tips for designing 3D terrain maps discussed during my keynote at the Hvar workshop. Space limitations prohibit including all of them here. However, the remaining tips are online at http://shadedrelief.com/3D_Terrain_Maps/.

2 Should You Make a 3D Map?

There are legitimate reasons for making 3D terrain maps: they look interesting, attracting the attention of readers. Oblique viewed terrain that is three-dimensional is easier for general audiences to understand compared to conventional shaded relief and certainly topographic maps packed with contour lines. They show the vertical dimension of a landscape in addition to the x, y spatial dimension (Figure 1). And it is also immensely satisfying to make 3D terrain maps.

However, despite offering real advantages, for most projects you should NOT go to the trouble of making a 3D map. These are prohibiting factors to consider:

Time – Producing a 3D terrain map takes from two to three times as long as a conventional map. You must first compile a 2D base map before rendering the elements in 3D. There are a great many design variables to account for: For example, will the terrain look better with slightly more vertical exaggeration? Designing 3D terrain maps is addictive. You can experiment for hours.

Cost – Directly related to the above.

Data – Mapping is not possible without essential data, such as DEMs and aerial imagery. Other data challenges include low resolution, poor quality, and compatibility—especially maps that straddle international borders. You can spend large amounts of time trying to enhance poor quality data and still end up with a map that looks bad.

Geography – Some terrain is not suited for 3D depiction. Such as when important features stay hidden regardless of the viewing direction. Or when the focus of the map is a boring area dominated by adjacent terrain that is more interesting. For example, on a 3D terrain map of the Coconino Plateau, Arizona, most of us would instead look at nearby Grand Canyon.

Purpose/audience – Serious backcountry users need topographic maps with contour lines (although 3D maps are useful for trip planning). If terrain is not an

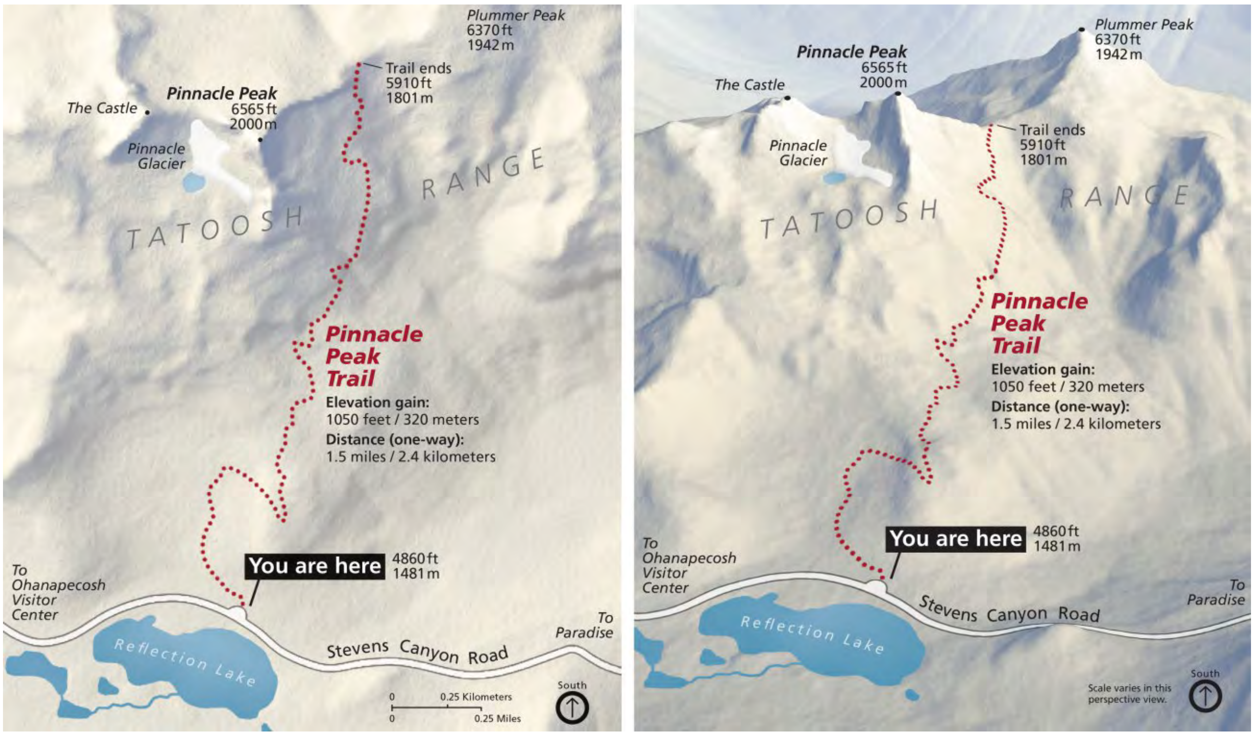

Figure 1: A 2D map (left) and 3D map (right) of Pinnacle Peak, Mount Rainier National Park, Washington, compared.

