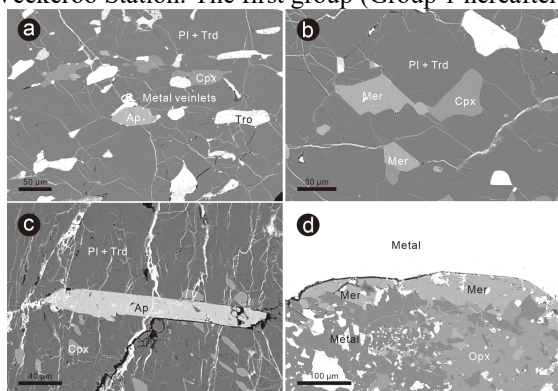


**IN SITU U-PB DATING OF PHOSPHATES IN WEEKEROO STATION IIE IRON.** S. Li<sup>1,2</sup>, W. Hsu<sup>2</sup>, A. Nemchin<sup>3</sup>, X. Che<sup>4</sup>, D. Liu<sup>4</sup>, T. Long<sup>4</sup>, Y. Luo<sup>1,2</sup>, C. Tang<sup>1,2</sup>, <sup>1</sup>State Key Laboratory of Lunar and Planetary Sciences, Macau University of Science and Technology (slli@must.edu.mo); <sup>2</sup>CAS Center for Excellence in Comparative Planetology, CAS Key Laboratory of Planetary Sciences, Purple Mountain Observatory; <sup>3</sup>Department of Applied Geology, Curtin University; <sup>4</sup>Beijing SHRIMP Center, Chinese Academy of Geological Sciences.

**Introduction:** Silicate-bearing iron meteorites record metal-silicate separation and mixing processes of planetesimals. Of particular interest is the IIE group as its silicate inclusions show a great petrological diversity probably resulting from the complex petrogenesis involving early differentiation, and impact-induced dynamic mixing, re-melting, and reduction [1]. These geologic records may have been documented by individual minerals to various extents, which blurs the chronological records on the formation of IIEs. This has hampered the understanding of the formation of IIE iron meteorite, and the nature of metal-silicate separation and mixing of planetesimals in general. To address these issues, we revisit the chronology of the most extensively studied IIE iron Weekeroo Station using the *in situ* secondary ion mass spectrometer (SIMS) technique.

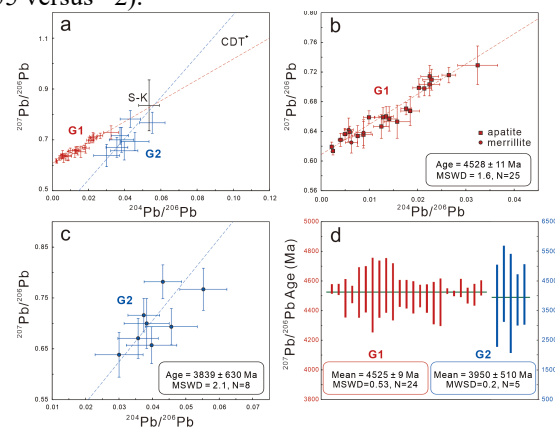
**Result:** Weekeroo Station contains silicate inclusions with sizes ranging from a few millimeters to a few centimeters [2, 3]. These inclusions vary considerably in mineralogy and texture and could be subdivided into four petrographic types, including glass-rich inclusions, crystalline felsic inclusions, crystalline mafic inclusions, and coarse-pyroxene-bearing inclusions [1]. Two petrographic groups of phosphates are observed in the silicate inclusions of Weekeroo Station. The first group (Group 1 hereafter)



**Figure 1.** Back-scattered electron images of Group 1 (a-c) and Group 2 (d) phosphates.

includes both apatite and merrillite set in the interstitial plagioclase and tridymite crystals with similar size (~20–50  $\mu\text{m}$ ). They typically have euhedral to subhedral outlines, but dendritic and acicular apatite crystals are also present (Figs. 1a–c). The other group (Group 2 hereafter) consists of only irregular merrillite with grain

size mostly > 100  $\mu\text{m}$  in the shortest dimension. These merrillite grains exclusively occur at the inclusion-metal boundary (Fig. 1d). The major-element compositions of these two groups of merrillite are homogeneous and indistinguishable from each other, but Group 1 phosphates have higher U content than Group 2 merrillite (3–18 ppm versus ~1 ppm). Its Th/U ratios are also over an order of magnitude higher (52–55 versus ~2).

