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1 **Petrography, geochemistry and U-Pb zircon age of the Matongo carbonatite**
2 **Massif (Burundi): implication for the Neoproterozoic geodynamic evolution**
3 **of Central Africa**

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19

20 **Abstract**

21 The Matongo carbonatite intrusion belongs to the Neoproterozoic Upper Ruvubu
22 alkaline plutonic complex (URAPC), that is located in Burundi along the western branch of
23 the East African Rift. Beside the Matongo carbonatite, the URAPC alkaline complex
24 comprises feldspathoidal syenites, diorites, quartz-bearing syenites and granites.

25 Three main facies have been recognized in the Matongo carbonatite: (1) Sövites
26 represent the dominant facies. Two varieties have been recognized. A scarce coarse-grained

1 sövite (sövite I), which is altered and poorly enriched in REE ($4 < \Sigma\text{REE} < 8\text{ppm}$), is
2 encountered in highly fractured zones. A fine-grained sövite (sövite II), which is made of
3 saccharoidal calcite, commonly associated with apatite, aegirine and amphibole, is abundant
4 in the intrusion. Sövite II is enriched in LREE ($442 < \Sigma\text{REE} < 1550\text{ppm}$, $49 < \text{La}_N/\text{Yb}_N < 175$). (2)
5 Ferrocarbonatites, that form decimeter-wide veins crosscutting the sövites, are characterized
6 by a LREE enriched patterns ($225 < \Sigma\text{REE} < 1048\text{ ppm}$, $17 < \text{La}_N/\text{Yb}_N < 64$). (3) K-feldspar and
7 biotite-rich fenite facies (silicocarbonatites) have been recognized at the contact between the
8 carbonatites and the country rock. They are likewise LREE-enriched ($134 < \Sigma\text{REE} < 681\text{ppm}$,
9 $25 < \text{La}_N/\text{Yb}_N < 46$). Additionally, “late” hydrothermal MREE-rich carbonatite veinlets can be
10 found in sövite I. They are characterized by moderate enrichment in REE ($\Sigma\text{REE} = 397\text{ ppm}$),
11 with a MREE-humped pattern ($\text{La}_N/\text{Yb}_N = 3.7$). The different facies represent the typical
12 magmatic evolution of a carbonatite, while the silicocarbonatites are interpreted as resulting
13 from the fenitisation of the country host-rocks. In addition, the most REE-depleted and
14 fractionated facies, i.e. the coarse-grained sövite facies and the “late” calcite veinlets testify
15 for hydrothermal processes that occurred after carbonatite emplacement and result from REE
16 mobilization and redistribution.

17 Large idiomorphic zircon crystals (megacrysts), found in the vicinity of the
18 carbonatite can directly be related to the carbonatite evolution. They have been dated at 705.5
19 $\pm 4.5\text{Ma}$ (U-Pb concordant age, LA-ICP-MS). Similar zircon megacrysts of the Lueshe
20 carbonatite (DR Congo) have been dated and give a concordant age at $798.5 \pm 4.9\text{Ma}$ (U-Pb,
21 LA-ICP-MS). Considering that an extensional tectonic regime occurred at that time in Central
22 Africa - what remains debated - both ages could relate to different stages of Rodinia breakup,
23 with uprise of mantle-derived magmas along Palaeoproterozoic lithospheric zones of
24 weakness.

1 **Keywords:** Matongo, Upper Ruvubu, carbonatite, alkaline magmatism, Neoproterozoic,
2 Burundi

3

4 **1. Introduction**

5 More than 850 alkaline complexes and carbonatites have been recognized in Africa
6 (Woolley, 2001; Fig. 1A). They represent about 40% of the world known occurrences. Their
7 ages range from 2 Ga (Phalaborwa, South Africa) to the present (Oldoinyo Lengai, Tanzania),
8 with two abundance peaks during the Lower Paleozoic and the Cretaceous. Half of the
9 African carbonatites are spatially associated to the African rift (Woolley, 2001). In central
10 Africa, Tack et al. (1984) and Kampunzu et al. (1985) have recognized 23 Neoproterozoic
11 alkaline plutonic massifs that are distributed over a distance of 1700 km along the present-
12 day Western Rift (i.e. the western branch of the East African Rift) (Fig. 1B).

13 Among these massifs, the Matongo carbonatite in Burundi is part of the
14 Neoproterozoic Upper Ruvubu Alkaline Plutonic Complex (URAPC, Fig. 2). This carbonatite
15 does not outcrop and was discovered by drilling in the 80's. It displays a classical magmatic
16 series, with a calciocarbonatite-ferrocarbonatite-fenite suite (Midende, 1984), and shows
17 exceptional mineralization features, including large (> 1cm) zircons (Burke, 1998; Fransolet
18 and Tack, 1992).

19 The Matongo carbonatite occurs in the central part of the URAPC, which consists of
20 an outer unit of quartz-bearing syenite, granite and gabbro-diorite and an inner unit,
21 characterized by the presence of feldspathoidal syenite and monzonite. The whole complex
22 was dated between ~760 and ~690 Ma (DemaiFFE, 2008; Tack et al., 1984; Van den Haute,
23 1986). Its emplacement has been related to a linear intraplate reactivation event (Tack et al.,

1 1996), which marked the breakup of the Rodinia Supercontinent (Kampunzu et al., 1997).
2 The relationship with Rodinia breakup has already been evoked for other Neoproterozoic
3 alkaline massifs in the area, e.g. for the Lueshe complex in RDC (Kampunzu et al., 1998;
4 Kramm et al., 1997; Maravic and Morteani, 1980; Maravic et al., 1989; Van Overbeke et al.,
5 1996).

6 This study represents a comprehensive petrographical and geochemical study of the
7 Matongo carbonatite (the petrological evolution of the complex is however beyond the scope
8 of the study), together with new LA-ICP-MS U-Th-Pb ages obtained on its zircon megacrysts.
9 For comparison, zircon megacrysts from the Lueshe carbonatite have also been dated. This
10 study is envisaged to describe the (post-)magmatic processes associated with the carbonatite
11 emplacement and to position the Matongo carbonatitic event in the Neoproterozoic
12 geodynamic context of Central Africa (Neoproterozoic supercontinent
13 fragmentation/amalgamation).

15 **2. Geological setting**

16 The Matongo carbonatite belongs to the Neoproterozoic Upper Ruvubu Alkaline
17 Plutonic Complex (URAPC), located in the western part of Burundi along the western branch
18 of the East African Rift (Tack et al., 1984). The complex is hosted in rocks belonging to the
19 Mesoproterozoic Karagwe-Ankole Belt (KAB; Fernandez-Alonso et al., 2012), which
20 consists of metasedimentary (phyllites, graphitic schists, metaquartzites and dolomite lenses
21 and interbedded metavolcanic rocks of Palaeo- or Mesoproterozoic age (Cahen et al.,
22 1984; Brinckmann et al., 2001; Fernandez-Alonso et al., 2012). The metasedimentary and
23 metavolcanic rocks of the Western Domain (WD) of the KAB were intruded by S-type

1 granites, which are part of the 1375 Ma old bimodal magmatic “Kibaran event” (U-Pb
2 SHRIMP on zircon; Tack et al., 2010). At 986 ± 10 Ma (U-Pb SHRIMP on zircon; Tack et al.
3 2010) “tin granites” were emplaced. The magmatism has been related to the ~ 1.0 Ga Southern
4 Irumides collisional orogeny, corresponding to the Rodinia amalgamation (Fernandez-Alonso
5 et al., 2012). The orogeny is responsible for the general fold-and-thrust-belt geometry of the
6 KAB (Fernandez-Alonso et al., 2012). The tin mineralisation was emplaced in a relaxational
7 setting following the deformation (Dewaele et al., 2011; Melcher et al., 2013). In the URAPC
8 region, pegmatites including feldspar, quartz, muscovite, biotite and more exceptionally black
9 tourmaline, cassiterite and garnet have been dated between 977 ± 8 Ma (Rb-Sr on muscovite
10 and feldspar; Cahen and Ledent, 1979) and 969 ± 8 Ma (Rb-Sr on muscovite and whole-rock;
11 Brinckmann and Lehmann, 1983).

12 Later events in the KAB have been related to Panafrican tectonothermal processes in
13 the Western Rift area as (1) brittle reworking of pegmatites along fractures at 628 ± 110 Ma
14 and 622 ± 56 Ma (Romer and Lehmann, 1995), (2) muscovite Ar-Ar resetting ages in Rwanda
15 (Sn-Ta pegmatite at 593Ma; Dewaele et al., 2011), and (3) N-S trending shear-controlled
16 gold mineralization emplacement at 535 in NW Burundi (Brinckmann et al., 2001). Such
17 Panafrican overprint has not been recognized in the URAPC area yet. At ~ 750 Ma, in
18 probable association with the Rodinia Supercontinent breakup (Kampunzu et al., 1997), some
19 23 alkaline complexes were emplaced along lithosphere-scale shear zones (Tack et al., 1996).
20 The URAPC, roughly NW-SE oriented, is made up of both a silica-oversaturated and silica-
21 undersaturated unit as well as a carbonatite (the Matongo carbonatite; Fig. 2). The “outer
22 unit” comprises an intimate association of plutonic rocks from olivine-bearing gabbros and
23 diorites, to granites and quartz-bearing syenites. The “inner unit” comprises feldspathoidal
24 syenites and monzonites. Numerous dykes of feldspathoidal syenite intrude the “outer unit”,

1 especially in its western part. The whole complex has undergone extensive supergene
2 lateritization. Kaolinitization, notably in the region close to Matongo where kaolinite has been
3 exploited (Inamvumvu), is developed on top of the subsurface carbonatite in a contact aureole
4 as a result of hydrothermal alteration of the host quartz-bearing syenites.

5 The Matongo carbonatite is only known by drilling in the Matongo area (Fig. 2). It
6 occurs at a depth of about 40-80 m and forms a NNE elongated intrusion of 2750m long and
7 250m wide. Interestingly, another hidden carbonatitic body is inferred in Burundi (Van
8 Wambeke, 1977), in the Gakara-Karonge area (60 km far from Matongo), which is known for
9 its REE hydrothermal deposits (Lehmann et al., 1994

10 Fine- and coarse-grained calciocarbonatite and a ferrocyanatite have been identified
11 in the Matongo carbonatite (Demaiffe, 2008; Midende, 1984). “Late” calcite veinlets that
12 crosscut the coarse-grained calciocarbonatite have been interpreted to represent a
13 hydrothermal event (Midende, 1984). Fensitization is also well developed in the external part
14 of the carbonatite (Midende, 1984). The Sr and Nd isotope compositions indicate a cogenetic
15 relation between the carbonatite and feldspathoidal syenites (Tack et al., 1996). Initial ϵ_{Nd}
16 values (+0.7 to +5.2) and low initial $^{86}Sr/^{87}Sr$ ratios of 0.7025-0.7030 support a mantle-
17 derived origin for the URAPC rocks without evidence for significant assimilation of crustal
18 material (Tack et al., 1984). The inferred source appears less depleted in incompatible
19 elements than the typical Depleted Mantle (DM) (Demaiffe, 2008).

20 Available ages on the URAPC show some inconsistency. For the “outer unit” U-Pb on
21 zircon fraction and zircon Pb-evaporation ages at 748 ± 2 Ma and 741 ± 2 Ma respectively
22 (Tack et al., 1995) have been obtained, while a Rb-Sr whole rock isochron yielded an age of
23 707 ± 17 Ma (Tack et al., 1984). U-Pb on bulk zircon on the “inner unit” of the URAPC gave
24 an age of 739 ± 7 Ma, while the Rb-Sr isochron age of this unit yielded an age of 699 ± 13 Ma

1 (Tack et al., 1984). Also, a fission track age on sphene of 762 ± 33 Ma has been obtained on
2 the “inner unit” (Van den Haute, 1986) and is questionable as being older than U-Pb zircon
3 age. On the Matongo carbonatite, a Pb-Pb isochron age of 690 ± 32 Ma (Demaiffe, 2008) is
4 consistent with the Rb-Sr age (699Ma) but significantly younger than the U-Pb zircon age
5 (739Ma) of the “inner unit”. Concerning the zircon megacrysts, lead-evaporation ages o
6 yielded an age of 738 ± 4 Ma (Tack et al., 1995). For the Lueshe Complex, the
7 geochronological data are Rb-Sr isochron ages on whole rocks, varying between 548 - 568
8 Ma (Kramm et al., 1997), 619 ± 42 Ma (Van Overbeke, 1996) and 822 ± 120 Ma (Kampunzu
9 et al., 1998), and a K-Ar biotite age (516 ± 26 Ma; Bellon and Pouclet, 1980). These ages
10 overlap the URAPC zircon existing ages.

11

12 **3. Zircon megacrysts from Matongo (Burundi) and Lueshe (DRC)**

13 Near Matongo, numerous idiomorphic zircon megacrysts, up to 6 cm in size, in
14 association with ilmenite megacrysts, are disseminated in a dismembered lateritic crust and in
15 the kaolin of the Inamvumu hill (Fig. 2). Trenching during carbonatite exploration works in
16 the 80's (British Sulphur Company, unpublished internal report), exposed zircon megacrysts
17 in “pegmatitic-like” veinlets intruding supergene weathered rock with preserved original
18 coarse-grained magmatic texture (quartz-bearing syenite or granite) (Nkurikiye, 1989; Tack,
19 unpublished data). No more outcrop still exists. At Kiziba (Fig. 2), a comparable, although
20 smaller (up to 1 cm in size) zircon megacrysts occur in coarse-grained veins within the
21 feldspathoidal syenite (Fransolet and Tack, 1992), in association with alkali feldspar,
22 nepheline, sodalite, fluorite, biotite, aegirine, calcite and ilmenite.

1 The zircon megacrysts of the Inamvumvu hill, from where our samples come from, are
2 characterized by Th- and U- rich homogeneous cores and partially metamict, oscillatory
3 zoned outer rims (Burke, 1998). They contain ubiquitous primary carbonate inclusions
4 (calcite, magnesian calcite and nahcolite; Burke, 1998) and are thought to have crystallized
5 from the circulation of alkaline fluids associated with the carbonatite-feldspathoidal syenite
6 emplacement (Fransolet and Tack, 1992), i.e. relatively late in the frame of the URAPC
7 emplacement.

