Report of TNA No. 028-TNA3

The nature and timing of the formation of sub continental lithospheric mantle beneath the NW. Kaapvaal Craton: implications for the formation of the Earth's early crust

Project outline

As a master thesis project we (Martijn Klaver and Quinten van der Meer) conduct a petrological and geochemical study on a selection of peridotites from the Venetia kimberlite pipe in the structural area of the Limpopo mobile belt (LMB), NW Kaapvaal Craton in Southern Africa (fig1). From our observations we aim to infer the formation history of the cratonic mantle and its consequences for the Archaean plate tectonics and crustal formation of the early Earth. Literature data from the Kaapvaal craton (e.g. Boyd 1989) and observed in the chemistry of our samples, an ancient melting event depleted the mantle in magmaphile elements that were partly reintroduced by subsequent metasomatism. An attempt to constrain the timing of initial melt depletion can be made based on the ^{187}Re to ^{187}Os decay system (e.g. Pearson 1999). This is due to the behaviour of Re and Os during melt extraction. Under mantle conditions, Os is a compatible element and Re is mildly incompatible. This means that Re leaves the system in melts and Os remains in the residue and build-up of radiogenic Os ceases. Unfortunately the Re-Os database on peridotites from LMB available prior to our analysis (Carlson et al., 1999) was unsatisfactorily small and allowed no major conclusions to be drawn on melt depletion, therefore we proposed to extend this database with analysis of our samples. The fruitful results show a significantly younger depletion age for LMB than for the entire Kaapvaal craton (Pearson & Wittig 2008) and are the basis of a presentation of the project on the Goldschmidt conference 2011 (see appendix: Goldschmidt 2011 abstract)

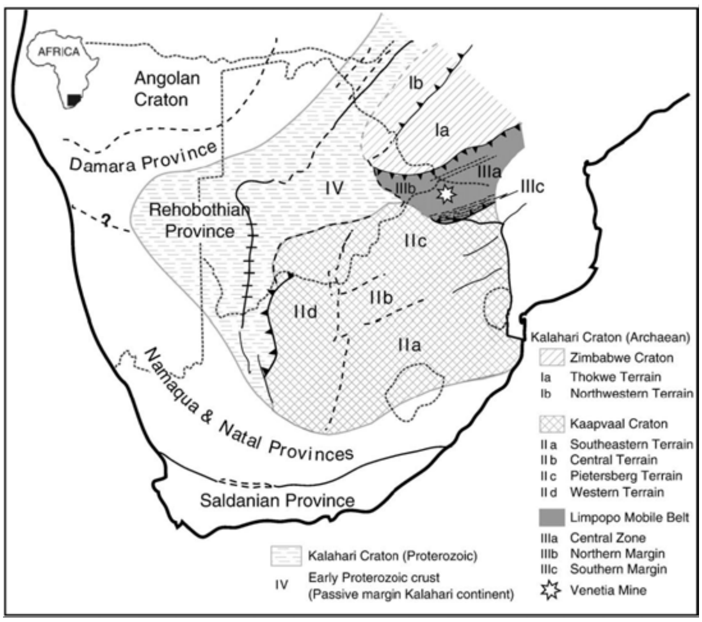

Fig 1. Simplified geological map of the Kalahari Craton from. Limpopo Mobile Belt (grey) lies between the Kaapvaal (crosshatched) and Zimbabwe (diagonal lines) cratons, all three of which were part of the Proto-Kalahari Craton. The Venetia Diamond Mine (star) is situated in the Central Zone of the Limpopo Mobile Belt.

Methods

From 14-02-2011 until 28-02-2011 and from 14-03-2011 until 28-03-2011 (2x14 days) we visited the CNRS/CRPG in Nancy, France. During our visit we were able to measure 24 samples and 6 duplicates as a control. Our starting material consited of finely ground whole rock powders which were spiked with Re and Os and subsequently dissolved in aqua regia under high pressure and temperature in a High Temperature-Ppressure Asher. The Os was then extracted using liquid-liquid separation techniques and micro distillation. Purified Os was loaded on Pt filaments and measured on the 262 N-TIMS, mostly using MC Faraday cups with the exception of small samples which were measured using an Ion counter by peak jumping. Re was separated from the Os in liquid-liquid extraction and purified from other constituents by column chromatography. Re isotopes were measured on an ICP-MS.

Results

The results of our analysis are listed below, included are Re and Os concentrations in the sample, relevant isotope ratios, γOs values (indicate radiogenic Os ratio relative to CHUR), TMA is the Os model age and TRD the Rhenium depletion age. The TRD is best applicable to our samples, it assumes total extraction of Re during melt depletion and assumes all existing Re in the sample is introduced at the time of Kimberlite eruption. TRD always represents a minimum age of melt depletion.

