Creating a National Geographic-Style Physical Map of the World

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Abstract

This paper examines digital techniques for producing a world physical map similar in style to the physical maps published by National Geographic. Discussed techniques include an improved bathymetry dataset of the world, the depiction of world environments with natural colors, and a new method of 3D relief presentation called plan oblique relief. The map also introduces a new pseudocylindrical world map projection. Manual manipulation of digital data was an overarching factor for all phases of map production.

1. Introduction

The physical world maps published by the National Geographic Society during the 1960s and 70s, as the manual era drew to a spectacular close, are some of the best maps of this type ever produced. Painted by artists Heinrich Berann, Tibor Tóth, and John Bonner, innovations included dramatic sea-floor topography and terrestrial environments depicted with natural colors. The resulting maps were attractive, easy to understand, and revealed the intricate natural world to readers. Attempts by digital cartographers to produce similar physical maps have been less than fully successful, however. Digital map art, although highly accurate, tends to have a mechanical appearance lacking the visual appeal of the best manual art. That National Geographic today still uses manual art for world physical maps indicates the existence of a quality gap. The techniques discussed in this paper attempt to raise the aesthetic level of physical world maps produced digitally.

The pages that follow describe the making of the "Physical Map of the World," a new map created with digital data and software, with the design inspired by classic National Geographic physical maps (Fig. 1). Creating this new map involved the synthesis of three digital products developed over several years by the author and associates. They include CleanTOPO2 world elevation data; Natural Earth II natural-color environment data; and plan oblique relief. A common element uniting these products was the necessity for significant manual intervention (using digital tools) to

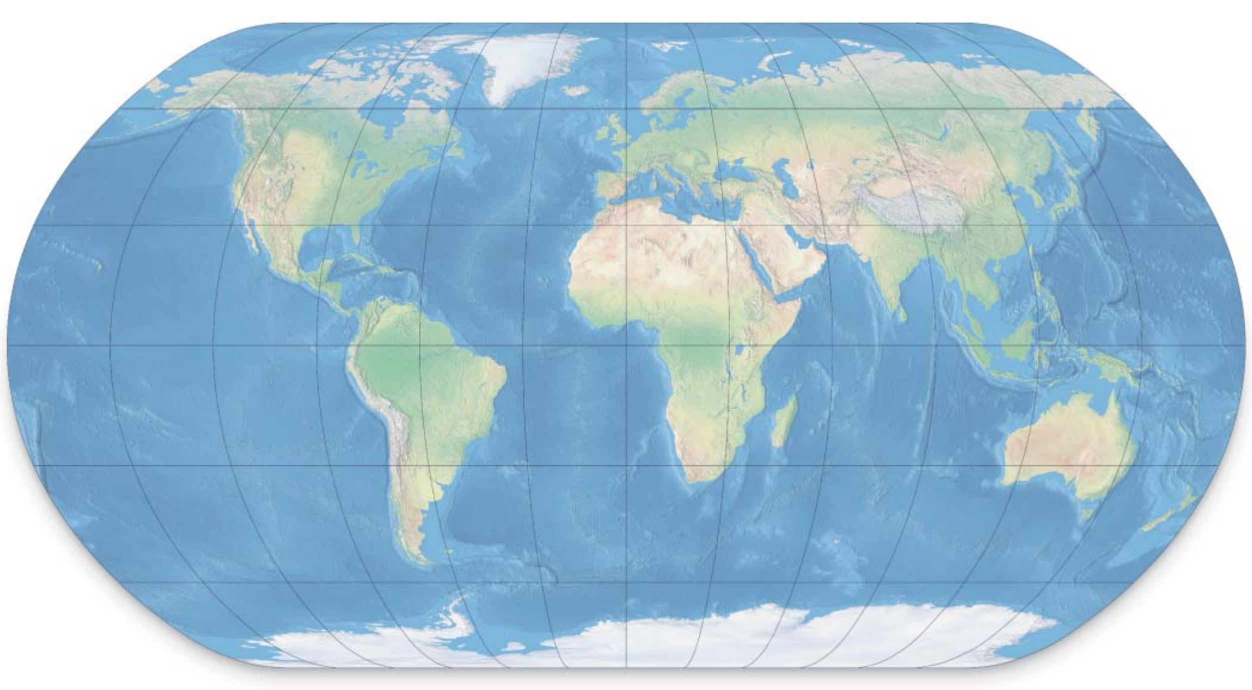

Fig. 1: Physical Map of the World without labels. The final wall map measures 91 x 160 cm and has over 3,100 labels.

