THE IGNEOUS DIVERSITY OF MARS: EVIDENCE FOR MAGMATIC EVOLUTION ANALAGOUS TO EARTH. P. R. Christensen1, H.Y. McSween, Jr.2, J. L. Bandfield3, S.W. Ruff1, A. D. Rogers1, V.E. Hamilton2, N. Gorelick1, M. B. Wyatt1, B.M. Jakosky1, H. H. Kieffer3, M.C. Malin6, J. E. Moersch6. 1Department of Geological Sciences, Arizona State University Tempe, AZ 85287, 2Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, 3Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822, 4University of Colorado, Boulder, CO, 5U.S. Geological Survey, Emeritus, 6Malin Space Science Systems, San Diego, CA 92191.

Introduction: Compositional mapping of Mars at 100-m scale from THEMIS has revealed a wide diversity of igneous materials. Volcanic evolution produced compositions from low-silica basalts to high-silica dacite in the Syrtis Major caldera. The existence of dacite demonstrates that highly evolved lavas have been produced, at least locally, by magma evolution through fractional crystallization. Olivine basalts are observed on crater floors and in layers exposed in canyon walls up to 4.5 km beneath the surface. This vertical distribution suggests that olivine-rich lavas were emplaced at various times throughout the formation of the upper crust; their growing inventory suggests that picritic basalts may be relatively common. Quartz-bearing granitoid rocks have been discovered, demonstrating that extreme differentiation has occurred. These observations show that the martian crust, while dominated by basalt, contains a diversity of igneous materials whose range in composition from picritic basalts to granitoids rivals that found on the Earth.

Background: The Mars Odyssey Thermal Emission Imaging System (THEMIS) provides IR spectroscopic data in eight surface-sensing wavelengths centered from 6.8 to 13.6 μm at sufficiently high spatial resolution (~100 m per pixel) to identify and map local geologic units [1]. A highly effective strategy for compositional mapping is to utilize the synergistic nature of THEMIS and MGS TES data in a coordinated way, selecting TES pixels within mapped THEMIS units for detailed spectroscopic analysis [1]. Combining TES and THEMIS data extends the mineralogic mapping achievable with TES to spatial scales relevant to many geologic processes. Recent in situ measurements from the Mars Exploration Rovers have provided information on mineral composition and abundance that have verified the interpretations determined from orbital data for these sites [2, 3], providing higher confidence in interpretations made elsewhere on the planet.

Magma evolution in the Nili Patera Volcano: Two distinct compositional units have been identified from THEMIS and TES data on the floor of the Nili Patera caldera in Syrtis Major. The more extensive of these (Unit B) is interpreted to be basaltic lavas that covered the floor of the caldera following its collapse. A second, later-stage units (Unit A) is a high-silica, glassy volcanic unit associated with, and possibly emanating from, a volcanic cone. Fractional crystallization of magma within a chamber commonly results in variations in the silica content of the erupted lavas over time. It appears that magmatic evolution has occurred within Syrtis Major producing low-silica basalts followed by higher-silica glassy dacites in cones and flows. Orbital TES data have identified two surface components (TES Surface Type I and II [4]) whose fundamental difference is silica content. The high-silica component in Type II material, which extends across much of the northern plains and throughout the southern highlands, has been attributed to primary volcanic glass in a basaltic andesite [4]. Type II has alternatively been interpreted as high-silica, poorly crystalline materials or other weathering/alteration products [5-9], in part based on the apparent necessity for a wet mantle to produce large volumes of andesitic material [10]. The close proximity and similar geologic ages of Units A and B argue against compositional differences based on differential weathering, whereas the geologic relationships support differences in primary volcanic composition. We therefore conclude that, at least locally, high-silica lavas do occur on Mars, and could be an important component of the globally-occurring TES Type II material.

Olivine: The occurrence of olivine is important because: (1) it indicates silica undersaturation (a critical parameter in recognizing primitive, mantle-derived magmas); and (2) it is readily weathered under common aqueous conditions and thus provides an indicator of environmental conditions in the time following rock emplacement. Olivine-rich rocks have been identified from orbit at regional (10’s of km) scales in several locations [11, 12]. THEMIS data now show that these occurrences are more common at localized (100’s of m) scales [1, 13-15]. The position and the composition and morphology of several of these units suggest that it was emplaced as lava flows and intrusions at a late stage in crust formation.

The composition of these units is basalt with 10-20% olivine with a composition Fo60-70. The
similarity in the derived composition of these units suggests that they formed by similar processes. The occurrence of the Ganges wall unit at a significantly lower stratigraphic level than the nearby Aurorae Planum unit suggests that olivine-rich basalts were erupted episodically at significantly different times throughout the formation of the martian plains.

Picritic basalts have also been observed in situ by the Spirit Rover in Gusev Crater using IR, Mossbauer, and Alpha Particle X-ray spectral techniques [2, 3, 16, 17], confirming the identification of olivine basalt mapped from orbit. Similar examples of olivine-rich basalts have been identified using both TES data and THEMIS data in Ares Valles [15], Nili Fossae [14], and elsewhere [13, 18]. This growing inventory of olivine basalts suggests that mafic basalts may be a relatively common variant of martian basalts.

Quartz-bearing Granitoid Rocks: THEMIS observations have revealed the presence of quartz-bearing rocks exposed in crater central uplifts in two 30-km diameter craters on the extreme northern flanks of the Syrtis Major volcanic construct [19]. The TES spectra match laboratory spectra of granitoid rocks composed primarily of quartz and plagioclase. The association of these outcrops with central peaks, together with the absence of exposures of this rock type elsewhere, suggests that these rocks were uplifted from depths as much as several km. The two craters in which these rocks are found are 95 km apart, suggesting that these rocks are from a large, buried granitoid pluton [19].

While fractional crystallization of magmas can produce highly differentiated, high-silica melts [e.g. 20], the volumes required to produce the Syrtis Major pluton would produce enormous quantities of mafic cumulates [19] which are not observed in any central peaks. A more likely process is partial melting of thick sequences of pre-existing basaltic rocks at relatively low pressures to form high-silica trondhjemites and tonalities [19-21].

Implications for Crustal Evolution: Multi-spectral IR imaging at 100-m scales has produced petrologic maps that are, for the first time, at scales that are appropriate for studying local geologic processes. At these scales we have identified rock units in basaltic terrains that have olivine abundances >20%, which on Earth would be classified as picrites. These rocks have been identified in eroded canyon walls and crater floors of ancient terrains in several areas, suggesting that they may be relatively common throughout the ancient martian crust but remain unexposed in most locations. Local eruptive sequences are observed in the Syrtis Major volcano that appear to have evolved in composition from basaltic to dacitic, demonstrating that fractional crystallization occurs in martian magma chambers. This diversity in composition is the result of igneous processes analogous to those found in large volcanic complexes on Earth. Rare occurrences of exposed quartz-bearing granitoid rocks have been discovered on Mars, suggesting that highly evolved magmas, possibly formed by partial melting of basaltic protoliths, occur. Taken together these observations show that the martian crust, while dominated by basalt, has produced a diversity of igneous materials whose range in composition from ultramafic to highly silicic rivals that found on the Earth.

References: