Chapter 5
Mapping the Deep Blue Oceans

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Abstract The ocean terrain spanning the globe is vast and complex—far from an immense flat plain of mud. To map these depths accurately and wisely, we must understand how cartographic abstraction and generalization work both in analog cartography and digital GIS. This chapter explores abstraction practices such as selection and exaggeration with respect to mapping the oceans, showing significant continuity in such practices across cartography and contemporary GIS. The role of measurement and abstraction—as well as of political and economic power, and sexual and personal bias—in these sciences is illustrated by the biographies of Marie Tharp and Bruce Heezen, whose mapping of the Mid-Atlantic Ridge precipitated a paradigm shift in geology.

Keywords Cartography · GIS · Abstraction · Simplification · Selection · Exaggeration · Oceanography · Bathymetry · Scale · Map projections · Marie Tharp · Bruce Heezen · Lamont–Doherty Earth Observatory · Heinrich Berann · Ocean charts · Physiographic diagrams · Panorama maps · Plate tectonics · Cold War · Women in science · Bias · Discrimination · Workplace harassment

Introduction

The cartographer and geologist Marie Tharp recounts meeting oceanographer Jacques Cousteau in person only once, sometime between August 31 and September 12, 1959, in a hotel ballroom in New York City at the inaugural International Oceanographic Congress. She attended the Congress but did not present a paper. She and Cousteau spoke after a historical film screening, a conversation Tharp said

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T. Tambassi (ed.), *The Philosophy of GIS*, Springer Geography,
https://doi.org/10.1007/978-3-030-16829-2_5

she enjoyed.[1] One imagines the conversation was filled with mutual admiration, and possibly curiosity about each other's eccentricities and achievements.

At a recent conference in France, Bruce Heezen, Tharp's long-term collaborator, had given Cousteau a copy of the epoch-making 1957 physiographic diagram of the North Atlantic's ocean floor (Fig. 5.1) that Tharp had drawn from Heezen's deep-sea sonar data. The map depicted a mountain ridge in the middle of the Atlantic. Cousteau was extremely skeptical that this Mid-Atlantic Ridge existed; even so, he had hung the map up in the mess hall of his famed *Calypso*, so that he and his crew could study it.

On the *Calypso*'s way to New York City and the conference at which he and Tharp would meet, Cousteau decided he would prove Tharp and Heezen wrong once and for all. There could not possibly be such a strange phenomenon, which seemed to corroborate the much-maligned theory of continental drift and plate tectonics—a topic of heated discussion at the International Oceanographic Congress. Kilometers above the supposed ridge, the *Calypso* lowered its submarine camera "sled", the *Troika*, into deep, cold Atlantic waters. Sure enough, as his film projected to a large, enraptured audience of scientists at the Congress, the *Troika*'s camera recorded a high mountain ahead in the distance; a climb up that mountain; a steep descent; a

Fig. 5.1 North Atlantic physiographic diagram. (Published in 1957; map inset to Ewing, Heezen, Tharp 1959.) As indicated in the information box, the vertical exaggeration is 20:1. This box is located where it is because they did not have much data for that region of the ocean. In part Tharp and her collaborators chose to draw physiographic diagrams, because exact depth data need not be shown, and this information, while they had access to it, was classified by the US Military until at least the late 1960s. Reproduced by kind permission of Lamont–Doherty Earth Observatory and the Estate of Marie Tharp/©Marie Tharp Maps, LLC Fiona Yacopino, 8 Edward St. Sparkill, NY 10976

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[1] Felt (2012), "enjoyed", Loc 2178.

trip across a plain filled with young lava; and a climb up another mountain. Cousteau and his team even turned the *Calypso* around and redid the whole exercise.

Tharp's map, Cousteau's film, and the Atlantic all agreed: The Atlantic ridge was real. *A map became the world through a film* (Winther 2020).

This chapter explores how mapping works, particularly with respect to abstraction practices of map-making, and with respect to the case of deep blue oceans. The oceans are not an immense, flat plain of mud. To map them accurately and wisely, we must understand how cartographic abstraction and generalization work both in analog cartography and digital GIS.

I see significant continuity between classic cartography and GIS (Winther 2015). The emergence of GIS, in my view, signals not the classic map's nostalgic swansong or tragic funeral, but rather a retooling and enrichment of possibilities for visual geographic practices. Differently put, a map-based science of data collection, management, and abstraction shifted to a computer based science of database management, spatial analysis and statistics, expert systems, and modeling.[2] In this shift, the power of the map was neither lost nor forgotten, as can be seen below with contemporary efforts of ocean floor mapping via satellite altimetry remote sensing.[3]

Finally, and perhaps most concretely, the intertwined biographies of Marie Tharp and Bruce Heezen capture many empirical and conceptual—as well as social and political—themes associated with mapping. By interweaving history and philosophy, I hope to interest you in how and why maps of the oceans are drawn; what importance this has for questions about power, values, and bias in science; and the relevance that mapping has for the future of the oceans, especially in a time of foreboding climate change and generalized ecological collapse.

Abstraction in Cartography and GIS

To create an analogy for how maps generalize and abstract from the world, imagine yourself sitting on an airplane as it leaves the terminal. You stare out the window and see the runway. As the plane accelerates, you feel the movement in your limbs and your gut. Buildings, cars, and hills whiz by, faster and faster. The plane climbs. The level of magnification changes. Trees and cars disappear. Rivers and highways become generalized curves. A quilt of greens, blues, and browns emerges.

Soon you are above it all, looking down with sweeping vision. The teeming world on the ground has become simpler and more abstract—the general features of a *map*. Whenever we compare a map to its territory, we find this flip from everyday, human-scale perception to a generalized abstraction.

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[2] On broadening the concept, methods, and purposes of cartographic generalization, see e.g., Abler (1987), Shea and McMaster (1989), Couclelis (1992), Goodchild (1992), Schuurman (2004), Lüscher et al. (2009).

[3] Smith and Sandwell (1997).

Maps are produced by practices of abstraction, to somewhat similar effect. Once data has been collected—size, position, boundaries, landscape features, and so forth—abstraction must be performed in order to produce maps, some of which are highly dynamic and complex. Cartographic abstraction is akin to scientific theorizing. Whether a map is made via classic analog cartography or a geographic information system (GIS), a standard, classic set of abstraction protocols is used, including *selection*, *classification*, *simplification*, *symbolization*, and *exaggeration*—to which I add *perspectivizing* and *partitioning* in Chap. 3 of my forthcoming *When Maps Become the World* (2020). Here I will focus on selection, simplification, and exaggeration, with examples from mapping the deep blue oceans.

Cartography is the study of principles and rules of map making and map use (Winther 2020). An important question shaping this discipline was how to engage in abstraction and generalization when creating maps.[4] These practices are similar across both classic analog cartography and digital GIS.[5] Even in the digital, computational age, map abstraction remains very much that switch from human-scale perception and navigation to graphic representations at extreme scales.

