Stable isotopes — signposts for mineralisation

A new regional exploration tool

John F. Lindsay[1] & Martin D. Brasier[2]

Stable isotopes are a proven tool for assessing regional fluid-flow history in highly mineralised regions, such as the McArthur and Mount Isa Basins. Whereas past stable-isotope studies in such regions have focused on the orebodies or their surrounding geochemical halos, we have adopted a more holistic approach. In a recent study, we appraised the stable isotopes of carbon in carbonate rocks for discriminating primary isotopic signatures and correlating them in turn with basin-fill architecture. By so doing, we have established a geochemical baseline against which the effects of mineralisation, especially fluid movement, can be compared. As a consequence of this work, we have accumulated an extensive database of carbon- ($\delta^{13}C_{carb}$) and oxygen- ($\delta^{18}O_{carb}$) isotope plus associated major- and trace-element analyses (Brasier & Lindsay 1998: Geology, 26, 555–558; Lindsay & Brasier in press: Precambrian Research).

Introduction

Since 1995, AGSO and Oxford University have been collaborating in an investigation of the use of stable-isotope chemostratigraphy for evaluating sediment-hosted metal deposits. This research is a contribution to the 'North Australian basins resource evaluation' project in the McArthur and Mount Isa Basins for the National Geoscience Mapping Accord (NGMA).

The stable isotopes, C^{13} and C^{14}, are fractionated during photosynthesis, and ultimately come into equilibrium with the global ocean. Their ratios, where preserved in carbonate rocks ($\delta^{13}C_{carb}$), provide an insight into biospheric activity, and record the rate at which organic carbon was being buried in sedimentary basins (e.g., Des Marais et al. 1992: Nature 59, 605–609). The pattern of secular variation of $\delta^{13}C_{carb}$ for the last billion years of Earth history is now moderately well documented (Fig. 18). Major excursions of >2‰ have been documented globally. They represent significant events in the history of the Earth, particularly its biogeochemical evolution (for a summary, see Knoll & Canfield 1998: The Paleontological Society Papers, 4, 212–243). The Neoproterozoic–Phanerozoic transition, for example, was a time of major biological, geological, and environmental revolutions. These revolutions were accompanied by major changes in the carbon cycle that produced a distinctive secular carbon curve (Fig. 18), which has proved of value in regional correlation (e.g., Calver & Lindsay 1998: Australian Journal of Earth Sciences, 45, 513–532).

The rocks of the Palaeoproterozoic McArthur and Mount Isa Basins offered a major challenge — first, because so little was known about them; and, second, because of their antiquity. Initially, we were concerned that, since the rocks were so ancient, diagenesis may have altered the primary carbon-isotopic values and left little indication of oceanic history. However, after an extensive pilot study in 1995, during which 48 samples were analysed in great detail, we found that diagenesis had occurred early in the carbonate rocks; consequently, early fluid movements had been restricted, and primary carbon-isotopic signatures were preserved. Thereafter, we began a more extensive program of acquiring $\delta^{13}C_{carb}$ data for both the McArthur and Mount Isa Basins. We analysed the carbonate intervals in drillcore from the main depocentres and the margin or platform successions of both basins (Figs. 19 and 20), to evaluate the potential of the data for yielding pointers to mineralisation.

The dataset

To date we have analysed ~600 samples taken at 10-m intervals from more than 12 km of core from 15 major drillholes. The samples provide information for every carbonate interval in the McArthur and Mount Isa Basins' successions (Figs. 19 and 20). The data provide the most comprehensive and best dated $\delta^{13}C_{carb}$ stratigraphy yet obtained from such ancient rocks anywhere on Earth.

Analysis of the data produced some surprises, as the secular carbon curve ($\delta^{13}C_{carb}$) proved to be extremely flat (Figs. 19 and 20; Brasier & Lindsay 1998: op. cit.). The $\delta^{13}C_{carb}$ values from both basins vary within a narrow range — around a mean of –0.6‰; extreme values seldom lie farther than 1‰ from the mean. These results, combined with those from earlier studies on younger rocks (e.g., in the Bangemall Basin; Buick et al. 1995: Chemical Geology, 123, 153–171), imply that the global ocean reached a state of equilibrium in the mid-Palaeoproterozoic and remained stable for almost a billion years. Current models of the ocean suggest that maintaining the carbon mass balance requires only minor tectonic activity. The implication that tectonic activity was moderate during this time is significant, as current plate-tectonic models suggest that it was a period of supercontinent assembly and dispersal (Hoffman 1989: Geology, 17, 135–138; Condie 1998: Earth and Planetary Science Letters, 163, 97–108).

