RADAR STUDY OF VENUS SURFACE BY VENERA-15 AND -16 SPACECRAFT

ЧV. A. Kotelnikov, A. F. Bogomolov and O. N. Rzhiga

Adv. Space Res. 1985, Vol. 5, № 5, P. 5–16

Description is given of the first results of radar study of Venus surface by Venera 15 and 16 spacecraft. Unique images of the Venus surface were obtained on which mountain ridges, craters, plateau, folds and breaks of the Venus crust are seen. Indications of tectonic activity of Venus were discovered. Areas with anomalous character of radio waves reflection were found.

Introduction

On June 2, 1983 an interplanetary station Venera 15 with radar equipment for mapping Venus surface was launched. On June 7 a similar interplanetary station Venera 16 was sent in the same direction. 130 days later, on October 10 and 14, 1983 both spacecraft were placed in the elliptical orbits of Venus satellites. After correcting the orbits and carrying out tests of radar equipment, on November 11, 1983 a regular mapping of Venus surface began.

The main aim of the cosmic experiment, which is underway for more than half a year is to obtain radar images of Venus surface, to measure of height profile along the path of the spacecraft, as well as the study of the local characteristics of radio waves reflection [1].

The synthetic aperture side-looking radar which was installed on the Venera 15 and 16 (Fig. 1) gives a surface resolution of 1–2 km. A radio altimeter has a rootmeansquare error not more than 50 m. The wave length of both systems, radar and altimeter, is 8 cm.

Principles of the experiment

To get a separate image of the elements of Venus surface, which have dimensions of 1–2 km, from a height of 1000–2000 km, the surface resolution must be such as an unequipped eye would give observing Venus surface from the same height, if there were no dense clouds. Ordinary antennas can’t ensure the necessary resolution. That is why a radar method with synthetic aperture was used.

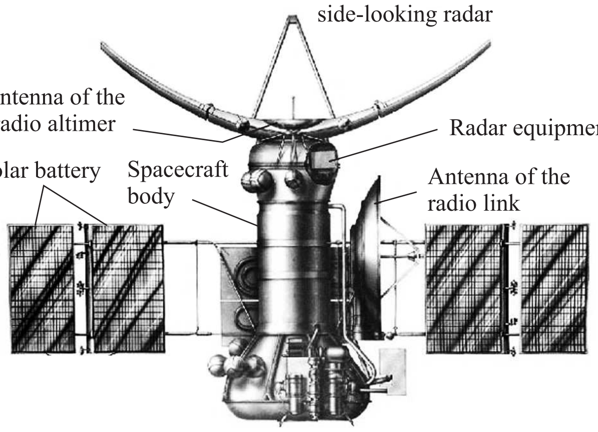

Fig. 1. General view of Venera 15 and 16 spacecraft

With the help of a radar transmitter and antenna which are installed on the spacecraft a region of the planet surface from the side of the path is «illuminated» by radio waves. The angle between the electrical axis of the antenna and the local vertical is 10° (Fig. 2). The surface elements in the limits of the «illuminated» spot are found on different distances and they move with different radial velocities when they are observed from the spacecraft. That is why the signals reflected by them and received on the spacecraft have a different tine delay and have a different frequency as a result of the Doppler effect. For example, point A is closer to the spacecraft the point B, and the signals reflected it come earlier. On the other hand, point C approaches the spacecraft, and the signals reflected by it have a higher frequency, than the signals, reflected by point D which moves off. This effect is used to separate the radio waves reflected by separate elements of the surface and to create an image. When the spacecraft approaches Venus a survey of a surface band stretched along the path is made. When the spacecraft approaches Venus next time the planet turns and a new survey is made. It must be said, that using an ordinary method the same surface resolution could be received installing an 70-m antenna on a spacecraft.

