

**MAJOR AND TRACE ELEMENT MODELING OF LREE-DEPLETED SHERGOTTITES VIA FRACTIONAL CRYSTALLIZATION FROM A Y980459-LIKE PARENT.** S. J. Symes<sup>1</sup>, L. E. Borg<sup>2</sup>, and C. K. Shearer<sup>2</sup>, <sup>1</sup>Department of Chemistry, University of Tennessee-Chattanooga, Chattanooga, TN, 37403, <sup>2</sup>Institute of Meteoritics, University of New Mexico, Albuquerque, New Mexico 87131.

**Introduction:** The martian basaltic meteorites display enormous variation in their trace element and isotopic compositions. A subset of the shergottites including NWA1195, SaU005/008, DaG476, Y980459, Dhofar 019, and QUE94201 have many similar geochemical features, in addition to being the oldest shergottites. Strongly light-rare-earth element (LREE)-depleted REE patterns, low initial Sr and high initial Nd isotopic ratios indicate that this group is derived from either a single source or several very similar source regions that are characterized by depletions in incompatible elements. Despite these similarities, a wide range of mineral modes and compositions, as well as major element abundances, indicates that they are derived from parental magmas of different composition.

One end of the mineralogical and compositional range defined by this group is represented by Y980459. This sample is a porphyritic basalt containing pyroxene and Fo<sub>86</sub> olivine that is in equilibrium with the groundmass. This rock is thought to represent a liquid that is in near-equilibrium with its mantle source [1, 2]. It is not surprising, therefore, that the bulk rock is characterized by low abundances of incompatible elements relative to many other shergottites belonging to the group. In contrast, QUE94201 is a coarse grained porphyritic basalt containing pyroxene, maskelynite, and phosphates with minor abundances of oxides and impact melt glass. The composition of this sample is also thought to represent a melt [3]. Nevertheless, a low bulk rock Mg# of 38, the presence of relatively Fe-rich silicates, and high whole rock incompatible element abundances relative to the other shergottites in this group demonstrate that QUE94201 is significantly more evolved.

The other samples (NWA1195, DaG476, SaU005/008, and Dhofar 019) are cumulates. Although accumulation of phases makes whole-rock compositional differences between these samples difficult to interpret, many geochemical traits not strongly affected by accumulation (e.g. mineral core compositions, parental liquid Mg#'s) are intermediate between Y980459 and QUE94201.

Compositional differences observed in this group may reflect either compositional differences in their sources or elemental fractionation processes that occurred after their primary parental melts left the

mantle. The most obvious differences, such as varying Mg# of phases and bulk rocks, are consistent with geochemical evolution by fractional crystallization. As a consequence, major and trace element compositions are modeled using closed-system-fractional crystallization.

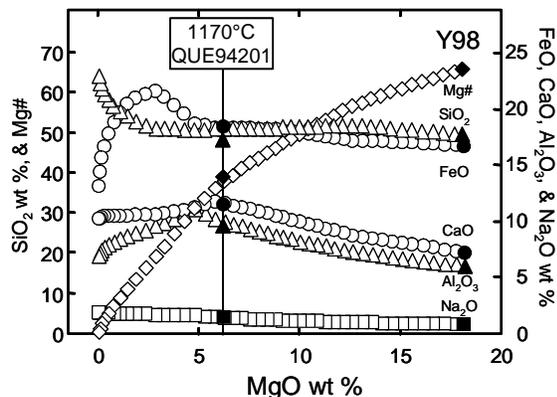
**Fractional crystallization models:** Major element abundances are modeled using the MELTS program and the REE abundances are modeled using simple fractional crystallization models and mineral modes defined by MELTS. The most primitive sample, Y980459, is used as the parent in these calculations. Likewise, QUE94201 is thought to represent a melt composition, so that its bulk rock composition is also used to represent a liquid. Unfortunately, QUE94201 contains large and variable amounts of phosphates, so that bulk rock REE abundances are not necessarily representative of the melt before crystallization. As a consequence REE abundances of the QUE94201 (and DaG476) parental liquids are calculated from REE abundances in pigeonite cores. Although pigeonite represents the earliest crystallizing phase for which REE data exist, LREE abundances in these minerals are very low and result in jagged, and irregular REE patterns for the parental melts. Consequently, emphasis is placed on reproducing the most abundant REEs.

*Major elements.* Fractional crystallization is modeled assuming an anhydrous melt at 1 bar pressure and fO<sub>2</sub> of QFM -3. The calculated liquidus temperature is 1430°C and is a close match to the experimentally determined value for a similar composition [2]. Spinel is the liquidus phase followed within 10°C by Fo<sub>86</sub> olivine. Olivine continues to crystallize until 1320°C, when orthopyroxene crystallization begins. Orthopyroxene crystallizes until 1220°C when pigeonite, followed by high-Ca clinopyroxene at 1150°C begins to crystallize. Pigeonite stops crystallizing at 1100°C, but high-Ca clinopyroxene continues at least until 1000°C, where the model calculations are terminated. Plagioclase begins to crystallize at 1130°C and continues throughout the model run.