create a new digital map with quality on par with older manual maps. The paper notes when and how manual intervention contributed to the mapmaking effort.

Just as the Physical Map of the World is a mix of products, much of the text that follows derives from previous articles published online and in print. The original sources appear at the beginning of each section.

2. CleanTOPO2

The following chapter derives from Patterson, T. (2006).

2.1. Preparing the world elevation dataset CleanTOPO2

To create acceptable sea floor shaded relief for the Physical Map of the World, it was first necessary to first create CleanTOPO2, a world elevation dataset with improved data quality. CleanTOPO2 is a modified and generalized version of SRTM30 Plus (NASA 2008), a public domain dataset that combines sea floor and land elevation data of the entire world. SRTM30 Plus and an earlier related dataset, ETOPO2, feature bathymetry data released by Smith and Sandwell (1997). As remarkable as this dataset is, it nevertheless contains numerous artifacts that mar map presentations. In CleanTOPO2, manual editing to the elevation data itself has removed many of the bathymetry artifacts (Fig. 2). Until the day arrives that the scientific community releases improved bathymetric data, CleanTOPO2 offers a stopgap solution for those creating shaded relief of the sea floor.

Shaded relief generated from SRTM30 Plus and ETOPO2 data invariably impresses readers with its sheer amount of detail and the unusual topographic forms found on the ocean floor. Upon closer inspection of the shaded relief, however, readers see elements that are decidedly unnatural – sharp incisions and rows of small bumps that cut straight through seamounts, abyssal plains, and trenches. These lines are in fact artifacts imbedded in the data that trace the routes taken by oceanographic survey ships. Because the artifacts create graphical noise and can mislead readers about the true character of the sea floor, they were removed wherever possible.

2.2. Creating CleanTOPO2

The author smoothed out the offending artifacts in SRTM30 Plus after importing it as a 16-bit grayscale image in Adobe Photoshop. Direct edits to the grayscale elevation data were not possible, however, because the image was dark and all but impossible to interpret. Instead, the author edited a shaded relief rendered from the elevation data that served as a proxy image – clearly seeing topographic detail was essential to success. Drawing edits to the shaded relief on a layer mask allowed their transferal afterwards to a duplicate Photoshop file containing the grayscale elevation data.

The first step was to render a detailed shaded relief from the grayscale elevation data downsampled to 2-arc-minute resolution (10,800 x 5,400-pixels wide). Both the grayscale elevation data and the shaded relief were the same size in pixels. Next, the author opened the shaded relief in Photoshop and duplicated the layer containing it. On the bottom shaded relief layer, applying Gaussian blur (a value 6 was used) smoothed the topography, including the artifacts found on it. The author then added a Layer Mask to the top shaded relief that did not receive Gaussian blur.

Having set up the file, performing edits on the layer mask was accomplished with a pressure sensitive Wacom stylus and tablet. The author painted with a soft brush set at 50 percent opacity until the artifacts disappeared or were diminished. If an artifact was bold, pressing harder with the stylus applied denser tone to the mask until it melted from view; removing faint artifacts required only light pressure. In this manner the author systematically canvassed the entire planet painting out the artifacts while at the same time taking pains not to alter actual bathymetry data. By replacing the original data with a softened version of itself, the potential for doing real harm was slight. When in doubt about whether features were natural or unnatural, they were left unaltered or slightly suppressed. The manual edits took six hours to complete.

