Venus, Earth's structural sister: Investigations using radar imagery

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Brief description: Ever dream of a planet with ~100% structural exposure (no nasty sediments, biology, or obfuscating water)? Venus is the place! We'll use Magellan radar imagery to examine planet-scale structure-tectonic problems for classroom use. Students conduct fieldwork on Venus without leaving the lab. Concepts include basic mapping principles, remote data interpretation, structure morphology and interaction, rheology, temporal relations, and large-scale planet processes. Perhaps most importantly students learn that geologic maps are interpretations.

This activity can be modified to: map exercise, case study, and long-term project, or 'lecturecise'. The exercise also includes a series of steps (1-4) that build one on the other, and although the steps/activities should be completed in sequence, there is no need to have the students complete all the steps through to the final step 4. That is, an instructor could have students make a geologic map and stop there, or make a geologic map and decipher/construct histories and stop there, etc.

Goals: For students to understand how one goes from nature, through observations, to constructing interpretive/predictive models/hypotheses.

- **Content or concepts**: Remote-sensing data interpretation; structural element identification; pattern recognition; temporal relations and constraints; bulk strain patterns.
- **Higher order thinking skills**: Students learn concepts of field mapping and interpretation—but in a setting in which they are not distracted by outside elements; they learn that geologic maps are interpretations; they learn data synthesis and how to make predictive models (hypotheses), and how to test models/hypotheses with further data collection. Goals include: data recognition and identification, assimilation, assembly and interpretation into a predictive models/hypotheses, as well as testing of student generated hypotheses. A key goal for this exercise (in addition to the nuts and bolts sorts of things) is to get students to think about processes, and to challenge them to think creatively—outside the box, but to do so while they address specific data requirements/constraints. Students experience thinking through time and space, as well as the importance of history/sequence in deformation.
- **Other skills:** Write up or oral presentation (instructor's choice) aspects can be incorporated; exercise can be run as group or individual activity. Students can present written flow charts that illustrate branching analysis and required assumptions. The sequence cartoons are particularly useful to get students to think about process and how various factors interact and change through the evolution of a feature or a surface. Requiring construction of sequence cartoons is particularly useful to get students to think about process and how various factors interact and change through the evolution of a feature or a surface. Skills goals are pretty broadly based and dependent on the level of individual students and classes.

Description

Students construct a geologic map of a region of Venus' surface using NASA Magellan synthetic aperture radar (SAR) data (provided) and/or synthetic stereo data (provided, and constructed using Magellan SAR and altimetry data)—3D anaglyph viewed through red-blue glasses. Mapping can be done digitally using Adobe Illustrator (or a similar graphic program) or using hard copy images and overhead transparencies for mapping. Students construct a complete geologic map, determine a geologic history for the area, and propose hypotheses for the evolution of a large quasi-circular geomorphic/geologic feature that occurs within the map area. Students also propose tests of their hypotheses (whether such tests can be accomplished through further mapping, future missions, experiments, theoretical arguments, calculations, etc.). Students must clearly identify assumptions they make in their hypotheses/models. Individual, or small group, write-ups and completed geologic maps summarize student analysis. This activity connects structural geology to other fields, and provides the students with an opportunity to experience geologic investigation in which there is no single right answer, but there are 'wrong' or unlikely hypotheses. This exercise helps students think outside the box with little fear given that they are dealing with—literally—an extraterrestrial world in which very little is known—and yet, we assume that chemistry and physics, as we know them, likely operated on Earth's sister planet. Students are given a short introductory presentation about the environmental conditions of Venus (which could have been different in the past), and an introduction to radar data before they begin. (I emphasis ***short introduction***—it is really not about reading the radar, it is not about Venus; it is not about ‘being right’)

Tips for Instructors

The value of this exercise is not to worry about being right—that’s right, I said, ‘don’t worry about coming up with the ‘right’ answer. The value is in the process and what students learn for themselves, as individuals or as a class, how geologic maps are made and used. As it turns out many geologic mapping is a pretty logical exercise and many people will actually make pretty decent maps without too much direction—it is all about observing patterns, categorizing structures and units. The beauty of this exercise is that ‘going to’ another planet frees both the instructor and the students about concerns about being ‘right’ and simply allows them to focus on the process of making a geologic map and interpreting geohistories. This exercise allows the students and the instructor to explore together—the students approach the exercise differently knowing that the instructor does not know the ‘right’ answer. This, after all, is how and why geologic maps are constructed—we map to discover, we don’t map because we know.

