

**MAGMAS PARENTAL TO THE CHASSIGNY METEORITE: NEW CONSIDERATIONS.** H. Nekvasil<sup>1</sup>, J. Filiberto<sup>1</sup>, M. Whitaker<sup>1</sup>, and D.H. Lindsley<sup>1</sup>, <sup>1</sup>Department of Geosciences, State University of New York, Stony Brook, NY 11794-2100, Hanna.Nekvasil@sunysb.edu.

**Introduction:** Comparisons with plume-associated magmas on Earth suggest major similarities between the Chassigny mineral assemblages and those that fractionate along the *hy*(hypersthene)-normative sodic alkalic trend exemplified by lavas from certain ocean island, continental hotspot and continental rift regimes.

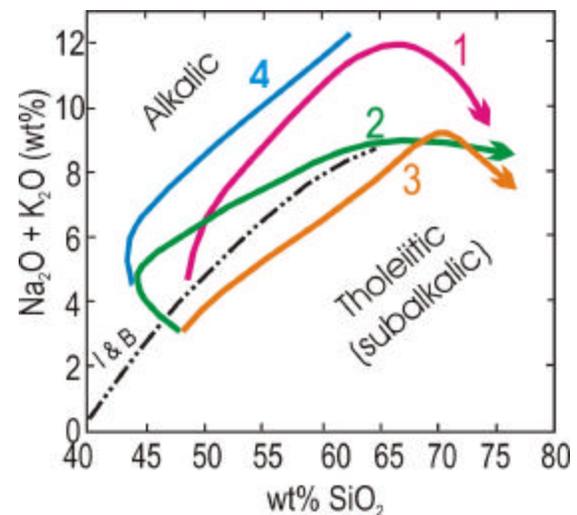
Plume-associated magmas on Earth are characterized by extreme diversity of associated rocks, with rocks ranging from alkali basalt, olivine tholeiite, and biotite gabbro to anorthosite, syenite, comendite, pantellerite, phonolite and potassic granite, and spanning the spectrum from silica-undersaturated to silica-oversaturated units, including peralkaline types. However, viewed globally, plume-associated magmatic suites, as defined by spatially and temporally associated rock units, fall into distinct patterns. These patterns emerge as four major trends (Fig. 1a).

Trend 1 shows the variation in bulk lava compositions of the sodic *hy*-normative mildly alkalic suites as a function of silica content. Rocks along this trend extend through the sequence alkalic basalt-hawaiite-mugearite-benmoreite-trachyte-rhyolite with occasional peralkaline members. This trend is exemplified by rock suites from Ascension Island [1] and the Azores [2]. Figure 1a shows that rock units within these suites are clearly alkalic according to the classification scheme of Irvine and Baragar [3], yet are not silica-undersaturated and differ distinctly from the alkalic rocks typical of ocean island such as Hawaii (Trend 4).

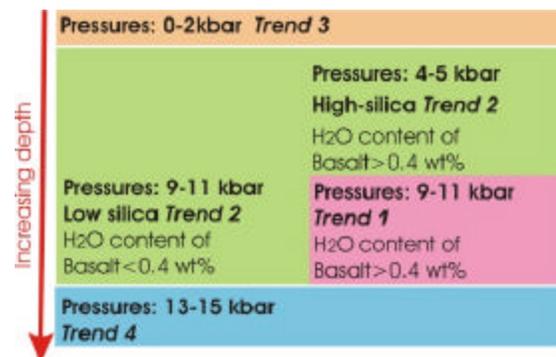
Trend 2 shows the variation in lava compositions of *hy*-normative potassic suites with silica content. These suites include fine-grained rocks of the Proterozoic anorthosite complexes and make up the sequence biotite gabbro-ferrodiorite (jotunite)-monzodiorite- monzonite-monzosyenite-syenite-and potassic granite [4]. Volcanic equivalents appear to be given by the basalt-ferrobasalts-trachyte-potassic rhyolite of the Snake River Plain [5,6]. This trend is characterized by rocks with low silica and alumina that contain as much as 25 wt% FeO<sub>T</sub> and are strongly enriched in Ti and P as well as silica-rich rocks (i.e. potassic granites) with high Fe/Mg ratios. Also distinctive is the subalkalic nature of the least evolved rocks, but alkalic nature of the intermediate rocks.

