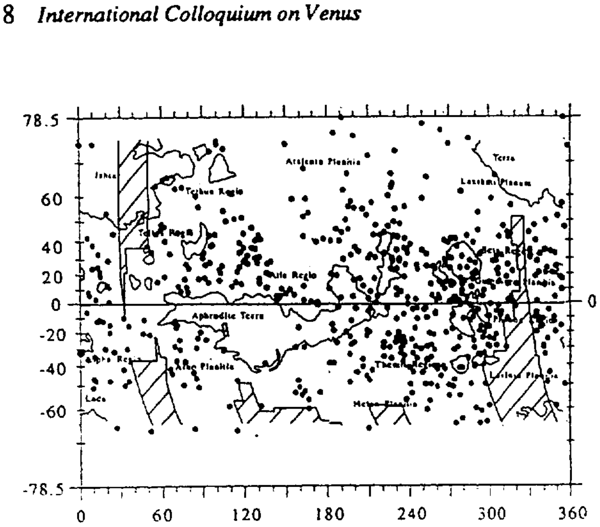

Fig. 3.

with larger volcanic features. Shield fields frequently occur within the inner rings of coronae; those associated with large volcanos often occur around the distal edges of, and occasionally are surrounded by, the radial lava flows forming the volcano flanks, but they also occur near the summit of a few large volcanos.

Implications: Although individual small shields can and do occur almost everywhere on the plains terrain of Venus, they most commonly occur in fields that are well-defined, predominantly equant, clusters of edifices. Major questions include why the edifices are concentrated in this way, how they relate to the source of the eruptive material, and what the possible relationship of shield fields to plains terrain is. There are three possible models for the origin of fields and small shields: (1) a field represents an "island" of higher topography subsequently surrounded by later plains material; (2) a field represents the area of a region of anomalous melting; or (3) a field represents the area of a magma reservoir. Model 1 would imply that the fields represent portions of a stratigraphic "layer" of small edifices produced globally in an earlier period of greater small shield productivity and that there has been a change in eruption style with plains formation occurring predominantly after the production of the small edifices. If the shield fields are isolated "islands" surrounded by flooded plains, the equant aspect of most fields could be explained; however, some fields show associated flows superimposed on surrounding plains and the manner in which shield fields appear to cover local structural patterns suggests that they are associated with plains-forming material themselves. In addition, local stratigraphic relationships show that there is a range of shield field ages in relation to the surrounding regional plains units and the associated larger volcanic features, implying that shield formation did not occur planetwide as a single event. Models 2 and 3 imply that the fields represent areas of melting anomalies. Model 2 implies that the area of the field is controlled by the extent of the region of melting. A variation of Model 2 uses small reservoirs to explain local groups and alignments of edifices or differences in edifice type due to variations in eruptive style or melt chemistry. Model 3 implies that the area of the field is controlled by the areal extent of a magma reservoir. The areal shape and density of most shield fields could be explained by postulating a shallow regional reservoir or trap located between the melt source region and the surface and approximately equal in size to the areal extent of the field. Given the stratigraphic evidence of the range of shield field ages, models 2 and 3 are favored over model 1 for most cases. Whether the shape and size of a field reflects the area of the melt anomaly or the area of a reservoir is difficult to determine. The formation of a field of small volcanos, rather than a single large volcano, must imply a difference in magma rates or reservoir/source area characteristics. The reservoir or source area characteristics of shield fields can apparently be related to the scale of the feature, as has previously been postulated for coronae [7]. An associated question is the relationship of shield fields to plains terrain. This can be expressed as four possibilities, some of which are also related to the model of origin of the "fields" described above. The possibilities are as follows: (1) The edifices may be the source of lava flows that form or resurface the plains, which would imply that the extrusive volume from each edifice is greater than the visible volume of the edifice and that the plains terrain is created from a stratigraphic sequence of edifices and associated flows; (2) the edifices and plains may be formed simultaneously, which would imply that the edifices are localized point sources within a large extrusive mechanism that creates plains; (3) the edifices may predate the plains, which would imply an early global edifice-building stage and subsequent change in eruption style and heat flow to large-volume-flow field-type eruptions; or (4) the edifices may postdate the plains, which would imply a change in eruption style to late-stage localized small-volume extrusions or hot-spot-type anomalies.

Detailed studies of several shield fields are continuing in an attempt to answer these fundamental questions and to select appropriate models for understanding shield fields and their role in volcanic resurfacing processes and crustal volume contributions.