So here are a few tips to get the students off and running (or yourself as an instructor off and running!).

1) Encourage the students to begin by mapping (tracing out) lineaments of different character, different orientation, or as suites of different patterns. This is actually quite intuitive—if my classes of students year after year are any measure. I help students to realize that mapping is a process and that one can start simply by tracing lineaments, and in doing so they will recognize that some differences in various lineament packages, and they come to decide how to lump these lineaments into different suites of lineaments. For example, lineaments might be differentiated based on character (e.g., straight and sharply defined, or sinuous, or as double versus single lineaments), by trend (e.g., ENE-trending versus NNW-trending), by spatial patterns that the lineaments describe (e.g., concentric lineaments, versus radial lineaments, versus suites of parallel lineaments).
2) Encourage students to think about what the spatial limits of the various suites of lineaments they have defined infers (tells them) about other aspects of the lineaments. That is, why to lineament suites end where and how they do? For example, a radial suite of lineaments might end simply because the ‘driver’ or source of the lineaments can only affect a localized area. Or perhaps a part of the radial suite is ‘missing’ because it is buried by younger deposits that cover the suite at that location, or perhaps the suite ends because a portion of a radially fractured region was rifted away, or…. You get the picture. The lineament suites must affect units, so the units must have been in place before the unit acquired the lineament suite.
3) Encourage the students to use the character of the lineament, and the pattern of the lineament suite to try and postulate what the lineaments might represent; that is, are they fractures? Are they troughs? And how could troughs form? Are they topographic ridges, and how could ridges form? Perhaps as folds? Again, there is not a single right answer and the students, through such an interactive inquiry begin to see how there are lots of different aspects of the lineaments suites and the individual lineaments within the suite, that help to tell a story, and provide clues for them to unravel/discover/propose a geologic history. I end up playing a lot of if then thought experiments with the students. For example, if these are suite of lineaments are fractures and radial what might we expect about their formation: if they are parallel and folds what might we expect about their formation; if they are troughs and parallel what might we expect about their formation? And we might be able to discover that different groups of observations and/or interpretations describe a self-consistent ‘story’ or an inconsistent ‘story’ and thus likely need to be revised.
4) I have used this exercise for many years and in a wide range of classes and I am really impressed with the first-order consistency between almost all of the students’ maps (Yup, almost all—once in a while I get some real cartoony nonsense—but perhaps that is the most valuable information to have in helping that particular student get ‘on track’.
5) I commonly lead a group/class discussion about maps by having one student show their map using the overhead projector; we talk about their suites of lineaments, and how they used these to define contacts between different material nits; and where contacts are well defined, and where they are poorly defined or gradational. Then we have 2, 3, or even 4 other students overlay their map on the first student’s map. Because the students have ‘registered’ their maps by the image corners the maps register with one another, and because the maps are on transparencies we can very easily compare the maps. What is so valuable about this comparison is that students see that despite the fact that they might have used different colors, or even styles of mapping, that fundamentally there are huge similarities with many of the maps. They also see the value in a range of people mapping the same area as one student might pick up on things another

did not, and visa versa. It also becomes very clear where sharp contacts are (very close agreement) versus more gradational contacts. After we have compared 3 to 5 maps ‘as a class, I have al the students place their maps on white background in a place in the classroom where all students can view all maps. This not only benefits a student from seeing how their map favorable compares with others, but also it provides a clear message where their map might have been improved.

