CURIOSITY ROVER MOBILITY ISSUES CROSSING MARTIAN MEGARIPPLE FIELDS. R. E. Arvidson¹, M. Maimone², ¹Earth and Planetary Sciences, Washington University in Saint Louis, Saint Louis, MO, 63130, arvidson@wunder.wustl.edu, ²NASA/ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109

Introduction: Unacceptably high wheel punctures and tears while traversing fractured bedrock shaped by wind into sharp surfaces led to commanding Curiosity to traverse terrains in which bedrock is thinly covered with regolith and wind-blown sands. Crossing wind-blown, sand-dominated megaripple fields has also proven to be problematic, inducing high wheel sinkage, increased compaction resistance, and 70-80% slip [1]. This abstract focuses on a ripple-crossing experiment conducted on sols 1181-1185 in which a dense array of engineering telemetry, mast-based imaging, and contact science measurements were acquired to understand mobility issues and their relationships to terrain and sand material properties for a ripple field adjacent to the Bagnold Dunes. The experiment was designed to better understand which Bagnold Dun sand deposits to avoid and those deemed safe to traverse across.

Background: Curiosity encountered significant mobility difficulties while traversing a sand-dominated megaripple field on sol 672 and again on sol 709 [1]. In both cases rover-based three dimensional slip in excess of 70% occurred when ripple wavelengths were comparable to the front to back 2.2 m wheel base, and sand depths large enough so that normal and shear stresses between the wheel and terrain were dominated by relatively loose sands. Automatic initiation of a visual odometry-based slip detection [2] was initiated in both cases, thereby halting the drives before the rover became embedded. Imaging and compositional measurements, together with modeling the traverse terramechanics, showed that the sands were weakly cohesive and dominated by basaltic materials [1].

Curiosity has traversed onto the northern edge of the Bagnold dune field and is continuing its way to the southwest, climbing from the base of Mount Sharp upward through the well-preserved stratigraphic section containing bedrock units of importance to detailing the paleoenvironments and potential habitable conditions during earlier periods of Martian history. Whereas the large Bagnold barchanoid and longitudinal dunes can be avoided, some sand deposits in the vicinity of the Bagnold Dunes must be traversed to continue the ascent of Mount Sharp. To test the ability of Curiosity to traverse relatively small and thin megaripple fields an explicit sand-crossing experiment was conducted on sols 1181 to 1185 adjacent to Bagnold High Dune, the first barchanoid encountered by Curiosity (Fig. 1).

Ripple Crossing Experiment: The sol 1181 experiment included a 7 m forward drive across a small megaripple field, followed by a 1.75 m backward drive, and a 20 degree turn to put the front right wheel track in the arm work volume for MAHLI and APXS measurements of undisturbed sand and material exposed within the track (Fig. 2). A dense array of engineering camera and telemetry data (at 64 Hz) were collected during the drives. Drives on sols 1183 and 1185 were also across the ripple field, providing additional mobility information.

Examination of Mastcam and MAHLI images of the right front wheel track (Fig. 3) show that wheel cleat imprints were well preserved, except at the very end of the forward drive. The sand is coarse-grained at the surface and mixed to finer sand sized grains in the interior, with a slight degree of cohesion. APXS data show basaltic compositions for undisturbed and disturbed materials.

Rover yaw, pitch, roll, and suspension angles recorded during the sol 1181 experiment were used to reconstruct pitch and elevation as a function of slip-corrected travel distance (Fig. 4). Pitch increases with the forward drive as does slip, with highest values of ~70%. Wheel sinkage was modest, less than a few centimeters. The ensemble of data indicate that traversing even through small ripple fields can be problematic. Initial modeling of the drives with Artemis [1] indicates that sand mechanical parameters are indistinguishable from values retrieved from crossing the megaripples on sols 672 and 709.

Implications for Future Traverses: Mars Reconnaissance Orbiter CRISM L data were used to retrieve spectral endmembers within a broad region to the south of Curiosity’s location on sol 1186 and along likely Mount Sharp traverse routes (Fig. 5). Linear unmixing and normalizing out shadowed areas allowed mapping of relative areal abundances of Murray formation outcrop and “fugitive” basalt sands from the main Bagnold Dune fields. HiRISE color images show that the regions of mixed outcrop and sand include megaripple fields, together with sand-covered outcrops without discernable ripples. Maps such as the one shown in Fig. 5 will be used together with rover-based lessons-learned crossing ripples to chart a course to the south that minimizes sharp rocks and extensive ripple fields, and maximizes crossing of bedrock thinly covered by wind-blown sands.

Fig. 1. Portion of a color HiRISE mosaic showing Curiosity’s traverses to High Dune and the location of the sol 1181-1185 experiment crossing the small ripple field adjacent to the dune. Traverses through sol 1196 are shown.

Fig. 2. Mastcam mosaic acquired after Curiosity traversed to the edge of the High Dune and looked back to the ripple crossing experiment site.

Fig. 3. Mastcam mosaic of the right front wheel track is shown, with an inset MAHLI mosaic acquired at a 25 cm height above the surface. Box shows location of the MAHLI image (on left) acquired at a 5 cm height. MAHLI processing courtesy Deirdra Fey.

Fig. 4. Top shows the pitch and elevation sensed by Curiosity during its forward and backward drives across the ripple field. Positive pitch indicates motion in an uphill direction. Bottom shows rover slip retrieved from visual odometry observations. High slip is associated with the 7 m long forward drive, with lower slip during the backward drive.

Fig. 5. Portion of a CRISM false color image regularized to 12 m/pixel showing the location of Curiosity on sol 1186 and overlain with a spectral endmember map derived from linear unmixing of 1 to 2.65 µm spectral reflectance values. Red represents Murray formation outcrops, blue the Naukluft Plateau rocks with spectral properties dominated by sands piled up against buttes, and green Bagnold Dune materials.