REE PATTERNS IN LUNAR ZIRCONS. A.A. Nemchin, R.T. Pidgeon and M.L. Grange, Department of Applied Geology, Curtin University of Technology, Bentley, Western Australia, 6102, Australia (nemchina@kalg.curtin.edu.au).

Introduction: The unique ability of zircon to concentrate U, its wide distribution in the variety of rocks of different origin and composition and its stability under a range of P-T conditions make this mineral one of the most extensively studied accessory phases. Our initial application of zircon U-Pb systems to lunar rocks has evolved into investigation of the chemistry and textural characteristics of this mineral, driven by the necessity to identify the petrological, geochemical and genetic significance of the recorded U-Pb ages. We have studied the trace element geochemistry of zircon, and here we describe results aimed at identifying the significance of chondrite normalised REE patterns and their variation. In particular we attempt to: (i) determine the limits of variation of REE concentrations in zircon formed from magma of different composition, with the further aim of using this information as a petrogenetic indicator and (ii) use recently determined zircon-melt distribution coefficients for REE ($^{zircon/melt}D_{REE}$) to calculate REE contents of melts coexisting with the zircon.

The great advantage of studying lunar zircons is the relative simplicity of these grains. Lunar zircons commonly preserve only one age showing no overprints or overgrowths. Complex reprecipitation-recrystallisation reactions, common in the terrestrial zircon, are not present. Metamorphic zircons are also absent in the lunar rocks, while hydrothermal alteration is not possible due to the lack of water on the Moon. Although, lunar rocks are dominated by mafic compositions, zircons are found to be associated with a variety of rocks, ranging in composition from mafic to felsic [1, 2] giving a necessary spread to make a comparison with their terrestrial counterparts. However, only few REE analyses of lunar zircons have been reported so far [3, 4, 5].

In this presentation we discuss variations of REE patterns observed in 15 zircon grains extracted from breccia sample 14321. This particular set was selected as previous studies [e.g. 6] showed that it represents a variable group of zircons with different origins and therefore can provide an initial indication of the possible range of REE concentrations in lunar zircons.

Sample: Polymict breccia 14321 from the rim of Cone Crater is the largest of the samples returned by the Apollo 14 mission. The breccia boulder 14321 is thought to be from 60-80 meters deep (well below the regolith) and within the underlying bedrock, referred as the Fra Mauro Formation. The components identified in the sample preserve a record of a remarkable series of large scale impact events.

The breccia has been the subject of an extensive and systematic study of the composition, texture and degree of metamorphism of clasts and matrix [7, 8]. It incorporates diverse lithic and single crystal fragments including basalt clasts, troctolites, anorthosites, granophyre and microbreccia [8, 9].

Fifteen zircon grains have been found in the sawdust collected during the initial cutting of the sample. U-Pb ages of these zircons determined by [6] show a significant spread of between 4.37 and 3.90 Ga. This variation as well as the large range of U and Th concentrations, from 8 to 787 ppm and from 3 to 312 ppm respectively, is inferred to reflect significant differences in the origin of the zircons, not only in terms of age, but also with respect to the potential source rocks.

Results: Multiple analyses of individual zircon grains indicate internal homogeneity of lunar zircons with respect to the REE concentrations, even when there is a significant variation in the cathodoluminescence response of different parts of the grains. However, REE distribution patterns of the fifteen zircon grains reveal significant differences between the grains (Fig.1), which can be separated into four types, mainly on the basis of variation in the LREE.

