

**Sm-Nd Age and Nd- and Sr- Isotopic Evidence for the Petrogenesis of Dhofar 378.** L. E. Nyquist<sup>1</sup>, Y. Ikeda<sup>2</sup>, C.-Y. Shih<sup>3</sup>, Y. D. Reese<sup>4</sup>, N. Nakamura<sup>5</sup>, and H. Takeda<sup>6</sup>, <sup>1</sup>Mail Code KR, NASA Johnson Space Center, Houston, TX 77058-3696, USA, laurence.e.nyquist@nasa.gov, <sup>2</sup>Dept. of Material and Biological Sci., Ibaraki University, Mito 310-8512, Japan, y-ikeda@mx.ibaraki.ac.jp, <sup>3</sup>Mail Code JE-23, ESCG/Jacobs Sverdrup, P.O. Box 58477, Houston, TX 77258-8477, USA, <sup>4</sup>Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, USA, <sup>5</sup>Dept. of Earth and Planet. Sci., Kobe University, Nada, Kobe 657-8501, Japan, <sup>6</sup>Research Institute, Chiba Institute of Technology, Narashino 257-0016, Japan.

### Introduction:

Dhofar 378 (hereafter Dho 378) is one of the most ferroan lithologies among martian meteorites, resembling the Los Angeles basaltic shergottite in lithology and mineral chemistry, although it is more highly shocked than Los Angeles [1,2]. All plagioclase (Pl) grains in the original lithology were melted by an intense shock in the range 55-75 GPa. Clinopyroxenes (Cpx) sometimes show mosaic extinction under a microscope showing that they, too, experienced intense shock. Nevertheless, they zone from magnesian cores to ferroan rims, reflecting the original lithology. Cpx grains also often contain exsolution lamellae, showing that the original lithology cooled slowly enough for the lamellae to form. Because all plagioclase grains were melted by the intense shock and subsequently quenched, the main plagioclase component is glass (Pl-glass) rather than maskelynite. Like Los Angeles, but unlike most basaltic shergottites, Dho 378 contains approximately equal modal abundances of Cpx and Pl-glass. The grain sizes of the original minerals were comparatively large (~1 mm). The original plagioclase zoning has been severely modified. Following shock melting, the plagioclase melts crystallized from the outside inward, first forming outer rims of Cpx-Pl intergrowths (~10  $\mu$ m) followed by inner rims (10's to 100  $\mu$ m) of An<sub>40-50</sub> feldspar, and finally Pl-gl cores of compositions An<sub>33-50</sub> with orthoclase compositions up to Or<sub>12</sub> [2].

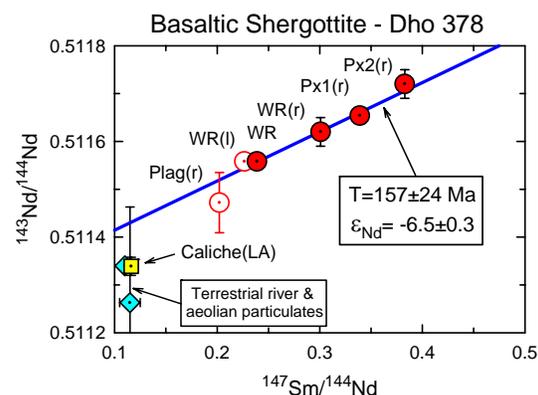
### Sample Preparation:

At JSC two bulk aliquants weighing 26 and 31 mg, resp., were taken from the 340 mg remainder of 550 mg of finely ground material used for major element analyses [2]. The smaller aliquant was analysed directly, the larger was sonicated for 10 min. in 2 N HCl prior to analysis. Mineral separates were prepared from a second ~400 mg sample. A PTS was made from an ~70 mg piece of this sample. The remainder was powdered and sieved to obtain fractions of grain size <74  $\mu$ m and 74-149  $\mu$ m, respectively. A 17 mg Pl-gl sample was obtained from the <74  $\mu$ m fraction by repeated separations with liquids of density 3.32 and 2.85 g/cm<sup>3</sup>, resp. A sample of Pl-gl from the 74 -149  $\mu$ m fraction was used for the Ar-Ar study [3]. Pyroxene samples, Px1 and Px2, resp., were obtained as more magnetic and less magnetic subsamples of density >3.45 g/cm<sup>3</sup>.

