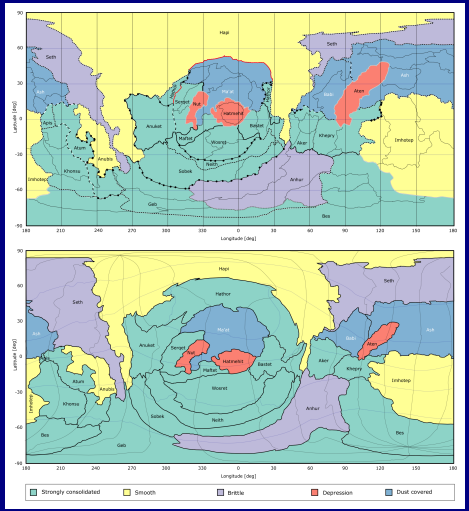
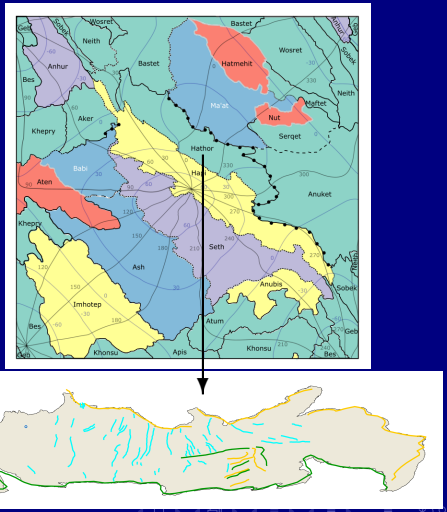
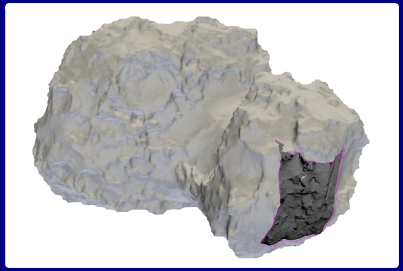
Mapping a Duck: Geological Features and Region Definitions on Comet 67P/Churyumov-Gerasimenko

Björn Grieger, Mireia Leon-Dasi, Sebastien Besse, Michael Küppers (ESAC, Madrid, Spain)

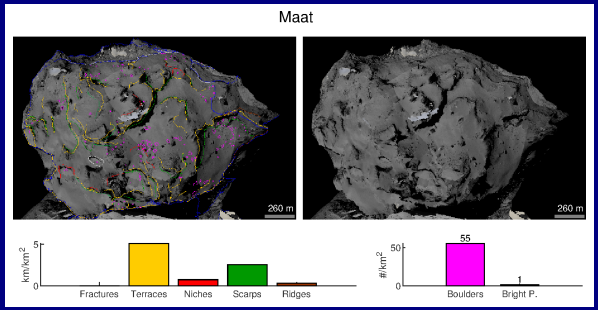




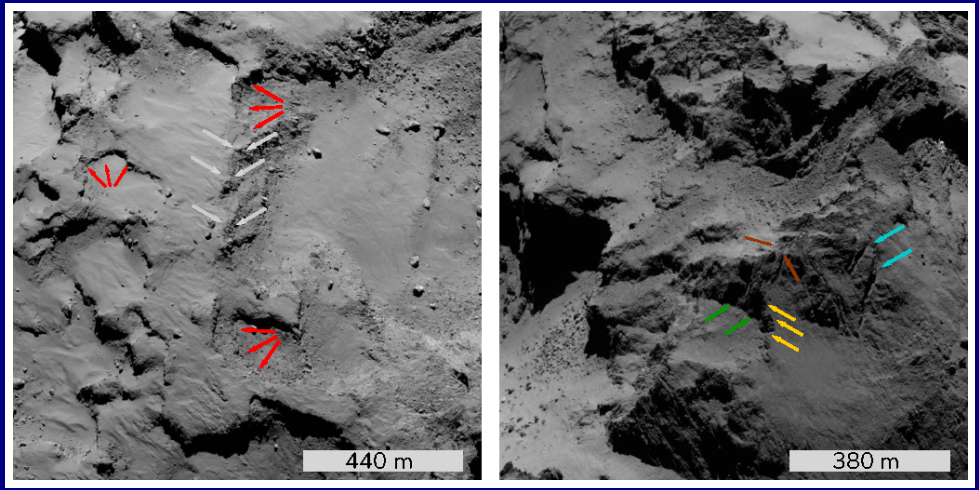
The Small Body Mapping Tool (SBMT)



SBMT: SHAP4S shape model of 67P with OSIRIS NAC images projected onto the surface. Features can interactively be marked and their 3D coordinates exported.

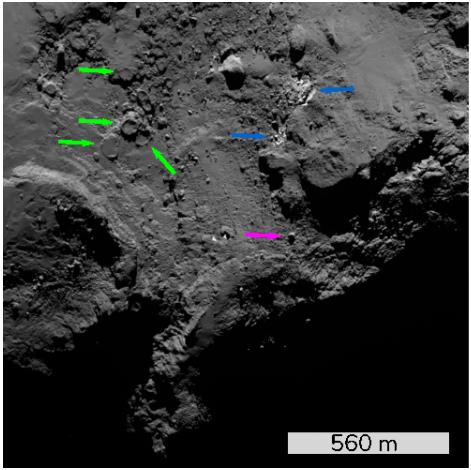


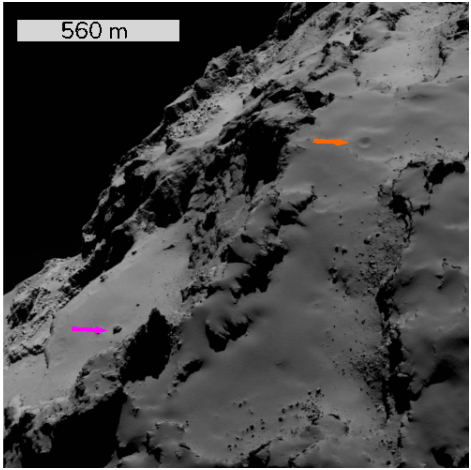
Examples of linear features (Hatmehit, Aker)



Depression rim, niches, fractures, ridge, terrace, scarp

Examples of circular features (Imhotep, Ash)



