EARLY PETROGENESIS AND LATE IMPACT(?) METAMORPHISM ON THE GRA 06128/9 PARENT BODY.

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Introduction: Initial studies of GRA06128 and GRA06129 (hereafter GRA 8 and GRA 9) suggested that these alkalic meteorites represent partial melts of a parent body of approximately chondritic composition [1-4]. A ^{147}Sm-^{143}Nd isochron age of 4.545±0.087 Ga was found for GRA 8, but plagioclase (oligoclase) plus whole rock and leachate samples gave an apparent secondary age of ~3.5 Ga [5]. The ~4.54 Ga age was interpreted to be the crystallization age of GRA 8; the ~3.5 Ga as an upper limit to a time of metamorphism. Here we extend Sm-Nd and Rb-Sr analyses to GRA 9.

^{147}Sm-^{143}Nd isochron age: ^{147}Sm-^{143}Nd analyses of whole rock and mineral separates of GRA 9 agree well with those of GRA 8 (Fig. 1). Combined data for whole rock and pyroxene residues after leaching define an age of 4.559±0.096 Ga. Initial $\varepsilon_{Nd,CHUR}$ [6] and $\varepsilon_{Nd,HEDR}$ [7,8] are +0.9±0.9 and +0.0±0.9, resp. A plagioclase sample from GRA 9 after leaching extends the secondary isochron previously observed for GRA 8. Data for plagioclase separates from both samples combined with data for whole rocks and whole rock leachates give an apparent age of 3.4±0.4 Ga. Phosphates contain the majority of the REE in GRA, and are sampled by the leachates. Thus, both whole rocks and whole rock leachates behave as approximately closed Sm-Nd isotopic systems, and lie at the intersection of the primary and secondary isochrons. Plagioclase is susceptible to Nd isotopic reequilibration in part because of the low REE abundances in plagioclase. We interpret the secondary isochron age as an upper limit to a time of metamorphism during which the Nd isotopic composition in plagioclase was partly reequilibrated.

^{146}Sm-^{142}Nd isochron age: Data for px from both GRA 8 and GRA 9 combined with data for whole rocks and whole rock leachates define ^{146}Sm/^{144}Sm = 0.0060±0.0014 and $\varepsilon(^{142}Nd)_{Earth}$= -0.26±0.02 at $(^{147}Sm/^{144}Nd)_{CHUR}$ = 0.1967 (Fig. 2). The ^{146}Sm-^{142}Nd age relative to ^{146}Sm/^{144}Sm = 0.0057±0.0005 at 4.542 Ga ago [8] is 4.549±0.036 Ga. The weighted average of the ^{147}Sm-^{143}Nd and ^{146}Sm-^{142}Nd ages is 4.550±0.034 Ga, and is interpreted as the crystallization age of both samples.

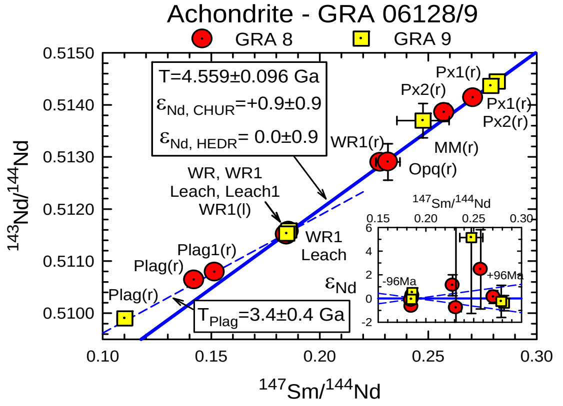

Figure 1. ^{147}Sm-^{143}Nd isochron for GRA 06128/9.

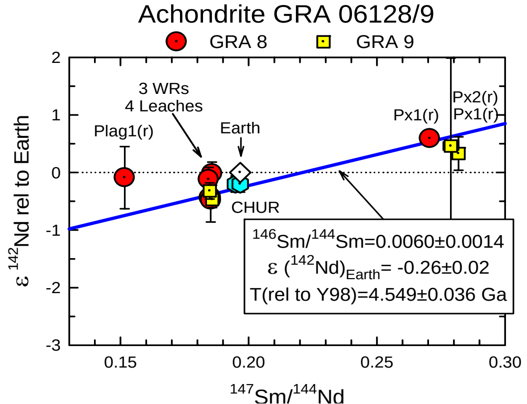

Figure 2. ^{146}Sm-^{142}Nd isochron for GRA 06128/9.