As an emerging discipline, an important phase for GIS in the early 1990s was, as Nadine Schuurman plausibly suggested, a "switch" from "a map to model-oriented approach to generalization" (1999, 83). In North America, the "culture of cartography" was dominant; the map as such was the focus. Conversely, "Europeans had developed a *landscape model* [the database] that is based on derived data" (ibid.). The key shift was from "working with mental models of maps" to committing to "the database" as generative of "map objects" (2004, 48–49). Schuurman highlighted Brassel and Weibel's (1988) article on automated map generalization as instrumental to this shift. Here Brassel and Weibel characterized generalization "as an intellectual process, [which] structures experienced reality into a number of individual entities, then selects important entities and represents them in a new form" (1988, 230–1). The authors then distinguished two kinds of "objectives for spatial modeling", corresponding to two kinds of generalization: "spatial modeling for purposes of data compaction, spatial analysis and the like [i.e.,] *statistical generalization*" and "*cartographic generalization*", which, "in contrast, aims to modify local structure and is non-statistical" (232). By identifying a broader set of modeling strategies and purposes—beyond visual display and map-making—Brassel and Weibel prompted the emerging GIS community to, I believe, transform cartography and the map. Yet, the map remains.

Let us now turn to specific practices of map abstraction.

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[4] I prefer the term "abstraction" for the process of inferring general features from the particulars of the world or our experience. Although most cartographers prefer to use "generalization", "abstraction" is the more appropriate, flexible, and general term. On my pragmatic account of abstraction and its shadow side, pernicious reification, see Winther (2014). Cartographic abstraction is structurally and substantively related to scientific abstraction (see Winther 2020, Chap. 3).

[5] The cartographic framework, and its take on abstraction, can be gleaned from close study of work such as Wright (1942), Koláčný (1969), Muehrcke (1969, 1972, 1974a, b), Wolter (1975), Robinson and Petchenik (1976), Wood (1992), MacEachren (1995), Harley (2001), Montello (2002). See also Winther (2015, 2020).

Selection: Scale

Selection in cartography is the intentional reduction of content, particularly as a consequence of choosing map scale and map projection. Scale sets a map's representational scope and granularity of detail,[6] while a map projection is a flat, two-dimensional geometric representation of a curved, two-dimensional surface of a globe, ellipsoid, or geoid. These are practices of abstraction because they involve the detachment of certain information from its context, generally emphasizing some features at the expense of others. The selection of scale and projection are also significant in that they constrain myriad other representational features of the map.

Scale is a ratio or proportion between features of the representation and properties of the world depicted. Depending on the map or model, the scale might be given in terms of time passage, the intensity of features, distances and sizes, or other parameters. Map scale can be shown visually (for example, with a graduated line representing 10 km), quantitatively (for example, 1:10,000,000), or in words. Scale affects all other abstraction practices.[7]

Scale should be selected based on how much area one desires to cover (*scope*), and at what level of detail (*grain*), while taking presentation constraints into account (for example, a book, a poster, or a screen with zooming capacities). The larger the scale, the more fine-grained, detailed, and concrete the map can be. At one logical limit is the famed one-to-one map of the world, a concept that is poetically and humorously exploded by authors such as Lewis Carroll, Mark Twain, and Jorge Luis Borges.[8]

Some authors classify maps according to scale.[9] World maps are small-scale; a map fitting on two leaves of an atlas could have a scale of 1–60 million (1:60,000,000).[10] In contrast, city maps have a larger scale, typically varying between 1:10,000 and 1:25,000 (see Footnote 9). Tharp and Heezen's maps (Figs. 5.1 and 5.2) represent at different scales—1:5,000,000 and 1:30,412,800 (480 miles:1 inch), respectively.

In general, many of the same considerations about the purpose-dependency and limits of scale from analog cartography pertain to digital maps. Selecting map scale is as necessary for digital maps as it is for analog maps. Digital maps such as Google

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[6] The sciences are distinguished by differences in scale. The boundaries of particle physics, biochemistry, neuroscience, anthropology, or cosmology, etc., are set (if permeably) by the minimum or maximum spatial scale of the objects and processes of its domain, from the tiny to the enormous. Temporal scales also vary across the sciences. For instance, quantum mechanics and quantum chemistry trade in extremely short time scales, developmental biology in days, weeks, and months, geology in millennia and millions of years, cosmology in billions of years (Winther 2020).

[7] For a rigorous, mathematical treatment of map scales, see Bugayevskiy and Snyder (1995, 17–20).

[8] Carroll ([1893] 2010, 162–163), Twain (1894, Chap. 3, 57), Borges ([1946] 1975, 325). With humor and irony, Eco ([1992] 1994) playfully deconstructs the very concept of a one-to-one map.

[9] Greenhood (1964, 48–49), Muehrcke and Muehrcke (1998, 13, 537–546), Kimerling et al. (2009, 22–33), and Krygier and Wood (2011, 94–95).

[10] ESRI (n.d.) provides a list of common map scales.

Fig. 5.2 An absolute panorama map of the Atlantic Ocean floor as painted by Heinrich Berann, under close collaboration with Tharp and Heezen. Berann painted many panorama maps for *National Geographic*, also of the Himalayas and the Alps. This map appeared in the June 1968 issue of *National Geographic*. Notably, this image also graces the cover of Naomi Oreskes' well-respected and excellent 1999 book on continental drift. But Tharp herself is mentioned on just two pages of the main text of Oreskes' book. Heinrich Berann/National Geographic Creative/National Geographic Image Collection

Maps are often zoomable,[11] but the grain can thus increase only because the system adds new information as we increase the scale—or else it would be like visually blowing up a photograph to reveal its basic pixels.

Selection: Projection

As for projections, the Mercator projection remains favored in the mapping of the oceans, including by Tharp and Heezen and ocean mappers and coauthors Walter Smith (of the National Oceanic and Atmospheric Administration) and David Sandwell (of the Scripps Institution of Oceanography).[12] Well known for its use in marine charts, the Mercator conformal projection projects the world onto a cylinder such that lines of constant bearing on Earth (i.e., *rhumb lines*) are transformed to straight lines on the map.

While still taught, the study of map projections, which filled geography and cartography classes and textbooks before the rise of GIS, has massively declined in importance. As I show in Chap. 4 of *When Maps Become the World*, part of the reason lies in the triumphant biography of the Mercator projection, in its various guises, including Johann Heinrich Lambert's 1772 "transverse Mercator", in which the cylindrical developable surface is oriented not around the equator, but along a meridian. In cartographic argot, this projection has a *transverse* rather than an *equatorial* aspect (orientation). The transverse Mercator became central to the ellipsoid datum's coordinate system (i.e., WGS 84) in the mid-twentieth century.[13]

Furthermore, for various cognitive and social reasons, such as familiarity and historical inertia, GIS and online mapping services such as Google Maps, Bing Maps, and ArcGIS Online employ a "Web Mercator". These equations render Earth in a near-conformal, cylindrical projection.[14] Perhaps Web Mercator has become the online and digital cartographic representation standard because "north is always the same direction"; it simply "look[s] right"; it "allows for simpler (and therefore quicker) calculations […] [and] continuous panning and zooming at any area, at any location, and at any scale"; and it "allows close-ups (street level) to appear more like reality."[15] But these are not sufficient explanations for Web Mercator's dominance, since computers could always retranslate projections, depending on which parts of the world one wishes to show.