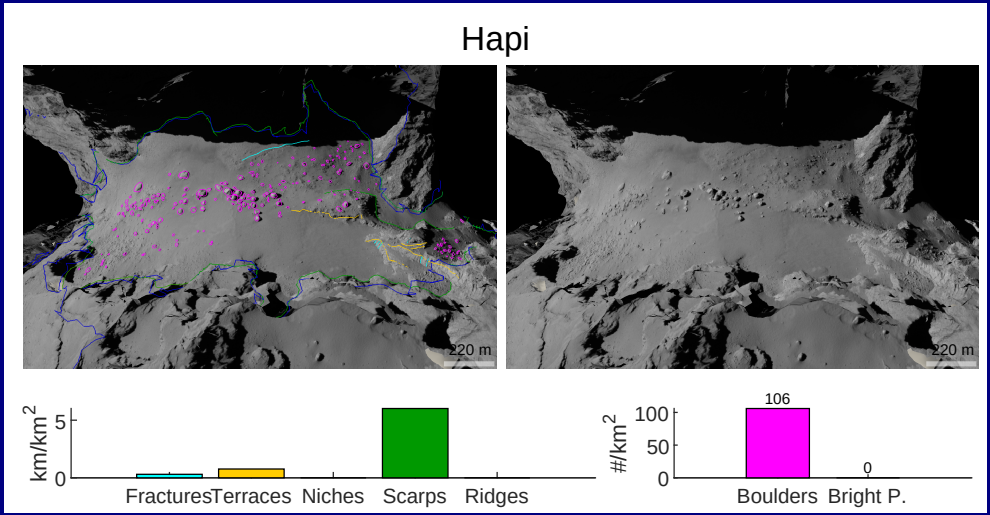


Circular mounds, bright patches, boulders, impact crater

Feature mapping criteria

Feature	Mapping criteria	Min. size	Map
	Linear features		
Terrace	Terrace margin	20 m	
Niche	Top of the feature	20 m	
Ridge	Upper edge	100 m	
Rim	Upper edge	100 m	
Fracture	Along the feature	15 m	
Scarp	Contact with lower plain	20 m	
	Circular features		
Boulder	Enclose the feature	∅5 m	
Mound	Enclose the feature	∅5 m	
Crater	Enclose the feature	∅5 m	
Bright Patch	Enclose the feature	∅2 m	

Hapi mapped features



Hapi wraps so much arround the comet that it cannot completely be captured in just one image.

How to display maps?

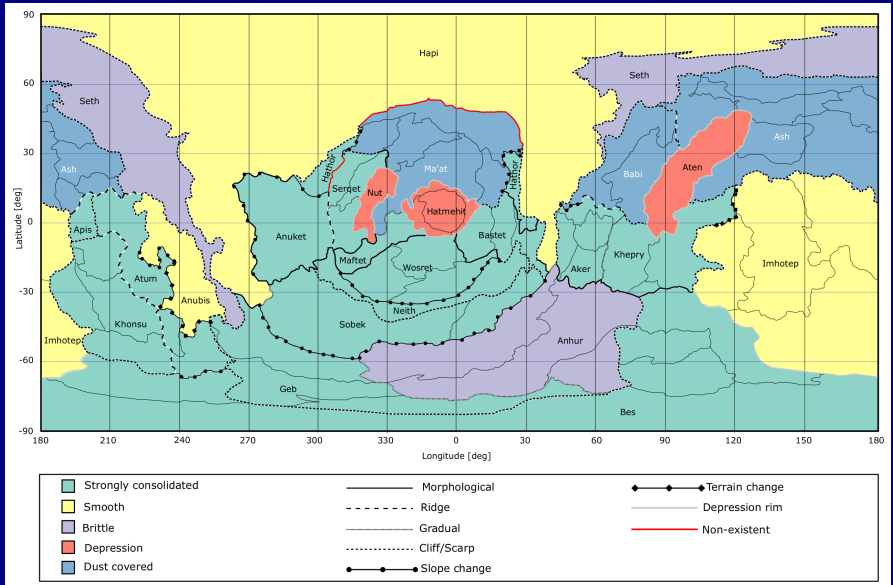
Displaying mapped features directly on real images or on renderings of a 3D shape model has shortcomings:

- Depends on the viewing angle, so no common framework
- Several different views are needed to cover the whole comet.
- Even for a single region, more than one view may be needed.

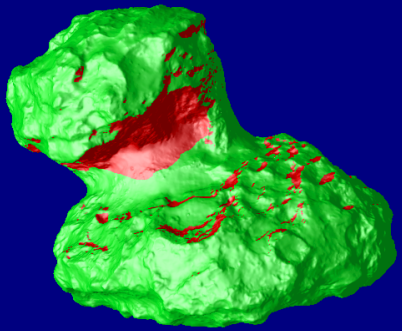
From the SBMT, we have 3D coordinates in the Cheops frame for all mapped features. Can we project them onto a 2D map?

- No common global map projection can display the complete surface of 67P.
- We employ the Quincuncial Adaptive Closed Kohonen (QuACK) map.
- The QuACK map is topologically equivalent to the Peirce quincuncial projection of the world.

Bluntly applied equidistant cylindrical projection

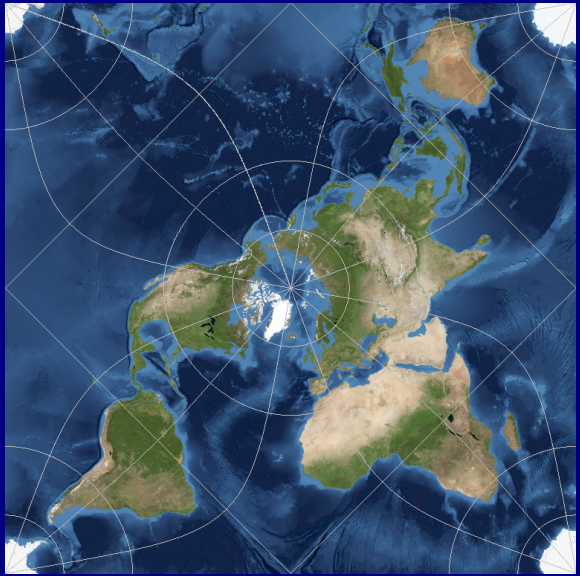


Invisible areas



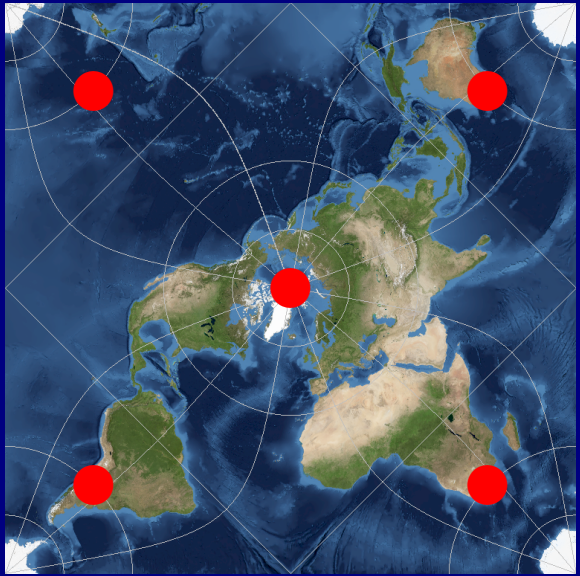
- This is not a particular problem of the equidistant cylindrical projection.
- There are different points on the comet with the same longitude and latitude.
- Any projection relying on longitude and latitude will fail.

