Chapter 7
New Suitors

Pioneer Venus Orbiter originally was not intended to do radar mapping of Venus. That was to be done by a separate *Venus Orbiting Imaging Radar* (VOIR) mission. Indeed the primary reason low-resolution SLAR radar was added to Pioneer was to facilitate planning for that VOIR mission. And when radar was added to Pioneer Venus, the emphasis was on gathering altimetry data, not radar imaging.[1] Planning for the VOIR mapping mission began well before Pioneer Venus Orbiter was launched, May 20, 1978.

In 1972, before the final Apollo 17 landing on the moon, NASA Advanced Programs head, Danny Herman, began convening informal meetings of scientists and Martin Marietta representatives to discuss putting Synthetic Aperture Radar (SAR) on a Venus orbiter. These were followed by forming competing study and planning groups at NASA Ames and at JPL. Its considerable experience with SEASAT SAR gave JPL the edge and it was picked to develop a Venus SAR radar orbiter.[2] SAR is capable of much higher resolution than the SLAR used on Pioneer Venus Orbiter. SLAR resolution is a function of antenna

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[1] A. Butrica, *To See the Unseen*, forthcoming, p. 6-397. My account of the origins of the Magellan mission that follows is heavily indebted to Butrica's research, especially his Chapter 7.
[2] *Ibid.*, p. 7-433–434

size and distance from the target, so increase in resolution requires a larger antenna or getting closer to the target. For satellites orbiting Venus with its dense atmospheres, there were significant practical limitations on both strategies. However, SAR uses more sophisticated electronics and involved computer data processing to simulate a much larger antenna than it actually uses, thereby achieving far better resolution than the same satellite equipped with SLAR could. (See Chapter 8 below.)

Interest in use of SLAR and SAR for gathering geological data goes back to 1961 when Goodyear developed the first operational SAR system. The Office of Navy Research (ONR) and the National Academy of Sciences held meetings that led to the beginning of ONR/University of Michigan Symposia on SLAR/SAR in February, 1962.[3] That same year NASA contracted with University of New Mexico, MIT, and Ohio State University to develop radars for future Venus missions. Following standard flight-test procedures where one uses proven units to test major experimental components, those early radar systems were first tested aboard aircraft, not satellites. October, 1967, the MIT Venus radar system was ready for flight testing using the NASA Ames Convair CV-990 aircraft.[4] In 1967-68 a Westinghouse radar system was used to map Panama,[5] and late 1971 the Aero Service/Goodyear RADAM Project mapped over 8.5 km^2 of Brazil using SAR.

JPL began the VOIR project in 1974 with R. Stephen Saunders as principal study scientist. He would still be Project Scientist sixteen years later when Magellan finally reached Venus and began mapping, and would continue in this role throughout the entire Magellan mission and subsequent data analysis and mapping, and would continue in this role throughout the entire Magellan mission and subsequent data analysis and mapping (VDAP). Both JPL and Martin Marietta/Environmental Research

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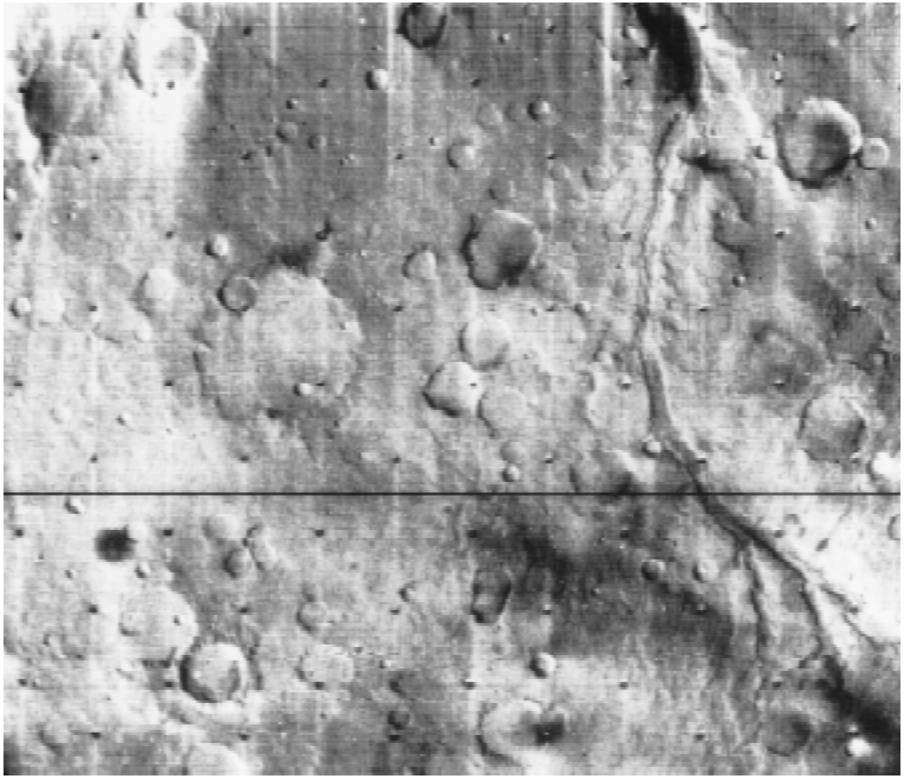
[3] *Ibid.*, p. 6-400.
[4] *Ibid.*, p. 6-390.
[5] *Ibid.*, p. 2-401 **[ck 2-401 or 6-401?].**



Mariner 9 was the first photographic mission to Mars that returned images with sufficient resolution to unambiguously identify surface features such as impact craters, rifts, and folds. For the first time there was data adequate for geological interpretation. Early in the planning of the Venus Orbiting Imaging Radar (VOIR) mission it was decided that radar images of Venus should exceed Mariner 9 resolution. [Mariner 9 image 4167-24; reprinted from P. Cattermole, *Mars: The Story of the Red Planet* (London: Chapman and Hall, 1992), p. 12.]

Institute of Michigan recommend a circular orbit because it would simplify the already complex data processing associated with SAR technology. It was decided to build the VOIR mission around existing technology, using left-over Pioneer, Mariner 10, SEASAT, and Galileo parts and technology where feasible.[6] JPL considered using the SEASAT SAR radar system as the VOIR radar around 1977, but during summer 1978 picked Goodyear, from among three proposals, to do the Phase A study of the VOIR SAR instrumentation needed for the mission.[7] Around this time Saunders and geophysicist Gerald Schubert introduced the requirement that VOIR SAR be high resolution, superior to the Mars Mariner 9 photographic resolution which for the first time could display topographic features in sufficient detail needed for geological interpretation.[8]

VOIR planning was done by a JPL Science Working Group consisting of Gordon Pettengill of MIT as Chair, Donald Campbell of Arecibo, Richard Goldstein of JPL, and Harold Masursky and Gerald Schaber of the USGS Astrogeologic Branch in Flagstaff. It defined four objectives for the VOIR mission:

- 100% of the Venus surface imaged at 600 meters mapping resolution, and a few percent at 100 meters high resolution.
- A global topographic map of Venus.
- A global gravity field map.
- New investigations of the atmosphere and exosphere (outer regions of the upper atmosphere).

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6 *Ibid.*, p. 7-433–434.
7 *Ibid.*, p. 4-733—734.
8 *Ibid./*, p. 7-443

The Science Working Group then was dissolved and an "Announcement of Opportunity" for VOIR experiments in three categories was issued in October, 1978:

- Surface and interior properties of the planet using SAR and altimetry data.
- Atmospheric and geophysical experiments using other instruments
- Other geophysical, atmospheric, and general relativity experiments using existing spacecraft technology.