To complete the procedure, the author prepared a two-layer Photoshop file similar to the shaded relief file described above, but using the grayscale elevation data instead. As before, the bottom layer received Gaussian blur and the top layer a layer mask. Copying and pasting the

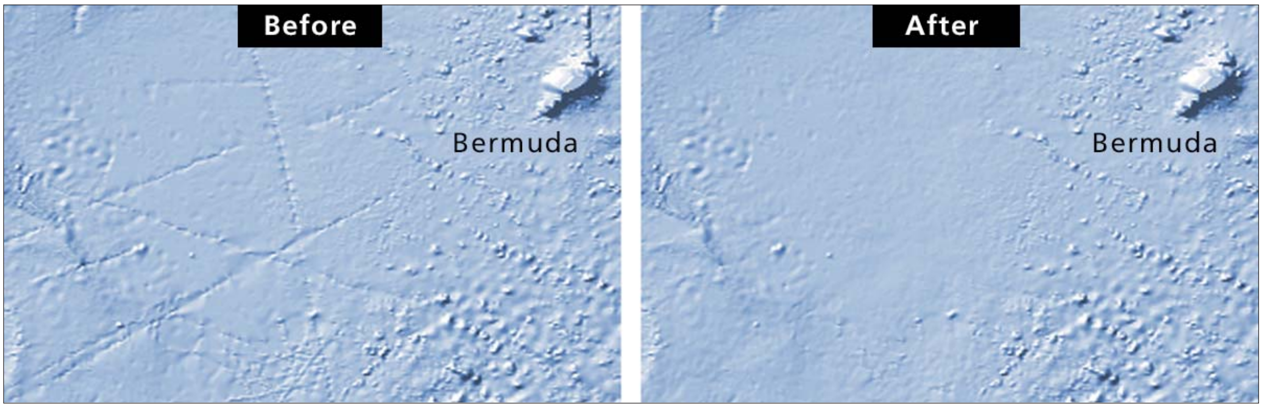

Fig. 2: Shaded relief rendered from ETOPO2 reveals linear artifacts on the Hatteras Abyssal Plain southwest of Bermuda (left). Artifacts are less visible in the shaded relief rendered from CleanTOPO2 (right).

layer mask contents from the shaded relief file to the grayscale elevation data file transferred the edits. The final step involved flattening and saving the elevation data as 16-bit grayscale TIF image, thus creating CleanTOPO2.

2.3. Deciding what to edit

The above procedure did not remove all of the bathymetry artifacts that permeated the original SRTM30 Plus data. Editing efforts concentrated on deep ocean basins where the artifacts were most noticeable because of the flat bottom, making the edits easier to accomplish. By contrast, the fractured topography of mid ocean ridges received minimal editing. Here the artifacts largely become lost amidst the topography and editing is prone to degrading the data.

Some oceans required more editing than others (Fig. 3). Problem areas included the North Pacific south of the Aleutians, a region marred by parallel north-south artifacts; the Atlantic off the US east coast; and, radiating linear artifacts found near Cape Town, Honolulu, and Tokyo. At 72 degrees North and South latitude the Smith and Sandwell bathymetry merges abruptly with polar datasets derived from other sources. The author erased the seam lines.

The Indian Ocean and central Pacific required little editing, perhaps because of the relative absence of data collected by survey ships in these areas. Not that these areas were completely clean. Much of the Smith and Sandwell bathymetry (2007) derives from satellite altimetry (NOAA 2008), a collection process that gives the ocean floor a slightly dimpled texture, which appears on CleanTOPO2. Besides the linear artifacts, the author removed or diminished other suspicious data, including included isolated pits and bumps on the continental shelves that appeared suspiciously deep or high, suggesting erroneous depth values.

