SOURCE TO SINK MINERALOGY IN LAKE TOWUTI, INDONESIA: PERSPECTIVES ON OPEN-BASIN LAKES ON MARS. T. A. Goudge[1], J. F. Mustard[1], J. W. Head[1], and J. M. Russell[1], [1]Dept. of Geological Sciences, Box 1846, Brown University, Providence, RI 02912. (Contact: Tim_Goudge@brown.edu)

Introduction: Geomorphic evidence for ancient lakes on the surface of Mars is widespread [e.g., 1-3], and a select few of these paleolakes contain lacustrine sedimentary deposits that show evidence for the presence of aqueous alteration minerals [e.g., 4-6]. An outstanding question is: What role has the fluvial activity that formed these paleolakes played in forming (or transforming) the observed alteration minerals [e.g., 4-8]? Here we present work on a modern terrestrial open-basin lake to further understand potential signatures of *in situ* aqueous alteration mineral formation in an analogous lacustrine environment.

Geologic Context and Samples: Lake Towuti is a large (area = ~560 km^2), hydrologically open lake on the island of Sulawesi, Indonesia [9,10]. The ~1280 km^2 catchment area of Lake Towuti [10] is largely composed of lateritic soils derived from, and overlain on, the ultramafic East Sulawesi Ophiolite [11,12], and so is mineralogically comparable to the basaltic martian crust [13,14].

We have analyzed bedload sediment from all the major input rivers to Lake Towuti, along with suspended sediment from the Mahalona river, the primary input to Lake Towuti [15]. We have also analyzed two piston cores from Lake Towuti that are located at the distal margins of a delta deposit at the mouth of the Mahalona river [15], to investigate both the source and sink mineralogy of this lake.

Methods: *Input Sediment.* Bedload samples were freeze dried and then dry sieved to >1 mm, 0.25-1 mm, 63-250 μm, 32-63 μm and <32 μm size fractions. Suspended load samples were freeze dried, wet sieved to the same size fractions, and freeze dried again. The reflectance spectra of all 5 size fractions, along with an unsieved bulk sample, were measured with an Analytical Spectral Devices (ASD) FieldSpec 3 over the wavelength range 350-2500 nm.

Cores. Small, full length subsections (U-channels) of the two piston cores were collected and freeze-dried. The reflectance spectra of these cores were measured at 1 cm depth intervals along the entire core lengths using the ASD FieldSpec 3 attached to a Geotek multisensor core logger.

Results: *Input Sediment.* The input sediment shows a diverse suite of spectral characteristics, with the most obvious changes relating to phyllosilicate mineralogy (**Figure 1**). Here we will primarily focus on the spectra of the bedload and suspended load samples from the Mahalona river, as this river is likely to be the major sediment source for the delta deposit in which the cores are hosted.

The Mahalona input sediment is spectrally dominated by serpentine (**Figure 1**), as evidenced by the prominent absorptions centered near ~1400, 2100 and 2320 nm [16,17]. The ~1400 nm absorption is due to the first overtone of the OH stretch, while the ~2320 nm absorption is due to a combination tone of the Mg-OH bend and OH stretch [16,17]. The ~2100 nm absorption is characteristic of serpentine, however, has never been fully assigned, although it may be related to Mg-OH [17]. Additionally, there is a strong absorption feature centered near ~1900 nm, which is likely to be caused by a combination tone of OH stretch and H-O-H bend from structural H_2O [16,17].

