AEOLIAN TRANSPORT AND AEOLIAN DEPOISTS ON VENUS: AN OVERVIEW OF REMOTE SENSING OBSERVATIONS.

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Introduction: Data about the surface of Venus are rather scarce. Here we present a concise inventory of known information about aeolian transport and aeolian deposits and summarize the outstanding questions.

Observed aeolian bedforms: Information about the geology and surface properties of Venus has been obtained mostly with microwave remote sensing techniques: radars and radiometers. Imaging radars have revealed a spectacular surface dominated by extensive volcanic plains and deformed by abundant tectonic features. The generally pristine appearance of the volcanic and tectonic features indicates a very low rate of exogenic resurfacing (including aeolian processes) during the last 200 - 500 Ma of geologic history recorded at the surface.

Only the largest aeolian bedforms are resolvable in Magellan SAR images, the highest resolution (100 - 200 m) images of the surface available so far. There are 2 fields of resolved transverse dunes [1-3]. Their total area is ~2×10^4 km^2, or ~4×10^{-5} of the total area of the planet, much less than the area covered by dune fields that would be resolvable with the same technique on Titan (~13%), the Earth land (~1.5%) and Mars (~0.7%). The total amount of sand in these dune fields is a few mm equivalent global layer (EGL). For comparison, Olympia Undae on Mars contain ~5 cm martian EGL of sand. These volume estimates are rough and give only a sensible lower boundaries.

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 [2] with steep slip faces [4]. Their total area is ~3×10^5 km^2, still small in comparison to the ergs on other planets; the total amount of sand in them is less than a mm EGL. Two different radar remote sensing techniques show independently that weak backscattering anisotropy is ubiquitous [4-6]. It was interpreted as ubiquitous decameter-scale aeolian bedforms without steep slip faces and possibly non-continuous surface coverage [4, 6]. Total amount of sand in these deposits is very poorly constrained between 1 mm - 1 dm EGL.

Radar images reveal also a wide variety of wind streaks [3,7]. It is quite possible that some of them or all of them are formed by fields and chains of small unresolved aeolian bedforms or gaps in such fields. Some wind streaks do correlate with backscattering anisotropy, however, no systematic analysis have been performed. There is a strong trend of concentration of the wind streaks near young large impact craters.

The largest dune field is probably inactive. It is not known, whether the other aeolian bedforms observed directly or indirectly are active now or they record wind action in the geological past. Surface changes in the most active terrestrial dunes hardly would be detectable by repeating Magellan coverage.

Two (2) of 4 Venera landing sites with available images of the surface have abundant loose material ("soil") at the surface; possibly, this soil contains a high fraction of sand-size particles. However, no apparent aeolian bedforms are seen in the panoramas. For comparison, on Mars, all 6 lading sites with available images contain some soil, in 5 of them small-scale aeolian bedforms are obvious, and in 4 of them the bedforms would be seen on images of the same quality as Venera panoramas.

Winds: Venus atmosphere is dense, and the saltation threshold is low, ~0.6 m/s according to wind tunnel experiments [9]. The wind regime in the surface boundary layer of the Venus' atmosphere is essentially unknown. First-principle estimates [10] bracket *typical* wind speeds between a few mm/s and a few m/s; these limits are well below and well above the saltation limit. Day-time wind speed measured [11] at two landing sites was on the order of ~1m/s. Some soil movement apparently caused by wind was noted in repeated Venera panoramas [12]. However, winds at the landing sites might be related to long-living atmospheric disturbances caused by the probe descent and landing and not representative of typical conditions. According to the poor constraints on the typical wind speed, two endmember scenarios for formation of aeolian bedforms can be envisioned.

W*indy regime*. Typical near-surface winds are above the saltation threshold, saltation occurs wherever sand is available. Slip faces and dunes form only when wind speed is close to the threshold, otherwise wind produces slightly undulating sand sheets and small ripples [9] responsible for the observed wind streaks and weak backscattering anisotropy. Statistics of slope streak orientation [7] is consistent with possible circulation pattern and thus with windy regime. The concentration of wind streaks around big craters and the absence of small bedforms in panoramas is explained by availability of mobile sand (see below). Windy regime predicts significant transport of sand and hence trapping of sand into impact craters, like it occurs on Mars. Such trapping is not observed. Old craters are somewhat shallower than young craters [13], which has been explained through volcanic infill. Unlike craters on Mars, old craters on Venus have no hint of aeolian bedfroms on their floors.

Calm regime. Typical near-surface winds are well below the saltation threshold, and rare short episodes of saltation occur in the aftermath of impact events due to atmospheric and surface thermal disturbances caused by impacts [14]. This naturally explains association of wind streaks with craters, the absence of aeolian bedforms in the panoramas and on the crater floors. The existence of two fields of big dunes (they need much time to form) has no straightforward explanation. They might be relics from ancient climate regime.

Variations. If we do not involve climate change, the presence of only two fields of big dunes might mean a fine tuning of wind regime, which is unlikely to occur by chance. This may point to the existence of some sort of feedback between saltation and winds. Fine dust knocked out by saltation and suspended in the lower atmosphere might be a feedback mechanism.

Sands: Scarcity of sand on Venus has been considered [2, 3] as explanation for the scarcity of observed aeolian bedforms. It has attributed [2, 3] to the fact that erosion by water, the main source of sand-size particles on the Earth, does not operate on Venus, and chemical weathering is not likely to produce sand [15]. On Mars, however, where erosion by water is extremely slow, sand is abundant, because the main terrestrial sink of sand, sedimentation at the sea floor, does not operate on Mars. Unlike Mars, Venus has an efficient sink of sand, lithification of beds accelerated by high surface temperatures. Some "stickiness" of particles at high temperatures has been predicted from the first principles [16] and observed in the wind tunnel experiments under Venus conditions [17]. "Stickiness" and quick lithification of sands can explain lack of saltation of Venus, even if the sand-size particles are abundant.

Impacts have been considered as the main source of sand on Venus; estimates [18] give ~ 1 mm EGL, while from considerations in [15] we got two orders of magnitude more optimistic value (~ 1 dm EGL). Material ejected by young large craters forms extended radar-dark diffuse features (DDFs) of parabolic planform, dm to meters thick. According to [15] they may contain a significant proportion of sand particles, but their surface usually remains flat for tens Ma [19]. Microdunes [2], however, are formed on DDFs, and possibly, from their material. As noted in [20], impacts cause a wave of strong compression of the air followed by rarefaction, which can disintegrate slightly lithified deposits, extract sand from topographic traps, etc. This gives another explanation for concentration of wind streaks around impacts.

In addition to impacts, tectonics and associated mass wasting can disintegrate rocks to produce sand-size particles. No association of wind streaks with the youngest tectonic fractures has been noted. Pyroclastics is obvious and probably rich source of sand-size material, however, there is no unambiguous association of wind streaks with young volcanoes.

Conclusions: Despite abundant morphological observations, is unclear if aeolian activity is / was able to move material for long distances to produce global material mixing, or the observed bedforms reflect only local reworking of the material. There is a set of indications that saltation on Venus is not pervasive, but we do not understand, if this is due to lack of winds or lack of sand.

What new data can help to understand the situation? The most principal point is the order of magnitude of typical winds in the boundary layer. The easiest way to assess it with remote sensing techniques is to measure diurnal variations of the surface temperature with accuracy of ~ 0.1 K. It is possible that advanced analysis of data from IR spectrometers VIRTIS and SPICAV onboard Venus Express can give some new constraints, but probably the right way to achieve required accuracy is well calibrated orbital microwave radiometer.

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