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THE GEOLOGY OF THE VENERA/VEGA LANDING SITES.
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We have performed a photogeological analysis of the Venera/Vega landing sites using Magellan radar images. These seven sites are the only places on Venus where geochemistry measurements were taken. In this study, the updated coordinates of the landing sites are used and the landing circle has a radius with an admissable error of about 150 km [1].

Photogeologic Description of the Landing Sites: Venera 8 landed on the equatorial plains within a small local topographic rise eastward of Navka Planitia.The coordinates of the landing site are 10.70°S, 335.25°E. Gamma-spectrometric analysis showed that the surface material contains relatively high contents of K, U, and Th [2,3]. A comparison with terrestrial K_2O-U-Th analogs of this material suggests that it may represent evolved subalkaline magmatic rock of intermediate silica content [4,5] or alkaline basalt [6,7,8,9], particularly lamprophyres [10].

Analysis of Magellan data shows that there are two plain-forming volcanic complexes within the landing circle. The older mottled plain and the younger plains complex both consist of radar-bright, -intermediate, and -dark subunits. Because some of these subunits have a flowlike morphology, we believe that these units are lava flows. The older mottled plain is dissected by northwest-trending swarms of fractures while the younger plain complex in the western half of the landing circle is not affected by these fractures.

In the northern part of the landing circle is a steep-sided pancake dome, approximately 22 × 25 km in diameter. Radar foreshortening measurements indicate a height of about 270 m and a slope of 12.6°. The dome is similar to other steep-sided volcanic domes described by Head et al. [11] and Pavri et al. [12]. Some smaller steep-sided domes, many small gentle-sloped domes, and a possible filled caldera can also be found within the landing circle.

Venera 9 landed on the northeastern slope of Beta Regio rise. The landing circle is centered at 31.01°N, 291.64°E. This slope of Beta rise, as well as the other slopes, is made up of tessera and plain embaying the tessera. Within the landing site, the plain predominates while tessera occupies less than 10% of the area. The plain is mostly fractured with a radar-bright fracture system extending eastward from Rhea Mons. The slopes of the east-west-trending fractures are radar-bright because of surface roughness from scarps and rock fragments. Small (a few kilometers across) gentle-sloped volcanic domes can also be seen in the vicinity of the landing site. No pancake features resembling the Venera 8 dome have been found at the Venera 9 site [13].

The Venera 9 spacecraft landed on a steep (~30°) slope covered with platelike decimeter-sized rock fragments and soil between these rock fragments [14]. This panorama is probably showing a slope on one of the numerous fractures seen in the Magellan imagery of the landing circle. The gamma ray spectrometer measured low contents of K, U, and Th, which suggests a tholeiitic basaltic composition for the sample [3].

Venera 10 landed on the lowland near the southeastern edge of Beta Regio rise. The landing circle is centered at 15.42°N, 291.51°E. The geology of this area includes large massifs of tessera and mottled plain that embays the tessera. The center of the landing site is on the plain about 30 km south of the tessera. The plain occupies 60–65% of the landing circle, while the tessera occupies the remaining 35–40%. Adjacent to the southern boundary of the landing site is a 60-km-diameter gently sloped volcano with lava flows emanating radially from it and entering into the landing circle. A few wind streaks, implying a west to northwest direction of aeolian transportation, are seen behind some small volcanic domes [13].

The television panorama of the site shows that the Venera 10 spacecraft landed on the plain and not on the tessera. The plain is covered with soil in local lows between the layered bedrock. The outcrops of bedrock are spaced a few meters from each other and are about 10 to 15 cm above the soil-covered lows. This implies that the soil thickness in the lows is not more than about 0.5 m [14]. Gamma ray spectroscopy measurements of K, U, and Th are very close to those measurements taken at the Venera 9 landing site [3].

Venera 13 landed at Navka Planitia on the eastern end of Phoebe Regio rise. The landing circle is centered at 7.55°S, 303.69°E. The landing site is dominated by radar-dark plain transected in its southwestern part by a northwest-southeast-trending fracture belt. The southeastern portion of the site is affected by part of a 200-km coronalike feature. This feature has radial lava flows emanating from it that enter the landing circle in the southeast. Northeast-southwest-trending subtle wind streaks can be seen behind some topographic obstacles, inferring a southwest downwind direction.

