**Low-FeO Silicates and Abundant Fe,Mg,Ti-Oxides: Indications from MELTS Modeling for a Complex Igneous History for Mercury.** Karen R. Stockstill-Cahill[1], Timothy J. McCoy[1], Deborah L. Domingue[2], David J. Lawrence[3], Larry R. Nittler[4], Patrick N. Peplowski[3], [1]Smithsonian Institution, National Museum of Natural History, Dept. of Mineral Sciences, Washington, DC 20013, USA, cahillk@si.edu; [2]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson AZ 85719 USA; [3]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; [4]Carnegie Institution of Washington, Dept. of Terrestrial Magnetism Washington, DC 20015, USA.

**Introduction:** Mercury is an especially important planet to understand because it is a compositional end member planet and hence holds answers to basic questions regarding the formation and evolution of the terrestrial planets as a group [1,2]. Despite this importance, it remains one of the least understood planets [1-3]. MESSENGER carries a suite of instruments optimized to make key measurements regarding the structure, composition and history of the surface and atmosphere of Mercury [2].

Earth- and spacecraft-based observations place several constraints on the composition of Mercury's surface. Earth-based [3, 4] and MESSENGER-derived reflectance spectra [5-7] of Mercury exhibit no 1-μm absorption feature, limiting FeO in silicates to <2-3 wt. % [3, 4]. Thermal emission spectra in the mid-infrared also suggest the presence of Fe-poor mafic silicates, with a total FeO abundance of 2-5 wt. % [8]. In addition, the average surface albedo of Mercury is very low; the albedo is even lower than that of the average lunar nearside [9], a third of which is covered by high-Fe, high-Ti basalts [10]. The low albedo argues against an anorthositic crust for the surface of Mercury, but is consistent with dominantly low-FeO ferromagnesian silicates and the presence of an Fe- and Ti-bearing opaque phase [5].

Using a radiative transfer model based on Hapke's equations, abundances of Fe,Ti-bearing oxides were estimated [5]. If all variations in reflectance are attributed to ilmenite ($FeTiO_3$) content, up to 15 volume % (or 22 wt. % [11]) ilmenite would be required to match the Mercury Dual Imaging System (MDIS) spectra of intermediate terrain (IT) on Mercury [5]. Supporting this inference is the observation that Mercury's equatorial surface is enriched in the neutron-absorbing elements Fe and Ti, equivalent to an ilmenite content of 7-19 wt. % [11]. However, equilibrium calculations carried out with the program QUILF (Quartz, Ulvöspinel, Ilmenite and Fayalite) indicated that Fe-rich ilmenite cannot co-exist with low-FeO mafic silicates unless there are high abundances of Fe-free plagioclase, which is prohibited by the low albedo of Mercury's surface [12]. Instead, Mg-rich Ti-bearing oxide phases have been suggested to explain the low albedo as well as the neutron absorption measurements of Mercury's surface [12].

To better constrain the range of magma compositions for which low-FeO silicates might co-exist with abundant Fe,Mg,Ti-oxides, we ran MELTS models for proposed Mercury magma compositions. We seek to address two fundamental questions. (1) What type of magmas would crystallize low-FeO (<2-3 wt. %) pyroxene and olivine? (2) What opaque phases would be in equilibrium with low-FeO ferromagnesian silicates?

**Modeled bulk compositions**: Among mantle compositions proposed for Mercury are Bencubbinite-type (CB) chondrite compositions [13, 14], which were modeled to see if they could be parental to high-Ti basalts. We have modeled 10% partial melt compositions derived from these parental compositions. Given the failure of these models (see below), we also modeled compositions derived from high-Ti lunar magmas likely derived from remelting of magma ocean cumulates, including average bulk-rock compositions of Apollo 11 and 17 high-Ti lunar basalts and bulk compositions of high-Ti picritic glasses [15]. A range of FeO/MgO ratios was achieved by replacing molar FeO with MgO to emulate expected magmas on Mercury.

**Methods**: Equilibrium and fractional crystallization MELTS [16, 17] models were run at the iron-wüstite buffer. The resulting mineralogy and mineral compositions were compared to the expected characteristics for Mercury (e.g., low-FeO silicates, abundance of opaque phases) and the reasonableness of the modeled composition was assessed.

**Results**: In general, partial melts from the Bencubbinite-based modeled compositions do not yield rock and mineral compositions that match constraints on Mercury surface compositions. The crystallization models produce mafic silicates (cpx ± opx ± olivine) that contain too much FeO for all models. Moreover, the models do not crystallize any ilmenite except when they crystallize mafic silicates with excessive amounts of FeO; instead, the models crystallize other opaques (spinel ± rutile) in very low abundances (≤ 2-5 wt. %).

