

Application of innovative geochronology techniques in geoscience mapping and exploration

by

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The John de Laeter Centre (JdLC) at Curtin University hosts \$35 million in high-precision microanalytical and characterization facilities that support basic and applied research. The Centre is named after its founder, John de Laeter (1933–2010), a physicist who applied mass spectrometry techniques to quantitatively understand the origin and evolution of the Universe. In collaboration with Alec Trendall at the Geological Survey of Western Australia (GSWA), Prof de Laeter established a geochronology capability at Curtin University that would permit a quantitative understanding of the geology of Western Australia.

A key milestone for the collaboration was the installation of a sensitive high-resolution ion microprobe (SHRIMP) for zircon U–Pb geochronology in 1993, which eventually led to the development of additional isotope capabilities relevant to geoscience research (e.g. $^{40}\text{Ar}/^{39}\text{Ar}$, ^{187}Re – ^{187}Os , ^{87}Rb – ^{87}Sr , U–He, Pb–Pb, Sm–Nd, Lu–Hf). In 2013, Curtin University amalgamated its sample preparation, electron microscopy and mass spectrometry capabilities within the JdLC in order to increase efficiencies in instrumentation management and analytical workflow. The purpose of this talk is to promote awareness of the applied research capabilities that are now available to industry and government geoscientists in Western Australia.

Geochronology of mineral systems

Zircon U–Pb geochronology using the SHRIMP has played an important role in the geological mapping of granite–greenstone terranes of Western Australia. GSWA uses the JdLC SHRIMP facility to analyse between 60 and 90 samples each year and has published about 1550 Geochronology Records since 1995 (Fig. 1).

However, zircon can rarely be directly linked to ore formation; therefore other minerals that incorporate U during ore deposition may need to be investigated. The rare earth element (REE) phosphates monazite and xenotime have proved particularly useful in determining the absolute timing of orogenic gold formation in the Yilgarn Craton (McNaughton et al., 2005). Vielreicher

et al. (2015) used this technique to determine that Kurnalpi Domain gold ores were about 20 million years older than similar orebodies formed about 100 km distant in Kalgoorlie at around 2640 Ma (Fig. 2). The difference in ages is thought to reflect the timing of orogenic processes linked to the westward accretion of granite–greenstone terranes onto the eastern Yilgarn Craton.

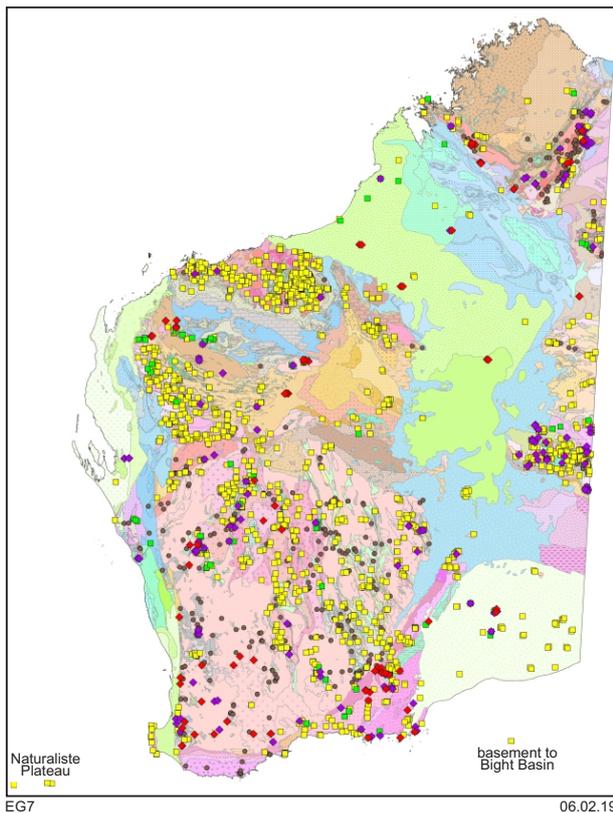
The direct dating of ore minerals can also be applied in geochemical exploration. For example, Sn anomalies detected in geochemical surveys may indicate the presence of cassiterite (SnO_2) derived from granite-related Sn–W mineralization. Due to its mechanical and chemical stability, cassiterite can survive transport and weathering and is commonly recovered during heavy mineral sampling campaigns. The incorporation of U and relative exclusion of Pb during crystallization makes this ore mineral a good candidate for direct U–Pb dating of Sn–W mineralization. As an example, Figure 3 shows an age comparison between detrital cassiterite (c. 1812 Ma) and adjacent granite country rocks (c. 1650 Ma) in the Birrindudu region. The distinct age difference sterilizes the granite as a Sn–W exploration target, and suggests a more distal (or eroded) provenance.