Peirce quincuncial projection of the world (1879)



- The Northern hemisphere is mapped to the inner square (standing on a corner).
- The Southern hemisphere is cut into four triangles, with the South pole in all four corners of the outer square.
- Thus the map is made of five pieces that form a quincunx.

Peirce quincuncial projection of the world (1879)



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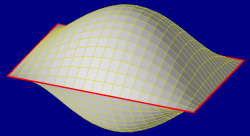
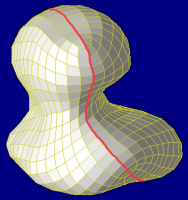
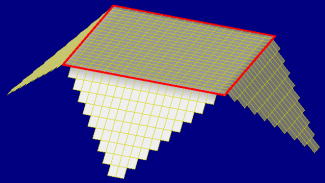
Fitting the QuACK map (toy model, 40×20 cells)



Two squares are sewed together to form a **closed** map.

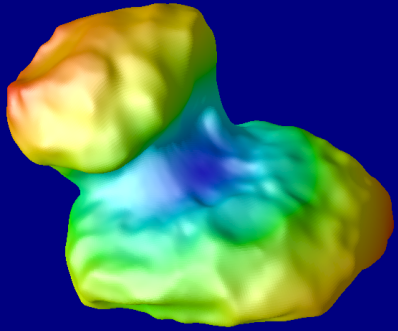


The **adaptive** map learns the shape from randomly presented sample surface points like a self-organizing **Kohonen** neural network.

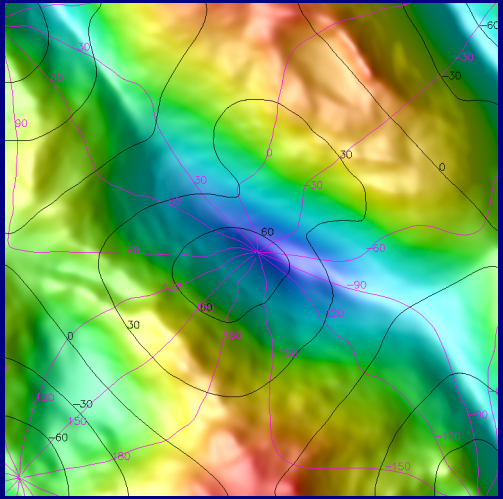


The result is a very special shape model that can be unfolded to a 2D map with **quincuncial** layout.

Full resolution QuACK map (400×200 cells)

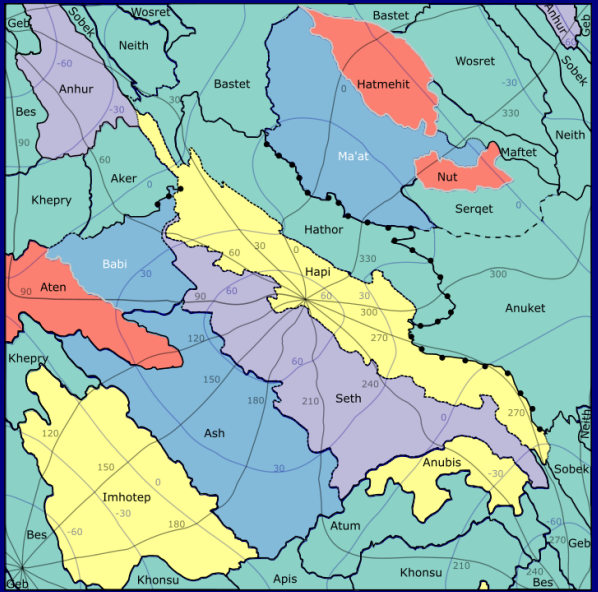


The QuACK map is a (relatively low resolution) shape model in its own right.



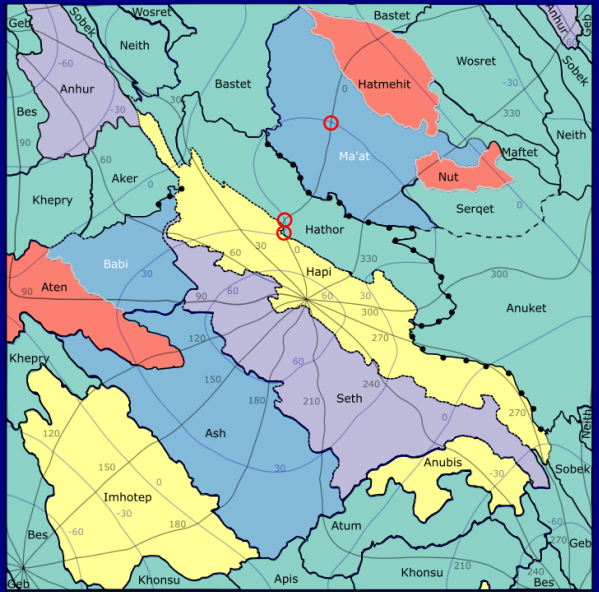
It can be unfolded to a 2D map of the complete surface of the comet.

Regions in the QuACK map projection



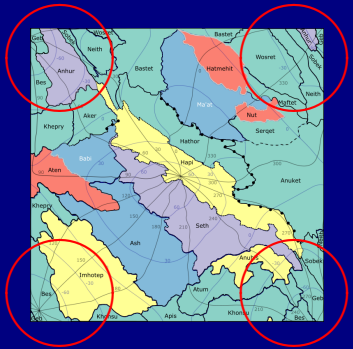
- Region boundaries (and any features) are mapped to the QuACK map with sub-grid accuracy by bilinear interpolation.

Regions in the QuACK map projection



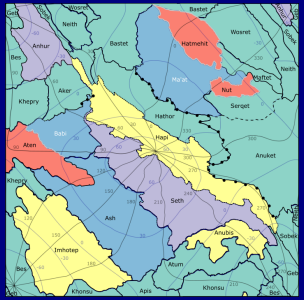
- Region boundaries (and any features) are mapped to the QuACK map with sub-grid accuracy by bilinear interpolation.
- Longitude and latitude lines provide an example of three different points with the same coordinates.

Tessellation



- It is inconvenient that regions are intersected by map edges, particularly in the South polar area.

