CHARACTERISTICS OF BASALTIC SEDIMENTS REVEAL DEPOSITIONAL AND TRANSPORT PROCESSES.

Robert A. Craddock[1], Tim Rose[2], Kathleen M. Marsaglia[3], Jon Cawley[1], and Alex Morgan[1] [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560 craddockb@si.edu; [2]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560; [3]Department of Geological Sciences, California State University, Northridge, CA 91330

Introduction: The physical and chemical characteristics of particles in sedimentary deposits can provide valuable clues about the provenance of the sediment, the processes responsible for sediment transport, and the distances the sediment has traveled [e.g., 1]. For example, a fundamental physical characteristic of a sediment is the shape of the particles, which is often diagnostic of transport process as well as the distance traveled. A number of studies have shown that it is possible to determine the transport history of sediments based entirely on the characteristics of quartz grains in a deposit. Another common physical analysis is grain-size sorting, which can be used in a general way to distinguish aeolian sediments (typically well-sorted) from fluvial sediments (typically poorly sorted in high energy environments). Chemically, the ratio of minerals contained in a deposit can also be useful. For example, because feldspar is more vulnerable to weathering than quartz, the ratio of these two minerals can also be used to assess the transport distance or "maturity," of a sedimentary deposit. Additionally, the componentry of a deposit has been used to help distinguish the provenance of the sediment [e.g., 2].

What we know about the nature of sedimentary materials is based primarily on sediments that have weathered from felsic rocks (e.g. granite). This is true because felsic materials compose most of the landmasses on the Earth. However, the surfaces of the terrestrial planets are composed predominately of mafic materials—basalt and sedimentary particles derived from basalt—that are much different than granitic detritus. Instead of quartz, feldspar, and nonlabile minerals commonly found in most terrestrial sedimentary deposits, basaltic sediments are typically composed of varying amounts of olivine, pyroxene, plagioclase, and vitric and lithic fragments [e.g., 3]. Both the persistence of basaltic particles and their characteristics are different than particles derived from granite. These differences are important because they will affect the nature of basaltic sediment as it is transported by wind, water, and ice, and currently we have little to no understanding as to how basaltic sediment will weather as a function of the transport mechanism and distance.

Research Goals: The goals of our research are to: 1) Determine the characteristics of pristine basaltic particles 62.5 μm to 64 μm in diameter (very fine sand to pebble size) created by a variety of geologic processes and identify the characteristics that are diagnostic of the formation process; and 2) Assess how different transport mechanisms, including wind, water and ice, affect those characteristics to see which (if any) characteristics are preserved after transport.

Sources of Sand on Mars: Primary processes for creating sand from felsic rock include chemical and physical weathering of coarser material. However, in situ chemical weathering is actually not a very good way to create sand from basaltic rock. Most basalt is aphanitic, so there are no sand-sized phenocrysts to weather out of a deposit. Instead, the glassy groundmass of the basalt weathers directly to clay minerals. Even porphyritic basalts (e.g., picritic flows) do not generate many loose sand grains when weathered [e.g., 3]. For example, phenocrysts of olivine or feldspar also weather into clay minerals, such as iddingsite or kaolinite, respectively, depending on environmental conditions. There must be other sources for the copious amounts of sand observed on the martian surface, which include several likely processes.

Magmatic eruptions are the most common eruptions on Earth and involve the decompression of volcanic gas that propels the magma forward. While basaltic magmatic eruptions are famous for their typical effusive nature, many effusive eruptions are often preceded by pyroclastic events, such as lava fountaining, due to the high amounts of volatiles contained in the fresh magma [e.g.,4]. Such events can produce large amounts of magmatic clasts consisting of cinders, scoria, pumice and other particles [4].

Phreatomagmatic eruptions result from the explosive thermal contraction of magma when it comes in contact with standing bodies of water, such as a lake or the ocean. Phreatomagmatic deposits consist of magmatic particles and accidental fragments of the surrounding country rock, which in the case of both Hawaii or Iceland is entirely basaltic [e.g., 5, 6]. Any magmatic particles that are produced typically have a lower vesicularity than similar particles resulting from purely magmatic eruptions [e.g.,7]. Phreatomagmatic deposits are also finer grained and better sorted than magmatic eruption deposits, containing large amounts of sand-sized material [e.g., 8]. An additional control on the morphology and characteristics of a phreatomagmatic deposit is the water to magma ratio. The deposits are fine grained and poorly sorted where the magma/water ratio is high, but when there is a lower magma/water ratio the deposits may be coarser and better sorted [8].

Phreatic eruptions are generated when magma heats ground or surface water. The extreme temperature of the magma [750° to over 1200°C at Kilauea; 9] causes near-instantaneous evaporation to of the water to steam, resulting in an explosion of steam, water, ash, and rock. There are no primary magmatic particles in the deposit.

Impact Cratering. On Earth, the greatest potential for creating basaltic sand is through interaction with water, which generates copious quantities of blocky, glassy particles [see 3 for a discussion]. In contrast, on Mars, the greatest potential may be fragmentation and melting of basalt flows by impacts.

