^{40}Ar/^{39}Ar THERMOCHRONOLOGY OF A FOSSIL LL CHONDRITE FROM MOROKWENG CRATER, SOUTH AFRICA.

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Introduction: Studies of meteorites are based mostly on samples recovered from meteorites that fell on Earth in a recent past (i.e. a few million years at most). The Morokweng meteorite is a rare specimen as it is the only complete fossil stony macro-meteorite clast (25 cm-in-diameter) found in the melt sheet of an end-Jurassic impact structure [1]. The ^{40}Ar/^{39}Ar chronometer has typical low closure temperature of few hundred °C and thus, has the potential to investigate heating events, such as large collisions between asteroids [2]. When applied to the Morokweng meteorite, ^{40}Ar/^{39}Ar thermochronology provides an interesting opportunity to study (1) effects associated with pre-impact and post-impact processes and (2) collision events within a potentially unsampled and different asteroid population.

Morokweng Impact Structure and Morokweng Fossil Meteorite: The Morokweng impact crater in South Africa is a complex, multiring structure with a ~130 km radius external ring and asymmetric radial sectors [3]. The preserved impact melt sheet is at least 870-m-thick and is particularly rich in platinum group elements [1]. Investigations of the age of the crater via U/Pb and ^{40}Ar/^{39}Ar dating techniques suggest an impact age of 145.2 ± 0.8 Ma (2σ; [4]). The Morokweng meteorite consists of an unaltered 25-cm-wide fragment classified as LL-chondrite breccia with a composition close to the Fe-rich end-member [1]. The chondrite includes olivine and orthopyroxene phenocrysts and the matrix consists of olivine, orthopyroxene, plagioclase, chromite, apatite and minor pentlandite and pyrrhotite [1].

^{40}Ar/^{39}Ar Systematics: Plagioclase grains (100-300 µm) were carefully separated from the Morokweng meteorite by hand-picking under a binocular microscope. Step-heating analyses were carried out on (1) individual plagioclase grains and (2) multi-grain aliquots wrapped in a 0-blank Nb-foil, at the Western Australian Argon Isotope Facility, Curtin University of Technology. Step-heating experiments yielded complex age and K/Ca spectra (Fig. 1), with generally Ca-poor domains showing a rough Jurassic age and Ca-rich domains showing ages ranging from ~200 Ma to ~2.3 Ga. A global inverse isochron plot including all the steps of all the aliquots (Fig. 2) shows (1) a shallow isochron with an age at 143 ± 16 Ma (MSWD=0.88; P=0.55), similar to the age of the Morokweng crater [4] and (2) the occurrence of radiogenic ^{40}Ar* undegassed during the Morokweng impact and that can potentially tells us about the thermal history of the Morokweng meteorite.

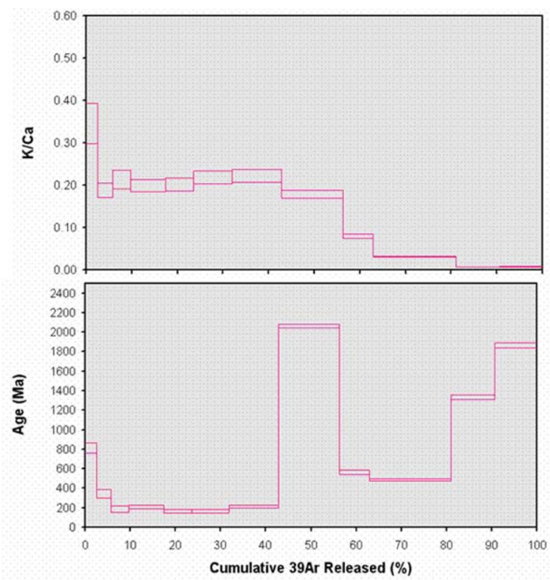

Fig. 1: K/Ca and age spectra of a selected multi-grain plagioclase aliquot of the Morokweng meteorite.

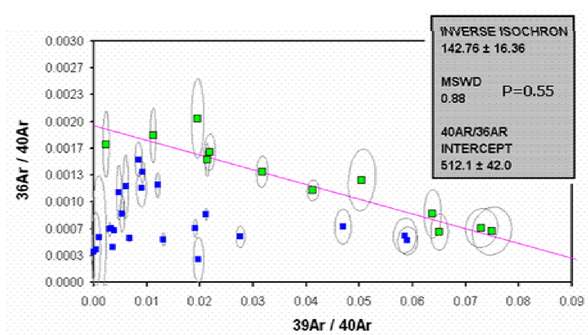

Fig. 2: Inverse isochron diagram of all experiments combined in a single plot. The age given by the shallow isochron (green symbol) reflects the age of the impact at ~143 Ma. Blue symbols are steps not included in this particular calculation.

Only one multi-grain aliquot experiment yielded a relatively simple inverse isochron with an age at 706 ± 130 Ma (Fig. 3; MSWD= 2.15; P=0.08) possibly indicating a major collisional event at this time.

