MAGNESIUM-RICH COMPOSITIONS ON MERCURY: IMPLICATIONS FOR MAGMATISM FROM PETROLOGIC MODELING. Karen R. Stockstill-Cahill[1], Timothy J. McCoy[1], Larry R. Nittler[2], Shoshana Weider[2], [1]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013, USA, cahillk@si.edu; [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA.

Introduction: The MESSENGER spacecraft now in orbit about Mercury carries a suite of instruments optimized to address the structure, composition, and history of the surface and atmosphere of Mercury [1]. Recent MESSENGER orbital measurements constrain the composition of Mercury's surface and provide new insights into the geologic history of the planet.

X-ray fluorescence spectra obtained by MESSENGER since orbit insertion indicate a surface that has relatively high Mg/Si and low Al/Si and Ca/Si [2], consistent with a lower abundance of plagioclase feldspar than expected for crustal compositions. Ratios have been shown to be intermediate between basaltic and more ultramafic compositions [2].

In addition, the S/Si ratio ranges from 0.05 to 0.15 with an average surface S abundance of up to ~4 wt % [2]. This S abundance is markedly higher than observed for the bulk silicate portion of the Earth or Moon and for stony meteorites from Mars and differentiated asteroids [2]. Low S abundance would be expected on bodies that lost volatiles during planetary formation or underwent S sequestration into a core.

Finally, the Ti/Si and Fe/Si ratios measured are very low (<0.03 and <0.15, respectively) [2]. These low ratios are not consistent with the proposal that opaque Fe,Ti-oxides contribute to the low albedo of Mercury's surface. It also implies that surface S must exist primarily as Mg,Ca-rich sulfides, which are stable under highly reducing conditions [2]. Highly reduced enstatite chondrites, such as the Indarch EH4 meteorite, formed under such conditions with abundant sulfur and therefore have been proposed as possible compositional analogs for Mercury [3,4].

To better understand possible petrogenetic scenarios for Mercury, we ran MELTS models [5,6] for XRS-derived compositions, including a northern volcanic plains (NVP) unit (flare no 2 of [2]) and a non-NVP unit (flares 4 and 5 of [2]) and possible analog compositions. We have also taken a closer look at the sulfides that crystallized from the melt (i.e., miscible sulfides) present in the 1425°C Indarch EH4 meteorite partial melt charge of [3] to better constrain the sulfide compositions (specifically, the Mg and Ca abundances) in this possible Mercury analog.

Modeled compositions: Elemental ratios for the NVP unit and the non-NVP unit were adopted as MESSENGER-based compositions for the surface of Mercury. To derive elemental abundances, the surface Si abundance was set to 25 wt % and the elemental ratios were multiplied by this abundance (after [2]). To derive oxide abundances, O was assigned to cations as inferred from the usual stoichiometry and then oxides were renormalized [2]. Analog compositions include the 1425°C partial melt of the Indarch (EH4) meteorite [3] and Mg-rich terrestrial rocks. This Indarch composition represents ~29% partial melting and contains ~4 wt % S [3], so the melt would be expected to contain ~6 vol % sulfides [4]. Mg-rich terrestrial rocks include magnesian basalt, basaltic komatiite, and peridotitic komatiite [7]. The FeO contents of these rocks were reduced to 3 wt % by replacing molar FeO with MgO to emulate expected Mercury magmas.

Methods: The MELTS [5,6] crystallization calculations are not well-calibrated for sulfur-rich compositions and hence did not run to completion (i.e., >20% magma remaining). It is anticipated that S would form sulfides with Mg and Ca [2,4]. Therefore, the S present in these compositions was reduced to zero, and equal moles of Mg+Ca were removed to form sulfides and renormalized to 100% prior to MELTS calculations.

To determine the ratio of MgS:CaS, two observations were made. First, MESSENGER-derived XRS elemental ratios of Ca/Si and Mg/Si were plotted against S/Si [2] and linear trend lines were calculated. The best-fit trends for Mg and Ca were obtained individually and then recast as Mg/(Mg+Ca). This method yielded the result that sulfides at the surface of Mercury would be ~$Mg_{0.65}Ca_{0.35}S$. Independently, SEM measurements of the miscible sulfides present in the 1425°C Indarch melt charge suggested an average sulfide composition of ~$Mg_{0.85}Ca_{0.15}S$. Therefore, we reduced the Mg and Ca mole for mole with the S with an Mg/Mg+Ca ratio of 0.75.

Equilibrium crystallization MELTS [5,6] models were run at the iron-wüstite buffer. The resulting mineralogies were compared with the results of potential analogs for Mercury. In addition, CIPW normative calculations were performed on the same compositions in order to estimate viscosities of these lavas.

Results: Mineral abundances are plotted on igneous rock classification diagrams in Figure 1. It is clear that the MESSENGER-derived compositions for Mercury's NVP and non-NVP units crystallize much less olivine than a typical Mg-rich terrestrial rock. The Mercury compositional models contain <5% olivine, whereas the Mg-rich rocks plot as olivine-bearing gabbros with 30-80% olivine (Figures 1a and 1b). The Mercury models appear to be more similar to highly-reduced enstatite chondrites models, such as the Indarch meteorite, in terms of the abundance of plagioclase, pyroxene, and olivine. In Figure 1a, these compositions all appear within the same gabbro/gabbronorite field. However, in Figure 1b, a difference in pyroxene composition is apparent between the Mercury models and the Indarch model. The Indarch model contains more Ca-rich pyroxene, an outcome expected due to the higher CaO abundance in the Indarch starting composition (12 wt % CaO for Indarch vs. 4-5 wt % CaO for Mercury models). More importantly, we see a variation in the plagioclase-to-pyroxene ratio between a more plagioclase-rich NVP and the non-NVP.