^{87}Rb-^{87}Sr data: Whole rock, whole rock leachate, and whole rock residue data for GRA 8 showed that the leachates are contaminated with Sr having ^{87}Sr/^{86}Sr >~0.715 [5]. Sr isotopic data for GRA 9 are significantly less contaminated. Fig. 3 shows the Rb-Sr data for both samples minus the leachate data. Data for acid-washed mineral separates shown with small interior yellow dots in the figure define apparent ages of 4.31±0.45 and 4.36±0.61 Ga for GRA 8 and GRA 9, resp. Although the two ages are similar, the GRA 8 isochron has a higher initial $(^{87}Sr/^{86}Sr)_I$ = 0.69975±65 compared to 0.69935±77 for GRA 9. Both ages are within analytical uncertainty of the Sm-Nd age, but appear to reflect some Sr isotopic reequilibration as observed for the plagioclase Sm-Nd data. A 4.55 Ga (Sm-Nd age) reference isochron passed through the

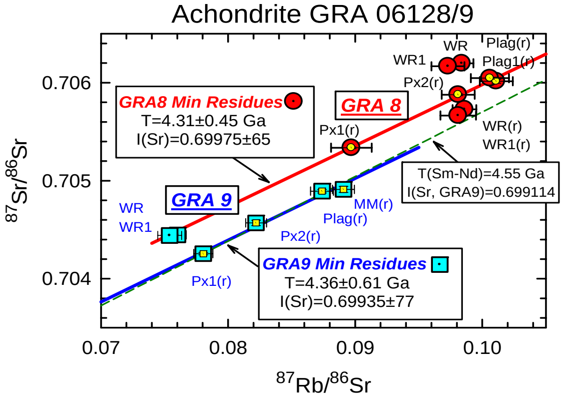

Figure 3. Rb-Sr data for GRA 06128/9.

GRA 9 data gives $(^{87}Sr/^{86}Sr)_I$ = 0.699114±0.000029 which we interpret as the best determination of $(^{87}Sr/^{86}Sr)_I$ for GRA 9. If most of the GRA 8 data are compromised by contamination, it is possible that it shares the same $(^{87}Sr/^{86}Sr)_I$ because two data points of GRA 8 (WR(r) and WR1(r)) lie nearly within their respective error limits on the extension of the 4.55 Ga isochron through the GRA 9 data. Nevertheless, our preferred interpration is that the GRA 8 lithology crystallized with a higher $(^{87}Sr/^{86}Sr)_I$ as would be suggested by its higher whole rock Rb/Sr ratio.

$(^{87}Sr/^{86}Sr)_I$: Fig. 4 compares $(^{87}Sr/^{86}Sr)_I$ for the GRA 8/9 samples to values for (a) Caddo County silicate inclusion 3Ba (CC-3Ba) [9,10], (b) a silicate inclusion from the Campo del Cielo IAB iron meteorite [10], and the Efremovka CAI E38. For GRA 8, $(^{87}Sr/^{86}Sr)_I$ is in complete agreement with that for CC-3Ba. Evolution from $(^{87}Sr/^{86}Sr)_I$ ~0.698934 for the CAI at typical chondritic $^{87}Rb/^{86}Sr$ (μ) ~0.82 would require ~15 Ma for GRA 9 and ~38 Ma for GRA 8, resp. These values probably are maxima. Similar calculations relative to $(^{87}Sr/^{86}Sr)_I$ ~0.698972 for the LEW86010 angrite [11] gives time intervals of ~ 12 Ma and ~35 Ma, resp. Time intervals this long are consistent with the Sm-Nd age, but exceed the ~3 Ma Al-Mg model formation interval reported by [12].

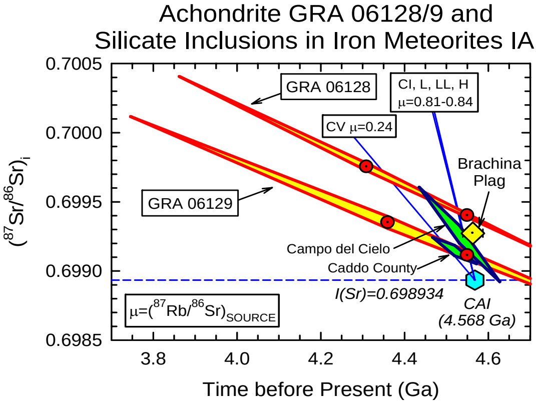

Figure 4. Initial $^{87}Sr/^{86}Sr$ for GRA 8/9 and inclusions in the Caddo County and Campo del Cielo iron meteorites [10].

