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3. Model of the internal structure and characteristics of the surface relief of Venus

Introduction

The main source of information about the Earth's interior is direct seismic data. Despite the lack of direct seismic observations on Venus, models of the internal structure of this planet have been developed, based on its global characteristics, such as mass, size, average density, gravitational measurements from artificial satellites, and analogy with Earth [2].

3.1. General model

It is assumed that Venus, like other terrestrial planets [30, 33, 34], underwent a process of gravitational differentiation early in its history. This means that heavier elements sank to the center, forming the core, while lighter silicate compounds formed the mantle and crust. Thus, the general model of the internal structure [8, 12] of Venus includes three main shells: a metallic core, a silicate mantle, and an outer crust (Fig. 3.1). This structure is similar to that of Earth, as would be expected given the similarity of the two planets in size and average density. However, the details of this structure, especially the state of the core and the thickness of the layers, remain the subject of modeling and much debate.

3.2. Core

Like Earth, Venus' core is thought to be composed primarily of iron and nickel. The slightly lower average density of Venus compared to Earth may indicate the presence of a certain proportion of lighter elements, such as sulfur, in the core. Estimates of the core radius vary across models, but are generally in the range of 2,900 km to 3,500 km. This means that the core occupies a significant portion of the planet's volume; perhaps a slightly smaller fraction than the Earth's core.

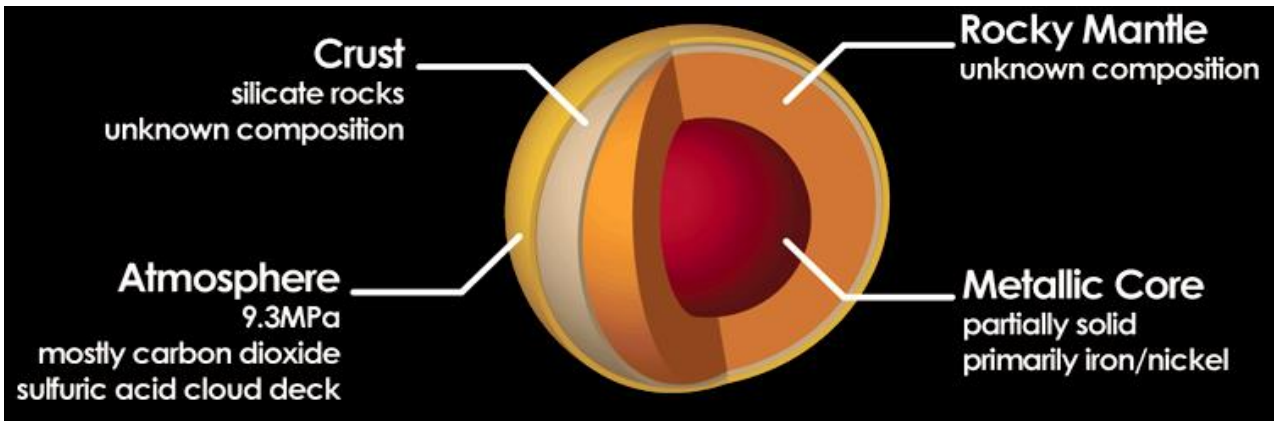


Рис. 3.1. Internal structure of Venus: the crust (outer layer), the mantle (middle layer) and the core (yellow inner layer) (http://invader-xan.pbworks.com/f/1160742297/venus-cutaway.png).

A key, still unresolved question today, is the physical state of the core of Venus [2, 25]. It is known that the Earth has a solid inner core and a liquid outer core, and convection in it generates a noticeable magnetic field [29]. For Venus, the situation is less certain. The absence of a significant global magnetic field may indicate either that the core has completely solidified, or that although it is liquid, the conditions for the dynamo effect are absent.

For example, the convection rate in the core is not suitable, or the planet rotates rapidly around its axis. Most modern models assume that at least the outer part of the core of Venus is liquid. After all, both planets are of similar size, cooled at approximately the same rate, and the Earth's core is still largely liquid today.

Analysis of the pressure in the center of Venus shows that it is significantly lower than the pressure at the boundary of the Earth's inner core. This means that the existence of a solid inner core on Venus is possible only if its core differs significantly from the Earth's in composition; for example, it contains fewer light impurities, or has a much lower temperature.

Recent analyses of gravitational data from satellites and tidal effects indicate a probable core radius of 3100–3500 km. But the data obtained so far do not allow us to unambiguously determine its state.

3.3. Mantle

The mantle of Venus, located between the core and the crust, makes up the bulk of the planet's volume. Its thickness is estimated at about 3000 km. It is assumed that, like the Earth's mantle, it consists mainly of silicate rocks rich in iron and magnesium.

Despite the extremely high temperature on the surface, the temperature inside the Venusian mantle is probably close to that of the Earth's mantle. This is due to the fact that the main mechanism of heat transfer from the interior of the planet is convection, that is, the slow movement of viscous mantle material.

If the temperature in the interior of Venus were much higher, the viscosity of the rocks would decrease, convection would accelerate, and excess heat would quickly be carried to the surface. It is believed that it is convective movements in the mantle of Venus that are the main driver of tectonic and volcanic activity [38] observed on the surface of the planet, in particular the formation of the so-called crowns and rift zones [3, 5, 7].

3.4. Crust

The outer hard shell of Venus – the crust – is relatively thin compared to the mantle and core. I

ts composition, according to the analyses carried out by the Venus landers at the landing sites, is mainly basaltic [17, 22, 27]. And this is a typical product of volcanic activity on the planet.

Estimates of the average crustal thickness vary considerably among studies. Some models based on tectonic deformation and viscous relaxation give values ranging from 10 to 30 km. Other models that take into account gravity data from orbiters suggest an average thickness of 20 to 50 km, or even up to 70 km. It is possible that the crust may be thicker under high-altitude plateaus such as tesserae.

Unlike Earth, where there is a clear division into thin (about 7 km) oceanic and thick (30–70 km) continental crust, the crust on Venus appears to be more uniform in thickness over most of the planet, according to gravity measurements.

3.5. Absence of a global magnetic field

One of the key differences between Venus and Earth is the almost complete absence of its own global magnetic field of the dipole type. Measurements show that Venus's magnetic field, if it exists, is extremely weak, at least 10 thousand times weaker than Earth's.

Instead of its own magnetosphere, Venus has only an induced one, which is formed as a result of the direct interaction of the upper layers of its atmosphere [18, 19, 28] (i.e., the ionosphere) with the solar wind.

The reasons for the absence of a strong magnetic field are still not fully understood. The most likely explanation for this is a combination of various factors.

First, this should be influenced by the extremely slow rotation of Venus (period 243 days), which does not provide sufficient Coriolis force for the effective operation of the dynamo mechanism in the core; and this is even if it is partially liquid and has some convection.

Second, it is possible that convection in the core is absent or too weak; for example, if the core is completely solidified, or if the heat flow from the core to the mantle is insufficient to support convection.

3.6. Comparison with the structure of the Earth

A comparison of models of the internal structure of Venus and the well-studied structure of the Earth allows us to highlight some key similarities and differences between them (Table 1). Thus, both planets have similar sizes, masses, and average densities; this implies a similar general differentiation into a metallic core, a silicate mantle, and a crust. The probable composition of the respective shells is also considered similar (iron-nickel core, silicate mantle, etc.).

The main differences between the planets concern the physical state of the core and the presence of a magnetic field. The state of the core of Venus (especially the presence or absence of a solid inner core) remains uncertain today, in contrast to the well-established structure of the Earth's core with a solid inner and liquid outer layer.

Table 3.1.

