

Dating mantle events by *in situ* Re-Os analysis of sulfides: Slave Craton, Canada

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Recent advances in the *in situ* analysis of Os isotopes using a multicollector-ICPMS laser ablation microprobe (LAM-MC-ICPMS) enable us to quickly obtain a statistically significant data set of mantle depletion ages from sulfides. These spectra are similar to those obtained from U-Pb dating of zircons in crustal rocks. We have developed a method for preparing large numbers of sulfide grains included in kimberlite-entrained mantle xenocrysts, so that each grain can be analysed for major and trace elements and isotopic composition. Combining the major and trace element data from the sulfide and the host mineral provides a petrological context for the isotope data, in terms of sample populations, temperatures (e.g. Ca-in-olivine geothermometry), deduced depths of derivation and secondary processes that may have corrupted the Re-Os signature.

Concentrate samples from the Lac de Gras area in the Slave Craton, Canada contain two main sulfide suites; one is Fe-rich, the other Ni- and Co-rich. Both appear to have been derived from a moderately depleted deep layer of the stratified lithosphere identified by Pearson et al. (1999) and Griffin et al. (1999). Trace-element data are consistent with a primary origin for part of the Fe-rich group, while other samples appear to have been depleted or enriched in some PGE and have either unsupported ^{187}Os or $^{187}\text{Os}/^{188}\text{Os}$ too low for their Re/Os. Age data for primary sulfides indicate that at least some parts of the mantle are significantly older than the overlying arc-related crust, but similar ages are found in the adjacent older terrane (the Central Slave Basement Complex, CSBC), which lies just 100 km to the west. This may suggest that ancient mantle was subducted beneath the Lac de Gras area during the collision of the terranes.

Introduction

The Re-Os isotope system is unique among the systems commonly used in geochronology in that the parent isotope is mildly incompatible whereas the daughter isotope behaves compatibly during mantle melting (Morgan 1986). Therefore, this system is ideal for tracing lithosphere forming events where extraction of a melt volume depletes the initially primitive mantle source in Re and leaves a residue enriched in Os, which retards the ingrowth of radiogenic ^{187}Os . Moreover, due to the high concentration of Os in the residue and the typically low Os concentrations in mantle-derived melts, this system is thought to be robust during subsequent metasomatism. This allows us to see through post-formation processes to the nucleation of the lithospheric mantle. The advent of *in situ* methods for the collection of Re-Os isotope data from individual sulfides removes the ambiguity that is inherent in whole-rock studies due to the common presence of at least two generations of sulfide within the same rock; it also allows for a relatively rapid acquisition of a large data-set compared to solution methods. Comparison of mantle Re-Os age spectra to crustal formation ages can constrain the interpretation of geophysical data (e.g. seismic reflection profiles) and the mapping of lithospheric terrane boundaries. Also, Re-Os data for different Archaean mantle sections should reveal whether there have been major mantle formation events in the early Earth history that led to the generation and stabilisation of continental lithosphere, or whether the formation and growth of continents has proceeded continuously.

Samples, Analytical Techniques, Results

72 sulfide samples were picked from heavy mineral concentrate, mounted *in situ* in their host in aluminium sleeves and polished. Major-element contents of sulfides and host olivine, orthopyroxene and clinopyroxene were collected using the CAMECA Camebax SX50 electron microprobe. Trace-element contents of the sulfides were obtained by quadrupole laser ablation microprobe (LAM)-ICPMS. Re-Os isotopic ratios were analysed by a LAM coupled to a Nu Plasma multi-collector ICPMS. Bulk sulfide compositions were obtained by image analysis.