### Sm-Nd Age:

Measured Sm and Nd concentrations in the whole rock powder were 1.12 and 2.83 ppm,

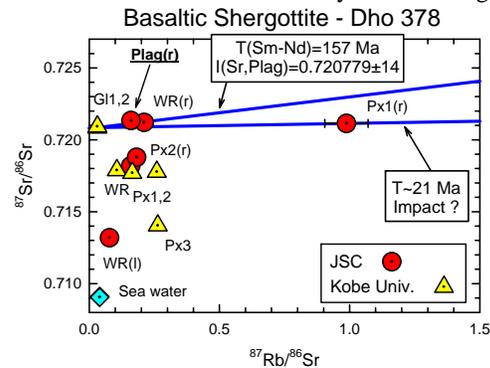
respectively, in good agreement with 1.13 and 2.7 ppm previously reported for another 97 mg bulk sample [4]. <sup>147</sup>Sm/<sup>144</sup>Nd = 0.239 is similar to 0.234 for Zagami ([5] and unpublished JSC data), and 0.232 for a bulk sample of Los Angeles Stone 1 (LA1, unpub. JSC data). The Sm and Nd abundances in our sample of LA1 were 4.5 and 11.8 ppm, significantly higher than those in Dho 378. Our analysis of LA1 may have been unrepresentative, however. Rubin et al. [6] report Sm = 1.94 ppm in LA1, but Sm = 3.4 ppm in LA2. Zagami, Dho 378, LA1, and LA2 show an approximately linear correlation of La to P<sub>2</sub>O<sub>5</sub>; i.e.; La (ppm) ~ 3 x P<sub>2</sub>O<sub>5</sub> (%). P<sub>2</sub>O<sub>5</sub> = 0.77 wt% in Dho 378 [2], in good agreement with 0.66 wt% in a 352 mg sample of LA1, but about 1/2 that of a 207 mg sample of LA2 [6].



**Figure 1. Sm-Nd isochron for Dhofar 378.**

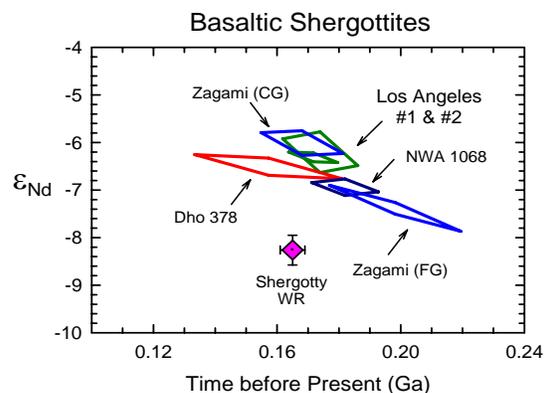
Sm and Nd concentrations in the two pyroxene separates are 0.30-0.35 and 0.53-0.55 ppm, respectively. These values are similar to 0.33-0.34 and 0.32-0.63 [2] for SIMS analyses of augitic cores; rim values are slightly lower [2]. They also are similar to Sm = 0.19-0.33 ppm and Nd = 0.26 -0.50 ppm in Zagami pyroxene separates and to Sm = 0.12-0.31 ppm and Nd = 0.17-0.42 in LA pyroxene separates. <sup>147</sup>Sm/<sup>144</sup>Nd = 0.38 for the most Fe-rich Dho 378 pyroxene, Px 2, is similar to values obtained for Zagami and LA. Wadhwa et al. [7] showed that REE abundances in shergottite pyroxenes are the result of closed system igneous crystallization. Mg/Fe zoning profiles and exsolution textures in Dho 378 pyroxenes were retained during the shock event. Nd = 0.3 ppm in the Dho 378 plagioclase residue after leaching is similar to Nd = 0.2 ppm for a plagioclase separate of LA2. The plagioclase and

whole rock leachate (WR(l)) data lie within error limits of an isochron determined primarily by the pyroxene and whole rock data. The WR(l) data are dominated by Sm and Nd from Dho 378 phosphates. Thus, we interpret the Sm-Nd isochron age of  $157 \pm 24$  Ma for Dho 378 as its crystallization age.