6) Since devising this exercise many years ago, I continue to use it, and I have built on it by then adding a series of map exercises using GOOGLE EARTH; it is extremely impressive to see the improvement of the students’ maps through the semester. Each map exercise provides the student with a virtual map exercise.

Venus, Earth's structural sister: Investigations using radar imagery

In this lab you travel to Earth's sister planet Venus through remote data collection. You will construct a geologic map of an area covering almost 500,000 km^2 (~6.5° by 7.5°), determine the geologic history of the surface, and outline proposals for the formation of a large (~500 km diameter) quasi-circular feature (Miralaidji Corona) might have formed. The data you have available to you include synthetic aperture radar (SAR) imagery, synthetic stereo imagery (SS; to see this data don the fashionable red-blue glasses), and topographic data. All data result from the NASA Magellan Mission to Venus and is part of a four-part global data set that includes radar, altimetry (topography), gravity data and emissivity data. *Ford et al*. [1993] present an excellent review of the data sets and cautions.

Although Venus is considered Earth's sister planet, Venus is a very different place indeed (Table 1). Venus' basaltic surface is currently hot (~475°C), dry (essentially without water), and blanketed by a dense (92 bars) atmosphere of mostly CO_2. Under these conditions the basalt surface—presumed to extend across the planet—is extremely strong. In the past Venus' surface could have been hotter and wetter—the potential result being significantly weaker (ductile) basalt.

For this exercise there is no single set of right answers—although there certainly are some 'wrong' or unlikely sets of answers. Geologic mapping and analysis is ultimately based on consistency arguments (e.g., *Gilbert* 1886) and I encourage you to consider multiple working hypotheses (e.g., *Chamberlin* 1897). As you work through this exercise constructing your geologic mapping and unraveling the geologic history of the area be sure to think hard about the implications of your evolving interpretations.

Included in the exercise is a figure that briefly introduces you to radar data interpretation, a specs sheet comparing Earth and Venus, and the SAR or SS data of your map area.

Tape your transparency along one edge of the data sheet such that it is firmly help in place, yet you can lift it and look directly at the data if you need to. The data is inverted (negative) right-illumination inverted SAR imagery. This means that smooth areas (reltive to radar wavelength) will be bright, and rough areas with be dark, and slopes tilted toward the right (east) will appear shadowed (dark) whereas slopes titled toward the lest (west) will appear bright—that is, the area will appear to be illuminated from the left or west (this is because the image is inverted; we invert the data because linear features are easier for our eye to see because they generally appear as dark lines on lighter back-ground as opposed to white lines on a dark background). A degree on Venus is ~100 km. As you develop a model for the formation of Miralaidji Corona (#3 and 4 below) be sure to think about the scale of the geologic elements you are considering.

1. Create a geologic map of the area illustrating primary (emplacement-related), and secondary (tectonic) structures, and unit contacts (solid, dashed or dotted). Do not color in the unit areas. Use different colors to indicate different types of structures (e.g., folds, fractures) as well as different suites of structures. Think about: what to the various lineaments represent; which structures are primary, which secondary, why? Which structures could comprise a suite of structures that is genetically related? What defines a

material unit, how do you best draw contacts? Are all contacts the same? Are you equally confident about each of the contacts you draw? How do the material units relate to secondary structures, and visa versa? Think about what units and structures look like three dimensionally; how thick are units? Does unit thickness vary? What would a cross section look like across various parts of your map area? How do structures start and end? Why do the various structures stop where they do? What structural patterns emerge through your mapping?

2. Label each of your material units and name each suite of structures that you have identified; write a brief description of each unit and each suite of structures (you description should capture the essence of how you identified the unit or suite of structures). Determine the geologic history of the region; indicate relative timing of unit emplacement and the formation of each suite of secondary structures that you identified. Remember that deformation can pre-date, post-date, or overlap in time with unit emplacement. Also realize that the 'units' you might divide across the map area might be time-transgressive; that is, they might not have been emplaced instantaneously. Be sure to consult the SS imagery in particular.

