About You

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Activity/Assignment Title: **Venus, Earth's structural sister: Investigations using radar imagery**

Type of Activity: This activity can be modified to be any of the following: map exercise, case study, and long-term project, or 'lecturecise'.

Brief description: Ever dream of an entire planet with ~100% structural exposure (no nasty sediments, biology, or obfuscating water)? Venus is the place! We'll use Magellan radar imagery (inverted and synthetic stereo) to examine planet-scale structure-tectonic problems for classroom use. In this exercise, students conduct fieldwork on Venus without leaving the lab. Concepts include basic mapping principles, remote data set interpretation, structure morphology and interaction, rheology, temporal relations, and large-scale planet processes. Perhaps most importantly students learn that a geologic map is an interpretation, and they are challenged to think outside the box (or outside their home planet).

Context: This exercise can be used in undergraduate structural geology course, or in an advanced structural geology course (advance undergraduate and/or graduate level); the exercise can be easily expanded to accommodate more or less concerns/lessons.

Briefly describe or list the skills and concepts that students must have mastered before beginning the activity: I have used this exercise in a grade school setting, junior-high school/senior high school science groups, girl scout/boy scout groups, structural geology setting, and I will use it in a graduate level course Fall 2004. The activity provides an opportunity for students to learn new concepts as well as apply known concepts. All this by way of saying, there is no single background required. Students apply the skills and concepts they know and learn new skills and concepts along the way.

Briefly describe how the activity is situated in your course:
I have used this project as a lecture-exercise ('lectursize') in which I direct student mapping and inquiry as an introductory lecture for structure—a 'to-do-what' sort of introduction to structural analysis. I have also used this exercise as a late-term lab project in undergraduate structural geology serving as a culminating 'field' exercise in which students apply various aspects of what they have learned over the course of the semester to address an integrative tectonic problem. I will also use the exercise this fall semester as an early-term project in advanced structure, in which context I hope that it will allow me a means to evaluate the levels of understanding/analysis of a wide range of student coming together with different backgrounds, as they complete the exercise. I will learn about the level of each student, structural background as well as investigative skills, but I hope that each of the students will also learn through the exercise so that it provides a service

to me as the instructor at the same time providing a valuable learning experience for the students; in this context it serves as a framework the exercise should also pose concepts for the course work ahead.

Goals of the Activity or Assignment:

To help your colleagues understand the role of this activity or assignment in your course, please provide a statement of the goals that you have for students in the following three areas:

- 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. They also learn that the real world is not quite as neat and tidy as they might think based on lectures and textbooks. 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.

Briefly describe the content/concepts goals for this activity:

The goal is for students to understand how one goes from nature, through observations, to constructing interpretive/predictive models/hypotheses. Through the course of the exercise they apply a wide range of expertise based on their own current experience and knowledge base.

Briefly describe the higher order thinking skills goals for this activity:

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 addressing specific data requirements/constraints.

Briefly describe any other skills goals for this activity:

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.

Evaluation

Evaluation is based on the nature of the geologic map (a full range of styles is allowed and encouraged; it is extremely useful for students to see how different individuals or groups mapped the same region), and the quality of the arguments (consistency!) of the developed history and range of proposed and evaluated hypotheses. Again, there a lot of latitude in this exercise for the instructor to chose goals dependent on the particular level of the students based on course level, or time of the semester/program. If write up or oral presentations are included, these are evaluated on both content and mechanics.

Basically the two obvious models for the formation of Miralaidji Corona are 1) punching from above (bolide impact) or 2) punching from below (diapiric rise of a rather large mass). Students learn much through thinking through the sequence of structures and flows that might occur in both of these cases, and in comparing their thought experiments (represented in a cartoon sequence) with the results of their geologic map and their interpretation of the geologic evolution of the feature (also represented in a cartoon sequence).

Materials

1. Synthetic aperture radar (SAR) image of the map area on Venus (downloadable); data is from the NASA Magellan Mission (can be laminated and used again). Each student needs a copy of this data set.
2. Copy of the lab exercise (downloadable); this can be modified to fit individual course level and course goals.
3. Venus-Earth stat sheet (can be included in lab packet).
4. Blank transparent sheets for each student to create their map.
5. Pens that will write on transparencies.
6. Synthetic stereo image of map area (downloadable) and beyond (not necessary—but fun; downloadable); can be as overhead transparency, digital file, or printed hard copy (a limited number of copies can be used for an entire class). You can have students map

directly on synthetic stereo image if you print off enough copies for each student. In this case each student will also require red-blue glasses.

