Dating mantle samples: examples from the Re-Os system in eclogites and diamonds

S.B. SHIREY1, M.D. SCHMITZ1, K.J. WESTERLUND3, S.H. RICHARDSON3, U. WIECHERT4, D.G. PEARSON5, R.W. CARLSON1 AND J.W. HARRIS6

1Carnegie Institution of Washington, DTM, 5241 Broad Branch Road NW, Washington, DC, 20015, USA (shirey@dtm.ciw.edu, carlson@dtm.ciw.edu)
2Department of Geosciences, Boise State University, 1910 University Drive, Boise, ID 83725-1535 (markschmitz@boisestate.edu)
3Department of Geological Sciences, University of Cape Town, Rondebosch 7701, South Africa (karl.westerlund@hifab.se, shr@geology.uct.ac.za)
4Institute of Isotope Geology, ETH Zentrum, Zurich, 8092 Switzerland (wiechert@erdw.ethz.ch)
5Department of Geological Sciences, Durham University, South Rd, Durham DH1 3LE, United Kingdom (d.g.pearson@durham.ac.uk)
6Division of Earth Sciences, Gregory Building, University of Glasgow, Glasgow, G12 8QQ, United Kingdom (jwh@earthsci.gla.ac.uk)

Absolute age determinations on mantle samples using radiogenic isotope systems such as Rb-Sr, U-Pb, and Sm-Nd have been difficult because of issues of metasomatic overprints, host contamination, and blank. The Re-Os system over the last 15 years has shown wide applicability both on the single grain and whole-rock scales. Combination with opportunistic U-Pb and Lu-Hf in zircon, garnet and whole-rock provides a comprehensive tool to understand, with increasingly precise chronological constraints, the petrogenesis of the lithospheric mantle beneath cratons.

Re-Os isotopic ages of individual eclogite sulfide inclusions in diamonds compared to the Re-Os model ages on depleted harzburgites supports a process whereby the Kaapvaal craton was created and then assembled from 3.1 to 2.9 Ga by Archean subduction. Independent corroboration of this model comes from two sources: Re-Os, U-Pb, O, and trace elements on Kaapvaal craton eclogite suites which allow for the reconstruction of an older than 3.04 Ga Archean ocean floor section preserved within the lithosphere; and metasomatic signatures in 3.57 ± 0.15 Ga Slave craton peridotitic sulfide inclusions in diamonds that suggest subduction can be key to forming the earliest cratonic nuclei.

Diamonds beneath an ancient continental rift: The Star kimberlite, South Africa

M.D. SCHMITZ1,2, S.B. SHIREY2 AND R.W. CARLSON2

1Department of Geosciences, Boise State University, Boise, ID 83725 (markschmitz@boisestate.edu)
2Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20018 (shirey@dtm.ciw.edu, carlson@dtm.ciw.edu)

The Group 2 Star Mine kimberlite dike of the central Free State province of South Africa intruded at 144 Ma across a key region of the southern African Kaapvaal craton for testing the effects of ancient cratonic rifting on the subcontinental lithosphere. An apparent paradox exists in the mutual presence at the Star Mine of: 1) abundant diamonds necessitating a thick cold mantle keel, and 2) ultrahigh-temperature lower crustal xenoliths formed at 2.71 Ga during deep crustal metamorphism in an apparent response to severe lithospheric thinning during Venterdorp rifting (Schmitz and Bowring, 2003). We initiated a geochemical and geochronological study of the Star Mine diamonds in order to constrain the thermal history of the deep lithosphere and unravel this paradoxical lithospheric assemblage.