Image analysis and major element data reveal that of 72 samples, 47 are Fe-rich mono-sulfide solid solution (mss), 12 Ni-Co-rich mss. Fe-rich mss have Me/S (metal-sulfur ratios) = 0.78 – 1.17, $\text{Ni}/(\text{Ni}+\text{Fe})$ =

0.06 – 0.45 and Co-contents of generally < 1 wt%. Trace element data were obtained for 18 samples of the Fe-rich suite. Chondrite-normalised contents of all platinum group elements (PGE: Os, Ir, Ru, Rh, Pt, Pd) range from the 100s to the 100,000s, regardless of their compatibility and Pd/Ir (i.e. incompatible over compatible PGE) range from 0.003 to 65. Ni-Co-rich mss have Me/S = 1.09 – 1.31, Ni/(Ni+Fe) = 0.64 – 0.91 and very high Co-contents of up to 13.1 wt%. Calculated oxygen fugacities range from $\log f\text{O}_2 = -7.29$ – -9.88 , with a mean at -7.92 . Four samples of the Ni-Co-rich suite yielded very high chondrite-normalised abundances of the compatible PGE (10,000s to 100,000s), whereas incompatible elements trend towards values an order of magnitude lower. Pd/Ir ranges from 0.09 to 9. Ni-Co-rich mss tend to have lower $f\text{O}_2$ ($\log f\text{O}_2 = -8.88$ – -13.54 , mean = -10.46) than Fe-rich mss. An enrichment in W can be observed in both Fe- and Ni-Co-rich suite, although a much higher percentage of the latter is affected (58% versus 21% for Fe-mss). Re-Os isotope data were collected for 40 of the Fe-rich mss and 4 of the Ni-Co-rich mss. Compositions for $^{187}\text{Os}/^{188}\text{Os}$ vary from 0.1003 (± 0.0010) to 2.0086 (± 0.0074). $^{187}\text{Re}/^{188}\text{Os}$ range from 0.00180 (± 0.00026) to 5.13 (± 0.58).

Discussion

Major-element and oxygen fugacity data suggest the presence of two distinct sulfide populations; one is Fe-rich and formed at relatively oxidising conditions, the other is Ni-Co-rich and formed in a relatively reducing environment. Primary sulfides that can be shown to be related by igneous processes may yield formation ages for the lithospheric mantle. In order to test which sulfides from our data-set meet this criterion, we have estimated the composition of a primitive mantle sulfide and calculated melts and complementary residues from this primitive sulfide using the distribution coefficients of Li et al. (1998). These hypothetical sulfides line up on an igneous trend in a plot of incompatible versus compatible elements, such as Pd versus Ir. Comparison of this trend with data from Lac de Gras sulfides shows that many samples could be related as melts and complementary residues, and could therefore be considered as primary. A number of samples, however, have very high Pd relative to their (high) Ir abundances, which is not consistent with single-stage formation of these sulfides and indicates that the trace element budget has been disturbed. The same is true for samples with highly radiogenic Os isotopic compositions that are not supported by their Re/Os.

After exclusion of these non-primary samples, there are three groups of sulfide inclusions from which we can confidently gather age data: (1) A group of Fe-rich mss (N=10) which have correlated $^{187}\text{Re}/^{188}\text{Os}$ and $^{187}\text{Os}/^{188}\text{Os}$. These lie on an isochron at 3.29 ± 0.24 Ga and have an initial Os isotopic composition ($^{187}\text{Os}/^{188}\text{Os}_i = 0.10734 \pm 0.00022$) that is higher than the chondritic mantle at that time, requiring an enriched source. (2) A group of Fe-rich mss (N=4) which have high Re/Os but unradiogenic Os isotopic compositions, indicating that the Re-enrichment is very recent and that the compatible trace element budget has not been disturbed. Re-depletion ages calculated for this group, assuming all their Re is secondary, range from 3.43 to 3.83 Ga. (3) The Ni-Co-W-rich mss (N=9) which, with its distinct composition, probably was formed in a separate event. Re-depletion ages range from 1.50 to 2.60 Ga.

The age data for these three groups can be integrated into a single cumulative probability plot, reflecting not only the frequencies of the different ages, but also their uncertainties. Figure 1 shows the mantle age spectra obtained from the sulfides compared to known crust formation and tectonic events in the Slave craton. The isochron age coincides with a period of crust formation between 3.3 and 3.4 Ga in the western craton, a continental complex. It is broadly overlapped by Re-depletion ages from three sulfides. The oldest Re-depletion age (3.83 ± 0.16 Ga) is within error of the oldest known rocks in the craton (Acasta gneiss complex). The evidence for >3.0 Ga old mantle beneath the 2.7 Ga arc terrane in the central craton where the study area is located may suggest that ancient continental mantle was subducted beneath the arc during collision and amalgamation of the Slave craton. In contrast, the ages obtained for Ni-Co-W mss do not overlap with any of the known events in the craton. This could suggest that the event during which they formed was not expressed at crustal levels. Alternatively, they may represent not a mantle formation episode, but mixtures from later reworking. Their age information may therefore be meaningless.

