MINERALOGICAL VARIATIONS AT THE SURFACE OF MERCURY. B. Charlier[1] and O. Namur[2], [1]University of Liège, Department of Geology, 4000 Sart-Tilman, Belgium (b.charlier@ulg.ac.be), [2]Leibniz University Hannover, Institute of Mineralogy, 30167 Hannover, Germany (o.namur@mineralogie.uni-hannover.de).

Introduction: NASA's MESSENGER spacecraft has revealed geochemical diversity across Mercury's volcanic crust [1]. Near-infrared to ultraviolet spectra and images have provided evidence for the Fe^{2+}-poor nature of silicate minerals [2], magnesium sulfide minerals in hollows [3] and a darkening component attributed to graphite [4], but existing spectral data is insufficient to build a mineralogical map for the planet.

In this study, we investigate the mineralogical variability of silicates in Mercury's crust using crystallisation experiments on magmas with compositions and under reducing conditions expected for Mercury [5]. We find a common crystallisation sequence consisting of olivine, plagioclase, pyroxenes and tridymite for all magmas tested. Depending on the cooling rate, we suggest that lavas on Mercury are either fully crystallised or made of a glassy matrix with phenocrysts. Combining the experimental results with geochemical mapping, we can identify several mineralogical provinces: the Northern Volcanic Plains and Smooth Plains dominated by plagioclase, the High-Mg province strongly dominated by forsterite, and the Intermediate Plains comprised of forsterite, plagioclase and enstatite. This implies a temporal evolution of the mineralogy from the oldest lavas dominated by mafic minerals to the youngest lavas dominated by plagioclase, consistent with progressive shallowing and decreasing degree of mantle melting over time.

Data and methods: The MESSENGER spacecraft included X-Ray (XRS) and Gamma-Ray (GRS) detectors that were used to characterise the elemental composition of Mercury's crust. Mercurian magmas are Mg-rich and Al-, Ca- and Fe-poor compared to terrestrial and lunar material [1], and are enriched in alkalis and volatile elements [6]. These data, especially in the northern hemisphere where the resolution is the highest, were used to distinguish various geochemical provinces, including the 4.2-4.0 Ga High-Mg (HMg) and Intermediate (IcP-HCT) Plains, the 3.9-3.5 Ga Smooth Plains (SP) and the low- to high-Mg Northern Volcanic Plains (NVP) [1,7].

We have examined XRS chemical maps of Mercury [8] and identified average compositions for the various provinces. We experimentally investigated the phase equilibria of 5 S-free compositions. Experiments were performed from 1480 to 1100˚C at 1 kbar under reducing conditions similar to those of Mercury's mantle (ca. IW-5).

Experimental results: All compositions fall within the forsterite stability field at low pressure. For the SiO_2-rich lavas of the NVP, stabilization of forsterite at the expense of orthopyroxene is due to the high Na_2O content of our starting composition (~ 7 wt.%). The liquidus temperature ranges from 1440 to 1290˚C with decreasing MgO content. With decreasing temperature, residual melts become saturated first in diopside, followed by plagioclase, ortho-enstatite and tridymite. At the lowest residual liquid fraction, the Al-poor HMg composition is dominated by forsterite and diopside with minor enstatite, plagioclase and tridymite. Owing to their Al-rich nature, the IcP-HCT and NVP compositions are dominated by plagioclase but still contain abundant forsterite and diopside. With progressive crystallisation, residual liquids become progressively enriched in SiO_2, Al_2O_3 and Na_2O, while MgO continuously decreases. At low residual melt fraction, they reach a eutectic point where they are saturated with forsterite, diopside, enstatite, plagioclase and tridymite. During complete solidification, no additional phases are expected to appear. Similar silicate phases would crystallise from S-bearing Mercurian lavas [9].

Modelling results: XRS maps from MESSENGER were converted to oxide compositions. For each composition, we calculated the mineralogy of erupted lavas for crystallinity of 15, 25 and 35%, and the mineralogy for fully crystallized rocks using mass-balance calculations. Details about modelling methods are in [5].

Mineralogy of lavas. We find that NVP and SP lavas contain a significant proportion of plagioclase, in addition to forsterite and diopside, while IcP-HCT lavas are dominated by forsterite or forsterite + diopside. Lavas from the HMg province, and especially those containing the highest amount of MgO, may contain only forsterite crystals (Figure 1).

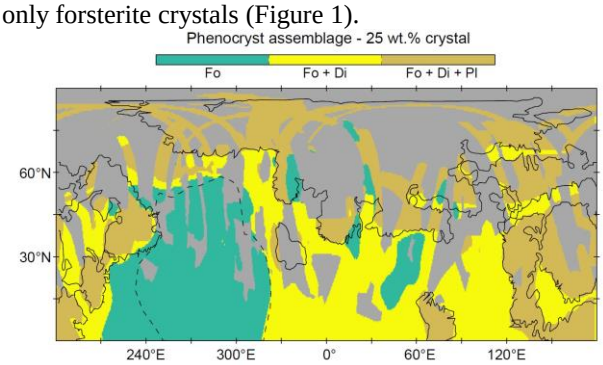

Figure 1: Mineralogy of crystal-bearing (25wt.%) glassy surface in the northern hemisphere of Mercury.