Optical microscopy and cathodoluminescence imaging on polished plates of the dominant population of white octahedral diamonds reveals abundant discordant diamond nuclei, thick mantles of oscillatory zoned octahedral growth and a major resorption surface followed by an outer rim of octahedral diamond. FTIR measurements yield relatively low nitrogen contents with a median IaB aggregation of 10% in the oscillatory zoned mantle, with lower nitrogen and degree of aggregation in the outer rims. These compositional variations have guided in situ carbon and nitrogen isotopic analyses, yielding typical mantle-like compositions. Chromite, olivine, rare harzburgitic garnet, and more abundant sulfide are present as inclusions in the diamonds. The targeted sulfides will facilitate geochronological and tracer isotopic investigations of diamond growth through ID-TIMS Re-Os and Pb isotopic measurements.

Reference
Os-Hf-Nd isotope Constraints on subcontinental lithospheric mantle evolution, Slave Craton (Canada)

S. AULBACH¹, W.L. GRIFFIN¹, N.J. PEARSON¹, S.Y. O’REILLY¹ AND K. KIVI³

¹GEMOC, Macquarie University, NSW 2109, Australia (saulbach@els.mq.edu.au, wgriffin@els.mq.edu.au, npearson@els.mq.edu.au, soreilly@els.mq.edu.au)
²CSIRO Exploration and Mining, North Ryde, Australia
³Kemnecott Canada Expl. Inc., Thunder Bay, ONT, Canada

The Slave Craton is an amalgamation of Meso- and Neoarchaean terranes, which is underlain by strongly stratified subcontinental lithospheric mantle (SCLM) with a ultradeposited shallow (SL) and a less depleted deep layer (DL) (Griffin et al., 1999). We have analysed the ¹⁸⁷Os/¹⁸⁸Os of peridotitic sulfide from the deep layer by LAM MC ICPMS and the ¹⁷⁶Hf/¹⁷⁷Hf and ¹⁴³Nd/¹⁴⁴Nd of garnet (gt) and clinopyroxene (cpx) from peridotitic kimberlite-derived xenoliths by solution MC ICPMS to obtain constraints on the origin and evolution of the SCLM.

¹⁸⁷Os/¹⁸⁸Os of DL-sulfide ranges from 0.1002 to 0.4732 (yos = -21.1 to +272), giving TMA up to 3.9 Ga. A subset of samples lies on an isochron with an age of 3.27±0.24 Ga. This is older than the 2.7 Ga overlying terrane but coincides with crustal ages in the neighbouring terrane, suggesting subcretion of older beneath younger mantle during collision.

Nd-Hf isotope date were obtained from 2 SL-harzburgites and 8 DL-lherzolites. The two SL-harzburgites were metasomatised by a carbonatite-like melt leading to low εNd (-54) in one sample (¹⁷⁶Hf/¹⁷⁷Hf not measurable) and moderate εNd (2.6) but high εNd in another sample (+181). Both samples are argued to be at least 3.2 Ga old, suggesting that the SL has been subducted beneath 2.7 Ga crust along with the DL. The age of metasomatism is more difficult to constrain, due to multiple modification of parent/daughter, but the minimum age for the oldest metasomatism (lowest εNd) is 2.3 Ga. Cpx in a DL-lherzolite with low εNd (-14.4) but radiogenic Hf (+43) may record the same metasomatic event. However, for most of the DL this older metasomatism was obscured by a younger overprint involving a silicate melt, which led to both Nd and Hf addition, and εHf and εNd around 0. The age of the younger metasomatism is constrained to <350 Ma based on near-constant εNd at variable Sm/Nd.

Reference

Proterozoic mantle lithosphere beneath the East African Rift (Southern Ethiopia):

In situ Re-Os evidence

KUO-LUNG WANG¹, SUZANNE O’REILLY¹, WILLIAM GRIFFIN¹, NORMAN PEARSON¹, RISA MATSUMURA³ AND RYUICHI SHINJO³

¹GEMOC Key Centre, Department of Earth and Planetary Sciences, Macquarie University, NSW 2109, Australia (kwang@els.mq.edu.au, soreilly@els.mq.edu.au, wgriffin@els.mq.edu.au, npearson@els.mq.edu.au)
²Department of Geosciences, National Taiwan University, P.O. Box 13-318, Taipei 106, Taiwan
³Department of Physics and Earth Sciences, University of the Ryukyus, Nishihara, Okinawa 903-0213, Japan (k048310@eve.u-ryukyu.ac.jp, rshinjo@sci.u-ryukyu.ac.jp)

The Os isotope compositions of sulfides in spinel lherzolites hosted by Quaternary alkali basalts from NE of the Turkana Depression, S. Ethiopia, reveal the presence of Proterozoic subcontinental lithospheric mantle (SCLM) beneath the continental rift setting in East Africa. Most of the sulfides have subchondritic ¹⁸⁷Os/¹⁸⁸Os (<0.129). A large range in ¹⁸⁷Re/¹⁸⁸Os (0.003-0.809) suggests recent addition of Re, perhaps reflecting the Paleogene mantle plume activity, which not only caused the East Africa Rift but also significantly perturbed the SCLM in the region. Sulfides with low ¹⁸⁷Re/¹⁸⁸Os (<0.075; Griffin et al., 2002) yield similar TMA and TRe model ages of 1.1±0.2 Ga, interpreted as the depletion age of the SCLM beneath the region. Re-Os mixing lines defined by sulfides in single samples give an initial ¹⁸⁷Os/¹⁸⁸Os (0.1184) consistent with formation of some volumes of the SCLM at ~1.3 Ga. TRe model ages of sulfides can provide minimum estimates for the SCLM age and record later metasomatic events. All model ages of the sulfides suggest a main SCLM depletion age at 1.1 Ga with a later metasomatic age at 0.4-0.5 Ga. A few older ages (1.5-1.8 Ga) suggest the presence of older parts of the SCLM, but no Archean model ages were found. The SCLM depletion age of 1.1 Ga is consistent with the known Meso-Neoproterozoic crustal evolution event of the East African Orogen (Stern, 2002), and the 0.4-0.5 Ga may be related to closing stages of the Paleozoic Pan-Africa orogeny. The sulfide Re-Os data show that Proterozoic SCLM has survived the extensive continental rifting due to the mantle plume.

References
A comparison of mineral and whole rock approaches to Re-Os dating of the Kaapvaal lithospheric mantle

BENJAMIN P. GARDEN1, RICHARD W. CARLSON2, D. GRAHAM PEARSON3, STEVEN B. SHIREY2 AND STEPHEN H. RICHARDSON1

1Department of Geological Sciences, University of Cape Town, Rondebosch 7701, South Africa
   (garden@dtm.ciw.edu, shr@geology.uct.ac.za)
2Carnegie Institution of Washington, DTM, 5241 Broad Branch Road NW, Washington, DC, 20015, USA
   (carlson@dtm.ciw.edu, shirey@dtm.ciw.edu)
3Earth Sciences, Durham University, South Road, Durham
   (d.g.pearson@durham.ac.uk), Great Britain

Re and Os are concentrated into trace Fe-Ni-Cu-sulfide and/or PGE-alloys in peridotite. Sulfide is largely removed during the high degrees of melt extraction experienced by many Archean cratonic peridotites. Whether or not metasomatically introduced sulfides influence whole rock peridotite Re-Os results can be evaluated by examination of the data set for mantle samples from southern Africa's Kaapvaal craton. Comparison of whole rocks with very low Re/Os (< 0.016), as expected for residues of melting, with similarly low Re/Os sulfides, shows that Re-Os model ages agree well, revealing a circa 300 Myr age difference between the lithospheric mantles of the Kaapvaal's eastern and western blocks, consistent with crustal age differences. Whole rock peridotites with higher Re/Os show little correlation between Os isotopic composition and Re/Os, implying that the range in Re/Os is caused by infiltration of the xenolith by the Re-rich host kimberlite. Sulfides in Kaapvaal peridotites [1] range from unradiogenic Os isotopic compositions typical of whole rock peridotites, to more radiogenic values that, along with Kaapvaal eclogite xenoliths, scatter about well-defined 2.9 Ga Re-Os isochrons with radiogenic initial Os (~0.155) defined by diamond inclusion sulfides from Kimberley and Bobbejaan. Similar Re-Os systematics in eclogite, eclogite-paragenesis sulfides in diamonds, and some peridotite sulfides are consistent with introduction of radiogenic Os from subducting crust into the lithospheric mantle during the 2.9 Ga assembly of the western and eastern Kaapvaal blocks. "Crustal" Os is now best preserved in Kaapvaal eclogites and eclogitic sulfide inclusions in diamond, whereas sulfides in peridotite range in Re-Os characteristics depending on the degree to which fluids/melts carrying crustal Os have interacted with depleted peridotite.

Reference
Griffin et al., 2004, *Chem. Geol.* 208, 89-118

Archean mantle beneath the Halls Creek Mobile Zone, W. Australia revealed by Re-Os isotopes

A. LUGUET1, D.G. PEARSON1, A.L. JAQUES2, G.P. BULANOVA1, C.B. SMITH3, S. ROFFEY4 AND M.J. RAYNER5

1Department of Earth Sciences, University of Durham, UK. 
   (ambre.luguet@durham.ac.uk)
2Geoscience Australia, Canberra ACT, Australia.
3Rio Tinto Mining and Exploration Ltd., Bristol, UK
4Rio Tinto Exploration Pty. Ltd., Perth, Australia
5Argyle Diamond Mines Ltd, West Perth, Australia.

The high-grade Argyle lamproite-hosted diamond deposit lies within the Palaeoproterozoic Halls Creek orogenic belt. The age of the lithospheric mantle beneath both the orogenic belt and adjacent Kimberley Craton has been a matter of debate since discovery of the deposit and resolution of this issue has important implications for diamond genesis and exploration models. During recent mining a xenolith-rich portion of the lamproite was discovered. We have selected a suite of the least altered peridotites from newly sampled xenoliths, together with 4 samples from an earlier xenolith petrology study [1] for Re-Os dating. A previous study [2] reported TRD ages of 1.6 and 1.4 Ga for 2 Argyle peridotites, with TMA ages of 2.6 to 3.3 Ga. All peridotites from the new study are heavily weathered and contain no primary sulfides, requiring us to use a whole rock dating approach. Rare secondary sulfides have been identified along grain boundaries. Whole rocks analysed so far have measured 187Os/188Os ratios ranging from 0.111 to 0.117. When corrected for Re in-growth since the 1200 Ma eruption age, Re-depletion ages vary from 2.3 to 3.0 Ga, clearly indicating the presence of Archean mantle beneath this region. The combined PGE and Re-Os systematics of our samples show that the peridotites have experienced metasomatic siderophile element addition, making TMA model ages [2] unreliable. Our data are hence the first reliable indication of Archean lithospheric mantle beneath this area. The Archean Re depletion ages are significantly older than the circa 1.8 to 1.9 Ga crustal basement age or the Sm-Nd ages for inclusions in Argyle diamonds which are predominantly of eclogitic paragenesis [3]. Our results are consistent with origin as refractory Archean mantle.

References
Re-Os isotopic systematics of the Neo-Tethys Dongqiao Ophiolite Complex, Northern Tibet: First data

X-C. Zhi1, Q-A. Xia1, Z-M. Jin2 AND Y-F. Wang2
1School of Earth and Space Sciences, University of Science and Technology of China, Hefei, 230026, China
(xczhi@ustc.edu.cn)
2School of Earth Sciences, China University of Geosciences, Wuhan, 430007, China

The Dongqiao ophiolite complex (DOC) is located in the eastern Neotethys Bangong-Nujiang suture zone (BNSZ) in Tibet, and extends for 60 km as dismembered fragments of a complete ophiolite complex. DOC blocks near Dongqiao include mantle peridotites and podiform chromitites, ultramafic and mafic cumulates, and mafic volcanics.

Re and Os concentrations of the podiform chromitites varies from 82-184ppt and 281-373ppb. Their 187Os/188Os varies between 0.12318-0.12346, averaging 0.12336. Podiform chromitites are characteristic of Phanerzoic suprasubduction zone ophiolites, and often contain isotopic and chemical records of mantle source conditions extant during ophiolite genesis. The DOC mantle source is depleted compared to the chondritic primitive upper mantle. DOC mantle peridotites comprise mainly serpentinized harzburgite and secondary dunite, with Re and Os concentrations between 3-71ppt and 1.193-6.033ppb. The 187Os/188Os is 0.12107-0.12612, average of 0.12362 is almost the same as the podiform chromitites. But one harzburgite has much lower value of 0.11582 indicating old SCLM is involved in the ophiolite melange. Ultramafic and mafic cumulates include olivine pyroxenites, pyroxenites, layered and isotropic gabbros and diabases, with Re and Os concentrations between 6-116ppt and 97-823ppt. The 187Os/188Os is 0.12979-0.14015. All data of mantle and cumulate blocks fall near a 150Ma reference isochron with initial 187Os/188Os of 0.12336. 

Radiometric dating of eclogite xenoliths from kimberlites

D.E. Jacob
Institut für Geowissenschaften, Universität Mainz, Becherweg 21, D-55099 Mainz, Germany (jacobd@uni-mainz.de)

Unlike orogenic eclogites, those brought up from the Earth’s mantle in kimberlites often consist only of clinopyroxene, garnet and rutile. Phases that would be especially interesting for dating purposes such as zircon (e.g. Heaman et al. 2002) are very rare. Sm-Nd age determinations of eclogite xenoliths based on garnets and clinopyroxenes (internal ages) yield results that scatter over several orders of magnitude between 4 G a and ages in the future and are not easy to interpret. The eclogite whole-rock system, however, often gives reliable age information (e.g. Jagoutz et al., 1984; Pearson et al., 1995; Jacob and Foley, 1999). Re-Os isotopes can be applied to bulk eclogites, but may give ages with high uncertainty, whereas Sm-Nd and Lu-Hf isotopic systems require reconstruction of the whole rock composition based on mineral analyses to avoid erroneous results due to infiltration of the xenoliths by kimberlitic material. However, reconstruction of a “clean” bulk eclogite requires knowledge of the rock’s exact modal composition which strongly depends on the sample size. In the case of Lu-Hf it can be shown that reconstructed whole rock eclogite ages can be too young if rutile occurs as an accessory whose exact modal amount is unknown (Jacob et al. 2005). Applying the U-Pb and Pb-Pb systems to eclogite silicates is probably the best method, because partitioning of Pb strongly favours cpx over gt (Dexp/gt = 16 for Udachnaya eclogites, Jacob and Foley, 1999) so that bulk rock reconstructions are not necessary. In the case of eclogite xenoliths from the Udachnaya pipe, it could be shown that the Pb-Pb isochron age on cpx was within error of the Os age on whole rock eclogites (Jacob and Foley, 1999; Pearson et al., 1995). Pb contents in eclogitic minerals, however, are generally below 1 ppm so that this method requires low-blank chemistry procedures.

Acknowledgements

This work is supported by the National Nature Science Foundation of China(Grant No. 40173009, 49873005)

References


References

**In-situ** Pb and Sr and Lu-Hf isotope systematics of mantle eclogites from the Diavik diamond mine, NWT, Canada

S.S. SCHMIDBERGER¹, L.M. HEAMAN¹, A. SIMONETTI¹ AND S. WHITEFORD²

¹Earth & Atmospheric Sciences, Univ. Alberta, Edmonton, AB, Canada (stefanie.schmidberger@ualberta.ca; lheaman@ualberta.ca; antonio.simonetti@ualberta.ca)

²Diavik Diamond Mines, Yellowknife, NWT, Canada (sean.whiteford@diavik.com)