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[11] Since 2009, Google Earth shows the oceans based on, among other data sources, Marie Tharp as well as Smith and Sandwell, and collaborator's maps and data. See Jha (2009).

[12] Heezen et al. (1959, 3), Smith and Sandwell (1997), Sandwell et al. (2014, 66). The mathematics, visualizations, and quandaries involved in and with map projections are discussed extensively elsewhere (e.g., Snyder 1993; Winther 2020), so I shall set it aside here.

[13] See Rankin (2016).

[14] E.g., Brotton (2012, Chap. 12), Strebe (2012), Battersby et al. (2014).

[15] First two quotes from Strebe (2012); third quote from Battersby et al. (2014, 88–9); last quote from Google representative Joel H., August 4, 2009. https://productforums.google.com/forum/#!topic/maps/A2ygEJ5eG-o.

To be fair, map projection distortions become less important as scale increases—after all, a large-scale map shows a roughly flat area, with just a little bit of curvature. However, there is no reason not to be able to compare map projections for small-scale maps. Consider map aficionado Tobias Jung's *Compare Map Projections* website.[16] While Mercator's projection is useful for navigational purposes and also the standard projection Marie Tharp and Bruce Heezen used, there is nothing to stop it from being just one among multiple projections in a flexible, GIS integration platform, where the context-dependency and advantages and disadvantages of each map projection are indicated and discussed, as per Jung's website, and as further discussed in Winther (2020).

Simplification

Simplification is the omission and streamlining of information such that general features of a pattern or process are represented on the map, but unnecessary detail is abstracted away. We can emphasize or omit any number of patterns from a rich data set, representing only some aspects of the data. For instance, houses and roads can be removed, a meandering river straightened out, or a large number of trees aggregated into a small simple patch of green.[17] And there is much that cannot be represented on a map. The more simplified a map is, the more abstract it is (even if abstraction involves much more than simplification).

We might also simplify because we are privy to limited data, because of limited technologies or imperfect surveying opportunities, or even because a map was "born classified",[18] all of which were the case with Tharp and Heezen's maps.[19] In such conditions, we would wish only to perform the *minimal* amount of interpolation within, and extrapolation across, the available data. As Hali Felt quotes Marie Tharp in her creative biography of the oceanographic cartographer, "Deep sea soundings obtained along a ship's track were as a ribbon of light where all was darkness on either side."[20]

An early protocol of automated line simplification is the Ramer–Douglas–Peucker algorithm, which outputs a simplified zigzag line from a complex real-world line, while preserving the latter's basic properties (Fig. 5.3).[21] The algorithm first connects

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[16] https://map-projections.net/index.php.

[17] An interesting *material* simplification strategy is described in *Hammond's Compact Peters World Atlas*: "Cartographers have struggled with the best way to create hillshading for hundreds of years. In this atlas the 3-D relief comes from photographing specially made plaster relief models and blending these photos with hand-rendered coloring" (Hardaker 2002, 7).

[18] Doel et al. (2006, 605).

[19] Tharp spoke thus: "The displacement of peaks and other topographic features [in physiographic diagrams] due to the vertical exaggeration blurred their actual positions as demanded by a classification regulation" (Felt 2012, Loc 1779).

[20] Felt (2012), Loc 1720.

[21] Ramer (1972), Douglas and Peucker (1973).

the two ends of the complex, real-world line and finds the real-world line bend point farthest from that connecting line. Releasing the first connection, the algorithm then connects the first end point and that farthest point, and the second end point and that farthest point. We now have two straight lines angled and embedded along the entire length of the real-world line. The algorithm subsequently operates recursively on each of these two lines, and so forth (Fig. 5.3). The recursion ends, overall, when *every* farthest point is within a set maximum *tolerance distance*.[22] The Ramer-Douglas-Peucker algorithm marks an important milestone in the development of the *digital*, computational map.

Exaggeration

Exaggeration is the technically inaccurate adjustment or reproportioning of the size and placement of map elements. The purpose of exaggeration is to increase legibility, comprehensibility, and communicative power. An example is expanding the width of streams or highways on a map to make them visible rather than razor-thin. More dramatically, Harry Beck's classic London Tube map sacrifices geographically accurate location of stations by exaggerating their relative location, fixing their placements into topologically accurate, user-friendly straight lines.[23]

Tharp exaggerated vertical cross section profiles of mountain ridges: "With a few exceptions all profiles are represented with a 40:1 vertical exaggeration"[24] (Fig. 5.5). She had to do this in order to show the Mid-Atlantic Ridge profile in a meaningful and memorable way. Otherwise, the profile would have nearly disappeared into a solid line barely crawling along the ocean bottom. The ocean is so wide that even towering mountains look small by comparison.

Map elements become exaggerated in various ways. When geographic features have to be shown at different scales of a GIS map, then the map elements often have to be exaggerated in distinct ratios. For instance, as we zoom in, that river need not become thicker in proportion to the scale. It could remain relatively thin and still be visually recognizable. However, the software platform will probably update

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[22] More concretely, Ramer's code selects every anchoring point of what becomes an irregular polygon constructed from the target real-world line. [An anchoring point was a farthest orthogonal point or vertex, in the prior step ($N - 1$).] Vertices exceeding maximum distance (see: lower left hand column box of Fig. 5.3) "open" the polygon at each step, and are labeled as such in the program stack. The polygon becomes "closed" when the two new line segments from that point to the original anchoring points are constructed. This automated procedure is repeated, until no further vertices (orthogonal points) are greater than d_m (the maximum tolerance distance) and the polygon becomes fully closed. For a dynamic rendition of the Ramer–Douglas–Peucker algorithm, see: https://en.wikipedia.org/wiki/Ramer%E2%80%93Douglas%E2%80%93Peucker_algorithm#/media/File:Douglas-Peucker_animated.gif.

[23] See the "Harry Beck's Tube map" post on the website of London's transit agency, tfl.gov.uk.

[24] Heezen et al. (1959, 15).

