IGNEOUS, SEDIMENTARY, AND METAMORPHIC PETROLOGY ON MARS: WE'RE MAKING PROGRESS. H. Y. McSween, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410, USA, mcsween@utk.edu.

Introduction: Petrology requires the identification of the mineral assemblages (compositions and proportions), interpretation of textures, and analysis of the geochemistries of rocks. This level of information for martian rocks is obtainable from surface (rover) data and from laboratory studies of meteorites. Petrological information can be integrated with orbital remote sensing data to check for consistency, place rocks into their geologic context, and evaluate global applicability. For sedimentary and metamorphic rocks on Mars for which complete petrologic data are not available, rock geochemistry can be used to predict mineral assemblages.

Igneous Rocks: Geochemical analyses of surface rocks and martian meteorites indicate that Mars is dominated by rocks with basaltic compositions and products of their fractional crystallization [1] (Fig. 1). Global GRS data are consistent with this interpretation.

Ancient (Hesperian) volcanic rocks in Gusev and Gale craters are mildly to strongly alkaline [2, 3]. These rocks tend to be silica undersaturated, as reflected in the abundance of olivine and sometimes feldspathoid. Mineral abundances and compositions have been determined using a combination of rover instruments [4]. Vesicular textures indicate exsolution of volatiles, likely H_2O. These rock compositions can be modeled by fractionation of primary basaltic magmas at various depths.

The old (early Hesperian) ALH84001 martian meteorite is an orthopyroxene cumulate. Its basaltic parent magma was isotopically similar to other martian meteorites [5].

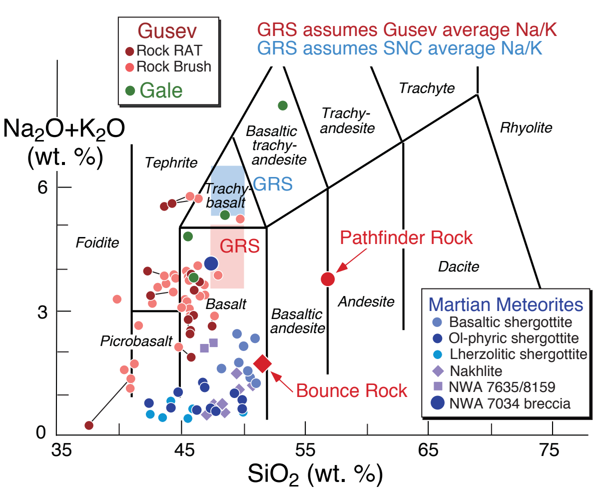

Fig. 1. Geochemical classification of martian igneous rocks and meteorites, and orbital (GRS) measurements.

Younger (Amazonian) volcanic and plutonic rocks are sampled as martian meteorites [6]. Cosmic-ray exposure ages indicate multiple launch sites, each sampling a single lithology. The age bias probably occurs because only hard rocks can survive launch, which also explains the absence of pyroclastic and sedimentary meteorites. Shergottites formed from subalkaline magmas, but include olivine-bearing lavas and cumulates. The question of dry versus wet magmas has been contentious, but new data support hydrous magmas [7] that lost water during ascent. Nakhlites and chassignites [8] are augite or olivine cumulates from a slightly alkaline, dry parent basaltic magma.

The recognition of almost ubiquitous alteration rinds on martian surface igneous rocks provides an explanation for some previous controversies or incorrect interpretations based on remote sensing data, e.g. identification of andesites from Mars Pathfinder APXS analyses and TES surface type II regions. In fact, highly fractionated (granitic) rocks are very rare; one dacite flow has been identified from TES spectra [9], a few VNIR spectra have been interpreted as felsic or feldspathic rocks [10, 11], and monzonite clasts have been described in a martian meteorite breccia [12].

Sedimentary Rocks: The basaltic protolith for sedimentary rocks in Meridiani was chemically altered [13]. Although sedimentary minerals have been identified in the Burns Formation [14], it has proven difficult to determine the full mineral assemblages. Mössbauer identification of minerals such as jarosite and hematite constrains the alteration environment. And the Opportunity rover has confirmed the discovery of clays [15] at lower stratigraphic levels, seen first in orbital spectra. Carbonates and amorphous silica have been identifed in altered outcrops in Gusev crater [16, 17].

The molar Al_2O_3 (A) – $CaO+Na_2O+K_2O$ (CNK) – FeO_T+MgO (FM) projection (Fig. 2) provides a means of quantifying chemical changes in sedimentary rocks and estimating alteration mineralogy. Known martian rock compositions (Meridiani sedimentary rocks and altered Gusev rocks) plot fairly close to this face of the 3D projection, so this diagram is fairly accurate. These rocks form a nearly linear array, with some dispersion reflecting mising of sulfates or clays. The linear trend of rocks has been interpreted as dissolution of olivine under acidic weathering conditions [18].

