THREE-DIMENSIONAL AND MULTI-TEMPORAL DUNE-FIELD PATTERN ANALYSIS IN THE OLYMPIA UNDAE DUNE FIELD. W. M. Middlebrook[1], R. C. Ewing[1], N. T. Bridges[2], [1]Department of Geology and Geophysics, Texas A&M University, College Station, Texas 77843 (will.d.middlebrook@gmail.com), [2]Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723.

Introduction: In the equatorial region of Mars, sediment fluxes comparable to those on Earth have been measured over barchan dunes [1]. In the north polar region, however, where dunes are common and sediment availability is seasonally limited due to CO_2 frost and subsurface ice, the level of aeolian activity and the timescales at which aeolian processes operate remain unknown [2].

Sand dunes are ubiquitous in the north polar region of Mars and provide a record of sand transport processes influenced by Mars' polar climate. CO_2 frost and a near surface ice table limit sediment availability and leave only a few months a year for dunes in this region to respond to transporting winds. How much sand is moved during the summer season when the sand is available for transport? Are dunes in the north polar region as active as equatorial dunes? We analyze spatial and temporal variations in dunes, ripples, coarse grained ripples and polygonally fractured interdune areas in the Olympia Undae Dune Field in order to assess the influence of the Martian polar boundary conditions on bedform development and activity.

Our objective is to use pattern analysis and time series imagery to study dune pattern organization and sand flux rates at different times in the Martian north polar summer in order to better understand the aeolian processes operating in Olympia Undae.

Methods:

Pattern Analysis. Pattern analysis provides a means to statistically assess dune-field pattern parameters. The crest line orientation and spacing of primary dunes, secondary dunes, wind ripples and coarse-grained ripples were manually measured in a geographic information system (GIS). All pattern statistics were traced from High Resolution Science Experiment (HiRise) image ESP_027713_261. Ripple statistics were measured in a ~ 2.17 x 2.17 km area by placing points on rippled areas and extracting the underlying topography.

Image Registration. The program Co-registration of Optical Sensed images and Correlation (COSI-Corr) was used to register HiRISE imagery [3]. 4 HiRISE images taken over 716 Earth days (Mars year 30, Ls 134 and Mars year 31, Ls 149) were processed in ISIS and correlated in COSI-Corr according to Bridges et al., 2012 and Ayoub et al., 2014's methodology [1, 4]. Images were first processed in ISIS to remove distortion and 4 reconstructed images composed of CCD red channel stripes were produced. Images were imported into COSI-Corr and the first image of the series was tied to an orthorectified image of 1 m resolution and all subsequent images were tied to the orthorectified first image. At least 50 tie points were added to each image in the interdunal areas.

Results:

Dunes. Dune crest lines (n = 1465), ripples (n = 804) and coarse-grained ripples (n = 811) were measured at Ls 130 to provide a baseline to detect changes in the pattern. Primary and secondary dunes have defect density values of .004 and .003. The primary dunes have the greatest mean spacing at 464 meters with a standard deviation of 160, while the secondary dune spacing is 238 meters with a standard deviation of 167. The greater coefficient of variation for the secondary dune spacing indicates higher dispersion of values. When plotted against the trend of Earth dunes, the primary dunes in the study area have a higher defect density compared to spacing [5]. In contrast, the secondary dunes are much closer to the trend [5]. The mean crest length of the primary dunes is 238 meters with a standard deviation of 199, while the secondary crests are longer at 321 meters with a standard deviation of 172. The primary crest line coefficient of variation indicates that the primary dune crest length values

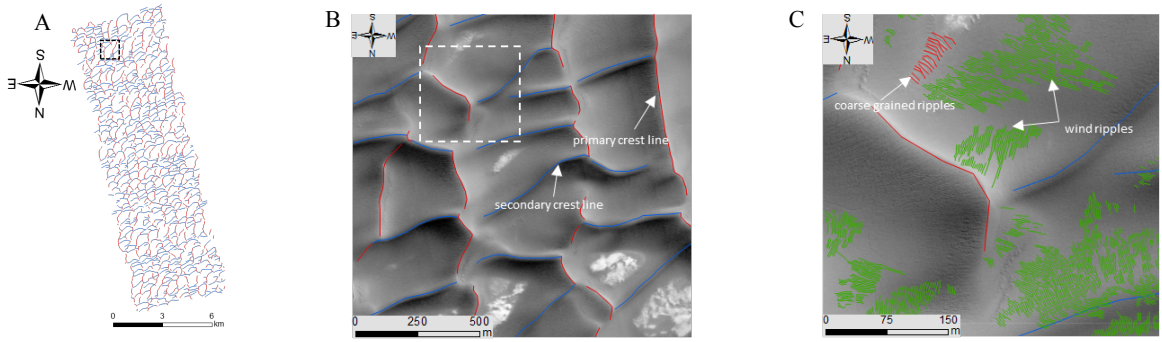

Figure 1. A) Digitization of primary and secondary dune crest lines in the study area with N/S trending primary crestlines (red) and E/W trending secondary crestlines (blue). The primary dunes have distinct stoss and lee sides, while the secondary dunes are indistinct. B) Inset of pattern digitization. C) Wind ripple transects and long wavelength ripples. Long wavelength ripples typically border the interdune, whereas wind ripples are common everywhere in the study area, except in the periglacial polygoned interdunal areas.

are more dispersed.