The ^{187}Re – ^{187}Os system is another example of using isotope methods to determine both the age of formation of ore deposits and the provenance of metals (McInnes et al., 2008). Following a successful demonstration of the technique on massive sulfide ores in Russia (Tessalina et al., 2008), a team from the JdLC was funded (MRIWA 446) to investigate the application of the technique at volcanic-hosted massive sulfide (VMS) deposits in Western Australia. The results of this work (Barrote et al., 2019) are highly encouraging in that they have successfully dated both the massive sulfide ore (c. 2705 Ma) as well as black shales (c. 2705 Ma) overlying the Nimbus Zn–Pb–Ag–Au deposit. Both ages are within error of zircon U–Pb ages for a dacitic volcanic rock hosting stringer sulfide mineralization at Nimbus (c. 2704 Ma; Hollis et al., 2017).

Geochronology of regolith materials

Perhaps more than any other continent, Australia has been shaped by the forces of chemical weathering. Regolith materials provide a time-integrated record of the weathering process, and particularly of the periods

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Geochronology sample locations, January 2019

- New results and data in preparation:**
- ◆ GSWA, new samples dated in 2018 (n = 90)
 - ◆ GSWA, in preparation (n = 158)
- Published data**
- GSWA, published in 2017–18 (n = 92)
 - GSWA, published 1995–2017 (n = 1436)
 - Geoscience Australia data

Figure 1. GSWA geochronology sample locations between 1995 and 2019. Analyses by Geoscience Australia are also shown. GSWA analyses were conducted using the SHRIMP in the JdLC at Curtin University (GSWA, 2019)

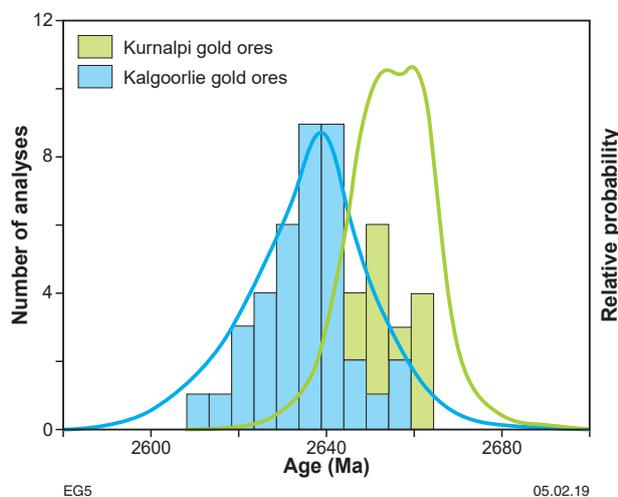


Figure 2. Monazite and xenotime U-Pb ages from gold ores in the Kalgoorlie and Kurnalpi regions (Vielreicher et al., 2015)

of relative groundwater abundance. The passage of groundwater over zones of economic mineralization increases the potential for soluble ore elements to be distributed over a wide area. Understanding the absolute timing of regolith formation, particularly where the regolith contains chemical anomalies, is therefore important in both exploration targeting and understanding the Australian climate record.

Goethite, hematite and maghemite are ubiquitous mineral phases occurring in the regolith. Multiple studies over the last decade have demonstrated that the (U–Th)/He isotope system can be used to determine the age of regolith materials (Pidgeon et al., 2004; Shuster et al., 2005; Wells et al., 2018) as well as the economically important channel iron deposits of Western Australia (Heim et al., 2006; Danišák et al., 2013).

A recent application of the (U–Th)/He technique on Fe-oxide pisolites and fragmental duricrusts at the Boddington gold mine (Wells et al., 2018) found evidence for episodic regolith formation from 5.8 to 1.0 Ma (Fig. 4). These ages are comparable to (U–Th)/He ages of the Toodyay pisolites (Pidgeon et al., 2004), suggesting that the processes of regolith formation and/or modification throughout the Darling Range were broadly synchronous. The relative youthfulness of regolith formation in the Darling Range is a remarkable finding, and further regolith dating studies are necessary to determine whether this is geographically unique.

Conclusions

Over the past 30 years, a series of deep collaborations between government, industry and academia in the application of mass spectrometry and isotopic analysis has dramatically changed the geological map of Western Australia and our understanding of its mineral systems. The SHRIMP facility, established in 1993 by Curtin University, The University of Western Australia and GSWA has produced almost 900 research publications which have been cited over 88 000 times (JdLC, 2019). The announcement by the Federal Government in January 2019 that it will provide \$5 million in new funding (AuScope, 2019) to replace the 25-year-old SHRIMP at Curtin University augurs well for continued partnerships leading to new innovations in isotope geoscience and a better understanding of Western Australia’s geology and mineral endowment.