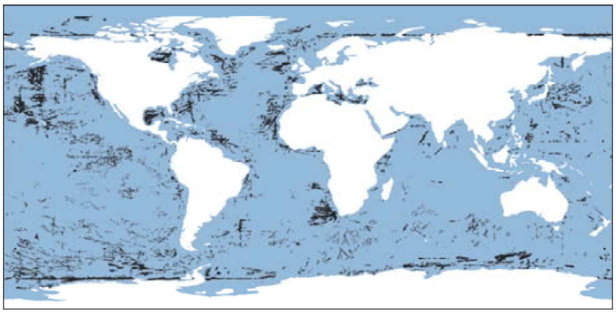

Fig. 3: The black marks show the extent of CleanTOPO2 bathymetry edits.

3. Natural Earth II

The following chapter derives from Patterson, T. (2007).

3.1. The land cover data set Natural Earth II

Natural Earth II derives from Natural Earth land cover data introduced in 2005. It improves on the older version by transforming fragmented land cover into smoothly blended environmental zones shown with natural colors. Natural Earth II attempts to do with environmental data what hypsometric tint maps do with elevation data – provide an informative, attractive, and unobtrusive base for small-scale maps, such as the Physical Map of the World (CIA 2007).

3.2. Potential natural vegetation

The way that Natural Earth II depicts the world is familiar to anyone who has seen a physical map in a National Geographic Society atlas (Fig. 4). Developed by Tibor Tóth in 1971 and expanding on the pioneering work of Hal Shelton (Patterson and Kelso, 2004), colors on the National Geographic maps show the natural vegetation (and non-vegetated environments) that potentially would exist without human influences on the land. Tóth used potential-vegetation maps compiled by A.W. Küchler, a prominent biogeographer who held positions at several U.S. universities in the 1950s and 60s, as a guide for his expressive hand-painted work.

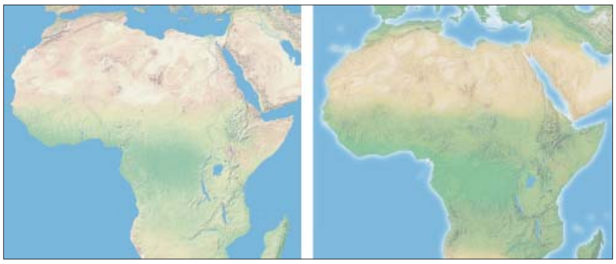

Fig. 4: Natural Earth II (left). A National Geographic physical map painted by Tibor Tóth in 1971 (right).

Compared to land cover that shows what exists on the land at a specific time, potential natural vegetation is a theoretical concept. Potential-vegetation maps assume that modern human-altered environments are a superficial and temporary phenomenon when viewed through the long lens of time. For example, representing Las Vegas with warm desert beige ignores today's urban landscape veneer. New York City in the humid East would appear as forest green. Tóth's palette for portraying potential vegetation uses colors that readers – even city dwellers with little day-to-day contact with the natural world – intuitively associate with the natural environment.

3.3. Making Natural Earth II

Creating Natural Earth II, a digital product, involved manual techniques similar to those developed by Tóth more than three decades ago. The starting point for production was the original Natural Earth land cover dataset, which is available on-line (Patterson, 2007). Modifications to the data in Adobe Photoshop included painting with the Brush tool, cloning, applying color adjustments, and masking. Polar, desert, and highland environments in Natural Earth II are mostly the same as those in the original Natural Earth. These environments tend to have little human population and are still relatively intact, or affected in ways not discernable on a small-scale map. Modifications to arid environments involved replacing light yellow-green irrigated croplands with desert beige. By contrast, humid forest environments in the mid-latitudes and tropics – places most favored for human habitation – received major modifications. In these areas, forest cover was restored to its estimated original extent before the significant growth of human population and activity in the last two or three thousand years.

3.4. Forest restoration

Restoring forest cover to its original extent was an inexact exercise involving multiple sources of information and visual interpretation. The best indicators that forest once existed in an area are remnant patches of forest that exist on contemporary land cover data. For example, the original Natural Earth dataset shows scattered patches of forest throughout northwestern Europe on a landscape otherwise dominated by urban and agricultural land. This information, plus the prevailing moist climate and common knowledge that forests once covered the entire region, made the decision easy. A continuous green tone fills northwestern Europe on Natural Earth II.