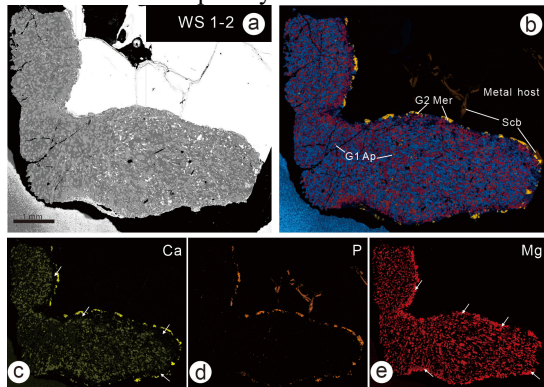


**Figure 2.** The Pb–Pb ages of phosphates.

The two groups of phosphates display two distinct linear trends on the Pb–Pb diagram, and both trends indicate the effects of terrestrial Pb contamination (Fig. 2a). When plotted separately, Group 1 phosphates fit into a well-defined line with a vertical axis intercept age of  $4528 \pm 11$  Ma (MSWD = 1.6,  $P = 0.03$ ), whereas Group 2 merrillite analyses fall away from this line and appear to form a separate trend with an intercept age equal to  $3839 \pm 630$  Ma (MSWD = 2.1,  $P = 0.05$ ). If the common Pb is corrected using modern terrestrial Pb composition [4], the weighted average  $^{207}\text{Pb}/^{206}\text{Pb}$  ages for Group 1 and Group 2 phosphates are  $4525 \pm 9$  Ma (MSWD = 0.53,  $P = 0.97$ ) and  $3950 \pm 510$  Ma (MSWD = 0.2,  $P = 0.94$ ), respectively. Seven U–Pb analyses on Group 1 phosphates yield a concordant age of  $4522 \pm 31$  Ma (MSWD = 4.0) on the 3-D linear U–Pb isochron diagram. A similar concordia age of  $4523 \pm 14$  Ma can be determined in the U–Pb concordia diagram for these analyses. It is impossible to extract meaningful concordia age from Group 2 merrillite, due to the large uncertainty associated with the terrestrial contamination correction of these very low U grains.

**Discussion:** *Formation of the phosphates.* A range of phosphate minerals, including apatite and merrillite,

panethite, etc., have been observed in silicate inclusions of IIEs and they are generally interpreted to be formed by the reaction between Ca-bearing pyroxene with a P-bearing metal component [1, 5–7]. The close spatial association of Group 2 merrillite with host metal and pyroxene in Weekeroo Station is compatible with such an interpretation. The pyroxene in Group 2 merrillite bearing inclusion can be grouped into two populations. Those with a distance < 300  $\mu\text{m}$  bordering the inclusion–metal boundary consist of almost exclusively orthopyroxene, whereas those close to the center of the inclusions are mainly lamellar pyroxene composed of either augite hosts with orthopyroxene lamellae or vice versa. This is illustrated by a  $\sim 300 \mu\text{m}$  Ca-depleted, Mg-enriched belt next to the chain-like Group 2 merrillite on the element mapping image of WS 1-2 inclusion, which is indicated by the arrows in Figs. 3c and e. Similar phenomena are not observed in other inclusions without Group 2 merrillite. Apparently, Ca was removed from the calcic pyroxene and incorporated into the chain-like Group 2 merrillite located on the inclusion–metal boundary, which is probably happened under subsolidus conditions. However, the contrasting occurrences and Th/U ratios between the two groups of phosphates in Weekeroo Station indicate their different origins. The small sized euhedral and acicular habit of Group 1 phosphates (Figs. 1a–c) provide strong evidence for their rapid crystallization from the melt.



**Figure 3.** The BSE image (a) and elemental maps (b–e) of the crystalline mafic inclusion WS 1-2. The blue color in (b) indicates the distribution of silicon.

**Ages of the phosphates and their significance.** Both the Pb–Pb isochron and the 3-D linear U–Pb isochron methods have the advantages of being independent of any priori assumption regarding initial, or common Pb. The Pb–Pb isochron age for Group 1 phosphates ( $4528 \pm 11$  Ma) from three different inclusions is consistent with the result from the 3-D linear U–Pb isochron ( $4522 \pm 31$  Ma), as can be expected for closed U–Pb systems. This suggests that the U–Pb system of Group 1 phosphates was not disturbed by later thermal events after their formation. When some of the analyses most

affected by common Pb are excluded from the calculations, the ages obtained by the 3 methods (i.e. Pb–Pb isochron, 3-D linear U–Pb isochron, and Pb–Pb model corrected ages) coincide with each other (Fig. 2). Because Pb–Pb isochron ages are least affected by the uncertainties associated with the common Pb correction and ion probe fractionation of U/Pb ratios, we suggest they represent the best estimates for both Group 1 ( $4528 \pm 11$  Ma) and Group 2 ( $3839 \pm 630$  Ma) phosphates. The Group 1 phosphates are at least  $\sim 50$  Myr older than Group 2 phosphates, taking uncertainties into account.

It is widely accepted that the metal–silicate mixing of silicate-bearing irons was triggered by impacts, as dynamical forces are required to drive liquefied metal into silicate materials, or vice versa [8]. The silicates in Weekeroo Station are mostly liquid when incorporated by the metal [3]. They are suggested to be the remelting product during metal–silicate mixing [1, 5], or engulfed intercumulus melt of crystal marsh within the partially melted parent body [6, 9]. The silicate melt must have experienced rapid cooling after the metal–silicate mixing to prevent metal–silicate gravitational separation. As one of the mesostasis phases, Group 1 phosphates likely crystallized within this rapid cooling period, and their Pb–Pb isochron age ( $4528 \pm 11$  Ma) thus represents the timing of the impact-induced metal–silicate mixing of Weekeroo Station. In contrast to Group 1 phosphates, Group 2 phosphates were probably formed by redox processes under subsolidus conditions, and their Pb–Pb ages should have recorded the timing related to this metamorphic event. Although there is a large uncertainty for the age of Group 2 phosphates due to the low U content, the age gap between the two groups is noteworthy ( $> \sim 50$  Myr). The U–Pb system of Group 2 phosphates unlikely records the continuous prolonged cooling following the crystallization of Group 1 phosphates, otherwise, the two groups of phosphates should have documented the same closure time. Instead, it probably reflects alteration of the later heating event(s), which is most likely an impact(s), at least  $\sim 50$  Myr after the metal–silicate mixing.

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