Comparison of models of the internal structure of Venus and Earth

Characteristics	**Venus (model data, uncertainties)**	**Earth (seismic data)**
Crust		
Thickness (km)	~10-70 (medium, possibly thicker under highlands)	~5-70 (thin oceanic, thick continental)
Composition	Mostly basaltic	Basalt (oceanic), granitic-metamorphic (continental)
State	Solid	Solid
Mantle		
Thickness (km)	~3000	~2900
Composition	Silicates (Fe, Mg)	Silicates (Fe, Mg)
State	Mostly solid, ductile (convection), possible partial melting in the upper part	Mostly solid, ductile (convection), asthenosphere (partially molten)
Outer core		
Thickness/ Radius (km)	Probably liquid, radius of entire core ~2900-3500	Liquid, thickness ~2200-2250
Composition	Fe, Ni, perhaps S	Fe, Ni, light impurities
State	Probably liquid (fully or partially)	Liquid
Inner core		
Radius (km)	Unknown, possibly absent or small	~1220-1300
Composition	Fe, Ni (?)	Fe, Ni
State	Unknown, possibly absent or small	Solid
Global magnetic field	Virtually absent	Present
Generation mechanism	No effective dynamo	Dynamo in liquid outer core

Venus does not have a global magnetic field, while Earth has a powerful magnetosphere generated by the dynamo effect in the liquid outer core. There are probably differences in the regime of mantle convection and, consequently, in the style of tectonic and volcanic activity [31, 36] at the surface (for example, the absence of plate tectonics on Venus).

There are also possible differences in the average thickness and structure of the crust between the planets [30].

The table above highlights both the similarity of the overall structure and the key differences and uncertainties, especially regarding the state of the core and magnetism, which may underlie the different geological evolution of these two planets: Venus and Earth.

3.7. The influence of internal structure on surface geology

The internal structure and processes in the interior of Venus directly affect its surface geology [6, 13]. The absence of terrestrial-type plate tectonics is likely a consequence of a combination of lithosphere properties and mantle convection. The high surface temperature may make Venus' lithosphere more plastic at shallower depths, or more buoyant than Earth's. This makes it more difficult for it to sink (so-called subduction) into the mantle.

The absence of water on Venus's surface also makes rocks stronger and less prone to the faults necessary for plate formation. However, the planet's internal heat, which is likely generated in volumes comparable to Earth's, must find an outlet to the surface.

In the absence of an effective cooling mechanism through plate tectonics, mantle plumes may play a major role in heat removal. These upward flows of hot mantle material lead to the formation of large volcanic uplifts, the formation of shield volcanoes [35], unique structures such as coronas, and large rift zones in which the lithosphere is stretched and thinned [9, 20, 24]. Thus, the geology of the surface of Venus is a direct reflection of its internal dynamics, which operate according to rules different from those of Earth.

The inability to accurately determine the state of Venus's core at present creates significant uncertainty in models of its thermal history. The state of the core (whether it is liquid, solid, or partially liquid) directly affects the planet's cooling processes and the possibility of generating a magnetic field. Crystallization of the inner core, as occurs on Earth, releases significant amounts of heat and changes the chemical composition of the outer core; together, this can sustain convection and the dynamo effect for billions of years.

If the core of Venus has a different structure, or its state, then the mechanisms of heat generation and transfer from the core to the mantle will be different. This, in turn, affects the intensity and nature of mantle convection, and therefore the long-term evolution of volcanic [14, 37] and tectonic activity on the planet's surface [32]. Understanding the state of the core is key to building accurate models of Venus' evolution and explaining its differences from the Earth.

3.8. Names on the surface of Venus

Of the classical planets, only Venus and Earth have female names. Therefore, the International Astronomical Union at one time made a unanimous decision that the names on the surface of Venus should have only female names. Thus, it was proposed that female names from the myths of different peoples of the world should be used for the names of relief details on the planet's surface. Moreover, their assignment should correspond to some specially established order.

For example, such relief details as hills, which include ridges, mountains, ridges, plateaus – will be given the names of goddesses, lowlands – heroines of various myths.

However, on Venus there was also a place for real names of women and their surnames; for example, it was proposed to use them in the names of many craters. At the same time, craters with sizes greater than 20 km should be posthumously named after famous personalities; while craters smaller than 20 km in size should receive ordinary proper names.

For example, on such a high-altitude plateau as Lakshmi, there are small craters with such names: Tamara, Lyudmila, Berta, etc.; they are located somewhat south of

the mountains named after the Scandinavian goddess of fertility and love and attractiveness Freya, and east of the large crater Osipenko. In the northern hemisphere of Venus, a noticeable mountain range is crossed by a rather long canyon, which was called the Stupa of Baba Yaga; and along one of the vast plains on Venus, the Witches' Ridges stretch.

Around the north pole is the plain of the mistress of the north in Karelian and Finnish myths - Louhi, and the plain of the Snow Maiden. Next to the crown of Nefertiti is the Potanin crater, and nearby is the crater of the author of the novel "The Gadfly" - the English writer Voynich.

And the entire harem of Abdullah from the film "White Sun of the Desert" – is located all over the surface of the planet; there is also and the wife of Comrade Sukhov from the same film – "kind Katerina Matveyevna". In general, on the map of Venus you can find names from the myths of about two hundred nations from all over the world.

The largest relief details on the planet Venus are large hills; they are a kind of continents or continents; therefore, they are also called "Earths". They have diameters of more than 5-10 thousand km; they are raised 3-5 km above the surrounding lowlands.

In total, there are three Earths on the surface of Venus, which were named after the goddesses of love, taken from different mythologies. For example, near the equator is the largest Earth, which was named after Aphrodite – the Greek goddess (Fig. 3.2).

Almost at the north pole – there is an Earth, which the noses named after Ishtar – the Babylonian goddess of love; тот far from the South Pole, the Earth is named after the Slavic goddess Lada.

Recall that of the 967 impact craters found on Venus (Fig. 3.3), the vast majority (≈80%) have diameters less than 30 km. The study of radar images of the surface of Venus showed that the bottom of these craters is quite dark. This indicates their smooth surface. However, the material ejected from these craters and the ring structures around them turned out to be very light.