Tessellation



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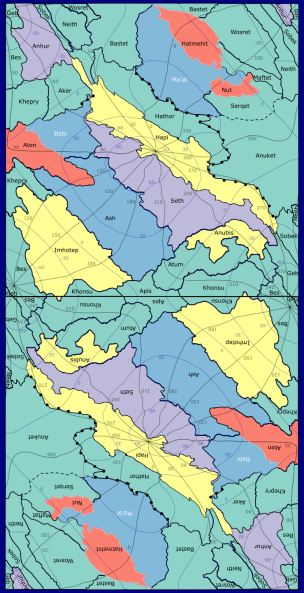
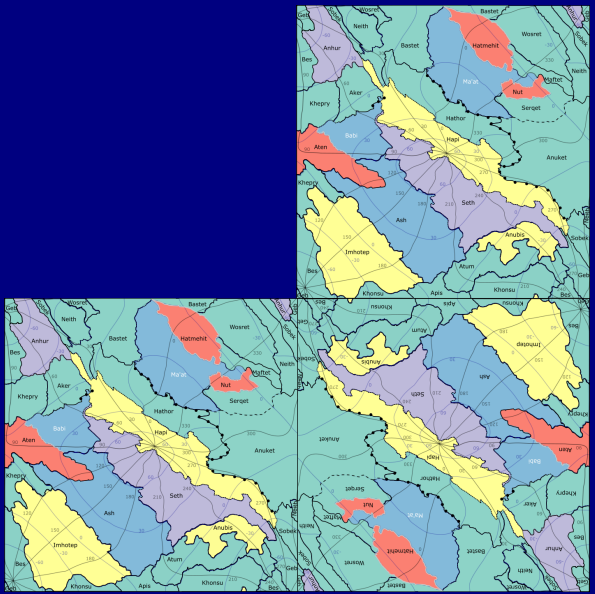
- However, . . .

Tessellation



- It is inconvenient that regions are intersected by map edges, particularly in the South polar area.
- However, this can be tessellated!

Tessellation



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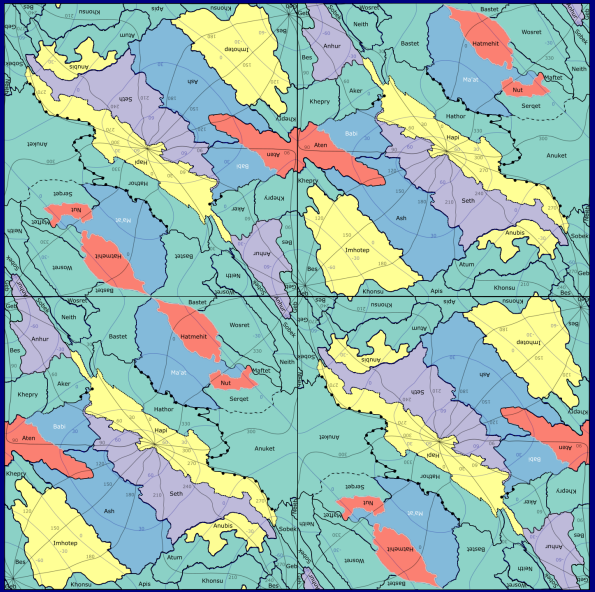

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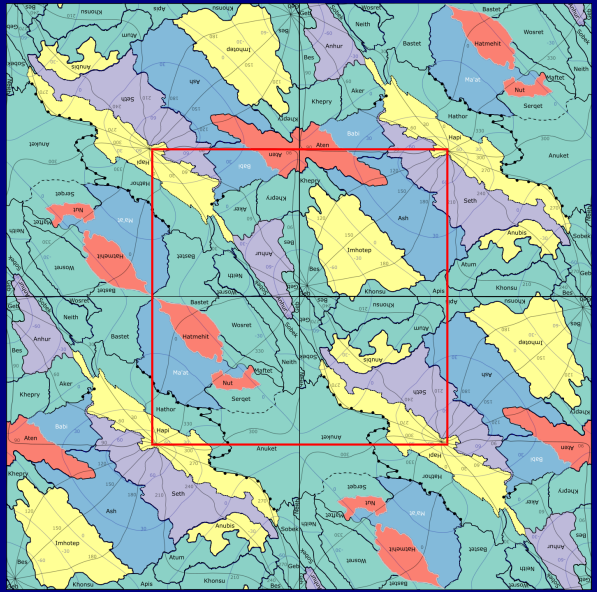
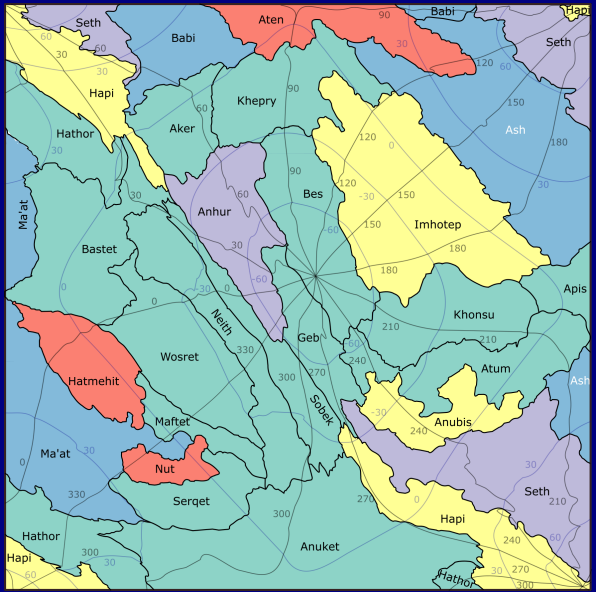


- It is inconvenient that regions are intersected by map edges, particularly in the South polar area.
- However, this can be tessellated!
- We can cut out a South centered version of the QuACK map.

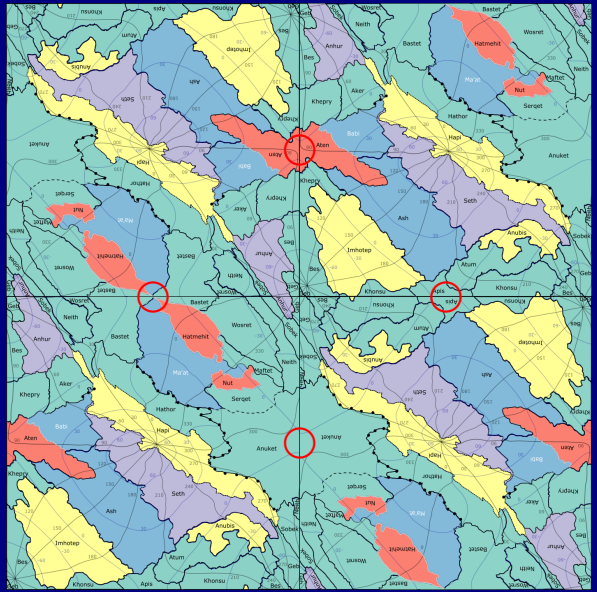
The South centered QuACK map projection



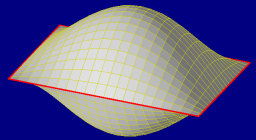
- Shows the many regions near the South pole without intersection.
- North and South centered versions both show the complete comet.
- The shapes of regions are exactly the same, may just be upside down.