It was envisaged that the VOIR radar image interpretation community would number 70 investigators plus 130 associates experienced in interpreting moon, Mars, and Mercury photographs.[9] Ultimately Magellan, the scaled-down VOIR mission, would have 47 investigators.[10]

That same year the itinerary for VOIR was set:

> Launch VOIR from the Space Shuttle May-June 1983, arriving at Venus that November, and spend five months in orbit mapping.

A major planning constraint was not overlapping with the Galileo mission since the Deep Space Network did not have resources to simultaneously control and receive data from two major planetary probe missions. A further concern was to preempt a possible Soviet attempt to obtain SAR Venus images before the US did.[11]

In February 1979 Gordon Pettengill responded to the "Announcement of Opportunity" with a proposal for a SAR experiment to use radar to investigate surface and evolutionary processes and produce a geological map. Included in his proposed group were most of the Science Working Group including

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[9] *Ibid.*, p. 7-444.

[10] P. 13,085 of R. S. Saunders and 26 others, "Magellan Mission Summary," JGR 97/E8(August 25, 1992): 13,067–13,090.

Harold Masursky, Gerald Schaber, and Laurence Soderblom of the USGS, Donald Campbell, James Head, and people from the MIT Center for Space Research and JPL. A Stanford proposal to study radar backscatter was piggy-backed to Pettengill's successful proposal. Around that time, proposals were solicited for Phase B of the JPL SAR study (October, 1979–June 1980) which would be the basis for determining what sort of VOIR SAR instrument ultimately would be built. Three proposals were submitted, and Goodyear and Hughes were selected. Only they would be allowed to bid for the contract to build the instrument.

Planetary geologists had little experience interpreting high resolution radar images such as VOIR would produce. Radar already was achieving such resolution in earth images. July 16-20, 1979, Masursky and Saunders organized a JPL/NASA Radar Geology workshop using SEASAT earth radar observations.[12] When the Venus mapping project became seriously delayed, plans for new radar workshops were made in July, 1986, by Pettengill, Saunders, and others. The first of these workshops was held in 1987. Thirty-two Magellan scientists and personnel participated in a field trip to the Mojave Desert and Death Valley where they compared geologic features with their SAR images. Another workshop, focusing on interactions between radar waves and planetary surfaces, was held in May, 1988. USGS Flagstaff organized a field trip focusing on comparing radar-geology targets in a semi-arid vegetation free environment with SAR images. A third workshop was convened by Gerald Schaber and Richard Kozak in 1989.[13] Campbell, Peter Ford, Nick Stacy, and Head collaborated to produce Arecibo radar images of the moon at 200-300 km resolution which were paired with lunar photographs as an aid to

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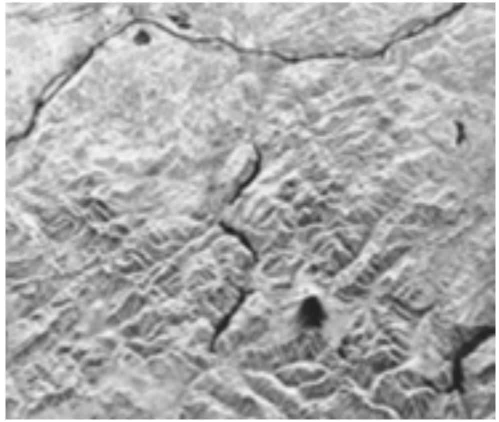
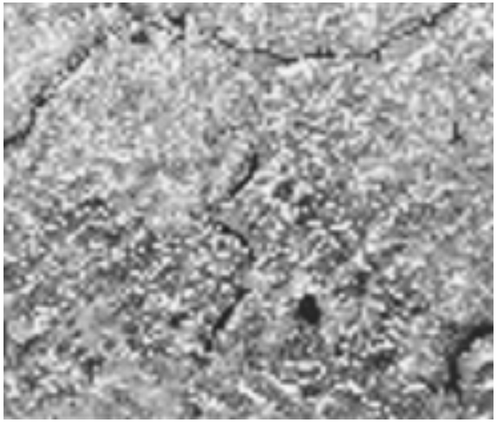
[11] Butrica, *op. cit.*, p. 7-442.
[12] *Ibid.*, p. 6-403
[13] *Abstracts for the Venus Geoscience Tutorial and Venus Geologic Mapping Workshop, Flagstaff, Arizona, June 12-15, 1989* LPI Contribution No. 708. (Houston: Lunar and Planetary Institute, 1989).

The 1979 radar image interpretation workshops included a stint in Death Valley where LANDSAT photographic images were compared with SLAR radar imagery, and both sorts of images were compared with *in situ* surface roughness features. Gerald Schaber of USGS shared his geological knowledge of Death Valley in these interpretative exercises. In the upper image a LANDSAT photo image of Death Valley a diagonal strip of SLAR imagery has been superimpsed bisecting a diagonal homogeneous region. The lower detail indicates the placement of the radar strip relative to the LANDSAT image. Combined with field examinations of the valley terrain, such exercises were intended to develop expertise in the geological interpretation of Venus VOIR/Magellan radar images. [Figs 5, p. 8, and 15a, p. 21, of M. Daily, C. Elachi, T. Farr, W. Stromberg, S. Williams, and G. Schaber, *Application of Multispectral Radar and LANDSAT Imagery to Geologic Mapping in Death Valley*. JPL Publication 78-19 (NSA/JPL, March 30, 1978).]

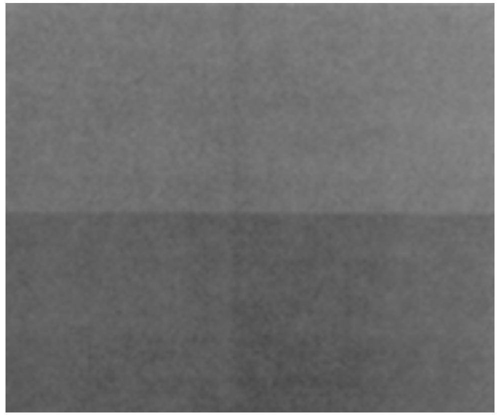
Mount St. Helens



Magellan resolution



Venera resolution



Pioneer resolution

Comparison of the resolution Magellan would achieve with that of Venera 15-16 and Pioneer radar using a well-known earth composite volcano, Mt. St. Helen's. The upper left image is a profile photograph of Mt. St. Helen's prior to it's recent explosion that blew off part of its top. To its right is a SEASAT earth radar image at Magellan resolution. Volcano Mt. St. Helen's (circled) is clearly identifiable as a volcano. Geological interpretations of features as small as 1 km are reliable. The lower left image has been degraded to Venera resolution. Mt. St. Helen's is shown, but it is impossible to tell if it is a volcano or an impact crater. This is about the same resolution Arecibo ultimately would achieve in 1988. Geological interpretation of features smaller than 8 km is unreliable. The right bottom image is a further degradation of the SEASAT image to Pioneer radar resolution. Mt. St. Helen's cannot even be seen. [The profile photograph of Mt. St. Helen's above right is by R. Greely, Fig. 3.18(b), p. 54, from his *Planetary Landscapes*, second edition. New York: Chapman and Hall, 1987.]; the others are fromFig 5-6, p. 78, from *The Magellan Explorer's Guide* (NASA/JPL Publication 90-24, August 1990).

interpreting the anticipated high resolution Venus radar images.[14]

NASA issued an April, 1981, “Request for Proposals” to build the SAR radar system and antenna design. Hughes and Goodyear submitted designs and Hughes was selected. That same year Ronald Reagan began his administration with a flurry of budget cutting and rifting. NASA was told to sacrifice a major project. They chose the $680 million VOIR mission, rescheduling it as a down-sized “new start” for fiscal year 1984. Around March, 1982, an ad hoc JPL group and NASA Headquarters sought means to pare VOIR to $200-$300 million by reducing personnel and cutting all experiments that did not use radar. Only altimetry, imaging, and gravity experiments survived. The redefined mission would focus on nine “Compelling Scientific Questions”:

1. What geological processes operate to form and modify the surface of Venus?
2. What is the age of the surface of Venus?
3. How old is the present atmosphere?
4. Did Venus have water and oceans?
5. Does Venus have plate tectonic activity?
6. What is the origin of the Venus highlands?
7. Why are topography and gravity positively correlated?
8. How does Venus rid itself of internal heat?
9. What can Venus tell us about Earth history?[15]

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[14] Butrica, *op. cit.*, pp. 7-462–464

[15] Solar System Exploration Committee of the NASA Advisory Committee, *Planetary Exploration Through Year 2000: A Core Program.* Part one of a report by the Solar System Exploration Committee of the NASA Advisory Committee. (Washington, D.C.: NASA, 1983), p. 140.

