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ISOTOPIC DATING OF ORE DEPOSITS — APPLICATIONS AND CASE STUDIES

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Knowing the age of ore deposition has long been a major concern of exploration and ore deposit geologists, and it has developed in recent years into a much more sophisticated research activity capable of answering questions of major import in minerals research. Addressing questions of the chronology of ore deposits has its roots in the tried and tested approach involving logical field-based reasoning. For example, cross-cutting relations, fossils which are either mineralised or post-date ore deposition, and stratigraphic arguments provide the fundamental framework for laboratory-based work. The isotopic researcher ignores these essential field relations at his peril! However, these classical techniques of inferring an age have their limitations. For example, lack of fossils in Precambrian rocks limits the absolute chronology, and lack of good exposure and/or crosscutting relations are common difficulties. These limitations can sometimes be overcome by a variety of isotopic dating techniques capable of providing an absolute chronological framework.

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DIRECT DATING OF ORE/HYDROTHERMAL MINERALS

The variety of ore deposit types has led to the development of quite varied isotopic applications, the only pre-requisite being that some mineralogical component must be analyzed which contains relative enrichment in a radioactive parent isotope (i.e. U, K, Sm, Rb, Re). Examples include analysis of fluid inclusions in quartz and sphalerite (by the Rb-Sr method; Darbyshire and Shepherd 1985), hydrothermal minerals in sericitic alteration (RbSr and Ar-Ar dating of micas), scheelite and fluorite (Sm-Nd method), hydrothermal monazite, rutile, sphene by the U-Pb method, and magmatic minerals such as perovskite, baddeleyite and zircon in layered intrusions by the U-Pb method. While these data can provide major insight into the chronology of ore-forming processes, and can for example document the age progression of mineralization in a mineral province, they too have limitations. Deformation and metamorphism will render some dates (i.e. Ar-Ar, Rb-Sr) unreliable as indicators of primary crystallization, fluid inclusions are easily destroyed, and often there is very limited enrichment in parent radioactive isotopes in the material being analyzed. In most cases, very tedious effort is required to search and select appropriate materials to not only guarantee a good analytical result, but attention to detail in the field and microscope is required to ensure that the date is meaningful !

Another approach is to comprehensively combine various techniques, paying close attention to field relations and sample selection, and date by high precision methods magmatic rocks which have a bearing on the relative chronology of mineralization.

THE CHRONOLOGY OF MINERALIZATION AT THE GIANT KIDD CREEK VMS DEPOSIT IN ONTARIO

A comprehensive U-Pb dating study was commissioned by Falconbridge, the owner of the Kidd Creek Deposit, to attempt to resolve a number of important long-standing questions about this poorly-exposed but giant Cu-Zn VMS orebody. This study was conducted by myself and colleagues at the Geological Survey of Canada (Bleeker and Parrish, 1996; Bleeker *et al.* 1999). The body is hosted in the Late Archean Abitibi greenstone belt of northern Ontario, and contains highly deformed but stratigraphically controlled sulphide bodies sandwiched between the famous komatiites with spinifex texture of the Kidd-Munroe Assemblage and overlying sedimentary deposits of the Porcupine Group. The whole region was strongly deformed following formation, and metamorphosed to greenschist grade, rendering dating techniques such as K-Ar and Ar-Ar incapable of providing information on the original age of the rocks. Although the deposit was thought to be the same age as a locally exposed rhyolite dated at 2717 Ma, the overall duration of the event, and its spatial-temporal variation were not known in detail. This made it difficult to draw modern analogues and to shed light on the tectonic setting of the deposit. In addition a number of long standing local mine-site geological problems were addressed by the programme of isotopic dating. U-Pb dating of numerous magmatic rocks in this volcanic province led to the production of about 30 high precision U-Pb ages with errors as low as 0.5 Ma at the 95% confidence level. The results showed that rhyolitic and basaltic bimodal volcanism occurred between 2718 and 2712 Ma, with the formation of five major orebodies interspersed with volcanism. One very interesting conclusion was that the time-integrated formation of massive sulphide deposits took place at a rate of between 10 and 100 tonnes per year. The tectonic setting envisioned is an extensional submarine back-arc basin underlain by a possible mantle plume, giving rise to the heat source which drove hydrothermal circulation beneath the ocean floor. It is thought that black smokers recognised on the modern ocean floor are a reasonable analogue of the manifestation of the hydrothermal processes.

This study demonstrated also that the greywackes that are structurally inverted and which underlie the main deposit are much younger, having detrital zircons as young as about 2690 Ma. This information laid to rest a 30-year controversy about the original relation (or lack thereof) of these sediments to ore deposition processes, and provided a very practical benefit to the geology of the mine site. The study was a cost-effective way to provide answers not available through traditional mineral exploration techniques such as drilling and geochemistry.

GEOCHRONOLOGY OF THE TIN DEPOSITS OF SOUTH WEST ENGLAND

The Cornish and Devon tin deposits have been mined for hundreds of years, and they are famous examples of hydrothermal deposits with a major magmatic influence, with regard to the source of both metals and heat from the cooling of plutons. The dating of these deposits has been addressed using a variety of analytical methods, and a precise chronology of the magnetic and hydrothermal processes has been revealed by using U-Pb dating of monazite and Ar-Ar dating of micas (Chen *et al.,* 1993, 1996; Chesley *et al.1993).* It is now clear that magmatism spanned nearly 20 million years time from 294 — 275 Ma, but there is no clear geographic progression. Both the oldest (Carnmenellis) and the youngest (Land's End) plutons occur in westernmost Cornwall. The cooling of these plutonic rocks provided considerable heat release which probably drove hydrothermal circulation and in favourable circumstances formed significant mineralization. Ar-Ar dating revealed that mica ages are generally about 4-5 Ma younger than U-Pb dates of magmatic monazites (which record a crystallisation age). Micas begin to retain their radiogenic argon once they cool below about 300°C-400°C, and therefore, an average post-crystallisation cooling rate of about 80-100C/Ma can be calculated. It is inferred that this period of cooling was accompanied by hydrothermally — induced mineralisation to form at least some of the ore minerals. Other veins containing fluorite (Geevor Mine) are 267+/-12 Ma (using the Sm-Nd method on fluorite), and they may have formed near the end of this process (Chesley *et al.* 1993).

These two examples illustrate the variety of both applications and methods relevant to both regional problems in metallogeny and to more local problems related to mine geology. Considerable insight into the detailed geological and mineralization processes is often revealed by careful isotopic work on well characterised materials, and the effort involved is well worth the effort when answers to definitive questions can be revealed.

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