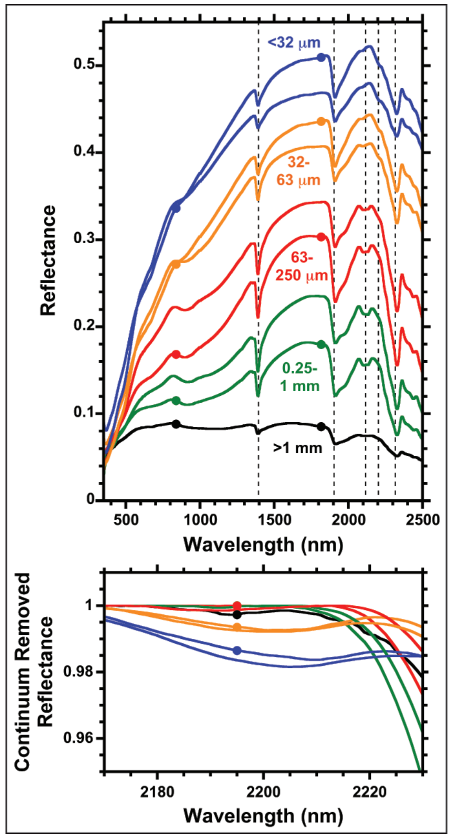

Figure 1: *Spectra of different size fractions of the input sediment from the Mahalona river. Solid lines are suspended load samples, lines with circles are bedload samples. Top plot shows reflectance with dashed lines at ~1400, 1900, 2100, 2200, and 2320 nm. Bottom plot shows continuum-removed reflectance with the same color coding as the top plot.*

While the Mahalona input sediment is spectrally dominated by serpentine, there are noticeable changes in the spectra of the different size fractions. Particularly, in the finest fraction, the presence of a subtle absorption feature centered near ~2200 nm is observable (**Figure 1**). This ~2200 nm absorption is due to a combination of the Al-OH bend and OH stretch within an Al-bearing phyllosilicate, such as kaolinite or montmorillonite [17,18]. The shape of the ~1900 nm absorption feature also changes with grain size – the coarsest fractions exhibit a broader absorption feature and the finest fractions exhibit a narrower absorption feature (**Figure 1**). We have quantified this change with a spectral parameter, BD1980:BD1910, which takes the ratio of the band depth at 1980 nm to the band depth at 1910 nm. The broader the ~1900 nm absorption feature, the higher the BD1980:BD1910 value, as shown in a plot of grain size versus BD1980:BD1910 (**Figure 2**).

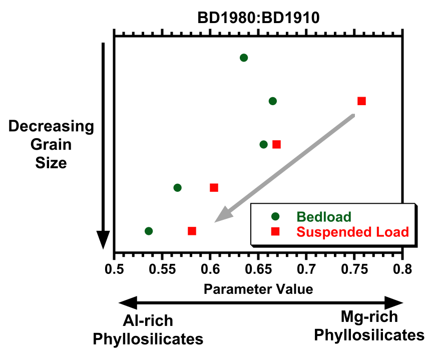

Figure 2: *Calculated BD1980:BD1910 parameter values for the Mahalona river input sediment.*

Cores. The cores show generally similar spectral characteristics to the input sediment, although there are slightly stronger ~2200 nm absorptions in some locations. Here we will primarily discuss the results from the sediment core closer to the Mahalona river mouth.

Large scale changes in the down core spectral signature are evident in a plot of depth vs. BD1980:BD1910 (**Figure 3**). This plot shows both high frequency variation in BD1980:BD1910 with depth in the core section, but also a long-term trend for the core, discussed below (**Figure 3**).

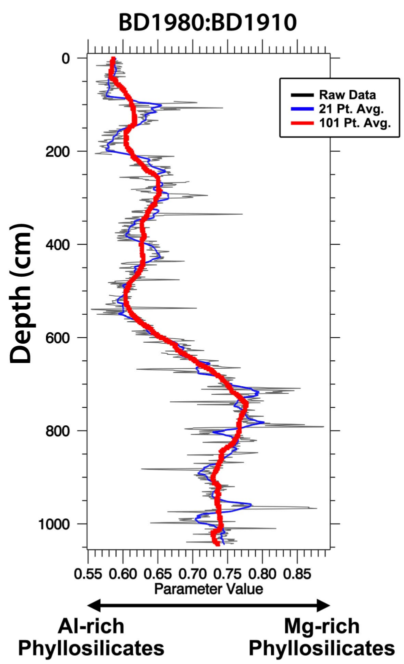

Figure 3: *Plot of depth versus BD1980:BD1910 parameter value for the analyzed lacustrine core. Note the transition from low to high parameter values between ~550 and 750 cm.*

Discussion: The input sediment from the Mahalona river is spectrally dominated by serpentine (**Figure 1**); however, there is also minor spectral contributions from an Al-rich phyllosilicate phase that increases with decreasing grain size (**Figure 1,2**). The process by which the fine fraction is enriched in Al-bearing phyllosilicates remains an open question, but it appears that this process is occurring within the watershed of Lake Towuti, and so may be related to the ultramafic ophiolite protolith of the soil. Regardless, to first order, variations in the mineralogy of the Mahalona river input sediment are correlated to grain size.

