MINERALOGY, GEOCHEMISTRY, AND PETROGENESIS OF ALKALINE VOLCANIC ROCKS AT THE GUSEV CRATER MER LANDING SITE. H. Y. McSween[1] and the Athena Science Team, [1]Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410 (mcsween@utk.edu).

Introduction: Hundreds of rocks encountered by the Spirit rover within Gusev crater constitute a related suite of mildly alkaline lavas and volcaniclastic materials [1]. Examples of each rock class have been analyzed by APXS, Moessbauer, and Mini-TES spectrometry, and their textures examined by the Microscopic Imager. The local abundances and distributions of each class are revealed by Mini-TES spectral surveys [2], and geologic context is provided by Pancam images. Synthesis of data from the Athena instruments permit the most thorough characterization of any igneous suite on Mars, and suggest a petrogenetic model for this complex magmatic province.

Petrography: Gusev rocks generally show textural features indicating that they are volcanic. Most rocks are fine-grained, sometimes with phenocrysts (probably olivine). Vesicles are common, and some rocks are scoriaceous (Fig.1), indicating high volatile abundances. Several rock classes exhibit clastic or lapilli–like textures (Fig. 2) and are likely pyroclastic in origin. Another rock class (Algonquin) contains coarse crystals of (possibly cumulus) olivine. Some altered rock classes on Husband Hill appear to be mixtures of one of these igneous lithologies (Wishstone class) with another chemical component, apparently introduced in an aqueous fluid [3].

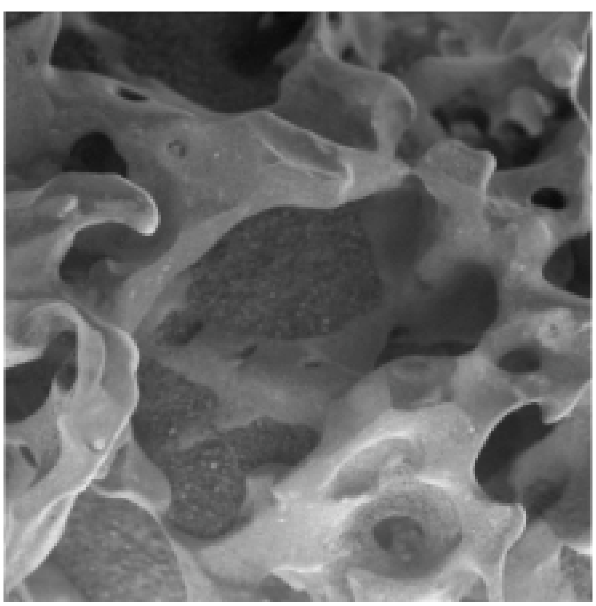

Fig. 1. Microscopic image of Gong-Gong scoria from the Inner Basin of Gusev crater.

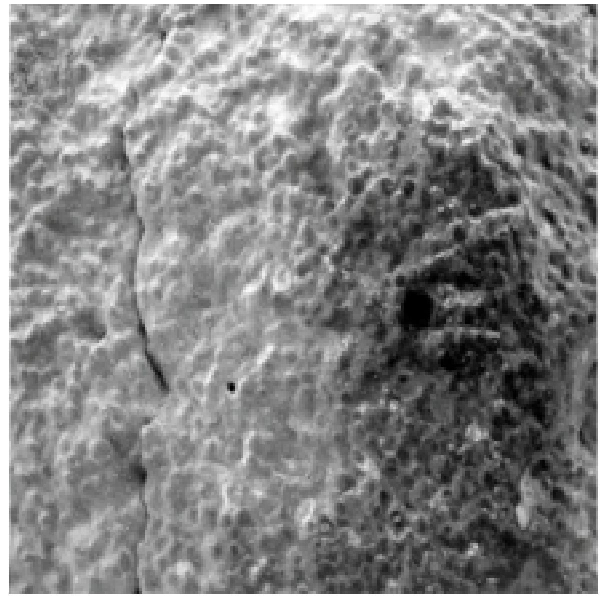

Fig. 2. Microscopic image of possible accretionary lapilli in Torquas rock, associated with Home Plate.

Geochemistry: Based on a total alkalis-silica diagram, Gusev rocks are classified as alkaline basalts, picrites, tephrites, and trachybasalts (Fig. 3). They generally plot within the alkaline field (lines delineating alkaline (Alk) and subalkaline (Sub) rocks are shown in Fig. 3), and are chemically distinct from Martian meteorites (SNCs), Mars Pathfinder dust-free rocks, and TES surface compositions. All Gusev rocks are iron-rich and fairly silica-poor, generally have higher Al_2O_3 and Na_2O and lower CaO/Al_2O_3 relative to SNC meteorites, and Wishstone class rocks are exceptionally rich in phosphorus and titanium. All rocks are fairly oxidized, as reflected in Moessbauer-determined high ratios of ferric to total iron. Pyroclastic rocks like those at Home Plate have high abundances of highly volatile elements like bromine, chlorine, zinc, and germanium [5].