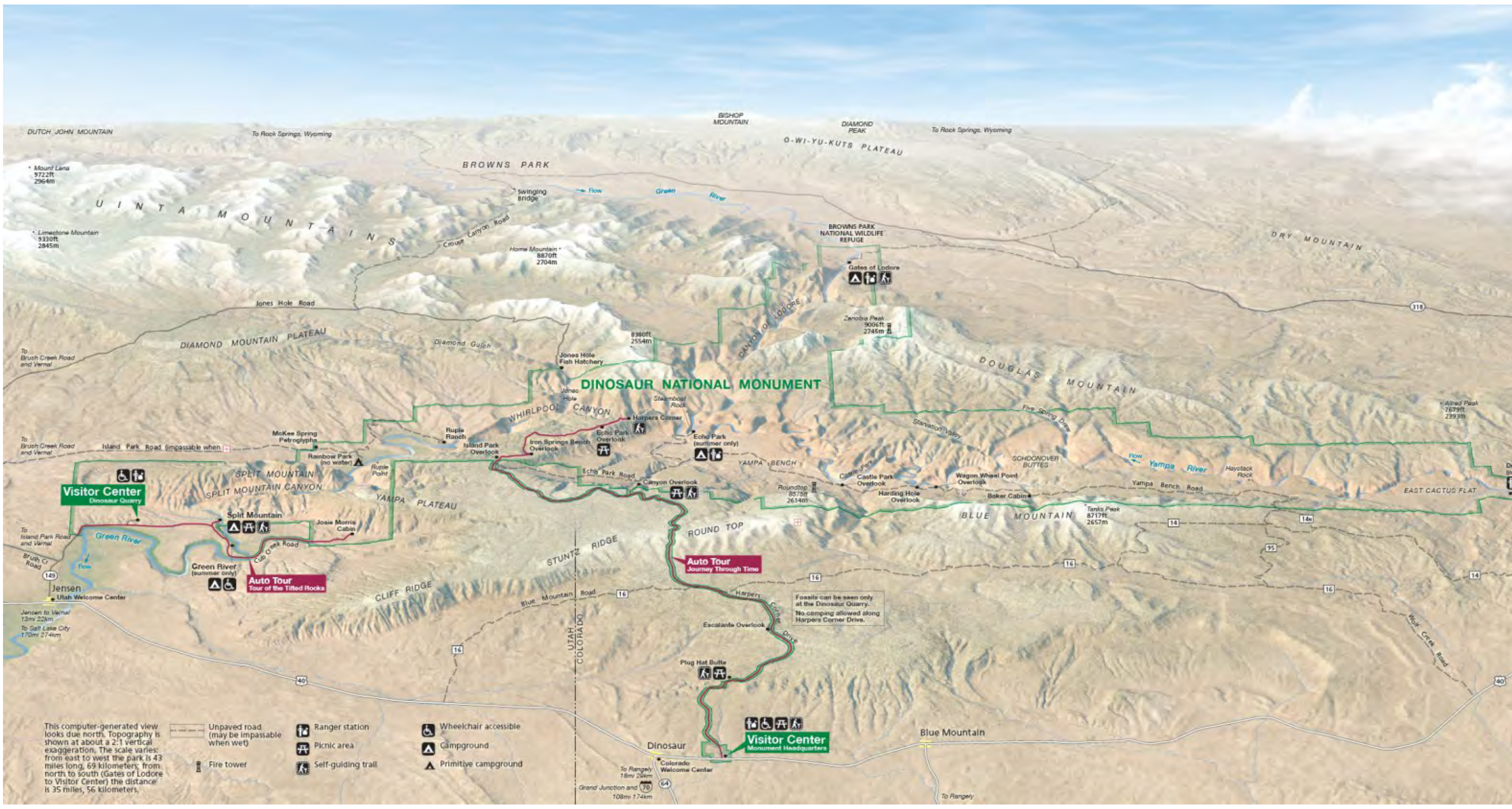

Figure 2: An inappropriate 3D map of Dinosaur National Monument, Utah and Colorado.

essential part of your map's message, going to the trouble of making a 3D map makes little sense.

Georeferencing – 3D terrain maps are pictorial products without georeferencing. On a mobile device there is no pulsing blue dot showing where you are.

Point of view – 3D terrain maps have a single point of view. Unlike a conventional map, it is not possible to navigate with a 3D map rotated 180 degrees. The mountains will appear upside down.

Foreshortening – The vertical dimension (from top to bottom on a page) of a 3D map is shorter than a conventional map of the same area because of the oblique viewing angle. The viewable area compresses. This is bad if your map must show important features in the background, or give equal emphasis to foreground and background features. Also, if your 3D terrain map must go in a layout with a portrait format, the fit can be awkward.

In the 1990s, with newfound enthusiasm for 3D digital techniques, I made a map of Dinosaur National Monument that I would come to regret (Figure 2). Among the problems: most of the map foreground was non-park land. In the middle ground, foreshortening compressed the already narrow main park area on the north-south (vertical) axis. As a consequence, the Green and Yampa rivers are mostly obscured in their deep canyons. Lastly, the sky and clouds devote too much precious map real estate to what is essentially a decorative element. Two years later for a routine reprint, I replaced the 3D map of Dinosaur National Monument with a more functional, albeit less interesting, 2D map. Lesson learned: I now wait for the right 3D mapping project to come along.

Tip 1 – Camera Direction

Selecting a direction of view is your first decision when setting up a 3D scene. All factors being equal, I prefer a camera direction looking from south to north for compatibility with conventional maps that usually are north oriented. In general, the smaller the map scale, and the less familiar the place, the more reason for selecting a north looking view. For example, many of us would not recognize, say, Ethiopia in a view looking south, but we *might* have a chance if the view looked north.

Staying on the subject of small-scale maps, rotating a scene by only 10, 20, or 30 degrees from true north (to either the east or west) can bring interest to a scene while still maintaining geographic familiarity. You often see maps in *National Geographic* magazine that do