8 Similar zircon megacrysts around 2 cm in size are also known from the Lueshe
9 complex (Fig. 1B), in particular in the silico-sövite parent rock predating the Lueshe
10 carbonatite (Maravic, 1983; Maravic and Morteani, 1980; Filippo, 2005), i.e. relatively early
11 in the frame of the Lueshe emplacement. Isolated zircon megacrysts are also found in the
12 lateritic crust, in association with pyrochlore, ilmenorutile and primary or secondary
13 phosphates. Idiomorphic and well-preserved megacrysts occur in the small Lueshe river
14 (sample RGM 9673, 5-6 mm wide, is one of these). These zircon grains likely derive from the
15 the silico-sövite upstream, with almost no transport.

16

17 **4. Sampling and analytical techniques**

18 Twenty-one samples of the Matongo carbonatite have been studied. The samples
19 originate from 10 drill cores (from 56 to 291 m depth), from a drilling program performed in
20 1976-1978 by the United Nations Development Program (location of the boreholes on Figure
21 2). Other samples studied are surface samples from the rock collection of the Royal Museum
22 for Central Africa (RMCA), Tervuren (Belgium).

1 Petrographic description was carried out by polarized light microscopy on thin
2 sections. Mineral compositions were measured by electron microprobe analysis (EPMA) at
3 the Université de Louvain (UCL, Belgium). Chemical compositions of rock samples were
4 obtained on finely grained powders (about 100g) by X-ray fluorescence (XRF) at the
5 University of Brussels (ULB, Belgium) for major elements analyses and at Liège (ULg,
6 Belgium) for major and trace elements (Rb, Sr, Ba, V and Nb). Other trace element
7 compositions have been determined at the Katholieke Universiteit Leuven (KULeuven,
8 Belgium) by neutron activation analyses (Midende, 1984). Additional chemical analyses were
9 performed by the Actlabs laboratory (Ontario, Canada) using ICP-AES and ICP-MS methods
10 for major and trace elements respectively.

11 The dated zircon megacrysts were mounted in epoxy resin, cut and polished (BGR,
12 Hanover, Germany). Characterization of internal textures was accomplished using back-
13 scattered electrons (BSE) and cathodoluminescence (CL) images generated on a CAMECA
14 SX100 electron microprobe at the BGR. Furthermore, zircons were quantitatively analyzed
15 using wavelength-dispersive spectrometry on the same instrument using 15 kV acceleration
16 voltage and 40 nA sample current. The following elements were measured (line,
17 spectrometer, standard, measurement time on peak): SiK α (TAP, zircon, 10); ZrL α (PET,
18 zircon, 10); HfM α (TAP, hafnon, 90); AlK α (TAP, metal, 20); FeK α (LLIF, metal, 60);
19 MnK α (LLIF, metal, 60); PK α (LPET, apatite, 20); CaK α (LPET, apatite, 10); TiK α (LPET,
20 metal, 20); PbM α (LPET, galena, 90); ThM α (PET, metal, 110); UM α (LPET, metal, 100).

21 Uranium, thorium and lead isotope analyzes were carried out by LA-ICP-MS at the Goethe
22 University of Frankfurt (Germany), using a slightly modified method, as previously described
23 in Gerdes and Zeh (2006, 2009, 2012). A ThermoScientific Element 2 sector-field ICP-MS
24 was coupled to a Resolution M-50 (Resonetics) 193 nm ArF Excimer laser (CompexPro 102,

1 Coherent) equipped with a two-volume ablation cell (Laurin Technic, Australia). The laser
2 was fired with 5.5 Hz at a fluence of about 3-4 J cm⁻². Raw data were corrected offline for
3 background signal, common Pb, laser induced elemental fractionation, instrumental mass
4 discrimination and time-dependent elemental fractionation of Pb/U using an in-house MS
5 Excel© spreadsheet program (Gerdes and Zeh, 2006, 2009). Laser-induced elemental
6 fractionation and instrumental mass discrimination were corrected by normalization to the
7 reference zircon GJ-1 (0.0984 ± 0.0003; ID-TIMS GUF value).

8

9 **5. Petrography and mineralogy of the Matongo carbonatite**

10 Midende (1984) provided detailed descriptions of the different rocks of the Matongo
11 carbonatite, which are complemented by our observations and new data on mineral
12 composition (see supplementary data).

13 5.1. Magmatic facies

14 The carbonatite comprises three main magmatic facies (DemaiFFE, 2008; Midende, 1984).

15 The sövite I facies is limited and localized in highly fractured zones of the carbonatite.
16 Calcite grains are euhedral, up to 2 cm in size (Fig. 3A), and close to pure calcite in
17 composition (CaO close to 55 wt%), with minor contribution of Mn and Mg (Table 1). At the
18 contact with the host rocks, sövite I can be silicified, Fe-stained and/or crosscut by fissures
19 filled with iron oxides and quartz.

20 The sövite II represents the dominant facies of the carbonatite. It mainly consists of
21 saccharoidal calcite (polygonal mosaic), with grain sizes ranging from 1 to 4 mm in width
22 (Fig. 3B). The calcite contains Fe (FeO between 0.5 and 3 wt. %), Mg (MgO between 0.1 and
23 1.6%) and Sr (SrO between 0.8 and 1.5). Sövite II commonly contains discrete zones with

1 vanadiferous aegirine (1.1-1.9 wt.% V_2O_3), occurring as euhedral elongated crystals up to 2
2 cm in length (Fig. 3C), and apatite occurring as small grains or small prismatic crystals up to
3 5 mm in size. Aegirine and apatite may represent local cumulates, in which pyrochlore
4 $((Na,Ca)_2Nb_2O_6(OH,F))$ and K-feldspar are also present. The vanadiferous aegirine is partly
5 transformed into amphibole (Mg-arfvedsonite; see supplementary data), which developed
6 along aegirine cleavages and/or crystal boundaries. Richterite, another alkali amphibole, with
7 8.1-12.4 wt.% Fe_2O_3 , 3.2-5.8 wt.% FeO, 14.2-16.6 wt.% MgO, 4.2-6 wt.% CaO, 3.6-5.1 wt.%
8 Na_2O and 0.6-2.0 wt.% K_2O , occurs as cm-long needles (Fig. 3D) and may constitute 30% of
9 the sövite rock volume. It is associated with calcite, apatite, clinopyroxene and phlogopite.

10 The ferrocarnatite facies forms decimeter-wide veins crosscutting the sövites. It
11 consists of fine-grained (< 1 mm in width) dolomite and ankerite (13.7-15.4 wt.% FeO, 11.3-
12 13.7 wt.% MgO, 0.3-0.7 wt.% MnO; Fig. 3E), with abundant euhedral V-rich magnetite
13 (V_2O_3 , up to 2 wt.%) and ilmenite crystals. Iron-stained silica veins locally crosscut this facies
14 (Fig. 3E).

