DETAILED STUDY OF ROUGHNESS ANISOTROPY OF THE VENUSIAN PLAINS.

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Introduction. We analyze properties of Venusian surface using processed Magellan radar altimeter (RA) data [1] stored in the SCVDR PDS data set (Surface Characteristics Vector Data Record). These data contain estimates of Doppler centroid shift f_D that characterizes along-track (north-south) anisotropy of the backscattering function of the surface. For plains, this anisotropy is caused by the north-south (N-S) asymmetry of the subresolution surface topography [1,2].

Our previous analysis of the f_D distribution has revealed a global hemispherical trend of roughness anisotropy: in general, equator-facing small-scale topographic slopes are steeper than pole-facing [2]. This trend is in general agreement with the global pattern of wind directions inferred from wind streaks [3], if we assume that the observed anisotropy is due to the presence of microdunes on the surface [2].

Here we report on detailed comparison of Doppler centroid shifts and geological objects using Magellan SAR mosaics.

Doppler centroid maps: The RA echo has been sampled according to the Doppler shift into 17 bins, 935 Hz per bin (details are in [1]). For a globally horizontal surface with an isotropic backscattering function, the radar echo Doppler spectrum is symmetric with respect to the Doppler frequency corresponding to the nadir, and the strongest echo comes from the nadir bin. Non-zero Doppler centroid shift f_D means that the strongest echo in the along-track direction comes from either ahead (f_D>0) or behind (f_D<0) the nadir.

With the f_D estimates from the SCVDR, we generated a gridded map of f_D. Our map provides better visual sharpness and more suitable for comparison with the radar images than an analogous map from the GVDR data set.

One Doppler frequency bin (935 Hz) corresponds to the surface tilt of 0.4° close to the orbit periapsis (low latitudes) and up to 0.8° in the polar regions. The single-burst RA footprint size is ~25 km near the Magellan orbit periapsis (~10°N) and up to 220 km in the polar regions. Thus both sensitivity of f_D to roughness anisotropy and the resolution change strongly with the latitude.

Observations: We searched Venusin plains for correlations between the f_D map and surface geology seen in the Magellan radar (SAR) mosaics. We found that there is no global direct correspondence between f_D and surface morphology. In many places, however, we do see a coincidence of sharp contrasts in the f_D map and boundaries of geological units. This gives the strongest observational evidence that f_D in the plains indeed reflects some intrinsic anisotropy of the surface.

Role of tectonic structures: The topography or roughness responsible for the observed anisotropy can be of very different scales ranging from centimeters to kilometers. The largest scales in this range, kilometers and hundreds of meters, are resolved by the Magellan SAR. Numerous tectonic features of these scales are seen amid the plains in the SAR images. There is no clear indication of pronounced asymmetry of these features.

The most abundant resolved tectonic features in plains are the wrinkle ridges. Their three-dimensional shapes are rarely resolved, however, the largest representatives as well as analogy with similar features on the other planets [4] indicate that the ridges often have asymmetric profile [5]. The sense of this asymmetry, however, often changes along individual ridges, and there is apparently no consistent asymmetry through large areas. Ridges typically occupy less than 10% of the footprint area [5]. Thus, we do not expect wrinkle ridges to play a significant role in formation of scattering anisotropy. We also do not see correlation between areas of high scattering anisotropy and the density of wrinkle ridges (according to [6]).

Typical regional plains. We found eight examples of relatively large (>$1.5 \cdot 10^5$ km^2) uniformly anisotropic areas in the very typical regional plains. These areas are far from apparent parabolas, diffuse halos and other features attributed to the presence of surficial deposits (e.g., [7] and references therein). All areas contain well-developed networks of wrinkle ridges. The areas are composed of different flow units; their boundaries have low or moderate contrast in the SAR images and do not appear in f_D maps. There is no clear coincidence seen between the flows boundaries and the edges of uniform areas in the f_D map. These typical uniform areas have rather high (although not extreme) values of f_D. Seven of the eight follow the hemispherical trend.

Correlation with volcanic units: There is a number of examples, where the distinctive contrasts f_D correspond to boundaries of distinctive volcanic units in SAR images. We found 24 examples of lava flows showing rather uniform f_D sharply different form the surroundings. All flows found are rather small; the largest of them, the bright lava flow in Sedna Planitia (**Fig. 1**), is about 10^5 km^2. This flow, located at high northern latitudes, has strong slope asymmetry ($f_D \approx$ -2 kHz) with steeper north-facing slopes, opposite to the hemispherical trend. Its surroundings show variable asymmetry, in average small but also negative $f_D \approx$ -0.2 kHz. A few wind streaks listed in [2] in the vicinity of this flow have the inferred wind direction to the north-west, also opposite to the hemispheric trend.

