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Indurated sand dunes of the Martian North Polar Region

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Martian eolian dunes exhibit very little evidence for sand movement under present conditions. For example, small barchan dunes that should have been expected to move a few to tens of meters over the past 5–15 Mars years do not exhibit evidence for movement [Edgett and Malin, 2000; Malin and Edgett, 2001; Edgett, 2002]. Viking, Mars Pathfinder, and Mars Exploration Rover sites exhibit abundant evidence for crusted/indurated fines [e.g., Arvidson et al. 1989; Arvidson et al. 2004]. It is therefore possible that sand transport is somewhat inhibited on Mars today, owing to induration of dune sediment. Geomorphic evidence for induration of Martian eolian dunes is abundant in high resolution images acquired from orbit in recent years by Mars Global Surveyor, Mars Odyssey, and Mars Express. In Herschel and neighboring craters, and in Nili Patera of Syrtis Major, barchan dunes are elongated relative to typical terrestrial counterparts, and have suites of ridges and grooves eroded into them [e.g., Edgett and Malin, 2000]. The ridges and grooves are yardangs; these low-latitude dunes are indurated and have been eroded by wind. Induration of eolian sands also explains the steep walls of avalanche scars on the slip faces of mid-latitude dunes in Noachis Terra (e.g., in Kaiser, Rabe, and Russell craters) [Malin and Edgett, 2001], the flattening and exposure of layered sands among dunes at high southern latitude, and, we propose here, the elongation of barchans and apparent elongation and merging of individual barchans to form linear dunes in the Martian north polar region.

In the Martian north polar region, particularly within the broad trough, Chasma Boreale, there occurs a suite of low albedo, barchan and linear dunes with rather unusual morphology (particularly between 83°–85°N, 14°–42°W). In this region, the suite of barchan dunes includes many that have evolved to an elliptical, domelike form.

Among these, slip faces are commonly very small or non-existent. These dunes occur among (i.e., within tens of meters of) linear dunes of moderately meandering form (as opposed to their more sinuous counterparts on Earth). The majority of the linear dunes appear to be the product of coalescence of aligned barchan dunes; upwind of some of the linear dunes are additional aligned barchans.

Terrestrial linear dunes are the products of a predominately bidirectional wind regime, while barchans form in unidirectional winds. To see the two forms together, and to see evidence that the linear dunes formed by coalescence of aligned barchans, suggests that the dominant winds in this region are unidirectional, but there must be some bi- or multi-directional influence (perhaps the product of local topographic setting, within the Chasma Boreale trough) that causes the barchans to become aligned and coalesce into linear forms. Groove marks on the ground parallel to the linear dunes indicate that erosion by strong winds in this direction plays a part. The importance of the dominant winds is further corroborated by computer simulations which show that linear dunes are unstable under parallel winds and reproduce humps observed in linear dunes on Mars.

The evidence that these two forms of Martian eolian dune required induration to achieve their present morphology comes from a combination of terrestrial field evidence and computer modeling. While the dunes are indurated, possibly by CO_2, H_2O, or mineral salts, it is believed that sand transport can still take place. This would especially be true if the pore-filling agent of induration is water or carbon dioxide ice, and seasonal sublimation of ice in the upper few millimeters of the dune permit remobilization of sand. The rounded, elliptical barchans observed in Chasma Boreale resemble field experiments of barchan stabilization done during the 1940s and early 1950s on Earth; in Saudi Arabia, wandering barchan dunes were repeatedly sprayed with oil to halt their downwind advance [Kerr and Nigra, 1952]. Additional sand blew in from upwind of these dunes, was transported over each dune, and deposited on their lee sides. Over time, the slip face in the lee of each dune became successively smaller, and the dune more rounded and elliptical, as more sand was deposited. This led to streamlined forms that look very similar to the rounded dunes on Mars. On Mars, instead of oil, ordinary, crescent-shaped barchans have become frozen or cemented by mineral salts, and additional new sand has been transported into the system, become indurated, then more sand is added, indurated, and so forth, leading to the rounded barchan forms with small slip faces. Eventually, with additional sand, the slip face can disappear and the dune has an elliptical, dome shape.

We have modeled this process in three dimensions using a computer code. It is based on a detailed microscopic model of saltation sand transport [Sauermann et al. 2001]. The ground shear stress of the air flow over a dune is computed according to Weng et al. [1991]. The sand flux, the amount of sand being transported per time and space interval, is calculated from the shear stress according to the saltation model. Then steep slopes are relaxed by avalanches before the cycle is repeated. On indurated dunes, the requirement that there can be no erosion is imposed. With this simulation model we obtain dune morphologies similar to those observed on Mars and in the oil-soaked Saudi Arabia examples [Kerr and Nigra, 1952].

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