15 5.2. Metasomatic and hydrothermal facies

16 Two types of fenite alteration, which are referred to as silicocarnatites (Demaiffe,
17 2008), have been recognized at the contact between the carbonatites and the Karagwe-
18 Ankolan metasediments: biotite-bearing fenite and K-feldspar-bearing fenite (Fig. 3F). The
19 latter occurs as replacement of the mica-bearing facies. In the biotite-bearing fenite, biotite
20 shows well-developed crystals up to 2 cm in size (see supplementary data, Fig. 3G). Biotite is
21 partly transformed into phlogopite (see supplementary data), both phyllosilicates being in turn
22 replaced by feldspars (mainly K-feldspar, with accessory albite grains). Other associated
23 minerals are titanite, richterite, calcite and apatite. In K-feldspar-bearing fenite, feldspar
24 constitutes up to 70% of the rock volume, and occurs associated with biotite, zircon, rutile and

1 pyrochlore. Feldspar crystals are present as grains with amoeboidal boundaries or form cm-
2 long lath-shaped aggregates.

3 “Late” hydrothermal calcite has been identified in association with sövite I. It occurs
4 as veinlets containing very fine-grained calcite (several tens of μm in size), slightly enriched
5 in Fe, Mn and Mg (up to 1.2 wt. % FeO, 0.7 wt. % MgO and 0.6 wt. % MnO) and coated by
6 iron oxides.

7

8 **6. Geochemistry**

9

10 6.1. Major and trace element composition (Tables 1, 2 and 3)

11 As expected from the mineralogy, the Matongo carbonatites plot in the sövite and
12 ferrocarbonatite fields of the ternary CaO-MgO-Fe₂O₃(t)+MnO diagram of Le Maitre (2002)
13 (Fig. 4A). The sövite I samples, which consist essentially of pure calcite, plot close to the
14 CaO apex of the triangle. Their MnO, MgO and Fe₂O₃(t) concentration is very low: ~0.7 wt.
15 %, ~0.5 wt. % and < 1 wt. % respectively. Their SiO₂ and Al₂O₃ concentration is also very
16 low, < 0.1 wt. %. The sövite II samples are characterized by a wide range of CaO
17 concentrations (25.6-56.9 wt.%) that are inversely correlated with the SiO₂ (0.9-28.7 wt. %),
18 Fe₂O₃ (1.1-16.6 wt. %) and Na₂O (0.1-5.4 wt. %) concentrations. The samples define a rough
19 trend extending from the typical sövite to the ferrocarbonatite field. In the Na₂O+K₂O-
20 MgO+Fe₂O₃(t)-CaO ternary diagram (Fig. 4B; Le Bas, 1984), the Matongo sövites define an
21 elongated trend that can be related to clinopyroxene and/or amphibole fractional
22 crystallization during carbonatite magma uprise and emplacement. Ferrocarbonatites also
23 display a wide range of CaO concentrations (29.7-50.5 wt. %) that are inversely correlated

1 with the Fe_2O_3 and MgO contents (1.2-9.5 wt. % and 0.7-3.2 wt. %, respectively). Fe and Mg
2 enrichments are likely linked to ankerite and dolomite formation. The “late” hydrothermal
3 carbonatite is characterized by geochemical features close to sövites (50.2 wt. % CaO , 2.5wt.
4 % MgO , 1.2 wt. % Fe_2O_3 and 0.6 wt. % MnO). The fenites occur quite scattered in the
5 $\text{Na}_2\text{O}+\text{K}_2\text{O}-\text{MgO}+\text{Fe}_2\text{O}_3(\text{t})-\text{CaO}$ ternary diagram (Fig. 4B; Le Bas, 1981, 1984). They show a
6 trend that likely represents a consequence of alkali enrichment of the host country rocks
7 (feldspathoidal syenite and metasediments) during the fenitization processes.

8 The chondrite-normalized rare-earth element (REE) abundance patterns of the various
9 carbonatite facies are heterogeneous (Fig. 5). The sövite I samples have a rather low total
10 REE abundance (ΣREE : 4-8 ppm) and display flat REE patterns with rather low $\text{La}_\text{N}/\text{Yb}_\text{N}$
11 ratios (3.1 to 4). The sövite II samples and the clinopyroxene-apatite cumulates (less
12 commonly amphibole cumulates) are strongly enriched in REE (ΣREE from 442 up to 1550
13 ppm), with a significant LREE enrichment ($\text{La}_\text{N}/\text{Yb}_\text{N}$ ranging from 49 to 175) but no
14 significant Eu anomaly ($\text{Eu}/\text{Eu}^* > 0.8$). The ferrocarnatites are similar to the sövites II
15 ($225 < \Sigma\text{REE} < 1048$ ppm, $17 < \text{La}_\text{N}/\text{Yb}_\text{N} < 64$ and $0.8 < \text{Eu}/\text{Eu}^* < 0.9$). The fenites are also largely
16 similar with ΣREE concentrations varying between 134 and 681 ppm, with LREE-enrichment
17 ($25 < \text{La}_\text{N}/\text{Yb}_\text{N} < 46$) and no significant Eu anomaly. The “late” hydrothermal carbonatite is also
18 enriched in REE ($\Sigma\text{REE} = 397$ ppm), but displays a peculiar pattern characterized by LREE
19 depletion ($\text{La}_\text{N}/\text{Sm}_\text{N} = 0.4$) and well-marked MREE-hump, with a small Eu negative anomaly
20 ($\text{Eu}/\text{Eu}^* = 0.8$) and a tetrad effect ($(\text{La}_\text{N} * \text{Sm}_\text{N}) / (\text{Ce}_\text{N} * \text{Nd}_\text{N}) = 2.3$).

21 Primitive mantle-normalized spidergram patterns (Fig. 6) illustrate that most of the
22 Matongo carbonatite and fenite rocks share common characteristics: (1) an overall enrichment
23 compared to the primitive mantle, except for the sövites I; (2) a general enrichment in large-
24 ion lithophile elements (LILE) relatively to high-field-strength elements (HFSE), in particular

1 for the fenites; (3) negative anomalies in Ti, Zr, Hf (and K for the sövites and
2 ferrocarbonatites); and (4) variable enrichments in Th, U, Nb and Ta that can be related to the
3 presence of Nb(-Ta)-rich oxides (pyrochlore, magnetite) and U-Th-bearing minerals
4 (pyrochlore). In general, the patterns observed are quite comparable to the “world average
5 carbonatite” (Chakhmouradian, 2006), except for Th, U, Nb and Ta. It should be mentioned
6 that sövite I samples display atypical patterns, with low global enrichment close to the
7 primitive-mantle level, together with positive Sr and Th anomalies and a negative Ti anomaly.