The low cost replacement for VOIR temporarily was renamed *Venus Mapping Mission* (VMM) during part of 1981-1982, and then the *Venus Radar Mapper* (VRM). Mapping resolution varied all over the place from the 1978 recommendations of the Science Working Group (SWG):

1978 SWG:	100% at 600 meters resolution, a few percent at 100 meters resolution, plus 100% altimetry coverage.
Early 1981:	Map 70% of planet at 600 meters resolution, 1% at 150 meter high resolution.
January 1982:	Map 70% of planet at 1 kilometer resolution, no high resolution.
February 1982:	Map 90% of the planet at 300 meters resolution.[16]
1983:	Near global map (> 70%) with sub-kilometer resolution.[17]
1984:	215 meters by 150 meters and 480 by 250 meters.[18]
Final Goals:	Map at least 70% of planet at resolution better than 300 meters, determine global relief (altimetry) at horizontal resolution of about 10 kilometers and a vertical accuracy of 80 meters or better.[19]
Actual:	100–250 meters by 110 meters, covering >98% of the planet, altimetry at 10-30 km footprints, with 50 meter or better accuracy.[20]

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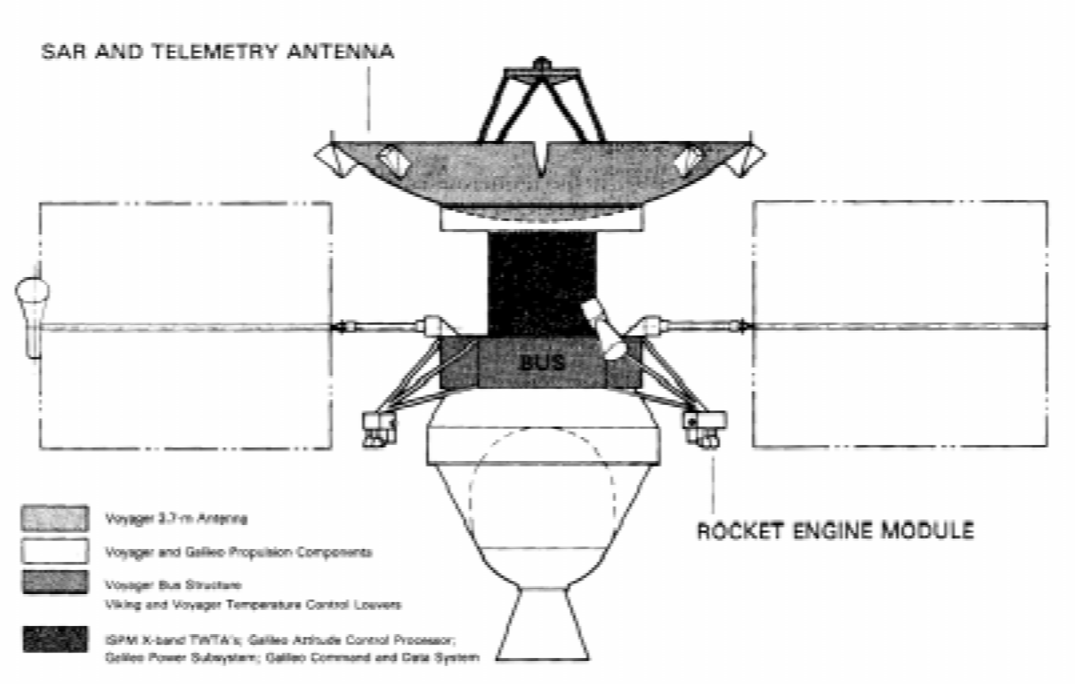
[16] Butrica, *op. cit.*, pp. 7-448-450.
[17] Solar System Exploration Committee, *op. cit.*, p. 140.
[18] Butrica, *op. cit.*, p. 7-450.
[19] P. 1 of J. P. Ford, J. J. Plaut, Catherine M. Weitz, T. G. Farr, D. A. Senske, Ellen R. Stofan, G. Michaels, T. J. Parker, *Guide to Magellan Image Interpretation* (NASA/JPL Publication 93-24, November 1, 1993).
[20] *Ibid*., pp. 9, 19; p. 13,110 of P. G. Ford and G. H. Pettengill, "Venus Topography and Kilometer-Scale Slopes," JGR 97/E8(August 25, 1992): 13,103-13,114.



Like its high-priced VOIR predecessor, the Venus Radar Mapper (VRM) was to be built out of spare parts left over from other planetary missions. VRM was renamed Magellan, and its launch was delayed by the Space Shuttle *Challenger* disaster. The decision to launch Magellan before Galileo precluded the use of its spare parts. That and a change in launch vehicle required redesign of the Magellan platform and antenna. [Color Fig 7, p. 73, from Solar System Exploration Committee, *op. cit.*]

Although Hughes was selected to build the SAR apparatus around the end of 1981, the actual NASA, JPL, Hughes contract would not be signed until January 14, 1984. By then Soviet Venera 15 and 16 would have completed about a third of its Venus SAR mapping. Martin Marietta, NASA, and JPL signed the contract to build what would become the Magellan spacecraft in 1983. Like its VOIR predecessor, VRM was to be built of spare parts from other missions. VRM also would use an elliptical orbit, not the VOIR recommended circular one, because it was cheaper than the aerobraking required to maintain a circular orbit.[21]

The Soviets had been holding off doing a radar mapping of Venus since they expected the US to do it prior to 1984. Then, taking advantage of the delays in the US Venus mapping project, they launched two SAR orbiting Mappers to Venus, Veneras 15 and 16, on June 2 and 7, 1983. Venera 15 arrived at Venus October 10, 1983, and began mapping. Venera 16 began mapping October 14, 1983.

