

SAND ON MARS: RECENT VOLCANICLASTIC SAND DUNES ON EARTH AS COMPOSITIONAL ANALOGS TO THE WIND-BLOWN SANDS OF MARS

Kenneth S. Edgett[†], Nicholas Lancaster^{*}, and Philip R. Christensen[†]

[†]: Department of Geology, Arizona State University, Tempe, AZ 85287

^{*}: Quaternary Sciences Center, Desert Research Institute, P.O. Box 60220, Reno, NV 89506

The prevalence of a particular mineral as a sand-forming material is dependent upon the abundance of the material in the source rock, the rate at which the material is formed, and the rate at which the material is destroyed by mechanical and chemical weathering. For these reasons, most aeolian dune sands on Earth are composed mainly of quartz [1-3]. Other commonly recognized dune sands are composed of evaporites [4,5], carbonates [6], or clay aggregates [7]. Still other dune sands are volcaniclastic in origin, but very few papers have been written which specifically address these dunes. Volcaniclastic dunes are of interest because: (1) they may be compositional analogs to martian dune sands, and (2) their physical characteristics might help to establish criteria by which to distinguish cross-bedded sediments formed by primary igneous processes (such as base surge) from secondary aeolian reworking of pyroclastic deposits, as discussed by Smith and Katzman [8]. Here, we discuss the martian dune case and describe terrestrial examples of dunes with $\geq 50\%$ volcaniclastic materials. The terms volcaniclastic, epiclastic, and pyroclastic are used as defined by Fisher and others [9-12].

Martian Aeolian Sands. Dunes are seen in a wide variety of locations on Mars [e.g. 13-16]. The composition of martian dune sands presently remains unknown, but several lines of evidence suggest that many might consist of mafic minerals and rock fragments [17,18]. Quartz sands are not likely on Mars because magmas probably never became differentiated enough to produce large amounts of quartz [19,20]. The *Viking* lander samples had low K_2O and Al_2O_3 abundances, indicating mafic rather than granitic parent materials for soils present in those regions [21]. Spectral reflectance results indicate the presence of an Fe^{2+} absorption band near $1\ \mu m$ (indicative of pyroxenes, olivines) for dark, sandy areas like Syrtis Major [22], and preliminary examinations of IRTM-derived mid-infrared emissivity results also suggest mafic sands on Mars [23]. In addition, all of the dunes seen so far on Mars tend to have a low albedo, suggestive of dark-colored materials like mafic or opaque minerals. Geissler *et al.* [24] identified one possible volcaniclastic dune field on the floor of Valles Marineris, proposed to consist of mafic, glassy pyroclasts. Other volcaniclastic sands might include the probable mafic sands on the volcanic shield, Syrtis Major [25].

Terrestrial Volcaniclastic Dunes. Our examination of terrestrial volcaniclastic dunes has included an extensive literature search (only the major references are given herein) and preliminary field examination of the North American examples. Dunes composed largely of basaltic sands are found in Iceland [26,27], Hawaii [28], east of the San Francisco volcanic field, Arizona [29,30], near Moses Lake, Washington [31], Peru [32,33], and the west coast of the North Island, New Zealand [e.g. 34-36]. Volcaniclastic dunes of other compositions occur in a variety of locations, including the Great Sand Dunes of Colorado [37], various dunes in S.E. Oregon [38-40], dune-forms near Mono Lake, California [41], Isla San Benedicto, Mexico [42], Viti Levu, Fiji [43], and New Zealand [e.g. 34,36,44].

Terrestrial volcaniclastic dunes have a variety of origins and occur in several different environments. Most of them are found in inland, arid regions, but coastal volcaniclastic dunes occur in New Zealand, Fiji, and other volcanic islands. Some of the sands are pyroclastic in origin. For example, much of the dune sands in S.E. Oregon are pumice and feldspar, and the dunes in Arizona and Hawaii (Ka'u Desert) are composed of basaltic ash. Other volcaniclastic aeolian sands are epiclastic in origin (eroded from lavas), such as the basaltic sands in the Quincy Basin, Washington, and the Great Sand Dunes, Colorado (which contain $> 51\%$ San Juan volcanic rock fragments). The dunes are generally composed of sands previously deposited by some other means. In some cases, a pyroclastic deposit has been directly reworked by the wind (and minor fluvial run-off); this may have occurred in the case of the ash dunes in Arizona and Hawaii, and it is the proposed mechanism by which cross-bedded pumice

VOLCANICLASTIC SAND DUNES: K.S. Edgett, N. Lancaster, and P.R. Christensen

sands investigated by Smith and Katzman [8] were deposited. Lake sediments are another source for volcanoclastic dune sands; for example, the dunes in the Quincy Basin, Washington, formed from reworking of epiclastic sands deposited by the Spokane floods [e.g. 31, 45]; and the feldspar-pumice dunes of S.E. Oregon formed from the reworking of Pleistocene lake bed sediments of both pyroclastic and epiclastic volcanic origins [39]. Finally, some volcanoclastic dune sands are reworked beach deposits, as in New Zealand, where wave and wind action have formed concentrated deposits of volcanically-derived titanomagnetite and mafic mineral sands.

Summary. Volcanoclastic sands and dunes probably occur on Mars, as volcanic deposits are common there [e.g. 46], and the mineralogic compositions inferred for martian aeolian sands are consistent with the presence of mafic materials, much of which could have come from the erosion of volcanic deposits. Terrestrial volcanoclastic dunes are probably the best compositional analog to martian dunes, because they commonly contain the types of unstable, mafic minerals and feldspars that might occur in martian sands. Terrestrial volcanoclastic dune sands have a variety of compositions, origins, and geologic settings.

