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# Precision topography of a reversing sand dune at Bruneau Dunes, Idaho, as an analog for Transverse Aeolian Ridges on Mars

James R. Zimbelman *, Stephen P. Scheidt

*Center for Earth and Planetary Studies, National Air and Space Museum, MRC 315, Smithsonian Institution, Washington, DC 20013-7012, USA*

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ABSTRACT

Ten high precision topographic profiles across a reversing dune were created from a differential global position system (DGPS). The shapes of the profiles reveal a progression from immature to transitional to mature characteristics moving up the dune. When scaled by the basal width along each profile, shape characteristics can be compared for profiles whose horizontal scales differ by orders of magnitude. The comparison of width-scaled Bruneau Dunes profiles to similarly scaled profiles of Transverse Aeolian Ridges (TARs) on Mars indicates that many TARs are likely similar to transitional or mature reversing sand dunes.

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## 1. Introduction

A reversing sand dune is defined to be "a dune that tends to develop unusual height but migrates only a limited distance because seasonal shifts in direction of the dominant wind cause it to move alternately in nearly opposite directions" (Jackson, 1997, p. 545). The seasonal wind pattern is therefore bidirectional for reversing dunes, where the two dominant winds from nearly opposite directions are balanced with respect to strength and duration (McKee, 1979). The Bruneau Dunes in central Idaho are an excellent place to conduct a study of reversing sand dunes because here the dunes have grown to impressive heights in a wind regime that supports the development of reversing dunes rather than horizontally migrating dunes. The dunes are protected from off-road vehicular traffic because the main dune complex is located within the boundaries of the Bruneau Dunes State Park (Zimbelman and Williams, 2007). The Bruneau Dunes are a 1.5-h drive SE from Boise, and they are only 29 km (18 mi) south of the city of Mountain Home.

Recent data from Mars has stimulated interest in the collection of detailed topographic information about reversing dunes. The High Resolution Imaging Science Experiment (HiRISE) camera on the Mars Reconnaissance Orbiter spacecraft has returned over 20,000 images that reveal the martian surface in exquisite detail, with many of the images achieving a ground spatial resolution of 25 cm per pixel (McEwen et al., 2007). Early HiRISE images included some dramatic examples of aeolian bedforms that have been given the non-genetic name 'Transverse Aeolian Ridges' (TARs), a general term proposed for linear to curvilinear aeolian features that could be the result of either dune or ripple formation processes (Bourke et al., 2003). Profiles derived from photoclinometry of TARs in HiRISE images showed that TARs larger than 1 m in height compared favorably to profiles of reversing dunes at Coral Pink Sand Dunes State Park in southern Utah, while TARs less than 0.5 m in height were very distinct from the reversing dune profiles but consistent with measured profiles of megaripples (Zimbelman, 2010).

In order to provide a test of the reversing dune hypothesis for large TARs on Mars, we collected a series of precision topographic profiles across one of the large reversing dunes at the Bruneau Dunes, as first reported at the Third Planetary Dunes workshop (Zimbelman and Scheidt, 2012). The resulting profiles provide valuable new information about probable stages of formation encountered during the growth of reversing dunes, as well as a possible tool for evaluating the relative state of evolution of reversing dunes. The profile series provides a template for evaluating the possible stages of evolution of individual TARs on Mars, under the working hypothesis that large TARs have profile shapes comparable to that of reversing dunes.

## 2. Background

The Bruneau Dunes State Park was formed in order to preserve a very unique natural area, as well as provide protection for the wildlife that make use of two lakes on the northwest side of the dunes (inset, Fig. 1). Established in 1970, the park covers 19.4 $km^2$ (4800 acres), including the tallest single-structured (i.e., not braced against other dunes or mountains) sand dune in North

* Corresponding author. Fax: +1 202 786 2566.
*E-mail addresses:* zimbelmanj@si.edu (J.R. Zimbelman), sscheidt77@gmail.com (S.P. Scheidt).

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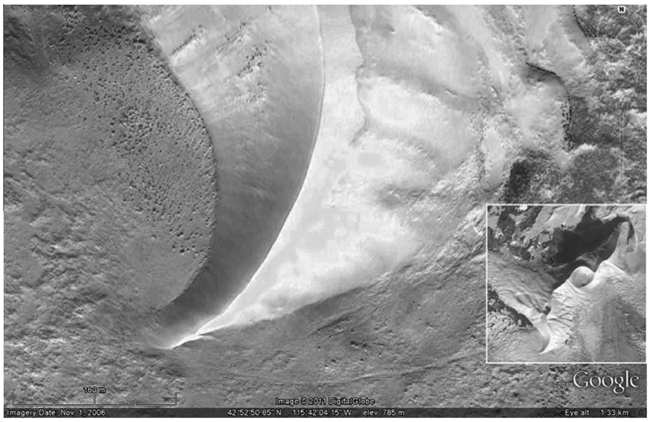


**Fig. 1.** Google Earth image mosaic of the study location at the southern end of the Bruneau Dunes, Idaho (11/1/06). North is to the top. Inset shows all of the largest dunes, and the lakes at their northern end.

America, which has 143 m (470 ft) of relief from the summit of the tallest dune to the lake level (for information about the park, see parksandrecreation.idaho.gov/parks/bruneau-dunes or www.idahoparks.org/state-parks/bruneau-dunes-state-park). The largest dunes are interpreted to be reversing dunes (Murphy, 1973), but features on the sides of the largest dunes suggest possible form flow interactions that can move sand in directions at large angles relative to the regional wind direction (Howard et al., 1978). There are some visual similarities between features observed on the Bruneau Dunes and patterns present on the arms of star dunes (e.g., Lancaster, 1989), where sand transport occurs oblique to crest orientation. The sheer size of the main Bruneau Dunes may induce complex local wind patterns on the sides of dunes.

