TERRESTRIAL ANALOGS FOR VENUSIAN DUNES: SUB-AQUEOUS, SEAFLOOR DUNE FIELDS

L.D.V. Neakrase[1], [1]Department of Astronomy, New Mexico State University, Las Cruces, New Mexico, P.O.Box 30001, 88003-8001, USA. lneakras@nmsu.edu

Introduction. Saltating sand grains on Venus have long been the subject of debate including a wealth of wind tunnel experiments and a handful of observations from the Venera landers. Since the probable identification of dune fields on Venus from Magellan radar data, there have been few terrestrial analogs for comparison to the high-pressure, high-temperature surface conditions present on Venus. One possibly over-looked environment that could help constrain formation, propagation, and evolution of dune forms on Venus could be sub-aqueous dunes found at the bottom of the ocean on Earth. Seafloor dunes form in a higher-pressure environment more analogous to the surface pressures of Venus.

Venusian surface pressures measured by Venera 9 and 10 averaged about 90 bar with measured wind speeds 0.4 – 1.3 m s^{-1} [1]. Surface images from the Venera landers (9,10,13,14) showed fine-grained material at some of the sites suggesting the presence of potential sand to dust-sized sediment capable of being moved through aeolian processes [2,3].

Laboratory experiments [4,5] tested near-Venus-like conditions for a range of particle sizes (30-650 μm, silica) and free-stream velocities (0.4-4 m s^{-1}). Threshold conditions yielded an optimal grain size of 75 μm for movement by the lowest wind speeds. Experiments suggested that grains can be mobilized under venusian conditions, but rock abrasion by sand impact is probably limited because of low particle velocities once grains are mobile.

One possible analog that has not been extensively studied is dunes at the bottom of the ocean on Earth. Given the high density of the venusian atmosphere, sand transport necessary for dune formation might better be represented by sub-aqueous, oceanic currents found at the seafloor. Typical current speeds near the seafloor tend to be ~0.1-1.0 m s^{-1} and produce dunes and ripples in seafloor fines (sand) at these velocities in areas where flow can be confined by topography (e.g., [6,7]). Perhaps dune fields discovered in Magellan radar images on Venus could form and evolve in similar ways to that of sub-aqueous seafloor dune fields on Earth.

Venusian Dune Fields. Dune fields on Venus were first described after acquisition of Magellan synthetic aperture radar (SAR) data [8,9,10]. Numerous features were identified that could be attributed to aeolian processes including possible dunes, windstreaks, and yardangs. [9] identifies the most common aeolian features on Venus as wind streaks. Dunes, though present and identified in two main locations, are relatively rare.

The dune fields are similar to each other in appearance and constrained by topography with possible source material being reworked crater ejecta lag deposits. The original studies used radar bright wind streaks as indicators of prevailing winds arguing that the dune fields are aligned transverse to the wind direction.

The Agloanice dune field (centered 25°S, 340°E) is situated ~100 km north of the impact crater Aglaonice covers an area ~1290 km^2 with individual dunes estimated to be between 0.5 to 5 km in length but spacing is not clear because of specular returns from the radar images. Orientation of the dunes and the wind streaks suggest wind direction to the west.

The Fortuna-Meshkenet dune field to the north (centered 67°N, 91°E) is situated in a valley between Ishtar Terra and Meshkenet Tessera. This field covers roughly 17,120 km^2. As was the case with Aglaonice, this dune field is marked with dunes and wind streaks that correspond to what are assumed as the prevailing wind directions; southeast-northwest flow in the southern part of the field and westward flow in the northern part. Most of the wind streaks in the Fortuna-Meshkenet field seem to originate from small cone-like features. Source material for this dune field is suggested to be from the surrounding complex terrain associated with tectonics of the tessera.

Backscatter effects seen in radar data show differences in dielectric coefficients, which do not necessarily denote changes in composition, but could also represent changes in particle size or changes in reflection orientation. This fact is part of the reason radar images are so hard to interpret for geologic context. Comparison to terrestrial dunes observed by radar systems (reviewed by [9,10]) suggest that viewing limitations for the Magellan SAR prevent ubiquitous detection of dunes in any orientation and may account for the paucity of dunes in other regions on Venus. [11] showed that with Seasat viewing dunes on Earth, these viewing effects are important for understanding the orientation and composite grain sizes of the observed dune forms.

A different approach to compare to the radar images from dune fields on Earth and Venus is to examine side-scanning sonar studies of dunes on Earth's ocean floors. A similar remote sensing technique to synthetic aperture radar, side-scanning sonar together with visible images of the seafloor dunes can yield other potentially useful constraints for venusian dune studies.

Terrestrial Seafloor Dunes. Sand dunes found on the seafloor have been studied since the 1960s and are typically found in areas confined by topography where oceanic sedimentation transitions from pelagic to current-driven [6]. The important part of this description is the dependence on ocean currents to transport various sediments along the seafloor. This flow dependency is capable of producing meter-sized to centimeter ripples along local regional slopes culminating in larger dune forms. Estimates of the flow velocities (ocean current velocity) over the seafloor features are measured at 0.3 to 2 m s^{-1}, but these estimates could be lower bounds not including higher energy events such as benthic storms, analogous to surface storm events causing bursts of dune activity over a short time.

Seafloor dunes are typically classified as crescentic (abyssal barchans) or transverse dunes. Sizes can range from 10 to 100+ m in length. Transverse dunes in most areas seem to be due to coalescence of strings of barchans [6,7]. [7] described tightly spaced barchans from the Faroe-Shetland Channel as having the appearance of a speckled backscatter signal in the side-scanning sonar. This effect made tightly spaced barchans nearly indistinguishable from transverse dunes. Higher-resolution photographs of the same area clearly separated barchanoid shapes. In almost all cases asymmetric barchanoids also had ripple patterns on the stoss slopes at centimeter to meter scales, typical of arid desert dunes.

Application to Venus. Seafloor dune studies potentially provide another source of study beyond traditional surface dune studies for comparison to environments with very thick atmospheres. Seafloor currents are of the same order as Venus wind tunnel experiments under near-venusian atmospheric viscosities suggesting a possible analog in the types of bedforms that are produced in both environments. In places where observations are limited to radar images with limited surface resolution, seafloor studies with side-scanning sonar and complementary photos could bridge the gap of the orbital resolution limitations.

Venusian dunes are presently limited to the Aglaonice and Fortuna-Meshkenet dune fields and many more indications of wind streaks planet-wide. There has been no indication of barchanoid dune forms in the venusian environment. The paucity of other identified dune fields and specifically barchan dune morphologies is most likely the limitation of the viewing angle effects of the SAR and lack of high enough resolution to resolve individual dunes. Instead the venusian dune fields appear to be collections of transverse dunes. [10] also noted that the viewing effects of the Magellan radar data also probably limited dune detection to dunes situated in N-S configurations potentially neglecting any other configuration suggesting that different orbital parameters for a space-borne radar platform would have the potential to detect many more aeolian features not presently accounted for in the Magellan data.

Future Work. Continued study of features on seafloor dunes and more specifically the scale and slipface orientations might aid in determination of the expected features for future higher-resolution radar studies of the venusian surface.

Another planetary surface that might also benefit from examination of the marine literature is potentially Saturn's moon Titan, where long systems of linear duneforms have been identified similarly to Venus. Titan's atmosphere presents its own challenges but is still thicker than Earth's with potentially higher viscosity similar to certain depths within the terrestrial ocean.

Clearly this is preliminary work and should benefit from further examination of the marine literature. It would be useful to create some sort of database of terrestial sub-aqueous seafloor dunes for comparison to similar areas on Venus and Titan in the future. Flow velocities and dissecting the individual parameters that influence the bottom currents in the ocean need to be more carefully compared to what is known about the venusian surface environment; specifically the atmospheric density and viscosity. Wind streaks and dune forms on Venus that are not associated with domes or other topographic sources should be considered candidates for future high-resolution radar studies if possible. These features (as they have been) can be considered diagnostic of prevailing wind directions but the sub-meter to tens-of-meter scale will be more important when diagnosing the capabilities of the venusian atmosphere to move sediment.

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