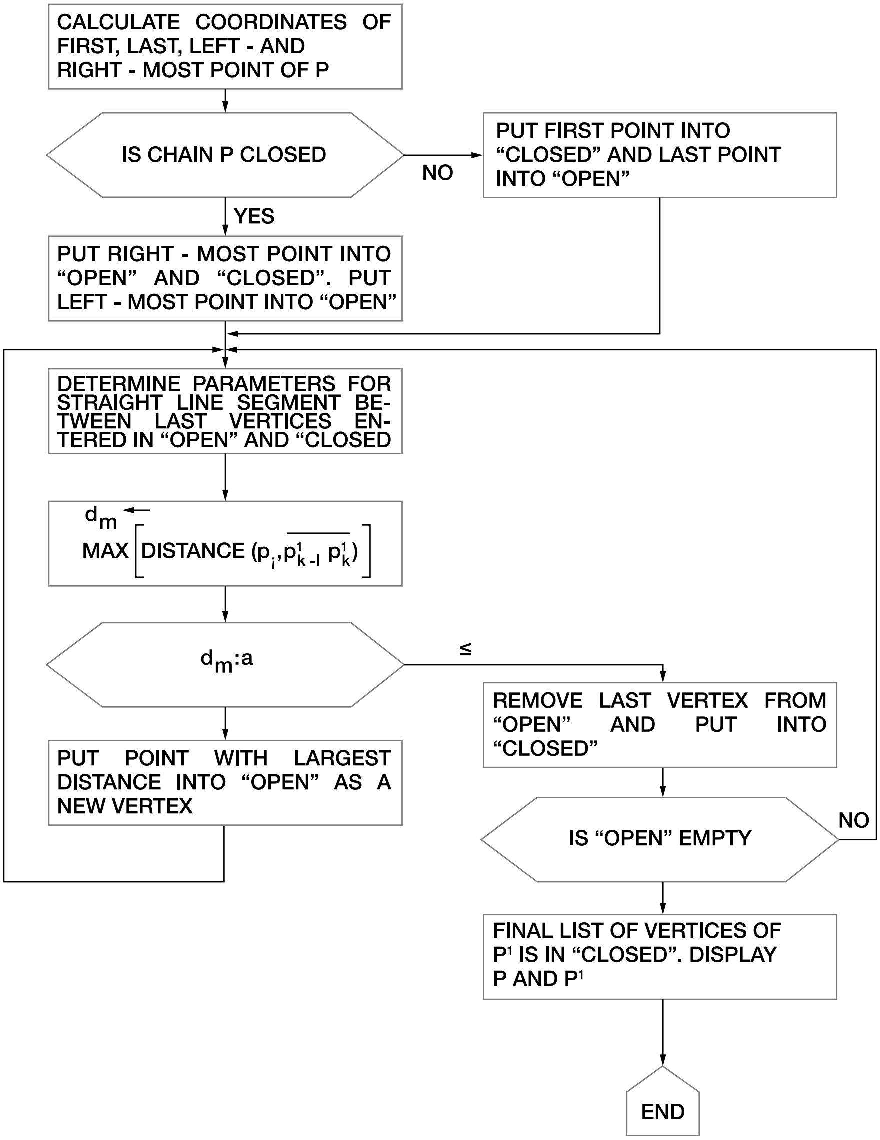

Fig. 5.3 Polygon generation flow diagram p. 248, Ramer (1972). Redrawn by cartographer and graphic designer Mats Wedin

the snakiness of the river, recalculating perhaps with the Ramer–Douglas–Peucker algorithm.

A digital map captures too much data and interpretation to represent in any split-second visualization on a screen or on paper. Software packages by Esri, for instance, store and sometimes compress data. Google Maps stores data elsewhere, far from users' computers. The digital map is more like an extended network, where the visualization is a tip of the iceberg, a hyperlocal mapping-as-you-go, rather than something you can hang on a wall.

Tharp-Heezen Maps

As a historical prolegomenon to a fuller story of abstraction in cartography and GIS, consider the case of Marie Tharp's maps of the deep. These maps changed the face of the Earth Sciences: "This physiographic map '*is* in some ways the ocean floor', former Heezen graduate William Ryan later mused: 'It's our only multi-dimensional picture of it… that map and every subsequent revision to it'."[25] Through her Mid-Atlantic Ridge *profiles*, her *physiographic diagrams* reminiscent of geographer Armin Lobeck's,[26] and her long-term collaboration with Bruce Heezen (and, to a lesser extent, Heinrich Berann) on *perspective* and *panorama* maps, Marie Tharp gave us the ocean floor. Tharp's representations also suggested a mechanism for explaining the ocean floor's features. Tharp's maps became the world.

Tharp shows the importance of characterizing a system *as a whole*, not merely as an aggregation of parts. My argument here resonates with Evelyn Fox Keller's analysis of Nobel Prize-winning corn geneticist Barbara McClintock in her *A Feeling for the Organism* (1984). There are clear indications that, just like McClintock, Marie Tharp possessed powerful capacities to see all the parts of a system in a holistic, dynamic, and interactive manner. She eschewed atomism and reductionism. She was also able to intuit hypothetical patterns via scientific interpolation and extrapolation. She actually *integrated the oceans* in her physiographic diagrams and in her coaching of Austrian painter Heinrich Berann's panoramas.

Both McClintock and Tharp had a perhaps more traditionally feminine (only weakly and statistically associated with actual sex) capacity to approach a set of complex biological or geological processes—genetic inheritance and ocean floor bottoms, respectively—with a broad vision. They investigate important scientific phenomena with their all-inclusive, embodied Gefühl.[27] Such a floodlight vision

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[25] Doel et al. (2006, 620).

[26] Lobeck was hired as a full professor in Geology at Columbia University, home of Lamont, in 1948. Tharp had "devoured" his 1924 *Block Diagrams* book (Felt 2012, Loc 1715). Lobeck developed the physiographic diagram and was involved with the US military, especially during the two world wars. His "Physiographic Diagram of the United States" (1948) was influential. For a brief biography, see Smith (1959).

[27] For early work on the epistemology of gender, sex, and science, see Harding (1986), Keller and Longino (1996).

complements the sharp cutting, analytic spotlight vision typically permeating science. Effective research at the community level requires a commitment to a panoply of distinct research styles, each expressed by changing constellations of individual researchers and research groups.[28]

The role of political and economic power and of personal bias in contemporary GIS is illustrated by Tharp's and Heezen's biographies.

Tharp-Heezen Timeline

1947. While an undergraduate geology student at Iowa State University, Bruce Heezen heard a lecture by Maurice "Doc" Ewing and was enraptured. Ewing invited him to join an expedition of the Mid-Atlantic Ridge on the *Atlantis I*. Heezen accepted, and eventually became a graduate student at Columbia, receiving his doctorate under Ewing in 1955.[29]

1948. Marie Tharp had completed a bachelor's in English literature and music at Ohio University, a master's degree in geology at the University of Michigan, and a bachelor's in mathematics at the University of Tulsa in Oklahoma. In 1948 she was hired by Ewing as a research associate.[30] After a few years, she was working almost exclusively with Heezen on their shared interests in ocean mapping (Fig. 5.4).

1949. The Lamont Geological Observatory was officially established in Palisades, NY, associated with Columbia University. Ewing was its founder and source of energy.[31] While Ewing and Heezen had a close and productive collaborative effort in the first years of this institution, their relationship would sour. Heezen was associated with Lamont for the remainder of his life, even with a much-diminished role, starting in 1966. Tharp was treated unjustly by Lamont after Heezen's death.