Determining original forest extent was more difficult for drier areas where remnant forest cover is scarce today, such as central India and northeastern Brazil. Classic physical geography references helped with this task, including Küchler potential-vegetation maps, Köppen climate maps, and precipitation maps, all obtained from *Goodes World Atlas*, 1978. Helpful online resources (see References for URLs) included the Global Distribution of Original and Remaining Forests, a map published by the United Nations Environment Programme UNEP-WCMC (UNEP 2008). The Degree Confluence Project is a website where GPS users post photographs of the 11,076 places on Earth where lines of latitude and longitude intersect on land (Degree Confluence Project 2008). Photographic evidence of forest at a coordinate intersection today is strong evidence that natural forest existed there in pre-modern times.

In drier forested regions, denser green tones occupy river valley bottoms and upland areas that are presumably moister. In some areas where small but significant forest stands exist, such as the Rocky Mountains of the western United States, appear with slightly more green. Conversely, in large regions with uniform forest cover, areas with relatively fewer trees received emphasis. The Black Belt prairie that traces a crescent through Mississippi, Alabama, and Georgia in the southeastern United States is one such example. These subtle modifications present a more complete picture of the natural environment and produce a more visually interesting map.

3.5. A moving target

In mapping restored natural vegetation difficult questions arise about how far back or ahead in time one should go. Even without human influence, the natural environment is in constant flux. Southwestern Alaska, for example, is now covered with tundra vegetation even though the climate there is just warm enough to support forest cover – it is hypothesized that not enough time has elapsed since the end of the last ice age for trees to colonize this remote area far from other forests and seed sources. In other regions, vegetation change can be rapid. The semi-arid Sahel bounding the southern edge of the Sahara is greener today than it was a few decades ago because of increased rainfall. The idea that plant succession will eventually lead to a climax community that will remain in stable equilibrium for a long time is refuted by scientists today because natural disturbances are not as rare as once thought.

When human influences are factored in, mapping potential -natural vegetation becomes even more complicated. That industrial societies have altered natural landscapes significantly is not debatable – the manicured suburbs where many of us live are evidence of this. However, should the more benign activities of indigenous peoples in former times, such as intentionally lighted fires to clear forests or drive game, be a valid consideration for mapping potential-natural vegetation? For example, fires set by the pre-Columbian inhabitants of North America expanded the extent of the Great Plains grasslands into adjacent forestlands.

Alan Weisman in The World Without Us (2007) deconstructs how contemporary cities would revert to a natural state relatively quickly if the human species were to disappear suddenly from Earth (a scenario that is both troubling and fascinating). According to Weisman, in a matter of days weeds would start to grow in the cracked pavement of Manhattan, establishing a beachhead for other plants and the eventual return of forest. Mid-latitude forest environments, such as New York City, are resilient to change. More fragile environments elsewhere might never fully recover to what they once were because of human influences. Consider the drier parts of the Hawaiian Islands where introduced kiawe (mesquite) trees thrive on land that once was native grassland, a vegetation type unlikely to return ever again. The small map scale, vegetation boundaries with fuzzy edges, and generalized classification of Natural Earth II partially circumvents these problems.

3.6. Classification

Using a generalized classification brought other benefits to Natural Earth II (Fig. 5). Because it is a base for mapmaking, a generalized classification with fewer environmental colors improved legibility. A base map that is too colorful and varied can distract from thematic information overlaid on it. A practical concern was the need to limit the shades of green representing forest types to a number that a reader could easily differentiate, a task made more difficult

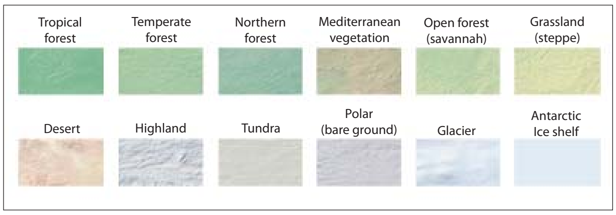

Fig. 5: Terrestrial environment classification for Natural Earth II.

by colors that merge together on the map just as forest types do in nature.