Separate surface elements of the planet, constructing mountain ridges, valleys, slopes of craters, are differently orientated as regards the incident waves. As a result of a strong dependence of the backscattering coefficient of the planet on angle φ (Fig. 3) which is made by the incident wave and the normal to the surface element, the variation of angle φ in the limits $\pm 10°$ relatively the mean value of 10°, which is determined by the orientation of the antenna electric axis, leads to a change of the reflected signal intensity in the limits $+10$ to -8 dB. This effect determines the contrast of the radar image.

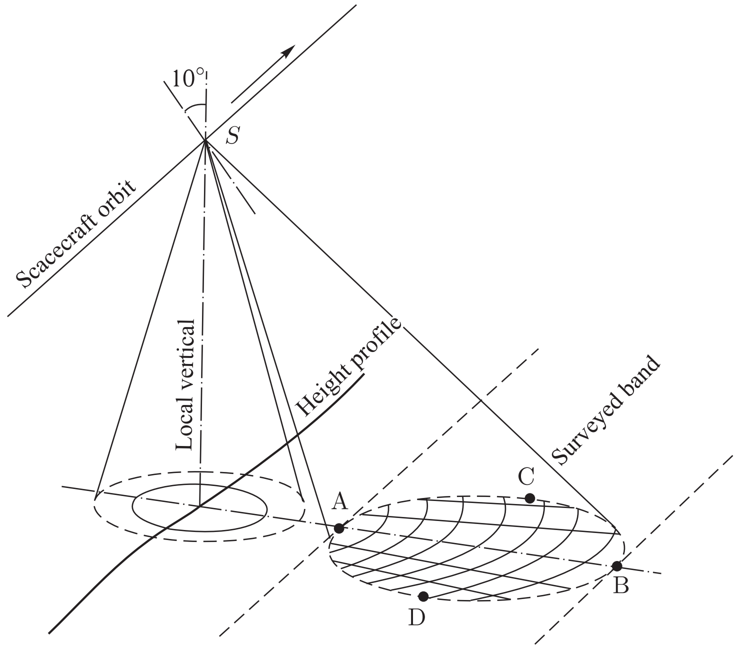

Fig. 2. Scheme of radar survey from the spacecraft

It is difficult to judge the height of the observed formation based on the radar image, as well as on a single photograph. The height profile of the planetary surface along the path the spacecraft is given by radio altimeter, the antenna electric axis of which is directed along the local vertical to the centre of the planet (see Fig. 2). During a single approach to the planet the radar image and the height profile of the surface do not coincide, however, in a few orbits of the spacecraft they will coincide as a result of the rotation of the planet.

Radar system

The reflector of the side-looking radar antenna has the shape of a parabolic cylinder the dimentions of which are 6 m by 1,4 m (see Fig. 1). The reflector of the radio altimeter antenna is a paraboloid the diameter of which is 1 m.

The polarization of waves when they are transmitted and received is linear. With the help of a high frequency switch to the transmitting and receiving equipment either one or the other antenna is periodically switched.

The transmitter of the radar system works by high frequency impulses, inside which the phase of the signal changes by 180° at the moment,

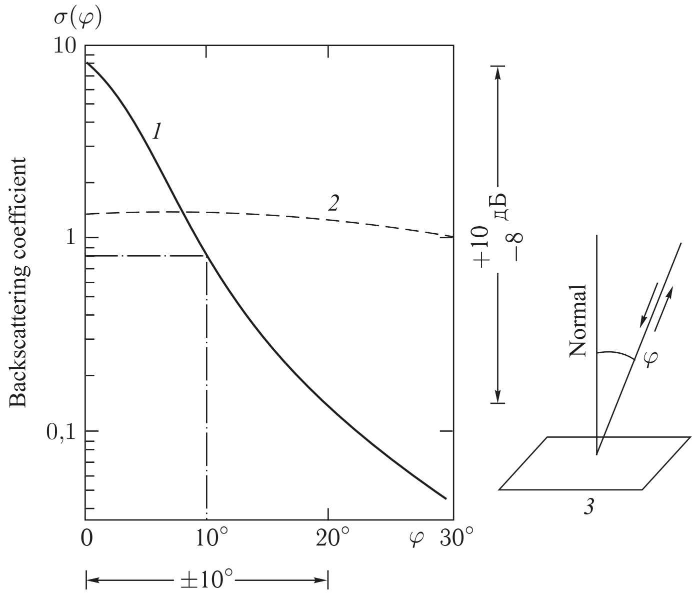

Fig. 3. Backscattering coefficient of surface element (3) which characterises reflected signal power versus incident angle: 1) Venus surface at 8 cm wavelength (according to the radar data obtained earlier from the Earth); 2) diffuse scattering (optics)