1952. Tharp completed six *profile drawings* of the Mid-Atlantic Ridge (Fig. 5.5) primarily using Lamont survey data, much of it collected by Heezen on *Atlantis I*, but also with some data from the German ship *Meteor* and other sources. These profiles were based on sonar sounding data, as ships crossed what turned out to be the Mid-Atlantic Ridge at different latitudes. Particularly striking about these drawings—and what took Tharp initially by surprise, and then approximately a year to convince Heezen of—was the *valley* depicted inside the ridge. According to Tharp, Heezen "initially dismissed my [her] [rift valley and continental drift] interpretation of the profiles as 'girl talk'". Ironically, the rift valley V-shape indentation was indeed a form of girl talk, in a genuinely productive way.[32] This smelled of continental drift, because it meant the plates were coming apart, with lava oozing out from the wound.

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[28] Longino (2001), Winther (2012, 2020).

[29] Tharp and Frankel (1986, 3).

[30] Tharp and Frankel (1986, 2–3), Barton (2002, 216–217). See Landa (2010) for discussion of Tharp's early biography, and her "ties" to her father, a soil surveyor.

[31] Consult Lamont–Doherty Earth Observatory (n.d.).

[32] Tharp (1999). Helen Longino provided constructive feedback.

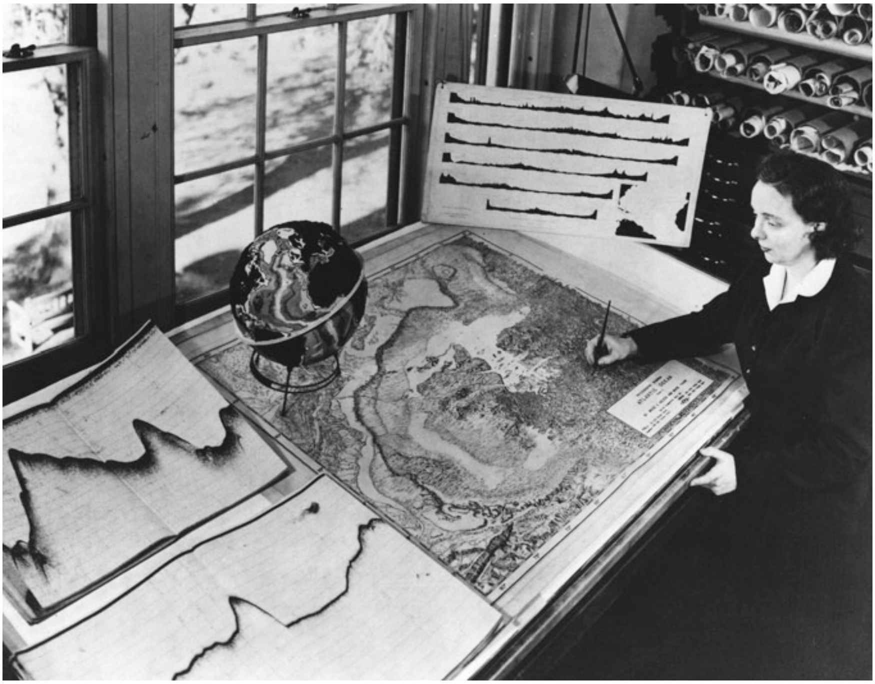

Fig. 5.4 Marie Tharp in front of profiles and globes that she, Heezen, and their assistants used in preparing and drawing physiographic maps. Pictured here is her first 1957 physiographic diagram. Some of their globes were made with "acrylic applied to a basketball" (Doel et al. 2006, ftnt. 72, p. 625). These globes remained unpublished, but avoided any map projection distortions. Cf: Bressan (2018). Reproduced by kind permission of Lamont–Doherty Earth Observatory and the Estate of Marie Tharp

(Heezen defended an alternative theory: an expanding Earth coming apart at its seams.)

1953. Given the profile drawings and further sounding data, Tharp started her first sketches of *physiographic* diagrams. Her diagram of the North Atlantic was completed in 1956,[33] officially published in 1957,[34] and presented as a map inset to Heezen et al. (1959) (Figs. 5.1 and 5.4). To aid in these efforts Lamont secured the research ship *Vema*, which became one of the most influential oceanographic research ships, with over 1 million kilometers of total sailing during its lifetime as a research vessel.

1954. Tharp and indirect collaborator Howard Foster, a Ph.D. student who was drawing maps of *earthquake data* on maps of the same scale on the table adjacent to hers

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[33] Felt (2012), "by the end of 1956" Loc 1880.

[34] It appeared as an addendum to Elmendorf and Heezen (1957). In the acknowledgments of that paper, Marie Tharp is thanked first and the last sentence reads "The encouragement and guidance of Dr. Maurice Ewing has been of great value" (1093).

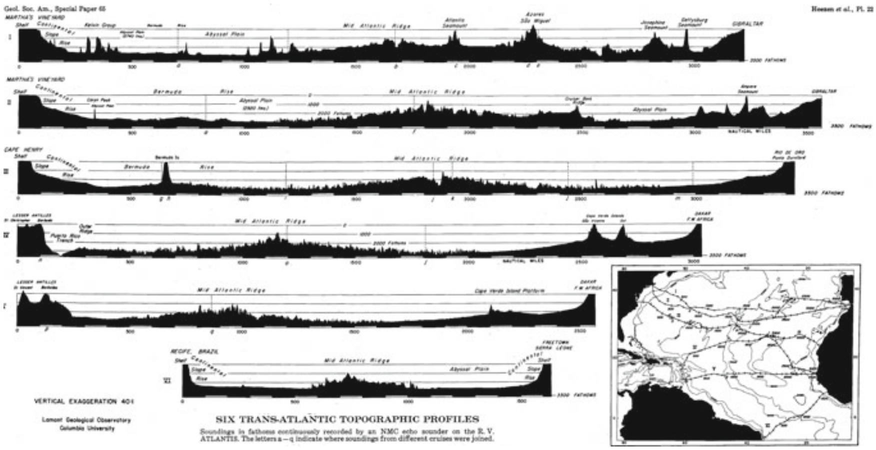

Fig. 5.5 "Six Trans-Atlantic Topographic Profiles" (with 40:1 vertical exaggeration). Bruce C. Heezen, Marie Tharp, and Maurice Ewing, (1959). The Floors of the Oceans: I. The North Atlantic: Geological Society of America Special Paper 65, https://doi.org/10.1130/SPE65. Heezen et al. (1959) (Lamont Geological Observatory, Columbia University), Plate 22

at Lamont, made an important discovery. Heezen had insisted that they draw their maps on the same scale.[35] While the exact date and circumstances are unclear, one (or both) of them, having superimposed the earthquake data map on the Mid-Atlantic Ridge valley map, noticed a strong concentration of earthquakes in the valleys and very few earthquakes beyond the ridge. This was of course further evidence for some kind of movement of the ocean floor. This earthquake data from Gutenberg and Richter (1954) and the USGS was shown as Plate 29 of Heezen et al. (1959).

1957. On March 26, 1957, Heezen gave a talk on the rift in the Mid-Atlantic Ridge to the Princeton Geology Department, at the end of which the influential geologist Harry Hess rose to his feet and declared, "Thank you, Bruce, for a lecture that shakes geology to its very foundations."[36] Some years prior, Hess had rejected a paper by Heezen on the very topic of the Mid-Atlantic Ridge, and its rift. Hess would become one of the key developers of modern plate tectonics.

