

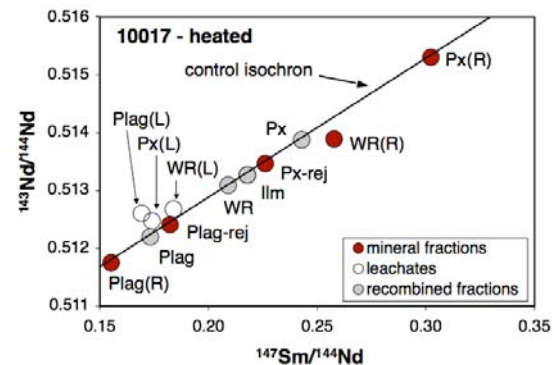
**DISTURBANCE OF Sm-Nd, Rb-Sr AND U-Pb ISOCHRONS DURING SHOCK AND THERMAL METAMORPHISM – AN EXPERIMENTAL APPROACH.** Amy M. Gaffney<sup>1</sup>, Lars E. Borg<sup>1</sup>, and Yemane Asmerom<sup>2</sup> <sup>1</sup>Lawrence Livermore National Laboratory, Chemical, Material and Life Sciences Directorate, 7000 East Avenue, L-231, Livermore, CA 94550; gaffney1@llnl.gov. <sup>2</sup> Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131

**Introduction:** Both shock and thermal metamorphism have the potential to disturb the radiogenic isotope systematics of a meteorite, and reset, rotate or destroy isochrons that would otherwise record the crystallization age and initial isotopic composition of the meteorite. In order to assign petrogenetic significance to the isotope systematics of a meteorite, it is necessary to determine how the sample has been affected by shock or thermal metamorphism. In the attempt to quantify disturbance to isochrons resulting from shock and thermal metamorphism, we undertook experiments to shock and heat a sample of 10017, a mare basalt, and analyzed the shocked, heated and control sample aliquots to determine their isotopic compositions.

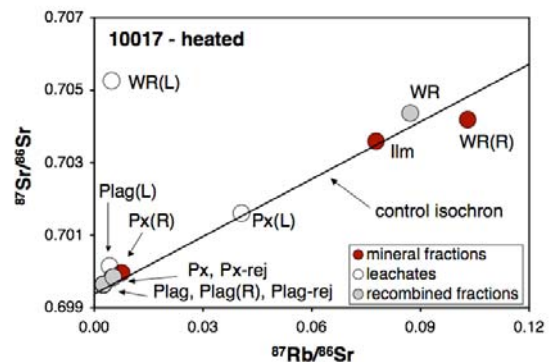
**Methods:** Three aliquots of 10017, a high-Ti mare basalt, were used in this study. One aliquot was heated at 1000 °C, in a vacuum ( $1 \times 10^{-5}$  torr), for one week. A second aliquot was shocked at 55 GPa, by F. Hörz at JSC. The third aliquot was left unshocked and unheated, as an experimental control [1]. Mineral separates of the control and heated aliquots were prepared by magnetic separation and hand-picking. Mineral grains rejected from the magnetic separates during hand-picking were also analyzed, and are designated with the suffix '-rej'. Mineral separates of the shocked aliquot were prepared by magnetic separation only. Most mineral and all whole rock fractions were leached in 2N HCl, at 25 °C, for 10 minutes. Residues from the leaching procedure are designated with the suffix '(R)', and the leachates are designated with the suffix '(L)'. All fractions were spiked with isotope tracers, purified using standard ion exchange techniques, and analyzed by thermal ionization mass spectrometry.

**Sm-Nd results:** The Sm-Nd age determined for the six mineral and whole rock fractions of the control sample is  $3.633 \pm 0.057$  Ga. For comparison, the best age determined for the shocked aliquot is  $3.650 \pm 0.140$  Ga. In contrast, an aliquot of 10017 shocked at 35 GPa and analyzed by Nyquist et al. showed rotation of the Sm-Nd isochron to a younger age of  $2.68 \pm 0.12$  Ga [2]. In our heated 10017 sample, the three leachate fractions fall to the left of the isochron defined by the mineral fractions in the control aliquot, whereas the WR(R) fraction falls to the right of the control isochron (Figure 1). The recombined WR fraction (WR(R) + WR(L)) falls on the control isochron, indicating that the whole rock remained a closed system during heating. The age derived from

the five heated mineral fractions (excluding WR(R)) is  $3.647 \pm 0.053$  Ga, which is nearly identical to the age determined for the control sample.



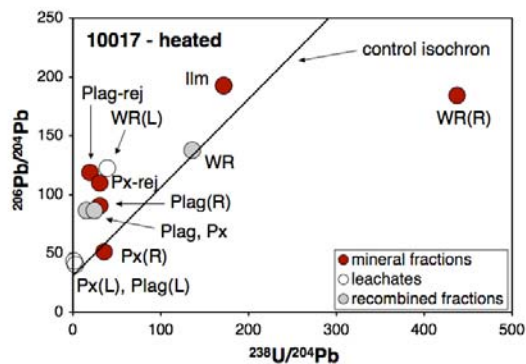
**Figure 1.** Sm-Nd isochron for the heated aliquot of 10017. 'Recombined fractions' show the reconstructed composition of leachate + leached residue (+ unleached reject) for the specified mineral or whole rock. Shown for reference is the 'control isochron' determined for the unshocked, unheated control aliquot of 10017.