The timing of eclogite formation and addition to the subcontinental lithosphere beneath Archean cratons in North America is currently little constrained. The highly diamondiferous A154S kimberlite was emplaced 55.4 Ma ago in the Slave Province (Lac de Gras area, NWT), Canada and hosts a suite of extremely well-preserved mantle eclogites. The eclogites consist of Cr-poor garnet and omphacitic clinopyroxene and exhibit a bimodal temperature distribution of last equilibration in the lithosphere (850-950°C and 1100-1250°C at 40kb). This study presents in-situ Pb and Sr isotope data and Lu-Hf isotope compositions of constituent clinopyroxene and garnet obtained by MC-ICP-MS (laser ablation & solution mode) from non-diamond bearing eclogites collected at the Diavik diamond mine; on-going studies will also include diamond-bearing eclogites.

Epsilon Hf values for the Diavik eclogites exhibit a very large variation ranging from +4 to +135 for garnets and -35 to +5 for clinopyroxenes at the time of kimberlite emplacement (at ~55 Ma). One garnet-clinopyroxene pair is characterized by extremely radiogenic Hf isotopic compositions corresponding to epsilon Hf values of +1739 and +328, respectively. Internal mineral isochrons for six eclogites yield ages ranging from 460 Ma to 1.5 Ga. Initial Hf isotopic ratios obtained from these regressions intersect the temporal depleted mantle evolution line between 460 Ma and 2.0 Ga. In-situ ⁸⁷Sr/⁸⁶Sr ratios obtained on individual Diavik clinopyroxene grains vary between 0.7029 and 0.7042, suggesting a derivation from depleted mantle compositions. In-situ ²⁰⁶Pb/²⁰⁴Pb (14.0-15.3) and ²⁰⁷Pb/²⁰⁴Pb (14.6-15.6) ratios for the clinopyroxenes yield Pb-Pb model ages of 2.5 to 2.0 Ga. The in-situ data are consistent with Paleoproterozoic formation for the majority of the eclogites and suggest that some of the samples could have formed in the late Archean.

**Dating mantle melting using the Lu-Hf isotope system**

D.G. PEARSON, G.M. NOWELL AND C.J. OTTLEY

Department of Earth Sciences, University of Durham, UK. (d.g.pearson@durham.ac.uk, g.m.nowell@durham.ac.uk, c.j.ottley@durham.ac.uk)

In contrast to geochronological constraints available for the crustal portion of the lithosphere, comparably precise dating of differentiation events that create lithospheric mantle are lacking. Such data are required to understand the behaviour of lithospheric mantle during tectonic events. Here we show that Lu/Hf fractionation and Hf isotopic compositions in clinopyroxene are strongly coupled with whole rock major element indices of melt depletion (e.g., Al₂O₃) in a suite of peridotites from the Beni Bousera peridotite massif, N. Morocco. These variations are considerably more systematic than those evident for the Sm-Nd and Re-Os isotope systems. Despite evidence for significant late-stage disturbance of the Sm-Nd system in clinopyroxenes, they define a Lu-Hf isochron of 1427 ± 71 Myr (2s). Because significant Lu and Hf can partition into orthopyroxene, especially in spinel peridotites, a cpx isochron will not necessarily be an accurate reflection of the melting age. Whole rocks also define an isochron correlation with more scatter, indicating more disturbance at the whole rock scale. Nonetheless, the Lu-Hf isochron age is within error of the most reliable Re-Os model age for the Beni Bousera peridotites and similar to published estimates of the differentiation age for the Ronda peridotite. The age systematics suggest a major mantle differentiation event in the western Mediterranean area 1.4 Gyr ago. This precise age for a mantle melting event shows the potential of the Lu-Hf system in improving age constraints on the timing of lithospheric mantle differentiation. Highly radiogenic Hf isotope compositions in some Beni Bousera peridotite clinopyroxenes extend well above the mantle Nd-Hf isotope array, with epsilon Hf values of up to 209 but at surprisingly unradiogenic Nd (epsilon Nd 4 to 27). This illustrates the level of disturbance of the Sm-Nd system compared to the robustness of the Lu-Hf system. Highly radiogenic Hf isotope compositions, forming sub-vertical array above the mantle Nd-Hf isotope array are unique to continental lithospheric mantle and make Hf isotopes a potentially powerful tracer of lithospheric source regions in magmas and of the recycling of mantle lithosphere into the convecting mantle.
Archean to Middle Proterozoic evolution of the Sandvik ultramafic body, Norway: Evidence from Sm-Nd and Lu-Hf isotope analyses
THOMAS J. LAPEN, L. GORDON MEDARIS JR., CLARK M. JOHNSON AND BRIAN L. BEARD
Department of Geology and Geophysics, University of Wisconsin-Madison, 1215 W. Dayton St., Madison, WI 53704, USA (lapen@geology.wisc.edu)