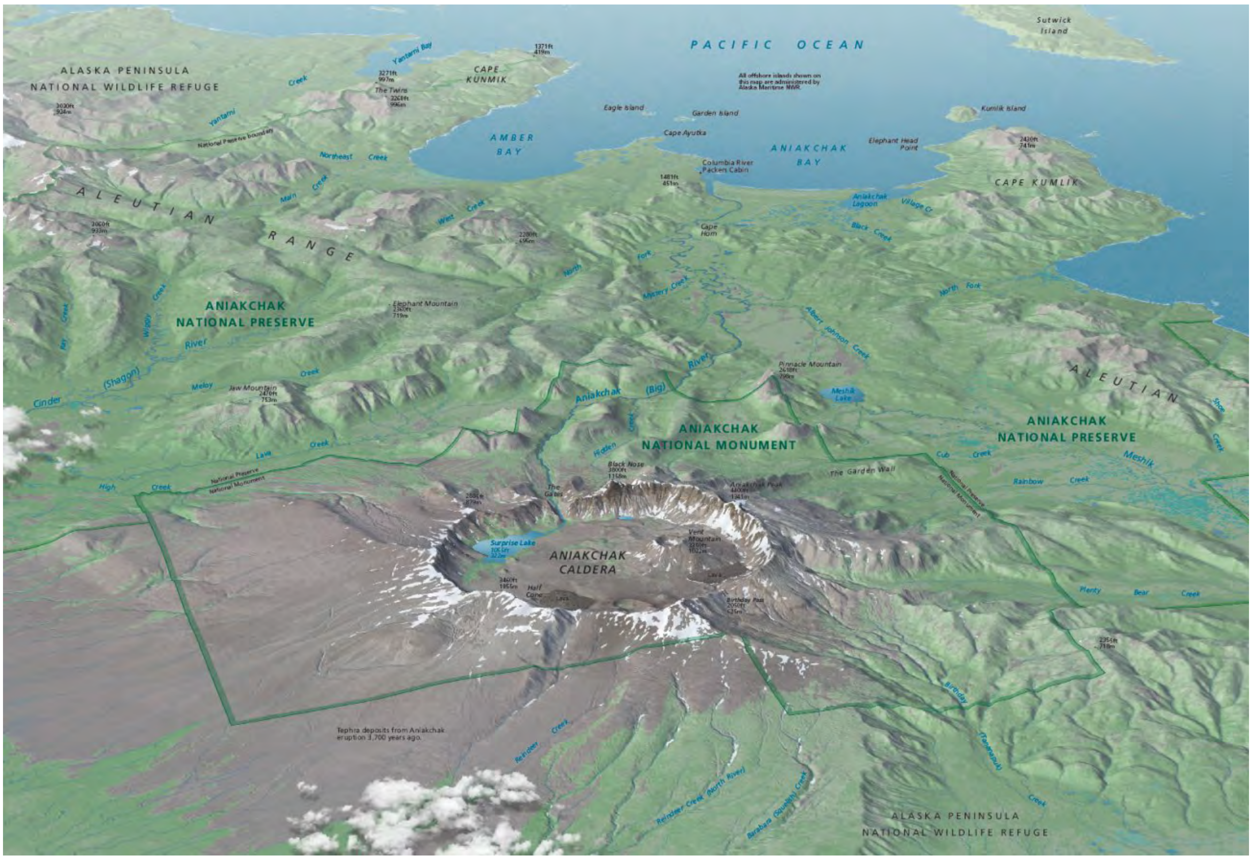

Figure 3: Aniakchak National Monument, Alaska, looking east-southeast. Although artists avoid centering the subject in a painting, it is accepted practice on 3D terrain maps.

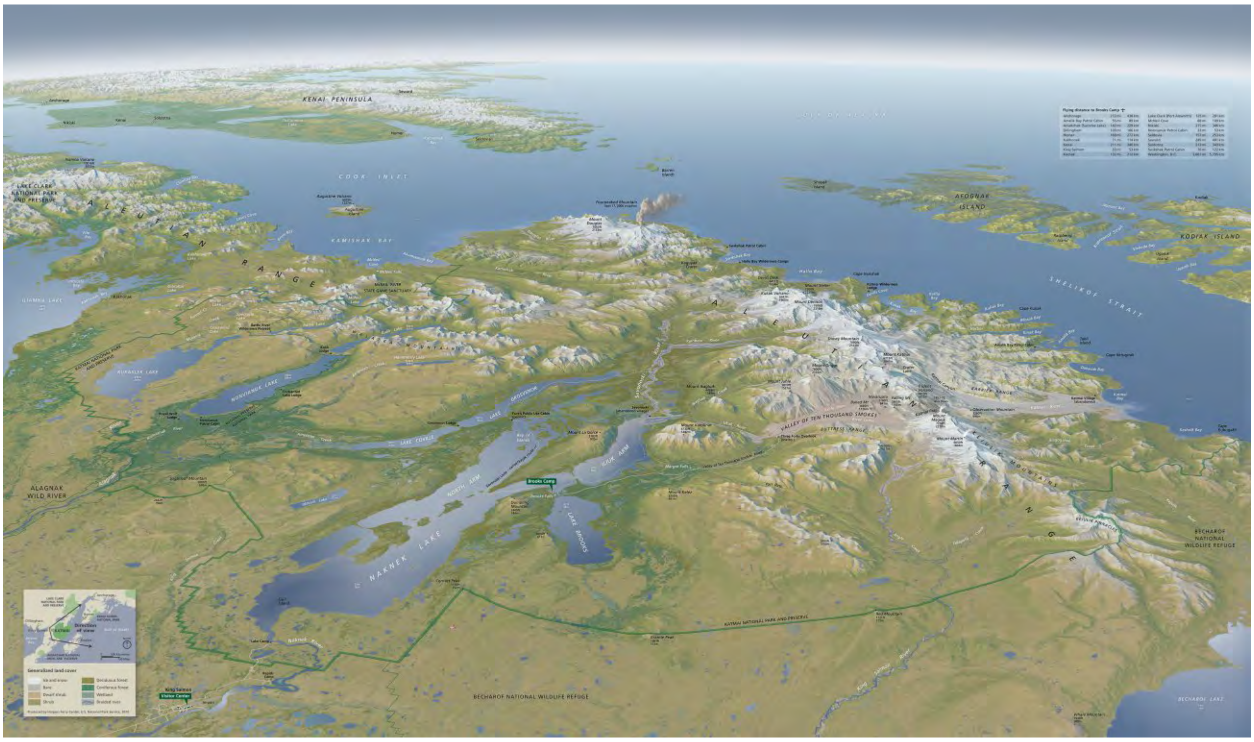

Figure 4: Katmai National Park, Alaska, looking southeast.

Figure 5: Pinnacle Peak Trail, Mount Rainier National Park, Washington.

this very successfully. Rotating the direction of view from north can give you more options when positioning a 3D map in a graphical layout, especially for geographic areas with an unusual or unbalanced shape.

Map focus is a key consideration when choosing a direction. From bottom to top on the page, 3D terrain maps have a foreground, middle ground, and background. Try to place the most important information in the upper foreground (do not crowd the bottom of the page) and middle ground. The background is for geographic context and graphic balance.

Unique terrain characteristics are a valid reason for selecting a camera direction other than north. On the map of Aniakchak National Monument (Figure 3), a southeast-looking view reveals the Aniakchak River flowing through a breach in the caldera wall to the Pacific, a route taken by river rafters, among the few visitors to this remote park.

Graphical composition is another reason for choosing a non-north view. For example, a northeast-looking view of Katmai National Park (Figure 4) takes advantage of the parallel lake and ocean coasts that are perpendicularly aligned, intersecting at an implied "X" near the center of the scene. The lake alignment is further implied by an erupting volcano plume that points through a gap in the coast toward the empty Pacific. This view direction also conveniently provided space in the lower left and upper right corners for an inset map and distance chart.

Large-scale 3D terrain maps used for site navigation are best served with a camera direction that looks in the direction of travel. The National Park Service employs site-specific views for trailhead maps. The map, sign on the ground, and person reading it is oriented in the same direction as the trail (Figure 5). Tightly cropping the map focuses attention on only those geographic features relevant to hikers.

Avoid a direction of view that looks down slope on a terrain. For example, the view from the summit of Pinnacle Peak to the trailhead at Reflection Lake, would not work as well as the opposite view looking up (Figure 5). In downhill views, because the terrain would fall away from the reader, foreshortening is severe. This limits the mappable area. Downhill views also can be disorienting. When it comes to terrain, most people are accustomed to looking up.

Most satellite images and aerial photographs are taken in mid-morning (there are fewer clouds and less haze at that hour), which places shadows on northwest-facing slopes in the northern hemisphere. On 3D terrain maps draped with satellite images, the embedded shadows interfere with views that look from north to south—slopes facing the reader will be dark

Figure 6: A 15-meter Landsat 8 image draped on a 30-meter DEM of Crater Lake, Oregon.

