Constant-Scale Natural Boundary Mapping and (I) Graphic Analysis of Shear Cracks on Enceladus, (II) Geomorphology on Comet 67P/Churyumov-Gerasimenko, and (III) Context of Tombaugh Regio on Pluto.

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Introduction: As in the 16th century when global explorations outmoded existing maps and led to Mercator's projection of 1564, we stand again on a similar threshold: current cartographic paradigms struggle with irregular planetary objects and with global dynamics as surely as Ferdinand Magellan and his contemporaries struggled with Ptolomeic maps. Mercator's projection, with later improvements, has been basic in cartography ever since its invention [1], yet those improvements happened long before the need arose to map irregular objects or track global dynamics. Here we apply our radical cartographic alternative to three current and noteworthy opportunities.

Background: Constant-scale natural boundary mapping [CSNB] transforms the surface of any essentially globular object—spherical, triaxial or irregular—to the 2-dimensional plane in a manner which, unlike orthodox projections, preserves proportions and logical adjacencies of natural surface districts [2]. Within resource limits, we continue testing this prototopological (foldable) cartography's applicability to planetary bodies, its suitability to foster contemplation about those bodies, its predictive possibilities, and its educational role in communicating to research colleagues and the wider community.

CSNB mapping of Enceladus to confirm dynamic origin of shear crack network: This Saturnian moon's surface is shaped by external and internal forces including impact cratering, tectonics and tidally stimulated cryovolcanism. It exhibits both east-west and north-south asymmetries in terrain distribution, due in great part to its tidally locked relationship to Saturn. Poles clearly differ: the south is erupting and resurfacing, whereas the north is part of the oldest, most heavily cratered terrain. At mid to low latitudes, cratered terrain, facing permanently toward and away from Saturn, alternates (every 90˚) with younger, more deformed terrains—striated, ridged and curvilinear—indicating complexity, resurfacing, and tensional stresses [3]. Last year, we proposed that 'tiger stripes' are gravitationally induced shear cracks [4, 5]; other researchers reach a similar conclusion [6]. Here we test a CSNB-modified Eisenlohr projection [7] (Figure 1 with deeper cusps), aligning map perimeter with minimum strain, as a Maxwell surface [8] to graphically resolve south polar stress as tidal force resultant.

CSNB mapping of 67P/C-G to characterize bimodal geomorphology: The Rosetta mission indicated that 67P has complex morphology on cm to km scales [9] (Figure 2). The shape of the approximately 4 km by 6 km object is bimodal. Its origin as two objects that collided at low velocity is indicated by 'terrrace' features (exposed layers of partially stripped icy volatiles), oriented differently on each mode. The irregularity of the highly porous surface is considered indicative of ongoing volatile removal through a combination of explosive release and sublimation. With the encouragement of Rosetta team members [10], who provided a digital shape model, we map the comet's surface comprehensively and in accurate regional proportions: two global maps arranged by geomorphological clarity rather than the customary pseudoclarity of, for example, a plate carrée (simple cylindrical) projection. A valley-bound map shows bimodal orientation of terrace 'hills'; a ridge-bound map shows basin distribution within the bimodal structure. Either map's edge may adapt to real-time shape evolution.

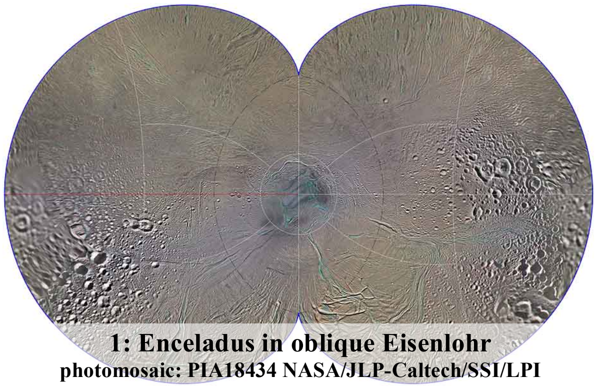
CSNB mapping of Pluto to provide context for Tombaugh Regio origin: The New Horizons mission provided unanticipated evidence for Pluto's rugged and dynamic surface, which formed without the gravitational interactions assumed to have shaped features on similarly sized icy moons of outer, giant planets [11]. Pluto's surface has canyons and mountains several kilometers in size. Of particular interest is the apparently geologically active, heart-shaped, volatile-rich Tombaugh Regio of unknown origin (Figures 3 and 4). Tombaugh has been observed as a spot of variable brightness in historical times and lacks evidence of cratering. As in our 2015 maps of coronae on Miranda [5], our two global maps are constructed pragmatically and from incompleteness: Tombaugh as map periphery (a), and as map center (b). Map (a) is edged by the network of points most central to Tombaugh (supplemented by prominent secondary features), and is used to derive a network of points most remote from Tombaugh, which, in turn, edge Map (b). Map (b) focuses on Pluto's observed surface, surrounded by a metrically precise, Tombaugh-complementary, irregular subdivision of its "away" face. Pending better information, map (b) is ideal for pondering and discussing Tombaugh's exo- or endogeneity, local or global influence, transcience or permanence.