Five sites from the set form a tight cluster of similar flows in Rusalka Planitia. These flows are in the southern hemisphere and are characterized by positive f_D contrary to the global hemispherical trend. Other sites do not occur in clusters. The remaining 9 flows in the southern hemisphere follow the global trend. The northern hemisphere flows exhibit both positive and negative f_D. Thus, in general, the distinctive lava flows do not follow the f_D global trend.

All flows found are rather bright and some of them are very bright in SAR images and hence have rather rough surface at the scales of meters and decimeters. All flows show the degree of slope asymmetry higher than surroundings. No apparent correlation is seen between sign of f_D and flow direction; this direction, however, cannot be reliably identified for some sites.

There is a principal possibility that the lava movement during the flow emplacement caused the observed surface roughness anisotropy. It is much more probable, however, that the high roughness favors accumulation of wind-blown material, and deposits of this material in wind shadows produce pronounced slope asymmetry.

Splotches appearance: Comparison between f_D map and SAR mosaics showed that several areas of peculiar f_D are associated with some largest splotches. Splotches are circular diffuse bright or dark features in SAR images (e.g., [8]) interpreted as "failed craters", the results of projectile explosion in the lower atmosphere. There are a few hundred of them on Venus. We found 17 clear examples of correspondence between a splotch and a feature in f_D map (one of the best example is shown in Fig. 2). In the majority of cases (14 of 17) splotches have higher anisotropy than surroundings; in all these cases the sign of anisotropy follows the hemispherical trend. The remaining 3 splotches appear in f_D map due to their weak anisotropy on highly anisotropic background.

Discussion: We believe that the deposits of wind-blown materials, either microdunes or deposits in wind shadows of topographic obstacles or both are the best candidates for explanation of the observed ubiquitous roughness anisotropy in Venusians plains. In the frame of the eolian hypothesis it is natural that we observe some correlation of anisotropy with geology, but this correlation is not universal and not uniform. Formation of anisotropic deposits is a complex process that depends on surface roughness characteristics, availability of proper loose material and its properties, and wind pattern during emplacement epoch. Furthermore, formation of anisotropic surface is interleaved with episodes of removal of anisotropy by emplacement of fresh lava flows, debris falls from large impacts, and eolian erosion. It is possible that eolian transport is active only episodically, during geologically short periods, for example, as has been hypothesized in [9], only after large impact events. Our observations further confirm that the surficial deposits of wind-blown material are ubiquitous on Venus and can be present even in regions where we do not see diffuse features or wind streaks in the SAR images.

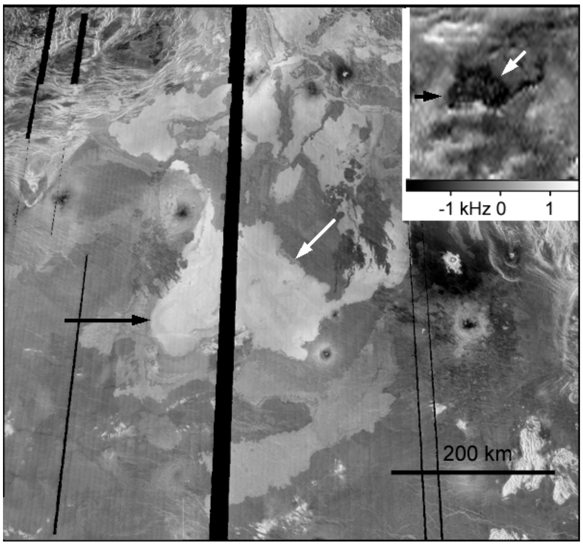

Fig. 1. Magellan SAR mosaic of Sedna Planitia (50°N, 345°E). Inset shows the Doppler centroid map of the same area. Arrow shows a radar-bright (rough) lava flow with a well-pronounced anisotropy signature.

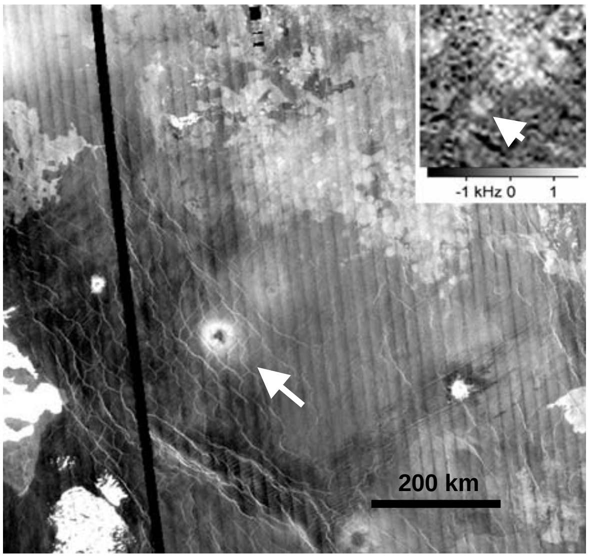

Fig. 2. Magellan SAR mosaic of Rusalka Planitia (2°S, 164°E). Inset shows the Doppler centroid map of the same area. Arrow shows a splotch with a well-pronounced anisotropy signature.

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