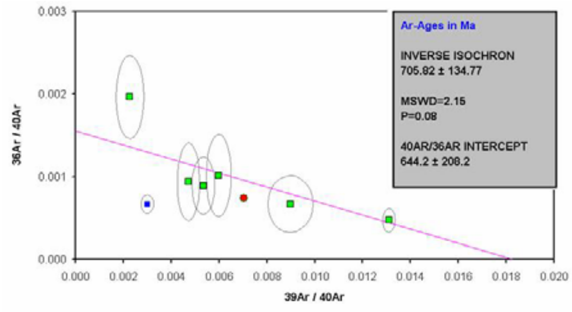

Fig. 3: Inverse isochron diagram of a step-heated 4-5 grains aliquot, suggesting a resetting event at 706 ± 130 Ma.

A ~2.0-2.3 Ga event recorded by the Morokweng meteorite? Individual steps show that the Ca-poor domains have a K/Ca ratio typical of the Morokweng plagioclase grains (~0.2; [1]), whereas Ca-rich domains (associated with comparatively older ages) are not typical of the Morokweng meteorite plagioclase composition. The Ca-rich phase could consist of refractory Ca-rich plagioclase domains not tapped during the EMP analyses, Ca-rich pyroxene with plagioclase inclusions, and apatite with plagioclase inclusions. In the last two cases, the pyroxene or apatite can have acted as a capsule, shielding plagioclase inclusions from being entirely reset during modest heating event(s). Age and K/Ca distribution of the Morokweng dataset is best explained by ~~a~~ mixing between Ca-poor plagioclase (K/Ca = 0.22) with an age of ~145 Ma and apatite with plagioclase inclusions (K/Ca = 0.22) having a maximum age of 2.3 Ga (when corrected for non-atmospheric trapped and cosmogenic argon, otherwise 2.04 Ga if corrected for atmospheric argon only; Fig. 4). It is not clear if the oldest apparent age indicates that the last total reset occurred at ~2.0-2.3 Ga or if it is the result of a partial reset of the $^{40}Ar/^{39}Ar$ system during a younger event. Two additional steps at ~2.9 Ga might reflect the true end-members of the mixing curves but the poor signal size and precision associated with these results prevent us to include them in the discussion.

Implications, Speculations and Conclusions: Apparent ages of all high-Ca samples (plagioclase inclusions shielded within apatite crystals?) suggest that the last total reset of a LL-parent body occurred ~2.0-2.3 Ga ago, although such an apparent age can represent an intermediate (and thus meaningless) partial reset age. A single multi-grain aliquot yielded an inverse isochron age of 706 ± 130 Ma possibly indicating a second major event recorded in the plagioclase. If real, any of these events are most probably related to large asteroid collisional (breakup?) events. Speculatively, the ~2.3 Ga event might have set the 2.02 Ga Vredefort impactor to its course to earth.

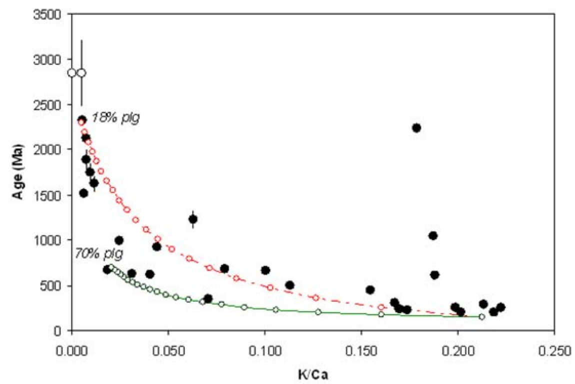

Fig. 4: Age (corrected for trapped and cosmogenic Ar) vs K/Ca for individual steps obtained on 5 plagioclase multi-grain aliquots. Mixing curves: mixing between Ca-poor plagioclase (K/Ca = 0.23; age = 145 Ma) and apatite with plagioclase inclusions (red curve: 18% plg, K/Ca = 0.005, age = 2300 Ma; green curve: 70% plg, K/Ca = 0.021 & age = 700 Ma). White symbol corresponds to excluded low-precision steps.

Finally, K-rich plagioclase yielded a global low-temperature isochron age of 143 ± 16 Ma indicating total reset of this phase (or crystallization of K-rich alteration product?) during the impact of the meteorite on Earth. More studies on fossil meteorites need to be carried out to understand if the rough ages proposed here correspond to major asteroid population destructions or rather, to isolated collision events.

References: [1] Maier W. D. et al. (2006) *Nature*, 441, 203-206. [2] Boggard D. D. (2002) 65th *Ann. Met. Soc. Meeting*, Abstract 5023. [3] Andreoli M. A. G. et al. (2008) *LPI Large Meteorite Impacts Planet. Evol. IV*, Abstract 3048. [4] Hart R. J. et al. (1997) *Earth Planet. Sci. Lett.*, 147, 25-35. [5] Korochantseva, E. V. et al. (2007) *Meteoritics & Planet. Sci.*, 42, 113-130.