Strongly consolidated
Smooth
Brittle
Depression
Dust covered

Four critical points

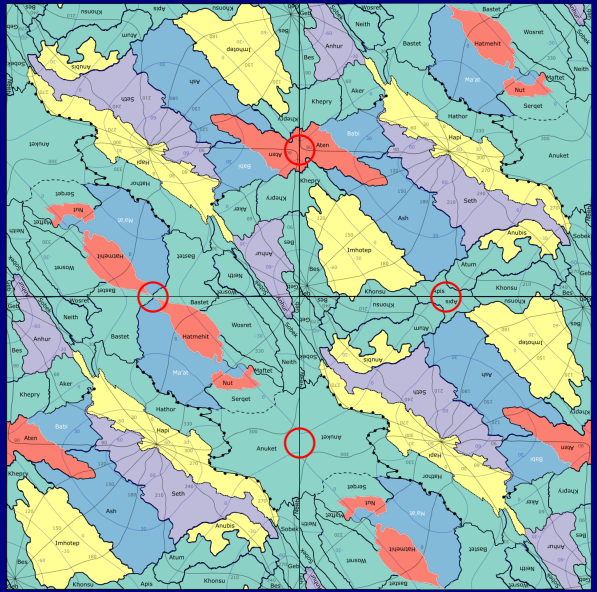


- There are four critical points at the centers of the edges which correspond to the corners of the sewed squares:



- At these singular points, approximate conformality breaks down.
- Regions encompassing such a point are strongly deformed.

Four critical points

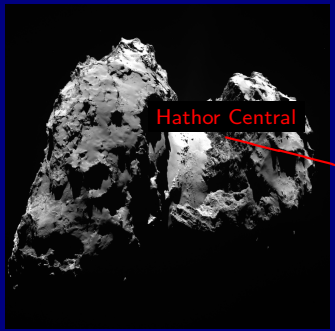


Affected regions are:

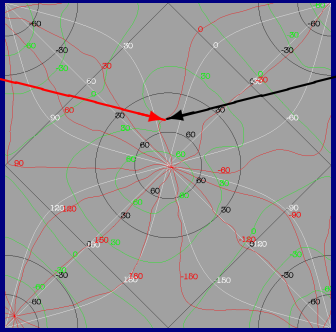
- Aten
- Apis
- Anuket
- Bastet (marginally)

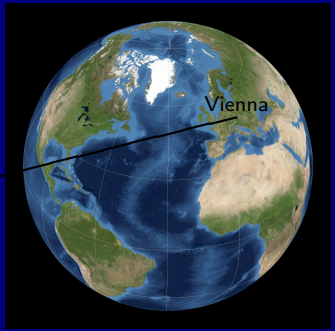
These cannot be nicely shown on the generic QuACK map.

Assigning generalized longitude and latitude



32°N, 0°E

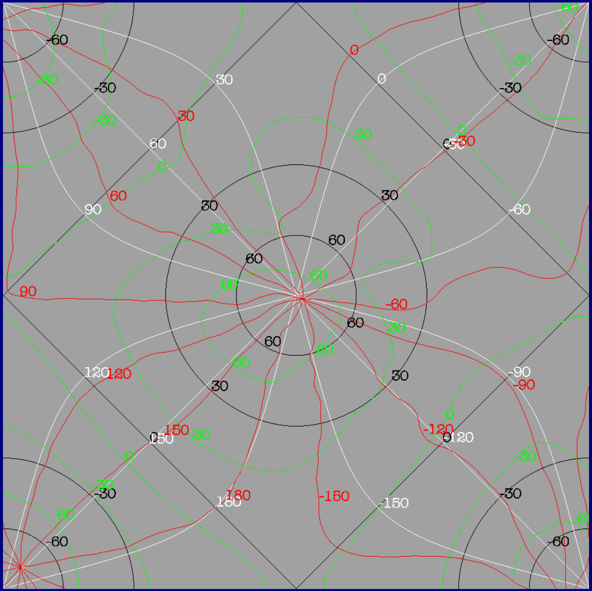




48°N, 16°E

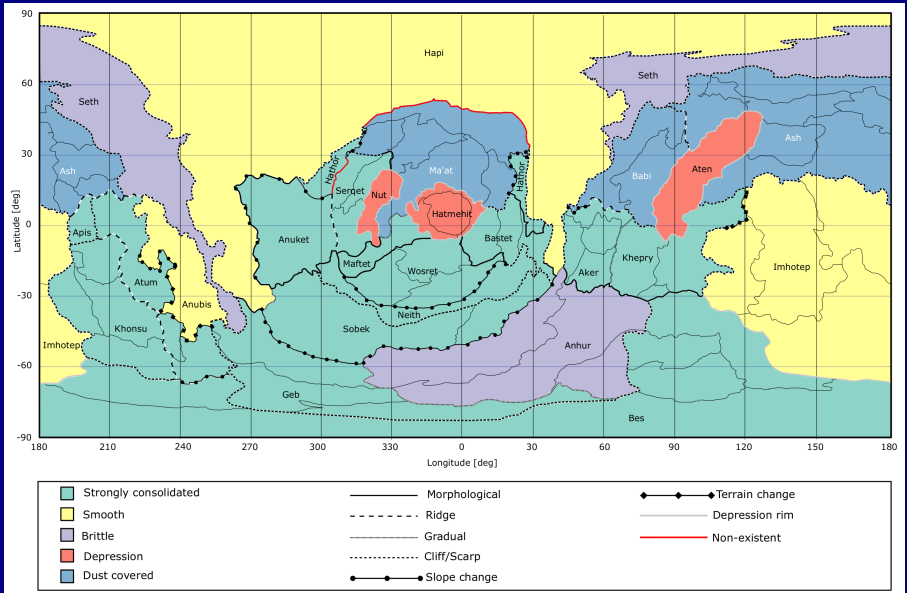
- Hathor Central and Vienna map to the same point on the QuACK map (respective Peirce quincuncial).
- We assign to Hathor Central the longitude and latitude of Vienna.
- Such **generalized** longitudes and latitudes are unambiguous over the comet.

