AN ~ 4.35 Ga Ar-Ar AGE FOR GRA 8 AND THE COMPLEX CHRONOLOGY OF ITS PARENT BODY.
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Introduction:GRA06128 and GRA06129 (hereafter GRA 8 and GRA 9) are partial melts of a parent body of approximately chondritic composition [1-3]. We [4,5] reported a conventional 147Sm-143Nd isochron age of 4.559±0.096 Ga and a 146Sm-142Nd model age of 4.549±0.036 for combined data for the two rocks. Plagioclase plus whole rock and leachate (~phosphate) samples gave a secondary 147Sm-143Nd age of 3.4±0.4 Ga [5]. An 39Ar-40Ar age of 4.460±0.028 Ga [3,6] was interpreted by [3] as dating metamorphism in GRA 9. We report 39Ar-40Ar ages in this study and discuss these ages in the context of the complex sequence of events that affected these samples (cf. [3]).

39Ar-40Ar Stepped Ar-Release Ages for GRA 8:
We did a stepped-temperature Ar extraction (49 steps) of a plagioclase separate of GRA 8 (12.7 mg) of low magnetic susceptibility (Fig. 1). Small age variations occurred among “phases” with different K/Ca at low, intermediate, and high extraction temperatures, and the summed age is 4354 Ma. Partitioned according to the fraction of 39Ar released, the calculated ages varied from 4326±18 to 4344±14 to 4362±18 Ma (10 steps) for 4-14%, 14-47%, and 52-96% 39Ar released, resp. A single temperature step for 47-52% of the 39Ar release appeared to mark a transition in the gas release mechanism as also seen in an Arrhenius plot constructed from the data (Fig. 2).

Discussion:Viewed in isolation, these 39Ar-40Ar data are well-defined and could be interpreted as giving a relatively unambiguous chronology for GRA 8 consisting of initial formation at 4366±19 Ma ("most reliable" high-T age for 52-80% 39Ar release) followed by final closure to Ar loss at 4344±14 or 4326±18 Ma as a result of subsolidus recrystallization (cf. [3]). However, consideration of all the chronological data for GRA 8/9 presents a more complicated picture.

Comparison to 39Ar-40Ar age of GRA 9. Fernandes [3,6] reports the 39Ar-40Ar age of GRA 9 to be 4460±28 Ma. Thus, the 39Ar-40Ar ages of GRA 8 and 9 appear to be clearly resolved, which we suggest is the result of different thermal histories for the two samples.

Comparison to 147Sm-143Nd isochron ages. The 147Sm-143Nd data for GRA 8 and 9 are complex (Fig. 3). With the assumption that both bulk rocks remained closed isotopic systems, the data appear to show a secondary age of 3.4±0.4 Ga for plagioclase/whole rock superimposed on a primary age of 4559±96 Ma.
for pyroxene/whole rock [5]. However, if the isotopic system were open due, e.g., to the introduction into a mainly plagioclase/pyroxene cumulate rock of a phase from which phosphate crystallization occurred, the necessity to include the “whole rock” (WR) data in a primary isochron fit would be removed. In this case, a plagioclase plus pyroxene tie-line gives an apparent age of 4.24±0.07 Ga (2) nearly within error limits of the intermediate-temperature 39Ar-40Ar age of 4344±28 (2). However, a similar exercise for GRA 9 results in an apparent age of 4.00±0.11 Ga. This age is younger than the 39Ar-40Ar age, but the first ~11% of the gas release gives a hint of a younger age near ~4.0 Ga [6].

**Figure 3.** 147Sm-143Nd data for GRA 8 and 9 [5]. Pyroxene-plagioclase tie-lines have been added to show the effect of the leachate (~phosphate data).

**Comparison to 87Rb-86Sr data.** The 87Rb-86Sr isochron ages are relatively poorly defined because of terrestrial contamination and the modest range in 87Rb/86Sr ratio [5]. Fig. 4 shows the Rb-Sr data in a (T, ISr) plot for those data judged to be most reliable. The 39Ar-40Ar ages for GRA 8 and 9 are plotted within the error parallelograms for the Rb-Sr data. The two data sets are consistent in showing that (a) GRA 8 and 9 differ, and (b) the 39Ar-40Ar ages are close to the nominal ages obtained from the Rb-Sr isochrons. We noted previously that evolution from (87Sr/86Sr) ~0.7030 to 0.7050 requires a precursor with lower 86Sr/88Sr ~ 0.125 like that in CV chondrites. Interestingly, Arai et al. [7] suggested a volatile-rich carbonaceous chondrite parent asteroid for GRA 01628/9.

**Alternative scenarios.** Shearer et al. [3] recognize three major post magmatic events: (1) subsolidus re-equilibration to form a granoblastic texture; (2) reaction between the primary magmatic phases and either a residual melt or a fluid phase; (3) low temperature alteration along grain boundaries and fractures. They equate the ~4.46 Ga 39Ar-40Ar age of GRA 9 [3,6] to (1) above. Because 40Ar would be rapidly outgassed at the corresponding temperatures, we equate subsolidus equilibration to the 4344±14 Ma age obtained for GRA 8 at intermediate temperatures. We furthermore equate the younger 3.4±0.4 Ma secondary Sm-Nd isochron to process (2) above. Low temperature alteration probably is manifested only as “isotopic disturbances”. Two alternatives for the primary crystallization ages of GRA 8 and 9 are: (1) Both formed ~4.56 Ga ago, and 39Ar-40Ar ages between ~4.56 Ga and ~4.34 Ga ago are due to slow cooling of the parent body or separate impact events. (2) The crystallization age of each stone may be close to its 39Ar-40Ar age, i.e., for GRA 8 the high temperature age of 4362±18 Ma. This interpretation implies late magmatism on the parent body, and allows easy interpretation of the Rb-Sr data, but requires the ~4.56 Ga ages to have been carried into the rocks via phosphates introduced via open system reactions with external melts or fluids. Shearer et al. [3] identify merrillite as one of the primary magmatic phases favoring (1) above, but Treiman et al. [1] note phosphate replacing pyroxene and merrillite replacing apatite, perhaps a hint of open system processes permitting (2) above.

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