Modeled compositions derived from high-Ti lunar basalts and high-Ti lunar picritic glasses but with reduced FeO contents (to make them applicable to Mercury) proved more promising, producing higher abundances of opaque phases and lower FeO mafic silicates. However, modeled compositions derived from high-Ti lunar basalts that produce low FeO (2-3 wt. %) mafic silicates do not crystallize the rhombic oxides (i.e., ilmenite and geikielite, $MgTiO_3$) that have been suggested for Mercury [5, 12]).

In contrast, modeled compositions derived from Apollo high-Ti picritic glass with the most reduced FeO do reproduce the estimated Mercury surface composition (Fig. 1). When FeO is sufficiently reduced (<3 wt %) in the modeled composition, the models crystallize mafic silicates at or below the 2-3 weight % FeO limit (Fig. 1a). In addition, the models result in opaque phases dominated by rhombic oxides with minor spinel and rutile (Fig. 1b). Both equilibrium and fractional crystallization models for the most-reduced FeO composition derived from high-Ti picritic glasses produce 12-13% oxide phases, solidly within the requirements set by albedo [5] and neutron spectrometry (7-19 weight %, [11]), as shown in green (Fig. 1c).

**Discussion and Conclusions:** No single stage melting of a chondritic precursor (e.g., CB) can have produced the surface of Mercury. Instead, modeled compositions derived from high-Ti picritic glasses are the best analog for the magmas that produced the IT. This result has several implications for the igneous history and surface composition of Mercury. On the Moon, high-Ti picritic glasses are thought to be the product of partial melting of late-stage lunar magma ocean cumulates [18, 19]. Melting occurred at depth (up to 2.2 GPa) and adiabatic ascent provided heat to assimilate ilmenite and clinopyroxene in a ~3:1 ratio [19]. The presence of picritic glasses are consistent with a late-stage, secondary melting event. Therefore, a complex igneous history may be implied for Mercury. Visible–near-infrared spectra, neutron-absorption cross section, and X-ray and gamma-ray peak counts have been derived for the compositions that best match the observations as a prediction of what might be observed at Mercury by MESSENGER during the orbital phase of the mission.

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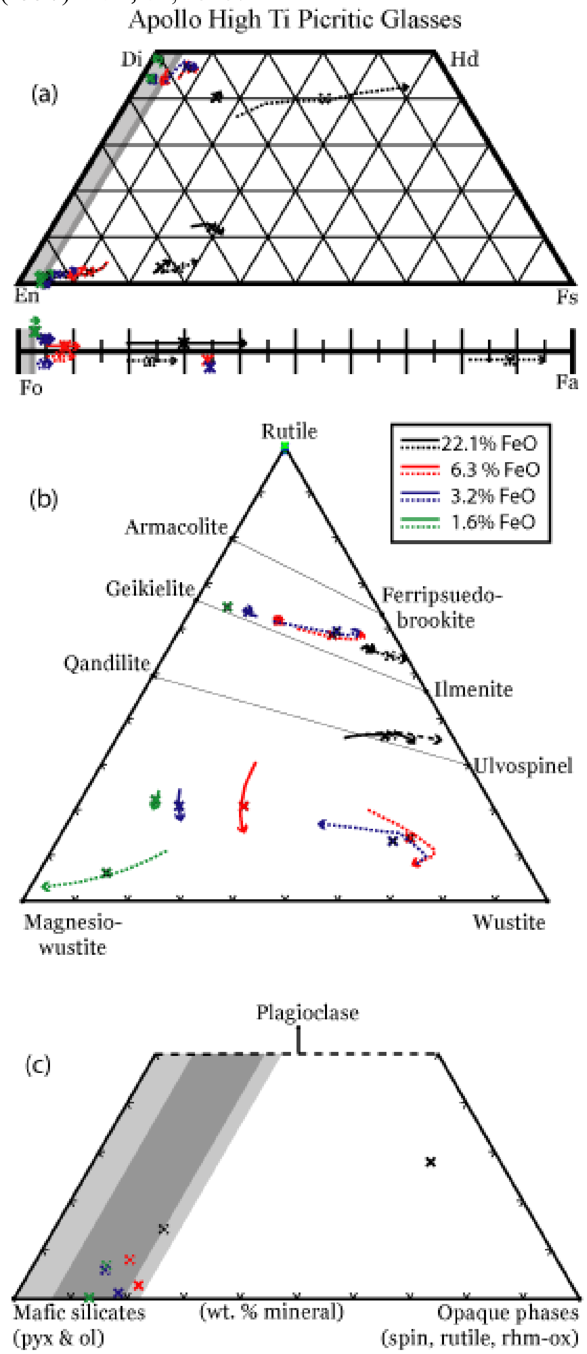


**Figure 1:** Mineral and rock compositions produced by MELTS models derived from the Apollo high-Ti picritic glasses. Full lunar-FeO compositions shown in black, reduced-FeO compositions shown in colors. (a) Pyroxene and olivine compositions; gray fields are allowed mineral compositions (2-3 wt.% FeO). (b) Coexisting opaque phases. (c) Rock compositions; gray fields are required opaque abundances to account for albedo (light gray) and neutron absorption (dark gray).