**Figure 2.** Rb-Sr isochron for the heated aliquot of 10017. Additional explanation is in the Fig. 1 caption.

**Rb-Sr results:** In the Rb-Sr system for all three aliquots of 10017, the leachates fall to the left of the isochron defined by the mineral fractions in the control aliquot (which corresponds to an age of  $3.678 \pm 0.069$  Ga). The mineral fractions from the shocked aliquot define an age of  $3.606 \pm 0.190$  Ga. In the heated aliquot, most of the fractions, both leachates and leached mineral residues, fall above the control isochron (Fig-

ure 2). The exception is the WR(R) fraction, which falls below the isochron. However, the recombined WR fraction (WR(R) + WR(L)) falls above the isochron, indicating that the whole rock does not remain a closed system during heating. This likely indicates that Rb, which is a volatile element, is lost from the sample during heating. Regardless of this effect, the age determined from the mineral fractions of the heated aliquot (excluding WR(R)) is  $3.586 \pm 0.150$  Ga, which, although low, is nonetheless concordant with the age determined for the control aliquot.



**Figure 3.**  $^{238}\text{U}$ - $^{206}\text{Pb}$  isochron of the heated aliquot of 10017. Additional explanation is in the Fig. 1 caption.

**$^{238}\text{U}$ - $^{206}\text{Pb}$  results:** In the shocked aliquot, all of the fractions, with the exception of WR(L), fall below the control isochron in the  $^{238}\text{U}$ - $^{206}\text{Pb}$  system. This may, in part, reflect Pb isotope heterogeneity in 10017, related to heterogeneous distribution of incompatible element-enriched mesostasis among the aliquots. Alternatively, this may be the result of terrestrial Pb contamination introduced to the sample during the shock experiment [3]. Regardless, the mineral fractions in the shocked aliquot do not preserve coherent age information: the best age, derived from the Px(R), WR(R) and Ilm fractions, is  $3.484 \pm 0.630$  Ga.

The heated aliquot shows considerable disturbance in the  $^{238}\text{U}$ - $^{206}\text{Pb}$  system (Figure 3). As with the Sm-Nd and Rb-Sr isotope systems in the heated sample, the WR(R) fraction falls to the right of the  $^{238}\text{U}$ - $^{206}\text{Pb}$  control isochron and the WR(L) fraction falls to the left of the isochron. The recombined whole rock fraction (WR(R) + WR(L)) falls on the control isochron, suggesting that the U-Pb system remained closed during heating. This contrasts with the inference for the Rb-Sr system. The rest of the fractions, with the exception of Px(R), fall above the control isochron. Further, the recombined plagioclase (Plag(R) + Plag(L) + Plag-rej) and recombined pyroxene (Px(R) + Px(L) + Px-rej) fractions fall a considerable distance above the iso-

chron. The simplest explanation for this is that plagioclase, pyroxene and ilmenite have gained radiogenic Pb during heating. However, none of the analyzed fractions show a complementary depletion in radiogenic Pb, as would be expected if the sample had remained a closed system. This may reflect the fact that the mineral separates analyzed do not represent 100% of the whole rock, and the possibility that the part of the sample that would show the complementary depletion in radiogenic Pb was not analyzed.

**Discussion and conclusions:** For Rb-Sr and Sm-Nd isotope systems, both thermal and shock metamorphism result in ages that are concordant with control ages, although in general, the ages derived from the metamorphosed samples have larger uncertainties than the ages of the control sample. Age information is lost from the  $^{238}\text{U}$ - $^{206}\text{Pb}$  system in the heated sample. Although the inference from meteorites, as well as previous experimental work [2 and references therein], is that rotation and resetting of isochrons are common results of metamorphism, our experimental data do not show either of these effects. No spurious age information appears to be reflected in our results. One possible explanation for this apparent discrepancy is that effects of metamorphism may be dominantly controlled by incompatible element-enriched mesostasis. Effective removal of mesostasis from the mineral fractions during magnetic separation and hand-picking may minimize apparent disturbance to isochrons. Another possibility is that rotation or resetting of isochrons, by equilibration through diffusion, requires heating for times longer than the duration of the experiment.

For all isotope systems in the heated sample, the leached whole rock fraction falls to the right of the control isochrons. This suggests that one common effect of thermal metamorphism may be preferential diffusion of the radiogenic daughter isotope to grain boundaries, from where it may be preferentially removed during leaching. Thus, the combination of heating with leaching, a procedure necessary to remove terrestrial contamination from meteorites, introduces disturbance to the whole rock fractions. The apparent gain of radiogenic Pb by the low- $\mu$  ( $^{238}\text{U}/^{204}\text{Pb}$ ) mineral components during heating indicates that these components may not be reliable indicators of initial Pb isotopic compositions in planetary materials.

**References:** [1] Gaffney, A. M. et al. (2006) *GCA*, submitted manuscript. [2] Nyquist, L. E. et al. (1988) *LPSC XIX*, p. 875-876. [3] Misawa K. et al. (2000) *LPS XXXII*, #1545.

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.