Other Dune Worlds

15

The last decade has seen a transformation in our understanding of the abundance of planets in our galaxy. From a handful of known exoplanets in the 1990s, the number of confirmed candidates (albeit mostly gas giants) is approaching 1000. Some of these planets have rocky surfaces, and it seems certain that our galaxy, and indeed the universe, is teeming with worlds on which dunes may exist. However, for the forseeable future, we can learn little about these planets and their moons and must content ourselves with our own solar system.

Beyond the terrestrial planets and Titan, which we have already covered, two moons in our solar system are presently known to have tenuous (and in fact rather variable) atmospheres that may be thick enough to transport particulate material: Triton and Io. We will discuss them briefly in this section in order of decreasing pressure; Triton also serves as a prototype for Pluto and perhaps other similar worlds in the chilly Kuiper belt of bodies at the edge of the solar system. However, as we discuss, it is at best marginal to think of these as 'Dune Worlds'. We may note that the acceleration of solid particles by gas is a known (and spectacular) process on comets, and on Saturn's moon Enceladus, but no details of horizontal gas flows are known and thus, even if these fell under the definition of aeolian transport (and they may not), there is nothing at present to say.

It is conceivable that other worlds (such as the Galilean moons) may have had atmospheres soon after they formed but which are no longer present. If this is the case, aeolian transport might have occurred, but there seems little hope that traces of such processes are preserved to an observable extent. Similarly, aeolian processes can occur in transient volcanic 'atmospheres' (witness, say, the bedforms generated in ashfall deposits during maar eruptions on the Earth) in which case perhaps some ripples or related features may have formed even on our own moon. Again, however, there is little more that can be said than to note the possibility.

15.1 Triton

Triton is the largest moon (radius 1353 km) of Neptune, and revolves around its planet in just under 6 days. Its density suggests it has a rock or rock/iron core, but substantial amounts of water and carbon dioxide ice. Unusually, its orbit is retrograde, suggesting perhaps that Triton is a 'captured' moon, rather than having formed in a protoplanetary disk. The orbital arrangement and Triton's rotation lead to very large changes in the amount of sunlight on different parts of Triton (its situation resembles the planet Uranus, where during the course of a year the sun passes nearly overhead each pole), with the result that there may be substantial seasonal migration of volatiles.

Triton has an atmosphere that is quite thin, predominantly of nitrogen. The surface pressure determined by the Voyager 1 radio occultation experiment was a mere 14 microbar: the gas appears to be in vapor pressure equilibrium with nitrogen frost on the surface; this frost makes Triton's surface very bright and thus it has an exceptionally low surface temperature—about 40 K.

Aeolian transport on Tritan was considered by Sagan and Chyba (1990). They found, given the pressure conditions and the low Triton gravity of 0.78 m/s^2, that even an atmosphere as tenuous as Triton's 16 microbars could lift 5 micron or smaller particles into suspension if cohesion between particles is small. They noted that, even though the Triton surface pressure is 400× smaller than Mars', the low temperature on Triton (6× less) mitigates the atmospheric density by that factor; also the Triton dust would be likely organic (as on Titan) and thus less dense than Martian rock. These factors, together with the low gravity, mean that the threshold friction speed on Triton would be only ~2.5 higher than on Mars.

Measurements of the atmosphere by stellar occultation in 1997 showed that the atmosphere had in fact thickened somewhat (at these conditions, even the observed small rise in surface temperature of ~2 K can increase the vapor

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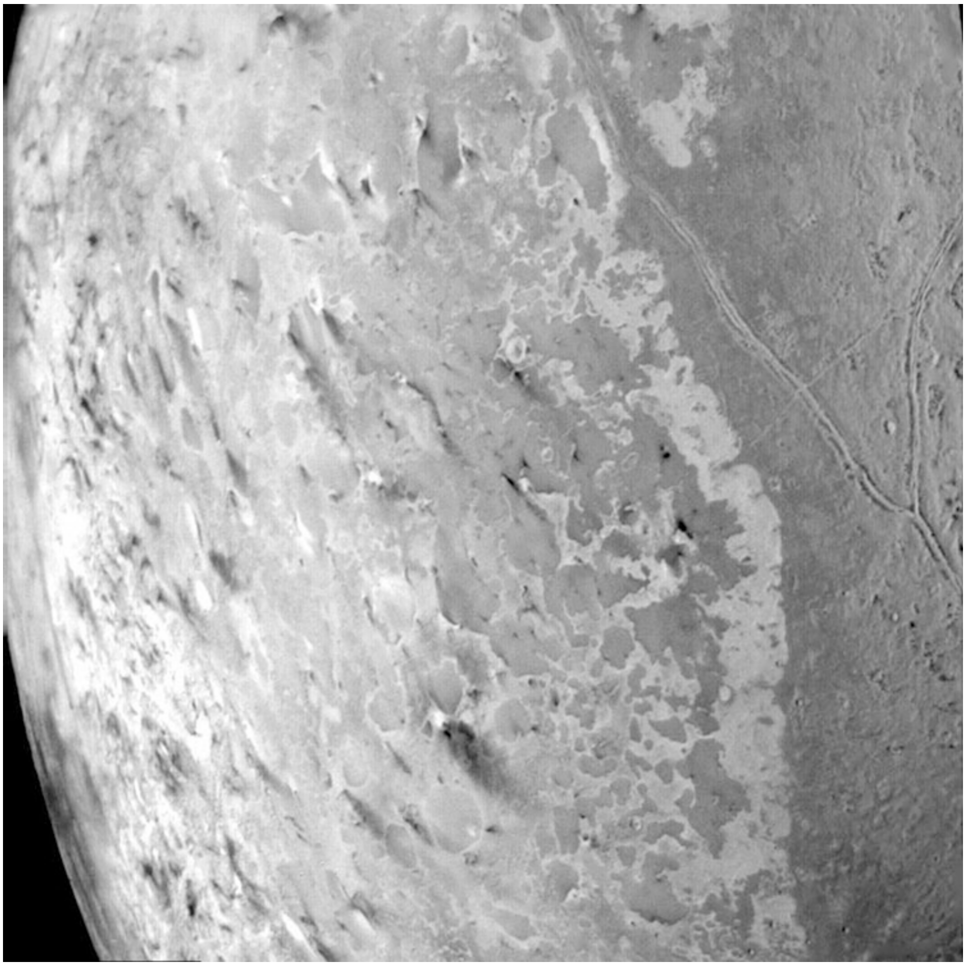

