CONSTRAINTS ON THE HISTORY OF OPEN-BASIN LAKES ON MARS FROM THE TIMING OF VOLCANIC RESURFACING. T. A. Goudge[1], J.F. Mustard[1], J.W. Head[1] and C. I. Fassett[2], [1]Dept. of Geological Sciences, Box 1846, Brown University, Providence, RI 02912, [2]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA. (Contact: Tim_Goudge@brown.edu)

Introduction and Science Objectives: Over 200 open-basin lakes have been mapped in the Noachian-Hesperian highlands of Mars [1]. These paleolakes are fed by valley networks that generally ceased activity at approximately the Noachian-Hesperian boundary (~3.7 Ga) [1,2]. Since then, these basins have been subjected to a variety of processes that have acted to resurface them. All of these paleolakes have been resurfaced to some degree [3], with the emplacement of volcanic smooth plains being the predominant resurfacing process [1,3]. The goal of the work presented here is to perform a detailed analysis of the morphology, surface properties, composition and age of emplacement of a subset of these volcanically resurfaced open-basin lakes. We present such an analysis on 30 of the 96 open-basin lakes identified as volcanically resurfaced by [3] in an attempt to help constrain the history of these paleolake basins. These 30 basins were chosen as they have the largest areas of identified volcanically resurfaced open-basin lakes [1,3], allowing for improved crater counting statistics.

Datasets and Methodology: Several aspects of the 30 open-basin lakes were examined including: **(1)** Morphology, using CTX [4], HRSC [5] and THEMIS visible [6] images; **(2)** Composition using CRISM [7] and OMEGA [8] hyperspectral data; **(3)** Topography using gridded MOLA data [9] and HRSC stereo [5]; **(4)** Surface roughness derived from MOLA data [10]; **(5)** Thermal inertia derived from TES [11]; **(6)** Bolometric albedo derived from TES [12]; and **(7)** Age of emplacement derived from crater counting. Crater counts were performed with the ArcMap extension *CraterTools* [13] and analyzed with the program *CraterStats* [14]. For this analysis, the production function of [15] was used along with the chronology function of [16].

Results: *Morphology*: The 30 analyzed open-basin lakes exhibit a distinctive morphology indicative of resurfacing by volcanic plains (Fig. 1). This morphology includes smooth floor deposits with high crater retention (suggesting a competent material) [1], the presence of wrinkle ridges (Fig. 1, white arrows), a common feature on martian volcanic plains [17] and lobate margins that appear to embay basin perimeters and older deposits (Fig. 1, black arrows). The analysis included a search for evidence of lava-water interaction, which would include, for example, lava-deltas for sub-aerial lava flowing into standing water [18] or rootless cones, for lava flow onto saturated sediment [19]. No evidence was found that suggests the open-basin lakes examined here contain such features.

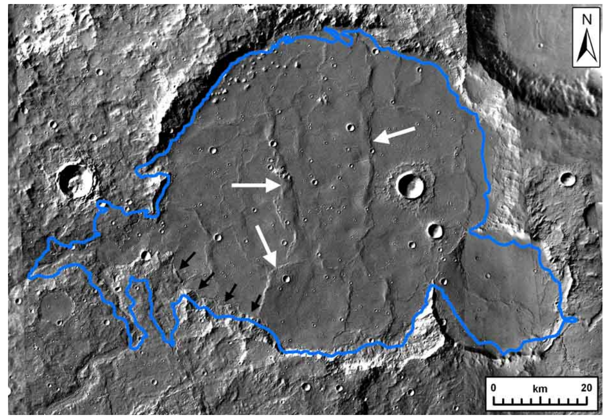

Figure 1: *Volcanically resurfaced open-basin lake at 11.5°S, 152.7°E. Mosaic of HRSC image h8425_0000 and CTX images B20_017403_1658 and P07_003703_1682 overlain on the THEMIS global IR daytime mosaic. Paleolake basin, defined on the basis of a MOLA contour, is outlined in blue, white arrows indicate wrinkle ridges and black arrows indicate basin perimeter embayment.*

Physical Properties: Based on topography [5,9] and the roughness map of [10], all of the analyzed basins show a smooth signature within the basin interior, consistent with other martian volcanic plains. Furthermore, 24 of the 30 basins (80%) have isolated areas of high thermal inertia [11] and relatively warm THEMIS nighttime IR temperatures [6] in their interior, suggesting a competent unit. The 24 basins with high thermal inertia have an average thermal inertia value of 264.77±72.58 (1σ) J m^{-2} K^{-1} $s^{-1/2}$, and an average albedo of 0.17±0.04 (1σ), which are towards the higher and lower end of the global trends for thermal inertia and albedo respectively. These higher thermal inertia and lower albedo values are expected for competent, volcanic plains units.