8 9 6.2. U-Th-Pb data of the Matongo and Lueshe zircon megacrysts

10 Zircon megacrysts selected for U-Th-Pb geochronology were 1-6 mm in size, euhedral
11 to subeuhedral (with the prevailing presence of the (101) pyramids; Fransolet and Tack, 1992)
12 and frequently show oscillatory zoning (Fig. 7A to D). The zoning can be related to variations
13 in Th (up to 0.34 and 2.2 wt% ThO₂ for Matongo and Lueshe zircon, respectively), U (up to
14 0.12 and 0.09 wt% UO₂, respectively) and Hf (0.36-0.90 and 0.39-1.45 wt%, respectively)
15 contents. The inner zones of the zircons often show darker luminescence colours, whereas in
16 many grains the primary zoning is replaced by cloudy to irregular patchy CL patterns related
17 to alteration. The primary zoning has commonly been obliterated, from inside to outside,
18 probably by a fluid phase entering the grains via small cracks. Sometimes the entire grain is
19 affected. The altered CL dark (low-luminescence) areas are characterized by lower total
20 oxides (ca. 95 wt%), higher U and Th contents, and detectable concentrations of Ti, Al, P, Ca,
21 Mn and Fe (up to 1 wt% each), whereas the alteration domains with bright luminescence
22 patterns differ by having low Th and U concentrations, often below detection limit of the
23 EPMA.

1 Results of U-Th-Pb isotope analyses on zircon megacrysts from Matongo (sample
2 RGM 9672) and Lueshe (sample RGM 9673) are presented in Figure 7E and F and Table 5.
3 Laser spots were set predominantly on the primary, oscillatory-zoned domains. Altered areas
4 were also analyzed: spots A36-A38 for Matongo and A19-A27 for Lueshe zircon. Within
5 analytical error, the results were, however, in both cases - indistinguishable from those of the
6 primary oscillatory domains, except for the slightly discordant analysis A37.

7 Seventeen U-Pb measurements on three zircon megacrysts from Matongo are
8 equivalent and concordant. They yield a concordia age of 705.5 ± 4.5 Ma (Fig. 7E),
9 significantly younger than the Pb-evaporation age of 738 ± 4 Ma (Tack et al., 1995). The 705
10 Ma age is consistent with the weighted average $^{206}\text{Pb}/^{238}\text{U}$ and $^{208}\text{Pb}/^{232}\text{Th}$ ages of 705.2 ± 4.6
11 Ma and of 697.3 ± 5.3 Ma, respectively.

12 In the case of Lueshe, twenty-two U-Pb analyses on three megacrysts also give
13 equivalent and concordant values with a Concordia age of 798.5 ± 4.9 Ma (Fig. 7F). This is
14 consistent with the corresponding weighted average $^{206}\text{Pb}/^{238}\text{U}$ and $^{208}\text{Pb}/^{232}\text{Th}$ ages of 801.0
15 ± 3.9 Ma and of 802.5 ± 4.0 Ma, respectively.

16

17 7. Discussion

18 7.1. Magmatic processes and sources

19 Petrographic observations and geochemical data illustrate that different magmatic
20 processes took place during the emplacement of the Matongo carbonatite: (i) fractionation of
21 clinopyroxene + apatite during carbonatite emplacement; (ii) ankerite formation during late-
22 stage carbonatite intrusion; and (iii) alkali loss inducing metasomatic fenitisation and the
23 formation of silicocarbonatites. These processes are recorded in the sövites II, the

1 ferrocarbonatite and the fenite (silicocarbonatite), which share similar geochemical
2 characteristics. These rocks show LREE and LILE enrichments and similar Sr and Nd
3 isotopic compositions. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ varies between 0.7028 and 0.7040 and initial ϵNd
4 values between +0.2 and +5.2 (Demaiffe, 2008; Table 6). These values plot in the mantle
5 array (Fig. 8) and point to a mantle source that is less depleted than the DM (Demaiffe, 2008).
6 The Matongo isotopic compositions are comparable to those reported for Lueshe sövites,
7 recalculated to 800 Ma (Kramm et al., 1997). This suggests that a similar source has been
8 sampled for the two carbonatite magmas, despite a difference in emplacement age of ca.
9 100Ma. A long-lived thermal anomaly could thus have persisted in the mantle beneath Central
10 Africa. The Neoproterozoic Matongo and Lueshe carbonatites differ from the young (< 200
11 Ma) East African carbonatites (Bell and Tilton, 2001), whose isotopic field is displaced
12 towards lower ϵNd values and which show extended range of Sr isotopic compositions. Their
13 field extends between the HIMU and EMI fields and reflects the heterogeneity of the young
14 East African carbonatite source. Several interpretations have been proposed to explain this
15 heterogeneity: (i) The lithospheric mantle itself is heterogeneous and results from enrichment
16 and/or depletion processes at different times and degrees (Kalt et al., 1997); (ii) Various fluid
17 or melt incursions influenced the lithosphere, at least since the Proterozoic (Bell and Tilton,
18 2001); (iii) Upwelling of a mantle cell or plume of HIMU affinities resulted in a recently
19 metasomatized EMI-type lithosphere (Bell and Simonetti, 1996); (iv) The EMI-HIMU mixing
20 trend could be due to the signature of a heterogeneous mantle plume carrying these
21 components from the deep mantle (Bell and Tilton, 2001).

22 In terms of isotopic compositions, the Proterozoic carbonatites of Matongo, Lueshe
23 and Deerdepoort (1340 Ma, South Africa; Verwoerd, 1967) constitute a rather homogeneous
24 group, significantly different from the recent East African carbonatites, in particular for their

1 higher ϵNd values. The mantle source sampled during the Proterozoic by carbonatitic magmas
2 is likely a deep-seated homogeneous reservoir, possibly contaminated by lithospheric material
3 rather than a heterogeneous lithosphere as proposed for the African carbonatites by Bell and
4 Tilton (2001), but rather. However, to confirm this statement complementary analyses of
5 different Proterozoic African carbonatites are needed.

6

7 7.2. Late hydrothermal processes

8 The geochemical and isotopic characteristics of the sövite II and the ferrocarnatites,
9 which represent the largest part of the Matongo carbonatite, are clearly distinct from the
10 sövite I and the “late” hydrothermal carbonatite. The sövite I was sampled in a deformed
11 zone with macroscopic fractures. The “late” carbonatite occurs as thin veins of hydrothermal
12 origin crosscutting the sövite I (Midende, 1984). Both rock types show petro-geochemical
13 evidence of interaction with hydrothermal fluids. They display peculiar REE patterns with
14 LREE fractionation. In addition, the late calcite (sample Gi17) shows intra-REE fractionation
15 with a significant tetrad effect resulting from the interaction with fluids (Bau, 1994). Also, the
16 very low REE content of sövite samples, illustrated by flat patterns (1 to 5 times the
17 chondrites; Fig. 5), is hardly explicable by magmatic processes. Similarly, the Sr and Nd
18 isotope compositions of the “late” calcite ($^{87}\text{Sr}/^{86}\text{Sr}(i) = 0.71425$ and $\epsilon\text{Nd}(i) = -44$; Fig. 8)
19 suggest the hydrothermal introduction of radiogenic Sr and non-radiogenic Nd from the
20 surrounding country rocks. Moreover, the non-radiogenic signature of the Nd isotope
21 composition indicates disturbance of the Sm-Nd system, possibly during interaction with
22 fluids. The particularly low enrichment, if any, of the sövite I in REE and other trace elements
23 indicates that this rock has been altered after the carbonatite emplacement.