Mineralogy of crystalline rocks. The mineralogy at the solidus also demarcates various mineralogical provinces on Mercury's crust (Figure 2). The HMg province has the highest forsterite (> 25 %) and diopside (> 20 %) contents, the lowest plagioclase content (< 40 %) and a relatively low amount of enstatite (< 15 %). NVP rocks are also rich in forsterite (> 10-15 %) and diopside (> 15 %), but contain abundant plagioclase (> 50 %). They are peculiar among Mercurian rocks because they do not contain enstatite. The Intermediate Plains (IcP-HCT) have the highest enstatite content (> 25 %) and are also fairly enriched in plagioclase (> 45 %). In the Smooth Plains, the Caloris Basin has the most striking mineralogy, with the highest plagioclase fraction (> 60 %) in the northern hemisphere and a low proportion of mafic phases, consisting of forsterite, diopside and enstatite in similar proportions. The plagioclase-rich nature of Caloris may imply that the source of magma has an important crustal component and/or that plagioclase floated to the surface of a large impact melt pool. In any case, the peculiar mineralogy of Caloris supports that this area might be the sole significant portion of tertiary crust on Mercury.

Structure and temporal evolution of the crust: The mineralogical variability that we identified for Mercury's crust has important implications for the physical properties of the crust, particularly its density. Our calculated mineralogy translates to pore-free crustal densities of 2800-3150 kg/m^3. These densities are similar to previously proposed values [10], but our results show that a non-constant density across the planet should be considered when estimating crustal thickness. The densest crust is observed in the forsterite-dominated and plagioclase-poor regions, where crustal density approaches the estimated density of the mantle (3200-3300 kg/m3; [10]). In these regions, lower crustal delamination and asthenospheric return are likely to have contributed to high magma productivity. A high density for the HMg province also implies a thicker crust than currently estimated, which is inconsistent with mantle excavation by a meteorite impact but supports a high degree of mantle melting beneath this region [11]. The presence of > 30 % of plagioclase in this region also supports the volcanic origin of the HMg rocks. The HMg province on Mercury is therefore not an equivalent to the South Pole-Aitken basin on the Moon where mantle rocks were excavated.

The silicate mineralogy at the surface of Mercury is closely related to the geochemical terranes [1]. It also has an obvious relationship to the age of the lavas, as defined by crater size-frequency analyses. Model ages range from 4.2 Ga for the high-Mg terrane to 3.6-3.5 Ga for some smooth plains [12]. Secular cooling of the interior of Mercury and the changes of adiabatic mantle melting conditions from deeper and hotter (1650˚C and 360 km) at 4.2 Ga to shallower and cooler (1410˚C and 160 km) at 3.5 Ga [11] produced lavas successively dominated by forsterite, then forsterite + diopside, and finally forsterite + diopside + plagioclase. The evolution of the mineralogy to a lower temperature assemblage in the last major volcanic event of the planet (NVP) is consistent with the termination of large-scale magmatic activity at 3.5 Ga due to mantle potential temperature becoming lower than the mantle solidus.

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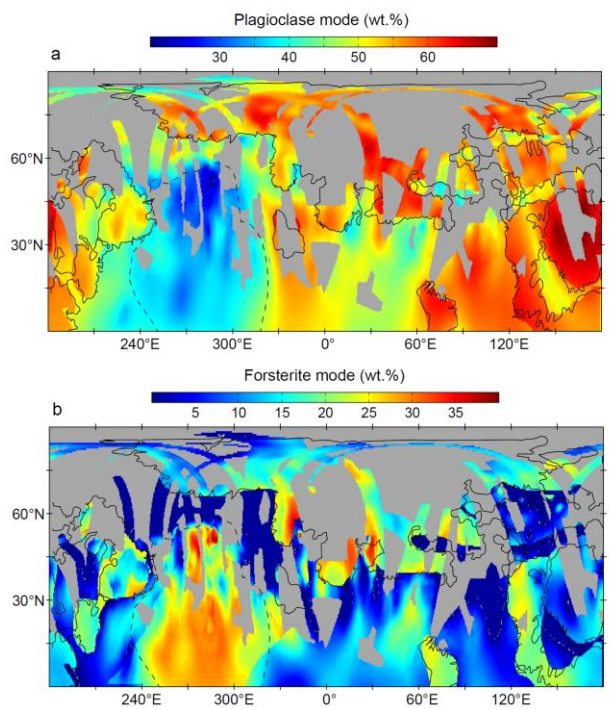

Figure 2: Mineralogy and mineral modes of the fully crystalline volcanic crust in the northern hemisphere of Mercury. A. Plagioclase mode (wt.%). B. Forsterite mode (wt.%).