1950 Ma ANNEALING OF RADIATION DAMAGE IN A COMPLEX ZIRCON FROM AN APOLLO 15 BRECCIA. R.T. Pidgeon[1], M. L. Grange[1] and A.A. Nemchin[1]
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Introduction: The ability of high resolution ion microprobes to measure the U-Pb isotopic systems of small areas on the polished surface of zircon grains from lunar breccias and soils has provided a new dimension in lunar geochronology. Also, the addition of other physical and chemical techniques such as Electron Back Scattered Diffraction, SIMS oxygen isotope analyses and Raman spectroscopy has added significantly to the U-Pb results. In this report we apply a combination of Raman spectroscopy and SIMS U-Pb results to investigate the history of a complex lunar zircon from an Apollo 15 Breccia.

SIMS U-Pb Analyses: SIMS U-Pb analyses have been made on zircon samples from breccias from Apollo 14 and 17 [1] and from lunar meteorites [2]. Whereas the U-Pb systems in most grains are undisturbed a number of zircon grains show complex U-Pb systems indicating a history of U-Pb disturbance due to impact metamorphism [3].

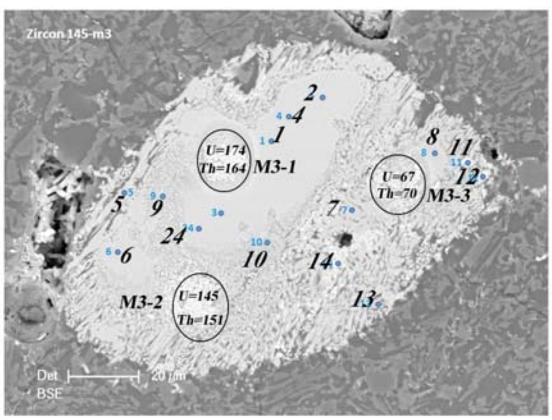

Figure 1. Zircon M3 showing SHRIMP and Raman Analytical spots

Disturbance of the U-Pb systems in these complex grains is accompanied by structural features indicative of shock and textural features reflecting interaction with surrounding minerals. An exceptional example of this is grain M3 from Apollo 15 breccia 15405 thin section 145. The U-Pb systems and the morphology of this grain, its alteration to baddeleyite and its relationship with surrounding minerals are described in detail by Grange et al (in preparation) and a BSE image of the grain is shown on figure 1. It can be seen from the BSE image that the grain consists of residual patches of primary zircon surrounded and penetrated by a reaction margin consisting of residual primary and finely bladed zircon with interstitial matrix material and granular baddeleyite. No shock features are evident on the grain. Three SHRIMP U-Pb analyses were made on the grain (Fig.1). One analysis (M3-1) was on the clear residual zircon and the others were on the complex reaction margin. The three data points on a Concordia plot (Fig. 2) are discordant and fall on a discordia with intersection with Concordia at ~1950 Ma and ~4345Ma. We interpret this as dating the original crystallization of the zircon at ~4345Ma and an age of disturbance of the U-Pb system at ~1950 Ma, possibly in response to a major impact. Further discussion of this result will be made elsewhere.

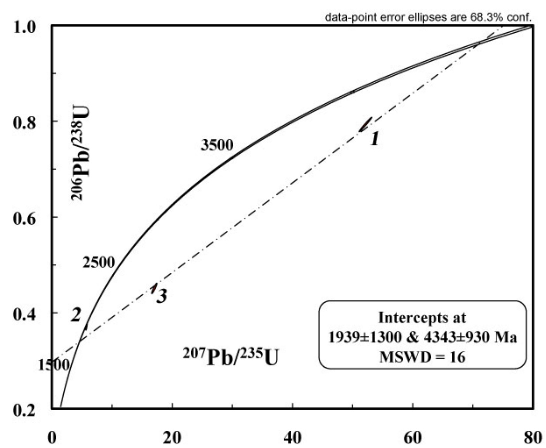

Figure 2. SHRIMP U-Pb results for three analyses on zircon M3 with locations shown on Fig.1

Radiation damage: To investigate the crystallinity of the grain we have used the width at half peak height (FWHM) and the spectral position of the ν3 stretching band of the SiO_2 tetrahedron as a measure of the degree of radiation damage. A number of papers describe the behaviour of these parameters with increasing radiation damage of zircon (e.g. [4]). The first question is whether the clear remnant part of grain M3 has the degree of radiation damage expected from its age and U and Th content. Assuming that the U and Th concentrations of