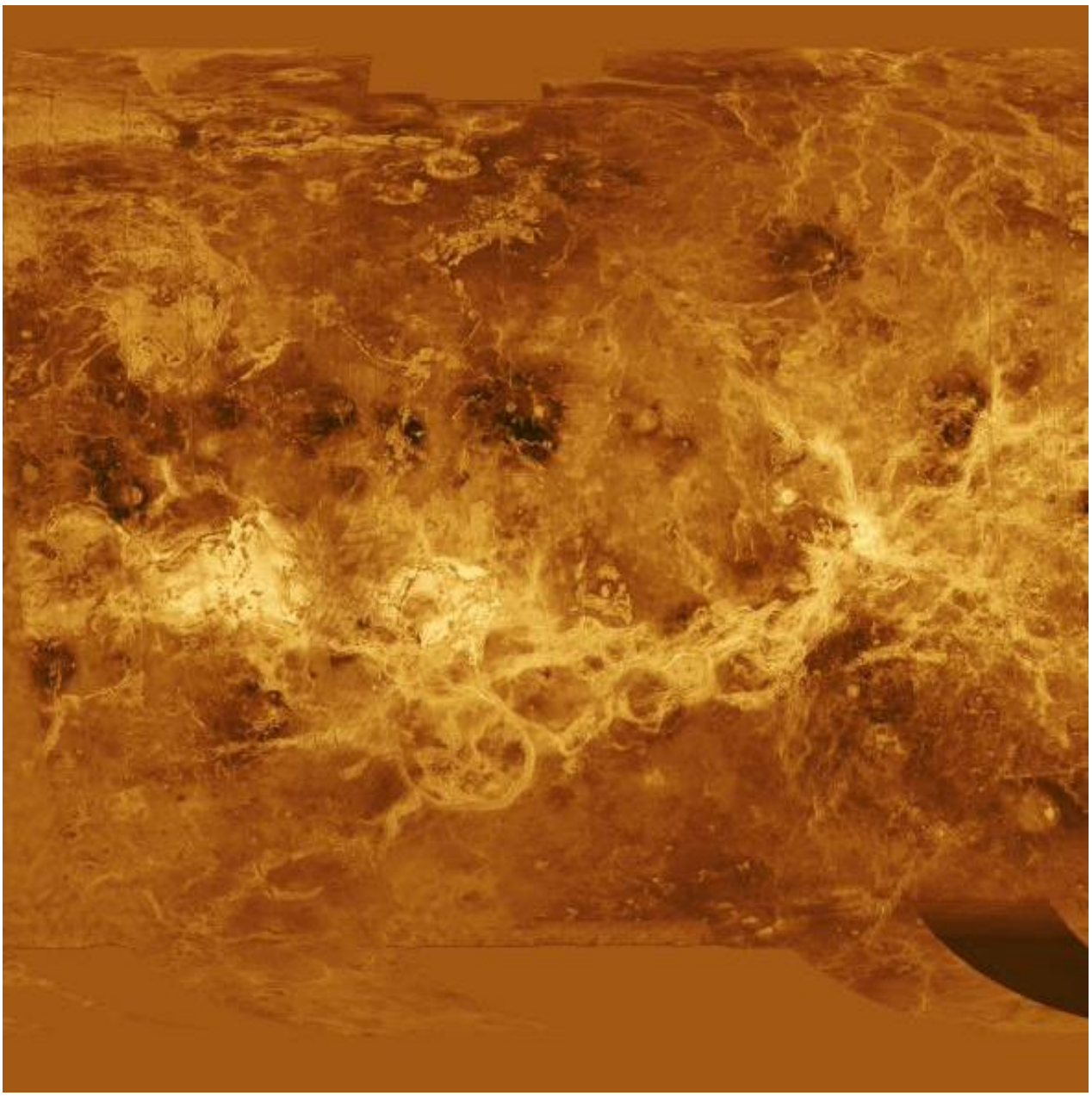


Fig. 3.2. View of the mainland of Aphrodite (http://photojournal.jpl.nasa. gov/).

This is observed due to the very strong scattering of the radar signal due to the significant roughness of these areas of the surface relief [16]; this situation is caused by the fact that the craters are surrounded by fragments of rocky material of the surface layers ejected by the explosion.

It also turned out that the most common type of surface on Venus is smoothed mountain formations in the form of ridges. They cover up to 65% of the planet's surface. Another 20% of the entire surface is occupied by flat, almost flat areas.

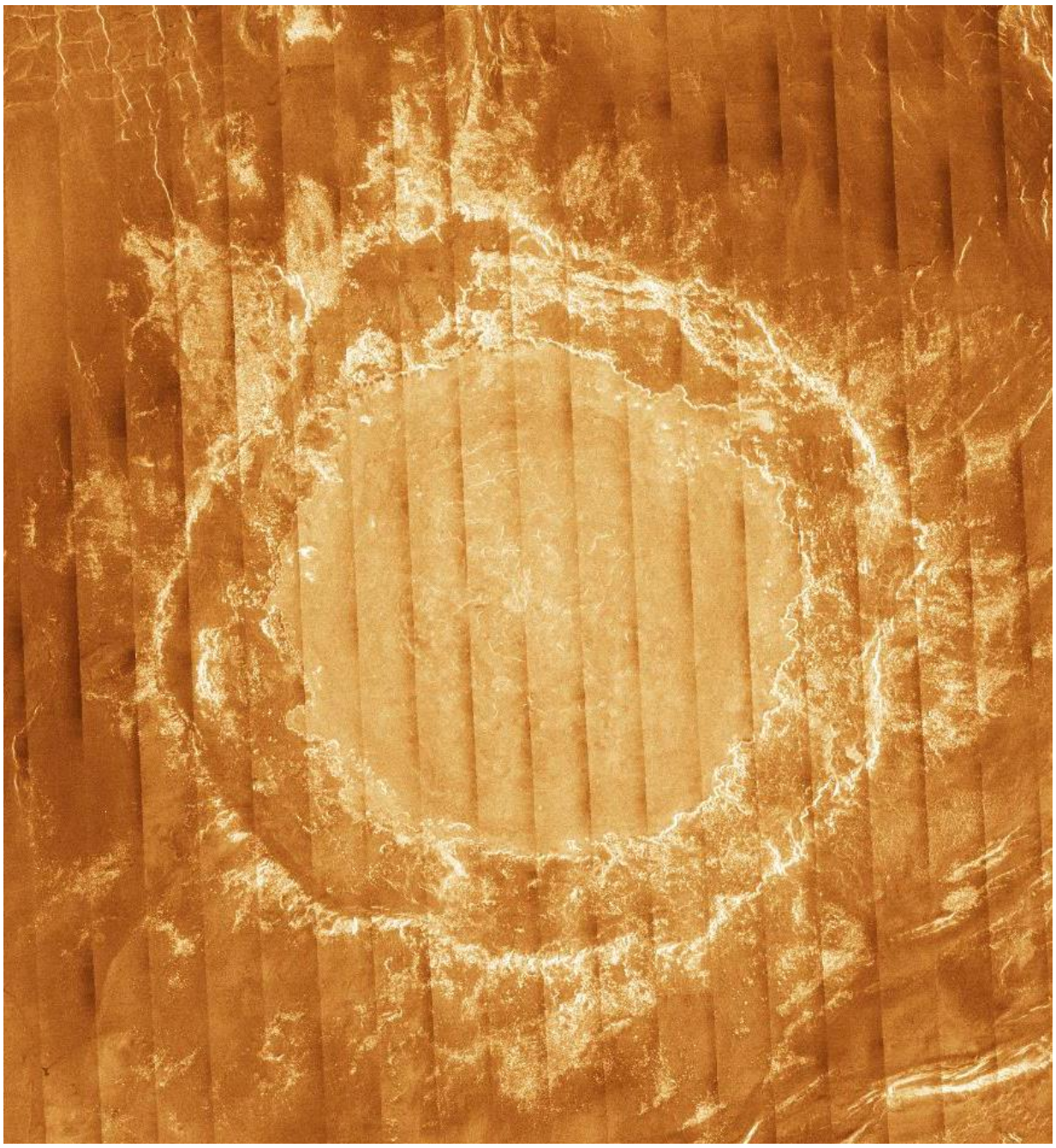


Fig. 3.3. The impact crater Mead with a diameter of 280 km has an outer and inner ring and small bright emissions around the outer ring. The surface on the slopes of the crater is morphologically very similar to the surrounding plain (http://photojournal.jpl.nasa.gov/)

3.9. Optical and chemical properties of the surface

From the landing sites of the spacecraft "Venus-9 and -10" and in October 1975, panoramic images of the planet's surface in integral light were first transmitted to Earth (Fig. 3.4). Their spatial resolution was close to 1 cm. These panoramas were

transmitted for 50 and 45 minutes, respectively, from the first and second modules, which were 2000 km apart.

The observed spectral range was determined by the energy distribution from a certain artificial source with known illumination and known sensitivity of the FEP-114 photoelectron receiver.