The Bruneau Dunes are located approximately in the center of an old cut-off meander of the Snake River, now called Eagle Cove, that was carved into lacustrine sediments of the Glenns Ferry and Bruneau Formations, which are from Upper Pliocene to Middle Pleistocene (respectively) in age (Murphy, 1973). The close proximity of Eagle Cove to the present day channel of the Snake River contributes significantly to a constraint for the probable initiation of the sand accumulation represented by the current large sand dunes.

The Snake River is the main drainage pathway for water to exit the southern portions of Idaho. This large river has carved a substantial canyon into the basalt lava flows that comprise the surface materials of the Snake River Plains, the largest physiographic province within southern Idaho. There is abundant geologic evidence that the present day Snake River is but a mere shadow of the major flood that passed through this river system during the Pleistocene (Malde, 1968). Glacial Lake Bonneville attained a level that overtopped its rim at Red Rock Pass in southeastern Idaho, leading to rapid downcutting at the site of the breach and the rapid release of 4700 $km^3$ of water onto the Snake River Plains; erosional features and flood deposits along the Snake River Canyon indicate that the peak discharge during this catastrophic flood was most likely $\sim$935,000 $m^3/s$, so that a minimum duration of about 8 weeks was needed to move the total volume of released water through the canyon at the peak discharge rate (Jarrett and Malde, 1987; O'Connor, 1993). The massive Bonneville Flood occurred about 15,000 years ago (Jarrett and Malde, 1987), and it is presumed that the flood would have easily removed any aeolian sand deposits from Eagle Cove that pre-dated the flood (Murphy, 1973). The sand at the Bruneau Dunes consists (by volume) of 62% quartz, 26% feldspar, and 12% basaltic (iron-rich) particles, indicating a closer affinity to the nearby Bruneau and Glenns Ferry Formation sediments than to the basalts and other rocks exposed upstream of Eagle Cove (Murphy, 1973). Aeolian or fluvial activity would not have needed to transport the sand very far to get it into Eagle Cove. However, once sand got into Eagle Cove, the wind pattern is such that it likely could not have easily exited later.

Reversing sand dunes form under a bidirectional wind regime, where two dominant winds come from directions that are almost directly opposite of each other (McKee, 1979). The Remote Automated Weather Station (RAWS) system, operated by the U.S. government, has >1900 individual instrumented weather stations (as of 2002) spread throughout the conterminous United States, Alaska, and Hawaii (Zachariassen et al., 2003, p. 2). The Mountain Home Air Force Base (MHAFB) RAWS station is located about 21 km NW of the Bruneau Dunes. Using a web-based access page, we obtained MHAFB RAWS data from 2010, which clearly demonstrates a strong bimodal annual wind regime for the region, although minor winds can blow from a variety of directions during spring and fall (Fig. 2). It is justifiable to ask whether wind records obtained 21 km away from the study site reflect the wind conditions experienced at the dunes. We attempted to address this issue by installing an inexpensive weather-proof timelapse digital camera (known commercially as a 'GardenWatchCam') to obtain hourly images of the study site at the Bruneau Dunes. Use of timelapse digital cameras has proved to be a cost-effective method for monitoring sand mobility in previous aeolian studies (Lorenz, 2011; Lorenz and Valdez, 2011). During more than 2 years of GardenWatchCam monitoring of the study site (from April 27, 2011, through August 31, 2013), images of bidirectional intense saltation occurring at the south end of the dunes (Figs. 3 and 4) correlate very well with strong wind events (taken here to be >6 m/s average winds sustained for >3 h) recorded at the MHAFB RAWS site, providing on-site validation that the bimodal wind pattern that dominates the RAWS data (Fig. 2) is consistent with the major sand-driving events observed to take place at the dunes.

In order to obtain precise topographic profiles of the sand dunes, we utilized a Differential Global Positioning System (DGPS). The equipment used in this project was a Trimble R8 Total Station, a carrier-phase DGPS system consisting of a stationary base receiver and a roving receiver to collect the individual survey points; this system provides horizontal accuracy of 1–2 cm and vertical accuracy of 2–4 cm, relative to the base station location (Zimbelman and Johnston, 2001). When combined with field notes and photographs tied to survey point locations, DGPS topographic data have proved to be very useful in addressing diverse geomorphic topics (e.g., Zimbelman and Johnston, 2001; Irwin and Zimbelman, 2012; Zimbelman et al., 2012). Precise topographic profiles across aeolian depositional features at diverse scales has proved to be very helpful in distinguishing between alternative formation mechanisms that have acted to generate the features (Zimbelman et al., 2012).

Topographic information for TARs on Mars have recently been derived from HiRISE image data (Zimbelman, 2010; Shockey and Zimbelman, 2013), generating profiles that can be compared to the measured profiles of aeolian features on Earth (Zimbelman et al., 2012). The study project at the Bruneau Dunes was carried out specifically in order to obtain a well constrained topographic data set for a reversing sand dune, to serve as a guide for evaluating the hypothesis that TARs > 1 m in height are most similar to reversing dunes (Zimbelman, 2010).

## 3. Methodology

The DGPS surveys were carried out across the southernmost reversing dune at the Bruneau Dunes (Fig. 1). This location was chosen for the study because this dune progresses steadily from a low sand ridge into a large reversing dune (going north),