SHRIMP analysis M3-1 are representative of the clear part of the grain (Fig.1 with U=174ppm and Th=164pm) and the U-Pb concordia age of 4345Ma is the primary age of the grain, it can be determined that the clear grain centre has received a total α-dose of 5.57 x 10^{15} a/mg. The radiation damage expected from this α-dose can be estimated from equation 5 of Palenik et al. [5] which gives the relationship between radiation damage (FWHM) and α-dose for the ideal case where a zircon has accumulated all its radiation damage, i.e. has not had any of its damage annealed. From this curve, (shown on Fig.3) the expected FWHM for a dose of 5.57 x 10^{15} a/mg is in the order of 31cm^{-1}. This can be compared with the actual crystallinity of the clear part of the grain measured using Raman analyses 1, 2, 4, and 24 made near but not within SHRIMP spot M3-1 (Fig.1). FWHM values from these analyses vary from 19.0 to 21.5 cm-1, and are considerably less than the expected value of 31 cm^{-1} based on the U-Pb age of the grain. This strongly suggests that early radiation damage in the zircon has been annealed.

An α-dose of about 1.6 x 10^{15} α/mg is required to generate the measured radiation damage as estimated from equation 5 of Palenik et al [5]. Using this dose and the U and Th concentration of the clear zircon from SHRIMP measurement M3-1 we find that a time of between 1850 and 2200 Ma

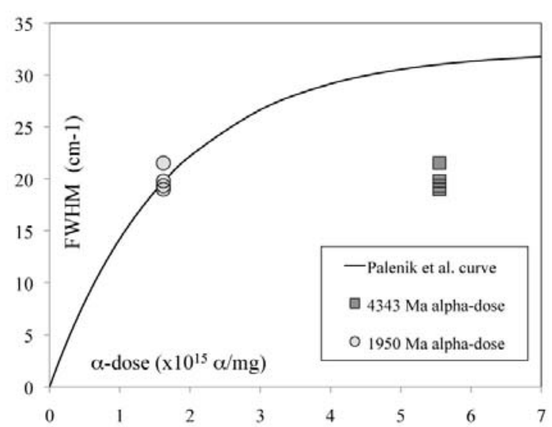

Figure 3. α-dose versus radiation damage

is needed to generate the model dose, assuming that U and Th are homogeneous across the clear part of the grain. This age range overlaps the age of disturbance of the zircon U-Pb system given by the U-Pb lower intersection age of ~1950Ma.

This interpretation is illustrated on Fig. 3 where data points determined assuming all radiation damage accumulated since crystallization of the zircon 4345 Ma ago fall well to the right of the model curve signifying that the measured radiation damage is much less than expected and has been annealed. Data points for the four Raman spots (1,2,4,24) using the zircon U-Pb age of 1950 Ma are seen on Fig.3 to fall almost exactly on the model curve. We interpret this as evidence that previous radiation damage has been annealed at ~1950 Ma under dry conditions at the same time as the disturbance of the zircon U-Pb system. Annealing of radiation damage requires elevated temperatures for a sustained time period. Such conditions might be present in an impact ejecta blanket. Annealing of the zircon could be accompanied by loss of radiogenic Pb resulting in the discordant U-Pb system. The increased discordance and lowering of U and Th in SHRIMP analyses on the reaction margin of the grain could reflect further complications involving the breakdown of zircon to baddeleyite and possibly dissolution of marginal zircon in the surrounding silicate melt followed by co-precipitation of simplectic zircon and matrix minerals..

References: [1] Nemchin, A.A., Pidgeon, R.T., Whitehouse, M.J., Vaughan, J.P. and Meyer, C. (2008). *Geochim. Cosmochim. Acta.*, 72, 668-689.**c** [2] Liu, D., Jolliff , B.L., Zeigler, R.A., Korotev, R.L., Wan, Y. Xie , H. Zhang, Y, Dong, C, Wang, W. (2012.) *Earth and Planet. Sci. letts*, 319-320, 277-286. [3] Grange, M.L., Pidgeon, R.T., Nemchin, A.A., Timms, N.E. and Myer, C. (2013) Geochim. Cosmochim. Acta., 101, 112-132. [4] Nasdala, L. Irmer, G. Pidgeon, R.T. and Wolf, D. (1998). *Mineral. and Petrol*. 62, 1-27. [5] Palenik, C.S., Nasdala, L. and Ewing, R.C. (2003) Radiation damage in zircon. Amer. Mineral., 88, 770-781.