3. Determine the geologic history of the evolution of Miralaidji Corona; focus on the spatial and temporal evolution of the surface units and the secondary structures; draw a sequence of at least 4 cartoons (map view, or block diagrams if you are up to the task!) that illustrate how this feature evolved spatially through time. Again, be sure to consult the SS image.

4. Outline at least two different models for the formation of the large (~500 km diameter) quasi-circular feature (Miralaidji Corona) in the map area. Discuss both models with regard to your map and geohistory analysis: what map relations (evidence) support the model; problems with your model, or how map relations do not support it. Outline any predictions each model would make, and describe data that might be collected that could 'test' either model. Clearly state any assumptions you make in each of your models.

Venus Statistics

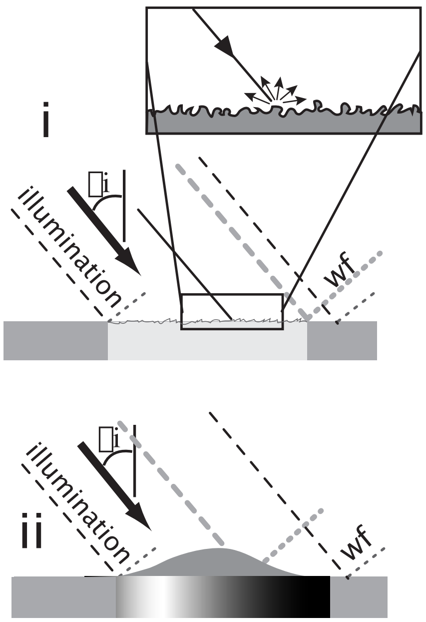
Mass (kg)	4.869×10^{24}
Mass (Earth = 1)	0.81476
Equatorial radius (km)	6,051.8
Equatorial radius (Earth = 1)	0.94886
Mean density (gm/cm^3)	5.25
Mean distance from the Sun (km)	108,200,000
Mean distance from the Sun (Earth = 1)	0.7233
Rotational period (Earth days)	-243.0187
Orbital period (Earth days)	224.701
Mean orbital velocity (km/sec)	35.02
Orbital eccentricity	0.0068
Tilt of axis (degrees)	177.36
Orbital inclination (degrees)	3.394
Equatorial surface gravity (m/sec^2)	8.87
Equatorial escape velocity (km/sec)	10.36
Visual geometric albedo	0.65
Mean surface temperature	482°C
Number of moons	0
Atmospheric pressure (bars)	92
Atmospheric composition*	96% CO_2
	3+% N

*Trace amounts of: sulfur dioxide, water vapor, carbon monoxide, argon, helium, neon, hydrogen chloride, and hydrogen fluoride

