WIND TUNNEL AND FIELD STUDIES OF COARSE-GRAINED RIPPLES, ANALOGS FOR FEATURES EXAMINED AT BOTH MER SITES ON MARS. R. Sullivan[1] and J. Zimbelman[2], [1]CRSR, Cornell University, Ithaca, NY 14853 (rjs33@cornell.edu), [2]CEPS, Smithsonian Institution, NASM, Washington, DC.

Introduction: Coarse-grained ripples (also called "granule ripples," "megaripples," or "aeolian ridges") are relatively large, durable, slow-moving aeolian bedforms with a bimodal grain size population. Finer grains capable of saltation dominate interior volumes, but crests and flank surfaces are comprised of coarser grains that move only in creep, driven by the saltating finer grains [1-5]. Although coarse-grained ripples on Earth generally are incidental to more extensive exposures of dunes and ordinary ripples having more uniformly-sized grains, on Mars coarse-grained ripples have been relatively more common at several landing sites, including: Meridiani Planum, where these features are ubiquitous [4,6]; Gusev crater [7]; the Viking Lander 2 site [8]; and possibly the Pathfinder site (e.g., features Mermaid and Jenkins have morphology consistent with coarse-grained ripples; cf. [9]).

Several characteristics of coarse-grained ripples contribute to their durability, increasing the potential for preserving associated sedimentary structures in ancient martian rocks. Crests of coarse-grained ripples migrate very slowly, at the pace of the coarse, creeping grains that concentrate there and on flank surfaces. The coarse grains at the surface of the ripple generally are impossible for the wind alone to move, thereby functioning as armoring for the bedform. For related reasons, coarse-grained ripples are not subject to erasure into plane beds at higher wind speeds, as ordinary impact ripples would be (composed only of saltating grains). In the absence of abundant upwind saltating material, coarse-grained ripples will remain immobile, even during strong wind events. These circumstances can lead to prolonged periods of immobility that can promote induration of the (self-armoring) ripple surface, making reactivation more difficult even if favorable conditions return in the future. The ubiquitous coarse-grained ripples covering the plains at Opportunity's Meridiani Planum landing site have not been active recently [10] and have orientations indicating they likely are relicts from a different formative wind regime [6].

Our wind tunnel experiments and fieldwork are concerned with how the signatures of coarse-grained ripple migration might be recognized in ancient martian rocks at image resolutions comparable to the MER MI and MSL MAHLI. Coarse-grained ripples might be incorporated into the rock record in several ways: (1) an immobile coarse-grained ripple could be buried by other sediments (e.g., encroaching dune slipfaces, or slow burial by sand saltating at insufficient flux to move the coarse-grained ripple); (2) a coarse-grained ripple could be buried while migrating more slowly than an inundating saltating sand flux, unable to climb rapidly enough during depositional conditions to escape burial; and (3) coarse-grained ripples migrating during bed-equilibrium or erosional conditions could leave a residue of well-sorted (by creep) coarse grains as a lag, which gets preserved later when buried by other material.

Wind Tunnel Experiments: There have been few previous laboratory experiments concerning coarse-grained ripples. Fryberger et al. used a relatively small wind tunnel (~10 cm x ~10 cm cross-section, cf. Figs 11-12 in [3]) and created coarse-grained ripples analogous to features they documented in Namibia. They were unable to make their coarse-grained ripples climb, but attributed this possibly to limitations of their wind tunnel [3].

Our experiments in the ASU Planetary Geology wind tunnel involve creation and migration of coarse-grained ripples under erosional and depositional, and bed-equilibrium conditions, but have focused initially on depositional conditions. A "sub tunnel" with a raised false floor, a declining test section floor, and an adjustable ceiling above the test section, was installed inside the main wind tunnel to allow conditions to be erosional, depositional, or bed-equilibrium at the test section [11]. Experiments begin typically with a smooth bed, formed by a 1-2 mm layer of rounded 600-850 μm sand overlying several cm of rounded 250 μm sand. A wind tunnel free-stream speed of 8 m/s is sufficient to saltate the 250 μm grains, but not the 600-850 μm grains (which creep along, as a result of impacts from the saltating 250 μm grains). (Coarser 1-2 mm grains were also tried, and could be driven by the saltating 250 μm grains, but required higher wind tunnel speeds that used resources less efficiently for our experiments.) From the initial smooth bed, coarse-grained ripples form spontaneously and migrate downwind. After an experiment is complete, cross-sectioning reveals any internal structures created during the experiment (in addition to those already visible against the glass walls). Cross-sections are documented (digital image mosaics) at resolutions exceeding or comparable to MER MI and MSL MAHLI. Under depositional conditions we were able to make our coarse-grained ripples climb, but not fast enough to escape burial by ordinary ripples of encroaching saltating sand. During this burial process, the upper, unburied portion of the ripple continued to migrate downwind, leaving behind a climbing trail of coarse grains preserved in cross-section, until burial was complete. Future experiments will investigate this process further, as well as evaluate the development of well-sorted lags during erosional conditions.