Composition: Basin floor compositions were investigated using CRISM and OMEGA spectral parameter maps [20,21] coupled with detailed spectral analysis. During spectral analysis, an emphasis was put on identifying crystal field absorptions in the 1 to 2 μm range, caused by electronic crystal field transitions of Fe^{2+} present in the mineral structure of olivine (absorption centered at 1 μm) and pyroxene (absorptions centered at 1 and 2 μm) [22-24].

Of the 30 basins investigated, 13 (~43%) have clear spectral signatures in their interior. All 13 basins with clear spectral signatures exhibit diagnostic crystal field absorptions caused by mixtures of olivine, high-calcium pyroxene (HCP) and low-calcium pyroxene (LCP) (Fig. 2). While a range of compositions are identified, an olivine/HCP mixture is most common. This mineralogy is consistent with the composition of Hesperian aged volcanic plains observed on other portions of the planet [25,26].

Additionally, the intra-basin mineral signatures identified are consistent across CRISM and OMEGA data (Fig. 2).

Age of Emplacement: Using crater counting and cumulative crater size frequency distributions, ages of emplacement for each of the volcanic resurfacing units were determined (Fig. 3). These ages range from the Noachian-Hesperian boundary to the Early Amazonian, with a large number (18;60%) falling at the Noachian-Hesperian boundary or in the Early Hesperian. These ages are of particular interest, as they are similar, although slightly younger than, the ages of cessation for valley network activity [2] (Fig. 3).

Discussion: The morphology, physical properties and mineral composition of the identified resurfacing units (Fig. 1 and 2) provide strong evidence for the volcanic resurfacing of the 30 paleolake basins examined here, consistent with previous morphologic classifications [1,3]. Based on crater counts, these volcanic resurfacing units were emplaced from the Noachian-Hesperian boundary to the Early Amazonian (Fig. 3), with many being emplaced near or shortly after the end of valley network activity that supplied these paleolake basins with water [1,2].

The most common composition of the volcanic resurfacing units is an olivine/HCP mixture, consistent with the composition of other Hesperian volcanic plains units [25,26]. Additionally, the consistency of intra-basin spectral signatures across CRISM and OMEGA, which have spatial resolutions that differ by a factor of ≥~15, suggests that the resurfacing units are compositionally homogeneous within each basin.

While the emplacement ages for the volcanic resurfacing units are similar to the timing of the end of valley network activity [2] (Fig. 3), the lack of mineralogic and morphologic evidence for lava-water interaction [18,19] suggests that the basins were largely devoid of water at the time of resurfacing. This then implies that the emplacement of the volcanic units onto the floors of these basins was not coeval with the fluvial activity that supplied the paleolake basins with water. This conclusion is supported by Mann-Whitney U statistical tests on the significance level of difference between the population of ages for the valley networks [2] and the population of resurfacing ages presented here. These statistical tests suggest that the probability that these two populations are not significantly different is <0.01 in all cases, with the exception of a subset of the populations using the upper error bounds of the oldest basins and the lower error bounds of the valley networks [2]. We therefore suggest that while the volcanic resurfacing of these paleolake basins is likely to have commenced shortly after the end of valley network activity, it is unlikely that the two occurred coincidently.

Acknowledgements: Thanks are extended to Bethany Ehlmann for the suggestion of performing Mann-Whitney U statistical tests on the paired populations of valley network and basin resurfacing ages.

