DISTURBED Re-Os ISOTOPE SYSTEMATICS IN IIIAB IRON METEORITES

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The clock provided by the radioactive decay of $^{187}$Re to $^{187}$Os with a half-life of $\approx 4.2 \times 10^{10}$ years has been applied to both terrestrial geologic problems as well as to the dating of iron meteorites and chondrites. Luck and Allègre [1] were the first to date iron meteorites and metal phases in chondrites using secondary ion mass spectrometry. Similarly Walker and Fasset [2] have pioneered the techniques of resonance ionisation mass spectrometry and applied it to a wide range of geological and cosmochemical problems. Recently, Creaser et al. [3] and Volkening and Heumann, [4] have demonstrated the efficient production of large ($\approx 10^{-11}$ A) ion beams by negative thermal ionisation mass spectrometry (NTIMS) using standard laboratory solutions of Os compounds. We have been independently pursuing a similar development with the direct aim of improving the time resolution obtainable from the Re-Os chronometer. We have applied NTIMS to Os extracted from the most common group of iron meteorites the IIIAB. These meteorites are believed to be of magmatic origin, formed by fractional crystallisation of molten cores of asteroidal bodies.

Samples of iron meteorite were obtained from the ANU meteorite collection. Small (100 to 600 mg) pieces were hand sawn using clean hack-saw blades lubricated with ethanol. Samples were cut from interior portions away from ablated surfaces. Each sample was degreased in acetone in an ultrasonic bath and rinsed with ethanol followed with high-purity water. Approximately 10% of the mass of each sample was removed by leaching the surface with HCl. Samples were dissolved in a mixture of HCl and ethanol, including Re and Os spikes, in teflon pressure vessels at 80 °C. Following dissolution the sample was dried and was redissolved in $\text{H}_2\text{SO}_4$ in the sealed pressure vessel at 80 °C. We believe that this last step is essential to ensure complete equilibration between the Os from the sample and the Os spike. The sample in $\text{H}_2\text{SO}_4$ solution was transferred to the distillation apparatus and gradually heated to 120 °C using a hot air gun while small amounts of $\text{H}_2\text{O}_2$ was added to help oxidise Os. The residue from distillation was passed through a 3 cm anion exchange column and Re eluted with $\text{HNO}_3$. A mixture of BaOH and KOH solutions were loaded into a V-shaped pocket in a single Pt filament followed by the addition of the sample in chloride form. All were then dried in air. We find that the presence of KOH enhances negative ion formation. Corrections for mass dependent isotope fractionation and for interference from minor oxygen isotopes were computed in a single step by first order expansion in terms of the fractionation factor. The contribution of minor tracer isotopes were handled in a similar fashion in a single step together with fractionation and $^{17,18}$O interferences. Statistical precision for individual runs, where $^{192}$Os beam intensity was larger than $5 \times 10^{-12}$ A, is $\pm 0.2\% \alpha 2\%$.

The data for the four iron meteorites Cape York, Duketon, Trenton and Kyancutta form roughly a collinear array on the $^{187}$Os/$^{186}$Os vs. $^{187}$Re/$^{186}$Os diagram (Fig. 1). In Figure 1 we have also plotted previous data from Luck and Allègre [1] and Morgan and Walker [5] covering an expanded region that include the present results. The data from Morgan and Walker have large error bars and scatter around the 4550 Ma reference isochron; some data points plot off the line outside the error limits. In contrast, data from Luck and Allègre [1] have smaller associated errors and clearly form a good straight line fit. The present data are in reasonable agreement with the results from Morgan and Walker, however, they are systematically offset from the Luck and Allègre reference line, indicating a difference in the gravimetric calibration of Re and Os standards. A straight line fit to the data cannot accommodate all of the four points within errors although, Kyancutta, Trenton and Duketon do form a tight collinear array. The lack of a strict correlation between $^{187}$Os/$^{186}$Os and $^{187}$Re/$^{186}$Os ratios in the present data, and to some extent in the data from Morgan and Walker, is in direct contrast to the results of Luck and Allègre [1]. It is possible that we have not achieved complete equilibration between samples and Os or Re spikes at the 5 to 10% level. Further uncertainty may arise from undissolved trace phases with high Os or Re concentrations.