Although Venera 15-16 mapped only the Northern 25% of Venus (where Pioneer data were especially low resolution or nonexistent), this had significant repercussions for the VRM mission. There would be little to be gained by remapping that portion of the planet at comparable resolution. During 1984, the NASA Space Science Board's Committee on Planetary and Lunar Exploration (COMPLEX) asked Gordon Pettengill to do an assessment of the Venera 15-16 capabilities compared to the proposed VRM apparatus. Pettengill's report also compared VRM to Arecibo's capabilities which had reached 1-3 km resolution by 1983.[22]

With all the emphasis on VOIR, earth-based radar observations went into near eclipse in the late 1970s. Haystack, Jodrell Bank, and the Goldstone Mars Station had disappeared or abandoned planetary science. By 1980 only Arecibo continued to work on planetary astronomy; the number of earth-based planetary radar astronomers shrank to about eight people.[23] But then three transforming things happened: First, Jim Head craved better data for understanding the geology of Venus and was unwilling to wait until Magellan eventually provided needed improvements in resolution. Second, 1983 upgrades at Arecibo

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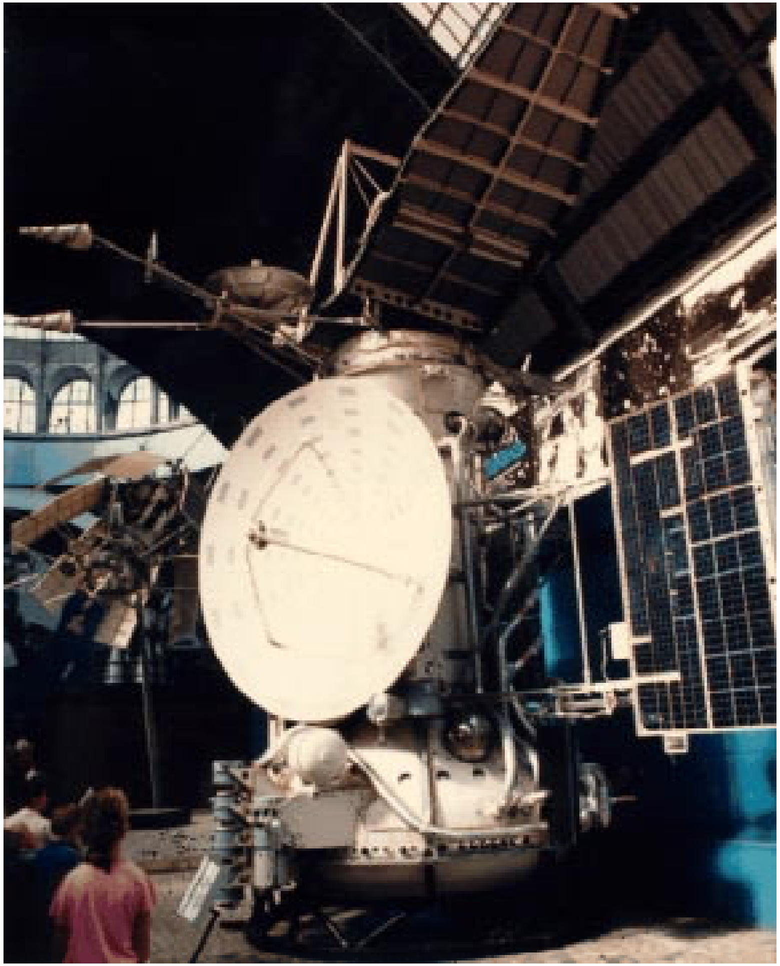
[21] Butrica, *op. cit.*, pp. 7-450–451.
[22] Butrica, *op. cit.*, p. 7-453, 7-467.
[23] *Ibid.*, p. 4-53.



When it became clear that the US VOIR mapping project would be delayed beyond 1984, the Soviets decided to launch their own SAR mappers which would map the upper 30% of Venus at 1 km resolution. Two duplicate mappers, Venera 15 and 16, were sent up January 2 and 7, 1983, and began mapping October 10 and 14, 1983. Information was received through July 10, 1984. American James W. Head III was enlisted as a Guest Investigator to help interpret the Venera data. Exchanged Venera 15-16 data proved critical in planning the Magellan mission, and three Soviets would become Magellan Guest Investigators. [Color image of Venera 15 exhibit in the Cosmos Museum, Moscow, courtesy Vernadsky Institute; downloaded from http://delcano.mit.edu/venera/GIF/ venera15a.gif] enabled it to obtain Venus images with 1-3 km resolution, followed in 1988 by another upgrade that achieved 1.5 km resolution.[24] This was far superior to Pioneer and approximated what the Soviet Venera SAR images could resolve. Third, Goldstone eventually would achieve higher resolution (~1 km.) and be returned to planetary observation use.

Figure overleaf: When delays postponed the US VOIR launch beyond projected 1984, Soviets took advantage of the delay and launched Venera 15-16 SAR mappers. NASA was concerned whether this obviated the scientific merit of VOIR and asked Gordon Pettengill to undertake a comparison of expected capabilities of Venera *vs*. VOIR; Pettengill included a comparison with 1983 Arecibo capabilities. Partially underlying this concern were doubts whether satellite-born radar was more cost-effective than upgrades in Arecibo. Before Magellan ground-based radar would perform comparably to satellite systems. The upper image of the first page is a Venera 15-16 image of Maxwell Montes, second highest edifice in the solar system. The prominent ~100 km diameter circular feature is not the summit of Maxwell, but rather Cleopatra, the only impact crater on Maxwell's flanks. Maxwell's summit is the high point of the prominent vertical ridge system to the left of Cleopatra. Below is a 1983 Arecibo detail of the same region. The differences in displayed features are more a function of different radar viewing angles than they are radar resolution. This is made clear by the upper image on the next page which is a 1988 Arecibo image having comparable resolution to Venera 15-16. The 1988 Arecibo coverage includes on the left portion of the other images; Cleopatra is not imaged. The differences in appearance between the Venera and the 1988 Arecibo images are due primarily to the articulation of radar signals relative to the surface rather than differences in resolution. The final picture is a full Magellan F-MIDR image showing a detail of the Maxwell/Cleopatra region. It is of obviously higher-resolution than the other images. Only Magellan images would be adequate for geological interpretation of small-scale Venus features. Even then interpretations of features smaller than 0.5 km would be problematic. Improved resolution does not resolve all problems of interpretation. Prior to Magellan there was controversy over whether Cleopatra was an impact crater or a volcanic feature despite the fact that it was a 100 km diameter feature well within Venera and Arecibo resolution. [Venera image is a detail from Sheet 3 of USGS *Maps of Part of the Northern Hemisphere of Venus: A Joint U. S./U. S. S. R. Mapping Project* 1:5,000,000 Map I-2041, 1989; a similar image can be downloaded from http://delcano.mit.edu/venera-maxwell2.gif. The 1983 Arecibo image is a detail from AVEN006P.IMG, USA NASA PDS MG 1001, version 2, "Pre-Magellan Radar and Gravity Data" CD-ROM; and the 1988 Arecibo image from AVEN017P.IMG, *ibid.*; the Magellan image is F-MIDR 65N006 from Magellan data set CD-ROM MG_0006. Both Arecibo images have been rotated 32° to approximate the orientation of the Venera and Magellan images.]