determined by the code of periodically repeated M-sequence (maximum length sequence). The length of the code sequence is 127 digits in side-looking mode, it may be 127 or 31 in radio altimeter mode. The length of the elementary impulse which determines the resolution along the slant range and altitude is 1,54 μs.

When the transmitter is switched of, the instant voltage of the reflected signal is recorded on board the the spacecraft in digital form and then transmitted to the Earth to construct a radar image and a height profile of the Venus surface. In every 0,3 s 2540 complex readings of the reflected signal in the side-looking mode (20 periods of 127 element sequence) and 434 complex readings of the reflected signal in the radio altimeter mode (14 periods of 31 element sequence) are recorded. Within 16 min., during which the radar survey is made, we get about 3200 of such groups.

Processing of the reflected signal

On the earth the processing of the reflected signal and the construction of the radar images and height profiles of the Venus surface is made with the help of computers. The separation of reflected signals according to time delay and the Doppler frequency is made by a special digital device — an electronic Fourier processor. A matched filtration of the reflected signal for 127 readings of time delay and 31 readings of Doppler shift is made. This corresponds to approximately 4000 points in the direction diagram of the antenna (see Fig. 2). The surface resolution in the direction ortogonal to the path of the spacecraft is 0,9–1,5 km and along the path is 1,2–2,7 km in the height range of 1000–2000 km.

Within 0,3 s, in which the groups of the reflected signal are recorded, the spacecraft shifts along the orbit to the part of the width of the spot which is in the direction diagram of the antenna. This ensures reciprocal overlapping and a possibility of averaging about 10 independent power measurements of the reflected signal to make the fluctuation errors which are caused by the radio wave interference smaller. The irregular illumination along the image which is caused by the irregular form of the direction diagram of the antenna and the backscattering diagram of the planetary surface are removed. The images which are received from different height get one scale. For this purpose data about the distance and velocity of spacecraft with respect to Venus are used.

In the radio altimeter mode the readings of the reflected signal are convolved with the replica of the code sequence modulating the transmitter phase. The received power distribution of the reflected signal according to the time delay then convolves with the model of this distribution for a number of the value of the roughness factors and a height dispersion. The height of the spacecraft and the possible inclination of the electric axis of the antenna from the local vertical was taken into consideration. The inclination of the electric axis is measured by the shifts of the spectrum central frequency of the reflected signal. The position of the convolution maximum gives the spacecraft height relative to the mean surface in the spot the diameter of which is 40–50 km (see Fig. 2) with a rootmeansquare error which was less than 50 m.

The Venera 15 and 16 spacecraft were launched on an elliptical orbit with a period of rotation of 24 hours. The minimum distance of the spacecraft from the Venus surface (periapsis) is 1000 km and falls on the 60° of the northern latitude (Fig. 4). The maximum distance (in apoapsis) is 65000 km. Under the influence of solar attraction the height in periapsis gradually increases and the orbit has to be corrected. When the spacecraft moves in the periapsis region of its orbit, a surface bend of 7000–8000 km long is surveyed within 16 min. The spacecraft begins the survey at an latitude of 80° beyong the North Pole of Venus, moves near it and, moving approximately along the meridian, ending the survey at latitude 30°.