Mineralogy: Moessbauer data (reported previously as subspectral areas [4]) have been recast into wt. % minerals, and renormalized to 100% minus the normative (wt. %) proportions of Fe-absent minerals that are not detected by Moessbauer. The rocks are dominated by olivine, pyroxenes, plagioclase, and FeTi oxides [6]. These new data are the most accurate mineral abundances that can be determined with the Athena instruments. Agreements of mineral modes with calculated norms are good (Fig. 4), except for rocks that could not be RAT-ground before analysis; olivine is depleted in rocks that were only RAT-brushed, apparently because of its surface dissolution by acidic fluids [7]. Comparison of synthetic Mini-TES spectra calculated for these mineral assemblages with actual rock spectra (Fig. 5) suggest that some rocks also contain other unmodeled phases.

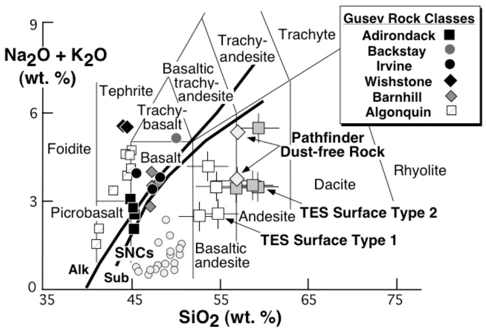

Fig. 3. Chemical classification diagram for volcanic rocks, showing that Gusev rocks have alkaline (Alk) compositions, unlike Martian meteorites (SNCs), Mars Pathfinder rocks, or TES surface types [1].

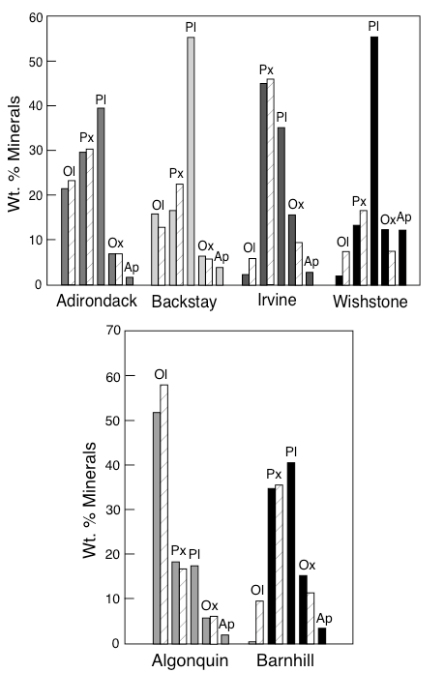

Fig. 4. Examples of modal mineral proportions (wt. %) for each Gusev rock class. The shaded bars indicate normative mineral abundances, and crosshatched bars indicate proportions of iron-bearing minerals from Moessbauer measurements that have been recast into weight percentages and renormalized to account for iron-absent minerals not analyzed by Moessbauer.