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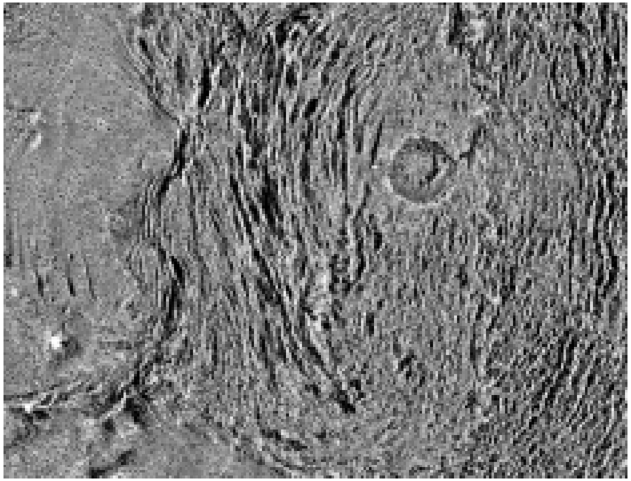
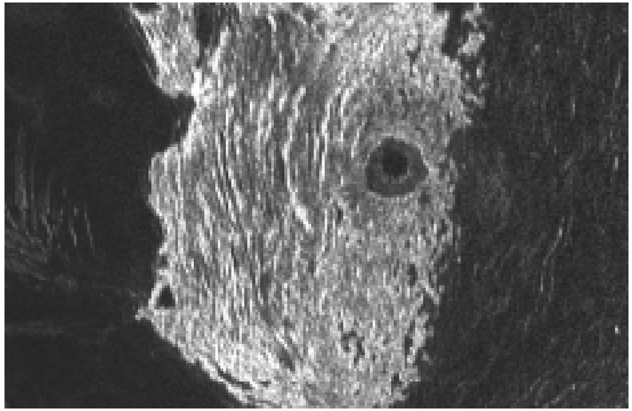
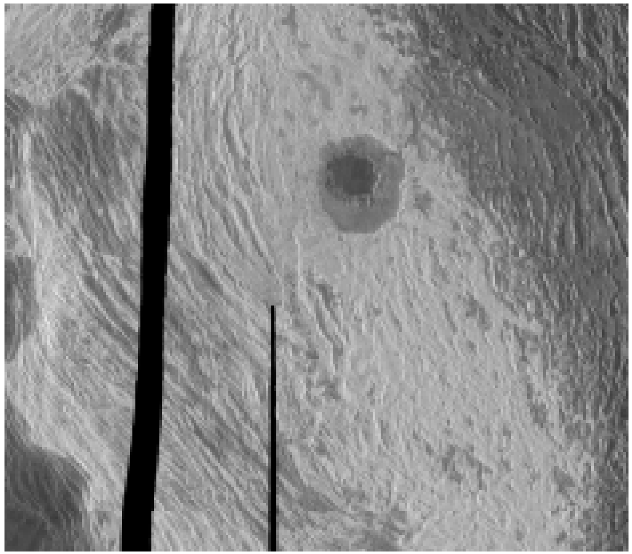
[24] *Ibid.*, p. 7-467.


Venera 15/16


Arecibo 1983


Arecibo 1988


Magellan

CLICK ON PICTURE TO SEE LARGER VERSION

Around 1980 Arecibo (NIAC) and Brown University entered into an accord for cooperative analysis of Arecibo Venus imagery. Head already had years experience interpreting lunar radar images; joining him were Richard W. Vorder-Bruegge and David A. Senske. The focus of interest was investigating tectonic activity on Venus. As early as 1970, Arecibo images had suggested earth-like tectonic features such as folds and faults, and 1983 images displayed rifting and tectonic activity around Maxwell Montes and southern Ishtar Terra. Later studies found similar signatures in a number of other regions. Donald Campbell of Arecibo collaborated with Head's group in investigating volcanic activity displayed in Arecibo images. By 1988 Arecibo images made it clear that there was significant volcanic activity in southern Ishtar Terra, Beta Regio, and Eistla Regio highlands as well as in the plains of Guenevere Planitia.[25]

Figure next four pages overleaf: On the eve of the Magellan mission much of the planet Venus had been radar imaged. There were five Venus radar data sets: Figure **(a)** shows the extent of the Pioneer radar altimetry coverage which has been rendered as a shaded relief map. It had the lowest resolution coverage, (100-200 km) but over far more of the planet. **(b)** From 45°N to 15°S the Pioneer imaging mode achieved higher resolution - about 30 km. Part **(c)** shows the extent of radar coverage by Goldstone images, which ranges from 5-10 km resolution in 1972 to almost 1 km from 1986 on. Coverage boundaries are superimposed on a Magellan image having resolution of 100-300 meters. Part **(d)** shows the 1983 coverage of Venera 15-16 at 1-2 km resolution. About the same resolution was achieved by Arecibo around 1988 whose coverage is shown in **(e)**. [Parts (a), (d), and (e) are details from Sheet 3 of USGS *Maps of Part of the Northern Hemisphere of Venus: A Joint U. S./U. S. S. R. Mapping Project* 1:5,000,000 Map I-2041, 1989. Part (b) is Plate 2(a), p. 8255, of Masursky et al, "Pioneer Venus Radar Results: Geology from Images and Altimetry." JGR 85/A13(December 30, 1980): 8232-8260; and part (c) is Fig. 1, p. 16,280, of "Comparison of Goldstone and Magellan Radar Data in the Equatorial Plains of Venus." JGR 97/E10(October 25, 1992): 16,279-16,291.]

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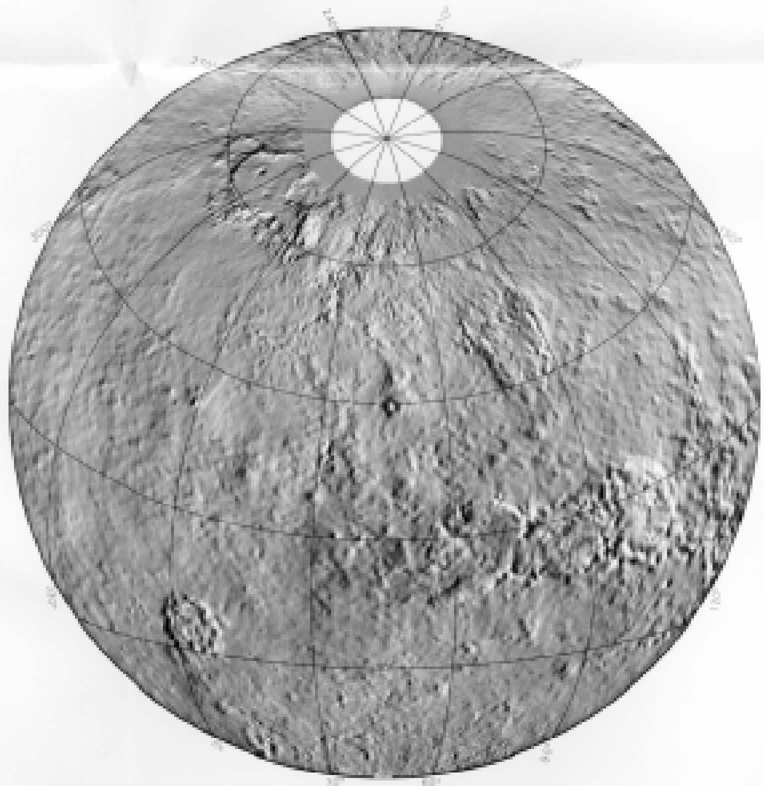
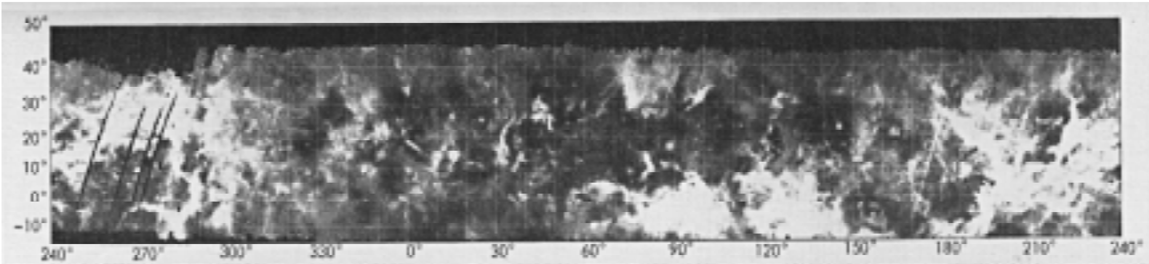
[25] *Ibid.*., p. 6-411.