Trend 3 reflects the typical subalkalic tholeiitic provinces of ocean islands such as Iceland with their olivine tholeiite-ferrobasalt-icelandite-sodic rhyolite sequences [7]. Trend 4 is more diffuse and less well defined, but includes the silica-undersaturated alkali

basalt - *ne*-hawaiite - *ne*-mugearite - phonolite sequence as well as the nephelinites of Hawaii, Tristan da Cunha, and Gough Island [8]. This trend typifies what most petrologists refer to as "alkalic".



**Figure 1a.** Four primary trends of bulk rocks in plume-associated magmatic suites.



**Figure 1b.** Conditions under which each of the trends of Figure 1a have been reproduced experimentally by fractionation.

Experiments have been conducted on each of these trends in order to assess how much of the compositional diversity seen in each trend could be ascribed to fractionation [9-14]. These experiments simulated crystal fractionation by incrementally using residual liquids as the new bulk compositions. They have provided a map of the conditions of pressure and water contents that produce the assemblages that lead to these liquid trends (Fig. 1b). The results of these experiments pro-

vide a foundation upon which to evaluate the assemblages of the Chassigny meteorite.

**Relation to the Chassigny cumulate and inclusion assemblages:** The Chassigny dunite consisting of unzoned  $Fe_{68}$  with possible cumulate augite,  $En_{50}Wo_{34}Fs_{16}$  (mol%), pigeonite,  $En_{63}Wo_{12}Fs_{25}$ , and unexsolved orthopyroxene  $En_{68}Wo_4Fs_{28}$  [15]. According to QUIIF [16] calculations, this assemblage could be in equilibrium at  $\sim 1050^\circ C$  (at pressures within the range 1-9 kbar), although the pigeonite appears metastable at this temperature. Evidence for a lower temperature assemblage appears preserved in the intercumulus assemblage that consists primarily of pyroxene, plagioclase, ilmenite, and other oxides [15]. Melt inclusions in the olivine of the Chassigny cumulate assemblage contain the additional assemblage kaersutite, augite, low-Ca pyroxene, chlorapatite, chromite, and silica-rich glass [15, 17]. QUIIF calculations on inclusion pyroxene and the olivine host suggest possible equilibrium between hosting olivine and inclusion pyroxenes and oxides in the Chassigny (albeit, under oxidized conditions -  $\log fO_2$  of 2.5 log units above FMQ).

Non-feldspathic glass in polyphase melt inclusions of the Chassigny meteorite [18] is of particular interest. Shown in red in Figure 2, this glass is an alkali-rich rhyolite and has remarkable similarities to the rhyolites of suites of the hy-normative alkalic trend (Trend 1 of Fig. 1a) exemplified in Figure 2 by rocks from Ascension Island, the Azores, Clarion Island, Mexico and the Nandewar volcano of N.S.W. Australia. The conditions under which fractionation could lead to the primary chemical diversity of rocks within this trend has been the focus of recent fractionation experiments by our group and data are now available for direct comparison with the cumulate and melt-inclusion assemblage.

Figure 3 shows experimental glass compositions (gray symbols) from fractionation experiments conducted on natural lavas (black symbols) from the Nandewar volcano at 9.3 kbar and 2 wt% initial bulk water content, starting with a mildly alkalic hawaiiite. Experimental mineral assemblages along the experimental fractionation path are shown in Table 1. All of the phases observed in the cumulate and inclusion assemblages of the Chassigny meteorite were obtained experimentally (olivine, orthopyroxene, clinopyroxene, kaersutite, apatite and late-stage plagioclase and ilmenite). Ti-biotite was obtained when the water contents of the least evolved hawaiiite along the path was slightly less than 2 wt%. Upon comparison of experimental mineral compositions with those of the Chassigny cumulate assemblage, it is clear that within the temperature range 1080-1040°C, which bridges the temperature obtained independently through QUIIF calcu-

lations ( $1050^\circ C$ ), experimental mineral compositions bracket those of Chassigny (Table 1).