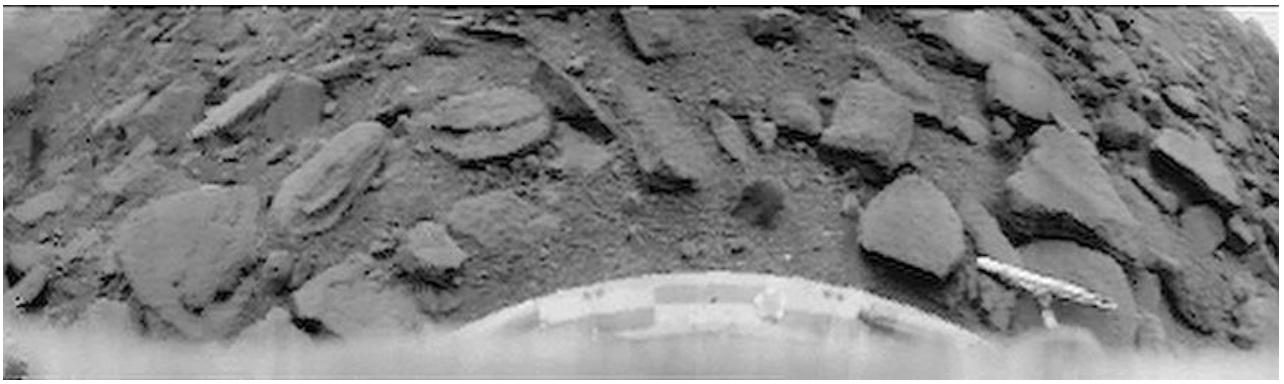


Fig. 3.4. Panoramas of the surface of Venus at the landing site of the "Venera-9" spacecraft in the 180° field of view sector, see [34].

From the results of these studies, it was obtained that the value of the surface reflectivity at the locations of the survey is very low, only 0.03-0.12 [18]. Morphological and geological analysis of the results obtained showed that the stony material in the placers around the landing modules has a flattened shape in the form of plates. The cross-section of larger stones was 50-70 cm and had a height of less than 15-20 cm. This indicated a typical ratio of their height to width of 1:3-1:6.

Seven years later, the "Venera-13 and -14" spacecraft again transmitted circular television panoramas with three times better spatial resolution from other places on the planet for 100 and 60 minutes, respectively (Fig. 3.5). These new panoramic images were obtained on March 1 and 5, 1982. They were transmitted in integral light. But they were also supplemented by three separate spectral regions in the blue, green, and red ranges. This allowed us to obtain panoramic images of the surface of Venus in color light for the first time.



Fig. 3.5. Panorama of the surface of Venus at the landing site of the "Venera-13" spacecraft (https://photomail.org/wp-content/uploads/2024/11/this-man-put-the-entire-soviet-space-program-on-his-back-he-deserves-our-respect_22-1200x248.jpg).

Morphological and geological analysis of these color images indicated that the rocks that reach the surface at the landing sites of these new spacecraft are of a significantly different nature; they have much thinner horizontal layering.

Recall that on the "Venera-8, -9, -10" landing modules, using γ - spectrometers installed there, it was possible to determine for the first time the content of such radioactive elements in the layer near the surface as uranium, potassium, and thorium (Table 3.2).

Table 3.2.

The content of radioactive elements such as thorium, potassium and uranium in the surface layer of Venus [27]

Spacecraft	Potassium, %	Uranus, 10^{-4} %	Thorium, 10^{-4} %
"Venus-8"	4	2.2	6.5
"Venus-9"	0.47 ± 0.08	0.60 ± 0.16	3.6 5 ± 0.42
"Venus-10"	0.30 ± 0.16	0.46 ± 0.26	0.70 ± 0.34

From the landing modules of the spacecraft "Venera-13, -14 and -16" it was possible to conduct much more detailed studies of soil samples. For this purpose, a multichannel spectrometer in the X-ray range was used [26]. Soil samples were extracted from different depths and then they were irradiated with radioisotopes Pu^{238} and Fe^{55}; these elements excited fluorescent glow in the X-ray range (Fig. 4.5).

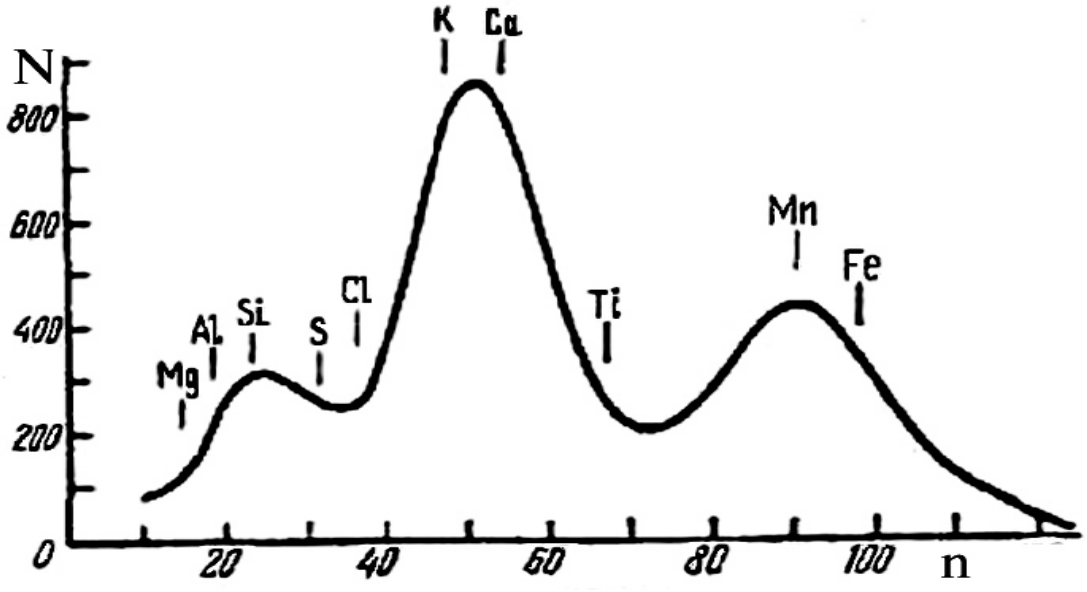


Fig. 3.6. Relative fluorescence spectrum of Venusian soil rocks at the landing site of "Venus-13" [27].

By analyzing this glow, it was possible to determine the chemical composition of the soil on the surface of Venus (Table 3.3).

Table 3.3.

Relative chemical composition of rocks on the surface of Venus [27].

Oxides of elements	«Venus-13»	«Venus-14»	«Vega-2»
MgO	11.4 ± 6.2	8.1 ± 3.3	11 ± 3.8
Al_2O_3	15.8 ± 3.0	17.9 ± 2.6	16 ± 1.9
SiO_2	45.1 ± 3.0	48.7 ± 3.6	45.6 ± 3.2
K_2O	4.0 ± 0.63	0.2 ± 0.07	0.1 ± 0.08
CaO	7.1 ± 0.96	10.3 ± 1.2	7.3 ± 0.7
TiO_2	1.59 ± 0.45	1.25 ± 0.41	0.2 ± 0.1
MnO	0.2 ± 0.1	0.16 ± 0.08	0.14 ±0.1
FeO	9.3 ± 2.2	8.8 ± 1.8	–
SO_3	–	–	4.7 ± 1.5
Fe_2O_3	–	–	8.5 ± 1.3

As follows from Fig. 3.6, the uranium-, thorium-, and potassium-rich rocks in the Venusian layer near the surface do not correspond to the primary composition for terrestrial rocks of volcanic origin. Therefore, these rocks have already undergone significant processing and are referred to as so-called secondary rocks [15].

The data obtained lead to the conclusion that on the surface of Venus there is large rubble and clastic material of very dark rocks with a density of 2.7-2.9 g/cm^3 [20]. Such an elemental composition is characteristic of basaltic rocks with volcanic lava layers. That is, on the surface of Venus the main igneous rocks that poured out from under the planet's crust are igneous rocks. And in this they are similar to similar rocks on the Moon, Mars, and Mercury.

3.10. Features of the surface relief

The very thick atmosphere of Venus [33] means that all observational data about the surface were initially obtained only by radar methods [14]. Somewhat later, and only for certain local areas, some data were obtained from panoramic images of the planet's surface transmitted from the landing sites of several modules.