Earth Statistics

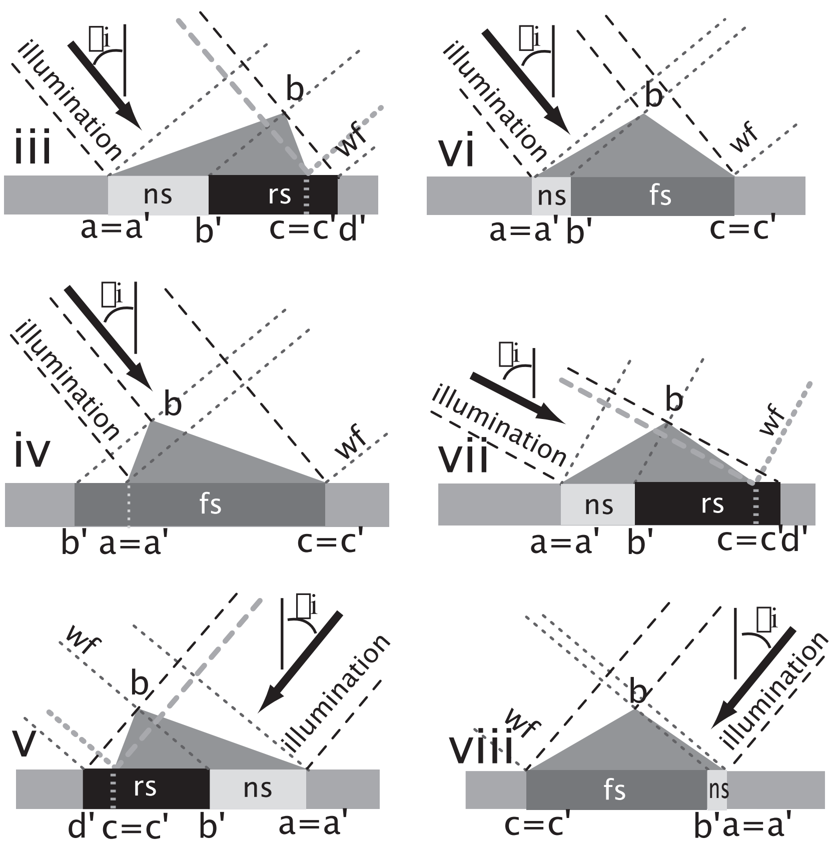
Mass (kg)	5.976×10^{24}
Mass (Earth = 1)	1.0000
Equatorial radius (km)	6,378.14
Equatorial radius (Earth = 1)	1.0000e+00
Mean density (gm/cm^3)	5.515
Mean distance from the Sun (km)	149,600,000
Mean distance from the Sun (Earth = 1)	1.0000
Rotational period (days)	0.99727
Rotational period (hours)	23.9345
Orbital period (days)	365.256
Mean orbital velocity (km/sec)	29.79
Orbital eccentricity	0.0167
Tilt of axis (degrees)	23.45
Orbital inclination (degrees)	0.000
Equatorial escape velocity (km/sec)	11.18
Equatorial surface gravity (m/sec^2)	9.78
Visual geometric albedo	0.37
Mean surface temperature	15°C
Number of moons	1
Atmospheric pressure (bars)	1.013
Atmospheric composition	77% N
	21% O
	2% Other

A very short course in radar interpretation



Radar ground range images (basal strip) resulting from (i) surface roughness (greater than the wavelength of radar), and differnet topographic forms, incidence angle (θ_i), and illumination direction (ii–viii). (b) Illustrates change in backscatter return as a result of gradual change in slope and resulting orienation toward receiver. (iii–viii) illustrate radar return based on straight slopes and illustrate radar foreshorteniing, layover, and radar shadow. Points on topographic forms (a, b, c) project parallel to wavefront (wf, perpendicular to illumination) to points on the ground range image (a', b', c'). Point d' marks the trailing edge of radar shadow on the ground range image. Projected location and size of near slope (ns), far slope (fs) and radar shadow (rs) shown with shades of gray indicative of relative radar return and hence brightness. Gray lines shown where surface locations would not be imaged

(iii) Left illumination of asymmetric topographic form; foreshortening and radar shadow result in apparent symmetric shape. Point a at the base of the near slope 'projects' to its correct location; point b at peak projects to b'; point c at the base of the far slope 'projects' to its correct location, but its presence is lost in radar shadow. The shallow near slope is imaged from a' to b' and 'foreshortened' in th eground range image; the entire far (steep) slope is lost in radar shadow from b' to d'.