Results

The first radar images of Venus surface which were received by the Venera 15 and 16 spacecraft in October 1983 are given in Figs. 5 and 6. The spacecraft moved from left to right, its path is above the surveyed bend. The length shown is 2×1100 km, the width is 156 km (the useful part of the image is somewhat narrower). The angular distance relative

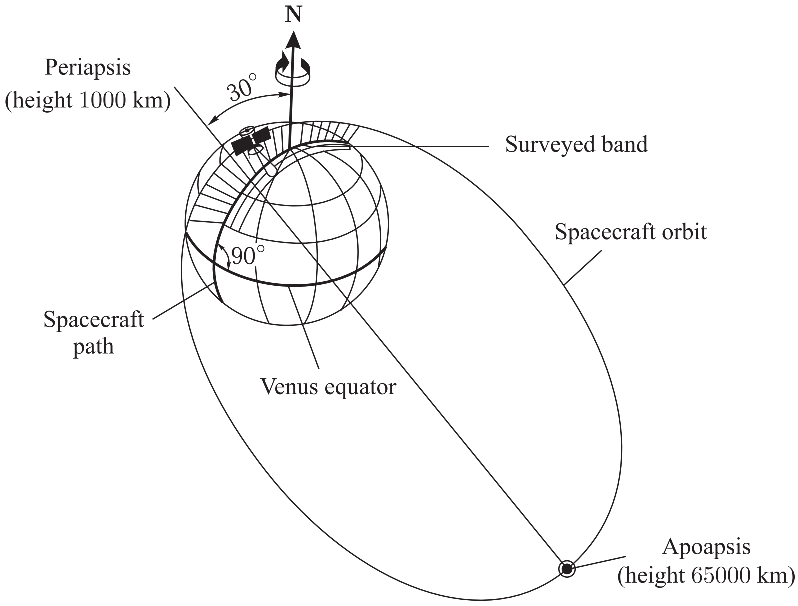

Fig. 4. Movement of Venera 15 and 16 spacecraft under radar survey

to the periapsis of the orbit is plotted on the horizontal axis, the angular distance relative to the orbit plain is plotted on the vertical axis. These distances are measured in degrees from the centre of the planet (one degree on the Venus surface corresponds to 105,6 km). The image is constructed assuming that the Venus surface is a sphere of a radius of 6051 km. The deviation of the local radius from this value caused an irregular shift of the boundaries along the vertical, which is seen on the image. A gradual change of the boundaries is caused by a change of the spacecraft height when it moves along the elliptical orbit.

An ancient folded area, covered with half destroyed craters of impact origin lies from the beginning of the image up to −29° from the periapsis. The remains of these craters the diameter of which is about 30 km are seen on −32,7° and −31,8° (Fig. 5). The slopes which face the falling ray look light; the slopes which do not face the falling ray are dark.

The folded formations are, evidently, younger. On Fig. 6 we see how the folded formations moved from left to right across the middle of the crater the diameter of which is about 100 km (the centre of the crater is −32,5°). Some areas of the bottom of the crater with a smooth surface look dark. Then we see a plain, which has no structure, that runs up to −24°. This region is the nearest to the North Pole of Venus, from which it is 4°–5° along the meridian.

The plain suddenly breaks at −24°, from where a young folded area spreading for about 500 km begins. Numerous parallel mountain ridges