Combined Sm-Nd and Lu-Hf age and isotope data indicate that Mg- and Cr-rich ultramafic rocks at Sandvik, Western Gneiss Region (WGR), Norway, originated from depleted Archean lithospheric mantle that was chemically and physically modified in Middle Proterozoic time. The Sandvik outcrop consists of garnet peridotite and thin garnet-olivine pyroxenite layers. These contain two principal mineral assemblages: an earlier porphyroclastic assemblage of grt+opx+cpx±ol (1200-1000°C, 50 kbar) and a later kelyphitic assemblage of grt+spl+am±opx±ol (700-750°C; 12-18 kbar). A CHUR Hf model age indicates a period of melt extraction at ca.3.3 Ga for garnet peridotite, reflecting extremely high Lu/Hf ratios and very radiogenic present-day 176Hf/177Hf (~1 have slightly higher εNd = +6.9.

Clinoxyroxene has HIMU-like Pb isotope signatures with 206Pb/204Pb = 19.70-20.25 and negative Δ7/4 (~–0.35 to –3.99), U, Th and Pb concentrations range between 0.07-0.65, 0.47-2.45 and 0.164-0.374 ppm, respectively, with extreme µ, o and k of up to 80, 573 and 11. Nd isotopes confirm the HIMU signature of the Moroccan SCLM with εNd = +3.1 to +4.8 for the LREE-enriched clinopyroxenes. Clinoxyroxene with [Sm/Nd]~1-1 have slightly higher εNd = +6.9.

HIMU lithospheric mantle beneath Northwest Africa
N. WITTIG1, S. DUGGEN1, J.A. BAKER2, A. KLUEGEL3 AND K. HOERNLE4
1Geological Institute-DLC, Copenhagen University, Oester Voldgade 10, 1350 Copenhagen, DK (nw@geol.ku.dk, sduggen@geol.ku.dk);
2School of Earth Sciences, Victoria University of Wellington, P.O. Box 600, Wellington, NZ (joel.baker@vuw.ac.nz);
3Department of Geosciences, University Bremen, Postfach 330 440, GER (akhuegel@uni-bremen.de);
4IFM-GEOMAR, Wischhof Straße 1-3, 24148 Kiel, GER (khoernle@ifm-geomar.de)

High-precision Nd-Pb (double-spike) isotope (MC-ICP-MS) and trace element data (LA-ICP-MS) for clinopyroxene from spinel-facies xenoliths (n=12) from the Middle Atlas region (Morocco) have been determined. Clinopyroxene is dominantly LREE-enriched with steep MREE-HREE chondrite-normalised patterns and shows similarity to the hosting basanites. Clinopyroxene has [La/Ce]~<1 and [Sm/Nd]<0.55 due to secondary La depletion unreported in the hosting basanites. Few clinopyroxenes lack secondary La depletion and have [La/Ce] = 3 and [Sm/Nd]~1.

