Earth and Planetary Science Letters 289 (2010) 30–42

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Investigation of the age and migration of reversing dunes in Antarctica using GPR and OSL, with implications for GPR on Mars

C.S. Bristow [a,c,*], P.C. Augustinus [b], I.C. Wallis [b], H.M. Jol [b,c], E.J. Rhodes [d]

[a] School of Earth Sciences, Birkbeck College, University of London, Malet Street, London WC1E 7HX, UK
[b] School of Geography, Geology and Environmental Science, The University of Auckland, Private Bag 92019, Auckland, New Zealand
[c] Department of Geography and Anthropology, University of Wisconsin-Eau Claire, 105 Garfield Avenue, Eau Claire, WI 54702-4004, USA
[d] Department of Environmental and Geographical Sciences, Manchester Metropolitan University, Chester Street, Manchester, M1 5GD, UK

ARTICLE INFO

Article history:
Received 19 June 2009
Received in revised form 7 October 2009
Accepted 17 October 2009
Available online 26 November 2009

Editor: T. Spohn

Keywords:
seasonal
climate
reworking
topographic steering
Mars analogue

ABSTRACT

GPR provides high resolution images of aeolian strata in frozen sand in the McMurdo Dry Valleys of Antarctica. The results have positive implications for potential GPR surveys of aeolian strata on Mars. Within the Lower Victoria Valley, seasonal changes in climate and a topographically-constrained wind regime result in significant wind reversals. As a consequence, dunes show reversing crest-lines and flattened dune crests. Ground-penetrating radar (GPR) surveys of the dunes reveal sets of cross-strata and low-angle bounding surfaces produced by reversing winds. Summer sand transport appears to be dominant and this is attributed to the seasonal increase in solar radiation. Solar radiation which heats the valley floor melts ice cements making sand available for transport. At the same time, solar heating of the valley floor generates easterly winds that transport the sand, contributing to the resultant westward dune migration. The location of the dune field along the northern edge of the Lower Victoria Valley provides some shelter from the powerful föehn and katabatic winds that sweep down the valley. Topographic steering of the winds along the valley and drag against the valley wall has probably aided the formation, migration and preservation of the dune field. Optically-stimulated luminescence (OSL) ages from dune deposits range from 0 to 1.3 kyr showing that the dune field has been present for at least 1000 yr. The OSL ages are used to calculate end-point migration rates of 0.05 to 1.3 m/yr, which are lower than migration rates reported from recent surveys of the Packard dunes and lower than similar-sized dunes in low-latitude deserts. The relatively low rates of migration are attributed to a combination of dune crest reversal under a bimodal wind regime and ice cement that reduces dune deflation and restricts sand entrainment.

1. Introduction

Antarctica is the coldest, driest and windiest continent on Earth. In the areas free of snow and ice, liquid water only flows in streams for around two months each year during the austral summer. However, winds blow throughout the year so that aeolian sediment transport is probably more important than fluvial transport. This is most evident in the Victoria Valley, one of the McMurdo Dry Valleys of Antarctica (Fig. 1), where there is a variety of types of sand dunes including transverse, barchanoid, and whaleback dunes, in addition to proto-dunes, embryonic dunes, sand-sheets and sand-ramps (Lindsay, 1973; Calkin and Rutford, 1974; Selby et al., 1974; Miotke, 1985; Bourke et al., 2009; Bristow et al., 2009). In this paper we focus on the Packard dunefield, which is located along the northern margin of the Lower Victoria Valley beneath the Packard Glacier (Fig. 1). The Lower Victoria Valley is around 15 km long and trends east to west. At its eastern end lies the Victoria Lower Glacier and at its western end is Lake Vida. The valley slopes from east to west from the toe of the Victoria Lower Glacier at around 400 m to Lake Vida at 350 m elevation above sea level (ASL). The valley walls are steep and rise to elevations of between 1000 and 1500 m ASL.

The first published report of the Victoria Valley dunefield was part of a wider investigation of the regional geology by Webb and McKelvey (1959), who described the dunes as barchan and longitudinal types formed under the influence of east–west winds. Research interest in the Victoria Valley dunes was stimulated in the early 1970's when the dunes were investigated by Morris et al. (1972a,b) as part of a geomorphological study that aimed to collect data for visual comparison with images expected from the Viking Mars Mission which was launched in1975, arriving at Mars in 1976. Further geomorphic and sedimentary studies of the dunes were undertaken by Lindsay (1973); Calkin and Rutford (1974); Selby et al. (1974); Miotke (1985); Speirs et al. (2008) and Bourke et al. (2009).

The dunes in the Victoria Valley are potential analogues for dunes on Mars because the low temperatures and high aridity are analogous to the surface conditions on Mars where a variety of dune forms have

* Corresponding author.
E-mail address: c.bristow@ucl.ac.uk (C.S. Bristow).