Already the very first radar observations [4] allowed in the frequency spectrum with Doppler broadening of the reflected radio signal to detect two features with anomalously different reflection characteristics near the equator [32]. They were called the α and β (Alpha and Beta) regions. Later, the Beta region was morphologically divided into three separate areas, which were called features B, C and D [1]. And areas C and D were additionally called by their own names: Gauss and Hertz. After some time, another feature was discovered next to them, which was called Maxwell's Mount [9]. And in the Beta region, two more shield volcanoes were found, which were named Theia and Rhea; their height reaches 4.3 and 4.2 km, respectively (Fig. 3.7). From the intensity of the reflected radio signal, it was possible to determine the so-called effective scattering area; it changed with the longitude of the central meridian almost 4 times [6]. Using radar observations, it was also possible to construct relief maps for individual sections of the surface [5, 9, 23] with a spatial resolution of about 80 km. According to the data obtained, the surface relief on Venus turned out to be very diverse both in shape and in height differences and in its physical characteristics. For example, a cliff was found not far from the equator, the length of which reaches almost 1500 km, and the width is about 150 km with a depth of about 2 km.

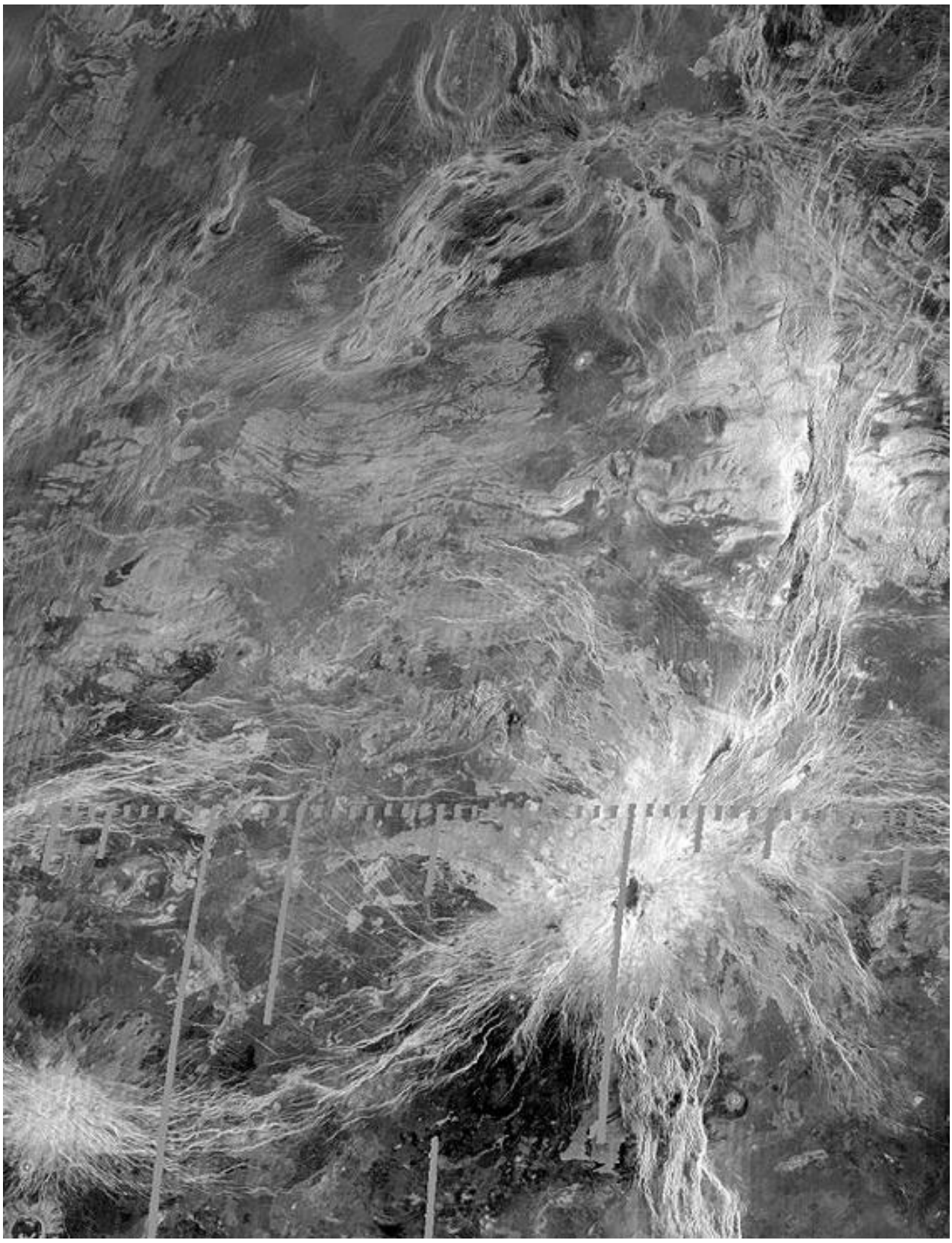


Fig. 3.7. Radar image of the Beta region from Magellan with two volcanic mountains – Theia (bottom – bright spot) and Rhea (bright spot above) (http://photojournal.jpl.nasa. gov/)

Morphologically, it is very similar to the giant system of Mariner valleys in the equatorial region of Mars. Radio interferometric observations at a wavelength of 12.5 cm over a small section of the surface of Venus with high spatial resolution allowed us to construct a map of changes in reflectivity and height of surface formations. A significant number of craters with a diameter of more than 30 km were found there; and the diameter of the largest of them exceeds 150 km at a depth of almost 500 m. A feature of this relatively small area of the surface is a significant difference in heights. Usually, this is characteristic of areas of much larger sizes.

Observations of the surface of Venus using a radio altimeter began in 1972 during the descent of the “Venera-8” spacecraft module. Then their studies were continued with orbital modules. The largest amount of data of this kind was obtained using equipment on the “Pioneer-Venus” spacecraft [17]. Based on the results of the radar images obtained by the device, cartographic data and numerous measurements of the height of surface details were prepared. The effective scattering area and the average statistical value of the angles of inclination of irregularities on the planet's surface were also determined by the power of the radio signal reflected by the surface. The data obtained of this type made it possible to calculate the reflection coefficients of the surface layer in the radio range, and the dielectric permittivity of materials on the soil surface was already determined from them.

With a surface resolution of almost 120 km, a topographic map was constructed for more than 90% of the planet's surface in the latitude range from 63°S to 74°N, based on observations made over more than one Earth year. The highest elevation value of 11.5 km is located in the Maxwell Mountains, and the lowest point was found just south of the equator in the Diana Basin, and had a depth of more than 2 km. In addition to this basin, the Atlanta and North Basin, located at latitudes (58-72)°N, are also quite deep; they also have depths of about 2 km.

This map especially highlights three large elevated plateaus, which are called continents. For example, the continent of Ishtar, located at latitudes (60-74)°N, is similar in size to Australia on Earth. Not far from it is the Lakshmi Plateau, raised to a height of 3.5-4.5 km, and the already mentioned highest mountains of Maxwell on

Venus. In the southern hemisphere at latitudes (24-36)°S there is another continent, called Aphrodite; the highest areas on it have heights of 5.5-5.7 km.

A detailed study of the relief on Venus has shown that even the largest craters are quite shallow. For example, two of them – with diameters of more than 600 km and 800 km - are located in the northern hemisphere near the equator, have a depth of only about 700 m; and another crater, located between them, has a diameter of about 400 km with a depth of only 200 m. Cracks (Fig. 3.8) of great length and width of almost 150 km have also been found on the surface of Venus; they turned out to be much deeper; several of them have a depth of about 5 km.

