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Gusev plains and Columbia Hills basalts

The Adirondack basalts (including Humphrey), encountered in the Gusev plains by the Spirit rover exhibit subalkaline whole-rock compositions, which are similar to the Martian surface as a whole [1]. These basalts are thought to approximate a primary mantle-derived magma [1,2]. Later, in the Columbia Hills, Spirit encountered Backstay, Irvine, and Wishstone class rocks, which are the first alkaline basaltic rocks discovered on the surface of Mars and are thus distinct from previously analyzed rocks, including the SNC meteorites [1]. Irvine has been classified as basalt, Backstay as trachybasalt (or hawaiite), and Wishstone as tephrite. Mildly alkaline rocks display similar mineral assemblages to subalkaline rocks, but the abundances and compositions of feldspar and glass are different. These differences are detectable using *in situ* instruments, such as the APXS, but may not be detected with orbital spectroscopy [3] and thus the alkaline composition could be widespread in some areas of the martian surface.

Petrogenetic links between the Gusev plain basalts and the alkaline basalts

[1] performed a series of liquid line-of-descent calculations using the MELTS algorithm [4] and attempted to fit the measured compositions by calculating the products of isobaric crystallization of the Adirondack-class magmas under different but static pressure conditions using various fO_2 and 0.5 wt% H_2O. As they were generally able to match the alkali and silica compositions, [1] inferred that the Gusev plains and alkaline basalts come from the same primary magmatic source with differences due to fractional crystallization at various depths. We know that alkaline rocks can be form on Mars and can be found at the surface based on Gusev alkaline rocks as well as the newly alkaline rock analyzed by Curiosity rover in Gale crater. However, we do not understand all the various pathways that can produce alkaline magma from known primary magma on Mars.

It has been previously shown that alkaline rocks can be formed from fractional crystallization of tholeiitic magmas. However, for that to happen, the presence of water and the preferential crystallization of pyroxene over plagioclase are required [e.g. 5-7]. These processes implies high pressure. Also, polybaric fractional crystallization might be involved in the formation of alkaline magmas, as commonly observed for terrestrial rocks. This was shown in the alkaline hypersthene-normative rocks from the Nandewar volcano, which formed from a continental hot-spot [5,6]. By looking at pyroxene and plagioclase composition, the authors argued that the Nandewar alkaline rocks formed from trapping of tholeiitic mantle-derived magma in the crust, with subsequent ponding and fractional crystallization with separation and ascent of residual liquids [5-7].

In this study, we attempt to constrain the formation of alkaline magma on Mars from primary magma. We consider a more realistic crystallization scenario, polybaric fractional crystallization, than the static pressure calculations assessed by [1]. We evaluated various P-T paths and the composition of residual liquids from fractional crystallization of the primary magma Humphrey as well as more complete range of fO_2.

We also investigated whether the alkaline basalt Backstay could have formed via polybaric fractional crystallization of a magma with a primary Humphrey composition. Thus, we attempted to find polybaric P-T paths leading to the formation Backstay and obtain the best fit for its compositions using various oxygen fugacities in our calculations (Fig. 1).

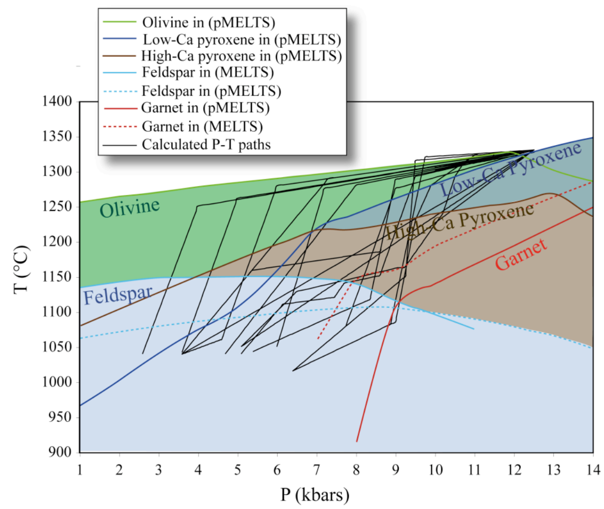

Fig. 1. P-T diagram representing the different saturation curves from fractional crystallization of important minerals calculated with both pMELTS and MELTS and using the Humphrey basalt composition + 0.5 wt% H_2O. *The black lines show the different calculated P-T paths, which were input in both pMELTS and MELTS, and calculated using 0.5 wt%* H_2O.