Just outside the landing site circle are four pancake volcanic domes and a steep-sloped volcano with a summit caldera [13]. Two of these steep-sided domes are located about 300 km southwest of the estimated landing point. The flat-topped pancake dome (25 × 30 km diameter) formed first and the steep-sided conical volcanic edifice with a summit crater (15 × 20 km diameter) formed on the western flank of the pancake dome. These domes are approximately 2.2 km in elevation above the surrounding plain. The flat-top dome located 200 km southeast of the estimated landing point is 35 × 45 km in diameter and rises 1.5 km above the surrounding plain. This dome lies on top of the southeastern portion of the coronalike feature. The two other pancake domes are a 15 × 20 km dome located 230 km northeast of the estimated landing point and a 12 × 15 km dome located 320 km east of the estimated landing point.

The television panoramas of the site show a landscape similar to that seen at the Venera 10 site: soil in local lows and layered bedrock outcrops at local highs [15]. X-ray fluorescence spectroscopy indicated a composition close to subalkaline (4% K_2O) basalt [16].

Venera 14 landed in southern Navka Planitia, about 800 km southeast of the Venera 13 landing site. The landing circle is centered at 13.05°S, 310.19°E, on the eastern flank of a 75-km-diameter gentle-sloped volcano. The landing site is dominated by lava flows from the volcano. There is much variation in the backscatter cross sections for the different lava flows, most likely related to the surface roughness of the flows. The flow lengths range from tens to several hundreds of kilometers. The western side of the volcano is heavily fractured by a northwest-southeast-trending fracture zone that also dissects the radar-dark plain at the Venera 13 landing site [17]. Inside the landing circle are some patches of complex fractured terrain embayed by lava flows. No steep-sided volcanic features resembling those observed in the vicinities of the Venera 8 and 13 sites are seen inside the Venera 14 landing circle. There is, however, a 12 × 17 km diameter complex volcanic dome, 165 km north of the Venera 14 landing site. The bright radar-illuminated western side and the darkened eastern side suggest radar foreshortening from steep slopes. Because the dome is small, isolated, and outside the landing circle, it is unlikely that the dome could have influenced the geochemistry measurements made at the landing site. Instead, we believe that the geochemistry inside the landing circle represents the lava flows from the gentle-sloped 75-km-diameter volcano.

Television panoramas of the Venera 14 site show a plain dominated by layered bedrock and a minor amount of soil in local lows. If the soil were removed from the Venera 10 and 13 sites, then the Venera 10, 13, and 14 panoramas would look remarkably similar. X-ray fluorescence spectroscopy indicates a composition close to tholeiitic basalt [16].

Vega 1 landed on Rusalka Planitia, north of Aphrodite Terra rise and about 1000 km west of Sapas Mons. The landing circle is centered at 8.10°N, 175.85°E. The landing site is dominated by a radar-dark plain with a network of narrow and low sinuous ridges. In some places, the plain looks brighter and the boundaries of these brighter spots are very diffuse. Outside the landing circle, there are vast areas of radar-bright plains. The ridges continue from the darker unit into the brighter unit. Near the center of the landing center is a radar-bright, gentle-sloped volcanic dome about 10–12 km in diameter. The dome has a radar-bright, fan-shaped wind streak indicating a preferential direction of aeolian transportation to the southeast. A few smaller volcanic domes, usually associated with bright spots, are also seen in the landing circle. No television panoramas were taken at the landing site. Gamma ray spectroscopy measurements indicate low contents of K, U, and Th, typical for tholeiitic basalts [18,4].

Vega 2 landed at the transitional zone between Rusalka Planitia and the eastern edge of Aphrodite Terra rise. The landing circle is centered at 7.14°S, 177.67°E, about 1500 km south of the Vega 1 landing site. Most of the landing site consists of a densely fractured radar-bright plain with radar-dark plain to the northeast. The southwestern portion of the site has ridges and fractures associated with a 300-km-diameter coronalike feature. No television panoramas were made at the site but both gamma ray spectroscopy and X-ray fluorescence spectroscopy measurements were taken. The gamma ray measurements of K, U, and Th and the X-ray fluorescence spectroscopy measurements of bulk chemistry indicate a composition close to tholeiitic basalt [18,4].

Discussion: We have shown that within all the Venera/Vega sites the dominant type of terrain is plains. These plains include (1) mottled (Venera 8, 10, and Vega 1), (2) homogeneously dark (Venera 13), (3) dominated by prominent lava flows (Venera 14), and (4) fractured (Venera 9 and Vega 2). The plains are associated with coronalike features (Venera 8(?), 13, 14, and Vega 2), fracture belts and swarms (Venera 8, 13), and tesserae (Venera 8(?), 9, 10). This diversity reflects the global diversity of the venusian plains.