Further work on this subject will include field and remote sensing studies of the North American volcanoclastic dunes. Preliminary results include: (a) identification of a Mount St. Helens 1980 ash layer in the Quincy Basin, Washington dunes, (b) identification of basalt fragments (previously not documented) in the S.E. Oregon dunes, and (c) observations of pumice and obsidian dunes near Mono Lake, California. The authors would appreciate correspondence and comments from others who can provide further details on the composition of volcanoclastic dunes outside of North America, especially for dune areas we may have missed in our literature review.

References. [1] Bagnold, R.A. (1941) *The Physics of Blown Sand and Desert Dunes*, Methuen, London, 265p. [2] McKee, E.D., ed. (1979) *A Study of Global Sand Seas*, U.S. Geol. Surv. Prof. Paper 1052, 429p. [3] Greeley, R. and J.D. Iversen (1985) *Wind as a Geologic Process*, Cambridge Univ. Press, 333 p. [4] McKee, E.D. (1966) *Sedimentology* 7, 1-68. [5] Jones, D.J. (1953) *Amer. Assoc. Petrol. Geol. Bull.* 37, 2530-2538. [6] McKee, E.D. and W.C. Ward (1983) in *Carbonate Depositional Environments*, *Amer. Assoc. Petrol. Geol. Mem.* 33, 131-170. [7] Bowler, J.M. (1973) *Earth Sci. Rev.* 9, 315-338. [8] Smith, G.A. and D. Katzman (1990) Discrimination of eolian and pyroclastic surge processes in the generation of cross-bedded tuffs, Jemez Mountains volcanic field, New Mexico; submitted to *Geology*. [9] Fisher, R.V. (1961) *Geol. Soc. Amer. Bull.* 72, 1409-1414. [10] Fisher, R.V. (1966) *Earth Sci. Rev.* 1, 287-298. [11] Fisher, R.V. and H.V. Schminke (1984) *Pyroclastic Rocks*, Springer-Verlag, 472p. [12] Smith, G.A. and W.J. Fritz (1989) *Geology* 17, 375-376. [13] Cutts, J.A. et al. (1976) *Science* 194, 1329-1337. [14] Cutts, J.A. and R.S.U. Smith (1973) *J. Geophys. Res.* 78, 4139-4154. [15] Breed, C.S. (1977) *Icarus* 30, 326-240. [16] Zimbelman, J.R. (1987) *Icarus* 71, 257-267. [17] Smalley, I.J. and D.H. Krinsley (1979) *Icarus* 40, 276-288. [18] Baird, A.K. and B.C. Clarke (1981) *Icarus* 45, 113-123. [19] McGetchin, T.R. and J.R. Smith (1978) *Icarus* 34, 512-536. [20] Francis, P.W. and C.A. Wood (1982) *J. Geophys. Res.* 87, 9881-9889. [21] Toulmin, P. et al. (1977) *J. Geophys. Res.* 82, 4625-4634. [22] Singer, R.B. et al. (1979) *J. Geophys. Res.* 84, 8415-8426. [23] Edgett, K.S. and P.R. Christensen (1991) *Lunar Planet. Sci. XXII*, this volume. [24] Geissler, P.E. et al. (1990) *J. Geophys. Res.* 95, 14399-14413. [25] Schaber, G.G. (1982) *J. Geophys. Res.* 87, 9852-9866. [26] Cailleux, A. (1939) *Bull. Volcanol.* 2, 19-64. [27] Iwan, W. (1937) *Gesellsch. Erdkunde Berlin H5-6*, 177-194. [28] Gooding, J.L. (1982) *J. Geol.* 90, 97-108. [29] Colton, H.S. (1937) *Museum Northern Arizona Bull.* 10, 50p. [30] Cooley, M.E. et al. (1969) *U.S. Geol. Survey Prof. Paper* 521-A, 89p. [31] Petrone, A. (1970) *The Moses Lake Sand Dunes*, M.S. Thesis, Washington State University, Pullman, 89p. [32] Finkel, J. (1959) *J. Geol.* 67, 614-647. [33] Hastenrath, S.L. (1967) *Zeitschr. Geomorph.* 11, 300-331. [34] Cockayne, L. (1911) *Report on the dune areas of New Zealand*, Department of Lands, Wellington, 76p. [35] Fleming, C.A. (1953) *New Zealand Geol. Survey Bull.* 52, 362p. [36] Schofield, J.C. (1970) *New Zealand J. Geol. Geophys.* 13, 767-824. [37] Wiegand, J.P. (1977) *Dune morphology and sedimentology at Great Sand Dunes National Monument*, M.S. Thesis, Colorado State Univ., Fort Collins, 165p. [38] Dole, H.M. (1942) *Petrography of Quaternary lake sediments of northern Lake County, Oregon*, M.S. Thesis, Oregon State College, Corvallis, 98p. [39] Allison, I.S. (1966) *Fossil Lake, Oregon: Its Geology and Fossil Faunas*, Oregon State Univ. Press, Corvallis, 48p. [40] Walker, G.W. (1977) *U.S. Geol. Survey Misc. Inv. Map* I-902. [41] Bailey, R.B. (1989) *U.S. Geol. Survey Misc. Inv. Map* I-1933. [42] Richards, A.F. (1965) *Bull. Volcanol.* 28, 381-403. [43] Dickinson, W.R. (1968) *Sedimentary Geol.* 2, 115-124. [44] Cockayne, L. (1908) *Report on a botanical survey of the Tongariro National Park*, Department of Lands, Wellington, N.Z., 42p. [45] Baker, V.R. (1978) in Baker, V.R. and Nummedal, D., *The Channeled Scabland* (special NASA publ.), p. 17-35. [46] Greeley, R. and P. Spudis (1981) *Rev. Geophys. Space Phys.* 19, 13-41.