References: [1] Fassett, C. and Head, J. (2008a) *Icarus*. **198**:37. [2] Fassett, C. and Head, J. (2008b) *Icarus*. **195**:61. [3] Goudge, T. *et al.* (2011) Submitted to *Icarus*. Submission #: **ICARUS-12063** [4] Malin, M. *et al*. (2007) *JGR*. **112**:E05S04. [5] Neukum, G. *et al.* (2004) *ESA Spec. Pub.* **ESA SP-1240**:17. [6] Christensen, P. *et al.* (2004) *Space Sci. Rev*. **110**:85. [7] Murchie, S. *et al*. (2007) *JGR*. **112**:E05S03. [8] Bibring, J-P. *et al*. (2004) *ESA Spec. Pub*. **ESA SP-1240**:37. [9] Smith, D. *et al*. (2001) *JGR*. **106**:23,689. [10] Kreslavsky, M. and Head, J. (2000) *JGR.* **105**:26,695. [11] Putzig, N. and Mellon, M. (2007) *Icarus*. **191**:68. [12] Christensen, P. *et al*. (2001) *JGR*. **106**:23,823. [13] Kneissl, T. *et al*. (2011) *PSS*. **59**:1243. [14] Michael, G. and Neukum, G. (2010) *EPSL*. **294**:223. [15] Ivanov, B. (2001) *Chronology and Evolution of Mars*. **96**:87. [16] Hartmann, W. and Neukum, G. (2001) *Space Sci. Rev.* **96**:165. [17] Watters, T. (1991) *JGR*. **96**:15,599. [18] Mattox, T. and Mangan, M. (1997) *Journal of Volcanology and Geothermal Research*. **75**:1. [19] Greeley, R. and Fagents, S. (2001) *JGR*. **106**:20,527. [20] Pelkey, S. *et al.* (2007) *JGR*. **112**:E08S14. [21] Salvatore, M. *et al*. (2010) *JGR*. **115**:E07005. [22] Burns, R. (1970) *Mineralogic Applications of Crystal Field Theory*. Cambridge Univ. Press. [23] Adams, J. (1974) *JGR*. **79**:4829. [24] King, T. and Ridley, W. (1987) *JGR*. **92**:11,457. [25] Mustard, J. *et al*. (2005) *Science*. **307**:1,594. [26] Skok, J. *et al.* (2010) *JGR*. **115**:E00D14.

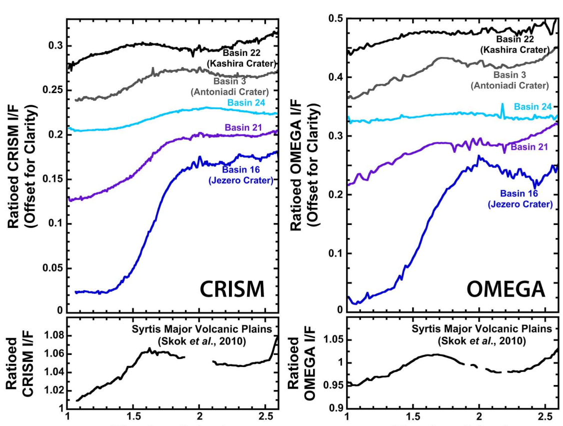

Figure 2: *Representative CRISM and OMEGA ratioed spectra from five separate volcanically resurfaced open-basin lakes compared to spectra of Syrtis Major volcanic plains from [26].*

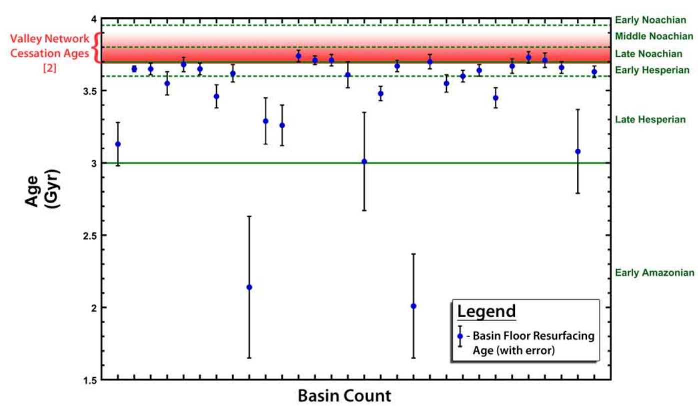

Figure 3: *Summary of emplacement ages for the volcanic resurfacing units in the 30 open-basin lakes examined, determined through crater-counts. Period boundaries are as defined by [16]. Shaded red area indicates range of ages for valley network cessation [2], excluding the four youngest valley networks, thought to be unrelated to open-basin lake activity [1,2].*