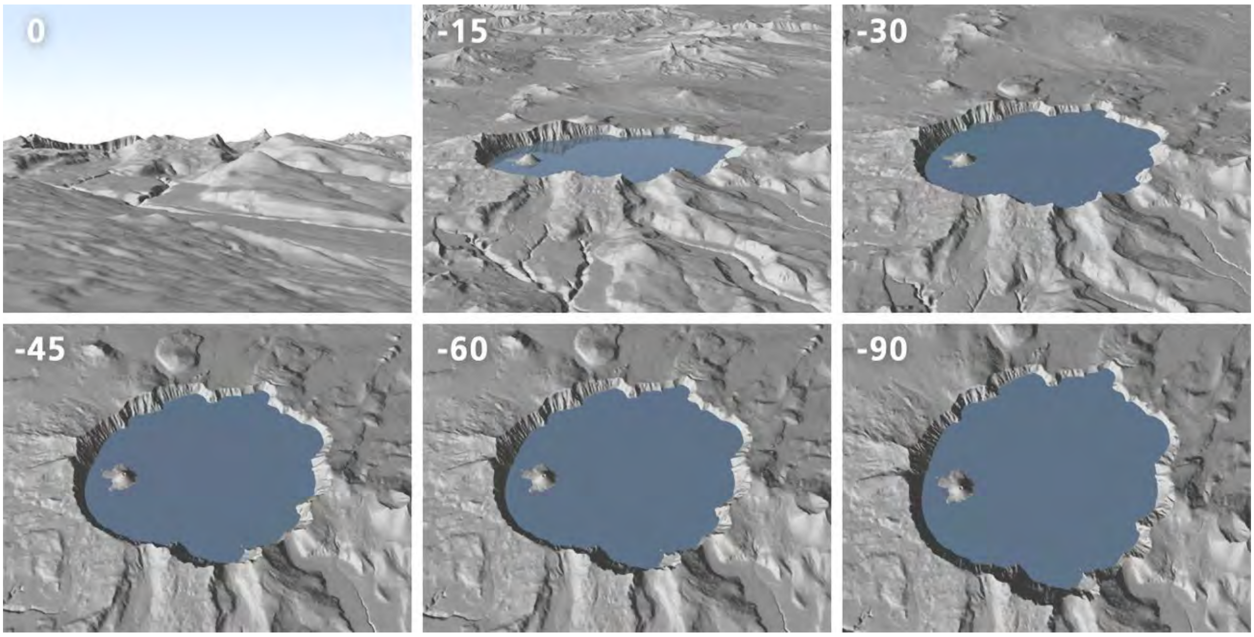

Figure 7: Camera pitch study, Crater Lake, Oregon. Shallow angles are where the action is. Changing the pitch from -15° to -30° has more noticeable influence on the view than from -60° to -90°.

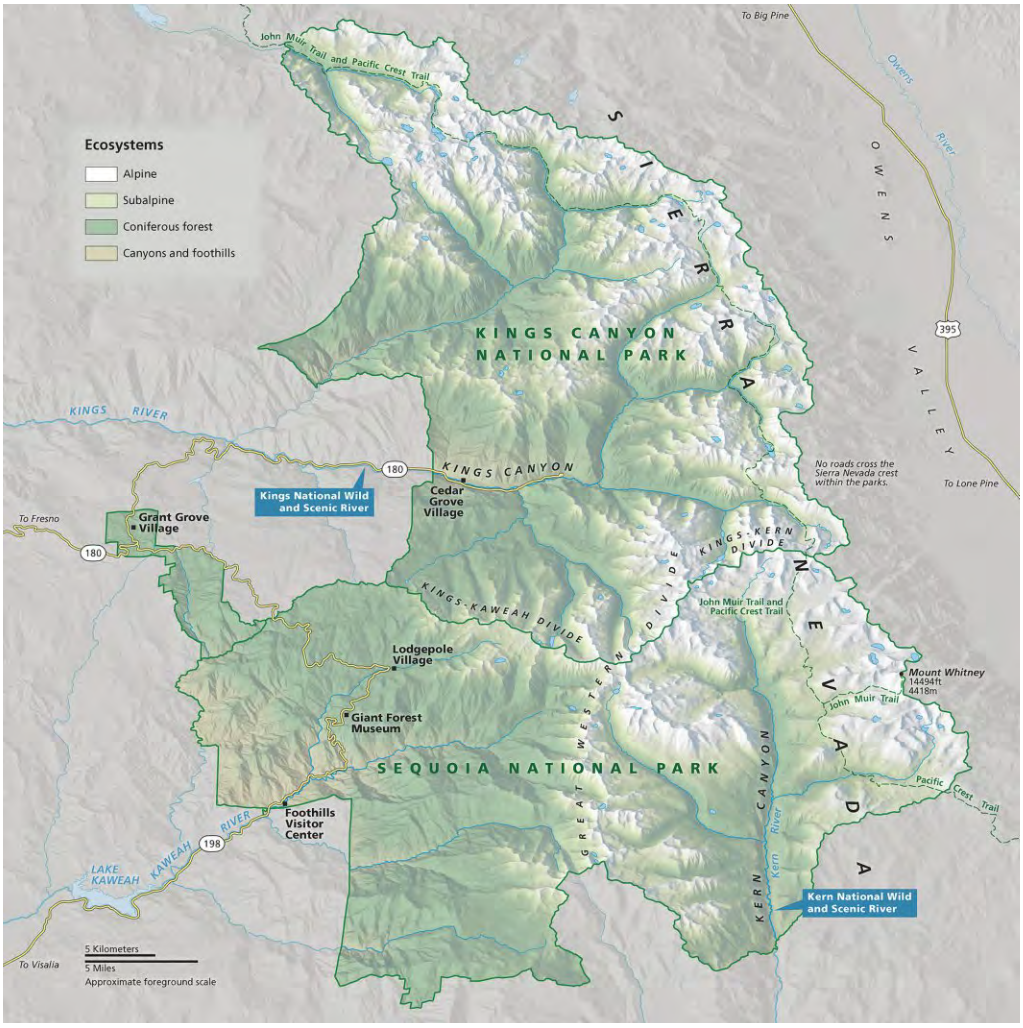

Figure 8: A high oblique view of Sequoia and Kings Canyon National Parks, California, with the camera pitch set at -46°.

and lack detail (Figure 6, top). You will instead have to use a view that looks generally from south to north (Figure 6, bottom).

Tip 2 – Camera Pitch

Viewing a place at an oblique angle from above is what fascinates us most about 3D terrain maps. In Natural Scene Designer Pro, *Pitch* controls the downward tilt of the virtual camera used to view the terrain (Figure 7). At 0° pitch the camera is horizontal. With this setting and from a low altitude, the rendered scene would look similar to what a person sees while standing on the ground. At -90° pitch the camera is vertical. With this setting and from a high altitude, the rendered scene would look indistinguishable from a conventional map. To make a 3D terrain map, the trick is finding an ideal pitch setting somewhere between these extremes.