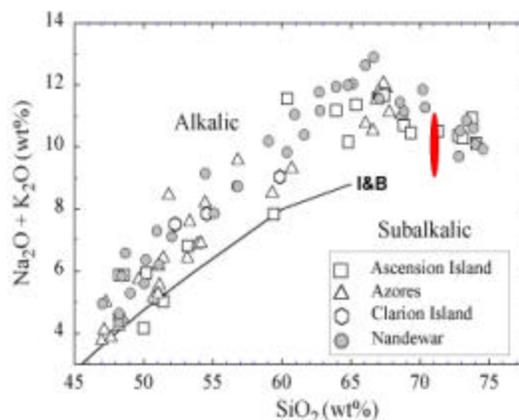


Figure 2. Total alkalis vs. silica for the Chassigny non-feldspathic glass of polyphase melt inclusions (Johnson et al., 1991) compared with natural bulk lava compositions along Trend 1 of Figure 1. The curve labeled I&B is the alkalic/subalkalic boundary of Irvine and Baragar (1971).

$T^\circ C$	Experimental Assemblage at 9.3kbar; 2 wt% $H_2O$	Chassigny Cumulate Assemblage
1200	Olivine ( $Fe_{82}$ )	
1080	Olivine ( $Fe_{72}$ ) Clinopyroxene ( $En_{54}Wo_{32}Fs_{14}$ )	
1050?		Olivine ( $Fe_{68}$ ) Clinopyroxene ( $En_{50}Wo_{34}Fs_{16}$ ) Orthopyroxene ( $En_{68}Wo_4Fs_{28}$ )
1040	Clinopyroxene ( $En_{48}Wo_{28}Fs_{24}$ ) Orthopyroxene ( $En_{62}Wo_5Fs_{33}$ ) Kaers + Ap	
1020	Orthopyroxene ( $En_{61}Wo_4Fs_{35}$ ) Kaers + Ap	
950	Kaers + Ap + Il Plagioclase ( $An_{24}Ab_{65}Or_7$ )	

Table 1. Experimental mineral assemblages and compositions compared to those of the the cumulate assemblage of Chassigny at the QUIIF temperature of  $1050^\circ C$ . Arrows connect like phases for ease of comparison.

Shown in green in Figure 3 is the trachyandesite liquid composition at  $1040^\circ C$  that is in equilibrium with

the experimental mineral compositions listed in Table 1. This liquid could readily fractionate to the rhyolitic glass of Chassigny (shown in red) at 9.3 kbar, producing in the process, volumetrically abundant kaersutite.

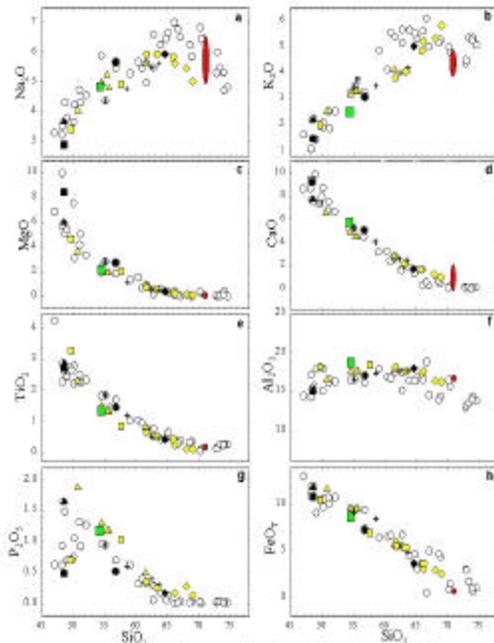


Figure 3. Experimental glass compositions along the fractionation path of a Nandewar basaltite at 9.3 kbar and 2 wt% initial bulk water content (yellow symbols). Black: Starting compositions for the fractionation steps. Clear: Bulk compositions of lavas from the Nandewar suite (Trend 1). Red: Non-ferridaphnic glass in the Chassigny polyphase melt inclusions. Green: Experimental liquid at 1040°C.