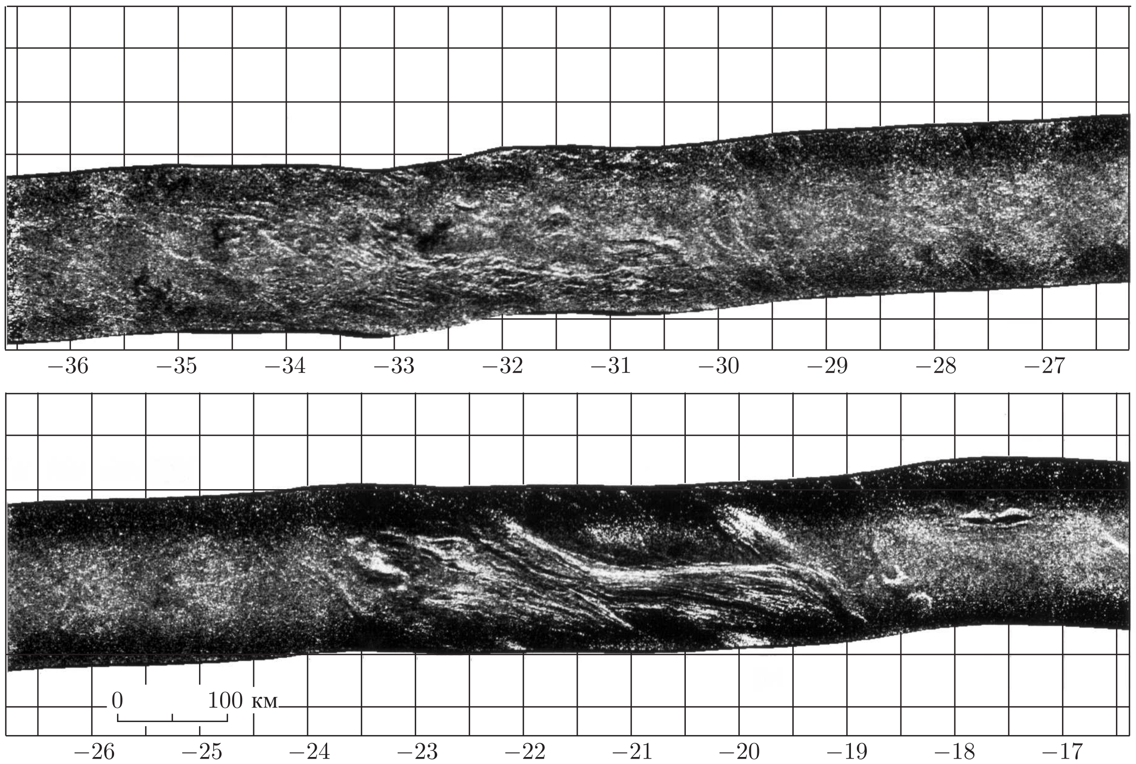

Fig. 5. Radar image of the Venus surface obtained by Venera 15 spacecraft on October 16, 1983