1959. Publication of the monograph *The Floors of the Ocean: 1. The North Atlantic* by Heezen, Tharp, and Ewing. Choice passages about map abstraction include one where they discuss the difference between preparing a terrestrial and a marine physiographic diagram: "In the former the major problem is to select from more-detailed maps the features to be represented. […] In contrast, the preparation of a marine physiographic diagram requires the author to postulate the patterns and trends of the relief on the basis of cross sections and then to portray this interpretation in the diagram."[37]

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[35] Felt (2012), "same scale" Loc 1737.

[36] Meritt (1979), 273.

[37] Heezen et al. (1959, 3).

1966. The long-term episode Tharp and Heezen came to call "the harassment", which had already started to rumble due to their 1965 trip to India, Thailand, Taiwan, and Australia, if not before, intensified and came to a head for all involved parties as a consequence of a press conference at the 1966 2nd International Oceanographic Congress in Moscow. Heezen and Tharp shared information at the Congress that they had not strictly been authorized by Ewing, and Lamont more generally, to circulate. Furthermore, a paper Heezen had co-authored with other "Lamonters" (but not Ewing) was initially rejected by *Science*, but then accepted by *Nature*. Ewing was upset because Lamont policy was to have two senior scientists approve every paper before these were submitted to conferences, conference proceedings, or specialist journals. This protocol had not been followed when Heezen and co-author's paper was sent to *Nature*.[38] Of various descriptions of the harassment available, Marie Tharp puts it most directly and authoritatively:

> We had planned to study the Mediterranean Sea next, but we were diverted instead to the Indian Ocean [Fig. 5.6], because a diagram of it was urgently needed to help plan the International Indian Ocean Expedition. Now our efforts were [eventually] thwarted by a long-lasting falling out between Bruce and Doc. There are two sides to that story, but the result was that Doc banned Bruce from Lamont ships and denied Bruce access to Lamont data. He tried unsuccessfully to fire Bruce, who had a tenured faculty position at Columbia, but he did fire me. From then on, I was paid through research grants that Bruce received from the Navy, and I continued the mapping working at home.[39]

1967. First angled panorama map (Fig. 5.6) produced by Tharp, Heezen, and Berann. Tharp and Heezen would, on several occasions over the years, stay at Berann's house near Innsbruck, Austria, for long periods of time. According to Felt "The story of how the Indian Ocean map came into existence unfolds rather like the plot of a *Mission: Impossible* episode," and the interested reader is invited to consult Chap. 17 of her book for background on Fig. 5.6.[40]

1968. First absolute panorama map (Fig. 5.2) by Tharp, Heezen, and Berann. Moreover, Figs. 1 and 7 of W. J. Morgan's influential and classic 1968 *Journal of Geophysical Research* article "Rises, Trenches, Great Faults, and Crustal Blocks" were based on Heezen and Tharp maps.

1977. Heezen dies off the coast of Iceland. Tharp reports: "On June 21, 1977, Bruce Heezen died suddenly of a heart attack in a submarine [NR-1] near the Reykjanes Ridge. I was on the research ship *Discovery* studying the Ridge from above. We had recently completed work on our world ocean floor panorama and each had proofs with us on our respective boats."[41] *The New York Times* published an obituary two days after Heezen's death, which included this sentence: "The Heezen-Tharp physiographic maps, first of the North Atlantic and then of all major oceans of the world, were widely circulated by the National Geographic Society."[42]

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[38] Felt (2012), "senior research scientists", Loc 2900.

[39] Tharp (1999).

[40] Felt (2012), Loc 2451.

[41] Felt (2012), Loc 3818.

[42] Sullivan (1977).

1977/1978. Appearance of World Ocean Floor Panorama Map.[43] The mid-oceanic rift system spanning the entire globe is now shown as a *single system*—Earth as a Frankenstein-monster patchwork of tectonic plates (Fig. 5.7).

1978. Tharp attends a session of the General Bathymetric Chart of the Oceans (GEBCO) guiding committee in Ottawa, Canada, where plans for future editions of the World Ocean Floor Panorama were being considered. GEBCO figuratively ripped her map out of her hands in an act that could appropriately be called "systemic piracy". An online article puts it dramatically, but accurately: "Marie Tharp […] had to sit still while a roomful of men dismembered her legacy and divvied up the remnants among themselves in a frenzy of violent opportunism […] She watched ocean after ocean snatched from her grasp, her prospects for future work

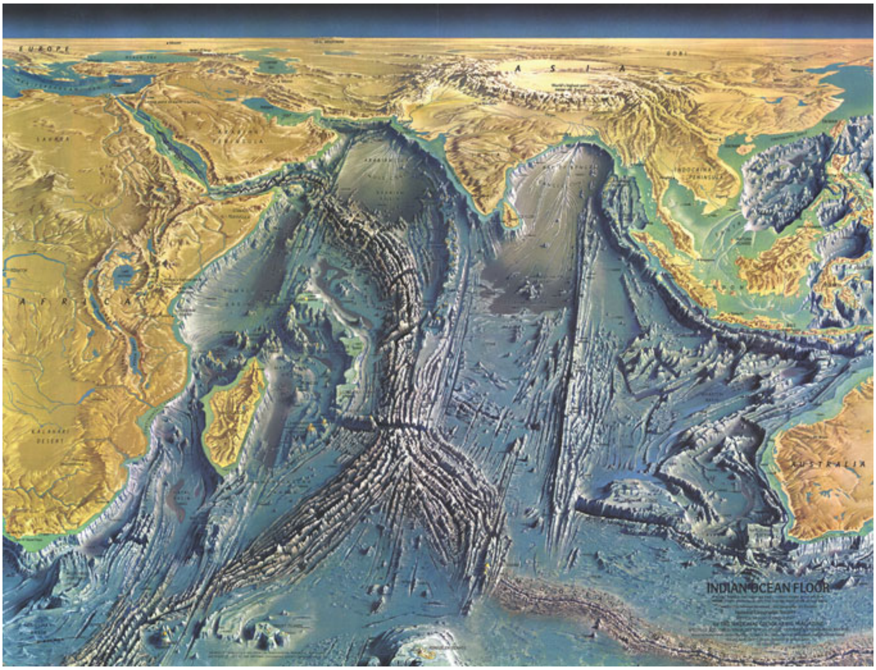

Fig. 5.6 The Indian Ocean Floor angled panorama map by Berann, Tharp, and Heezan was a supplemental, foldout map in the October 1967 issue of *National Geographic*. Subscriptions to that magazine numbered six million in the USA alone (Felt 2012, Loc 2810). Heinrich Berann/National Geographic Creative. National Geographic Image Collection

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[43] Proofs completed in 1977. Felt (2012), Loc 4121: "The first copy of the World Ocean Floor Panorama—conceptualized by Marie Tharp and Bruce Heezen, painted by Heinrich Berann with assistance from Heinz Vielkind, and funded by the U.S. Office of Naval Research—rolled off the presses at about 7:00 p.m. on May 17, 1978." In the final stretch of producing the WOFP, Tharp had hired a Ukrainian cartographer, Luba Prokop. WOFP has since appeared in many places, in various avatars, and even in poster format.