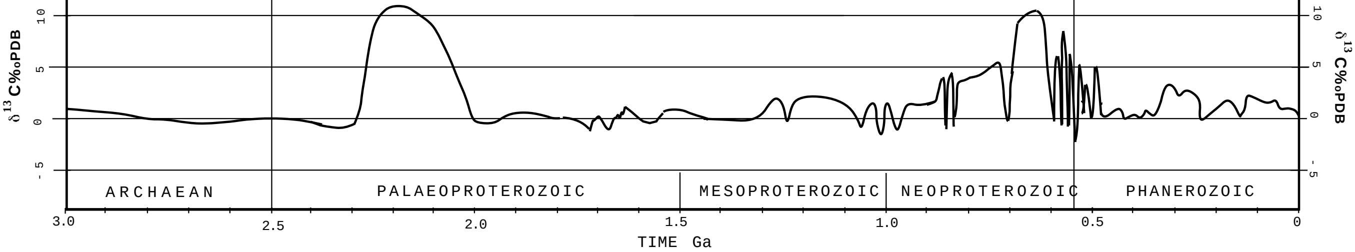

Fig. 18. Carbon-isotope ($\delta^{13}C_{carb}$) summary curve for the last 3 billion years of Earth history. Note the long period of low activity throughout the Palaeoproterozoic (adapted from Brasier & Lindsay 1998: op. cit.).

The results are, however, consistent with earlier AGSO work which supports a supercontinent model, but indicates that crustal evolution was anorogenic and plate motions slow (Wyborn 1988: Precambrian Research, 40/41, 37–60; Idnurm & Giddings 1988: Precambrian Research, 40/41, 61–88). Perhaps significantly, this period also coincides with the worldwide development of sediment-hosted Pb–Zn deposits.

Applications to exploration

Along with the more esoteric understanding of planetary history, there are clear pragmatic reasons for assembling a database of carbon and oxygen isotopes, for