The MELTS liquidus temperatures for the models range from 1376°C to 1680°C (Table 1). The liquidus temperatures of the Mercury model composition match more closely to the most Mg-rich terrestrial rock compositions (i.e., peridotitic komatiite). The CIPW-norm-derived dry viscosities range from 0.3 to 2.9 Pa·s (Table 1). In contrast to the liquidus temperatures, the magma viscosities of the Mercury models match the Indarch meteorite composition or the magnesian basalt more closely than more Mg-rich rocks.

Table 1: MELTS liquidus temperatures (°C) and CIPW-norm-calculated liquid viscosities (Pa·s) for sulfide-free modeled compositions.

	NVP	**Non-NVP**	**Indarch 1425°C**	**Magn Basalt**	**Basaltic Kom.**	**Perid. Kom.**
$\mathbf{T_{Liq}}$	1652	1680	1376	1396	1571	1680
Viscosity	2.9	1.9	1.2	1.6	1.0	0.3

Discussion and Conclusions: Liquidus temperatures for the NVP and non-NVP compositions are commensurate with those for Mg-rich komatiites. They also have very low viscosities, orders of magnitude lower than for terrestrial basalt magmas that are not enriched in Mg, which have viscosities of at least 100 Pa·s [7]. The temperatures at which these units may have erupted as well as the viscosity of the lava flow have important implications for the morphology of flows observed at the surface. These compositions would have been relatively magnesian magmas that erupted at high temperatures as very fluid flows. This would have required high temperatures within the mantle and produced very thin, laterally extensive layered lava flows on the surface.

Newly available data (not included in this modeling) show that the northern plains unit has twice the K abundance of more equatorial regions such as the non-NVP [8]. This, along with lower Mg/Si ratios for the northern plains unit (0.361 vs. 0.545), is consistent with real compositional variations on the surface of Mercury. If this difference reflects more alkali feldspar in the NVP, differences in the feldspar abundance between the NVP and non-NVP could be even greater than the results here indicate. Additional modeling with these refined compositional data may help distinguish the rock types further, allowing a better understanding of the petrogenesis of these units.

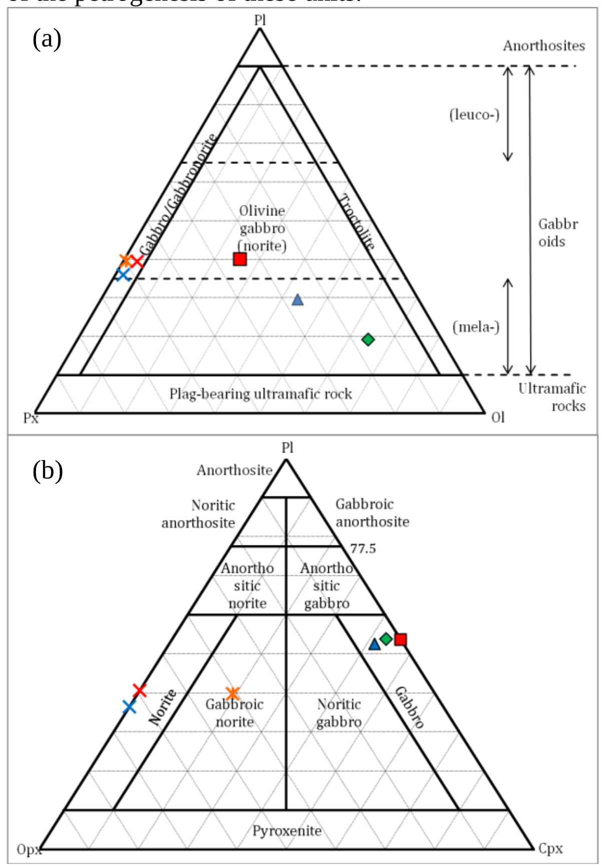

Figure 1: Rock classification diagrams showing MELTS-derived mineralogies for: magnesian basalts (red square), basaltic komatiite (blue triangle), peridotitic komatiite (green diamond), Indarch 1425°C (orange asterisk), and MESSENGER-derived NVP unit (red x) and non-NVP unit (blue x).

References: [1] S.C. Solomon *et al.* (2001) *PSS*, *49*, 1445. [2] L.R. Nittler *et al.* (2011) *Science*, *333*, 1847. [3] T.J. McCoy *et al.* (1999) *MaPS*, *34*, 735. [4] T.H. Burbine *et al.* (2002) *MaPS*, *37*, 1233. [5] M.S. Ghiorso and R.O. Sack (1995) *CMP*, *119*, 197. [6] P.D. Asimov and M.S. Ghiorso (1998) *Am. Min.*, *83*, 1127. [7] Basaltic Volcanism Study Project (1981) *Basaltic Volcanism on the Terrestrial Planets*, p. 16. [8] P.N. Peplowski *et al.* (2012), *LPSC*, *43*, this mtg.