^{40}AR-^{39}AR AGES OF METAMORPHISM PRESERVED IN THE ACHONDRITE GRA 06129

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GRA 06129: The recently recovered paired Antarctic achondrites Graves Nunatak 06128 and 06129 (GRA) are meteorites representing high-temperature asteroidal processes that are identified in only a few other meteorites [1,2]. The high temperature assemblage in the GRA meteorites (high abundances of sodic plagioclase, relatively Fe-rich pyroxenes and olivine, abundant phosphates), in part, represents an episode of very early planetesimal melting (~4.566 Ga, [1]) of a geochemical reservoir from an asteroid that has characteristics similar to the brachinite parent body [1,2]. Superimposed on the high-temperature magmatic assemblage are multiple events such as subsolidus cooling, metamorphism, shock, and potentially interactions between fluid and the mineral assemblage. Using Ar-Ar, we attempt to reconstruct the events following the initial period of crystallization.

Analytical method: The ^{40}Ar-^{39}Ar laser stepped-heating technique has been applied to three fragments of GRA 06129 weighing 1.85, 2.30 and 2.95 mg. The aim was to possibly determine the time of crystallisation and the age of event(s) that may have caused the observed metamorphism. Prior to analyses, the fragments were irradiated for 100 hours in a Cd-shielded (to minimize undesirable isotopic interference reactions) CLICIT facility of the TRIGA reactor at Oregon State University, USA. Samples and the neutron fluence monitor PP-20 hornblende (the same as Hb3gr) were loaded into pits within aluminium disks. The J-values were calculated relative to an age of Hb3Gr = 1073.6±5.3 Ma [3] and using the decay constants of [4]. All measurements were corrected for blank, mass discrimination, interference and radioactive decay.

Results: ^{40}Ar-^{39}Ar step heating data for the three bulk fragments of GRA 06129 are reported in Table 1, age spectra in Fig. 1, ^{40}Ar/^{36}Ar vs. ^{39}Ar/^{36}Ar plot in Fig. 2, and in Fig.3 is plotted ^{38}Ar/^{36}Ar vs. Fraction of ^{39}Ar release.

Table 1 Summary of ^{40}Ar-^{39}Ar measurements for three bulk fragments of GRA 06129.

GRA06129 aliquot	Weight (mg)	Plateau Age (Ga)	Slope Age (Ga)	^{39}Ar release (%)	Total ^{38}Ar (moles x10^{-16})
1	1.85	4.425±0.016	4.424±0.032	35	1.80±0.03
2	2.95	4.473±0.016 2.673±0.038[a]	4.460±0.008	89	1.50±0.01
3	2.30	4.467±0.018 3.845±0.034[a]	4.463±0.009	92	2.27±0.01

[a]Minimum apparent age during IR-laser step heating sorresponding to maximum age for an event that caused the partial re-setting observed at low-temperature steps. The preferred age for this resetting is ≤2.673±0.038 Ga which is not fully shown in the release spectrum of aliquot-3 (Fig.2) due to differences in the step heating schedule - the step heating schedule for aliquot-2 began at lower temperature (i.e. power) than that for aliquot-3.

A total of 69 heating steps were acquired for aliquot-1 giving a complex release namely for the low and intermediate temperature steps, comprising ~65% of the total ^{39}Ar release (Fig.1). The apparent ages for these steps are in most part well above the age of the Solar System and thus have no chronologic meaning. Based on attempts to correct for either trapped and/or cosmogenic ^{40}Ar/^{36}Ar the complex release over the low temperature steps suggest likely the redistribution of radiogenic argon rather than the contribution from trapped and/or cosmogenic components. For the last 10 heating steps, a plateau comprising ~35% of the total ^{39}Ar release gives an age of 4.425± 0.016 Ga. This age is the same as that obtained for the slope of the correlation line in a ^{40}Ar/^{36}Ar vs ^{39}Ar/^{36}Ar plot, 4.424±0.032 Ga, over these high temperature steps. The trapped ^{40}Ar/^{36}Ar component for these high temperature steps is negligeable, thus no correction was performed.