7. Topography image of map area and beyond (not necessary—but fun; downloadable); can be as overhead transparency, digital file, or printed hard copy (a limited number of copies can be used for an entire class).

Activity:

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 yo uhave 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.

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

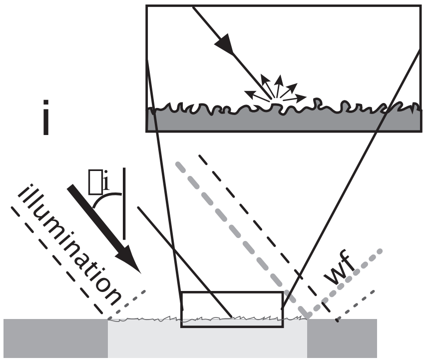
Mass (kg)	4.869×10^{24}
Mass (Earth = 1)	0.81476
Equatorial radius (km)	6,051.8
Equatorial radius (Earth = 1)	0.94886
Mean density (gm/cm^3)	5.25
Mean distance from the Sun (km)	108,200,000
Mean distance from the Sun (Earth = 1)	0.7233
Rotational period (Earth days)	-243.0187
Orbital period (Earth days)	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

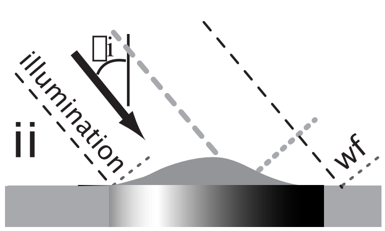
Earth Statistics

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

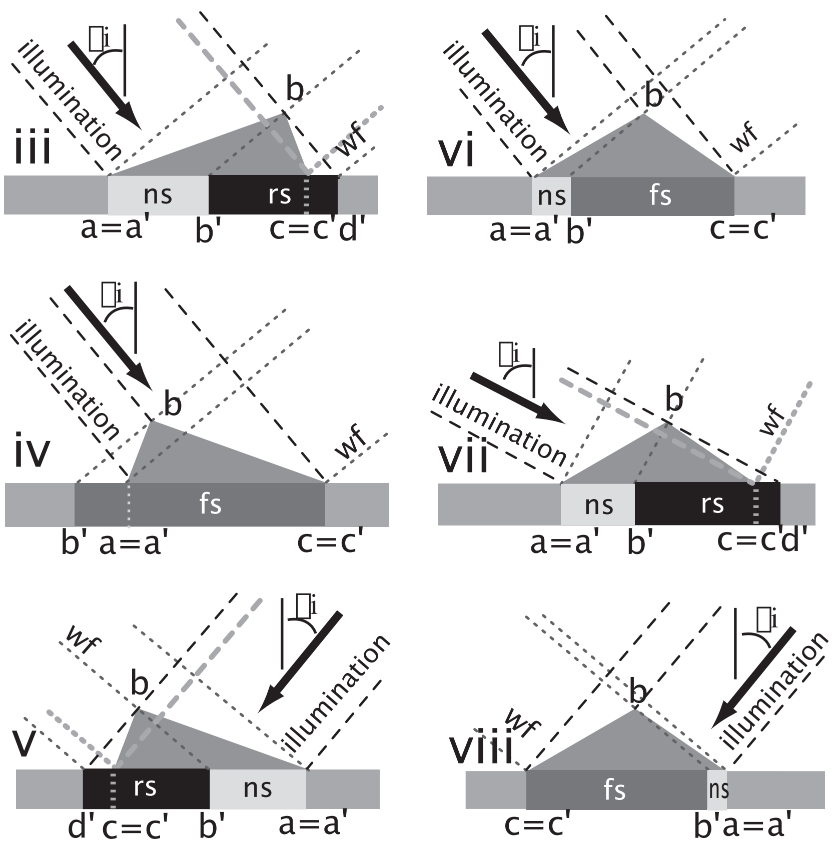
A very short course in radar interpretation



Radar ground range images (basal strip) resulting from (i) surface roughness (greater than the wavelength of radar), and differnet topographic forms, incidence angle (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).

For Instructors:

Useful websites for Instructors:

Venus Geologic maps, 1:5Million scale, including V37, covering the map area: http://geopubs.wr.usgs.gov/docs/wrgis/venus.html

USGS Map-a-Planet web site with all sorts of NASA data, including NASA Magellan SAR:
http://pdsmaps.wr.usgs.gov/maps.html

USGS Planetary Geology Mapping web site:
http://astrogeology.usgs.gov/Projects/PlanetaryMapping/PGM_home.html

Lunar and Planetary Institute: Impact crater data (Venus relevant here):
http://www.lpi.usra.edu/lpi/sci_database.shtml