This variation in input sediment mineralogy is also reflected in the deposited lacustrine sediment. The analyzed core has a section with low BD1980:BD1910 parameter values in the modern era, preceded by a section of high BD1980:BD1910 parameter values deeper in the core (**Figure 3**). Based on the input sediment spectra (**Figure 1,2**), this is interpreted to indicate a transition from finer material with a larger component of Al-bearing phyllosilicates in the modern era, to coarser material with a larger component of Mg-rich serpentine in the past.

This core is likely to represent a time span of ~20 kyr, or approximately since the Last Glacial Maximum (LGM). Our interpretation of the change in sediment deposited at this site is consistent with the work of previous authors, who have suggested that during the LGM, precipitation rates in Indonesia were lower, and water level in Lake Towuti dropped [15]. This lake level drop is likely to have led to progradation of the delta at the mouth of the Mahalona river, resulting in the studied core site being closer to the river mouth and receiving coarser sediment in the past compared to the present, precisely what is observed here.

Conclusions: Our analysis shows that the major spectral changes with depth in a sediment core from Lake Towuti can be best explained by variations in mineralogy correlated with the grain size of the input sediment. These results do not suggest any strong signature of authigenically produced alteration phases, and indicate more of a detrital nature for the observed phyllosilicate minerals within the lacustrine sediment.

Our results show that the observed spectral variations within lacustrine sediment of Lake Towuti reflect paleoenvironmental changes, and that the sediment is likely to have been altered primarily in the watershed of this lake. These results are also similar to those observed in remote analysis of the mineralogy of the watershed and delta deposits of the Jezero crater, Mars paleolake system [19,20]. In both cases, it appears that the formation of the spectrally dominant alteration phases observed within the lacustrine sediment is not genetically linked to solely the fluvial activity that has transported and deposited this sediment, but requires an earlier period of alteration.

References: [1] Cabrol, N. and Grin, E. (1999), *Icarus,* **142**:160. [2] Irwin, R., et al. (2005), *JGR,* **110**:E12S15. [3] Fassett, C. and Head, J. (2008), *Icarus,* **198**:37. [4] Ehlmann, B., et al. (2008), *Nat. Geosci.,* **1**:355. [5] Dehouck, E., et al. (2010), *PSS,* **58**:941. [6] Goudge, T., et al. (2012), *Icarus,* **219**:211. [7] Bristow, T. and Milliken, R. (2011), *CCM,* **4**:339. [8] Ehlmann, B., et al. (2011), *Nature,* **479**:53. [9] Haffner, G., et al. (2001), *The Great Lakes of the World (GLOW): Food-web, health and integrity* (M. Munawar and R. Hecky, Eds.), Blackhuys Publishers, pp. 183-192. [10] Tierney, J. and Russell, J. (2009), *Org. Geochem.,* **40**:1032. [11] Monnier, C., et al. (1995), *Geology,* **23**:851. [12] Kadarusman, A., et al. (2004), *Tectonophysics,* **392**:55. [13] Mustard, J., et al. (2005), *Science,* **307**:1594. [14] McSween, H., et al. (2009), *Science,* **324**:736. [15] Russell, J., et al. (2013), *Quat. Sci. Rev.,* in prep. [16] King, T., and Clark, R. (1989), *JGR,* **94**:13,997. [17] Clark, R., et al. (1990), *JGR,* **95**:12,653. [18] Bishop, J., et al. (2008), *Clay Min.,* **43**:35. [19] Ehlmann, B., et al. (2008), *Nat. Geosci.,* **1**:355. [20] Goudge, T., et al. (2014), *LPSC 45,* this meeting.