U-PB CHRONOLOGY OF APOLLO 17 SAMPLES. A. A. Nemchin[1], M.J. Whitehouse[2], J.F. Snape[2], F. Thiessen[2] and R. T. Pidgeon[1], [1]Department of Applied Geology, Curtin University, Perth, WA 6845, Australia, a.nemchin@curtin.edu.au, [2]Department of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden.

Introduction: The U-Pb system is one of the most widely used chronometers available to investigate absolute ages of both terrestrial and extraterrestrial samples. On the Moon it provides an extended set of unique capabilities, but also has some distinctive issues, both due to the well known depletion of lunar materials in Pb. This depletion appears to have taken place during the early stages of lunar evolution, probably connected to volatile (including Pb) loss following formation of the Moon as a result of the Giant Impact. As a consequence of this depletion all lunar samples are characterized by very radiogenic Pb isotope compositions, which contrast sharply with the majority of all other materials available for study, both from the Earth and other planetary bodies. Importantly, Pb depletion results in a low proportion of initial Pb, which accumulated in the sources of the studied samples and was subsequently inherited by rocks and minerals during their formation. This opens an opportunity to obtain relatively precise ages for samples that are not commonly considered as viable chronometers, assuming that the contribution of initial Pb in these samples is relatively low and the correction for this contribution can be ignored. Measured Pb isotope compositions are thus interpreted as largely representing Pb accumulated in-situ from U decay and, hence, can be used to obtain the ages of the rocks and minerals. This approach, however, also has limitations, restricting the level of accuracy that can be obtained from the data. It is especially important to consider that the potential issue is not always immediately obvious in the obtained data, but can lead to extremely precise calculated ages that, nevertheless, deviate significantly from the true ages of studied rocks and minerals. The problem can be alleviated by applying proper correction for initial Pb, which is a relatively trivial procedure in many planetary materials outside the Moon. However, as mentioned above, the general depletion of Pb on the Moon also results in highly radiogenic Pb, which both complicates determination of the initial isotope composition to be used for the correction and makes distinguishing between initial Pb and in-situ accumulated Pb difficult. Nevertheless, significant progress has been made in applying the U-Pb system to a wide range of lunar samples and gradually reducing uncertainties of the obtained ages to the level often better than 10 Ma during the last decade. The Apollo 17 landing site provides the best illustration of this progress and the range of the samples where this isotope system can be used to obtain precise chronological information.

Volcanic glass spherules and mare basalts: Volcanic glass beads are believed to result from lava fountains on the Moon whereby micrometre to millimitre size, droplets of basaltic magma solidify rapidly after eruption and rain down to be incorporated into the lunar soils. This process is assumed to effectively degas small quantities of initial Pb present in the melt, allowing accurate U-Pb ages of individual spherules to be determined, for example using micro-analytical techniques such as Secondary Ion Mass Spectrometry (SIMS). The assumption of profound Pb loss during the formation of the glasses is confirmed by the relatively high $^{206}Pb/^{204}Pb$ of the spherules, often in excess of a few thousand. The age uncertainties of individual glasses are often relatively large (40-60 Ma, 2σ), resulting from the very low U content (200-300 ppb). However, the data obtained for chemically similar spherules can be combined to to calculate average U-Pb ages with the precision of just a few Ma (Fig.1).

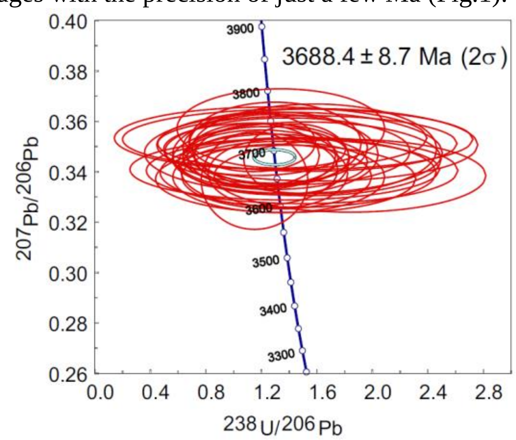

Figure 1: U-Pb age of high-Ti glass spherules from Apollo 17 landing site.

In contrast to the volcanic glass beads, different components of mare basalts contain various quantities of initial Pb, inhibiting simple determination of U-Pb ages of these rocks. However, most of the basalts also contain pockets of partly crystallised residual/interstitial melt, often consisting of small (few micrometres to few hundreds of micrometres) crystals of K-feldspar, K-rich glass, phosphates and Zr-rich phases. The K-feldspar is U-poor and the main carrier of initial Pb, while the remaining phases are typically enriched in U (and in-situ accumulated radiogenic Pb) Consequently SIMS analysis of different constituents of the interstitial material in most mare basalts allows Pb-Pb isochrons to be constrained, which define both basalt ages (with uncertainties often better than 10 Ma) and initial Pb compositions (Fig.2).