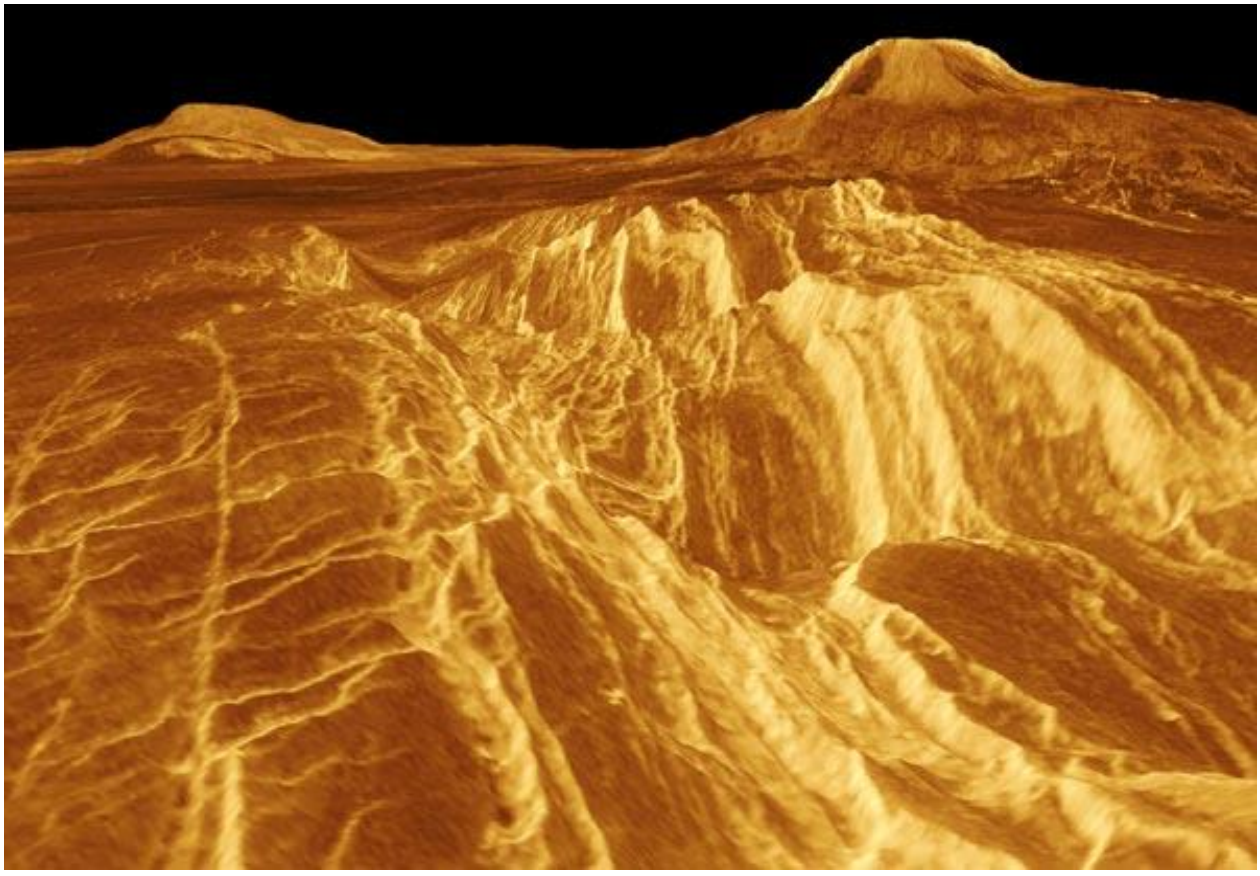


Fig. 3.8. Fissure in Eistla Regio. Lava flows spilled many kilometers down the slopes of Sif volcano (left, up to 2 km high) and Gula volcano (up to 3 km) (http://photojournal.jpl.nasa.gov/).

Using bistatic radar at a wavelength of λ=32 cm, the effective value of the dielectric permittivity (ε'=3÷11) was determined on the orbital modules of the

spacecraft “Venera-9, -10” [11]. According to the results of radar measurements of altitude from the spacecraft “Pioneer-Venera” and from the spacecraft "Magellan" [3], it was possible to obtain quite complete data on changes in the angle of inclination σ_α. According to these data, it was found that the surface layer in the lower areas usually has a smaller value of the reflection coefficient. These areas are quite smooth with values of $\sigma_\alpha \approx (1–3)°$. While the mainland regions of Aphrodite, Ishtar, Beta have several times higher values of σ_α. The Maxwell Mountains, which are located on the mainland of Ishtar, are characterized by the roughest details on the entire surface of Venus; their value is 4.5-10°.

Comparison of maps of the distribution of inclination angle values with a map of changes in elevation on the surface of Venus showed a significant correlation between them for mountainous areas around the plateau. For example, for all mountainous areas – the Lakshmi and Maxwell mountains, the Aphrodite archipelago, the Alpha region – the inclination angle value increases with height. The correlation for the area on the Beta elevation is significantly less pronounced.

From the end of 1983 to mid-1984, the surface of the circumpolar regions in the Northern Hemisphere of Venus was first studied by radar with a spatial resolution of 1-2 km from the spacecraft “Venera-15 and -16". The total area of the studied surface was almost 100 million km2. Then it was possible to obtain that the diameter of the crater, called Patera Cleopatra, is almost 95 km; and in its middle another crater was found, the size of which was 55 km. From the analysis of the elevation profile, it was obtained that the depth of the larger outer crater was 1.5 km; while the bottom of the inner crater was deepened by an additional 1 km.

The most complete data on the surface relief of Venus were the results obtained from the autumn of 1990 to the autumn of 1994 by bistatic radar methods from the Magellan spacecraft. The spatial resolution of the surface images was from 120 to 180 m; altimetry was performed with a height resolution of up to 80 m. Also, radiometric temperature measurements were made with an accuracy of better than 2 K; temperature changes were recorded over more than 96% of the planet's surface area. Some of the

results of the work can be found in [3, 15, 21]. Some examples of the obtained topographic maps are given in Fig. 3.9-3.11.