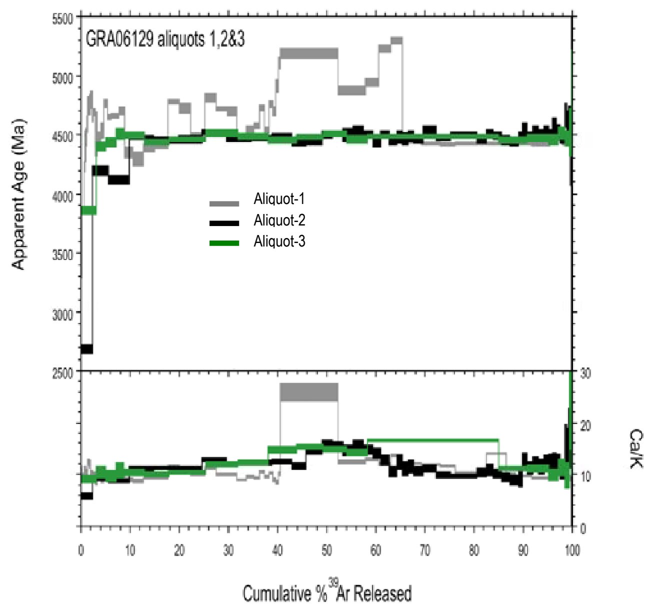

Fig. 1 Apparent age (Ga) vs. Cumulative ^{39}Ar (%) released per step heating for three whole rock aliquots of GRA 06129.

Argon age spectra for aliquots-2 and 3 suggest a partial degassing over the initial 8-11% of ^{39}Ar release and corresponding to an age of ≤2.673±0.038 Ga. The reminder 89-92% of ^{39}Ar release gives well defined plateaux corresponding to ages of 4.473±0.016 Ga (aliquot-2) and 4.467±0.018 Ga (aliquot-3), and having no contributing trapped ^{40}Ar/^{36}Ar. These ages are indistinguishable from those obtained from the slope on the ^{40}Ar/^{36}Ar vs. ^{39}Ar/^{36}Ar isochron line, 4.460±0.032 Ga (aliquot-2) and 4.463±0.010 Ga (aliquot-3). In Fig. 2 it is shown the data for the three aliquots analysed in a ^{40}Ar/^{36}Ar vs. ^{39}Ar/^{36}Ar plot. The correlation line corresponds to a regression over all the three aliquots data considered on the three plateaux. The slope of this line corresponds to an age of 4.460±0.028 Ga. The overall pattern of the Ca/K spectra for the three GRA 06129 aliquots (Fig.1) show a constant value of ~10 along the individual spectra. However, there is a slight increase (Ca/K=13-16) at intermediate temperatures suggesting argon release from a phase(s) relatively enriched in Ca (e.g. apatite and/or pyroxene).

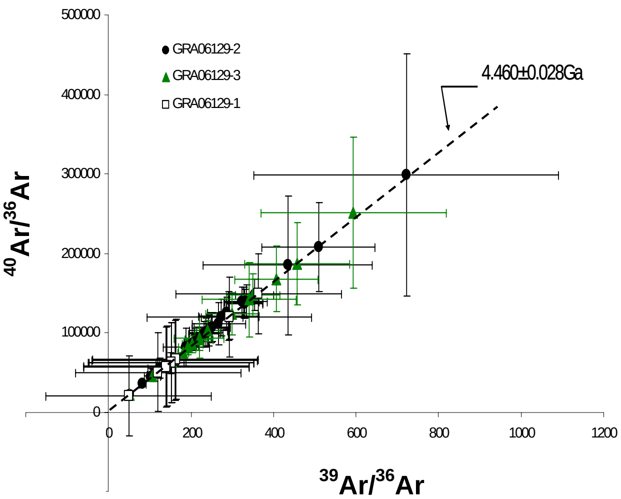

Fig. 2 $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ for the three bulk aliquots of meteorite GRA 06129. The correlation lines was acquired over all the data obtained for the three aliquots.

The $^{38}Ar/^{36}Ar$ values show complex patterns likely to involve one or more Cl-rich phase(s), Fig.3. In Table 1, ^{38}Ar (moles) are reported for each aliquot and shows that the three aliquots have different amounts of ^{38}Ar, with aliquot-3 having ~1.5 times more ^{38}Ar than aliquots 1 and 2. Aliquots 2 and 3 show $^{38}Ar/^{36}Ar$ values at intermediate temperatures well above the cosmogenic value (1.54), between 2.2 and 13.1. For these steps there is no evidence for terrestrial contamination, which is usually seen as an increase in the Ca/K most notably at low-temperature heating steps. This is likely due to the existence of a Cl-rich phase(s) within GRA 06129 which, due to the nucleogenic reaction during irradiation, decays into two argon species. During irradiation, ^{37}Cl captures a neutron, becoming ^{38}Cl, which will β-decay to ^{38}Ar at a half-life of 37.3 min. The release patterns are not the same for the three aliquots, suggesting different Cl-rich components and proportions in each aliquot. Consequently, and due to the difficulty in determining the spallation-derived $^{38}Ar_{Ca}$, no cosmic ray exposure ages were calculated.