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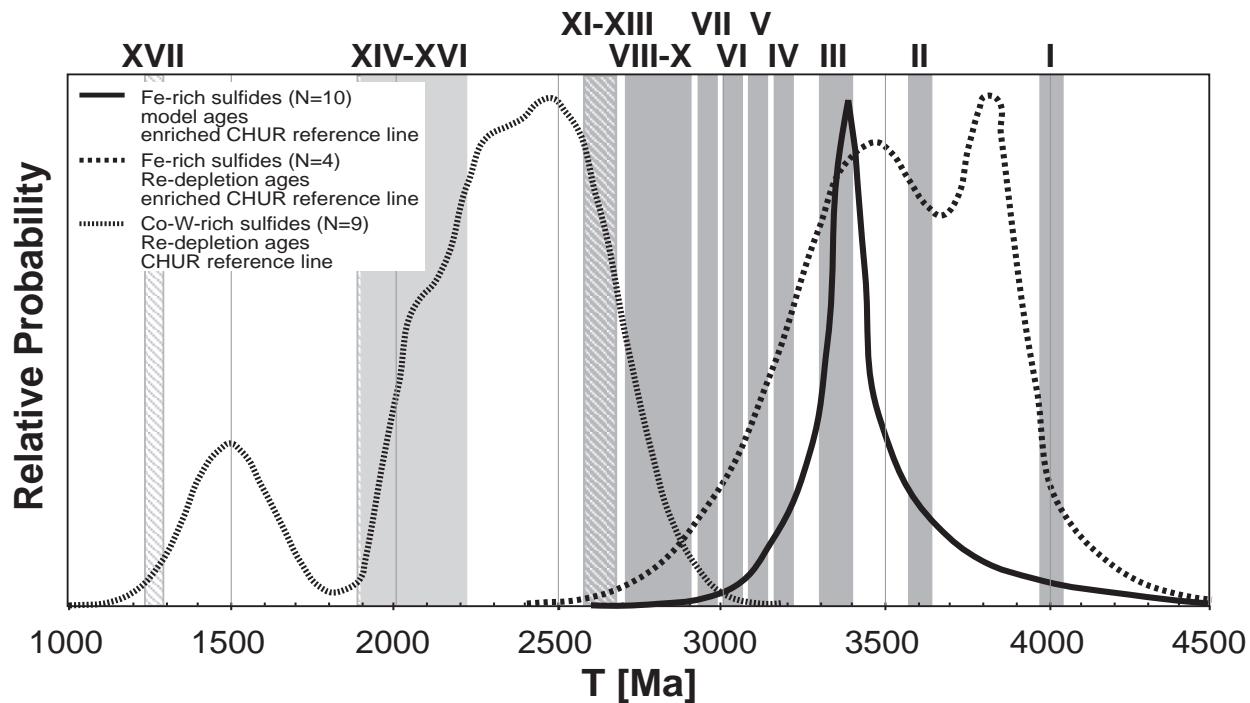


Figure 1. Superposition of Re-Os mantle age spectra for sulfides from the Slave craton. The Fe-rich sulfide group was referred to evolution of an enriched source (chondritic mantle (CHUR)+30% Archaean oceanic crust), consistent with its enriched initial Os isotopic composition. Model ages were then calculated for ten samples with correlated $^{187}\text{Os}/^{188}\text{Os}$ and $^{187}\text{Re}/^{188}\text{Os}$ (all Re primary). Re-depletion ages were calculated for four Fe-rich sulfides with recent Re-enrichment (all Re secondary). The Ni-Co-rich sulfide group, thought to have formed separately, is referred to CHUR evolution. Known events in the Slave craton, numbered I through XVII (data of Bleeker & Davis 1999, Hoffman 1989, Davis 1997) are also marked.