Fig. 5.7 World Ocean Floor Panorama, Bruce C. Heezen and Marie Tharp, 1977. Copyright by Marie Tharp 1977/2003. Reproduced by kind permission of Marie Tharp Maps LLC image provided by Lamont–Doherty Earth Observatory

chopped to a few sectors around Australia, hardly enough to sustain her financially or intellectually for more than a few months."[44]

1982. An official version of what Tharp calls her "Opus" appears in a commemorative volume on Heezen.[45] For the remainder of her life, she works and revises this autobiographical writing, which otherwise remains unpublished.

1997. Tharp is named one of the four greatest cartographers of the 20th century by the Library of Congress's Geography and Map Division's Philip Lee Society. That same year, her work is shown in a Library of Congress exhibition *American Treasures from the Library of Congress*, marking the 100th anniversary of the Jefferson Building. At the opening gala, for which President Clinton is present, she sees the original draft of the Declaration of Independence, maps drawn by George Washington, and the Emancipation Proclamation, among other treasures, from her wheelchair. The friend accompanying her recounts how she cried when her eyes finally fell on one of her ocean floor maps. She tells him, "I wish that Papa and Bruce could see it."[46]

2001. Tharp receives the first annual Lamont–Doherty Heritage Award.[47]

2006. Tharp dies of cancer in Nyack, New York.

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[44] Debakcsy (2018).

[45] Tharp (1982).

[46] Felt (2012), Loc 4637.

[47] Bizzarro (2001).

Map Types

Tharp and Heezen produced five kinds of maps:

> *Physiographic diagrams* provide a "45 degree view" from above, with stylized iconography and shading (Figs. 5.1 and 5.4).
>
> *Profiles* are cross-sections of the ocean floor, with vertical heights exaggerated 40 times (Figs. 5.4 and 5.5).
>
> "*Panorama maps*" painted by Berann, are of 3 kinds:
>
> *Perspective maps* by Berann, under Tharp and Heezen's guidance, were similar to Richard Edes Harrison's World War II perspective maps, as if looking at Earth from a satellite some 40,000 km above Earth's surface (Northern Atlantic Ocean[48]; Winther 2020, Chap. 3).
>
> *Angled panorama maps* are a kind of bird's-eye, abstracted view where the whole image is angled/curved, yet the horizon is flat (Fig. 5.6).[49] Berann painted the Himalayas and Alps in this manner, and – under the guidance of Tharp and Heezen – the ocean bottoms. Mapping the deep blue oceans indeed.
>
> *Absolute panorama maps* are painted as an all-knowing view from an absolute vantage point – the Mercator projection is appropriate for this purpose, and was used (Figs. 5.2 and 5.7).

Cartopower and the Future of Mapping

The depths of the oceans are a mystery. No comprehensive, fine-grained bathymetric map exists. Not yet. Only 5% of the ocean bottoms have been fully mapped.[50]

Recent satellite technologies permit precise measurements of sea surface topography and gravitational anomalies across the planet. With satellite altimetry and gravitational potential measurements, new comprehensive, small-scale maps can be drawn (Fig. 5.8). Such maps do not, for better *and* worse, use interpolation and extrapolation. These coarse-grained maps precisely portray the data at the highest level of resolution the data permit. Yet, much work remains to be done.

Whatever our future mapping will look like, one thing is certain: Like all forms of representation, they will exist within a power structure. I call the specific forms of power encoded in maps "cartopower". Cartopower is twofold: first, it is the political, economic, and social power structure, often invisible, behind a map; second, it is the power that a map exerts in the world via its ontological assumptions. Power scaffolds maps, and maps exert power—maps thereby build worlds.[51]

An anatomy of the cartopower of Tharp and Heezen's maps illuminates, yet again, the ubiquity and disproportionate importance of military and corporate interests in many scientific endeavors.

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[48] *National Geographic*, June 1968. Found here: http://www.berann.com/panorama/archive/image/PN_W_10.jpg. Accessed November 8, 2018.

[49] Patterson (2000) explores this kind of panorama map.

[50] See Copley (2014) for a clear exposition of what this actually means.

[51] I discuss cartopower in terms of my multiple representations account of ontologizing in Chap. 5 of Winther (2020). See Harley (2001) and Wood (1992) for related views.

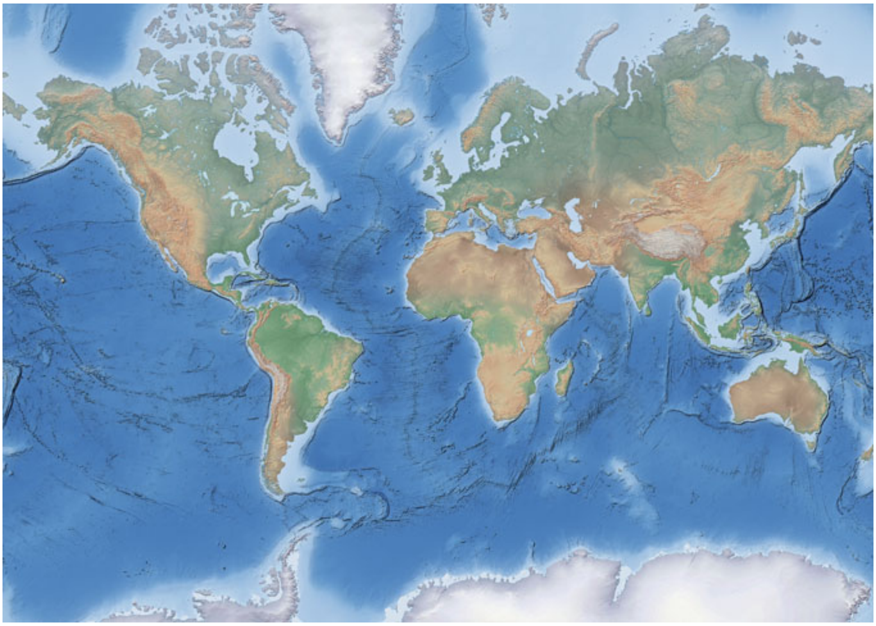

Fig. 5.8 Bathymetric map using gravitational anomalies and satellite altimetry from data provided at the Scripps Institution of Oceanography (UCSD), and originally explained in Smith and Sandwell (1997). Data available here: https://topex.ucsd.edu/WWW_html/mar_topo.html Drawn by cartographer and graphic designer Mats Wedin

Consider the power structures that enabled Tharp and Heezen's groundbreaking research. A historical article by Doel et al. (2006) explores how underwater bathymetry became very secretive during and after WWII, after an initial global free information/open source period immediately following WWI. The US Navy now wished to collect secret information about where their submarines could hide, the location of seamounts and mountains into which submarines could crash, and the whereabouts of enemy submarines.[52] To these ends, the Navy was busy developing an underwater "SOund SUrveillance System" (SOSUS)—listening devices that could detect Soviet submarines. In all of this, the Pentagon decided that "creating a comprehensive map of the ocean floor" was essential.[53] Thus, "Lamont Geological Observatory was a quintessential Cold War institution, largely dependent on military contracts to support its research programs."[54] Heezen's and Tharp's research was funded by heavy military interests.