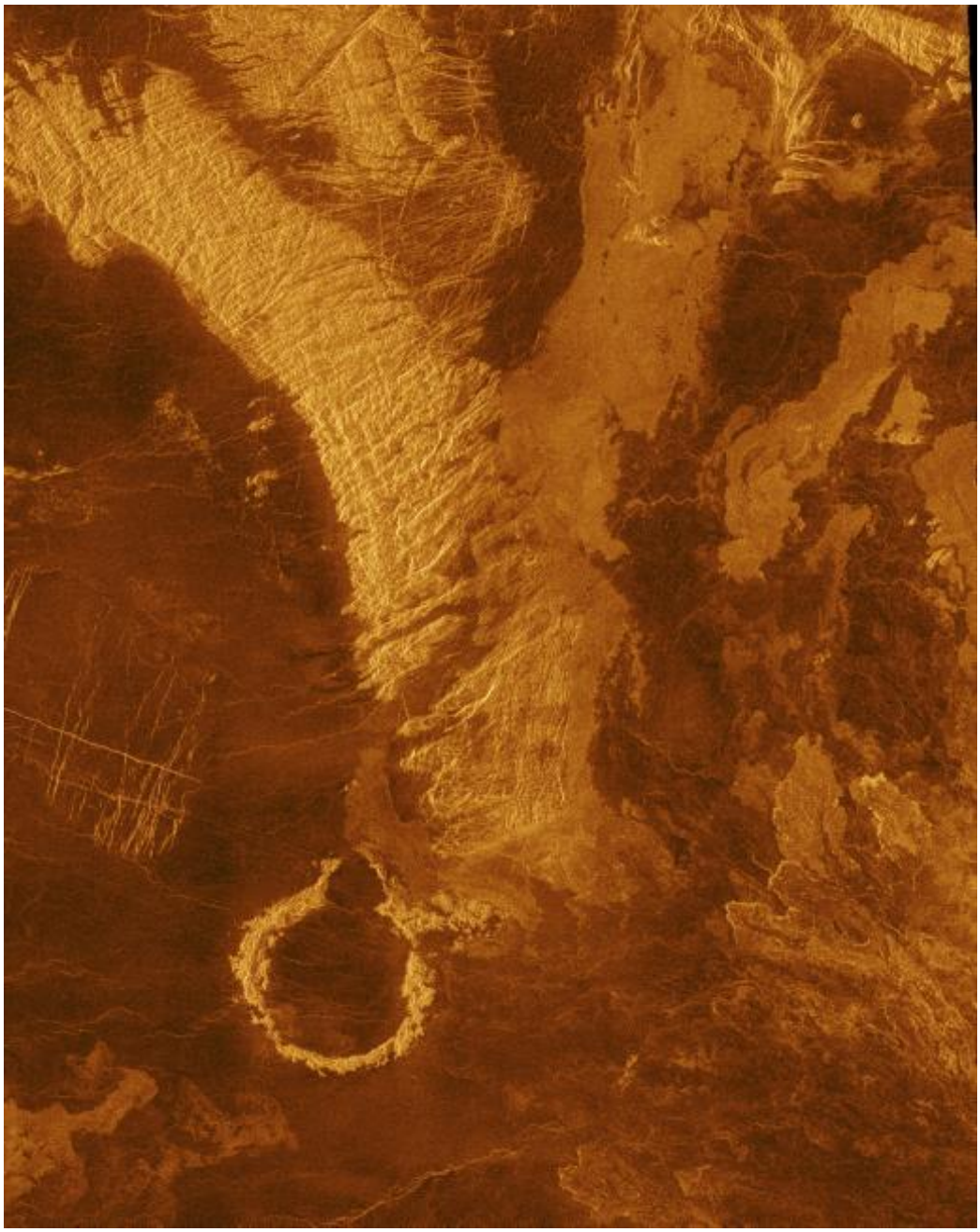


Рис. 3.9. Leda Planitia на широті 41°N – є старим геологічним ландшафтом на Венері. Показано зруйновані гори з потоками вулканічної лави. Внизу ліворуч – видно ударний кратер Елоїз з кільцевою структурою діаметром у 40 км (http://photojournal.jpl.nasa.gov/)

Fig. 3.10 shows the so-called pancake domes; Fig. 4.10 – grids of rectangular valleys, etc.

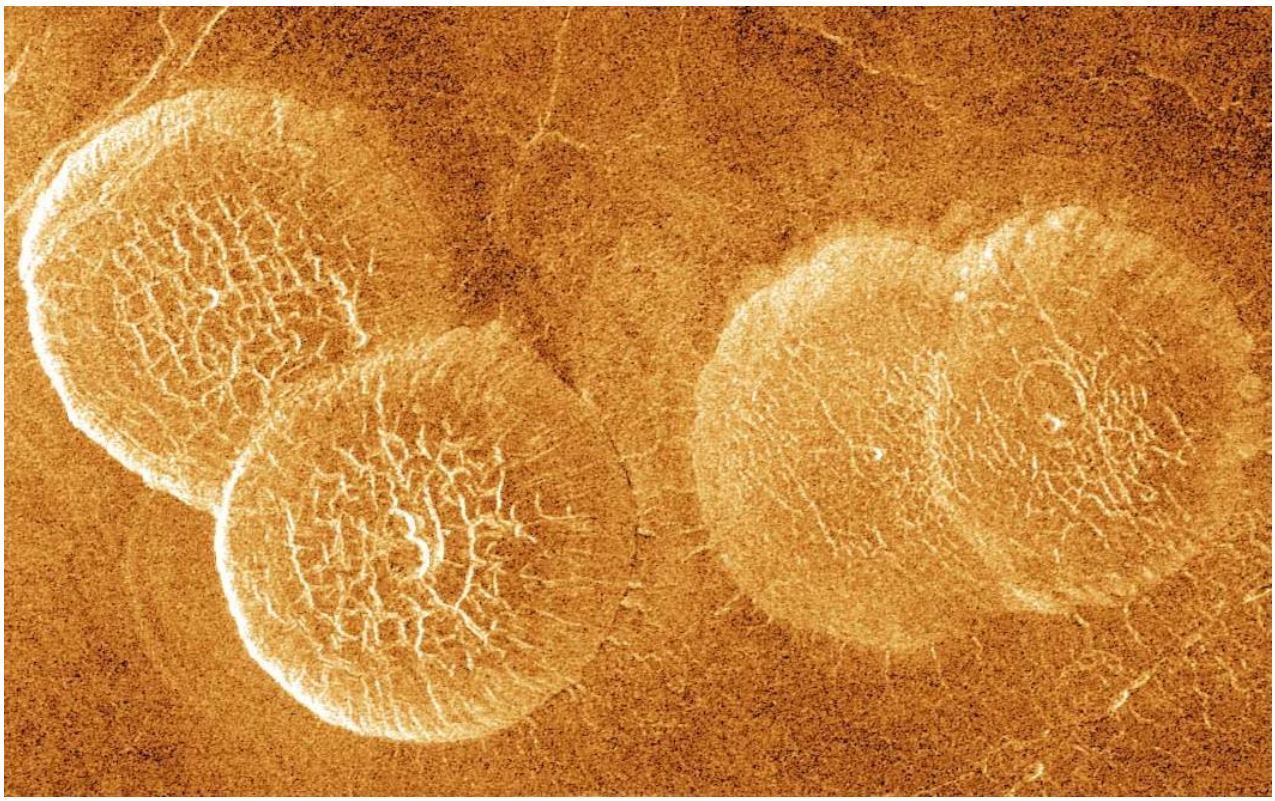


Fig. 3.10. Pancake-shaped “volcanoes” on Venus (http://photojournal.jpl. nasa.gov/).

According to the results of processing the data obtained by the “Venus-15 and -16” spacecraft, it was possible to find such specific areas, which are called tesserae (cubes). They turned out to be systems of furrows that can often intersect; they are found on almost 8% of the surface of Venus. They are somewhat higher than their surroundings and areas of plains are wedged between them.

It is believed that such systems could have arisen as a result of multiple tectonic movements in the upper layers of the planet's crust. Usually they are accompanied by uplifts, splits and subsidence of some of the areas on the surface [22, 25]. According to the data of the “Magellan” spacecraft, the structure of more than six hundred tesserae was studied in detail [10]. Table 3.4. gives the names and coordinates of some of the largest tesserae. They are located quite unevenly in latitude and longitude. The largest number of tesserae have been found near the equator in the west of the continent of Aphrodite, in the Ishtar region and in the Beta region.