Fieldwork: Coarse-grained ripples have been the subject of few dedicated field studies (e.g., [2-5]) but sometimes have been mentioned incidentally to other topics. Our fieldwork involves examining the textures and internal structures of active coarse-grained ripples, and examining aeolian sandstones for evidence of ancient coarse-grained ripple migration. At last year's meeting we discussed cross-sections from active coarse-grained ripples in Coachella Valley, CA and White Sands, NM, and cross-sections of ancient coarse-grained ripples preserved in the Entrada SS (Moab, UT) that probably were buried and preserved by encroaching dune sand [11]. Guided by this year's preliminary wind tunnel results, we examined outcrops of Navajo SS along Buckhorn Wash, UT, and near Moab, UT. The Navajo SS is well known for its uniform grain size of 200-250 μm (e.g. [12]). An early work described a horizon of "pebbles" ~20 m below the top of the Navajo exposed at Buckhorn Wash, UT [12], but later workers recognize this as the top of the Navajo at the regional J-2 unconformity [13,14]. Above this is aeolian sandstone of the lower Carmel Fm, texturally identical to the Navajo SS because it likely consists of eroded and reworked Navajo (e.g., [14]). The J-2 unconformity along Buckhorn Wash was documented at resolutions comparable to MER MI or MSL MAHLI to allow size-frequency measurements (still being evaluated). Coarse materials scattered along this contact are matrix-supported and include angular clasts (some obviously chert) with long dimensions occasionally as much as several mm, but these are rare compared with abundant ~1 mm grains which tend to be somewhat more equant and less angular than the largest clasts (Fig. 1). Previous workers have interpreted chert and limestone clasts at the J-2 unconformity as lags of erosional fragments sourced from isolated interdune freshwater pond environments: During the J2 erosional event, Navajo SS with scattered interdune pond deposits eroded away, leaving widely distributed isolated lags of angular chert and limestone debris derived from interdune pond environments that were once stratigraphically higher. The angular nature of the clasts argues against water transport during the J-2 erosion event [14]. We currently are evaluating our preliminary interpretation of the abundant, well-sorted ~1 mm component of the debris exposed at the J-2 unconformity along Buckhorn Wash as a (well-sorted) creep-fraction involved in aeolian coarse-grained ripple migration. Future work will involve wind tunnel experiments testing this hypothesis that will lead to refined guidelines for recognition of coarse-grained ripple migration in the martian rock record.

References: [1] Bagnold R. (1941) *Physics of Blown Sand and Desert Dunes*, pp. 144-166. [2] Sharp R. (1963) *J. Geol.*, *71*, 617-636. [3] Fryberger S. (1992) *Sedimentology*, *39*, 319-331. [4] Jerolmack D. et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002544. [5] Zimbelman J. et al. (2009) *Icarus*, *203*, 71-76. [6] Sullivan R. et al. (2005) *Nature*, *436*, 58-61. [7] Sullivan R. et al. (2008) *JGR*, *113*, doi:10.1029/2008JE003101. [8] Sharp R. and Malin M. (1984) *Geol. Soc. Am. Bull.*, *95*, 1398-1412. [9] Greeley R. et al. (1999) JGR, 104, E4, 8573-8584. [10] Golombek M. et al. (2010) *JGR*, *115*, doi:10.1029/2010JE003628. [11] Sullivan R. et al. (2012) *LPSC XLIII* Abstract #2161. [12] Kiersch, G. (1950) *Bull. AAPG*, *34*, 5, 923-942. [13] Pipiringos G. and O'Sullivan R. [1978] *USGS Bulletin 1035A*. [14] Fillmore R. (2011) *Geological Evolution of the Colorado Plateau.*, pp. 190-192.

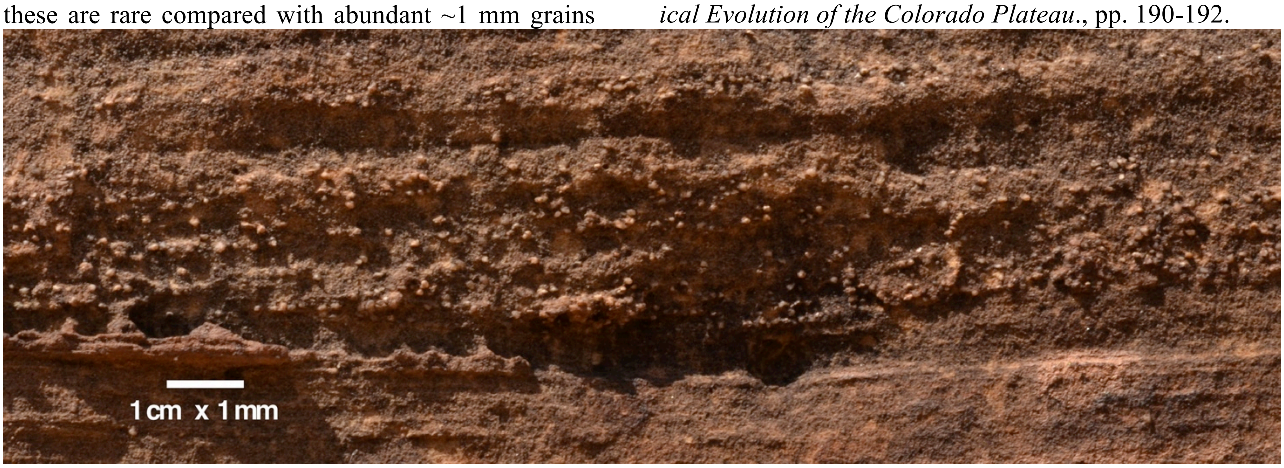

Fig. 1. J-2 unconformity exposed along Buckhorn Wash, UT, showing well-sorted ~1 mm grains supported in a matrix of 250 μm sand.