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Review Article

# Recent developments in planetary Aeolian studies and their terrestrial analogs

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ABSTRACT

This report summarizes the many advances that have been made in the study of planetary Aeolian processes that have taken place since the first Planetary Dunes Workshop was held in May of 2008, through 2011. Many of the recent studies are facilitated by the wealth and variety of high resolution imaging and spectra data still being returned by multiple spacecraft in orbit and on the surface of Mars, as well as Cassini radar and imaging data for the unique linear dunes on Titan, the large moon of Saturn. The report is divided into seven broad topics: exploring the Martian rock record, the action of the wind, sediment composition, sediment transport, Aeolian bedforms, modification processes, and Titan. Analog studies of terrestrial landforms and processes continue to improve our understanding of the operation of Aeolian processes on other planetary surfaces in each of these topics. Four subjects are likely to see increased emphasis during the coming years: Martian aeolianites, sand compositional diversity, active versus inactive features, and deposition versus erosion. Continued growth of the planetary Aeolian literature is expected as several spacecraft continue to provide high-quality data, including the successful arrival of the Curiosity rover at Mars in August of 2012.

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## 1. Introduction

Aeolian studies encompass a range of processes and landforms that are the result of the interaction between the wind and the rocks or soils that comprise the surface materials. The work of the wind on the surface is primarily accomplished through the motion of loose particles induced by the wind flow over them (e.g., Bagnold, 1941; Greeley and Iversen, 1985; Lancaster, 1995), although some would argue that wind alone is capable of producing geomorphic work (e.g., Whitney, 1978). Distinctive landforms result from various Aeolian processes, including (but certainly not limited to) sand ripples, various types and shapes of sand dunes, yardangs (bedrock materials eroded into a myriad of shapes), ventifacts (rocks abraded by the wind and sand), loess (dust deposits), sand sheets, and certain gravel plains. If loose particles and wind sufficient to move them is readily available, Aeolian activity is not restricted to only the surface of the Earth. Robotic spacecraft missions to the planets have revealed how prevalent Aeolian deposits and landforms are on practically any solid planetary surface possessing an atmosphere, and in particular a host of recent spacecraft have examined the Martian surface in unprecedented detail, leading to new documentation of many Aeolian features across the Red Planet. Supplementary to these wonderful new data sets from the planets, an improved understanding of the details associated with how certain Aeolian features form and evolve often requires careful observation and instrumentation of terrestrial analogs for features observed on other planets. The purpose of this report is to provide a brief review of recent developments in Aeolian studies of planetary bodies, along with recent studies of analog sites for some planetary landforms and deposits.

Studies of Aeolian processes throughout the solar system have benefited greatly from two recent NASA-supported workshops devoted to this subject. The first Planetary Dunes Workshop was held in Alamagordo, New Mexico, during May of 2008, where about 50 participants presented research results and also took part in a one-day field excursion to nearby White Sands National Monument (Titus et al., 2008a,b). Participants included roughly equal numbers of researchers focused either on the study of planetary Aeolian features or investigations of diverse planetary Aeolian environments; the synergistic interchange between these groups resulted in the identification of several specific subject areas needing further study in the future (Titus et al., 2008b). This first workshop resulted in publication of a special issue of *Geomorphology* (September, 2010) containing nine papers dealing with a wide range of Aeolian topics, including a paper that served both as an introduction to the special issue and as a review of planetary Aeolian studies up to the time of the first workshop (Bourke et al., 2010). The Second Planetary Dunes Workshop was held in Alamosa, Colorado, during May of 2010, where about 60 participants from both the planetary and terrestrial Aeolian communities presented results and took part in a one-day field excursion to nearby Great Sand Dunes National Park and Preserve (Titus et al., 2010; Fenton et al., 2010). Plans are in place for a special issue of *Earth Surface Processes and Landforms* to publish papers built around work presented at the second workshop. The present report is restricted to a discussion of various published results that came after the first workshop, through all of 2011 (with only sparing citation of later work that bears directly upon the results being discussed). Readers are referred to Bourke et al. (2010) for treatment of results prior to and including the first workshop, and to Greeley and Iversen (1985), Lancaster (1995, 2009) for more in-depth discussion of a host of earlier Aeolian studies.

This review is divided into seven broad topics or themes: exploring the Martian rock record, the action of the wind, sediment composition (including possible sources), sediment transport, Aeolian bedforms, modification processes (particularly gullies on dunes), and Titan. The first six topics are dominated by results derived from the new data from Mars, but the seventh topic indicates that the on-going Cassini mission continues to reveal surprises about the intriguing but perplexing dunes on Titan. Venus is not mentioned here because most of the Aeolian studies for this planet resulted from the Magellan mission in the early 1990s, as reviewed in Bourke et al. (2010), and there are no major revisions at present to the Magellan conclusions. Relevant terrestrial analog studies are covered under each topic that is most closely associated with the reported results, emphasizing terrestrial projects that have a particularly strong potential as analogs for the interpretation of planetary Aeolian features. However, the reader should be cognizant that this report is not intended to represent a thorough review of recent terrestrial Aeolian studies; see Livingstone et al. (2007) for an excellent review of recent studies of terrestrial dunes.

## 2. Exploring the Martian rock record

There is considerable evidence that the rock record on Mars includes many examples of sedimentary (layered) deposits (e.g., Malin and Edgett, 2000), some of which are more likely the result of transportation by the wind as opposed to deposition out of water. Perhaps the most dramatic evidence of massive wind-driven sandstones comes from the Opportunity rover's explorations in the Meridiani Planum region of Mars. In particular, exposures in Victoria crater reveal dramatic examples of cross-bedded sandstones (Fig. 1) that are at least a dozen meters in thickness (Squyres et al., 2009; Hayes et al., 2011), greatly expanding the stratigraphic thickness of the Aeolian sandstones seen earlier in Endurance crater (Grotzinger et al., 2005). Opportunity also found evidence of dunes with a strong sulfate signature (perhaps more the result of pore-filling materials than of the sand itself), with wet interdune areas, during exploration of Erebus crater (Metz et al., 2009). Hematite concretions within the sulfate-bearing sandstones are interpreted to indicate that a considerable flow of groundwater took place through the sandstones following their emplacement (Squyres et al., 2004a). Orbital data are providing evidence that the discoveries made by Opportunity likely represent large portions of Meridiani Planum (Hynek and Phillips, 2008). Sedimentary rocks derived from wind-blown sands thus appear to represent a