Comparing actual and generalized longitude and latitude

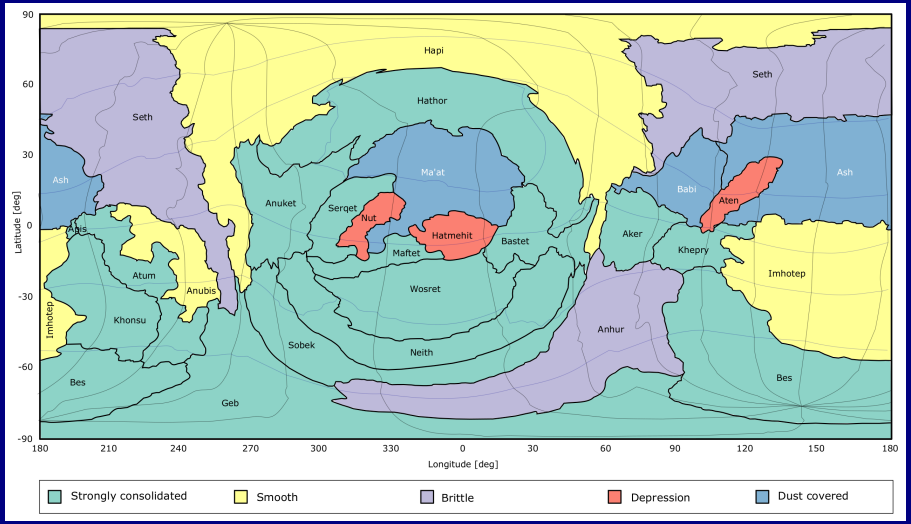


- The original comet longitudes and latitudes can be identical for different points.
- The assigned generalized longitudes and latitudes are unambigous.
- These can be used with any map projection — e. g., cylindrical equidistant — to obtain an unambigous generalized version.

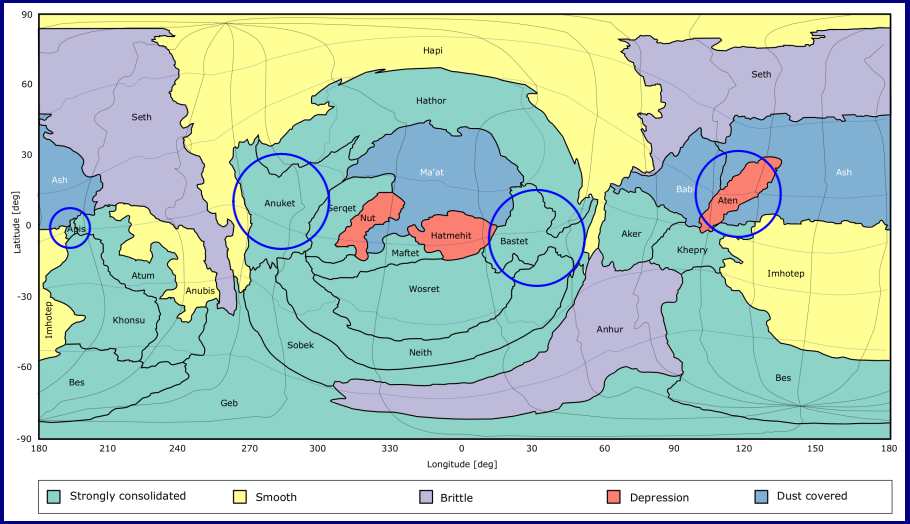
Common equidistant cylindrical projection



Generalized equidistant cylindrical projection

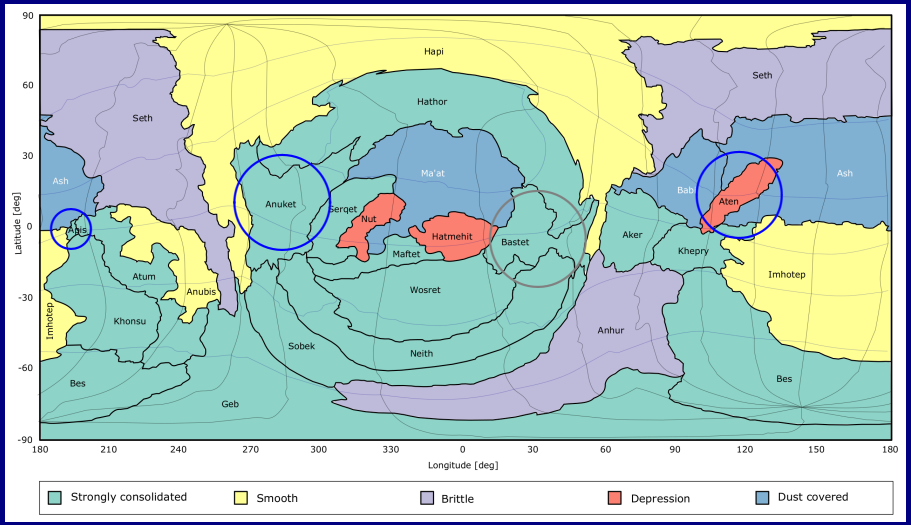


Generalized equidistant cylindrical projection



The QuACK generic projection does not work for blue circled regions.

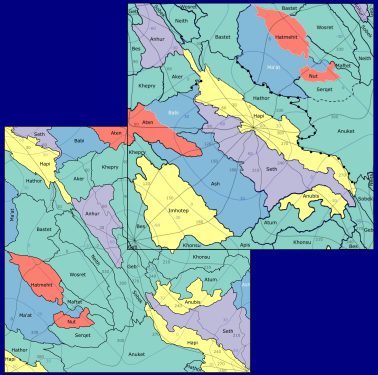
Generalized equidistant cylindrical projection



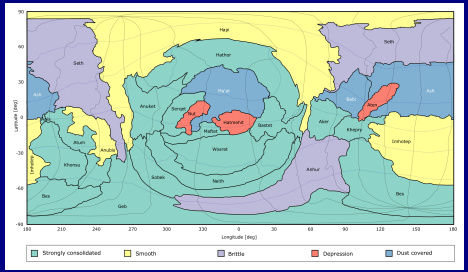
We used this generalized equidistant cylindrical (though we did not map Bastet).

Regional maps (5 examples)

We need two different map projections to display all regions nicely:

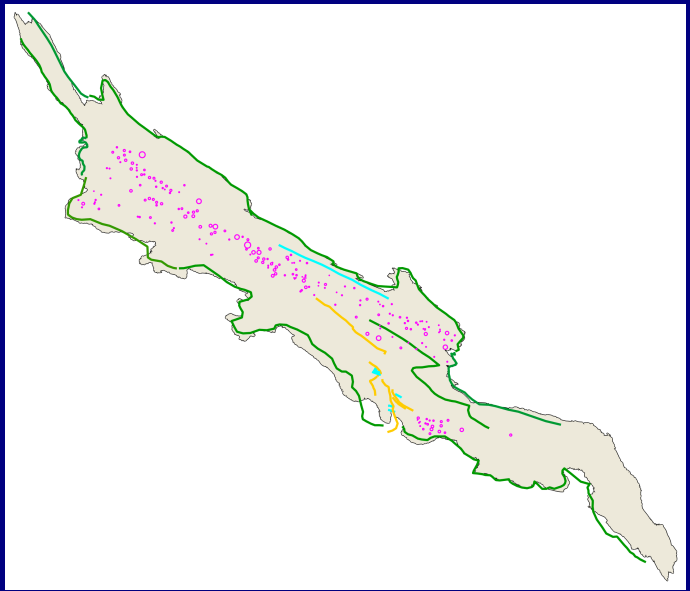


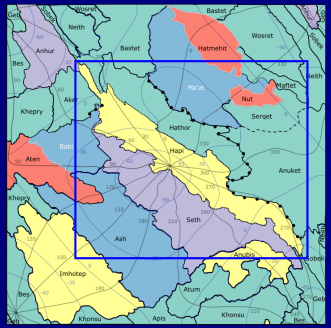
The generic QuACK map projection (We count North and South centered versions as one projection, because one is just a tessellation of the other.)