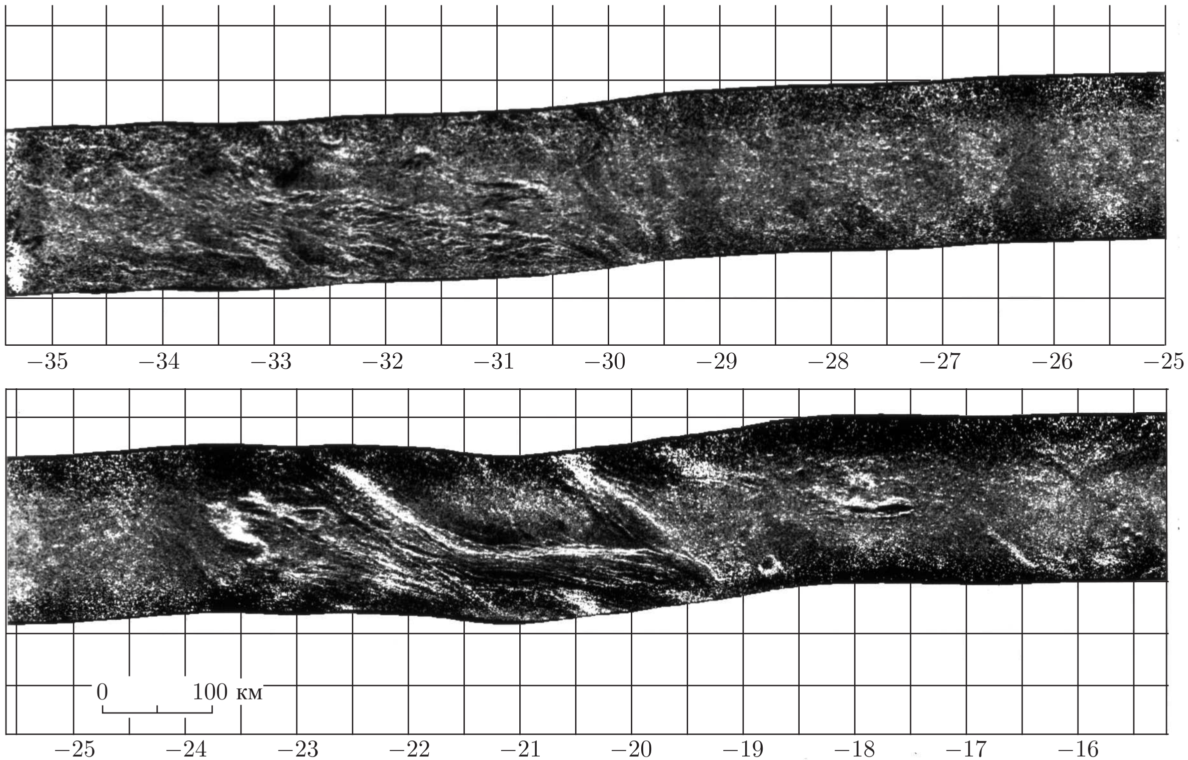

Fig. 6. Radar omage of the Venus surface obtained by Venera 16 spacecraft on October 20, 1983

cross the path at an angle of 45° and then run along the path hundreds of kilometers on and on, gradually separating. Where the mountains end a second mountaneous area appears at an angle of 45°. A big crater of elliptical form the dimentious of which are 80 km to 60 km with a central hill at −20,7° can be seen inside the sharp angle, which is formed by the two groups of folds (See Fig. 6). As is seen the mountain folds do not bear visible traces of water erosion which creates transversal ravines and valleys. On earth photographs they have a «fir-tree» shape.

Now the relief becomes less-montaneous. The most outstanding objects in this area are two mountains from −18,3° to −17,7° (Fig. 5) running along the path for about 80 km. At the base they are 15–20 km wide. The slopes facing the spacecraft look light, the opposite look dark. Two halfruined craters with a diameter of 15–20 km can be seen at −19,0° and −18,7°. These formations can be seen on Fig. 6 with the exception of the second crater, which couldn't be surveyed because Venus moved around its axis by 6,5° between the surveyes.

Radio altimetery helps to decipher the formations on the surveys. Fig. 7 shows the area of Maxwell Monts with a huge crater of Patera Cleopatra the diameter of which is about 100 km. The height profile is matched with the radar image. The white line shows the path of the spacecraft when the profile was measured. The radius of the planet surface in a given point in kilometers is plotted to the right on the vertical axis. This value is the difference of the distance of the spacecraft from the centre of the planet and measured height.

The maximum height of the mountain range for the given profile is 11 km above the mean radius of Venus which is according to the International Astronomic Union 6051 km. The crater which was crossed by the path of survey is on a mountain slope and has a complex shape. The comparison of the image with the profile shows that inside the big crater 1,5 km deep there is a second of a smaller, diameter the bottom which is 1 km deeper. It should be noted, that considerable deviation of the local radius from value 6051 km which is a sphere radius on which the image is plotted, has resulted in a considerable distortion of the crater shape and its dislocation. This was taken into consideration when the path of radio altimeter was plotted on the image.

Interesting phenomena were discovered on the Venue surface that were caused by an anomalous character of the wave reflection. Fig. 8 shows an image of two big craters of impact origin. The bottom of one of them looks unusually bright as compared to the locality. To cause this phenomenon structure of crater bottom must creats an intensive reflection of the radio waves in the direction of the spacecraft. For example, if there are dunes on the bottom of the crater similar to ones on Mars and the path of the spacecraft is parallel to the dunes, the signal will mainly be reflected in the direction of the spacecraft if the steepness of the slopes is about 10°.