DIGITAL SHADED RELIEF MAP BASED ON PIONEER
VENUS ALTIMETRIC MEASUREMENTS
(LAMBERT AZIMUTHAL EQUAL-AREA PROJECTION)

(a)



PIONEER VENUS RADAR IMAGING COVERAGE

(B)

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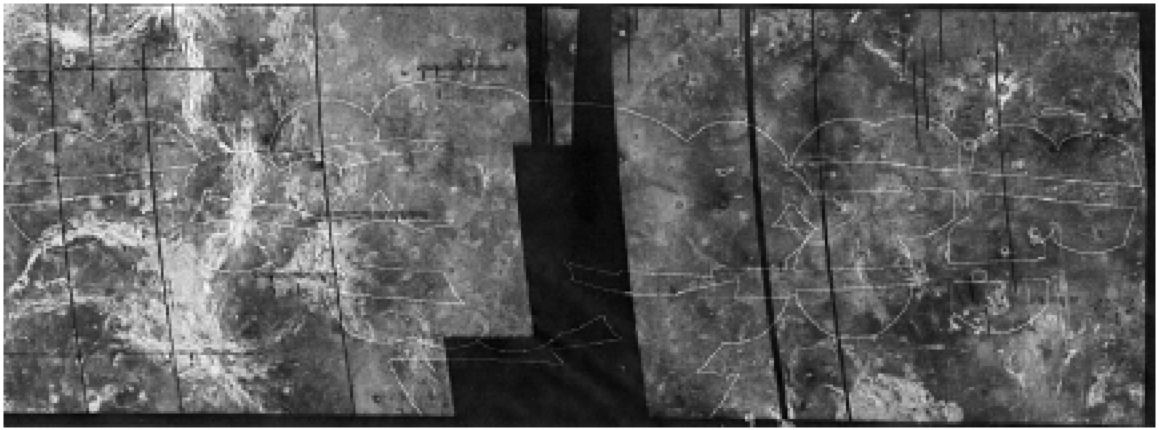
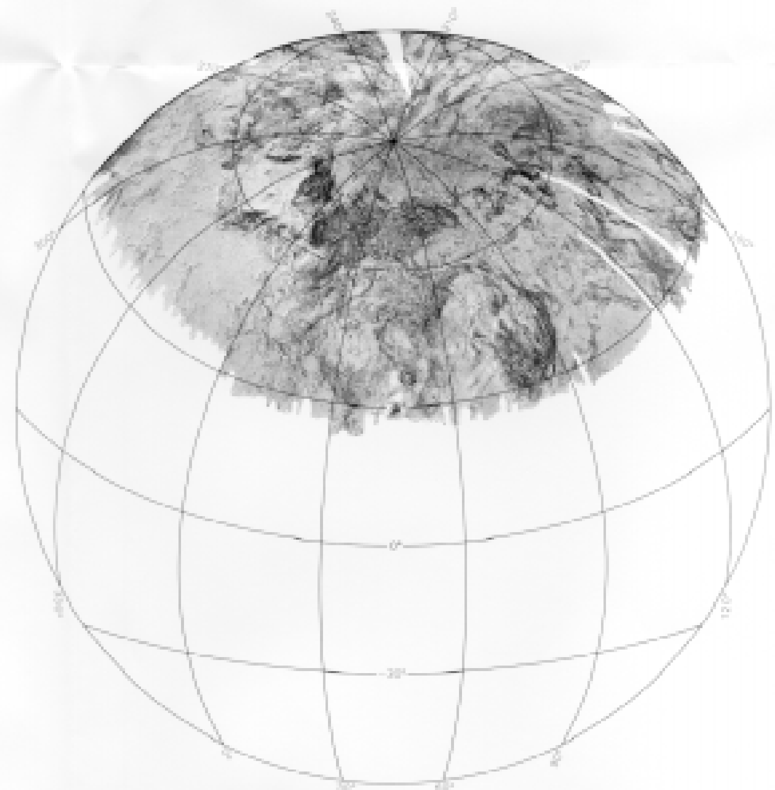


23S260 23S32

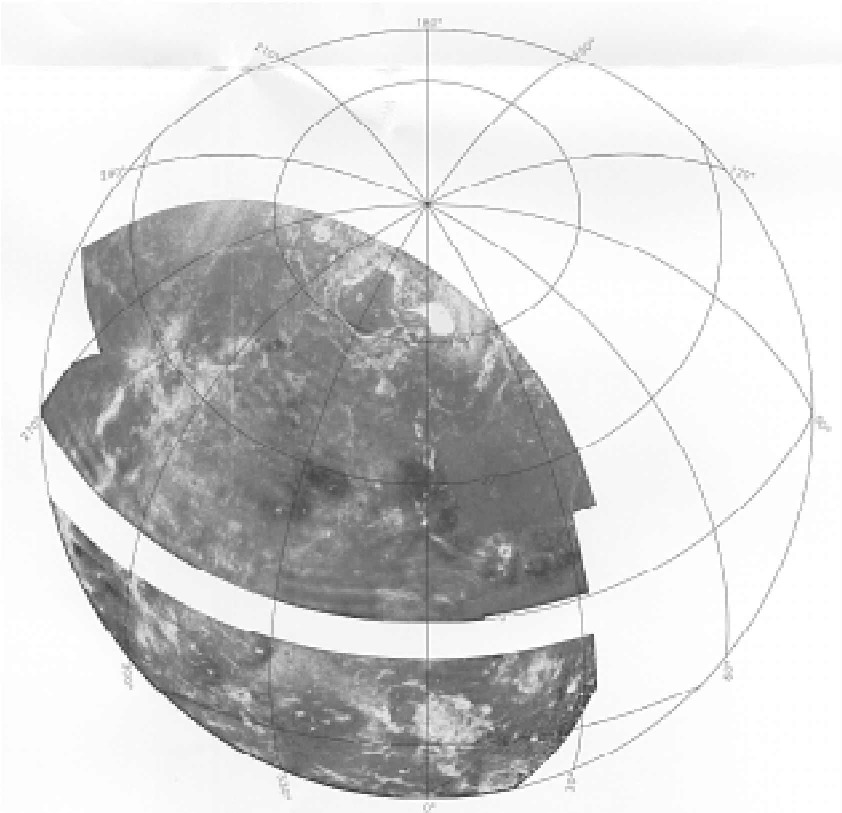
GOLDSTONE 1972-1988 COVERAGE

(C)



LOCATION OF VENERA 15 AND 16 RADAR IMAGES
(LAMBERT AZIMUTHAL EQUAL-AREA PROJECTION)

(d)



LOCATION OF EARTH-BASED RADAR IMAGES
(LAMBERT AZIMUTHAL EQUAL-AREA PROJECTION)

(e)

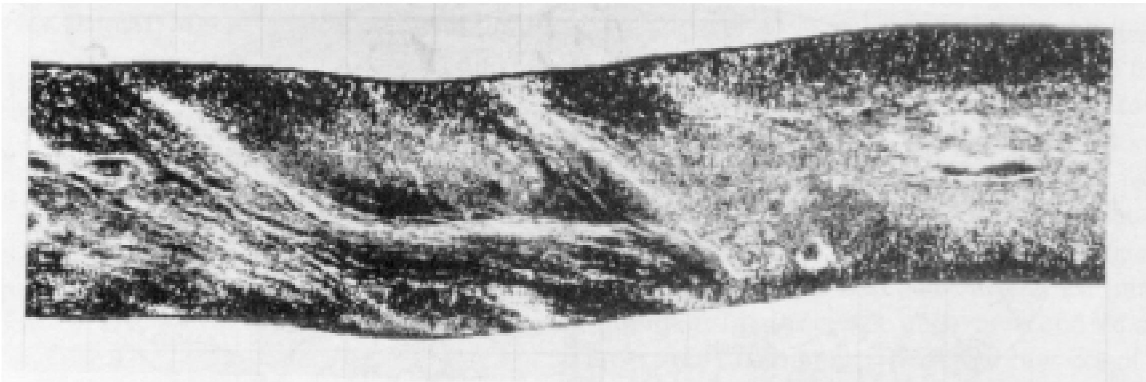
Head's collaboration with Arecibo marked the first time that planetary geologists were so systematically involved with the interpretation of high-resolution Venus radar images. With his work at Arecibo, building upon prior lunar radar experience, Head would come to have a radar interpretative expertise that no other planetary geologist possessed. By comparison the sophistication of the various radar interpretation workshops and associated field trips paled, as did the expertise of their organizers. As Venera 15 and 16 images were received, the Soviets needed American help in their interpretation. The problem was that interpretation required more information about Venus surface features than was provided by the Venera landers. They needed Arecibo ground-based and Pioneer orbiter altimetry data, and turned to Masursky and Head for aid. Head's interpretative expertise was superior to Masursky's and only Head became a Guest Investigator on the Venera 15-16 project. His Venera involvement, of course, gave Head further expertise with the geological interpretation of high-resolution (1-3 km) Venus radar images.