Methods

We attempted to determine the P-T crystallization path of the Gusev alkaline rocks using the adiabat_1pH front end of the pMELTS algorithm [8]. Balta and McSween (in prep.) conducted a series of isobaric calculations on various Martian compositions using both MELTS and pMELTS calibrations. They determined that pMELTS gives more accurate results of the olivine-orthopyroxene multiple saturation pressure point. Our calculations started from the Humphrey APXS composition [9], at 1330°C and 12.5 kbars with 0.5 wt% H_2O (same H_2O value as [1] calculations).

Results and discussion: Backstay rocks

After we calculated the various P-T paths starting from Humphrey composition (Fig. 1), we looked at the composition of residual liquids produced by fractional crystallization. We represented the liquid line of descent for the various calculated P-T paths on a TAS diagram (black curves in Figure 2). Out of the eighteen calculated paths, seven follow a subalkaline path whereas the rest of them are located in the alkaline field superposing the Nandewar volcano trend. We observed that the P-T paths leading to residual liquids with alkaline composition follow higher pressure fields and fractionate pigeonite alone but not pigeonite + augite or solely augite. Thus, the alkaline compositions can be obtained with higher pressure conditions, perhaps showing longer time of crystallization in the martian upper mantle / lower crust.

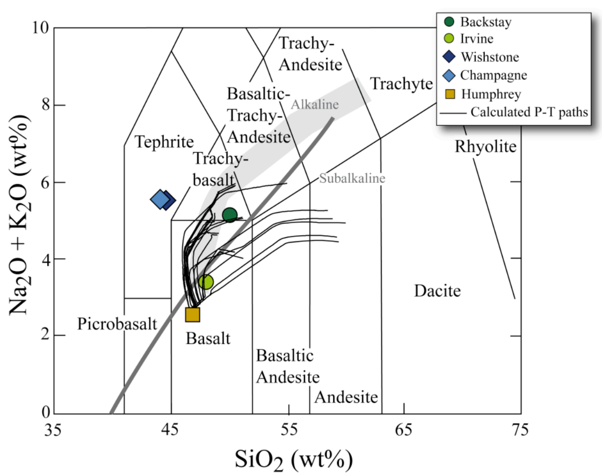

Fig. 2. TAS diagram modified from [1]. Wishstone, Champagne, and Backstay show alkaline compositions whereas Irvine is on the alkaline-subalkaline boundary. Liquids were produced by sequential polybaric fractional crystallization of the Humphrey composition. The thick light grey band represents the fractionation line of the volcano Nandewar. The boundary between alkaline and subalkaline rocks is indicated by the grey lines (after [10]).

Backstay may be formed as a residual liquid from Humphrey composition that separated with fractional crystallization at around ~5.0 kbars and 30-35 % fractionation with 0.5 wt% H_2O (Fig. 2). We are able to fit the Fe_2O_3 content of Backstay using an fO_2 of QFM +1, which is elevated relative to SNC meteorites and the Adirondack basalts. However, preliminary results show some discrepencancies in composition. Our best-fit composition is elevated in FeO and depleted in MgO relative to Backstay, and is slightly depleted in both Na_2O and K_2O (~ 0,6 wt %). This could indicate a slight amount of interaction with crustal material, involving simultaneous formation of olivine (to reduce MgO) and melting of evolved feldspars (to supply Na_2O and K_2O) implying AFC processes.

Further work

We will continue to explore alkaline rock formation using different variables such as variations of fO_2, water content and starting composition. The starting compositions, representing different primitive magmas, such as the Homeplate rock Fastball [11] and Y-980459 [12], may also lead to alkaline composition. In addition to Backstay, Irvine and Wishstone petrogenesis will be explored. Nakhlites intercumulus liquid [13], also presenting an alkaline composition, will be investigated in further studies.

References

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