1 Despite the close spatial association of the sövite I and late hydrothermal calcite, the
2 precise relationships between the REE signatures of these facies still remain incomplete. The
3 timing of hydrothermal fluid circulation responsible for the observed alteration is also not
4 well constrained. However, hot fluids could have circulated during a quite long time span
5 after magmatic intrusion, as illustrated by long-lived (10-30 Ma) hydrothermal systems
6 associated with large granites (e.g. Kontak and Clark, 2002; Zhao et al., 2004).

7 8 7.3. Geodynamic setting of the carbonatite emplacement

9 7.3.1. Significance of the zircon megacryst ages

10 Zircon megacrysts are well-known in carbonatitic systems (e.g. Caruba and Iacconi,
11 1983; Hoskin and Schaltegger, 2003). In the URAPC, the occurrence of the zircon megacrysts
12 close to the Matongo carbonatite and their ubiquitous primary calcite, magnesian calcite, and
13 nahcolite inclusions (Burke, 1998) obviously argue for the carbonatitic affinity of these
14 minerals, as already proposed by Fransolet and Tack (1992). The latter authors related the
15 crystallization of these zircons to the circulation of alkaline pegmatitic fluids in the URAPC
16 system. Regardless of the exact origin of these zircon grains (magmatic vs. hydrothermal),
17 their crystallization is associated with the carbonatite and, thus, the U-Pb age that we have
18 obtained (705.5 ± 4.5 Ma) provides a robust age of the carbonatite emplacement and rapid
19 cooling. Regarding the discrepancy of 30 to 40 Ma between this age and older ages obtained
20 on the Massif with other techniques, two explanations are suggested: (1) although unlikely
21 because of the size of the URAPC, the possibility of a long time span between the main
22 magmatic building stage of the intrusion and the latest stages of hydrothermal activity around
23 the central Matongo carbonatite remains and (2) previous ages in the range 735 – 750 were

1 not as accurate as the new La-ICP-MS age obtained in this study. New geochronological work
2 on the magmatic facies would help to constrain this hypothesis.

3 For Lueshe, regardless of the exact origin of the zircon megacrysts (magmatic vs.
4 hydrothermal), the age obtained here is significantly different from the La-ICP-MS age of the
5 Matongo megacrysts and also from the ages around 735-750 Ma for the URAPC. Therefore,
6 the crystallization age of the Lueshe zircon dates the emplacement of the Lueshe intrusion at
7 ca. 800 Ma, significantly older than the age of the URAPC-Matongo emplacement.

8

9 *7.3.2. Structural reactivation of the present-day region of the Western Rift and relation to*
10 *Rodinia breakup*

11 As suggested by several authors (Burke et al., 2003; Hanson, 2003; Kampunzu et al.,
12 1997, 1998; Tack et al., 1984, 1996), most of the Proterozoic ages obtained for the 23
13 envisaged alkaline complexes and/or carbonatites along the present-day Western Rift seem to
14 reflect uprise of mantle-derived magmas along lithospheric weakness zones in relation with
15 the breakup of Rodinia (Fig. 9). This breakup is recorded at ca. 705Ma at Matongo by the La-
16 ICP-MS age of the zircon megacrysts and at ca. 798 Ma at Lueshe by the same method.

17 In addition to alkaline magmatism, Neoproterozoic reactivation of older structures is
18 also illustrated by the formation of intracratonic basins (Fernandez-Alonso et al., 2012; Tack
19 et al., 1992): (1) the Malagarazi basin located across the Burundi-Tanzania border(Fig. 1B).
20 CFB-type rocks (“Kabuye-Gagwe amygdaloidal basalts”), intercalated in the sedimentary
21 succession of the Neoproterozoic Malagarazi – Nyamuri (formerly Bukoba) Supergroup,
22 yielded a crystallization age of 795 ± 7 Ma (Deblond et al., 2001);and (2) the Itombwe
23 syncline (DRC, Fig. 1B), This narrow N-S elongated structure contains a sedimentary

1 succession (Neoproterozoic Itombwe Supergroup), with a maximum deposition age of ~ 710
2 Ma (Fernandez-Alonso et al., 2012; Villeneuve, 1987; Walemba and Master, 2005).

3 The considered ~ 700 - 800 Ma time-period tracing both endogenic and exogenic
4 extensional processes thus records diachronous reactivation and breakup of Rodinia
5 supercontinent in response to differential intraplate stress, in agreement with geodynamic
6 processes invoked by Li et al. (2008), Eyles and Januszczak (2004) and Eyles (2008). In the
7 nearby Congo Craton and at its margin, the diachronicity of the breakup and the succession of
8 extensional regimes have been evidenced in the time frame ~1 Ga - ~500 Ma by the formation
9 of sedimentary basins (e.g. Delpomdor et al., 2013) and alkaline magmatism (e.g. Pedrosa-
10 Soares and Flecha de Alkmim, 2011).

11 However, the configuration, evolution and even existence of the Rodinia
12 supercontinent remain debated. Even though most of the authors consider that the
13 supercontinent fragmentation and dispersal began about 800-750 Ma (Hoffman, 1999;
14 Pisarevsky et al., 2003) or even 1 Ga ago (Eyles, 2008), others argued that (1) Rodinia
15 breakup occurred between 750 and 600 Ma (Eyles and Januszczak, 2004; Li et al., 2008) or
16 even not before 725 Ma (Powell et al., 1993) and (2) the formation of Gondwana by the
17 reassemblage of the dispersed terranes ended at about 550 Ma (Meert and Van der Voo,
18 1997). It has also been proposed that the early Pan-African tectonic phase began around 725
19 Ma (Lenoir et al., 1994). In this context, the emplacement of late mylonitic granites along
20 shear zones at 724 ± 6 Ma (U-Pb age on zircon fraction) in the Ubendian belt of SW Tanzania
21 could be the result of a continental collision in the frame of the early Pan-African orogen
22 (Theunissen et al., 1992). On a larger scale, Fritz et al. (2013) have proposed that the
23 consolidation of the East African orogen was achieved during distinct phases between ~850
24 and 550 Ma, with the accretion of microcontinents during the ~850-620 Ma time range. The

1 abundance of granitoid magmatism occurring between ~850 and ~650 Ma in the East Africa
2 domain may be related to this continental aggregation leading to the formation of the
3 Gondwana supercontinent (Kröner and Cordani, 2003). If an extensional tectonic setting is
4 considered for that period, what remains debated, the URAPC would represent one of the last
5 episodes of the magmatic activity associated with this event, before the “renewal” of
6 alkaline/carbonatitic activity in the area several hundred millions years later during the
7 Cretaceous (e.g. Chilwa in Malawi; Simonetti and Bell, 1994), in relation with the
8 development of the East African rift system.