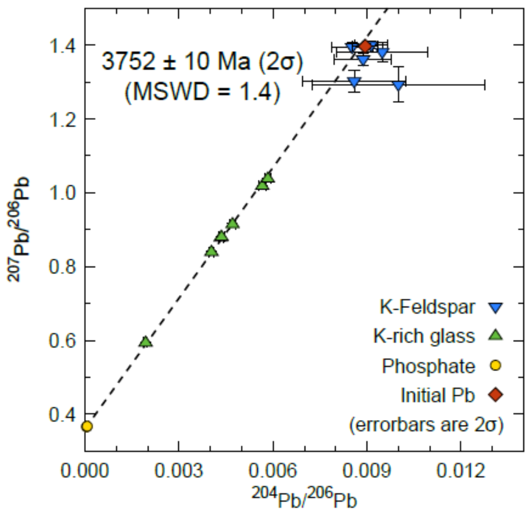

Figure 2: Pb-Pb isochron constrained for the Apollo 17 sample 75035

Impact breccias: The overall complexity of available lunar brecca samples, many of which contain multiple components with different origins and ages, makes it difficult to apply the U-Pb system for extracting chronological information from these rocks, even when using common U-bearing accessory phases such as phosphates and zircon. In particular, combining analyses of different grains to improve precision of estimated ages, with the assumption that they represent similar materials and processes, is hard to validate unless these grains are located in individual lithic clasts within the breccias. Even within separate lithic clasts, some of these U-bearing grains can experience variable degrees of resetting of the U-Pb system, thus potentially providing age estimates with no real chronological meaning. Paradoxically, despite an increase in analytical precision in recent years, with uncertainties of about 20 Ma reduced to just a few Ma, interpretation of chronological information has become more difficult. The issue is perfectly illustrated by the analyses of phosphates (apatite and merrillite) from Apollo 17 breccia samples. The U-Pb system of phosphates is relatively easy to reset compared with that of zircon, and it is suggested that at the relatively high formation temperatures of lunar impact melt breccias all phosphate grains will define the age of breccia formation. However, analysis of phosphates in different textural types of Apollo 17 breccias indicates slight (~10 Ma) age differences between some poikilitic and aphanitic samples (Fig.3). This difference argues against their formation in a single impact. However, it is also difficult to link these samples to two separate basin forming events following one another during a 10 Ma time interval. Consequently, the data indicate that either one or both of these breccia types originate from a relatively small impact crater or phosphate grains contain a small proportion of residual Pb that was not lost completely during the impacts that formed their host samples.

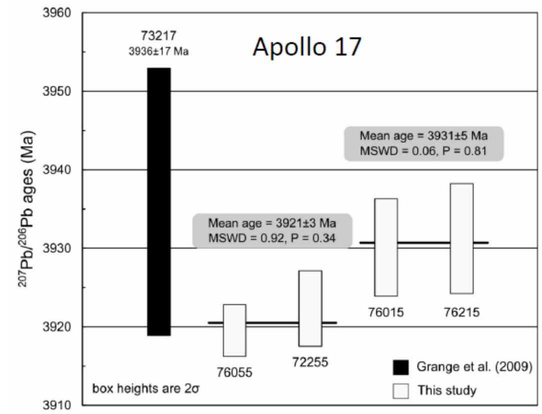

Figure 3: Average phosphate U-Pb ages from Apollo 17 breccias

Zircon, which is abundant in the aphanitic breccias from the Apollo 17 landing site, is considered to be one of the most stable U-Pb chronometers that can survive high temperature magmatic and metamorphic overprints. It is therefore expected that it will preserve information about its formation prior to its incorporation into the lunar breccias. Nevertheless, analysis of several large (a few hundred micrometers across) zircon grains from the Apollo 17 landing site indicates that parts of these grains have been completely reset during old (pre-3.9 Ga) impacts. Some of these large grains clearly show signs of partial resetting of the U-Pb system. Consequently, the problem of partial resetting of the U-Pb system in lunar zircon could be a much wider issue than is commonly thought, which raises questions regarding the reliability of zircon ages based on single analyses of small grains.

Conclusion: Previous work established the applicability of U-Pb chronology to a wide range of lunar samples as well as identifying several potential pitfalls associated with the highly radiogenic nature of lunar Pb. The significance of U-Pb data for understanding lunar evolution in general is still difficult to determine, even for the Apollo 17 landing site where a relatively large number of samples have been investigated. Ultimately, defining this significance will require much larger data sets for a variety of lunar samples from different landing sites and lunar meteorites.