Primitive-mantle-normalised multi-element diagrams of clinopyroxenes reveal marked depletion at Nb-Ta and Zr-Hf for clinopyroxene unlike associated basanites that only have distinct Zr-Hf troughs. Zr/Hf ratios vary between Zr/Hf = 30-61 whereas Nb/Ta ratios are generally sub-chondritic ranging between 3.6 and 14.5.

Clinopyroxene has HIMU-like Pb isotope signatures with 206Pb/204Pb = 19.70-20.25 and negative Δ7/4 (~–0.35 to –3.99), U, Th and Pb concentrations range between 0.07-0.65, 0.47-2.45 and 0.164-0.374 ppm, respectively, with extreme µ, o and k of up to 80, 573 and 11. Nd isotopes confirm the HIMU signature of the Moroccan SCLM with εNd = +3.1 to +4.8 for the LREE-enriched clinopyroxenes. Clinoxyroxene with [Sm/Nd]~1-1 have slightly higher εNd = +6.9.

Radiogenic Pb isotope ratios, low εNd, LREE enrichment in clinopyroxenes and the overall resemblances with associated basanites in addition to the strong U-Th-Pb enrichment suggest recent metasomatism of the sub-continental lithosphere probably during passage of the Quaternary basanitic melts in the Middle Atlas. This resulted in a relatively homogeneous lithospheric mantle with HIMU characteristics. The distinct HFSE depletion and the overall enrichment of incompatible elements in clinopyroxenes requires strong affinity of the most recent metasomatic agent with carbonate (-silicate) melts overprinting the Moroccan sub-continental lithospheric mantle (SCLM).
Sr-Nd-Hf isotope constraints on lithospheric mantle evolution beneath Olot, NE Spain

G. Bianchini1, L. Beccaluva1, C. Bonadiman1, G.M. Nowell2, D.G. Pearson2, F. Siena1
AND M. Wilson3

1Dep. of Earth Science Department, University of Ferrara, Italy (bcc@unife.it)
2Dep. of Earth Sciences, Durham University, UK
3School of Earth Sciences, University of Leeds, UK

Mantle xenoliths exhumed by alkaline basalts in the Olot volcanic field, provide a bi-modal population consisting of LREE-depleted protogranular lherzolites (cpx 12-14%, and traces of pargasite) and LREE-enriched harzburgites (cpx < 1-2 %) showing secondary recrystallization textures. New TIMS and MC-ICP-MS analyses carried out on cpx separates show the following compositional ranges:

\[ \varepsilon_{\text{Sr}} = -15 \text{ to } -26, \varepsilon_{\text{Nd}} = 9 \text{ to } +11, \varepsilon_{\text{Hf}} = 18 \text{ to } +68 \]
for lherzolites that approach the DM isotopic end-member; \[ \varepsilon_{\text{Sr}} = -10 \text{ to } +13, \varepsilon_{\text{Nd}} = -1 \text{ to } -6, \varepsilon_{\text{Hf}} = 3 \text{ to } +8 \]
for harzburgites that approach the EM(1) isotopic end-member. On a Nd-Hf isotope diagram all the cpx plot close to or significantly above the mantle array, i.e., they are typical of lithospheric mantle in general. These isotope compositions are closely comparable to those recorded in other xenolith suites from European Cenozoic volcanic fields. The petrological features of Olot lherzolites are also similar to those of the External Liguride peridotite massifs, while the Olot harzburgites share the EM1 component with cpx-poor peridotites from the Lanzo, Lherz and Ronda. These analogies with Massifs-peridotites (some of which were exhumed before the Middle Mesozoic) suggest that similar petrogenetic processes were effective over a wide area at the paleo-European margin during pre-Middle Mesozoic times. An isochron-like correlation, probably reflecting the timing of melt depletion, is evident for the Lu-Hf system (450 Ma), although 3 of the samples have subchondritic Lu/Hf. In the only unmetasomatized sample (lherzolite Olt4f) both the Sm-Nd and Lu-Hf systems still appear to record Lower Paleozoic depletions.