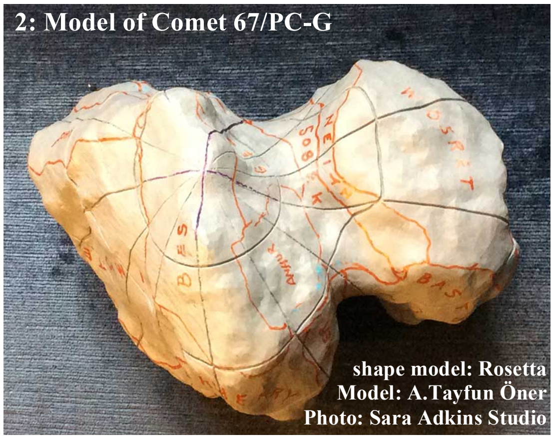
Summary: Comprehensive, well-focused and accurately proportioned images increase our ability to think and communicate about planetary objects and processes when global matters are at issue; we thank researchers and chroniclers who find the CSNB product useful [12, 13].

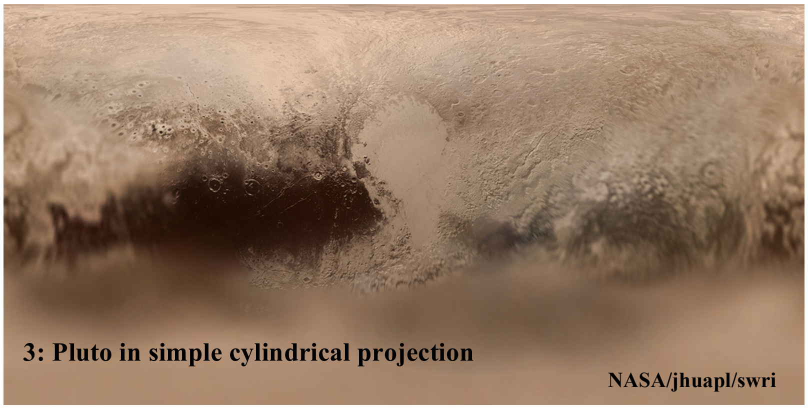
CSNB generates comprehensive and accurately proportioned images, but it is not an incremental improvement. Instead, it is a disruptive reimagining.

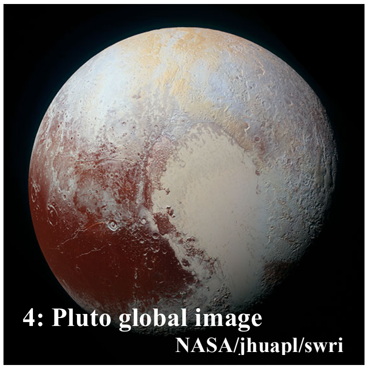
We enthusiastically seek collaborations with science teams with technical and financial resources to digitize CSNB, thereby actualizing its potential more powerfully than currently possible.

References: [1] Boyer C. B. (1968) *A History of Mathematics*, p. 329. [2] Clark P. E. and Clark C. (2013) “Constant-Scale Natural Boundary Mapping to Reveal Global and Cosmic Processes,” *SpringerBrief,* 116 pp. [3] Crow-Willard E. N. and Pappalardo R. T. (2010) *LPS XLI,* Abstract #2715. [4] Clark C. S. and Clark P. E. (2015) *LPS XLVI*, Abstract #1389. [5] http://www.hou.usra.edu/meetings/lpsc2015/eposter/1389.pdf. [6] Yin A. and Pappalardo R. T. (2015) *Icarus* 260, 409–439. [7] Snyder J. P. (1989) *An Album of Map Projections*, USGS Prof. Paper 1453, p. 184–185. [8] Maxwell J. C. (1869) “On Reciprocal Figures, Frames and Diagrams of Forces,” *Trans. Roy. Soc. Edin.* 26, 1–40. [9] Sierks H. et al. (2015) *Science*, 23, 347, 6220. [10] H. Sierks, L. Jorda and S. Ulamec (2015) personal communication. [11] Betz E. (2015) Astronomy.com/new/2015/07/plutos-icy-plains-pits-and-mountains-take-shape-in-Tombaugh-Regio [12] Byrne C. J. (2016) *The Moon’s Largest Craters and Basins*, DOI 10.1007/978-3-319-22032-1, p. 236. [13] Stooke P. J. (in press, March 2016) *The International Atlas of Mars Exploration: Volume 2, 2004 to 2014: From Spirit to Curiosity*, ISBN-13: 978-1107030930, Figure 210.


1: Enceladus in oblique Eisenlohr
photomosaic: PIA18434 NASA/JLP-Caltech/SSI/LPI


2: Model of Comet 67/PC-G
shape model: Rosetta
Model: A.Tayfun Öner
Photo: Sara Adkins Studio


3: Pluto in simple cylindrical projection
NASA/jhuapl/swri


4: Pluto global image
NASA/jhuapl/swri