The choice is between dramatic terrain at shallower pitches and more map-like scenes at steeper pitches. As a cartographer, my first priority is to clearly show spatial relationships on the terrain surface. At the same time, I strive to create a scene that presents the terrain with considerable drama. Increasing the terrain vertical exaggeration can compensate somewhat for steeper pitches that I prefer. Of the seven 3D terrain maps that I am currently working on, the average pitch is -37°.

Terrain characteristics often dictate camera pitch. The map of Sequoia and Kings Canyon National Parks (Figure 8) uses a steep pitch to show Kings River and Route 180 deep within Kings Canyon. At shallower pitches the river would be completely hidden. The narrowing shape of the parks from south to north was another factor. At shallower pitches the northern apex would be very far away.

The map of Maui, Hawaii (Figure 9), employs a shallow camera pitch to emphasize Haleakala (the shield volcano in the foreground) that otherwise would look inconsequential because of its gradual slopes. The protruding West Maui Mountains in the background obscure parts of the island unimportant to the map's purpose. By contrast, in the foreground, Haleakala's eroded valleys slope from summit to sea, tilting toward the reader.

Camera pitch causes foreshortening, the compression you see from foreground to background in a scene, which is sometimes useful for layout purposes. Take

Figure 9: A low oblique view of Maui, Hawaii, with the camera pitch set at -12°, which is low enough to show the horizon.

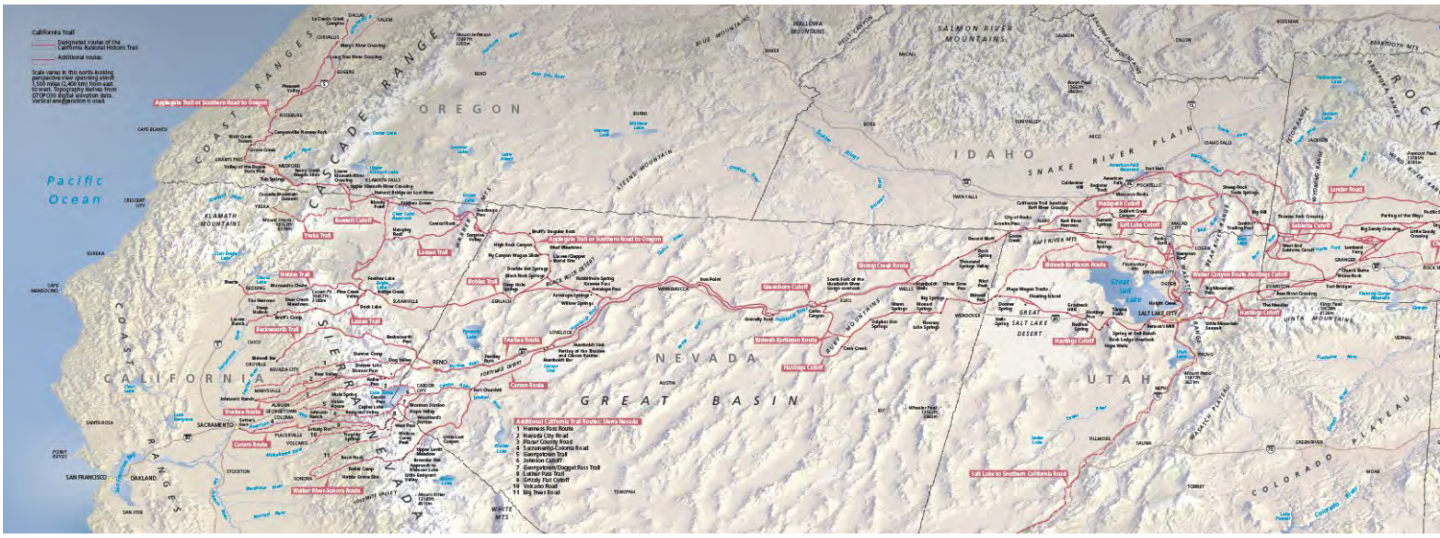

Figure 10: The California Trail.

for example the California Trail map (Figure 10). This primarily east-west trail has western branches going as far north as Salem, Oregon, and as far south as the central Sierra Nevada. Fitting the map on an A12 sheet of paper was only possible by rendering it as a 3D oblique view, which lessened the height.

Tip 3 – Camera Lens (Focal Length)

Changing this often-overlooked camera setting—in Natural Scene Designer Pro, the tendency is to stay with the default 35-millimeter lens—will greatly alter the appearance of your final map. The illustration below (Figure 11) shows a sampling of the choices available, from a very wide-angle 20-millimeter lens to a very telephoto 200-millimeter lens. Wide-angle lenses result in scenes with considerable perspective convergence; the foreground is magnified and the background pinches toward an unseen vanishing point. By contrast, telephoto lenses have less perspective convergence; the foreground and background are similar in size.

I prefer telephoto lenses to wide-angle lenses for general mapmaking. I start by setting up a scene with a 70-millimeter lens and then change the focal length as needed. Besides depicting the foreground and background more equal in size, telephoto lenses are better suited to making maps that must fit within a rectangular formatted shape (Figures 12 and 13).

Despite my preference for slightly telephoto 3D terrain maps, they are not problem free. The lack of optical perspective can result in boring scenes with little foreground to background depth. To counteract this, I will add background haze, foreground shadows, valley fog, and clouds.

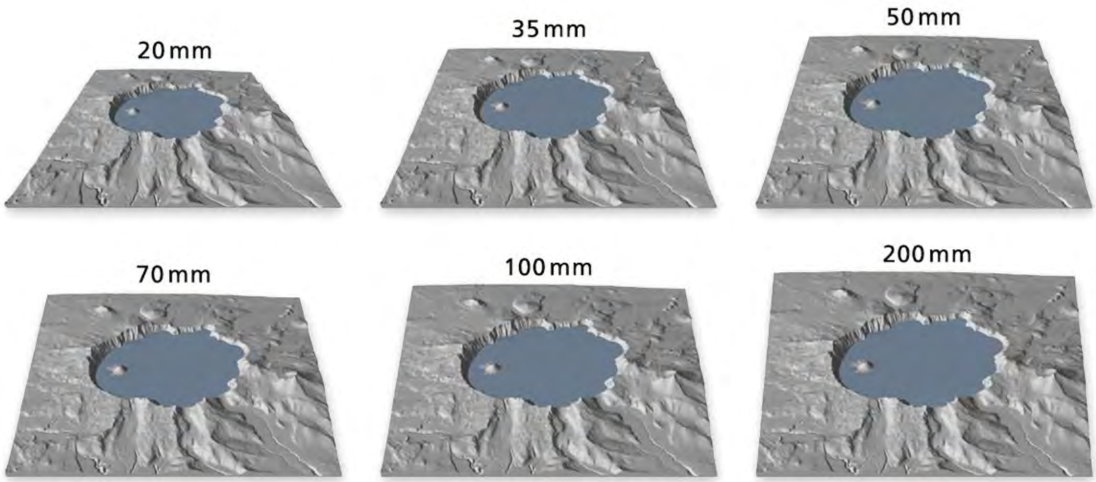

Figure 11: Camera lens study, Crater Lake, Oregon. The camera pitch is a constant -35° for all scenes.

