PROGRESS 2019: CONSTANT-SCALE NATURAL BOUNDARY MAPPING TO DEPICT MATERIAL TRANSPORT ON COMET 67P/C-G. C.S. Clark[1] and P.E. Clark[2], [1]Chuck Clark architect, 1100 Alta Ave., Atlanta, GA, rightbasicbuilding@gmail.com, [2]JPL, California Institute of Technology, pamela.e.clark@jpl.nasa.gov.

Introduction: Constant-scale natural boundary mapping [CSNB] is a prototopological projection method that transforms the whole surface of any essentially globular object—even rubber duckies—to the 2-dimensional plane in a manner which, unlike conventional projections, minimizes distortion of shape, delineate overhangs, and preserves logical adjacency of natural districts [1]. Because CSNB uses natural features to create projections, global maps may be organized to clearly depict global-scale phemomena. We make a complementary pair of global maps suited to depict 67P/Churymov-Gerasimenko's south-to-north material transport.

Background: Cometary nuclei have far more transient morphologies than asteroids. Ongoing change of the 67P/C-G nucleus, which may have begun as a contact binary [2], results from differential loss of gas and solid material due to solar-induced heating, varying as a function of solar distance and seasonal exposure [3]. Southern hemisphere "summer" occurs at perihelion, northern summer at aphelion. *See Figure 1.*

In 2016 we mapped 67P with a ridge-hugging edge. The map folded to a volume within which the comet's shape fit snugly, indicating that regional shape distortion was minimal, [5]. But our map poorly served an object whose surface modification is driven by migration of sublimated surface material from the warmer, sun-facing hemisphere to the colder, opposite side [6]. Logical depiction of the relevant morphology requires a map that encircles the receiving hemisphere with the wasting hemisphere: north surrounded by south. And a complementary map: south surrounded by north.

In 2017, using boundaries of geomorphological districts as map edge, we sketched such maps [7]. In 2018 we drafted them. From feedback that Ash wastes material in two directions, with Imhotep acting as a secondary trap [8], we subdivided it along its spine.

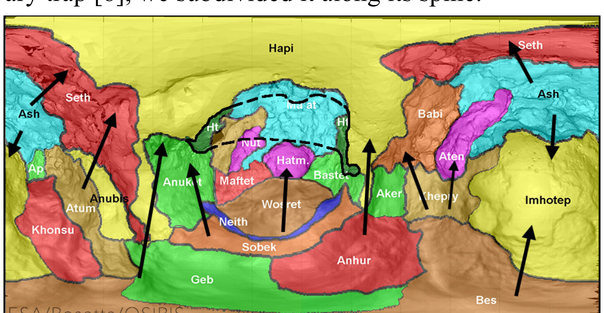

Figure 1: 67P/C-G Geomorphological Districts. *We add material transport arrows. Full extent of Hathor shown dashed. Note that Ash wastes in two directions.*

Method: Critical linear features were traced from a physical model. Portions of traverses were assembled into map-sections, adjusted proportionally, and gridded by latitude and longitude. (See [1], pp. 27–42.)

Results: Preserving rubber-duck proportions was challenging: our 2018 maps were substandard (for CSNB), as seen by comparing those maps' midregions with the model. We checked the cross-map ratios with five measurements rather than the two that had sufficed for multi-lobed Itokawa and Ida [9,10]. We plotted Tissot ellipses [11] to characterize local distortion, and re-annotated hinges and nodes. Because the design limits each tree's extent, the maps fold not to facsimiles but rather to enigmatic shape-model condensations. *See Figure 2.*

Discussion: Proportional fidelity required "pruning the tree" in the neck region; local considerations yielded to global. This geometric imperative increased scale in the neck, relative to the edge. Thinking a little on the soap-bubble theory of minimal surfaces [12,13] applied to CSNB's branch-node-hinge structure, shows this novelty should be expected. But we were surprised nonetheless because we missed it on the earlier maps, likely because Itokawa and Ida's concavities are much less than on 67P.

Future: We seek additional feedback on our boundaries; we'll then proceed to photomosaics.

Limitation: CSNB is a graphic experiment. It differs substantially from digital transmutations of analytic projection geometry. Our results are proof of concept, suitable for general study and communication. We invite collaborators for software creation.

References: [1] Clark P.E. and Clark C. (2013) "Constant-Scale Natural Boundary Mapping to Reveal Global and Cosmic Processes," *SpringerBrief*; [2] Sierks et al. (2015) *Science* 347, doi:10.1126/science .aaa1044; [3] Lamy et al. (2007) *Space Science Reviews 128*, 23–66; [4] El-Maarry M.R. (2016) pers. comm.; [5] Clark C.S. et al. (2016) *LPS XLVII* Abs. #1044 E-POSTER; [6] Lee J.C. et al. (2017) *MNRAS 462*, doi:10.1093/mnras/stx450; [7] Clark C.S. and Clark P.E. (2017) *LPS XLVIII* Abs. #2367 E-POSTER; [8] *vide supra* (2018) *LPS XLIX* Abs. #2879 E-POSTER; [9] *vide supra* (2010) *LPS XLI* Abs. #1264 POSTER; [10] *vide supra* (2009) *LPS XL* Abs. #1133 POSTER; [11] Snyder J.P. and Voxland P.M. (1989) *USGS Prof. Paper 1453*, 8; [12] Meeks W.H. III and Perez J. (2011) *Bull. Amer. Math. Soc. 48*, doi:10.1090/s0273-0979-2011-01334-9; [13] Newman J.R. (1956) World of Math. Vol. 2, *George Allen and Unwin*, 882–909.