For the two sites (Venera 8 and 13) where nontholeiitic compositions of the surface material were determined, the steep-sided domes resembling those described by Head et al. [11] and Pavri et al. [12] have been found. For the five sites where geochemical signatures of tholeiitelike basalts were identified (Venera 9, 10, 14, and Vega 1, 2), these steep-sided domes have not been observed inside the landing circle. We believe that this correlation favors a nontholeiitic origin for these steep-sided domes.

The television panoramas from the Venera 9, 10, 13, and 14 landers show a microlandscape with characteristics that correlate well with the Magellan observations. At these four sites, the panoramas all showed bedded outcrops. Before the Magellan mission, these bedded rocks were considered as either basaltic tuffs or lavas [14,15]. Magellan imagery does not resolve the lava vs. tuff issue, although the presence of prominent lava flows at the Venera 14 site favors a lava interpretation of the bedded rocks. The very low bulk density of these rocks estimated from Venera 13 and 14 overload measurements (1.5 g/cm^3) favors the tuff interpretation. Therefore, the origin of these bedded rocks still remains an enigma.

Conclusion: Joint analysis of Magellan and Venera/Vega data on the Venera/Vega landing sites has shown that the panoramas and geochemistry measured by the landers agree well with the morphology seen in Magellan imagery of the site. This observation suggests that it is possible to extrapolate our geochemical and morphologic results to the remaining Magellan imagery of Venus.

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GLOBAL DEFORMATION ON THE SURFACE OF VENUS.

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Large-scale mapping of tectonic structures on Venus shows that there is an organized global distribution to deformation. The structures we emphasize are linear compressive mountain belts, extensional rifted zones, and the small-scale but widely distributed wrinkle ridges. Ninety percent of the area of the planet's compressive mountain belts are concentrated in the northern hemisphere whereas the southern hemisphere is dominated by extension and small-scale compression [1,2]. We propose that this striking concentration of fold belts in the northern hemisphere, along with the globe-encircling equatorial rift system, represents a global organization to deformation on Venus. A great circle that connects the northernmost branches of a globe-encircling rift system roughly separates the tectonic hemispheres [1] (Fig. 1). South of this tectonic equator [1] there are a few well-formed fold belts at the edges of small crustal blocks within the global rift system, but the globally significant deformation is the rift system and the wrinkle ridges.

Compressional structures on Venus can be divided into two major styles: linear fold belts and wrinkle ridges. Figure 2 shows that the major difference between these two styles is the distribution and localization of strain. Wrinkle ridges represent deformation that is distributed over thousands of kilometers whereas fold belts show concentrated deformation along narrow bands. Venus is the only terrestrial planet other than Earth that has linear compressive mountain belts [3]. Venusian fold belts, similar to those at plate margins of the Earth, are the dominant compressional structures in the northern tectonic hemisphere. They are typically about 100 km wide and thousands of kilometers long. The relatively small amount of erosion on Venus allows us to image fault-related folds forming over regionally extensive decollement horizons within the belts [4]. This supports the notion that these mountain belts are analogous to the thin-skinned fold-and-thrust belts of Earth. Wrinkle ridges are the dominant style of compressional deformation in the southern

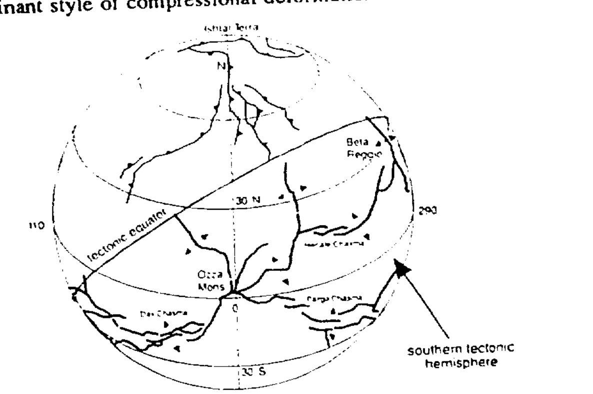

Fig. 1. Generalized tectonic map of Venus after [3]. Rift zones are indicated by the heavy black lines. Ninety percent of the area of foldbelts lies in the northern hemisphere while the southern tectonic hemisphere is dominated by extension and small-scale compression in the form of wrinkle ridges.