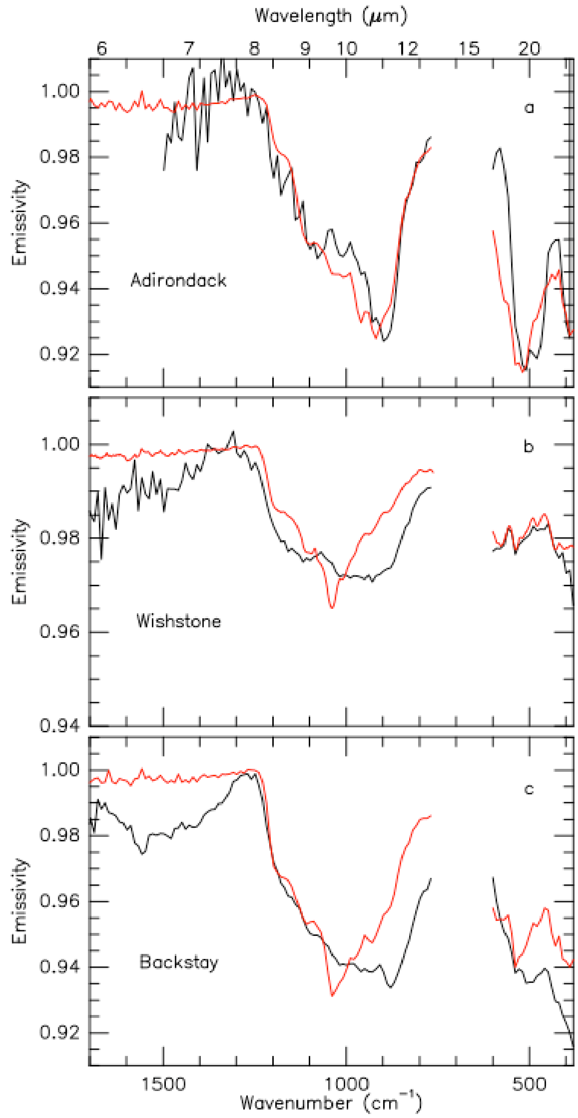

Fig. 5. Examples of measured Mini-TES spectra (black) and their synthetic equivalents (red) produced from Moessbauer/APXS-derived mineralogy. (a) Adirondack illustrates a case where the measured spectrum is well fit by the synthetic spectrum, an indication of an accurate set of derived mineral modes. (b) Wishstone shows good agreement at low wavenumbers (<600 cm^{-1}) but a poor fit between 800-1200 cm^{-1} likely due to a discrepancy in plagioclase composition, differences in the actual versus modeled phosphate phase, and the presence of an unmodeled sulfate alteration phase. (c) Backstay is not well fit by its synthetic equivalent, probably due to a combination of sodic feldspar and unmodeled pigeonite.

Petrogenesis: One rock class (Adirondack) has been proposed to be a primitive magma composition, based on experiments that indicate it is multiply saturated with olivine, orthopyroxene, and spinel at 1.1 GPa [8]. Adirondack class rocks are thought to have formed by 15-20% partial melting of a Dreibus-Waenke Mars mantle composition. Thus this rock class offers a suitable starting composition for fractional crystallization models. Using MELTS, we have tested the hypothesis that other rock classes could be related to Adirondack through fractionation at various pressures. In reality, ascending magmas may have crystallized polybarically, in which case the determined pressures would correspond to average pressures during ascent. Fractional crystallization models at varying pressures between 1.0 and 0.1 GPa under oxidizing (QFM to QFM-1), hydrous (0.5 wt. % H_2O) appear to produce liquids having the compositions of Gusev rocks on the alkalis-silica diagram (Fig. 6). The amount of fractionation required to produce these rocks is generally 25-35%. Algonquin class rocks also require accumulation of olivine with the composition (Fo50-60) observed in those rocks. Liquid lines of descent for some other elements are shown in Fig. 7. Note that [8] determined that the experimental and MELTS-calculated liquid lines of descent at low pressure (0.1 MPa) showed good agreement up to the point where plagioclase and pigeonite appeared (~1165°C), after which paths diverged. They suggested that more iron-rich residual liquids may not be well modeled by MELTS, although no comparisons were made at elevated pressures). The portions of the liquid evolution lines after plagioclase appears in the MELTS calculations are illustrated as dashed curves in Figs. 6.

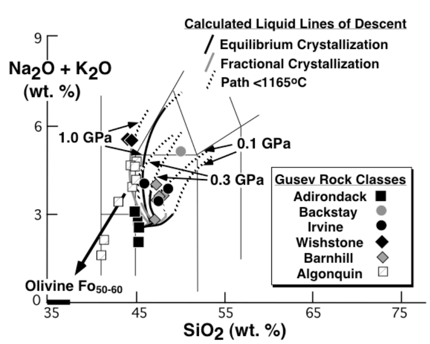

Fig. 6. MELTS-calculated liquid lines of descent for Adirondack class parent magma at various pressures under equilibrium and fractional crystallization. Magmas were oxidized (QFM and QFM-1) and hydrous (0.5 wt.% water).

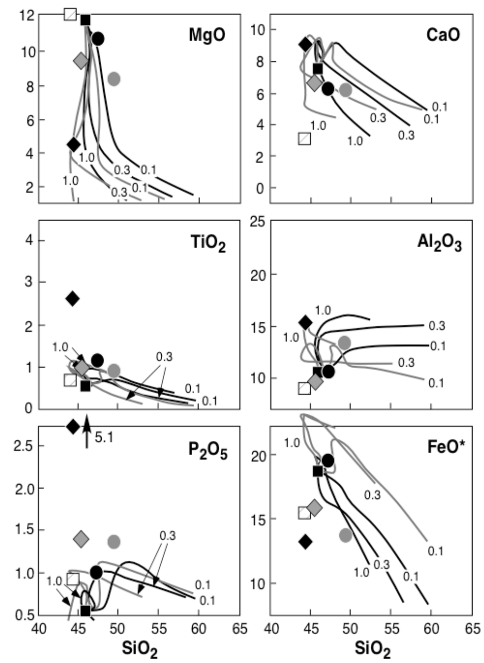

Fig. 7. MELTS-calculated liquid lines of descent for various oxides at different pressures (numbers indicate GPa) under equilibrium (black curves) and fractional crystallization (gray curves) conditions. Symbols for rock classes as in previous figures.