	sample	Re [ppt]	Os [ppt]	187Os/188Os	γOs	187Re/188Os	(187Os/188Os)i	TMA [Ga]	TRD [Ga]
1	AT 1198	409.2	56.1	2.074	1533.2	44.107	1.681	2.616	#
2	AT 1315	222.2	3055.6	0.119	-5.912	0.350	0.116	8.138	1.567
3	AT 1324	64.5	145.5	0.123	-2.810	2.135	0.104	-0.124	3.286
4	AT 1333	133.8	4875.3	0.113	-10.915	0.132	0.112	3.007	2.205
5	AT 1361	512.0	11325.1	0.121	-4.738	0.218	0.119	1.930	1.177
6	ATC 720	46.0	3056.3	0.108	-14.618	0.072	0.108	3.290	2.803
7	ATC 722	56.5	3275.5	0.111	-12.894	0.083	0.110	3.006	2.504
8	ATC 724	94.7	4558.7	0.110	-12.995	0.100	0.110	3.194	2.544
9	ATC 725	111.5	2158.3	0.111	-12.234	0.248	0.109	5.792	2.595
10	ATC 726	44.8	2693.1	0.110	-13.730	0.080	0.109	3.167	2.652
11	ATC 727	157.1	2351.2	0.115	-9.470	0.321	0.112	8.364	2.184
12	ATC 731	1033.4	2988.1	0.124	-2.098	1.666	0.109	-0.127	2.562
13	ATC 740	196.4	6129.6	0.112	-11.884	0.154	0.111	3.550	2.411
14	ATC 745	192.2	3922.2	0.111	-12.242	0.236	0.109	5.369	2.580
15	ATC 747	306.2	6521.1	0.119	-6.628	0.226	0.117	2.807	1.539
16	ATC 752	78.4	3362.0	0.112	-11.496	0.112	0.111	2.951	2.286
17	ATC 753	24.7	6198.1	0.114	-10.201	0.019	0.114	1.998	1.929
18	AT 1304	206.2	6467.6	0.111	-12.833	0.153	0.109	3.812	2.582
19	AT 1305	299.0	4390.1	0.113	-10.815	0.328	0.110	10.187	2.438
20	AT 1311	821.1	6325.1	0.119	-6.227	0.625	0.114	-2.166	1.981
21	AT 1334	88.3	4064.5	0.112	-12.022	0.105	0.111	3.006	2.372
22	AT 1338	46.2	107.3	0.124	-2.458	2.072	0.105	-0.112	3.143
23	AT 1348	78.9	1139.2	0.112	-11.971	0.333	0.109	11.976	2.655
24	AT 1355	193.1	3847.0	0.113	-11.293	0.241	0.111	5.141	2.415

A compilation of TRD ages of our samples (new) with the pre-existing dataset (Carlson) is shown in the fig 2 with a close up of the highest concentration in fig 3.

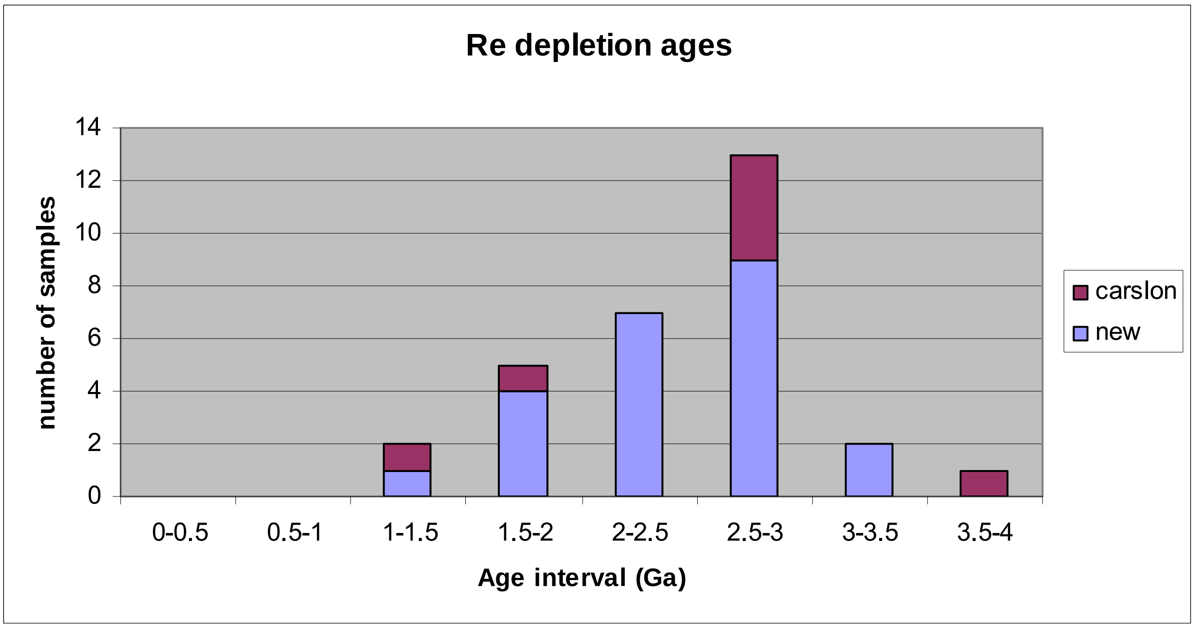

Fig 2. Histogram of Re depletion ages.