One of the original motivations for the VOIR mission was to beat the Soviets to the SAR punch, but when VOIR began to stall as victim of Reagan's slash and ruin ideology, the Soviets jumped into the breach and tossed up two SAR orbiting imagers, Veneras 15 and 16, for a limited mapping mission. How, in the face of such opportunistic politics, Jim Head came to be invited to be a Venera 15-16 Guest Investigator is a fascinating story in the politics of international science well worth telling.[26]

The story begins with a few American scientists, including Harold Masursky and James Head, making frequent trips to international meetings where they met Soviet planetary scientists. In 1972 Harold Masursky and Alexander ("Sasha") Basilevsky become friends. Frequent trips by both Masursky and Head to Moscow followed. After the Reagan administration allowed the 1972 "Détente" USA–USSR Space Treaty to lapse, beginning around 1982-83 American and Soviet scientists resorted to informal

[26] The story is Andrew Butrica's and follows his account in *To See the Unseen, op. cit.*, pp. 7-451–457.

exchanges to continue scientific collaboration and exchange.[27] Such arrangements presumed upon personal friendships such as Masursky's and Basilevsky's and involved end-runs around US and USSR bureaucracies which, for all their treachery, nonetheless ignored such activities. Head eventually came to be invited to be Guest Investigator on the October 1983 to July 1984 Venera 15-16 mission. This proved to be the beginnings of a most amazing turn of events leading to a new space "treaty" between the Soviet Academy of Sciences and the State of Rhode Island, and then Soviet involvement in the NASA Magellan mission.



The first image strip delivered by Venera 15. Area covered is 150 km by 620 km. Ridge belts and furrows are clearly discernible. The sinuous shape reflects Venera 15 orbital effects as it does its mapping swath. These strips will be mosaiked together to provide composite images. Swath has been rotated ~90° from its mosiaking orientation. [Fig. 5, p. D380, of V. L. Barsukov and 30 others, "The Geology and Geomorphology of the Venus Surface as Revealed by the Radar Images Obtained by Veneras 15 and 16" *Proceedings of the 16th Lunar and Planetary Science Conference, Part 2* JGR 91/B4(March 30, 1986): D378-D398.]

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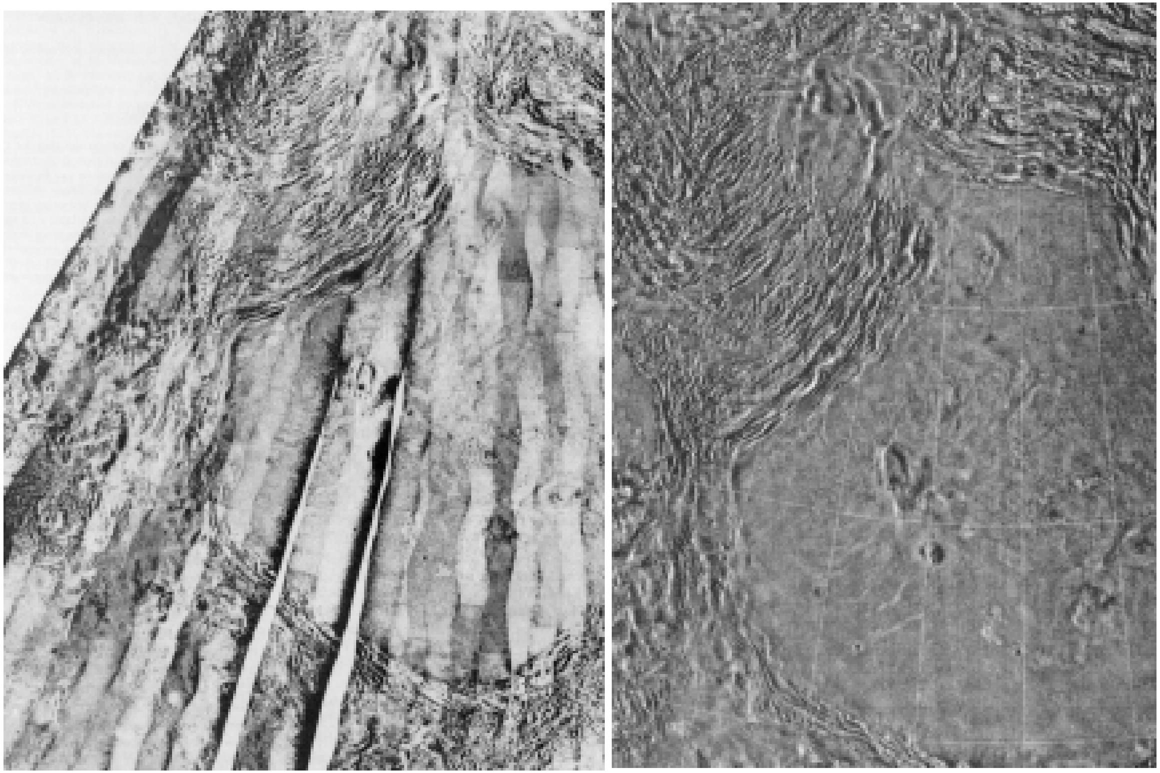
[27] H. S. F. Cooper, *The Evening Star: Venus Observed* (Baltimore: Johns Hopkins University Press, 1993), p. 143.