There is another supposition that the bottom of this crater is covered with spherical stones. The incident wave, refracting on the boundary with

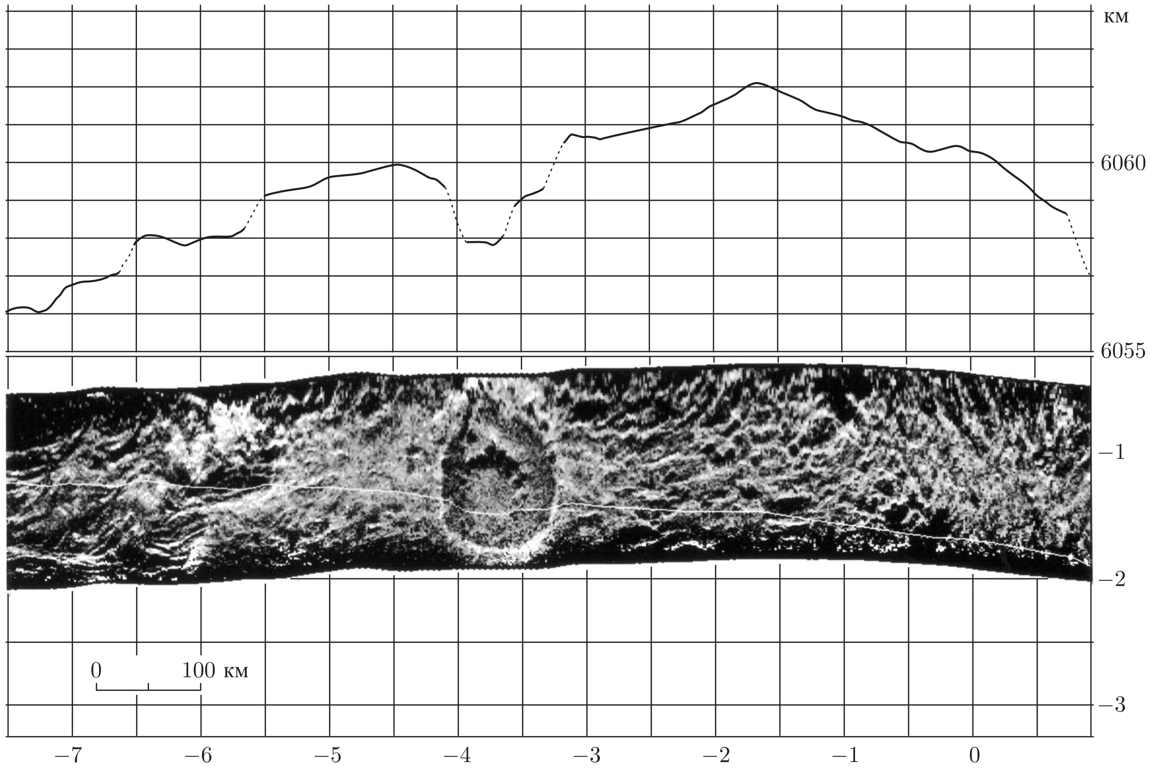

Fig. 7. Radar image of Maxwell Monts obtained by Venera 16 spacecraft on January 20, 1984. Above is given the height profile along the spacecraft path on January 17, 1984 which is marked with a white line