The Natural Earth II classification contains three forest types (tropical, temperate, and northern) and two types of partial forest (Mediterranean vegetation and open forest/savannah). Coloring these forests involved visually comparing Köppen climate maps and the restored forest extent on Natural Earth II and applying an assigned color in Photoshop where they coincided. For example, brownish green Mediterranean vegetation found in scat-tered pockets around the globe correlates with Mediterranean (Cs) climates in Köppen's system. Following this approach, northern forest correlates to Köppen's Db, Dc and Dd climates, tropical forest to Af and Am climates, and temperate forest to several intermediate climates in his system.

A generalized environment classification also must come with omissions. Natural Earth II does not classify shrub land or wetlands as distinct environments. Shrub land – a vegetation type that garners little respect – is subsumed by Mediterranean vegetation, open forest, grassland, and desert in the Natural Earth II classification. Wetlands are also part of other classifications. The Everglades of Florida appear as grassland and the bogs of the Western Siberian Lowlands, the largest wetlands on earth, appear as lightly tinted northern forest. Delineating the boundary between grassland (steppe) and forest environments was difficult. Natural Earth II reclassifies herbaceous land cover (a category that includes croplands and pasture) in the original Natural Earth dataset as grassland. Factoring in the absence of intentional burning by humans, forest cover encroaches on and blends softly into the Hungarian Alföld, Great Plains of North America, Llanos of Venezuela, and other grasslands of the world.

4. Plan Oblique Relief

The following chapter derives from Jenny, B., and Patterson, T. (2007).

Plan oblique relief is a digital technique for rendering three-dimensional terrain on otherwise planimetric maps. When created from CleanTOPO2 elevation data, the technique produces a depiction of undersea topography that is similar to Heinrich Berann's ocean floor maps painted for National Geographic (Lawrence 1999). Following Berann's successful example, the Physical Map of the World uses plan oblique relief.

Plan oblique relief contains the characteristics of both conventional shaded relief and 3D perspective views, such as panoramas. As the "plan" in its name suggests, plan oblique relief uses a planimetric base for its initial construction as do most shaded relief maps. The "oblique" in its name refers to the shallow angle used for rendering the terrain – but in a manner that eliminates the occurrence of perspective. On conventional shaded relief maps, terrain rendering occurs from a theoretical position directly overhead and infinitely distant. Plan oblique relief uses a lower position, somewhere between directly overhead (90 degrees) and the horizon (0 degrees). This results in 3D terrain that projects upwards perpendicular to the bottom of the map and parallel to the reader's view.

The effect of plan oblique relief is not unlike axonometric city maps, such as the famous Bollmann map of Manhattan (Hodgkiss 1973), but with three-dimensionality applied not to buildings but to terrain. Because plan oblique relief portrays the landscape in a way that people see it in their everyday lives – from a horizontal perspective – the author contends that novice readers (and even experts) have an easier time understanding it at a glance compared to understanding conventional shaded relief. High solitary mountains, such as Mt. Fuji and Mt. Kilimanjaro, which appear as indistinct dots on a small-scale shaded relief map viewed from above, reveal their recognizable forms and appear as the major mountains that they are when rendered as plan oblique relief. Compared to 3D perspective views, which look most natural of all, plan oblique relief better preserves geographic shapes without any front-to-back foreshortening and convergence toward a distant vanishing point. 3D perspective views mimic the view from an airplane window; plan oblique relief is suited to map making and reading.

The author used an alpha version of Natural Scene Designer 5.0 (Natural Graphics 2008) to create plan oblique relief for the Physical Map of the World. Although rendering plan oblique relief from CleanTOPO2 data was simple – placing the light source in the southwest, determining the right amount of vertical exaggeration, and clicking the render button – it required considerable Photoshop manipulation afterward. Much as in making a 3D panorama, map elements, such as drainages, were rasterized, draped on the plan oblique terrain, and rendered as separate elements. The author had to fix misalignments between the map elements and plan oblique relief manually.