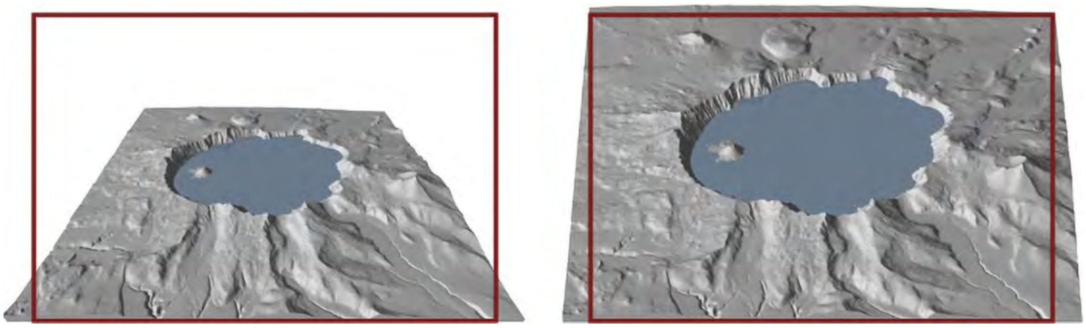

Figure 12: Map in a box: Compared to a wide-angle lens (left), the same data rendered with a telephoto lens (right) completely fills the red bounding box.

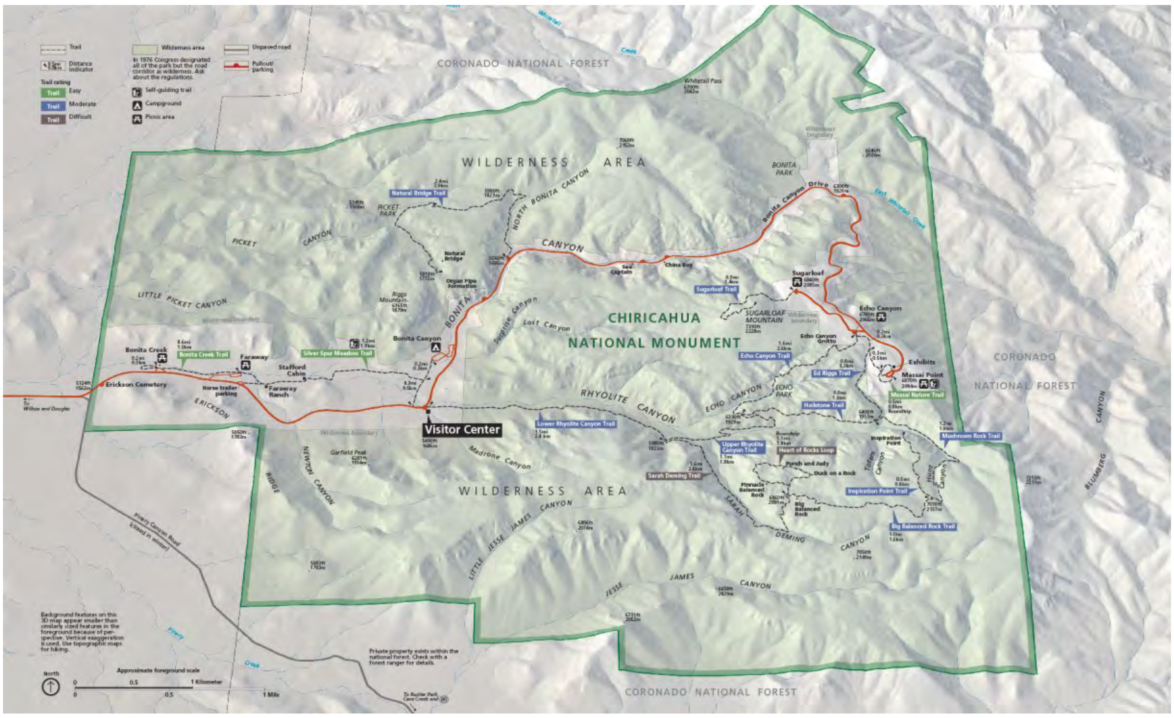

Figure 13: Chiricahua National Monument, Arizona, rendered with a telephoto camera lens and steep camera pitch. With these settings the distinctive park shape remains recognizable on the up-and-down terrain.

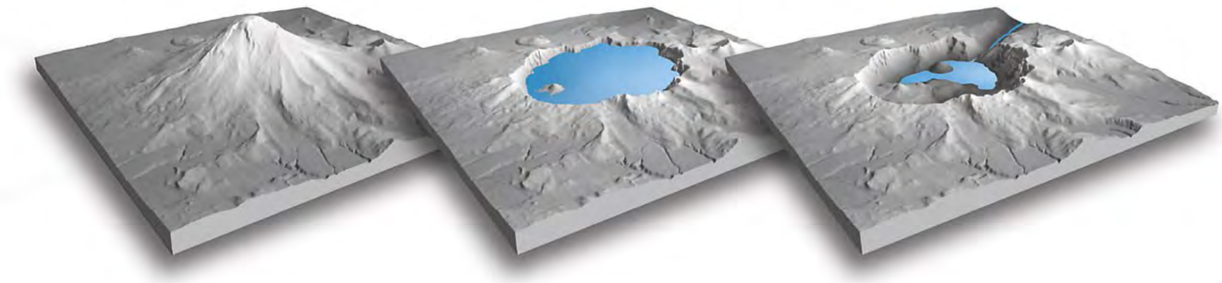

Figure 14: Crater Lake geology: (left) Ancient Mt. Mazama, a stratovolcano. (Middle) The lake today. (Right) Possible future breaching of the caldera wall.

Figure 15: The Grand Canyon of the Yellowstone by Thomas Moran. Source: Smithsonian American Art Museum.

I tend to use wide-angle-lenses for making geology block diagrams and illustrative maps with few labels and lines. For example, the Crater Lake block diagrams (Figure 14) looked more dynamic—as are geologic processes—when rendered with a wide-angle lens. Using a partial side view adds to the visual interest.