**Figure 2. Rb-Sr data for Dho 378.**  
**Rb-Sr Data**

Rb-Sr data obtained at JSC and in prior analyses at Kobe University are shown in Fig. 2. The data from both laboratories show the pervasive effect of terrestrial weathering and contamination. The effect of contamination was minimized by leaching four samples of high Sr content: two Pl-gl samples analysed at Kobe, and Plag(r) and WR(r) analysed at JSC. The data for these samples, combined with the the Sm-Nd age of 157 Ma, yields initial  $^{87}\text{Sr}/^{86}\text{Sr} = 0.720779 \pm 14$ . Combining this initial  $^{87}\text{Sr}/^{86}\text{Sr}$  value with data for Px1(r) gives an apparent age of ~21 Ma. Possibly this “age” is that of a minor Rb-rich phase produced during shock melting and contained within the Px1 separate. The possibility that the Px1 analysis simply shows less contamination than evident for the other pyroxenes cannot be excluded.



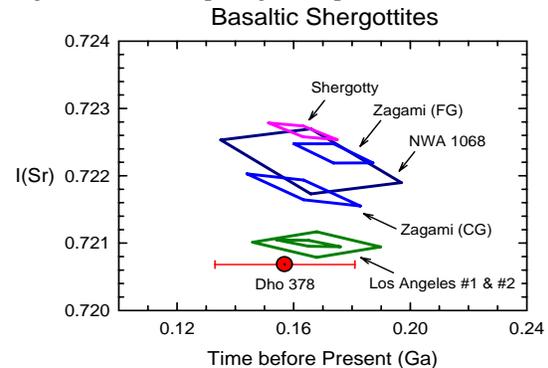
**Figure 3. (T,  $\epsilon_{\text{Nd}}$ ) plot for Dho 378.**  
**Initial  $\epsilon_{\text{Nd}}$**

Negative  $\epsilon_{\text{Nd}} = -6.5 \pm 0.3$  at  $T = 157$  Ma ago for Dho 378 is similar to that of other shergottites of its class (Fig. 3). NWA 1068 is classified among the Ol-bearing doleritic type of the Ol-phyric subgroup [1]. Negative  $\epsilon_{\text{Nd}}$  values indicate assimilation of LREE-enriched crustal materials by basaltic shergottite magmas. The occurrence of the same REE

and isotopic signatures among different shergottite subgroups shows the REE- and P-rich “crustal” component has no detectable impact on the major element composition of the magma, suggesting contamination by metasomatic fluids. The ( $T$ ,  $\epsilon_{\text{Nd}}$ ) data for Dho 378 data match most closely to those of NWA 1068 and Los Angeles.

#### Initial $^{87}\text{Sr}/^{86}\text{Sr}$

Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  (Fig. 4) confirm Los Angeles as the closest isotopic match to Dho 378. They were either co-magmatic or derived from similar source regions via similar petrogenetic processes.



**Figure 4. (T, ISr) plot for Dho 378.**

#### Discussion

The similarity in lithology and mineralogy of Dho 378 and Los Angeles has already been noted [2]. This study extends the similarity to include Nd- and Sr- isotopic systematics. If the three stones, LA1, LA2, and Dho 378 were indeed co-magmatic, the slightly younger Sm-Nd age of Dho 378 compared to previously determined Sm-Nd ages of  $172 \pm 8$  Ma and  $174 \pm 12$  Ma for LA1 and LA2, respectively, may reflect some resetting during shock melting. Park and Bogard [3] suggest that an Ar-Ar isochron age of  $143(+18,-10)$  Ma for Dho 378 may date Ar outgassing in an impact event predating the ~ 3 Ma ejection event. If so, the Sm-Nd age may have been partially reset at that time. However, some other volatile species show no evidence of post-magmatic losses. Bulk  $\text{Na}_2\text{O} = 2.08$  wt% [2] is nearly the same as for LA1 (2.22 wt%) and LA2 (2.13 wt%). The more refractory alkali, K, also is lower in Dho 378:  $\text{K}_2\text{O} = 0.17$  wt% in Dho 378 vs 0.24 and 0.31 wt% in LA1 and LA2, resp. The K/Rb ratio has been shown to be a sensitive indicator of *in vacuo* volatile loss of alkalis. The K/Rb ratio of Dho 378 (~256) is nearly identical to that of LA2 (~245). The possibility that the Ar-Ar age approximates the age of crystallization of very high K phases (alkali feldspar, rhyolitic glass) stochastically enriched in the feldspar sample used for Ar-Ar analysis merits thorough evaluation.

#### References:

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