Wishstone class rocks have very high phosphorus and titanium contents that are not adequately modeled by MELTS (Fig. 7). These rocks appear to be be tuffs and might have experienced aerodynamic sorting of minerals. However, their chemical compositions are similar in many respects to Fe/P/Ti-rich rocks associated with carbonatite in terrestrial alkaline complexes [9]. Although no carbonate minerals have been found in Gusev, these magmas probably formed at depth and associated carbonatite did not erupt. In any case, the acidic fluids that altered some Gusev rocks [7] would have dissolved any carbonate that reached the surface.

The petrogenetic model for Gusev rocks is summarized in Fig. 8. All these rocks except Wishstone class can be related through fractional crystallization of a common parental magma at depths ranging from the mantle source at ~85 km to the near surface. Although Adirondack class basalt appears to be an appropriate parent liquid, these lavas occur mostly on the plains of Gusev and lap onto the older rocks of Husband Hill. Thus an older parental magma with similar composition is required. Wishstone might have been produced in association with carbonatite magma within the mantle source.

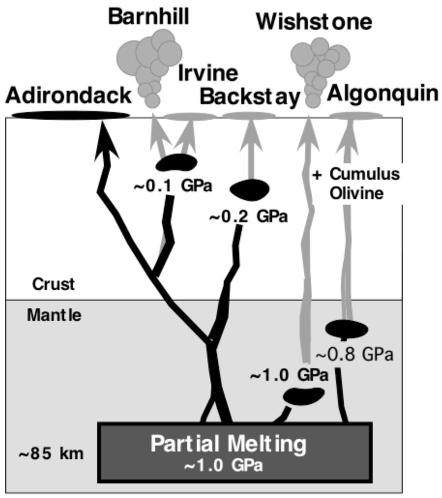

Fig. 8. Petrogenetic model of possible relationships between the various alkaline rock classes in Gusev crater, based on MELTS calculations [1]. Partial melting of the Martian mantle at ~1 GPa (~85 km depth) yields a primitive magma similar in composition to Adirondack class basalt [8]. Ascent without fractionation (heavy black arrows) then accounts for Adirondack picritic basalts. Fractional crystallization of a similar magma at various depths between ~85 and ~10 km during ascent (illustrated by magma chambers with pressure labels) yields residual magmas with compositions similar to other Gusev rock classes. Algonquin class rocks apparently require the addition of cumulus olivine to a residual liquid. Wishstone and Barnhill (Home Plate) rocks appear to be pyroclastic materials. Although they are also alkaline, their compositions are not as easily related to Adirondack basalt. In particular, the very high phosphorus and titanium contents of Wishstone class rocks are not well modeled, and may require that this magma formed in association with carbonatite at depth. Barnhill class rocks are highly oxidized and may be more altered than the other rocks considered here.

Despite its petrologic and geochemical complexity, the Gusev magmatic province is now the most thoroughly characterized igneous site on Mars. Perversely, the source for Gusev eruptions is not clear. Igneous rocks on the Gusev plains and on the northwest face of Husband Hill are commonly float and may be ejecta, whereas outcrops are common on the southeast face and in the Inner Basin. Some workers have proposed that these flows and tuffs might derive from the huge Apollinaris volcano [10] north of Gusev, although its flows have not been traced into the crater. Others [1] have suggested that the magmatic source may underlie the crater itself, and that these lavas may have erupted from fissures. A proximal source might be more consistent with the localized nature of Gusev lithologies. In any case, the probable petrogenetic relationships between these diverse rocks imply that they all came from the same mantle source.

In hindsight, it should not be surprising to have found alkaline igneous rocks on Mars. Compositional models for the Martian mantle are rich in volatiles (and hence sodium and potassium) relative to the Earth, and partial melts of an alkali-rich source would be more likely to yield alkalic magmas. It has recently been recognized that nakhlite intercumulus melts follow mildly alkaline fractionation paths like those inferred for Gusev rocks [1]. Alkaline rocks are commonly silica undersaturated, and orbital thermal emission spectra spectra suggest that olivine is widespread [11] and quartz is uncommon. Deconvolution of TES spectra using a library augmented with alkaline minerals suggest that mildly alkaline rocks can be distinguished but analytical uncertainties suggest they might be confused with other basaltic terrains on Mars [12].

References:

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