Venus antidunes: lessons from unconfined terrestrial density currents. K. E. Williams[1] and T. N. Titus[1], [1]USGS Astrogeology Science Center, 2255 N. Gemini Dr, Flagstaff AZ 86001 – kewilliams@usgs.gov.

Abstract: At present, dunes have been identified on the surface of Venus [1]. Previous efforts have considered the possibility that some dunes in the Al-Uzza Undae dunefield (67.7 ° N, 90.5 ° E) could be antidunes [2-3]. In this work, we summarize the equations used for calculating depth-averaged flow of unconfined density currents, which are the primary agents of terrestrial subaqueous antidune formation. Terrestrial pyroclastic flows have also been claimed to produce antidunes [4]. Given putative antidunes in a geologic setting and some assumptions regarding sediment concentration, we show that flow characteristics may be calculated. We also suggest that terrestrial Venus analogs for antidunes may be more plentiful than previously considered, as both turbidity currents and pyroclastic flows may produce antidunes.

Background and Model: Previous work has noted that subaqueous dunes may provide useful analogs to Venusian dunes [5-6], where slope winds were postulated to transport sediment downslope in a manner analogous to density currents [6]. Terrestrial pyroclastic flows have also been claimed to produce antidunes [4]. In either case, given some assumptions regarding dune provenance, flow properties may be inferred from dune characteristics such as height, wavelength, and slope. Subaqueous terrestrial antidunes are surprisingly common, occurring at nearly all depths and settings. The requirements appear to be adequate sediment availability and a supercritical (upper) flow regime.

One of the critical dimensionless numbers for flow regime characterization is the internal Froude number (Fi):

$$Fi = \frac{u}{\sqrt{g'L}},\qquad (1)$$

where u is the depth-averaged flow velocity, the reduced gravity $g' = g\left(\frac{\rho_f - \rho_a}{\rho_a}\right)$ for the ambient density ρ_a, the flow front density ρ_f and a length scale L. In the case of non-Boussinesq flow fronts (i.e. where density gradients are large), the following reduced gravity formulation has been used instead [7-8]:

$$g'' = g\left(\frac{\rho_f - \rho_a}{\rho_f}\right)\qquad (2)$$

Most of the parameters in eq. (1) are difficult to estimate for a given flow, especially the depth-averaged velocity. An alternate form, favored by the terrestrial density current research community, calculates the Froude number (Fi) using properties of the slope (β), drag coefficient (Cf) and an entrainment coefficient E in the following manner [9-10]:

$$Fi^2 = \frac{\sin\beta}{Cf+E}\qquad (3)$$

The slope angle is relatively easy to estimate, provided the dune field is on a simple slope with few breaks. The entrainment coefficient E, which is in principle a function of the Richardson number, has been estimated to be 5×10^{-4} for subcritical flows and 2×10^{-3} for supercritical flows [10]. Similarly, the drag coefficient Cf has been estimated to be 19.5×10^{-3} for subcritical and 8×10^{-3} for supercritical flows [10]. Note also that antidune formation ordinarily requires supercritical flow, which implies internal Froude numbers of at least 0.7-0.8 [9].

Flow thickness (h) may then be calculated for dune wavelength (λ):

$$h = \frac{\lambda}{2\pi Fi^2}\qquad (4)$$

Given a sediment concentration (C), depth-averaged flow velocity (u) may then be calculated [11]:

$$u^2 = Cg''h(Fi^2)\qquad (5)$$

Applying eqn. (2) to a flow front density ρ_f = 1000 kg/m³ (mixture of vesiculated basalt particles and Venus atmosphere), Venus atmospheric density of 69.6 kg/m³, and gravity =8.87 m/s², we find the reduced gravity g''= 8.25 m/s². Terrestrial density currents have produced antidunes on a slope with an angle of 0.37° [9]. We note also that the Al-Uzza Undae dunefield appears to occur on nearly flat ground, hence we choose a similar slope to [9]. We calculate the internal Froude number by then assuming Cf and E are supercritical cases, where Fi= 0.80.

