Re-Os Isotope Evidence for Meso-Archaean Mantle Beneath 2.7 Ga Contwoyto Terrane, Slave Craton, Canada: Implications for the Tectonic History of the Slave Craton

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Major, trace element and Re-Os isotopic data were obtained *in situ* from individual sulfide grains enclosed in concentrate-derived minerals from the Lac de Gras area, Slave craton, by electron microprobe, quadrupole laser ablation microprobe (LAM) ICPMS and multi-collector LAM ICPMS, respectively. The *in-situ* method for the collection of Re-Os isotope data from individual sulfides removes much of the ambiguity inherent in whole rock studies due to the usual 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 conventional methods, 72 samples in the present study.

Sulfide samples from Lac de Gras mainly define two distinct populations: one of Fe-rich monosulfide solid solution (mss) and another that is Ni-Co-rich but S-deficient mss. They were derived from the deeper layer of the stratified lithospheric mantle at Lac de Gras. Several lines of circumstantial evidence suggest that this layer, including the two sulfide populations, was derived from the lower mantle via plume subcretion. Re-Os geochronology reveals that there have been several mantle formation events, or that different regions of a heterogeneous plume were sampled. Ten of the Fe-rich mss lie on an isochron of 3.29±0.24 Ga, with an enriched initial $^{187}Os/^{188}Os$. Four samples with high Re/Os but low $^{187}Os/^{188}Os$ give Re-depletion ages (referred to the same enriched source) > 3.4 Ga. These ages are significantly older than the overlying crust, which forms part of the arc-related 2.7 Ga Contwoyto terrane, but correspond to crust formation ages in the adjacent continental-type Central Slave Basement Complex (CSBC).

The lack of agreement between crust and oldest mantle ages for the Contwoyto terrane contrasts with the broad agreement observed in some other lithosphere sections (e.g. Kaapvaal: e.g. Pearson et al. 1995). Several scenarios could account for this apparent discrepancy. They include preservation of a previously ultra-depleted shallow layer during rifting of a CSBC-like continental terrane and formation of the less depleted deep layer by plume-subcretion in the eastern block (Contwoyto terrane). This is followed by continental arc formation and emplacement of juvenile arc material onto the old crust, and collision of CSBC and Contwoyto terrane (autochtonous deep mantle layer). An alternative would be formation of the deep layer by plume-subcretion in the west (CSBC), and formation of the ultra-depleted shallow layer during later island arc formation in the east (Contwoyto terrane), followed by collision and subduction of CSBC-type mantle beneath the Contwoyto terrane (allochtonous deep mantle layer). While both scenarios could explain the "age paradox", the second model shows the best fit with available geological and geophysical data for crust and mantle.

Results

The samples analysed here are sulfide inclusions in olivine grains taken from the coarse concentrate of the A154 kimberlite. Of 72 samples, 47 are Fe-rich mss, and 12 are Ni-Co-rich mss. Fe-rich mss have Me/S (metal-sulfur ratio) = 0.78 – 1.17, Ni/(Ni+Fe) = 0.06 – 0.45 and [Co] generally < 1 wt%. For Fe-rich mss (N=18) chondrite-normalised contents of all platinum group elements (PGE_N) range from the 100s to the 100000s, regardless of their compatibility and Pd/Ir (i.e. incompatible over compatible PGE) ranges from 0.003 to 65. Oxygen fugacities range from log fO_2 = -7.29 to 9.88 (mean –7.92). Ni-Co-rich have Me/S = 1.09 – 1.31, Ni/(Ni+Fe) = 0.64 – 0.91 and [Co] up to 13.1 wt%. Four samples yield compatible PGE_N from the 10000s - 100000s; incompatible elements trend towards values an order of magnitude lower. Pd/Ir ranges from 0.09 to 9. Log fO_2 is from -8.88 to -13.54, (mean -10.46), lower than Fe-rich mss. A W-enrichment can be observed in both suites, but a much higher percentage of the Ni-Co-rich suite 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. $^{187}Os/^{188}Os$ varies from 0.1003±0.0010 to 2.0086±0.0074, and $^{187}Re/^{188}Os$ from 0.00180 ±0.00026 to 5.13± 0.58 (including unpubl. data of Alard et al., N=4). Ten of the Fe-rich mss lie on an isochron giving a 3.29±0.24 Ga and an enriched $^{187}Os/^{188}Os_{initial}$ of 0.10734±0.00021 (γ_{Os}=2.74±0.21). A chondritic mantle ("CHUR") plus ~30% oceanic crust is a possible source. Seven samples have unsupported $^{187}Os/^{188}Os$ pointing to ^{187}Os-gain or Re-loss, while samples with high Re/Os yet low $^{187}Os/^{188}Os$ lie on a trend of recent Re-enrichment. Their Re-depletion (i.e. minimum) ages, assuming the same source indicated by the isochronous samples, range from 3.42±0.44 Ga to 3.83±0.16 Ga (N=5), and from 3.0±1.2 Ga to 3.87±0.33 if referred to CHUR. W-enriched samples including all Ni-Co-rich mss (N=9) give Re-depletion ages from 1.50±0.26 Ga to 2.60±0.32 Ga if referred to CHUR, and from future to 3.26±0.16 with a mode at ~3.2 Ga if referred to the enriched source. Samples falling off the isochron could be part of a heterogeneous plume, with variable enrichment, initial $^{187}Os/^{188}Os$ and isotopic evolution, rather than pointing to different formation ages.