0012-821X/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsl.2009.10.026

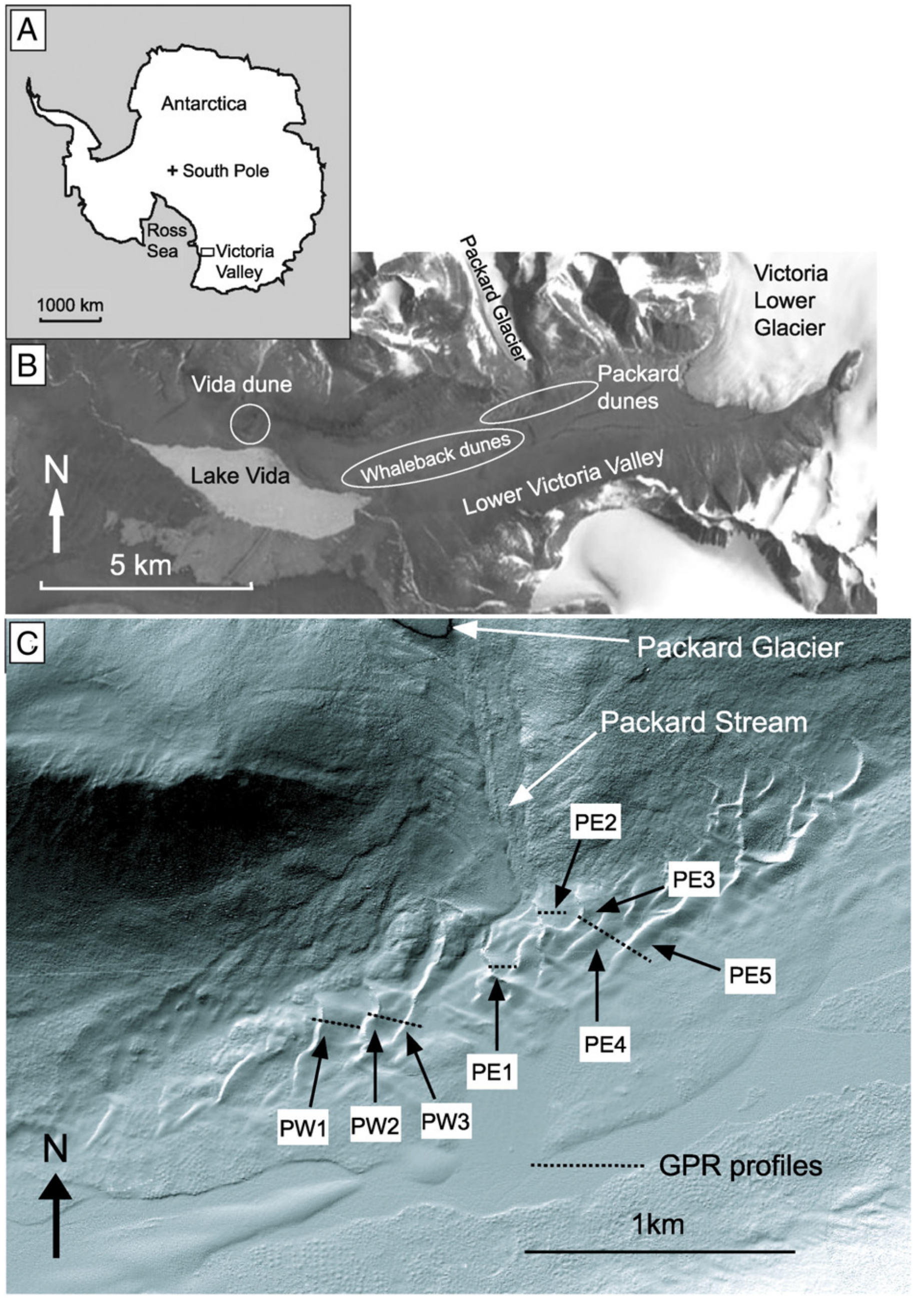

Fig. 1. A) Map of Antarctica showing location of the McMurdo Dry Valleys. B) Satellite image of the Lower Victoria Valley showing the dunefields. C) LiDAR image of the Packard dune field in the Lower Victoria Valley showing the location of the GPR profiles across the dunes that are described in this paper. The dunes described are labelled PW1–3 for those west of the Packard stream and PE1–5 to the east of the Packard stream.

been observed (Malin et al., 1998; Hayward et al., 2007) including reversing transverse dunes and barchanoid dunes with reversing crest-lines (Fenton et al., 2005). The success of the Mars Exploration Rovers, Spirit and Opportunity, and high resolution images of the Martian surface have created renewed interest in the geology and surface processes operating on Mars (e.g.; Squyres et al., 2004a,b; Grotzinger et al., 2005). The European Space Agency (ESA) ExoMars mission planned for launch in 2013 will include a rover which will carry ground-penetrating radar (GPR) as part of the Pasteur payload. The WISDOM (Water Ice and Subsurface Deposit Observation on Mars) instrument will be the first space borne GPR on a rover (Plettemeier et al., 2009). The WISDOM experiment plans to characterise the soils on Mars and then map their variability such as alluvial or aeolian layering (Ciarletti et al., 2009). GPR has previously been deployed within the McMurdo Dry Valleys for Mars analogue studies (Arcone et al., 2002), and in this paper we present a detailed analysis of aeolian strata of sand dunes in the Lower Victoria Valley imaged by GPR.

The Victoria Valley dunes are also potential analogues for the extensive mid-latitude periglacial aeolian deposits of the Northern Hemisphere (e.g. Koster, 1988; Seppälä, 2004). Although cold climate dunes are now recognised in many parts of the northern hemisphere (Good and Bryant, 1985; McKenna-Neuman and Gilbert, 1986; Koster, 1988; Koster and Dijkmans, 1988; Dijkmans, 1990; Mann et al., 2002; Mountney and Russell, 2004; Bateman and Murton, 2006) their structures remain poorly documented. This may be due in part to the presence of permafrost which prevents excavation of trenches. However, ice is no barrier to GPR and the structure of cold climate dunes can be successfully imaged using this approach, as we demonstrate in this paper.