Discussion: The "young" secondary Sm-Nd isochron age of ~3.4 Ga is similar to Ar-Ar degassing ages found for some eucrites, and suggests impact-resetting by the same "cataclysmic" meteoroid bombardment within the solar system ~3.4-4.1 Ga ago that affected the HEDPB [13]. Textural evidence that GRA 8/9 was severely shocked was cited by several authors (e.g., [1], [2]); [2] suggested extensive post-shock annealing. Different $(^{87}Sr/^{86}Sr)_I$ values for GRA 8 and 9 indicate they are products of different magmatic events. Both observations suggest a sizable parent body.

$\Delta^{17}O$ ~ -0.21 for the GRA meteorites may link them to the parent body of the brachinite achondrites, possibly as flotation cumulates [4]. A bulk sample of Brachina has Sr, Nd, and Sm abundances ~4X and Rb abundances ~3X lower than GRA, consistent with a common parent body [5]. The O-isotopic compositions of silicate inclusions in IAB iron meteorites also are similar to those of the GRA samples. An "andesitic" plagioclase/diopside silicate inclusion from the Caddo County IAB iron [9] has feldspar of composition $Ab_{80-84}An_{12-16}Or_3$ [14] similar to that for GRA. It has similar Rb and Sr abundances as GRA, and Sm and Nd abundances ~2X higher. A model calcuation [5]showed that REE abundances in GRA 9 [3] could be derived from those in the Caddo County 3Ba inclusion by plagioclase accumulation. Fig. 5 shows this model applied to Sm and Sr abundances in GRA 8 and 9. The required enrichment in Sr and REE for CC-3Ba can be modeled by ~15-20% equilibrium partial melting of a chondritic precursor [10]. This model is more compatible with a sizable parent body than ones relying solely on disequilibrium melting of chondritic precursors, for example (*cf.* [12, 15]).

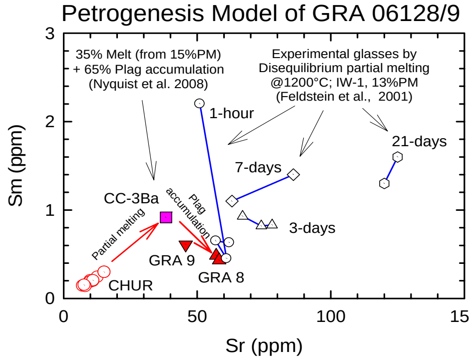

Figure 5. Model for Sm and Sr variation during petrogenesis of GRA 8/9. Solid symbols are measured values for CC-3Ba [10] and GRA 8,9 (this investigation.)

References: [1] Treiman A. H. et al. (2008) LPS XXXIX, Abstract #2214. [2] Arai T. et al. (2008) *ibid.* Abstract #2465. [3] Shearer C. K. et al. (2008) *ibid.* Abstract #1825. [4] Zeigler R. A. et al. (2008) *ibid.* Abstract #2456. [5] Nyquist L. E. et al. (2008) *Meteoritics & Planet. Sci., 43,* A119. [6] Jacobsen S. B. and Wasserburg G. J. (1984) *EPSL,* ***67***, 137-150. [7] Nyquist L. et al. (2006) *GCA, 70, 5990-6015.* [8] Nyquist L. E. et al. (2008) LPS XXXIX, Abstract # 1437. [9] Takeda H. et al. (2000) *GCA, 64,* 1311-1327. [10] Liu Y. Z. et al (2003) LPS XXXIV, Abstract #1983. [11] Nyquist L. E. et al. (1994) *Meteoritcs, 29,* 872-885. [12] Shearer C. K. et al. (2008) *Am. Mineral., 93* 1937-1940. [13] Bogard D. D. (1995) *Meteoritics, 30,* 244-268. [14] Takeda H. et al. (2002) *Meteoritics & Planet. Science, 37,* A139. [15] Feldstein S. N. et al. (2001) *Meteoritics & Planet. Science, 36,* 1421-1441.