9

10 *7.3.3. Early continental rifting in the Rodinia breakup history: the involvement of a plume?*

11 Many alkaline complexes of Central Africa were emplaced between ~750 and 650 Ma.
12 However, some complexes record significantly older ages, in the range ~830-750 Ma, among
13 which the now dated Lueshe complex, of which the zircon megacrysts have been dated at
14 798.5 ± 4.9 Ma. These old emplacement could also be related to the Rodinia breakup,
15 especially to an earlier step of intraplate continental rifting. This could possibly be associated
16 with the presence of a superplume below Rodinia (Li et al., 2008) that eventually led to the
17 breakup of the supercontinent. In the western branch of the East African Rift, the presence of
18 flood basalts spatially and temporally associated with the alkaline complexes favours the
19 involvement of a superplume (Bell, 2001; Ernst and Buchan, 2003). Tholeiitic fissural flood
20 basalts, like the Kabuye-Gagwe amygdoidal lavas, emplaced in the Malagaraszi basin (De
21 Paepe et al., 1991) at 822 ± 30 Ma (K-Ar ages; Briden et al., 1971 in Deblond et al., 2001;
22 Fig. 9) and between 815 ± 14 and 709 ± 2 Ma (Ar-Ar ages; Deblond et al., 2001; Fig. 9). They
23 are also coeval with the shallow-depth Nyaganza dolerites that are intrusive in the
24 Malgarasian Subgroup (815 ± 14 Ma; K-Ar age; Cahen et al., 1984) and with the doleritic

1 gabbros of Kavumwe, dated at 803 ± 30 Ma, 806 ± 30 Ma (K-Ar method; Briden et al., 1971)
2 and 795 ± 7 Ma (Deblond et al., 2001). However, additional arguments should be found for a
3 proper demonstration of a mantle plume involvement in the URAPC genesis; this hypothesis
4 would be especially challenging if a convergent plate tectonic setting (Pan-African orogeny)
5 is favoured in the future rather than an extensional setting (Rodinia Breakup).

6

7 *7.3.4. Panafrican overprint*

8 In the present-day Western Rift region, discrete Panafrican tectonic overprint with a
9 climax at ~ 550 Ma is considered a far-field effect of the distant East African Orogen
10 facilitated by the palaeogeography of the Archean Tanzania Craton, which plays as an
11 indenter squeezing the Proterozoic rocks (De Waele et al., 2008; Fernandez-Alonso et al.,
12 2012; Dewaele et al., 2011). Due to the easy diffusion of radiogenic ^{87}Sr and ^{40}Ar and the
13 high mobility of K, Rb and Sr, this Panafrican overprint resulted in disturbance and partial
14 resetting of the K-Ar, Ar-Ar and Rb-Sr isotopic systems with a huge scatter of apparent ages
15 as documented in Fig. 9, explaining some if not most of the younger 580-450 Ma ages for
16 several alkaline complexes (Fig. 9). It is particularly obvious for the Kirumba complex
17 (RDC), where the Rb-Sr and K-Ar ages are situated between 800 and 240 Ma (Bellon and
18 Pouclet, 1980; Cahen et al., 1979; Cahen and Snelling, 1966; Kampunzu et al., 1998). This
19 could also be the case for Lueshe, where most of the previously obtained ages (see Geological
20 context) are significantly younger than the new LA-ICP-MS age on zircon megacrysts (798.5
21 ± 4.9 Ma). This may not be the case for the URAPC for which the U-Pb age on zircon
22 megacryst at 705 Ma is indistinguishable from the Rb-Sr whole rocks age (699 Ma).

23

1 **8. Conclusion**

2 Petrographic observation and geochemical data (major and trace element analyses)
3 show that different magmatic processes occurred at the scale of the Matongo carbonatite:
4 fractionation of clinopyroxene (and apatite) during carbonatite emplacement, ankeritisation,
5 and alkali loss inducing fenitisation. “Late” hydrothermal processes developed after
6 carbonatite emplacement and affected the primary facies of the carbonatite.

7 In the hypothesis of an extensional setting, the ~800 and ~705 Ma ages obtained on
8 carbonatite-related zircon crystals from Lueshe (DRC) and Matongo (Burundi) could confirm
9 the relationship between carbonatite emplacement and Rodinia breakup, either during an early
10 stage of the fragmentation (at ~800 Ma, for the Lueshe complex) or at a later stage (at ~705
11 Ma for the Matongo carbonatite). The ages of the alkaline complexes would also illustrate the
12 reactivation of Palaeoproterozoic lithospheric weakness zones during extension. Other
13 expressions of the continental rifting process at that time could be found in the formation of
14 Neoproterozoic intracratonic basins documented in the KAB (Fernandez-Alonso et al., 2012;
15 Tack et al., 1992). Consequently, the major lithospheric weaknesses remain the “key factor”
16 controlling the emplacement/location of the carbonatites and alkaline complexes in the East
17 African Rift system.

18 The Panafrican event (660-550 Ma) induced deformation in the KAB, which could be
19 responsible for the disturbance and partial resetting of some isotopic systems. In the area of
20 the western branch of the East African rift, the URAPC could correspond to one of the last
21 episodes of the magmatic activity associated with Rodinia breakup, before the “renewal” of
22 alkaline/carbonatitic activity during the Cretaceous in Central Africa.

23

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6

7 **References**

- 8 Bau, M., 1996. Controls on the fractionation of isovalent trace elements in magmatic and aqueous systems:
9 Evidence from Y/Ho, Zr/Hf, and lanthanide tetrad effect. *Contributions to Mineralogy and Petrology*
10 123, 323-333.
- 11 Bell, K., Simonetti, A., 1996. Carbonatite magmatism and plume activity: Implications from the Nd, Pb and Sr
12 isotope systematics of Oldoinyo Lengai. *Journal of Petrology* 37, 1321-1339.
- 13 Bell K. 2001. Carbonatites: relationships to mantle-plume activity, in: Ernst, R.E., Buchan, K.L. (Eds.), *Mantle*
14 *Plumes: Their Identification Through Time*, GSA Am. Spec. Pap. 352, pp. 267-90.
- 15 Bell, K., Tilton, G.R., 2001. Nd, Pb and Sr isotopic compositions of east African carbonatites: Evidence for
16 mantle mixing and plume inhomogeneity. *Journal of Petrology* 42, 1927-1945.
- 17 Bellon, H., Pouclet, A., 1980. Datations K-Ar de quelques laves du rift-ouest de l'Afrique centrale ; implication
18 sur l'évolution magmatique et structurale. *Geologische Rundschau* 69, 49-62.
- 19 Bizimis, M., Salters, V.M.J., Dawson, J.B., 2003. The brevity of carbonatite sources in the mantle: evidence
20 from Hf isotopes. *Contributions to Mineralogy and Petrology* 145, 281-300.
- 21 Briden, J.C., Piper, J.D., Henthorn, D.I., Rex, D.C., 1971. New palaeomagnetic results from Africa and
22 related potassium-argon age determinations, in: *15th Annual Report Research Institute African*
23 *Geology*, University of Leeds, pp. 46-50.
- 24 Brinckmann, J., Lehmann, B., 1983. Exploration de la bastnaésite-moncite dans la région de Gakara, Burundi.
25 Rapport sur la phase I. Unpublished report, Bujumbura/Hannover, 157 p.

