APPLICATION OF (U-TH)/HE GEOCHRONOLOGY TO DATE HEMATITE AND OTHER IRON MINERALS PRODUCED DURING WEATHERING

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DATING WEATHERING PROCESSES

The dating of weathering processes and laterite formation is not straightforward due to constraints that the weathering products and ferruginous materials place on many of the geochronological methods. Also, there is the possibility that weathering can continue in a sporadic way for long periods (e.g., Anand & Paine 2002). Weathering in Western Australia is thought to extend well into the Palaeozoic (Butt 1988) precluding the application of short half-life uranium series and nucleosynthetic dating methods, such as ^{230}Th,^{14}C, and ^{10}Be. The K-Ar technique on potassium-bearing manganese oxides and alunite (Segev *et al* 1992, Hautmann & Lippolt 2000) has been used successfully for dating weathering events (e.g., Bird *et al.* 1990, Dammer *et al.* 1999, Vasconcelos *et al.* 2000). Also, the use of oxygen isotope analysis on kaolinite has provided combined geochronological and palaeotemperature information (Bird & Chivas 1993). Palaeomagnetic dating of ironstones (Schmidt & Embleton 1976) has been used by Anand & Paine (2002) as a basis for proposing stages in the evolution of regolith-landform evolution of the Yilgarn Craton. However, these techniques are limited by the availability of suitable materials to date (e.g., suitable manganese minerals and clays for K-Ar dating), or the non direct nature of the dating technique (e.g., oxygen isotopes, palaeomagnetism). There is a clear need for a additional techniques that can be applied to common regolith materials. The (U-Th)/He dating of hematite, magnetite and maghemite could be one such technique.

THE (U-Th)/He METHOD

The natural radioactive decay of U and Th produces ^{4}He. The rate of ^{4}He production from these elements is known, so measurement of the accumulated ^{4}He and the remaining U and Th in a rock or mineral sample provides a potential means of dating the sample.

Prior to the 1950s the (U-Th)/He technique was the most important dating method (e.g., Hurley & Goodman 1943). However, numerous cases of apparent age discrepencies in early studies using this method led to it being essentially abandoned in favour of more modern methods such as K-Ar, Ar-Ar and Rb-Sr. These discrepancies reported by the early researchers related to the ease with which many minerals lost He, resulting in calculated ages that were too young. However, as in the case of early K-Ar studies, apparent past failures of the (U-Th)/He method can, in part, be attributed to the early lack of understanding of closure temperatures and the distinction between emplacement and cooling ages. The low closure temperatures for He retention in minerals is now seen as uniquely valuable for numerous applications. For example, the closure temperature for He loss from apatite, of about 70^{o}C (Wolf *et al.* 1996), has resulted in (U-Th)/He dating of apatite becoming an increasingly important technique for low temperature geochronological and thermochronological studies, including basin evolution, hydrothermal fluid migration, lower limits of kerogen transformation and near surface tectonic activity. (U-Th)/He dating can also be applied to ironstones, which is particularly relevant to problems of weathering.

Hematite formed at low temperatures can contain small but significant amounts of U and Th. The presence of significant common Pb normally precludes the use of the U-Th-Pb technique for dating the hematite but, the presence of inherited He is very unlikely and the (U-Th)/He method provides a potential technique for dating magnetite and hematite. Fanale & Kulp (1962) produced the first helium isochron age on the Pennsylvania Cornwall magnetite deposit (194 ± 4 Ma), and demonstrated concordance with K-Ar ages on cogenetic muscovite. H.J. Lippolt and colleagues in Heidelberg, Germany, have successfully applied (U-Th)/He dating of hematite to determine the ages of mineralised veins in crystaline rocks from the Black Forest and elsewhere in Germany (Wernicke & Lippolt 1994, 1997). A key to the application of the technique is the closure temperature for diffusive He loss from hematite and magnetite. Lippolt and colleagues have undertaken a number of experimental heating studies of He retention charactersitics of hematite dependent on grain size, cooling rate and form. For instance Båhr *et al.* (1994) reported ^{4}He closure temperatures as a function of cooling rate for specular (500 µm radius) and microcrystalline botryoidal hematite. For a cooling rate of 10°K/10^{6}years the calculated closure temperatures were 219°C for specular hematite and 122°C for botryoidal hematite. These authors comment that, under thermal conditions of the uppermost crust, He loss from specularite by diffusion should not be measurable and from botryoidal hematite they are expected to be negligible (< 2%). Lippolt *et al.* (1998) also investigated the potential of (U-Th)/He dating of goethite and limonite from veins in crystalline rocks from a number of locations in Germany. The results were encouraging, as the young ages determined are in accord with ideas regarding the uplift history of the mountain where samples were taken. Research on the application (U-Th)/He dating of hematite, goethite and other ironstone minerals is in its infancy. Much more needs to be done. Nevertheless the potential application of the technique for dating ironstones in the regolith is evident. If successful the technique could revolutionise our understanding of the timing of weathering processes in Western Australia.

DATING HEMATITE AND OTHER Fe-MINERALS IN DEEPLY WEATHERED REGOLITH

Anand & Paine (2002) report that hematite and maghemite are widely distributed in the deeply weathered regolith including supergene iron ore deposits. Up until now it has not been possible to determine the age of formation of the major iron ores deposits in the Hamersley Basin and elsewhere in Western Australia. These ores formed by a low temperature supergene enrichment processes. The question is whether this was during a single event or whether Fe formation has occurred at a number of different times. The application of the (U-Th)/He method to date hematite, which forms the main ore mineral in a number of iron ore deposits, could solve this problem. However, care must be taken in interpreting the results as subsequent metamorphism in the Pilbara might have resulted in loss of He from the hematite and a resetting of the (U-Th)/He ages. Another wide application is the dating of ferruginous pisoliths in deeply weathered terrains. Subprojects include the dating of ferruginous pisoliths in Tertiary palaeochannel sediments. Hematite-bearing pisolites occur in horizons in palaeochannel sediments in the Eastern Goldfields, and the dating of these pisoliths would place constraints on the age of formation of the channels and also give information on the provenance within the catchment of the paleochannel. The dating of hematite- and magnetite-bearing pisoliths associated with deep weathering in the NE Goldfields could also provide key information on the timing and rate of regolith formation in the region. However, it must be further stressed that the geological significance of the results will need to be carefully assessed. For example, there is strong evidence from field samples and laboratory simulation studies that alumina (corundum), maghemite, and hematite form by heating during bushfires. This process may reset the isotopic clock for the (U-Th)/He system and enable dating of the heating event. This hypothesis will need to be tested. A combination of (U-Th)/He and Ar-Ar dating studies of weathering profiles and associated mineralisation promises to be an extremely powerful in determining weathering and cooling histories.

In summary (U-Th)/He dating of hematite and other ironstone minerals has enormous potential for investigating the geochronology of the regolith, with long term benefits to researchers, students, government bodies and industry concerned with problems of regolith evolution, tectonics and palaeoclimatology in Western Australia.

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