Obviously, determining the provenance for any sand on the martian surface has implications for deconvolving the volatile and volcanic history on Mars. One of our ultimate goals is to determine whether it is possible to distinguish between the different potential sources of basaltic sand on Mars after transport.

Effects of Different Geologic Transport Processes: We conducted analyses of basaltic sediments transported by a variety of different geologic processes on the Big Island of Hawaii, including volcanic tephra, aeolian dunes, fluvial deposits, and glacial (Figure 1). In general, we found that lithic fragments can be particularly important for characterizing basaltic sediments because unlike olivine or vitric fragments, they always account for some size fraction of the deposit. They also bear some of the same physical characteristics to quartz grains, including hardness, specific gravity, and the way these grains fracture (Table 1).

Table 1. Comparison of quartz and basaltic fragments

Quartz	*Basalt*
Hardness = 7.0	Hardness = 6.0
Specific Gravity = 2.6	Specific Gravity = 2.8
Fractures Chonchodially	Fractures Chonchodially
Anisotropic	Isotropic

Aeolian sediments. The Ka‘ū Desert is ~350 km^2 in size and contains one of the largest basaltic dune fields on Earth [10]. The source of basaltic materials comes from periodic phreatic eruptions that Kīlauea has experienced over the last 2,000 years [11]. Collectively material from these eruptions has created the Keanakāko‘i Tephra deposit. This tephra was deposited in a series of eruptions that were close to the same scale and intensity each time [12]. The continuous Keanakāko‘i Tephra is located in an ~3-km swath around Kilauea’s central caldera, and transport distances can exceed 12-14 km. Samples from several different dune types located in various parts of the desert indicate that lithic fragments transported by aeolian processes become rounded quickly even over short transport distances of a few hundred meters to a couple of kilometers. It has also been noted that the percentage of olivine fragments tends to increase with increasing transport distances [13, 14], probably because the shape of olivine is typically elongated, making it easier to be lifted..

Fluvial sediments. The fluvial sediments that we examined were collected from a series of gullies and channels that have incised the Keanakāko‘i Tephra deposit [15] as well as in a number of empheral streams located on the western and southern side of the island. We observed that the sediment sizes of the particles often decrease rapidly, even over short transport distances (100s m). However, the particles generally maintained a sub-angular shape regardless of transport distances. Typically, the componentry increased in both lithic and clays with increasing distances.

Glacial sediments. The Makanaka Glacial Member is the youngest known glacial unit on Mauna Kea, and because it superposes the other glacial deposits, it is also the most readily accessible [16]. We observed some changes in angularity and the amount of clays with increasing transport distances.

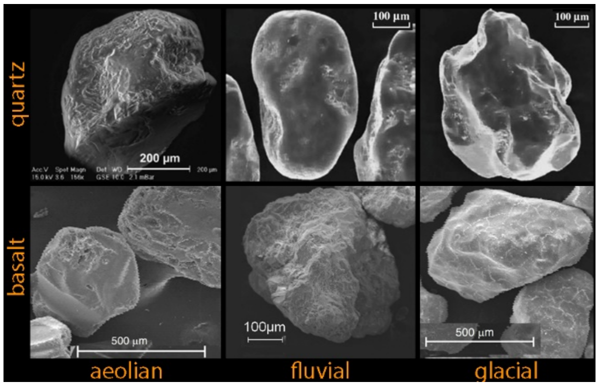

Figure 1. Scanning electron microscope photographs comparing quartz grains (top) to lithic basalt fragments bottom) transported by aeolian (left), fluvial (middle), and glacial (right) processes.

References: [1] Folk, R.L. (1980) *Petrology of Sedimentary Rocks*, 182 pp. [2] Muhs, D.R. et al. (1996) *Geomorph.*, **17**, 129-149. [3] Marsaglia, K.M. (1993) *GSA SP* **284**, 41-65. [4] Stovall, W.K. et al. (2011) *Bull. Volcanol.,* **73**, 511–529. [5] Swanson, D.A. et al. (2012) *Jour. Volcanol. Geotherm. Res.*, **215-216**, 8–25. [6] Gudmundsson, M.T. et al. (2012) *Sci. Rep.* **2**(572), 1-12. [7] Houghton, B.F., and C.J.M. Wilson (1989) *Bull. Volcanol.*, **51**, 451-462. [8] Carey, R.J. et al. (2007) *Bull. Volcanol..*, **69**, 903–26. [9] Pinkerton, H. et al. (2002) *Jour. Volcanol. Geotherm. Res.*, **113**, 159-176. [10] Gooding, J.L. (1982) *Jour. Geology,* **90**, 97-108. [11] Fiske, R.S. et al. (2009) *Geo. Soc. Amer. Bull.*, **121**, 712–728. [12] *McPhie*, J. et al. *(*1990) *Bull. Volcanol.*, **52**, 334-354. [13] Mangold, N. et al. (2011) *EPSL,* **310**, 233-243. [14] Tirsch, D. et al. (2012) *ESPL*, DOI: 10.1002/esp.2266. [15] Craddock, R.A. et al. (2012) *JGR,* **117**, E08009. [16] Porter, S.C. (1979) *Quat. Res.,* **12**, 161-187.