The experimentally determined liquidus temperature for QUE94201 is 1170°C [4]. The liquid composition calculated at 1170°C is a close match to the QUE94201 bulk rock composition (Fig. 1). The modeled liquid composition is produced by 43% fractional crystallization of olivine, orthopyroxene,

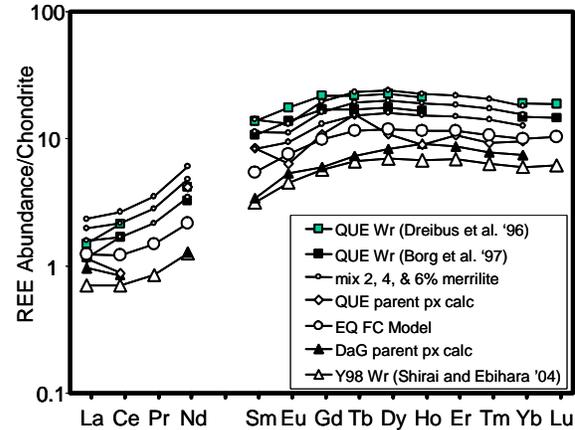
pigeonite, and spinel from the parent in the proportions 38:40:19:3.

Model results are shown in Figure 1. The model reproduces  $\text{Al}_2\text{O}_3$ ,  $\text{FeO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ , and  $\text{MgO}$  abundances of QUE94201 within 1 to 3 percent of the measured value. However, bulk rock abundances of  $\text{P}_2\text{O}_5$  and  $\text{TiO}_2$  are significantly higher than the calculated abundances, whereas the bulk rock  $\text{SiO}_2$  is slightly ( $\sim 7\%$ ) lower than the calculated abundance. The elevated bulk rock  $\text{P}_2\text{O}_5$  and  $\text{TiO}_2$  most likely reflect accumulation of phosphates and ilmenite (the major oxide phase). Low  $\text{SiO}_2$  in the bulk rock could reflect unrepresentative measurements of  $\text{SiO}_2$  in QUE94201 possibly as a result of differing proportions of a high  $\text{SiO}_2$  component, such as mesostasis, in the analyzed aliquots.



**Figure 1.** Liquid compositions, starting at Y980459, calculated in  $10^\circ\text{C}$  increments. Filled symbols = whole-rock values; open symbols = calculated values.

*Trace element models.* Trace element models also use the bulk rock composition of Y980459 as the parent. The amount of crystallization and the mode of the fractionating assemblage is identical to that described above. There are relatively large amounts of uncertainty in the REE concentrations in the DaG476 and QUE94201 parental liquids as a result of analytical uncertainties associated with pigeonite measurements. Nevertheless, the composition of the QUE94201 parent is modeled reasonably well (Fig. 2). This is particularly true for the most abundant rare earth elements (La, Ce, Gd, Dy, Er, and Yb) in the calculated QUE94201 parental melt. This indicates that fractional crystallization of Y980459 can also reproduce the REE systematics of QUE94201. Likewise, the REE abundances in the calculated DaG476 parent can also be reproduced by  $\sim 15\%$  fractional crystallization of Y980459. This suggests that DaG476 and QUE94201, as well as NWA1195, SaU005/008, and Dhofar 019 represent steps down a liquid line of descent from Y980459-like parents.



**Figure 2.** REE patterns for various whole-rocks (Wr) [2, 7, 8] and parental liquids calculated from pigeonite compositions compared with results of equilibrium fractional crystallization (EQ FC) of a Y98 liquid.

**Ramifications of models:** The success of fractional crystallization models in reproducing the compositional variations observed in the oldest martian basalts suggests that their mineralogy and major element compositions are primarily controlled by crystallization processes. In contrast, the incompatible trace element systematics, particularly the REE patterns, as well as the radiogenic isotope systematics are dictated by the composition of their source regions [5, 6]. Thus, compositional variations among the martian basaltic meteorites appear to reflect the combined effects of source composition and fractional crystallization which, in turn, suggests that assimilation of evolved crustal material by a common parental magma is not required.

It is important to note that although the models are able to reproduce the characteristics of this group of meteorites from a common parent (Y980459) it is highly unlikely that all of these samples are derived from the same parent. This stems from the observation that this group of samples has crystallization ages that span  $\sim 250$  Ma. Rather, the success of the models indicates that numerous parental magmas derived from very similar source regions and having very similar geochemical characteristics have been produced recently in martian history. Thus, the source region for Y980459 is likely to be large and represent some significant fraction of the martian mantle.

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**References:** [1] Mikouchi et al. (2004) *Ant. Met. Res.*, 17, 13-34 [2] Dalton et al. (2005) *LPS XXXVI*, #2142 [3] McSween et al. (1996) *GCA*, 60, 4563-4569 [4] Mikouchi et al. (2001) *LPS XXXII*, #2100 [5] Borg et al. (1997) *GCA*, 61, 4915-4931. [6] Borg et al. (2003) *GCA*, 67, 3519-3536. [7] Dreibus et al. (1996) *MAPS*, 31 A39-40. [8] Shirai and Ebihara (2004) *Ant. Met. Res.*, 17, 55-67.