Corporate interests did not take a backseat. In the early 1950s, AT&T Bell Labs was busy trying to create the first trans-Atlantic commercial marine telephone lines.

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[52] Doel et al. (2006, 608).

[53] Doel et al. (2006, 608).

[54] Doel et al. (2006, 609).

Interestingly, these labs also worked closely with the American military on its classified SOSUS project. Heezen's direct (and Tharp's indirect) collaboration with AT&T Bell Labs provided them with two crucial resources: "a rich, vastly expanded source of seafloor data" and "invaluable financial resources."[55] I would also go so far as to agree with Doel et al's statement that "Bell Labs funding made the Heezen-Tharp North Atlantic physiographic map *possible*."[56]

Much like the Cold War growth of physics, space technology, and computer science, the emergence of maps of the ocean floor by Tharp and Heezen was suffused with cartopower. This was a high-stakes mapping project. As precise, beautiful, scientific, and creative as Marie Tharp's maps were, they were also buffeted about in a perfect storm of political, culture, military, and economic power.

Just as there is a continuity of positivist, scientific abstraction practices across cartography and GIS, so there are ongoing concerns with bias, discrimination, and moneyed interests.[57] For instance, in a milestone article, feminist GIS'er Mei-Po Kwan asks: "is GIS an inherently masculinist technology or social practice? How are particular subjectivities or gendered identities constituted through routine interaction with GIS technology? Do women and men interact with or use GIS technology differently? […] How may GIS technology perpetuate gender inequality or occupational segregation in the information technology labor market and women's status in geography?"[58] These questions are clearly important to any perspective on critical issues in GIS, and the ongoing nature and deployment of cartopower. They also point to issues of sexual and other forms of bias that researchers may suffer, shaping the way that their work becomes available or not.

Consider the problem of what I will call "personal style harassment", which is when creative spirits, with independent flair, find themselves moving around restlessly—both in their minds and in the world—unable to fit into the power structures at their institutional home. In the case explored in this chapter, Heezen's creative personal style conflicted strongly with the power structure of Director Ewing's Lamont. The institution issues rules, which are open to interpretation. Even when there is some modicum of clarity about such rules, there are many of them, and a reasonable and overworked human being is simply not able to follow all of them. Such limitations are tacitly accepted by the upper administration, which ignores small infractions or suppresses, to some extent, enforcement of narrow rule-following. They do this *until* a creative thinker comes upon the scene, trying to contribute on her own terms, in her own tempo, sometimes shaking the foundations of her field. She then gets every rule thrown at her. Tharp and Heezen were both subject to such a personal

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[55] Doel et al. (2006, 610, 611).

[56] Doel et al. (2006, 611).

[57] Discussions of the simultaneous empirical and technological *and* social and political facets of GIS can be found in, e.g., Kwan (2002), Schuurman (2004), Pavloskaya (2006), St. Martin and Wing (2007), Cope and Elwood (2009), Crampton (2010), Dodge et al. (2009, 2011).

[58] Kwan (2002, 275, footnotes suppressed).

style harassment, with Tharp experiencing further bias or harassment in the form of sexism.[59]

Science journalist Stephen S. Hall made the point clearly and forcefully in his obituary of Tharp:

> Maurice (Doc) Ewing, the brilliant and autocratic director of what is now the Lamont-Doherty Earth Observatory at Columbia, remained famously unpersuaded by the growing evidence of continental drift and began to clash with Heezen over both ideas and ego. Heezen had become a tenured professor, but Ewing did what he could to thwart the mapping project. He refused to share important data about the sea floor with the map makers — data that Heezen's graduate students sometimes surreptitiously "exported" to Tharp and her assistants. He stripped Heezen of his departmental responsibilities, took away his space, drilled the locks out of his office door and dumped his files in a hallway. Most important, Ewing blocked Heezen's grant requests and, as [Paul J.] Fox said, "was essentially trying to ruin Bruce's career."[60]

We must address scientific and technical features of cartography and GIS *as well as* these complex and interrelated fields' social, political and economic aspects. This includes social conditions at institutional as well as interpersonal scales. Science is data, theory, and knowledge; but science is also politics, economics, and ethics. Whatever the fate of the map within GIS, its conceptual framework developed within cartography has much to teach us, even those of us working on GIS.

Conclusion: Ocean Mapping and Gratitude

The first part of this chapter reviewed some basic map-making abstraction practices. Whenever we compare a map to its territory, we shift from everyday, human-scale perception to something more detached and abstract. I tried to show the continuity between analog and digital cartography in strategies of abstraction. As abstraction practices, selection, simplification, and exaggeration apply as much to old-school cartographic maps as to cutting-edge GIS efforts.

I also surveyed the tremendous careers of Marie Tharp and Bruce Heezen. In addition to carefully studying Tharp's maps, if we also learn about how she turned her house, and later Heezen's house, into a cartographic data management center, training zone, gourmet kitchen, studio, and library, we are left with no doubt about how remarkable these researchers were. In the end, Tharp looked back at her life with gratitude:

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[59] Doel et al. (2006, 609) proclaim: "Their early careers offer a snapshot of the divergent opportunities for men and women in the earth sciences in mid-twentieth century America. One of the very few female researchers at Lamont during its first decades, Tharp had limited financial security and few opportunities to attend scientific meetings. Typical for this period, her contributions often remained invisible." Moreover, recall the 1978 GEBCO affair above, where Marie Tharp's work was forcefully removed from her—in my moral universe, this was an act of piracy against Tharp. For a discussion of the "climate and consciousness" (9) of women in geography (not geology) see Monk (2004).

[60] Hall (2006).

> Not too many people can say this about their lives: The whole world was spread out before me (or at least, the 70 percent of it covered by oceans). I had a blank canvas to fill with extraordinary possibilities, a fascinating jigsaw puzzle to piece together: mapping the world's vast hidden seafloor. It was a once in a lifetime—a once in the history of the world—opportunity for anyone, but especially for a woman in the 1940s. The nature of the times, the state of the science, and events large and small, logical and illogical, combined to make it all happen.[61]

The stories of Tharp and Heezen also remind us, however, that politics, greed, and discrimination die not. We have much to do not only on environmental and ecological matters but also on social equity. In gratitude for what we have today and with hope for a genuinely sustainable future let us please get to work.

Acknowledgements Kristine Sergejeva provided expert project coordination. Laura Laine secured figure permissions. Mats Wedin processed and finalized figures. Lucas McGranahan and Gloria Sturzenacker provided outstanding editorial commentary. Heidi Svenningsen Kajita and Mette Bannergaard Johansen were sounding boards. Gratitude to all.

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[61] Tharp (1999).

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