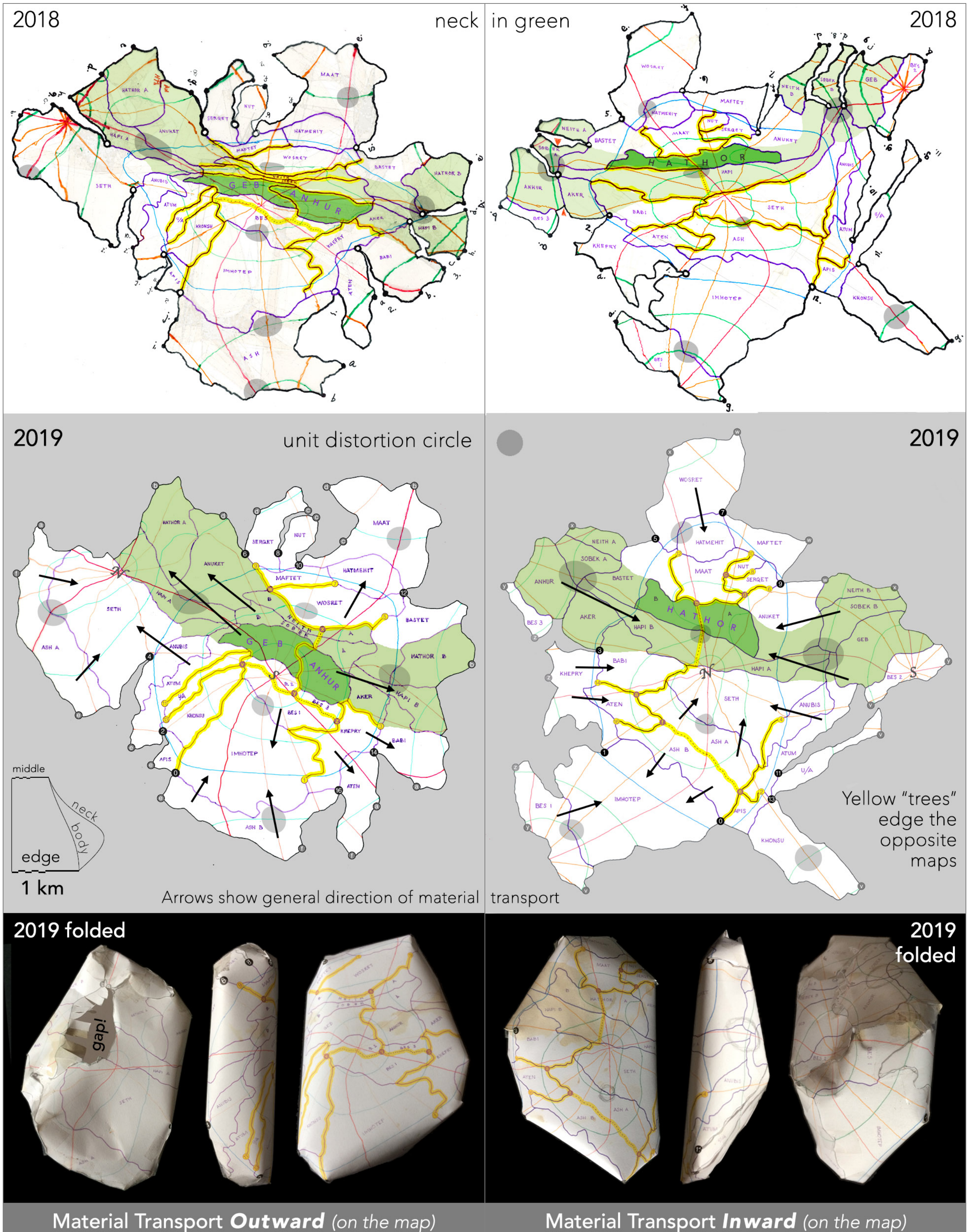

Figure 2: 2018–2019 Progress of Two CSNB Material-Transport Global Maps of 67P/Churyumov-Gerasimenko. *Compare top and middle rows: the maps change in both proportion and outline; note the change in shape of Geb/Anhur (left column) and Hathor (right column). Note too that Hathor is not obscured. The gap in the 2019 "Outward" folded form is due to a drafting shortcut when subdividing Ash (see text).*