Discussion

Origin of the deep lithospheric mantle layer

Previous studies have shown the mantle beneath Lac de Gras to be strongly stratified, having an ultra-depleted shallow layer (>100-140 km), possibly complementary to the overlying arc-related crust, and a less depleted deep layer (140-220 km), possibly plume-derived (Pearson et al. 1999; Griffin et al. 1999). Comparison of the composition of the grains containing the sulfide inclusions (olivine, orthopyroxene, clinopyroxene) and xenolith compositions suggests that almost 3/4 of the samples are derived from the deep layer, and the remainder have compositions common to either layer. It is possible that no primary sulfide occurs in the shallow layer as all sulfur may have been exhausted during the melting that caused its severe depletion. Based on the strong stratification of the Lac de Gras mantle and the occurrence of diamonds with lower mantle inclusion assemblages at the same locality, Griffin et al. (1999) suggested the deeper stratum formed by subcretion of a plume carrying the diamonds from the lower mantle. The superchondritic initial Os isotopic composition of the isochronous Fe-rich samples is consistent with derivation from an enriched reservoir, such as the upper mantle-lower mantle or core-mantle boundary where subducting slabs pond.

Ni-Co-rich mss equilibrated at fO_2 low enough for metal saturation to be reached. This is consistent with the occurrence of native Fe as an inclusion in olivine; this metal phase shows negative Ni and Co anomalies relative to elements of similar siderophile character. In melting experiments on synthetic sulfides with Me/S similar to the Ni-Co-rich mss from Lac de Gras, quench products were mss with elevated Ni and Co contents and Fe alloy (Ballhaus and Ellis 1996). Such melts might be trapped during a later stage of core formation when sulfide melts drained to the core, percolating through a solidified perovskite layer, whereas the molten upper mantle was cleared of all metal (Ballhaus and Ellis 1996). We suggest a similar origin for the Ni-Co-rich mss and the Ni-Co-poor native Fe at Lac de Gras. The occurrence of Co-rich sulfide together with lower mantle phases and of native Ni in the diamond-inclusion suite, where ~25% of all inclusion assemblages indicate a lower mantle source (Davies et al. 1999), may establish a further link between the metal phases, Ni-Co-rich mss and the lower mantle.

Implications of petrogenetic and geochronological data for tectonic history

The possibly plume-derived deep lithospheric mantle layer has ages significantly greater than the overlying arc-related crust (Contwoyto terrane), but corresponding to a period of major crust formation in the adjoining continental terrane (CSBC) (Northrup et al. 1999). These age constraints and those from crust (Kusky 1989; Bleeker et al. 1999) and mantle geology suggest two principal scenarios (or combinations of the two) to explain the data, illustrated in Fig. 1.