Ripples. 4 ripple types were identified in the study area. Type A includes straight crested 2-D and sinuous 3-D wind ripples. Type B ripples are a cross-hatch pattern with intersecting crest lines. Type C is a mottled broken-up pattern. Type D is long wavelength ripples, interpreted as coarse-grained ripples [5].

Type A and C both occur at high average slopes (12.4°, 11.19°), while Type B and D occur at the lowest (8.75°, 4.86°). Type C occurs at the highest average elevation (22.82 m), while Type B and D occur at the lowest (9.61 m, 0.67 m), in comparison to a local interdune elevation of ~ 0 m.

Multi-Temporal Analysis. Ripple defect migration and crest line pattern breakup were observed. Dune lee faces are active. Between Ls 134 and Ls 95, or 601 Earth days, wind rippled lee faces were covered or reworked by grainfall/grainflow deposits.

The first and last orthocorrected images of the time series (ESP_019023_2620, ESP_028214_2615), which were taken 716 Earth days apart (Ls 134 to Ls 149), were used to manually track the displacement of 25 Type A or Type B ripples. For error analysis, 10 interdunal polygons or stratigraphy were tracked. The average ripple displacement is 1.27 m and the maximum is 2.30 m. The average interdunal displacement error is 1.71 m and the maximum is 3.74.

Discussion:

Dune Pattern Analysis. The uniformity and magnitude of the primary dune spacing in comparison to the secondary dunes is indicative that the primary dune pattern is older and more well-developed. The greater than expected defect density may be indicative that the primary dune pattern is being reworked. Older primary dunes indicate that the pattern in the study area is complex and represents at least two generations of dune formation.

Ripple Pattern Analysis. The orientation of measured Type B ripples is similar to the orientation of measured Type A crests. This indicates that Type B ripples form in areas of convergent primary or secondary flow and are similar to ladderback ripples on Earth. Type C ripples occur at the highest average elevation above the interdune area, and occur near the brink of primary dunes. This type of ripple may represent the degradation of Type A and B patterns due to high wind velocities generated by the stoss-slope wind speed-up. Type D ripples occur at low slopes nearer to the interdune areas and are similar to armored coarse grained ripples.

Multi-Temporal Analysis. Wind ripples are active under current climate conditions. Wind ripple defect migration and pattern reworking were observed. The average measured ripple displacement over 716 Earth days (Ls 134, Mars year 30 to Ls 149 Mars, year 31) is 1.27 m ± 1.71 m. In comparison, displacements of 4.6 ± 0.09 m were measured over 105 Earth days in Nili Patera [1]. The significantly lower ripple displacement in Olympia Undae is intuitive given that sediment availability is seasonally restricted for a significant portion of the year.

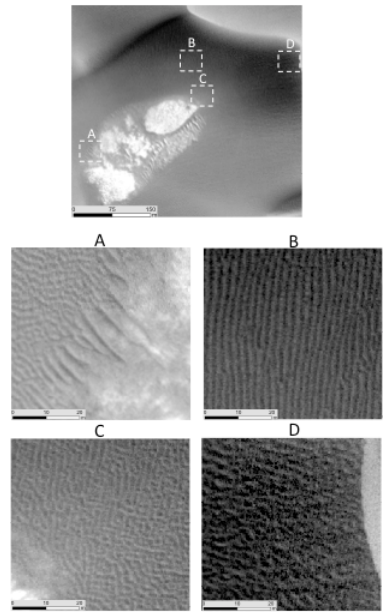

Figure 2. Ripple type locations (top) and detail of patterns types (A-D).

The reworking of Type A ripples and change in lee face deposits from Ls 134 to Ls 94 can be explained by a multi-modal wind regime. The more oblique wind of Ls 134 may be related to the Coriolis deflected katabatics descending the polar cap, while the more perpendicular wind may be related to the polar easterlies. In the future, more work will be done to constrain the orientation of these wind events.

Conclusion: Dune pattern statistics and time-series imagery were used to study the Olympia Undae dune field at a regional and local scales. Pattern statistics indicate that the dune field is a complex pattern that records multiple generations of dune formation. Sediment is mobile during the Martian summer. Ripple interactions were visually observed, but the average rate of ripple displacement is at least ten times lower than in the equatorial region of Mars.

References: [1] Bridges, N.T., et al., (2012) *Nature*, 485, 339-342. [2] Feldman, W.C., et al., (2008), *Icarus*, 2007.08.044. [3] Leprince, S., et al., (2007) *IEEE Transactions on Geoscience and Remote Sensing,* 45, 6, 1529-1558. [4] Ayoub, F., et al., (2014) *Nature Communications,* 5:5096. [5] Ewing R.C., et al., (2010) *Journal of Geophysical Research,* 115, E08005.