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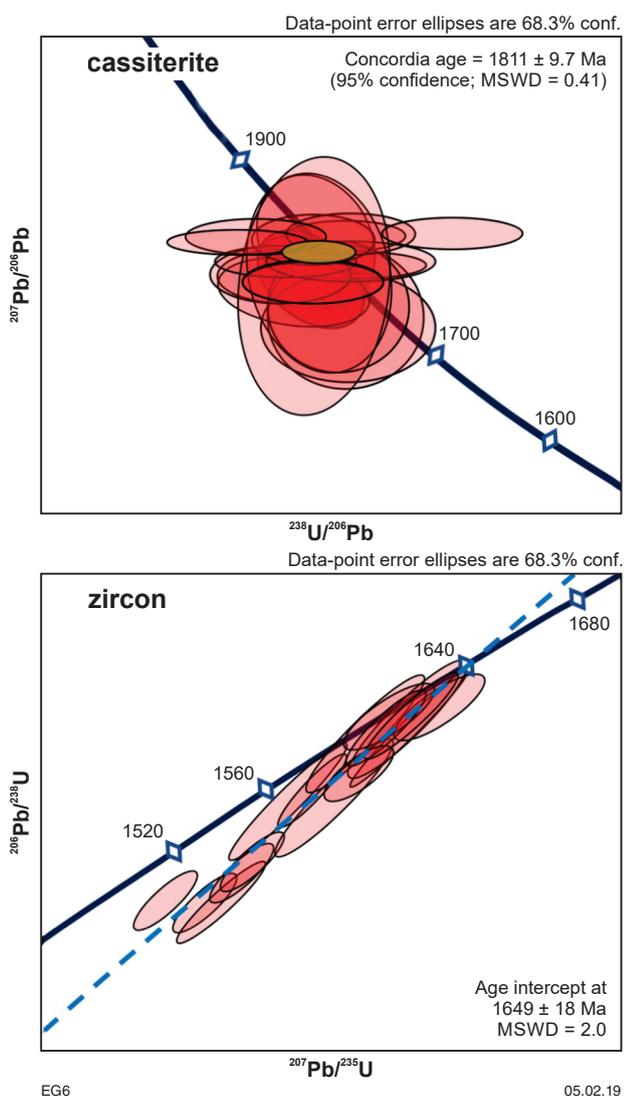


Figure 3. SHRIMP U-Pb dating of detrital cassiterite (SnO₂) can be used to determine the age of its original Sn-W granite host. In this example from the Birrindudu region, the zircon age of the adjacent granite is too young to be the source of the detrital cassiterite

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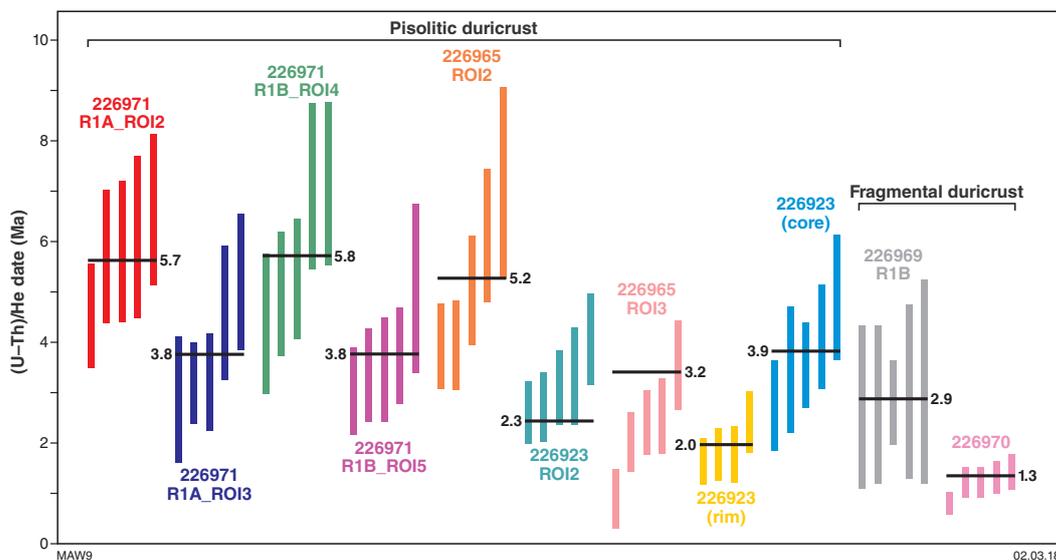


Figure 4. (U-Th)/He dates (Ma) for Fe-oxide duricrust samples from the Boddington gold mine. Each coloured bar represents individual replicate measurements; ‘size’ (height) is measurement error (±1 sigma). Black horizontal bars indicate the average (U-Th)/He age (in Ma) assigned to each duricrust sample (Wells et al., 2018)