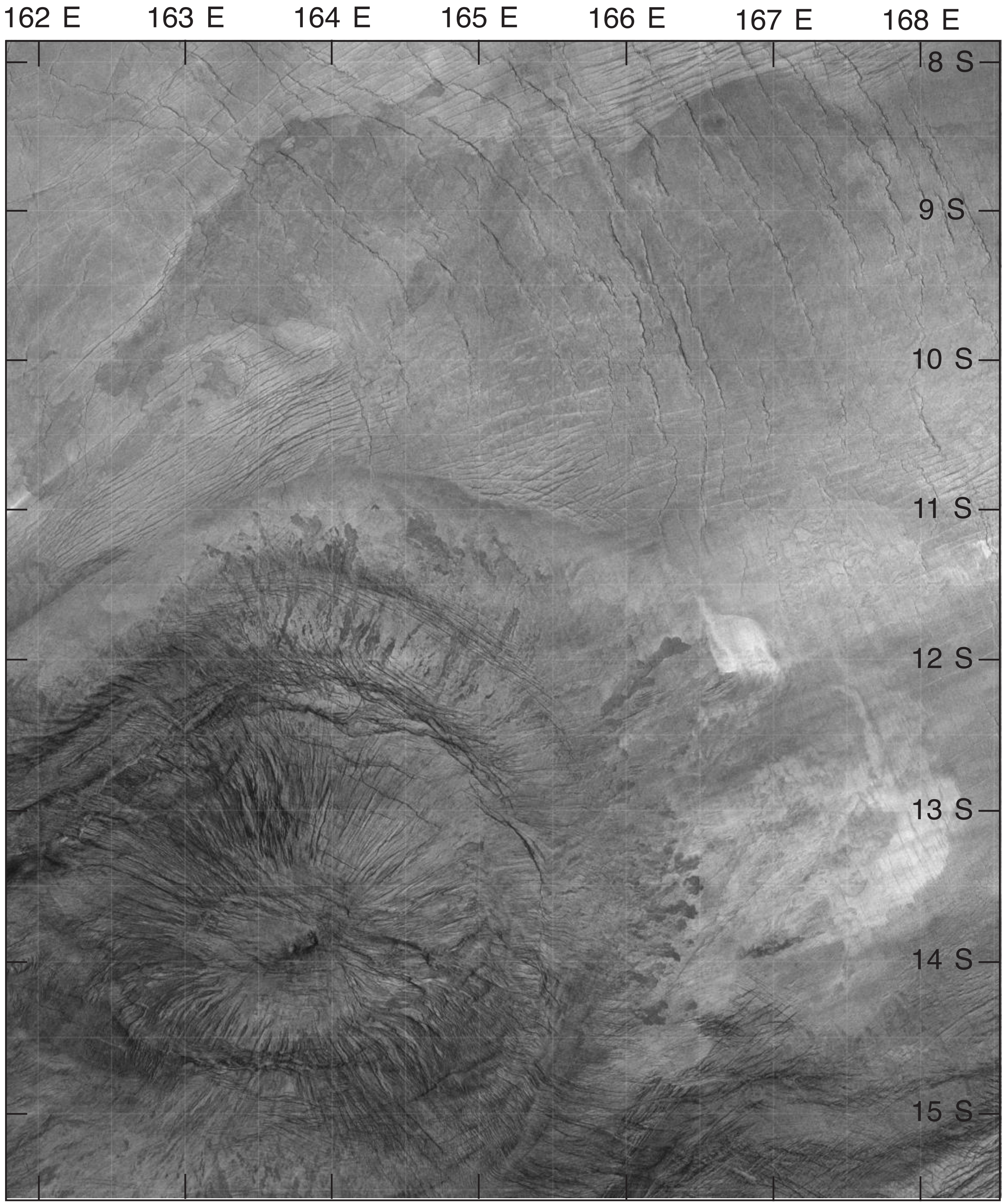
(iv) Left illumination and an asymmetric topographic form with steep slope facing radar results in extreme foreshortening, or "layover". Only the far slope is imaged because b projects to b' and a, projected to a', is lost in extreme foreshortening. Although the near slope is lost to layover, none of the far slope is lost to radar shadow in this case.

(v) Right illumination of asymmetric topographic form with steep slope facing away from radar; foreshortening and radar shadow result in an apparent near symmetric image in contrast with topographic reality.

(vi) Left illumination of symmetric topographic form; foreshortening and far slope imaging results in apparent asymmetric image in contrast with topographic reality.

(vii) Left illumination of symmetric topographic form with a higher incidence angle than in (vi) leads to less foreshortening, but the entire far slope is in radar shadow.