Tip 4 – Background Haze and Foreground Shadow

Thomas Moran's inspirational "The Grand Canyon of the Yellowstone" (Figure 15) was on display at the US Capitol in 1872, the same year that Congress established Yellowstone National Park. His art is relevant to 3D terrain mapping for its treatment of visual depth with light and shadows. The dark foreground tones guide your eyes to the Grand Canyon of the Yellowstone depicted with luminous colors in the middle ground. Your eyes then go to Lower Yellowstone Falls, partially obscured by mist, and eventually find three steaming geysers in the hazy background.

It is easy to apply Moran's classic painting techniques—background haze and foreground shadows—to your 3D scenes. To create background haze, first render a distance mask in Natural Scene Designer Pro, which you will find it as one of the options in the "Render" menu. The image below (Figure 16) is a distance render for a random location in North Cascades National Park. Areas closest to the virtual camera are dark and the tones get progressively lighter with distance.

The next steps are in Photoshop. Create a new layer above the terrain to which you want to apply haze, fill

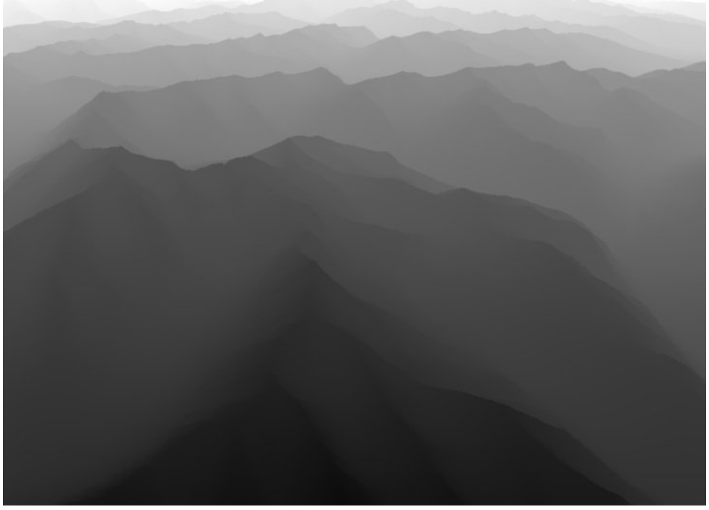

Figure 16: A distance mask of North Cascades National Park, Washington.

the layer with white or blue-white, add a layer mask, and paste the distance mask into the layer mask. Decrease the opacity of the haze layer to lessen the amount of haze. You can optionally apply a curves adjustment to the distance mask to precisely control where the haze starts in your scene.

Adding a foreground shadow works much the same way. In Photoshop, create another layer on top of your terrain, fill it with black or some other dark color, and add a layer mask. Then use the gradient tool in the layer mask to modulate the shadow intensity (tip: hold down the shift key to constrain the gradient to a vertical alignment). For most scenes, just a little darkening is all that you will need in the immediate foreground. Vary the layer opacity to control darkness.

The illustration below (Figure 17) shows background haze and foreground added to a typical mountain scene.

Using a distance mask rendered in Natural Scene Designer Pro to create haze works best with large-scale scenes viewed from a shallow angle. Rendered distance masks, however, are unnecessary for small-scale scenes viewed from high above. Instead, place a simple gradient in a Photoshop layer mask in the same manner that you used to create the foreground shadow, such as on the Bering Land Bridge below (Figure 18).

Additional Comments

- I use background haze on all 3D terrain maps, sometimes copiously. By contrast, I use a foreground shadow less often and then only sparingly.
- Although Natural Scene Designer Pro has a haze option in the Sky settings tab, I rarely use it. The built-in Natural Scene Designer haze covers too much of the foreground in the typical scenes I create from a high oblique angle. I prefer to add haze in Photoshop, which offers precise control and the ability to edit haze at later stages of map production.
- Haze and shadow gradients can appear with banding artifacts when applied over smooth water surfaces. Adding a little noise with Photoshop to the gradients can lessen this problem.
- Haze and shadows are an excellent way to give the illusion of depth to 3D scenes created with telephoto camera lenses previously discussed here.

Tip 5 – Sun Glints on Water

Those of you who have perused other pages on this site may have noticed this: water bodies on most of the example maps have sun glints—one of my favorite devices for beautifying 3D terrain maps.

Flat tones do not exist in nature and nor should they exist on even the simplest maps. Take for example the before-and-after geologic diagram of Grand Teton National Park during the ice age (Figure 19). The flat lake without sun glints suggest that the entire scene is static.

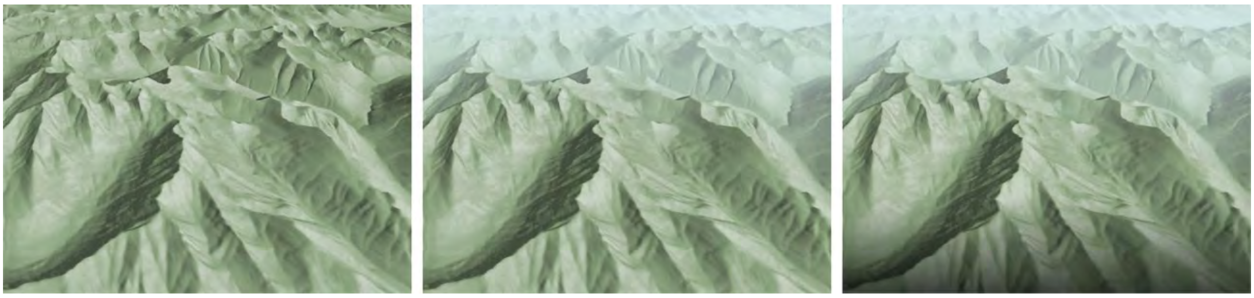

Figure 17: (left) A plain 3D terrain of North Cascades National Park, Washington. (middle) The same terrain with background haze. (right) And the terrain with a foreground shadow.

Figure 18: An unpublished draft map of Bering Land Bridge National Preserve, Alaska, with a foreground shadow and background haze made with Photoshop gradients.