Because plan oblique relief contains vertical offset (terrestrial topography projects upwards and bathymetry downwards), the Physical Map of the World is planimetric only at sea level. The graticule does not shift vertically for differences in elevation. Although this is not a major problem because of the small map scale, it nevertheless is evident where high mountains and the graticule lines coincide. For example, the summit of Mount Kenya lies 17 kilometers south of the equator but it appears slightly north of the equator because of the vertical offset.

A more serious issue with plan oblique relief on the Physical Map of the World is poor rendering quality. Imperfect elevation data is the underlying problem. Despite efforts to remove artifacts from CleanTOPO2, poor quality bathymetry data is still widespread, especially in the oceans of the southern hemisphere. Plan oblique relief, because it is truly three-dimensional, is more revealing of data imperfections than conventional shaded relief. Consequently, the author had to change plans and publish two versions of the Physical Map of the World, one a large wall map and the other a small wall map. The large wall map uses conventional shaded relief generated from CleanTOPO2 at full resolution. The small map uses plan oblique relief generated from downsampled CleanTOPO2 data that better hides the data artifacts.

5. Conclusions

The final Physical Map of the World is in the public domain and available for free on-line at: www.shadedrelief.com/world. Visitors to the website will find versions of the map with plan oblique relief and conventional shaded relief, with and without labels. A separate Adobe Illustrator file containing over 3,100 map labels is also available.

Although National Geographic physical maps inspired the design of the Physical Map of the World, it differs significantly. From color to typography to map projection, all facets of the design received scrutiny and modifications according to the preferences of the author. For example, the Physical Map of the World has a cleaner, more open appearance compared to a typical National Geographic physical map. Because fewer lines make for a less busy map, the Physical Map of the World dispenses with shoreline casings and instead relies on figure-ground contrast and shoreline embossment applied in Photoshop to distinguish land areas from water.

A unique feature of the Physical Map of the World is its projection. Rather than using a traditional projection, such as the Miller or Robinson, or the Winkel Tripel now favored by National Geographic, it uses an entirely new projection created with an alpha version of Flex Projector, the first-ever software for designing custom map projections (Jenny and Patterson 2008). The new projection, called the Natural Earth projection, is a pseudocylindrical projection designed specifically for presenting Natural Earth II environmental data. The Natural Earth projection combines characteristics of the Robinson and Kavraiskiy VII projections and compares well to them in regard to map distortion. A unique feature of the Natural Earth projection is its rounded corners (where the pole lines and lateral meridians meet), which imply that the world is spherical instead of rectangular in shape.

Labels on the Physical Map of the World originated from numerous cross-referenced sources, including published atlases and web sites, most notably Wikipedia. Most city and water body labels derive from the Physical Map of the World, and available online as a PDF (CIA 2007). The GeoNet Names Server database maintained by the U.S. National Geospatial Agency (NGA) was the main reference for place name spellings of smaller physical features (NGA 2008). Because the map will cater to an international audience, endonyms (Appennino) were favored over exonyms (Apennines) for place names based on Romance and Germanic languages, which are often cognates of familiar English names and easy to identify. For other languages, transliterated names of major features (mountain ranges, plateaus, deserts, etc.) received English place name descriptors. For example, Verkhoyansk Khrebet in Russia is labeled on the map as Verkhoyansk Range. Smaller physical features, such as mountains within ranges, have entirely local names.

Before releasing the final Physical Map of the World, the author placed a draft with preliminary labels online and invited the public to comment. Many people responded to the invitation, catching spelling errors and offering greatly appreciated advice about map content, most of which was used. It is appropriate that this paper end by acknowledging Bernhard Jenny, Stefan Räber, Michael Borop, Will Pringle, and Félix Pharand for their valuable contributions to the Physical Map of the World.

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(Note: All Websites were verified January, 2008.)

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