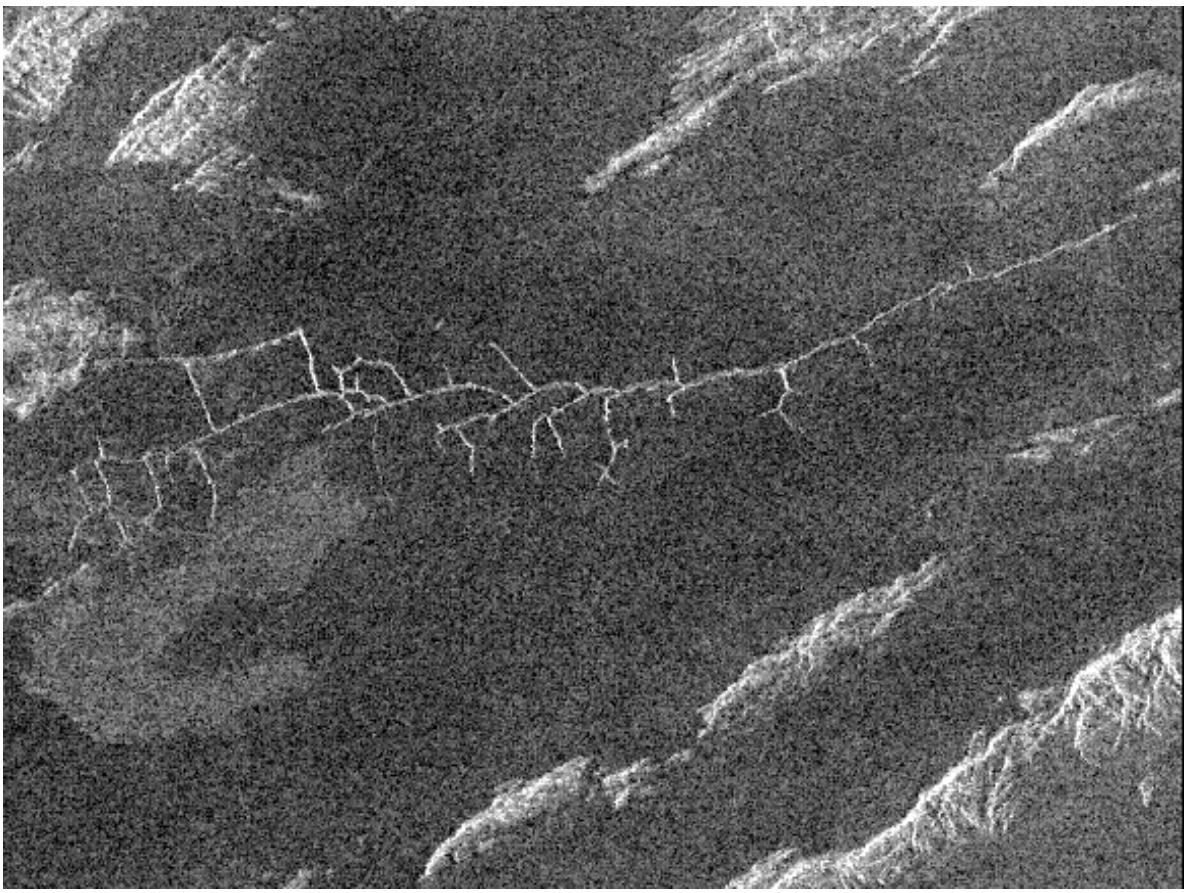


Fig. 3.11. Network of narrow (<1 km wide) bright channels (http://photojournal.jpl.nasa.gov/).

Table 3.4.

Some characteristics of large tesserae [7].

Name	Area, thousand km^2	Coordinates ψ^o	L^o	Length, km	Width, km
Ovda	9068	-5	80	5683	2083
Fortuna	3228	+67,5	35	3872	1918
Tellus	2461	+35	80	2400	1977
Thetis	2257	-8	127	2612	1447
Laima	2021	+50	47	2165	2042
Alpha	1487	-25	5	1624	1341
Phoebe	1219	-7	282	3424	812
Beta A	576	+33	277,5	1899	594

Between these relief details, about 40% of the total number of details of volcanic origin are located [2, 12, 13]. According to numerous radar observations, four main types of relief structures are distinguished in the northern hemisphere of Venus [37].

These are volcano-tectonic formations, tectonic dislocations, volcanic [37] and impact craters. A careful study of the surface relief confirmed the predominantly magmatic composition of the bedrock on Venus.

Rift regions turned out to be quite widespread. In the tropical regions of the planet, three significant areas with tectonic faults were discovered, which extend for thousands of kilometers. The largest of them runs in the direction from the Aphrodite mainland to the Beta region. Rift structures extend along the southern part at the foot of the Thetis and Ovda heights; their total length reaches 21 thousand km. From the Thetis region towards the northwestern edge of the Atlas region, another similar structure stretches over 14 thousand km long. From the Beta region to the Phoebe region in the meridional direction for 6 thousand km, a third such structure stretches.

However, the main part of the surface layer of Venus is covered by somewhat hilly plain areas. One of this type of elevations resembles the Martian volcano Olympus. It has a diameter of 300-400 km at the base. However, its height is only 1 km. In the very center of this peak there is a depression with a diameter of up to 80 km, and it is very similar to a caldera. A large number of craters have been found in the equatorial region of Venus, which in appearance are very similar to lunar ones. The vast majority of them have diameters of several tens of kilometers, and only a few of them reach almost 150 km. However, all these craters on Venus are significantly flatter than lunar ones. And the depth of even the largest of them is less than 400 m.

A significant number of fairly large tectonic structures have also been discovered on Venus. They are quite similar to the same structures on Mars and Earth. For example, not far from the equator is the large Beta Upland. It is most likely a huge basalt shield volcano. A little south of it is the Phoebe Upland.

The soil on color panoramic images of the surface of Venus looks yellow-brown. It acquires this shade due to the absorption features of the planet's powerful atmosphere [19, 30]. After all, it transmits sunlight to the surface only in the yellow and brown spectral ranges, almost completely absorbing blue rays [28]. The studies conducted have shown that the Phoebe and Beta areas should be attributed to relatively young

volcanic areas with a fairly fresh surface. After all, there are practically no chemical weathering processes on it.

Volcanic features such as large plains occupy the majority of the entire surface of Venus. On such fairly smooth surfaces, bright stripes and spots ranging in size from tens to several hundred kilometers can sometimes be observed in the radio range. Systems of furrows and ridges have also been found there. And these systems are similar to similar structures on the Moon [31]. It was noted that the same older formations sometimes protruded through the upper surface material. On these same plains, many small cones and domes with a diameter of 5-10 km have also been found; often there are craters on their tops.

Tectonic formations on the surface of Venus also include the so-called dome-shaped hills (an example is Mount Rhea, Fig. 4.6) and “ovoids”. Ovoids are formations with concentric ridges and furrows that have strongly deformed ring structures. Their diameters range from 150 km to 600 km. Thin layered rocks have also been found on the surface of Venus; their formation is attributed to the deposition of volcanic ash and dust from the combustion of meteorites in the planet's atmosphere.

Observational data on the intensity of radiation in the short-wavelength region of the spectrum mainly concern the upper part of the atmosphere; while the surface layer becomes visible only at $\lambda>3$ cm.

3.11. Formation of the surface structure of Venus

The basic principles of the formation of relief structures on the surface of Venus can now be discussed only in principle. So, most likely, the primary crust of the planet should be of the basaltic type; although it may well be that its granitoid composition. Analysis of the observational data obtained to date shows that approximately 500 million years ago the crust of Venus was subjected to intense deformation. It was then that the formation of tesserae could have occurred. It is rather difficult to say anything about the possible causes of such a strong deformation. However, it can be suggested that the crust could have broken, for example, as a result of upward convective flows from the mantle of Venus. Their action could well have caused the appearance of elastic

forces of compression and extension and led to the formation of the currently observed tesserae structure.

The consequences of such a step could have been the pouring out of a significant amount of basaltic lava from the upper part of the mantle. Such processes could well have led to the fact that the surface of Venus became able to preserve its original composition. This type of scenario is indicated by the increased content of uranium, potassium and thorium in the rocks. Most likely, such outpourings of basaltic lava should have been repeated [36, 38]. Therefore, during periods of reduced volcanic activity, lava plains could cool over time. And it was then that the time favorable for the formation of ridge and crack belts began.

At this stage of the events with the formation of the surface of Venus, there was a release of huge amounts of heat, the outpouring of lava flows and deformation of ancient parts of the primary crust. It is clear that such a period should have been short: no more than 300-500 million years. And the last time such a scenario took place about 500 million years ago. Traces of basaltic volcanism are visible everywhere on the modern surface of this planet, and a significant number of crustal faults indicate noticeable activity in its interior. And such high activity of the interior of Venus, most likely, is the main reason for the rather young age of the surface on Venus, compared to Earth and Mars: only 300-500 million years.

The lower mantle of Venus, or the so-called asthenosphere, consists of molten silicate rocks. The lithosphere of Venus is formed by the upper mantle, which is formed by a mixture of solid silicate rocks together with a basaltic crust. And the thickness of the lithosphere [8] of Venus, most likely, is now less than that of Earth and Mars.

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