For samples of Henbury our data (Fig. 1) indicate an isotopic disturbance which redistributed and equalised radiogenic $^{187}$Os between different phases. The subsequent evolution resulted in a new array defined by the four Henbury points in Fig. 1. The line drawn through these points, if interpreted as an isochron, indicates a poorly defined (±100 Ma) age of about 700 Ma. The disturbance in the case of Henbury may have been caused by the presumed collision event that released the metallic core from the parent asteroid. In this context, cosmic-ray exposure ages of...
IIIAB iron meteorites tend to cluster around an interval of 650±100 Ma [6]. The Re-Os isotope systematics of Henbury samples are consistent with such an interpretation.

The Re-Os isotope pattern displayed by Sacramento Mountains is striking. There is a 55% spread in the Os concentration of the 3 samples whereas the Re concentration remains roughly the same (Fig. 1). We do not believe that such a variance can be caused by any inadequacy in our analytical procedures involving partial equilibration between Os spike and sample Os. The line drawn through the Sacramento data points indicates essentially zero age disturbance in the Re-Os system. Buchwald [7] has described Sacramento Mountains as an 'unusually deformed meteorite,... which show to the naked eye dense slipband systems'. He concludes with: 'The deformation is so thorough that it must be due to "geologic" forces on the parent body'. If we apply the same arguments to this meteorite as we did to Henbury, then the final disturbance resetting the Re-Os clock must have occurred within the last 100 Ma. Indeed, it may be highly significant that in the cosmic-ray exposure age frequency diagram for IIIAB iron meteorites all samples cluster around an age of 550±100 Ma with the exception of a single sample at 315±55 Ma identified as Sacramento Mountains [6].

The data for San Angelo also exhibit a similar pattern compatible with essentially a zero age resetting of the Re-Os chronometer. Buchwald [7] describes this meteorite as having 'plastic deformations visible to the naked eye', and that 'the deformations resemble those described for... Sacramento Mountains and others and they are preatmospheric, probably due to "geologic" processes on the parent body'. However, in contrast to Sacramento Mountains, the cosmic-ray exposure age for this meteorite is given as 580 Ma by Voshage [6] and is within the 550±100 Ma band observed for other IIIAB iron meteorites.

Luck and Allegre [1] have obtained an excellent correlation between $^{187}\text{Os}/^{187}\text{Os}$ isotopic composition and Re/Os abundances not only for IIIAB iron meteorites but also for IA, IIA, IVB and for H, L and LL chondrites, within errors. More recently Morgan and Walker [5] obtained similar results for iron meteorites. However, earlier experiments by Walker and Morgan [8] revealed large offsets from the reference iron meteorite isochron for two chondrites. A closer examination of the iron meteorite data of Morgan and Walker [5] shows significant scatter in their data around the reference isochron outside of their reported error bars. Most of the sample sizes used in all studies are similar, ranging from 0.1 to 0.4 g. Therefore, it is unlikely that the samples used by Luck and Allegre [1] are a better representative of the whole meteorite. It is possible that neither we or Morgan and Walker [5] were able to achieve complete Os spike and sample equilibration. However, the spread in Os concentration in samples of Sacramento Mountains is larger than 50%. It is difficult to ascribe this to analytical problems. The three iron meteorites exhibiting late disturbance in Os may not be typical of most of the other iron meteorite samples so far studied and some of the scatter observed in the data of Morgan and Walker [5] may be due to a similar effect. Further careful studies are required to investigate such a possibility.


Fig. 1. Re-Os evolution diagram. The first 4 ANU samples in order of decreasing $^{187}\text{Re}/^{188}\text{Os}$ ratio are: Kyancutta, Trenton, Duketon and Cape York.