Generalized (by employing the QuACK map) equidistant cylindrical projection

Hapi (smooth)

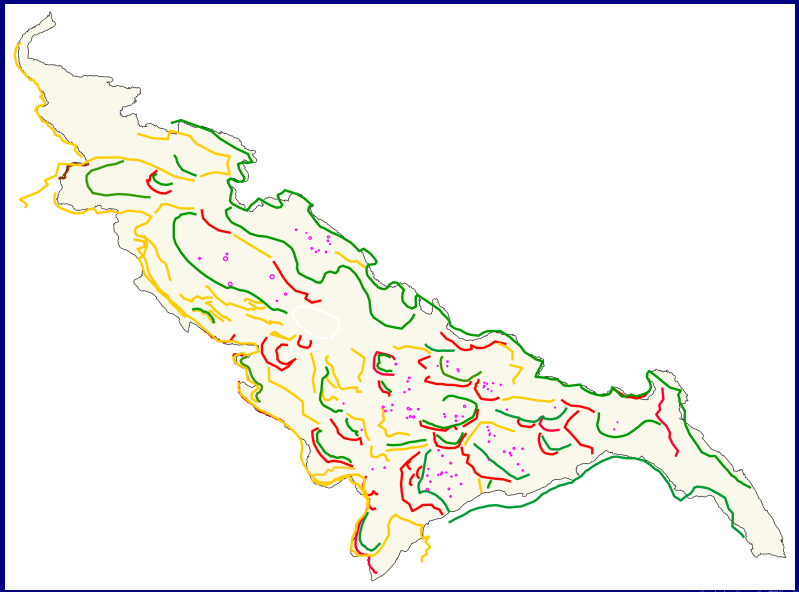


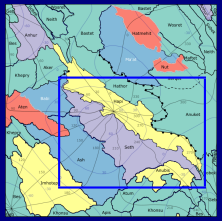


Terrace
Niche
Ridge
Rim
Fracture
Scarp

Boulder
Mound
Crater
Bright Patch

Seth (brittle)

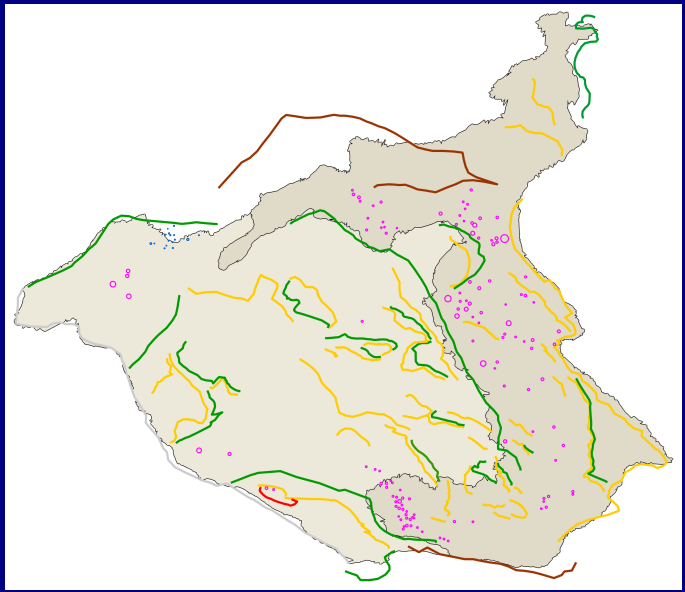


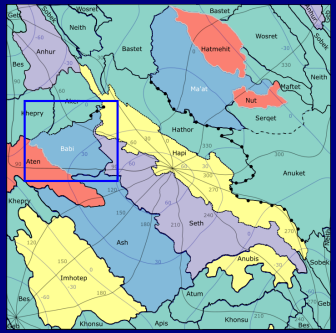


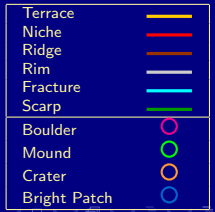
Terrace
Niche
Ridge
Rim
Fracture
Scarp

Boulder
Mound
Crater
Bright Patch

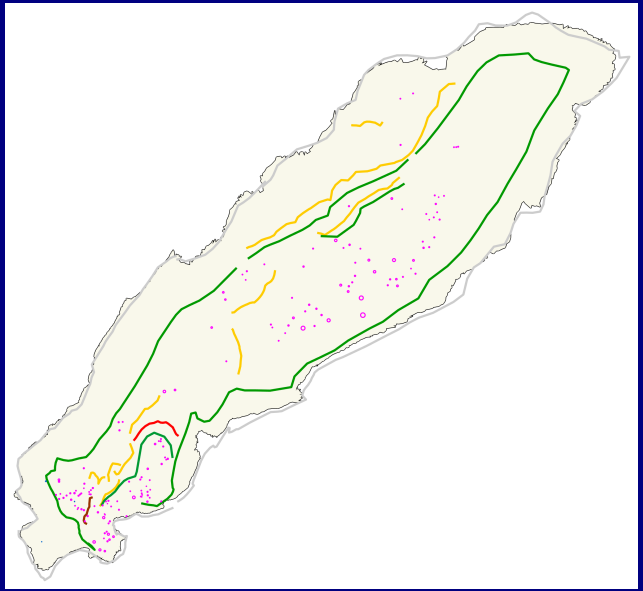
Babi (dust covered)

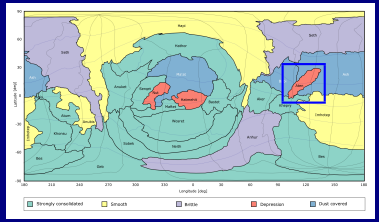






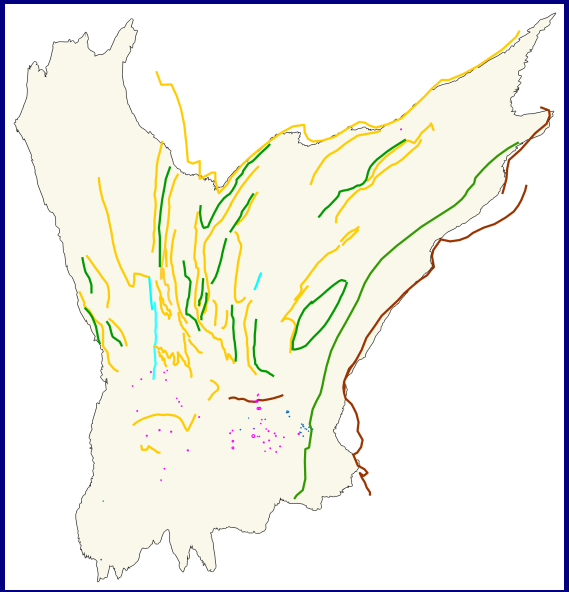
Aten (depression)