(viii) Right illumination of symmetric topographic form; foreshortening and far slope imaging results in apparent asymmetric form in contrast with topographic reality. Compare with (vi) and (vi).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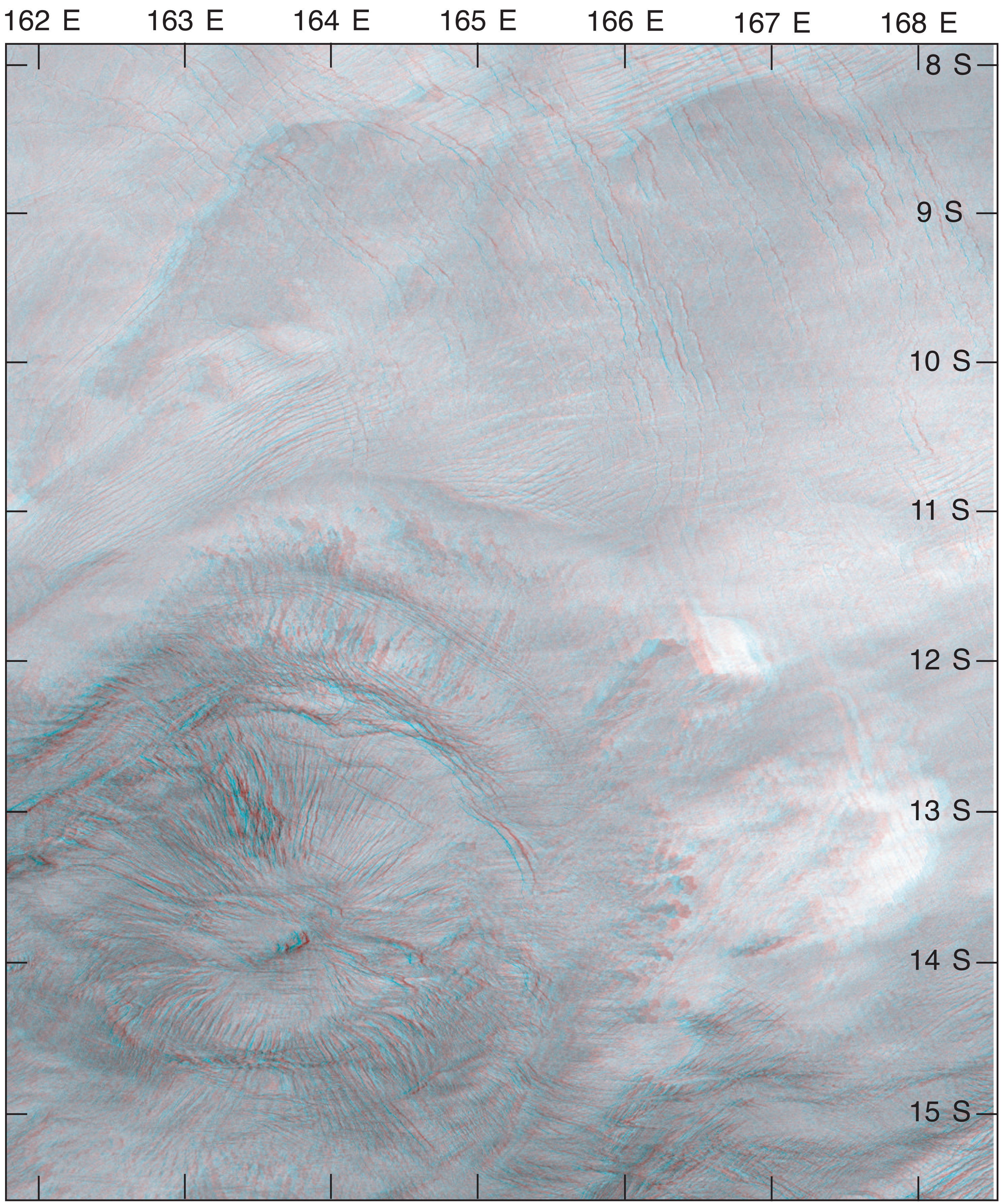
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