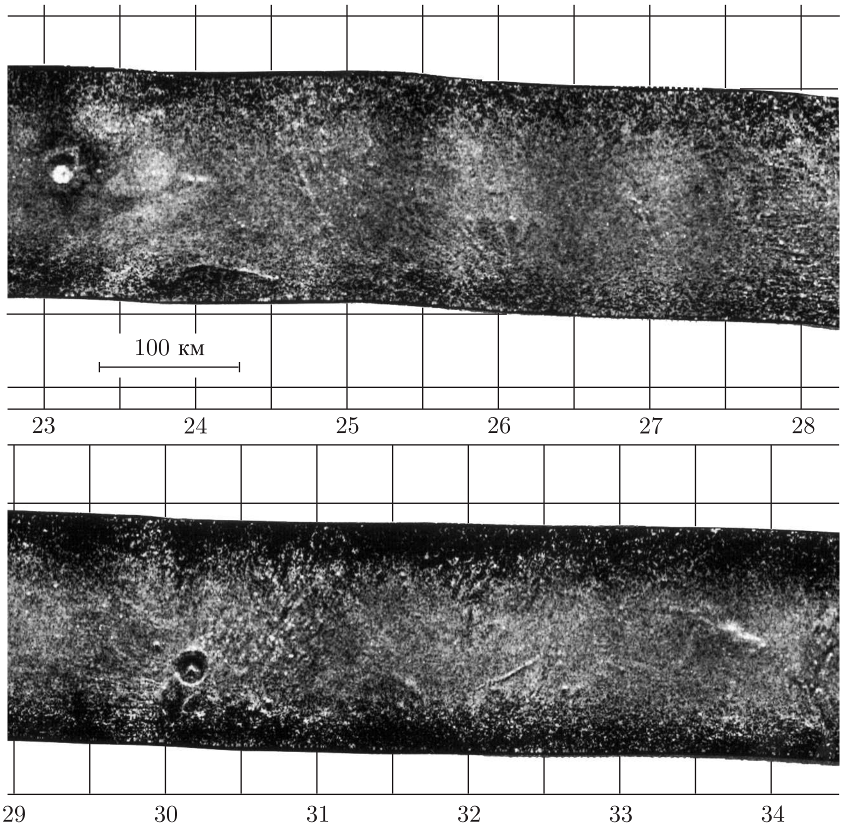

Fig. 8. Image of two craters of impact origin, one of which has a very bright bottom

the atmosphere, passes inside the sphere, partly reflects from the opposite boundary and returns to the atmosphere. If the refraction coefficient of the sphere material is about 2 (the relative dielectrical permeability is about 4), the sphere acts as retroreflector and the wave returns in the same direction from where it came.

In some other areas of Venus with a reduced radiowave backscattering under a sloping incident look dark on the surroundings. The average signal power at the output of the side-looking radar receiver reduced to 5–10 dB passing one of such plots of land 200–300 km long. At the same time the average signal power of the reflected signal at the cutput the radio altimeter receiver the electric axis the antenna which is directed vertically not only became less but somewhat increased. We may conclude that wave backscattering under sloping incident in this case is caused by a greater smoothness of the surface in this area.

Conclusion

As a result of a radar survey carried out by Venera 15 and 16 spacecraft unique images of the Venus surface were obtained on which mountain ridges, craters, plains, folds and crushes of the Venus core can be seen. Indications of tectonic activity of Venus were discovered. We may state that geologically the Venus surface is much more interesting than that of the Moon, Mercury and, probably, Mars, where craters of impact origin prevail. A dense atmosphere protects the Venus surface from meteorites of not very large size. Water erosion dosn't exist, wind erosion is reduced (these kinds of erosion exist on the Earth and Mars). That is why the Venus surface has fixed and preserved like a photo plate all the changes that have taken place for billions of years under tectonic forces.

By the beginning of June 1984, the Venera 15 and 16 spacecraft has surveyed an area of 100 million km^2, which comprises 20 percent of the whole surface of Venus. Within 8 months in which Venus makes a full rotation around its axis it is possible to survey the northern hemisphere of Venus above $30°$.

Based on these data it will be possible to make maps which will help to study the processes taking place on the Venus surface and to made a conclusion about the history of the planet development. The data will help to decide the question of the geologic activity of Venus. Detailed maps are necessary, for example, to investigate climate, atmosphere circulation and structure of the gravitation field of the planet. Such maps are necessary for a purposeful investigation of Venus by spacecraft. They will give a possibility to extend the interpretation of data which were obtained by landers of interplanetary stations to other areas of the planet.

References

1. O. N. Rzhiga, Through Venus clouds, Zemlja i Vselennaja, № 1, 2 (1984).