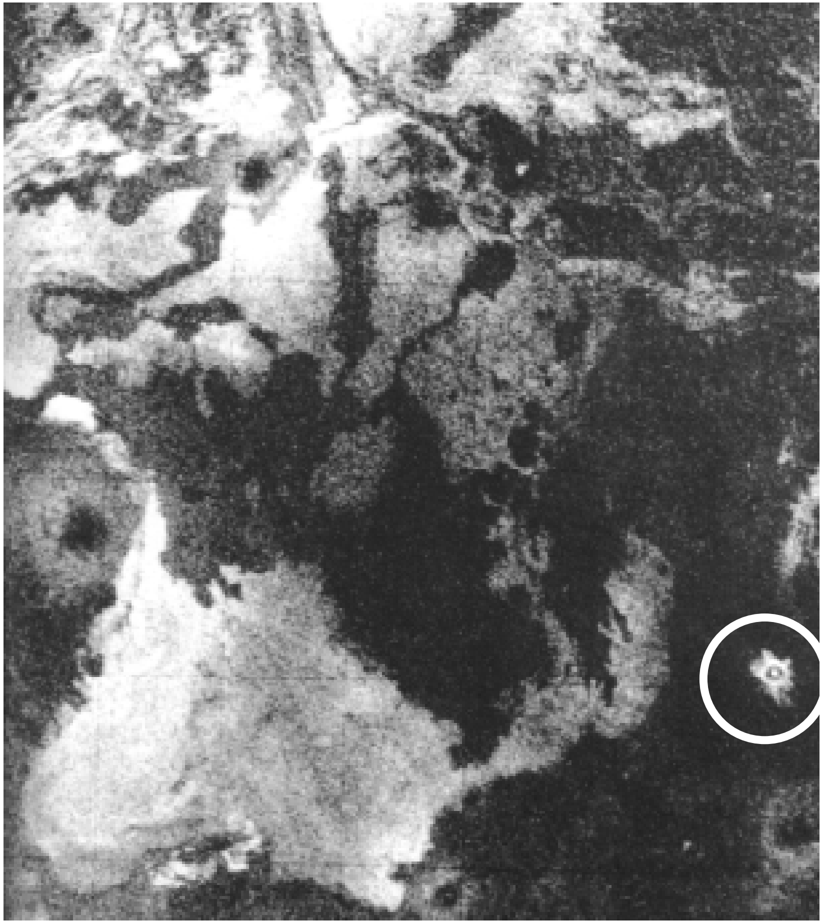


Composite image made by mosaiking individual orbit swaths. The mosaiking is evident in the lower left image of Laksmi (to the west of Maxwell Montes and Cleopatra crater shown in the comparative images above and rotated ~90°.) Computer enhancement removes the obvious seam lines and interpolates for missing data, producing a more easily interpretable image such as the lower right image of roughly the same portion of Laksmi. Such images are, of course, models of the radar data. [Upper image is the lower right image is a portion of *ibid*., Fig. 8, p. D381; the lower left image is a portion of Fig. 1, p. D400, of A. T. Basilevsky, A. A. Pronin, L. B. Ronca, V. P. Kryuchkov, A. L. Sukhanov, and M. S. Markov, "Styles of Tectonic Deformations on Venus: Analysis of Venera 15 and 16 Data" *Proceedings of the 16th Lunar and Planetary Science Conference, Part 2* JGR 91/B4(March 30, 1986): D399-D411.]

Basilevsky and his boss, V. L. Barsukov (Head of the Vernadsky Institute of the Soviet Academy of Science–rough equivalent of the USGS), were invited to attend the 1984 Lunar and Planetary Science Conference (LPSC); these conferences are organized by the Lunar and Planetary Institute and held in a gymnasium at the NASA Johnson Space Flight Center in Clear Lake, Texas, outside Houston. LPSC arguably is the most important planetary science conference each year. Mosaiking of Venera 15-16 images was mostly complete, and March 25, 1984, at LPSC Basilevsky and Barsukov presented Venera 15-16 results, offering tantalizing glimpses of Venus to American scientists.

A repeat performance, involving Basilevsky, Barsukov, and two other Soviets, was given March 11, 1985, and presented new data. A week later, March 19-20, 1985 at Brown University, a joint Brown-Vernadsky Institute "Microsymposium" was held at Brown, with the same Soviets, Head, Campbell, Masursky, and Pettengill in attendance. During this microsymposium overlapping portions of Arecibo and Venera imaging were compared and preliminary agreement is reached where to locate the Venus prime meridian on both sets of images using tiny impact crater "Ariande" as the 0° benchmark–as replacement for the earlier Alpha which was now inappropriately large given much improved radar resolution. Head reported indications that the Soviets were receptive to the idea of exchanging data

This cooperation escalated, and November 1985 Head received a single strip of Venera SAR image data and associated altimetry. He distributed copies of the tape to Saunders, Pettengill, Campbell, and Masursky. They easily could display the images using standard American image processing equipment. This informal exchange was followed by a formal agreement to exchange Venus and other planetary data. Since there was no US/USSR scientific exchange agreement in place and Brown University was not a government entity, the memorandum of agreement improbably is between the Vernadsky Institute of the Soviet Academy of Sciences and the State of Rhode Island (where private Brown University is located). It calls for scientific cooperation including a continuation of the Brown/Vernadsky Microsymposiums twice a



Arecibo image of *Sedna Planitia* with small (27 km) impact crater "Ariande" at 44°N 0°. Both Arecibo and Venera imaged this feature with sufficient resolution to coordinate both sets of images. The resolution of both the Arecibo and Venera instruments was such that using it as a longitude "tie" made sense: Ariande was an unambiguous impact crater in size close to the limits of interpretatively reliable radar resolutions and very close to the earlier "low-resolution" prime meridian defined by ground-based detection of Alpha. More importantly, it appeared unambiguously in both the ground-based Arecibo radar images and the orbiting Venera images. This meant that its distinctive signature was not an artifact of either sensing geometry. [Fig. 3-1, p. 15, from Carolynn Young, ed., *The Magellan Venus Explorer's Guide* (NASA/JP Publication 90-24, August 1, 1990).]

year, once in the US and once in the Soviet Union. The arrangements were orchestrated by Head for the US and Barsukov for the Soviets. They Microsymposia continue to be important events in the Venus planetary science community.

April 11-15, 1986, the third Brown/Vernadsky Institute Microsymposium was held at Brown. Basilevsky, Barsukov, and four other Soviets attended. They presented preliminary Venera 15-16 scientific results and a description of the SAR radar system. They also presented the Magellan project with three Venera tapes containing unpublished SAR data under the proviso that it was strictly for planning purposes for the Magellan mission, and not for scientific publication or distribution until after the Soviets had published it. In exchange, the Soviets received high resolution Viking data needed for planning their mission to Mar's moon Phobos.

Soviet-American collaboration continued to mount. Donald Campbell had been attending Brown/Vernadsky Microsymposia, and as a spin-off in 1987 began to collaborate with Basilevsky and other Soviets on the interpretation of Venera 15-16 images. Several joint Soviet-US papers resulted

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Figure Overleaf: The upper Venera radar raster image covers a 300 by 480 km region, Vesta Rupes, that forms the southern and south-eastern boundary of Laksmi (see above). The lower vector image is a geological mapping of the same region in which the following kinds of features are delineated: (1) Surface of Laksmi Planum, (2) lava filling on the floor of intermountain depressions, (3) patchy rolling plains, (4) groove-and-ridge terrain, (5) belt of subparallel ridges around Laksmi Planum, (6) geological boundaries, (7) faults, (8) scarps, and (9) impact craters. These raster images are composites of small grey colored rectangles, where the shade of grade represents a particular average radar brightness value over some region. For Venera these regions were 1-2 km. Vector images represent data as lines with characteristic directions and junctions. The first step in the geological interpretation of radar or photographic raster images is to delineate regions comprised of similar or distinctive features. These vector images become the basis for geological analysis and interpretation. [Fig. 3, p. D402, of Basilevsky et al, "Styles of Tectonic Deformation...," *op. cit.*]


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involving Head, Campbell, Ellen Stofan, Basilevsky, B. A. Ivanov, and others as co-authors.[28] At the March 1987 Microsymposia additional tapes were traded. Eventually Basilevsky, E. L. Akim, and A. V. Zakharov would be made Magellan Guest Investigators, and in the 1990s Basilevsky would spend part of each year at Brown University collaborating with Head.

Venera images revealed two new types of morphological features not previously seen. Coronae are circular or ovid ringlike structures of considerable size. A full corona is seen on the right, a portion of another to its left in this image from Mnemosyne Regio west of Ishtar Terra where a number of 200-500 km coronae were found Image width is 780 km. [Portion of Fig. 25 in Barsukov and 30 others, *op. cit.*, p. D390.]

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[28] E.g., Basilevsky et al, "Impact Craters on Venus...," *op. cit.*.; E. Stofan, J. Head, B. Campbell, S. H. Zisk, A. F. Bogomolov, O. N. Rzhiga, A. T. Basilevsky, and N. Armand, "Geology of a Rift Zone on Venus: Bell Regio and Devana Chasma" *Geological Society of America Bulletin* 101(1989): 143-156.