AEOLIAN BEDFORMS ASSOCIATED WITH RADAR-DARK DIFFUSE FEATURES ON VENUS.
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Introduction: Data about the surface of Venus are rather scarce. Magellan radar images with resolution ~120 m have revealed only two dune fields [1,2]. Indirect indications of small-scale, unresolved aeolian bedforms came from azimuthal anisotropy of radar backscattering. The only reasonable explanation for such anisotropy is unresolved decameter-scale asymmetric topography, and in many geological settings aeolian bedforms are the only possible explanation for such asymmetric topography. A few areas of strikingly strong anisotropy have been interpreted as dense fields of microdunes [1,2] with steep slip faces [3]. Two different radar remote sensing techniques show independently that weak backscattering anisotropy is ubiquitous [3-5]. This fact was interpreted as ubiquity of decameter-scale aeolian bedforms without steep slip faces and/or sparse surface coverage [3, 5]. Here we report on some typical geological settings where such deposits systematically do and do not occur, and discuss possible implications.

Areas of weak backscattering anisotropy associated with the extended crater-related features. Many craters on Venus have specific associated extended deposits; they appear as diffuse dark areas in Magellan radar images and are dubbed dark diffuse features (DDFs) [6]. They are thought to form by particulate material ejected by crater-forming impacts and slowly descending through the atmosphere [7]. There are two kinds of DDF planforms: parabolas and halos. Parabolas are forming due to transport of descending particles by superrotating atmosphere [7]. Halos were thought to be a result of degradation of older parabolas [8], although it cannot be completely excluded that the halos were formed during an epoch without the atmospheric superrotation.

We analyzed microwave (12 cm wavelength, Magellan data) remote sensing signatures related to DDF. The data included: (1) radar *images*, spatial distribution of radar cross-section under oblique radar incidence at moderately high spatial resolution (~120m); (2) microwave *emissivity* at low resolution (~10 km); (3) Hagfors' *roughness* parameter derived from nadir-looking radar altimeter echo; this parameter characterizes typical slopes at meter and longer baselines; (4) *Doppler centroid* shift of the radar altimeter echo [4,5] that quantifies asymmetry between north- and south-facing slopes at meter and longer baselines and thus characterizes the presence of asymmetric aeolian bedforms.

Although there are many individual peculiarities in microwave signatures of the largest and the most pronounced DDFs, there is prominent similarity schematically depicted in **Fig. 1**. There are two distinctive units associated with DDFs. Dark parabola or halo (unit **A**) is characterized by low radar cross-section (dark in radar images), low roughness, uniform microwave emissivity and zero Doppler centroid (isotropic meter-scale topography). Surrounding area (unit **B**) is characterized by regular radar-cross-section (the boundary with parabola is diffuse), regular or slightly decreased roughness, the same microwave emissivity as unit A, and consistently high Doppler centroid, typically positive in the N hemisphere and negative in the S hemisphere.

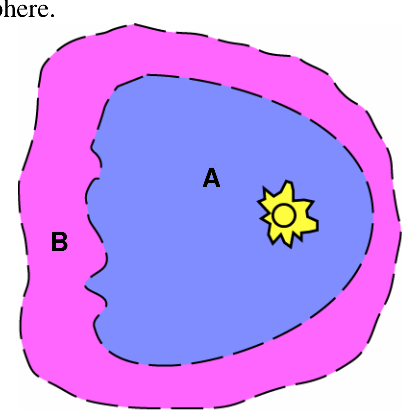

Fig.1

The remote sensing signature and diffuse boundary of unit A indicates that the surface of the deposit is flat, and particles forming the deposit are millimeters in size or smaller. The emissivity signature of unit B indicates that the surface is covered with the same material that forms unit A, but this cover is thinner (decimeters) [9].

The Doppler centroid signature indicates that unit B is covered with anisotropic aeolian bedforms, while unit A made of the same material and exposed to the same winds has flat surface.

Discussion. The density of the Venus' atmosphere is a factor of ~50 higher than terrestrial air density and a factor of ~15 lower than water density. In a sense, venusian air is more similar to water than to terrestrial air. Given that the gravity is very similar to terrestrial, it is reasonable to expect that aeolian bedforms on Venus are rather similar to terrestrial sub-aqueous deep water bedforms. Recently, the observed morphologies of such bedforms have been systematically correlated against grain size and free-flow velocity [10]. **Fig. 2** is a result diagram from that work. Although classic barchan dunes do form under deep water, they occupy a very limited domain in the grain size - flow velocity space. Small gentle ripples with characteristic wavelength of centimeters and amplitude of millimeters are typical for sub-aqueous sand sheets. Such ripples would be indistinguishable from flat surfaces in microwave data.

Wind tunnel experiments with the same air density as on Venus [11] also revealed that microdunes are typical for only a small domain in the same parameter space. Therefore it is possible that saltation of sand-size particles on Venus do not produce bedforms with any distinguishable microwave signatures.

Thus, one of possible explanations for our observations is the following. Within unit A saltation does occur, the bedforms do form, however, they are too small and gentle to be indirectly detected with 12 cm wavelength remote observations. Within unit B decimeter-scale roughness elements protruding through smooth crater-related deposit cause bedforms to be taller, which results in the observed signature.

Another possible explanation is that all sand-size particles are already removed from unit A, and only well-sorted few-millimeter-size granules that are too large to be moved by saltation form the deposit. Time needed to remove all sand fraction from the deposit is scaled as $(H\,L)\,/\,(s\,f\,h\,v)$, where $L \sim$ 100s km is a typical spatial scale of the DDF, $H \sim 1$ m is the sand thickness, $v \sim 1$ m/s is a typical saltation velocity, $h \sim 2$ mm is saltation height [12], $f \ll 1$ is a poorly constrained factor describing filling of the saltation layer with saltating particles, our terrestrial-experience-based guess is $f \sim 10^{-4}$, and $s \leq 1$ is a fraction of time, when winds exceed saltation threshold; for the dense atmosphere of slowly rotating Venus we assume stable winds and $s \sim 1$. These give ~1 Ma for the time scale of sand removal, which would mean that all DDFs except only a few may be already sand-free. A few DDFs with sand remaining are consistent with only a few DDFs having distinctive microdune signatures [2]. Under this scenario decimeter-scale topographic obstacles in unit B are responsible for catching sand and preserving bedforms.

If the bedforms in unit B were lee dunes (aka shadow dunes), the observed Doppler centroid signature would imply poleward dominant winds in both hemispheres, while the global wind streak pattern [1] is consistent with Hadley-cell-driven equatorward winds. This discrepancy requires some additional complications in both proposed explanations.

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