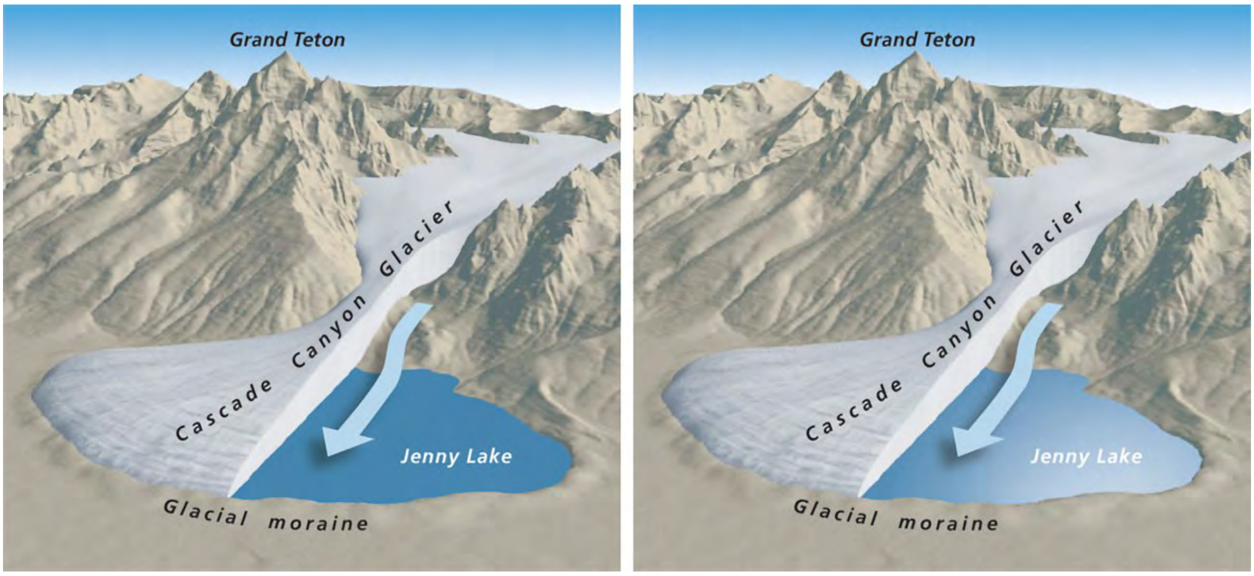

Figure 19: Jenny Lake geology diagram, Grand Teton National Park, Wyoming.

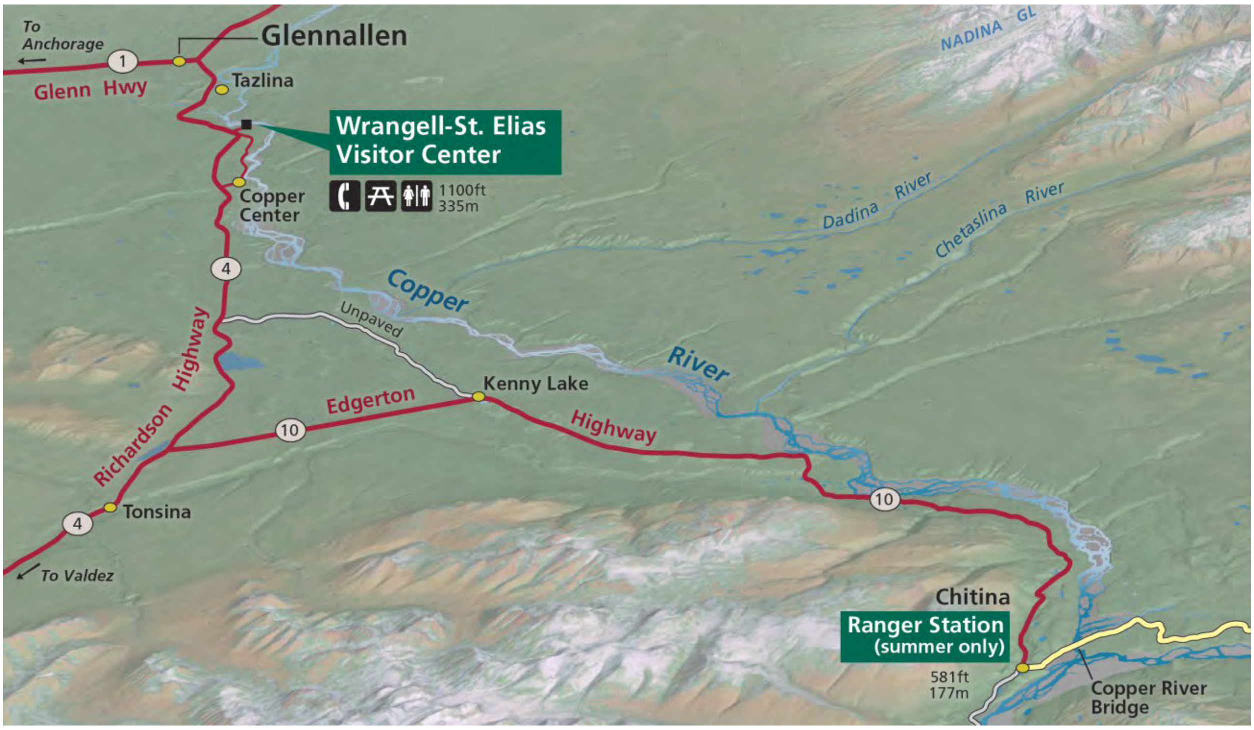

Figure 20: Wrangell-St. Elias National Park, Alaska.

But with sun glints the diagram come to life, suggesting to the reader on a subliminal level that glaciers are highly dynamic.

Procedure

Adding sun glints to water bodies could not be easier in Adobe Photoshop. First, open your 3D terrain map in Photoshop. Use the Magic Wand Tool to select water bodies. Next, create a new layer and then create a layer mask. Your selection will then become the printable area on the new layer. Select the Brush Tool and a very large, soft brush. Set the brush opacity at 10 percent. Finally, repeatedly dab on the water bodies to create the sun glints.

Comments

- If you don't like the sun glints that you initially draw, delete what is on the layer and try again. I typically have to redraw sun glints several times before I am satisfied with their size and brightness.
- There is an art to drawing sun glints on water bodies. Fewer large glints generally look better than many small glints.
- If the terrain adjacent to a water body is light, avoid drawing a sun glint there because the two will have a similar value, making the shoreline indistinct.
- Should your sun glints have banding artifacts, applying a small amount of noise to the glints will usually remove the banding (Filter/Noise/Add Noise).
- Sun glints are an excellent method for depicting flowing rivers. In the illustration below (Figure 20), sun glints suggest the continually changing course of the braided Copper River.

3 Conclusion

Designing 3D terrain maps is a complex undertaking that must take into account many variables. Because no two maps are alike, universal design solutions are often not applicable, forcing the cartographer to make decisions based primarily on the local geography, the map purpose, and their personal aesthetic preference. The tips presented here (and on http://shadedrelief.com/3D_Terrain_Maps/) provide newcomers to this field a general approach on how to start designing 3D terrain maps. Ultimately, however, designing successful 3D terrain maps also requires a large investment of time and effort.