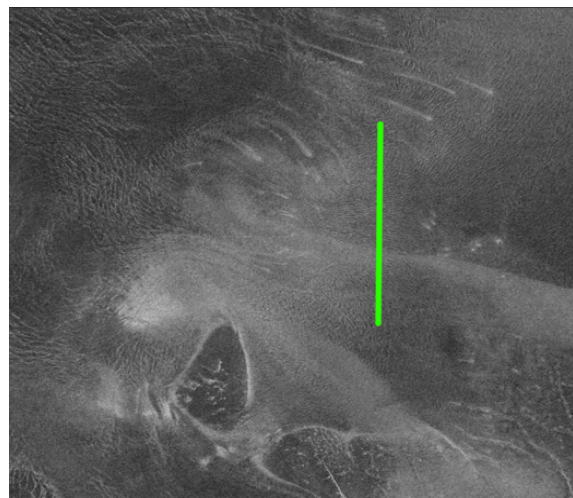**Figure 1. Al-Uzza Undae dunefield. The annotation shows the approximate transect location used for Fig. 2.**
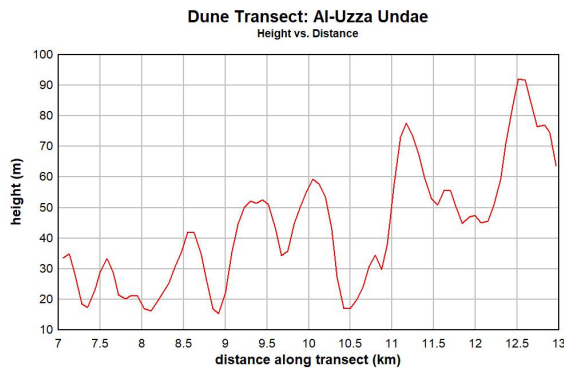
Figure 2. Transect from Lorenz[13]. Note the approximate wavelength of 1 km.

Next, we note that the Al-Uzza Undae dune wavelength (Figs. 1 and 2) for a particular transect by Lorenz [12] was approx. λ= 1000 m and therefore the flow thickness h=246.46 m.

The sediment flow concentration C is assumed to be similar to terrestrial density currents, where a value of 17.5×10^{-4} was used for turbidity currents [10], though others have used values between 5×10^{-5} and 5×10^{-4} [9]. We therefore used an averaged value of $C=1 \times 10^{-4}$. Given the parameter values stated above, the depth-averaged flow (eqn. 5) is then u= 36 cm/s.

Discussion and Conclusion: As shown in Fig. 3, the calculations for Froude number and flow thickness are somewhat sensitive to the slope angle. The depth-averaged flow-velocity, not shown, is largely insensitive to slope angle.
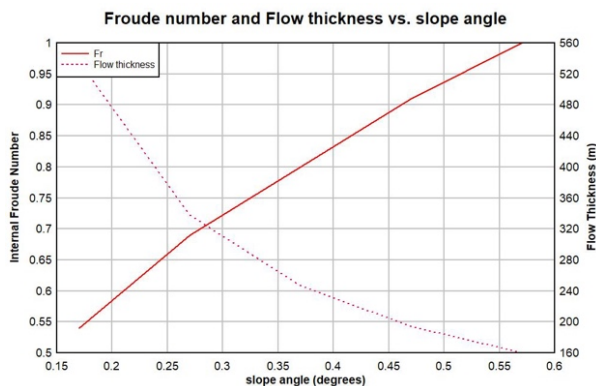

Figure 3. Internal Froude number and flow thickness as a function of slope angle (beta). Note that the Froude number is nearly linear with slope angle.

The observed horizontal surface wind speeds recorded by Venera 9 ranged from 0.4-0.7 m/s, and Venera 10 recorded 0.8-1.3 m/s [13]. It is therefore possible that the Al-Uzza Undae bedforms are antidunes, given

that the calculated wind speed of 36 cm/s corresponds to a Froude number of 0.8. The majority of terrestrial antidunes are subaqueous, with the possible exception of pyroclastic flow cases. If aeolian antidunes are possible on Venus, then their presence would support claims by earlier researchers [14] that the dunes of Venus would have characteristics of both aeolian and subaqueous environments. More generally, the presence of aeolian antidunes on Venus would indicate that aeolian sediment transport behaves differently on Venus than on Earth.

Confirmation whether Venus dunes are actually antidunes will require higher quality topographical profiles (horizontal and vertical resolution) which are not currently available. The proposed US Discovery Class Mission VERITAS will include the Venus Interferometric Synthetic Aperture Radar (VISAR) with an order of magnitude better resolution than the Magellan synthetic aperture radar [15]. The proposed European mission, EnVision, also has an instrument similar to VISAR but with comparable or slightly better spatial resolution than VISAR. The actualization of either of these proposed missions would provide new insights into Venus dunes.

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