Pyroxene compositions of the Chassigny meteorite also give information about potential pressures of fractionation. Figure 4 shows the Al:Ti cation ratios of experimental clinopyroxenes as a function of pressure, natural clinopyroxenes from the Nandewar rocks, and Chassigny inclusion pyroxenes (in red) [18]. The Chassigny clinopyroxenes are fully consistent with fractionation at ~9 kbar.

If the Chassigny assemblage can indeed be reproduced by crystallization along Trend 1, as suggested by our evaluation above, then a variety of implications arise.

- The magma trapped in the olivine (represented now by polyphase melt inclusions) and in equilibrium with the co-existing "cumulate" clino- and orthopyroxene could be similar to basaltic trachyandesite of the mildly alkalic *hy*-normative magmatic suites on Earth.
- Parental to the basaltic trachyandesite melt that can produce the Chassigny cumulate assemblage is mildly alkalic *hy*-normative hawaiite. [Importantly, this is not an alkali basalt since it is *not* normative and hence, not silica-undersaturated.]

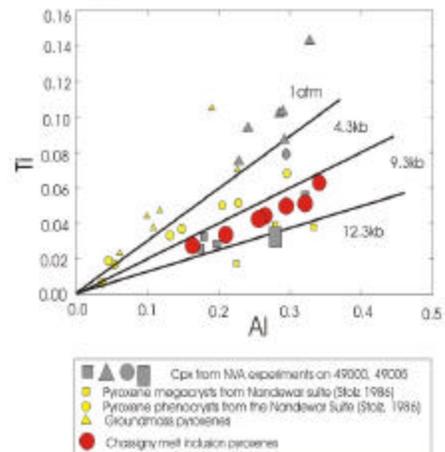


Figure 4. Ti:Al cation abundances in Chassigny melt inclusion clinopyroxene (red; Johnson et al., 1991). Heavy lines separate regions defined by experiments (gray symbols) of Nekvasil et al. (in review). The polybaric nature of natural pyroxenes of such suites are shown by natural pyroxenes of the Nandewar suite (yellow).

- On Earth, such parental magmas have low Mg#s due to earlier fractionation histories. For this reason, the low Mg#s of the Chassigny assemblages cannot be used to support the concept of a martian mantle that is more Fe-rich than that on Earth.
- Further fractionation of the trachyandesite would give rise to volumetrically abundant trachyte and finally rhyolite of the variety found as glass within the polyphase melt inclusions of the Chassigny meteorite.
- Magmatic water contents needed to produce the Chassigny assemblages lies between 0.4 and 2 wt%.
- Although the silica content of basaltic trachyandesite (i.e., the suggested Chassigny assemblage host magma) is consistent with the mafic material of Surface Type 1 of the martian southern highlands suggested by deconvoluted TES spectra [19], the alkali content of a basaltic trachyandesite is significantly higher.
- Fractionation of basaltic trachyandesite would produce volumetrically abundant trachyandesite with silica contents of the Surface Type 2 of the northern lowlands, but again lower alkali contents.

- The fractionation (or ponding) pressure indicates the presence of a physical barrier to magma ascent within the upper layers of Mars. If, as on Earth, this barrier marks the crust/mantle interface, then this may provide independent estimates of the thickness of the martian crust in the regions of Elysium and Tharsis. Assuming a depth to pressure ratio of  $\sim 7.7 \text{ km/kbar}$  on Mars (based on a density of  $3.5 \text{ g/cm}^3$  for the martian upper mantle and crust and a gravitational constant of  $3.7 \text{ m/s}^2$  [20]), this depth and therefore crustal thickness, is  $\sim 70 \text{ km}$ .

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