Also plotted on Fig. 2 are the compositions of some common alteration minerals. Most altered rocks fall between clays and sulfates, although detrital igneous minerals must dominate. Estimating the full mineral assemblage of altered sedimentary rocks on Mars has not been attempted, but they might have similar mineralogy to martian soils. Soil mineralogy has been estimated by combining rover data from different instruments [19]: Gusev and Meridiani soils are mixtures of unaltered basaltic minerals (70-83%) plus silica, Fe-oxides, clays, sulfates, and chloride, interpreted as admixed igneous and altered components.

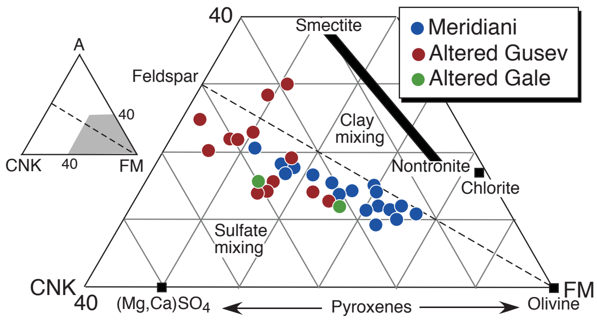

Fig. 2. A-CNK-FM diagram showing compositions of martian sedimentary or altered rocks.

XRD analyses of mudstone in Gale crater have identified detrital basaltic minerals plus sulfates, Fe-oxides, sulfide, smectitte, and amorphous material [20].

NWA 7034/7533 are martian regolith breccias, composed of comminuted alkalic basalt, monzonite, and impact melts [12]. An admixed alteration component is perplexingly absent.

Metamorphic Rocks: The mineralogy of low-grade metabasalts on Mars can be predicted from molar ACF diagrams, where A = Al_2O_3+Fe_2O_3-Na_2O-K_2O, C = CaO-3.3P_2O_5, and F = MgO+FeO+MnO. Of the diagnostic metamorphic minerals in these plots, only prehnite and chlorite have been positively identified from spectra [21], although unspecified zeolite spectra could include laumontitte and pumpellyite was suggested based on radiative transfer modeling. Under the same pressure-temperature conditions, ultramafic rocks should yield serpentine and talc + magnesite. Study of the Nili Fossae region using VNIR spectra indicates the occurrence of these minerals [21. 22], and a global inventory of hydrous phases also identifies some higher-grade minerals like epidote and possible amphibole [23]. Metamorphic rocks may have formed under a higher Noachian geothermal gradient, aided by hydrothermal activity [21]. Without plate tectonics, exposure of such rocks formed deep within the crust depends on large impacts, and subduction of surface sediments likely did not occur, so metamorphic rocks on Mars may be restricted to mafic and ultramafic compositions.

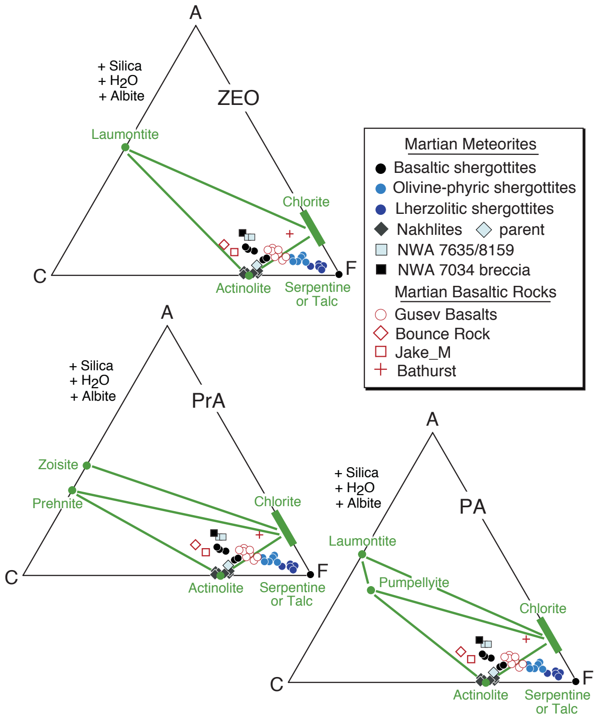

Fig. 3. ACF diagrams predicting the mineralogy of metamorphosed martian basaltic rocks at zeolite (ZEO), prehnite-actinolite (PrA), and pumpellyite-actinolite (PA) facies conditions.

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