In Day et al (2009) and Shearer et al (2009), it is reported that GRA 06129 contains low-temperature alteration products such as clays and chlorides and also igneous apatite containing high Cl content (~5wt%, [1]). It is likely that both phases are the culprits for the high $^{38}Ar/^{36}Ar$ values observed at intermediate and high temperature steps. However, due to the high Cl content of the apatite and the slight increase in Ca at the intermediate temperature heating steps (see Fig. 2 and 3), it is likely that the apatite is the major contributor for this excess ^{38}Ar, and which released over most of the intermediate and high temperature steps of aliquots 2 and 3.

Age of Metamorphism: The primary crystallization age of ~4.566 Ga inferred here from the Al-Mg systematics for GRA [1] is ~106 million years older than the 4.460±0.028 Ga Ar-Ar age calculated from the slope of the correlation line in Fig. 2. This complete K-Ar system reset age may correspond to the age of metamorphism and/or the formation of the granoblastic texture. This event is not uniquely preserved in this meteorite as it has also been observed in HED-achondrites and chondrites (for a complete list see [5,6] and references therein). A more recent thermal event at ~2.67 Ga, only partially reset the K-Ar system as observed in the initial ~10% ^{39}Ar release (Fig. 1). This event maybe that which produced the low-temperature alteration observed in this meteorite. Similar partial reset ages at 2.5-2.6 Ga have been reported for other meteorites such as the impact melt in H-chondrite NWA 2457, Johnstown diogenite and Netschaëvo IIE [7-9].

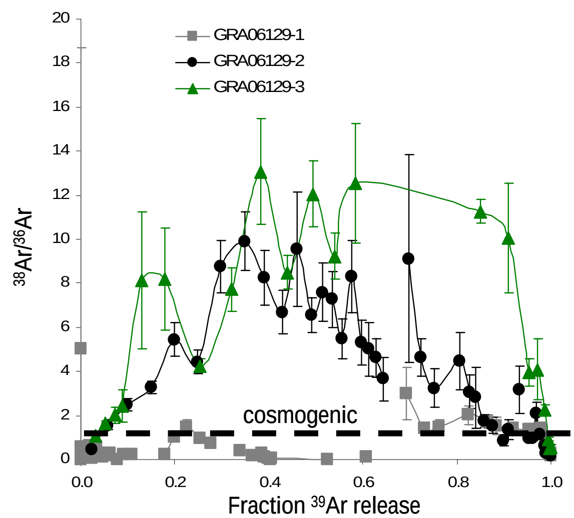

Fig.3 $^{38}Ar/^{36}Ar$ vs. Fraction ^{39}Ar release for the three bulk aliquots of meteorite GRA 06129. The $^{38}Ar/^{36}Ar$ values at low and intermediate temperature steps for aliquot-1 (~90% of ^{39}Ar release) suggest a predominance of the trapped $^{38}Ar/^{36}Ar$ component with a value of ~0.1869. The last 10% of argon release suggest the predominance of the cosmogenic component with a value of ~1.54. Most steps for aliquots-2 and -3 (75-92% ^{39}Ar release) show high contribution from ^{38}Ar indicating contribution from a Cl-rich phase, e.g. apatite. Only the last 3-10% ^{39}Ar released show a mixture of the trapped $^{38}Ar/^{36}Ar$ component (0.1869) and cosmogenic $^{38}Ar/^{36}Ar$ component (1.54).

Acknowlegdgements: Financial support from the Ann and Gordon Getty Foundation

Referencess: [1] Shearer et al. (in press) Geoch. et Cosmoch. Acta, 0.1016/j.gca.2009.10.029; [2] Day et al. (2009), Nature 457, 179-182; [3] Jourdan et al. (2006) Geoch. et Cosmoch. Acta, 44, 1829-1840; [4] Steiger & Jäger (1977) Earth Planet. Sci. Lett. 36, 359–362; [5] Bogard (1995) Meteoritics, 30, 244-268; [6] Swindle et al. (2009) Met. And Planet. Sci. vol. 43, 747-62; [7] Balacescu & Wänke (1977) Meteoritics 29, 439-440; [8] Niemeyer (1980) Geoch. et Cosmoch. Acta 44, 1829-1840; [9] Fernandes et al. (2006) 69th Met. Soc. Conf. abst#5308.