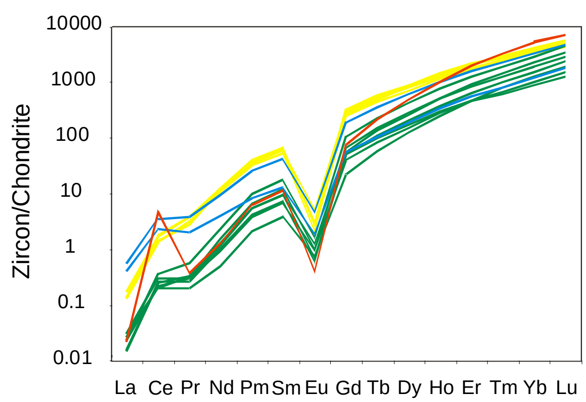

Figure 1: Chondrite normalized REE patterns in the zircon grains from sample 14321 (green line-type-1 grains; yellow line-type-1 grains; blue line-type-3 grains; red line-type-4 grain)

Type-1 includes seven grains and is characterized by a relative depletion in LREE. Five grains (type-2) show a very narrow range of REE concentrations and significant enrichment in LREE compared to the type-1 zircon. Two grains (type-3) show even stronger enrichment in LREE and slight depletion in HREE which makes the overall pattern flatter relative to the type-1 and -2 zircons. Finally a single grain shows a unique pattern characterized by strong Ce anomaly and has the largest Yb/La ratio.

There is no apparent correlation between the age of the grains and their REE composition. For example, five grains are older than 4.3 Ga and have identical ages within the error, with an average of 4340±6 Ma. Three of these grains are characterised by a LREE enriched (type-2) pattern while the other two belong to type-1 zircon. The different REE patterns observed in the analysed zircons cannot result from fractionation of the same melt. Rather a combination of zircon ages and REE concentrations suggests that the analysed grains must represent at least eight different rock units preserved as clasts within the breccia sample.

Discussion: Unlike many terrestrial zircons lunar grains show remarkable internal homogeneity with respect to the REE concentrations and chondrite normalized patterns. However, the range of variation in REE within the group of analysed lunar zircons is similar to that shown by the entire set of terrestrial grains from a variety of magmatic rocks ranging in composition from gabbro to aplite [e.g. 10]. On the discrimination diagrams recently proposed to distinguish between zircons associated with Earth's continental and oceanic crust [11] lunar zircons fall close to the line separating two types, but in the field of continental crust zircons,

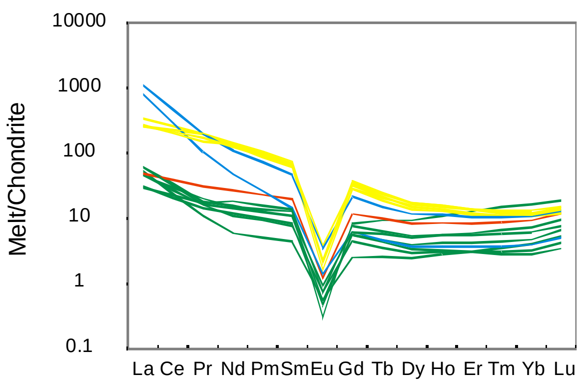

Figure 2: Chondrite normalized REE patterns calculated for the melts coexisting with the zircon grains from the sample 14321 (colours are similar to those in figure-1)

which is not surprising considering the association of lunar zircons with the rocks enriched in the incompatible elements (KREEP). Patterns with flat LREE found in some zircons from highly evolved terrestrial granites and also discovered in the oldest terrestrial zircons from the Jack Hills (Western Australia) [12], are not observed in lunar zircons, supporting the interpretation that such patterns are the result of hydrothermal alteration.

Typical slightly V-shaped patterns have been determined for melt co-existing with lunar zircons (Fig. 2), using recently published distribution coefficients [13], based on ion probe analyses of coexisting glass, zircon and apatite. Type-1 and 4 grains appear to co-exist with the melts, showing REE patterns similar to those observed in the Mg-suite rocks, while type-2 zircons result in model melts resembling some of more evolved rocks of the Alkali-suite. Type-3 zircons define REE pattern with a substantial enrichement in LREE observed in some Alkali-suite anorthosite samples. The latter however, contain an order of magnitude smaller amounts of REE.

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