Fig. 15.1 Voyager 2 image of the surface of Triton. Many dark streaks can be seen, all pointing at around 5-o'clock, suggesting transport by a regional wind pattern. The extent to which the material merely drifts downwind while settling out from a vertical plume, versus being transported by saltation along the surface, is not known. *Image* NASA

pressure substantially, and only a small change in heat flux can change the surface temperature). The changes are likely caused by the elliptical orbit of Neptune around the sun, and thus further change (unobserved at present) has likely occurred.

Groundbased spectroscopy (Grundy et al. 2002) suggests that nonvolatile materials are widely distributed on Triton: the fact that such materials are evident even though sublimation and condensation of nitrogen and methane should seasonally deposit 'clean' frosts may imply that winds can redistribute finely-grained material quite quickly. The material should not be produced fast enough by photochemical processes to be detectable in seasonal frosts (Fig. 15.1).

The particles appear to derive from point sources, likely associated with eruptive plumes (e.g., Hansen et al. 1990; these probably solar-driven plumes have been sometimes referred to, almost certainly incorrectly, as 'geysers') in which case the streaks are more likely just the downwind fallout of dust blasted into the sky by the plumes, rather than being saltated along the ground and forming dunes or ripples. There is, however, no observational evidence for or against the existence of bedforms.

While no near-term exploration of Triton is expected the New Horizons spacecraft, launched in 2006, is set to fly past Pluto and its moon Charon in 2015. Pluto may in some respects resemble Triton, although the best imaging resolution of Pluto will likely be of the order of 50 m/pixel, so dunes—if present at all—would have to be large to be detectable. On the other hand, the saturation length in a thin atmosphere, and thus the expected bedform length scale, is large. Another moon, Io, offers a tentative example.

15.2 Io

Jupiter's innermost large moon, Io, has a constitution rather similar to the terrestrial planets, with iron, sulphur and silicates. It is in an orbital resonance with Europa and Ganymede, that maintains a substantial eccentricity to its orbit

Fig. 15.2 The margin of the lava flow field associated with the Prometheus volcano on Jupiter‘s moon Io is seen in this 12 m/pixel image, acquired by the Galileo spacecraft on February 22, 2000. The dark lava has margins similar to those formed by fluid lava flows on Earth. This entire area is under the active plume of Prometheus, which is constantly raining bright material. The older plains (*upper right*) are covered by ridges with an *east—west* trend. These ridges may have formed by the folding of a surface layer or by deposition or erosion. Bright streaks across the ridged plains emanate from the lava flow margins, perhaps where the hot lava vaporizes sulphur dioxide. The bright material must be ejected at a low angle because it only coats the lava-facing sides of the ridges. North is slightly to the *right* of straight up. *Image credit* NASA/JPL/University of Arizona, Photojournal image PIA02557

around Jupiter. This eccentricity leads to strong tidal forces which deform the world slightly and this tidal kneading generates appreciable heating of Io’s interior, with the result that Io is volcanically very active. This activity was discovered by Voyager 1 in 1979, when a large fountain-like plume was observed on Io’s limb. Further Voyager and Galileo observations have found many active volcanic centers, some with exposed silicate lavas with temperatures in excess of 1400 K, others merely sulphur dioxide plumes jetting into space before falling back down (as sulphur dioxide frost).

Io’s atmosphere is predominantly of sulphur dioxide, but is very tenuous indeed. Spectroscopic measurements from Earth show that the pressure on the sub-Jovian hemisphere is only about a tenth of a nanobar, although the same data show that the antiJovian hemisphere has a pressure of several nanobar. This large discrepancy can be sustained because the gas can condense out onto the surface before it is transported around the moon. The discrepancy suggests some uneven supply of gas—perhaps a greater supply from volcanic plumes, which are also more abundant on the antiJovian hemisphere, or perhaps more abundant or warmer frost deposits. This spatial variability might similarly imply that temporal variability can occur too.

Aeolian transport in such a tenuous atmosphere seems unlikely. However, the 'atmosphere' in the immediate vicinity of volcanic plumes might be substantially thicker, and while particle transport here may severely stretch the definition of 'aeolian', it cannot be ruled out entirely and is instructive to consider.

Figure 15.2 shows sulphur dioxide frost that appears to have jetted horizontally (perhaps from a frost deposit overrun by silicate lava) that highlights the rippled texture of the ground. This rippled texture may simply be tectonic, but the possibility of aeolian deposits cannot be ruled out. The ridge spacing is 100−200 m: it seems possible to contrive scenarios (using the drag length or saltation path arguments discussed in Chaps. 4 and 5) wherein such wavelengths are consistent with particle movement in a thin atmosphere.

Future missions to Io are being considered in NASA's planning, although would not arrive until the mid 2020s at the earliest. We may hope that such missions have the capability to explore these features in more detail.