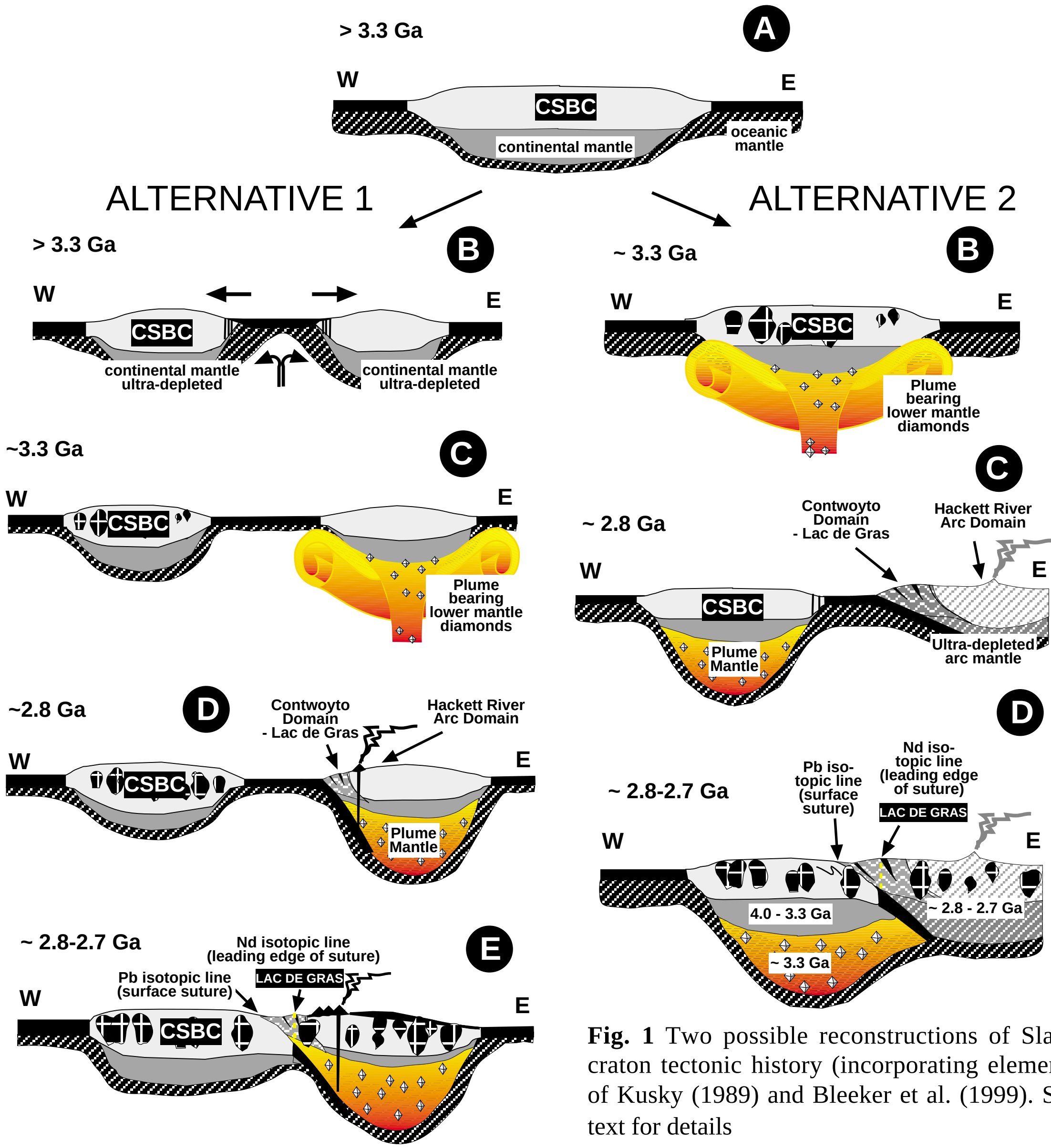

Fig. 1 Two possible reconstructions of Slave craton tectonic history (incorporating elements of Kusky (1989) and Bleeker et al. (1999). See text for details

(1) Rifting of the CSBC (e.g. Padgham 1995), with preservation of a previously ultra-depleted lithosphere, was followed by plume subcretion in the eastern block at about 3.3 Ga. At ~2.8 Ga east-oriented subduction led to formation of a continental arc, followed by collision between the two continental blocks. This would require the continental crust in the eastern fragment to be either entirely reworked or buried beneath arc-related rocks, as there is no evidence for ancient crust in this part of the craton.

(2) Plume subcretion and crustal thickening in the CSBC at ~3.3 Ga was followed at ~ 2.8 Ga by subduction, island arc (e.g. Kusky 1989) and ultra-depleted mantle formation to the east, and at ~ 2.7 Ga by collision between the two terranes and subduction of CSBC mantle beneath the Contwoyto terrane.

While gravity data suggest a very steep trans-lithospheric suture (Poudjom Djomani et al. 2001), a shallower subduction model would be consistent with the geometry revealed by seismic reflection profiling southwest of Lac de Gras (Cook et al. 1999). Extrapolation to Lac de Gras (Fig. 2) would place CSBC mantle beneath the Lac de Gras area at ~150 km depth.

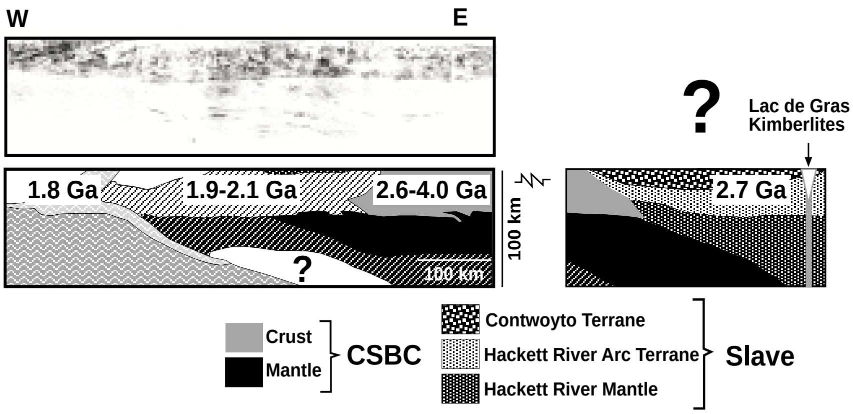

Fig. 2 Seismic reflection profile taken from Cook et al. (1999) and their interpretation underneath. To the right a possible extrapolation to the study area ~ 150 km northeast of the profile.

This model and the seismic data also explain well the existence of the inferred collisional suture at depth (Bleeker et al. 1999), traced by the north-south trending Nd isotopic line (indicating juvenile crust east and ancient crust west of the line, Davis and Hegner 1992) just to the north of Lac de Gras, which lies ~100 km east of the surficial suture. An east-dipping crustal suture and a link to the CSBC also has been adopted by Gruetter et al. (2000) to account for >3 Ga lower crustal material from an area in the younger Contwoyto terrane just north of Lac de Gras, and led to their prediction that equally old mantle underlies this region.

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