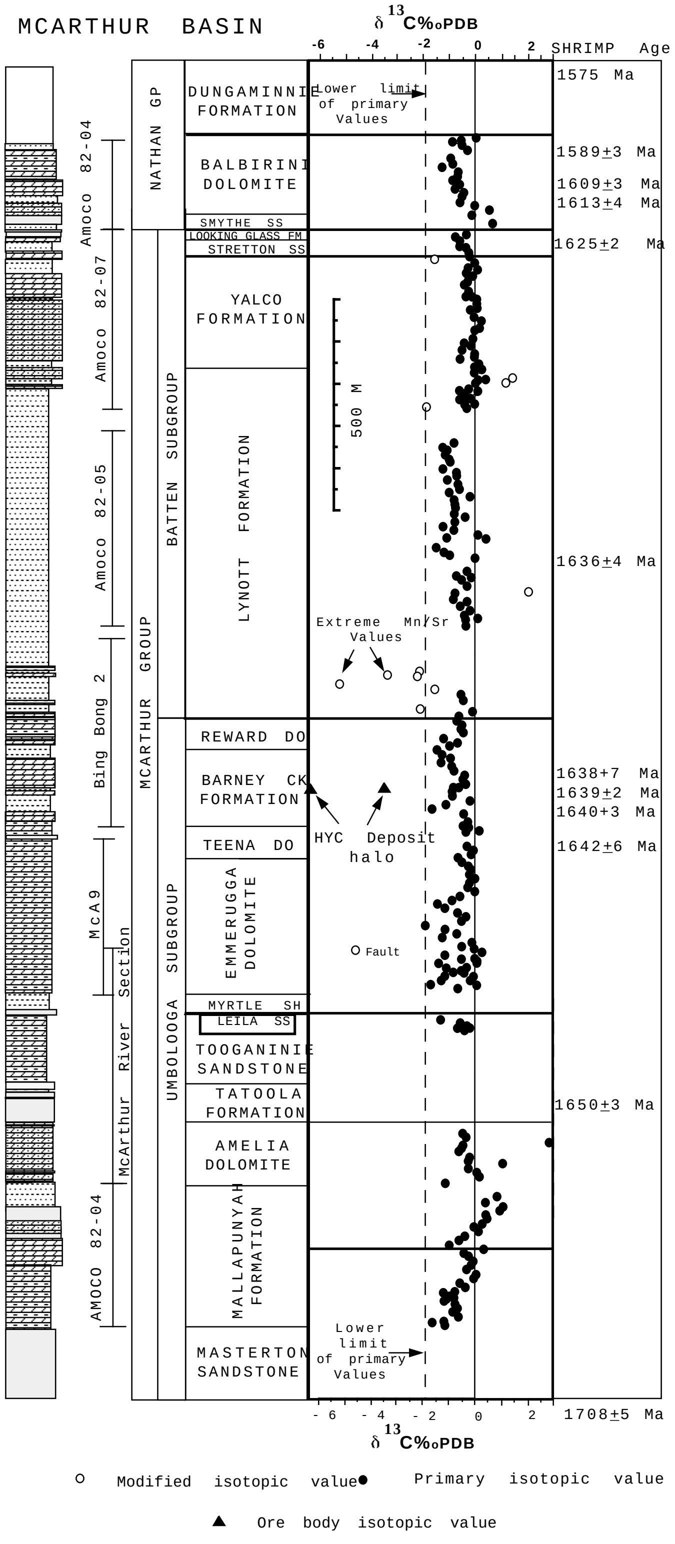

Fig. 19. Carbon-isotope ($\delta^{13}C_{carb}$) data from the main depocentre of the McArthur Basin (after Brasier & Lindsay 1998: op. cit.; Page 1997: AGSO Record 1997/12; Page & Sweet 1998: Australian Journal of Earth Sciences, 45, 219–232). Isotopic data for the HYC deposit from Rye & Williams (1981: op. cit.).