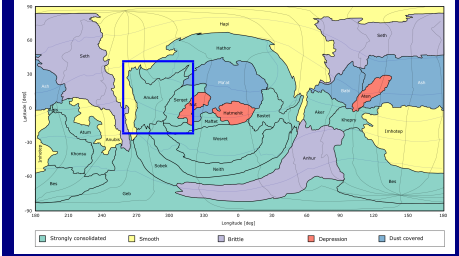




Terrace	
Niche	
Ridge	
Rim	
Fracture	
Scarp	
Boulder	
Mound	
Crater	
Bright Patch	

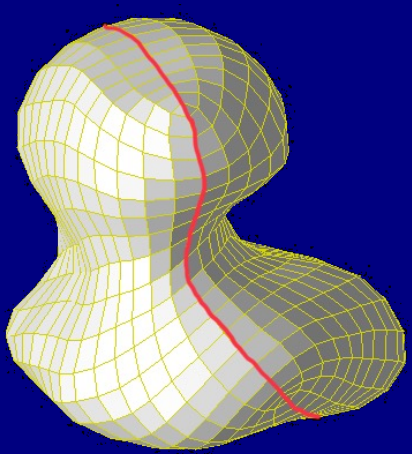
Anuket (strongly consolidated)





Terrace	
Niche	
Ridge	
Rim	
Fracture	
Scarp	
Boulder	
Mound	
Crater	
Bright Patch	

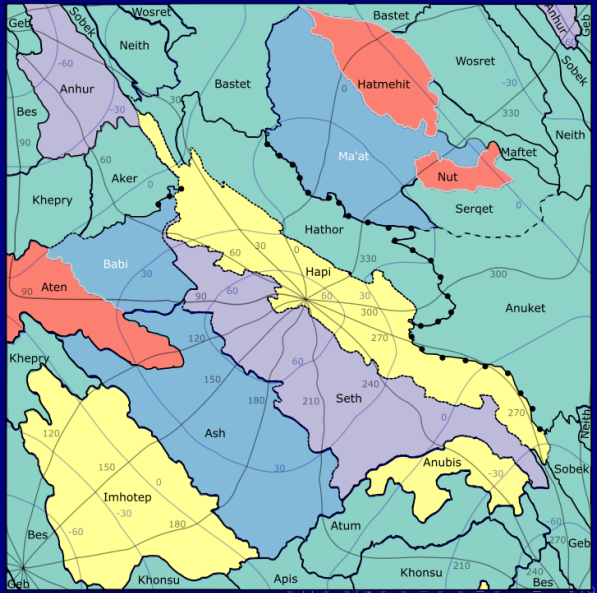
Conclusions



- We present previously published and newly identified geological features in a common framework, employing the QuACK map.
- These significantly expand on the complexity of the morphology of comet 67P.
- All global and regional maps, original SBMT shape files, and more are available in the Guest Storage Facility of ESA's Planetary Science Archive (see References).

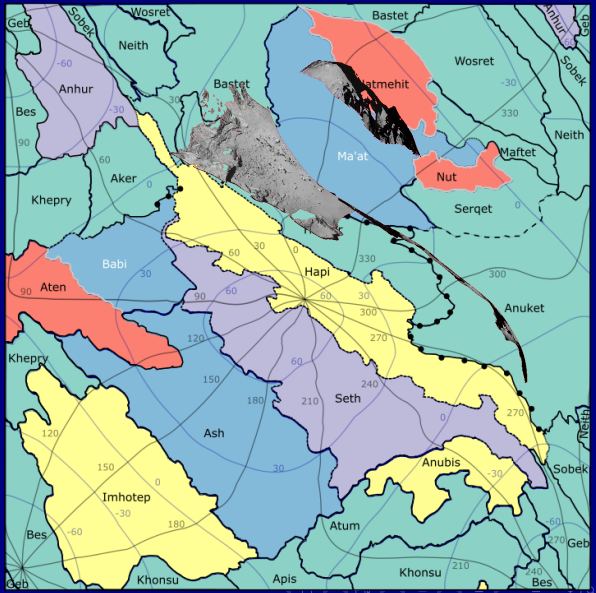
Outlook

- Map also the Southern hemisphere (requires updated shape model on the SBMT).



Outlook

- Map also the Southern hemisphere (requires updated shape model on the SBMT).
- Map features on top of projected images or mosaics (requires careful selection and mosaicing of images; preview to the right is the other way round, a projected image on top of the map).



References (1)

Geological mapping of 67P

- Leon-Dasi, M., S. Besse, B. Grieger and M. Küppers. "Mapping a Duck: Geological Features and Region Definitions on Comet 67P/Churyumov-Gerasimenko". Submitted to A&A.
- Products at ESAs Guest Storage Facility: European Space Agency, 2021, ESA-AURORA_67P-GEOMAP_OSIRIS_V1.0,

  https://doi.org/10.5270/esa-kokoti7

  (not yet public, will be shortly)

References (2)

QuACK map projection

- Grieger, B. (2019). "Quincuncial adaptive closed Kohonen (QuACK) map for the irregularly shaped comet 67P/Churyumov-Gerasimenko". A&A 630, A1.
  https://doi.org/10.1051/0004-6361/201834841
- Software to apply the QuACK map:
  https://github.com/esaSPICEservice/QuACK
- Kohonen, T. K. (1982). "Self-Organized Formation of Topologically Correct Feature Maps". Biological Cybernetics 43, 59–69.

References (3)

Quincuncial projection

- Peirce, C. S. (1879). "A quincuncial projection of the sphere". American Journal of Mathematics 2 (4): 394–396. doi:10.2307/2369491. Available at
  https://www.jstor.org/stable/2369491

- Grieger, B. (2020). "Optimized global map projections for specific applications: the triptychial projection and the Spilhaus projection". EGU2020-9885.
  https://doi.org/10.5194/egusphere-egu2020-9885

Terrestrial surface data used

- File
  world.topo.bathy.200407.3x5400x2700.png

  in NASA's Blue Marble collection at
  https://visibleearth.nasa.gov/collection/1484/blue-marble