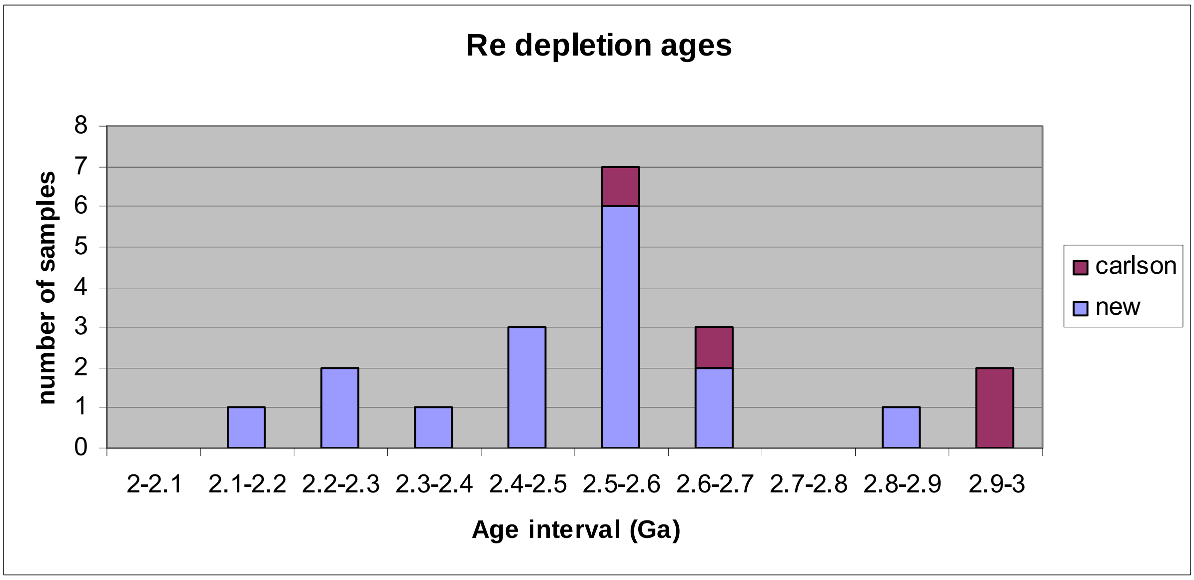

Fig 3. Close up of peak in Fig 2. Smaller intervals unravel a distinct peak between 2.5 and 2.6 Ga.

Conclusions:

The Mantle beneath LMB underwent severe melt depletion between 2.5 and 2.6 Ga. This is later than melt depletion in most of the Kaapvaal craton but coeval with addition of mantle-derived melt to the central zone of LMB (Zeh et al., 2007).

References:

Boyd, F.R., 1989. Compositional distinction between oceanic and cratonic lithosphere. Earth and Planetary Science Letters, 96(1-2): 15-26.

Carlson, R.W., Pearson, D.G., Boyd, F.R., Shirey, S.B., Irvine, G., Menzies, A.H. and Gurney, J.J., 1999 Re-Os Systematics of Lithospheric Peridotites: Implications for Lithosphere Formation and Preservation. Proceedings of the 7th international Kimberlite conference p 99-108

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Pearson, D.G. and Wittig, N., 2008. Formation of Archaean continental lithosphere and its diamonds: the root of the problem. Journal of the Geological Society, 165(5): 895-914.

Zeh, A., Gerdes, A., Klemd, R. and Barton, J.M., 2007. Archaean to Proterozoic Crustal Evolution in the Central Zone of the Limpopo Belt (South Africa-Botswana): Constraints from Combined U-Pb and Lu-Hf Isotope Analyses of Zircon. Journal of Petrology, 48(8): 1605-1639.

Appendix

The age and origin of the Limpopo sub-continental lithospheric mantle

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The Limpopo Mobile Belt (LMB) represents the suture zone between the Kaapvaal and Zimbabwe cratons, but the timing of the collision is still highly debated. Mantle tomography indicates a clear continuation of subcratonic mantle beneath LMB and the adjacent cratons. The origin of both the crust and lithospheric mantle of the LMB is also the subject of controversy and a Zimbabwean, Kaapvaal and allochtonous origin have all been proposed.
The Venetia kimberlite cluster is located within the central zone of the mobile belt and mantle xenoliths from the diamond mine provide an excellent opportunity to address the origin of LMB. We present an extensive petrology-geochemical dataset on a selection of Venetia peridotitic xenoliths, including 24 Re-Os isotope analyses.
Whole rock and mineral major element analyses of garnet-harzburgites and lherzolites indicate that the Venetian lithospheric mantle underwent up to 50% melt depletion, at least partially in the absence of garnet and by implication <70km. The depleted residue was subsequently re-enriched in silica and incompatible elements by subduction-related and asthenospheric melts. The mode of whole rock rhenium depletion ages is 2.6 Ga, which is significantly younger than both the Zimbabwe and Kaapvaal cratons.
Based on combined Os-Nd-Hf isotope systematics of the xenoliths we argue that the majority of the SCLM beneath LMB stabilised at ~2.6 Ga in a separate terrain, which is coeval with major crust forming recorded by zircon Hf and U-Pb model ages.