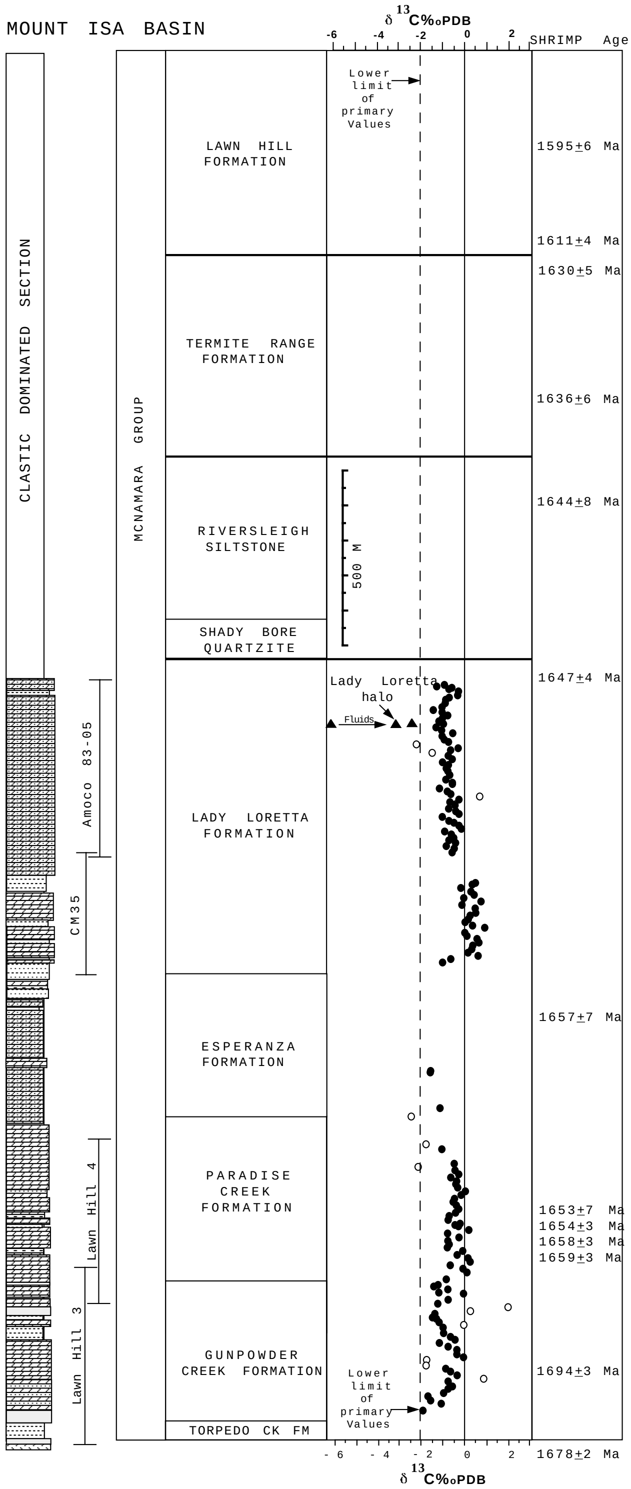

Fig. 20. Carbon-isotope ($\delta^{13}C_{carb}$) data from the main depocentre of the Mount Isa Basin (after Brasier & Lindsay 1998: op. cit.; Page 1997: op. cit.; Page & Sweet 1998: op. cit.). Isotopic data for the Lady Loretta deposit from McGoldrick et al. (1998: op. cit.).

they can be used as vectors for mineralisation. Organic carbon is, of course, an important reductant in the deposition of some stratiform orebodies. During ore genesis, the isotopic ratios of both carbon and oxygen are altered, providing a useful indicator of the passage of mineralising fluids.

Williams (1978: Economic Geology 73, 1005–1035 and 1036–1056) first put forward the idea that the stratiform orebodies at McArthur River are not precisely syngenetic, but were deposited in response to early diagenesis in unconsolidated sediments. Detailed work on the highly mineralised zone associated with the Barney Creek Formation in the McArthur Basin (Rye & Williams 1981: Economic Geology, 76, 1–26; Hinman 1995: AGSO Record 1995/5; Lindsay & Brasier 1997: AGSO Record 1997/12) has shown that the passage of fluid can be detected as much as 40 km from the nearest known orebodies, and is directly controlled by the sequence stratigraphy. The passage of fluids depresses the $\delta^{13}C_{carb}$ curve by up to 10‰ (Fig. 19); the $\delta^{18}O_{carb}$ curve is similarly depressed. The data suggest that fluid movement was early, as Williams (1978: op. cit.) suggested, but did not occur until after the carbonates had been sealed diagenetically, such that they acted as aquicludes.

As a result of seismic interpretation bearing on the framework of the McArthur Basin, the stable-isotope data can place the movement of fluids in both spatial and temporal contexts, and accordingly can be used as a predictive tool (Lindsay 1998: AGSO Record 1998/38).

In the Mount Isa Basin, McGoldrick et al. (1998: in Arehart & Hulston, Editors, 'Proceedings of the 9th International Symposium on Water–Rock Interaction', Balkema, Rotterdam, 561–564) have found distinctive isotopic signatures associated with the Lady Loretta deposit, including depressed carbon- and elevated oxygen-isotope values (Fig. 20). Farther afield, at Broken Hill, $\delta^{13}C_{carb}$ values in carbonates from the main lode are depressed dramatically to –22‰ (Yibao et al. 1987: Transactions of the Institute of Mining and Metallurgy, 96, B15–B30). The only other $\delta^{13}C_{carb}$ values that lie below –2.0‰ are from samples close to fault planes or major erosional surfaces that apparently have not been associated with mineralisation (Fig. 19).

Conclusions

The primary isotopic curves from Palaeoproterozoic successions are extremely flat. Consequently, an explorer in the McArthur and Mount Isa Basins can examine isotopic data from any carbonate interval without knowing its precise stratigraphic location, and quickly determine if mineralising fluids have passed it at some time in the past. As the primary carbon-isotope signature reflects the geochemistry of the ancient global ocean, it represents a tool that is not only of value to exploration in Australia but potentially has a global application.

Acknowledgments

We thank Aberfoyle Resources, Pasminco Exploration, and the geological surveys of Queensland and the Northern Territory for providing access to drillcore; Julie Cartlidge, John Pyke, and Owen Green for laboratory support; and Duncan Davidson and Kurt Barnett for assistance with gamma-ray logging of cores. John Lindsay thanks the former Australian Departments of Industry, Science & Tourism, and Primary Industries & Energy, for financial support while he was a visiting scholar at the Earth Sciences Department, Oxford University.

[1] Minerals Division, Australian Geological Survey Organisation, GPO Box 378, Canberra, ACT 2601; tel. +61 2 6249 9428; fax +61 2 6249 9956; email John.Lindsay@agso.gov.au.

[2] Earth Sciences Department, Oxford University, Parks Road, Oxford, OX1 3PR, UK; tel. +44 1865 27 2074; fax +44 1865 27 2072; email Martin.Brasier@earth.ox.ac.uk.