- 1 Brinckmann, J., Lehmann, B., Hein, U., Höhndorf, A., Mussallam, K., Weiser, T., Timm, F., 2001. La Géologie
2 et la minéralisation primaire de l'or De La Chaîne Kibarienne, Nord-Ouest Du Burundi, Afrique
3 Orientale. *Geologisches Jahrbuch Reihe D : Heft 101*, 195 p.
- 4 Brock, P., 1968. Metasomatic and intrusive nepheline-bearing rocks from the Mbozi syenite-gabbro complex,
5 southwestern Tanzania. *Canadian Journal of Earth Sciences* 5, 387-419.
- 6 Burke, E.A.J., 1998. New data on zircon from Matongo (Burundi). *Aardk. Mededel.* 8, 1-4.
- 7 Burke, K., Ashwal, L.D., Webb, S.J., 2003. New way to map old sutures using deformed alkaline rocks and
8 carbonatites. *Geology* 31, 391-394
- 9 Cahen, L., Snelling, N., 1966. The geochronology of Equatorial Africa. North-Holland Publishing Cy,
10 Amsterdam, 195 p.
- 11 Cahen, L., Ledent, D., Snelling, N., 1975. Données géochronologiques dans le Katangien inférieur du Kasai
12 oriental et du Shaba nord-oriental (République du Zaïre). Rapport annuel 1974 du Département de
13 Géologie et Minéralogie, Musée royal de l'Afrique centrale, Tervuren, pp. 59-70.
- 14 Cahen, L., Ledent, D., 1979. Précision sur l'âge, la pétrogenèse et la position stratigraphique des « granites à
15 étain » dans l'est de l'Afrique centrale. *Bulletin de la Société belge de Géologie* 88, 33-39.
- 16 Cahen, L., Ledent, D., Villeneuve, M., 1979. Existence d'une chaîne plissée protérozoïque supérieur au Kivu
17 oriental (Zaïre). Données géochronologiques relatives au Supergroupe de l'Itombwe. *Bulletin de la*
18 *Société belge de Géologie* 88, 71-83.
- 19 Cahen, L., Snelling, N.J., Delhal, J., Vail, J.R., Bonhomme, M., Ledent, D., 1984. The geochronology and
20 evolution of Africa. Clarendon Press Oxford, 512 p.
- 21 Caruba, R., Iacconi, P., 1983. Les zircons des pegmatites de Narssârssuk (Groënland). L'eau et les groupements
22 OH dans les zircons métamictes. *Chemical Geology* 38, 75-92.
- 23 Chakhmouradian, A.R., 2006. High-field-strength elements in carbonatitic rocks: Geochemistry, crystal
24 chemistry and significance for constraining the sources of carbonatites. *Chemical Geology* 235, 138-
25 160.

- 1 De Paepe, P., Tack, L., Moens, L., Van de Velde, P., 1991. The basic magmatism of the Upper Proterozoic in
2 South-East Burundi. Rapport annuel 1989-1990 du Département de Géologie et Minéralogie, Musée
3 royal de l'Afrique central, Tervuren (Belgique), pp. 85-104.
- 4 De Waele, B., Johnson, S.P., Pisarevsky, 2008. Palaeoproterozoic to Neoproterozoic growth and evolution of the
5 eastern Congo Craton : Its role in the Rodinia puzzle. *Precambrian Research* 160, 127-141.
- 6 Deblond, A., Punzalan, L.E., Boven, A., Tack, L., 2001. The Malagarazi Supergroup of SE Burundi and its
7 correlative Bukoban Supergroup of NW Tanzania: Neo - and Mesoproterozoic chronostratigraphic
8 constraints from Ar-Ar ages on mafic intrusive rocks. *Journal of African Earth Sciences* 32, 435-449.
- 9 Delpomdor, F., Linnemann, U., Boven, A., Gärtner, A., Travin, A., Blanpied, C., Virgone, A., Jelsma, H., Pr at,
10 A., 2013. Depositional age, provenance, and tectonic and paleoclimatic settings of the late
11 Mesoproterozoic-middle Neoproterozoic Mbuji-Mayi Supergroup, Democratic Republic of Congo.
12 *Palaeogeography, Palaeoclimatology, Palaeoecology* 389, 4-34.
- 13 Demaiffe, D., 2008. Le magmatisme alcalin et carbonatitique: synth se sur la province pal ozo ique de Kola
14 (Russie) et caract ristiques g n rales du massif prot rozo ique de Matongo (Burundi). *Bulletins de*
15 *S ances de l'Acad mie Royale des Sciences d'Outre-Mer* 54, 171-196.
- 16 Dewaele, S., Henjes-Kunst, F., Melcher, F., Sitnikova, M., Burgess, R., Gerdes, A., Fernandez, M.A., De Clerq,
17 F., Muchez, P., Lehmann, B., 2011. Late Neoproterozoic overprinting of the cassiterite and columbite-
18 tantalite bearing pegmatites of the Gatumba area, Rwanda (Central Africa). *Journal of African Earth*
19 *Sciences* 61, 10-26.
- 20 Ernst, R.E., and K.L. Buchan, 2003. Recognizing mantle plumes in the geological record. *Annual Review of*
21 *Earth and Planetary Sciences* 31, 469-523.
- 22 Eyles, N., 2008. Glacio-epochs and the supercontinent cycle after ~3.0 Ga: Tectonic boundary conditions for
23 glaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 258, 89-129.
- 24 Eyles, N., Januszczak, N., 2004. 'Zipper-rift': a tectonic model for the Neoproterozoic glaciations during the
25 breakup of Rodinia after 750 Ma. *Earth-Science Reviews* 65, 1-73.
- 26 Fernandez-Alonso, M., Cutten, H., De Waele, B., Tack, L., Tahon, A., Baudet, D., Barritt, S.D., 2012. The
27 Mesoproterozoic Karagwe-Ankole Belt (formerly the NE Kibara Belt): The result of prolonged

- 1 extensional intracratonic basin development punctuated by two short-lived far-field compressional
2 events. *Precambrian Research* 216, 63-86.
- 3 Fransolet, A.M., Tack, L. 1992. Les zircons de Matongo (Burundi) et leur signification. *Annales de la Société*
4 *géologique de Belgique* 115, 113-118.
- 5 Fritz, H., Abdelsalam, M., Ali, K.A., Bingen, B., Collins, A.S., Fowler, A.R., Ghebread, W., Hauzenberger,
6 C.A., Johnson, P.R., Kusky, T.M., Macey, P., Muhongo, S., Stem, R.J., Viola, G., 2013. Orogen styles
7 in the East African Orogen : A review of the Neoproterozoic to Cambrian tectonic evolution. *Journal*
8 *of African Earth Sciences* 86, 65-106.
- 9 Gerdes, A., Zeh, A., 2006. Combined U–Pb and Hf isotope LA-(MC-)ICP-MS analyses of detrital zircons:
10 Comparison with SHRIMP and new constraints for the provenance and age of an Armorican
11 metasediment in Central Germany. *Earth and Planetary Sciences Letters* 249, 47-61.
- 12 Gerdes, A., Zeh, A., 2009. Zircon formation versus zircon alteration – new insights from combined U-Pb and
13 Lu-Hf in-situ LA-ICP-MS analyses, and consequences for the interpretation of Archean zircon from
14 the Limpopo Belt. *Chemical Geology* 261, 230-243.
- 15 Hanson, R.E., 2003. Proterozoic geochronology and tectonic evolution of southern Africa, in: Yoshida, M. et al.
16 (Eds.), *Proterozoic East Gondwana: Supercontinent assembly and breakup*, Geological Society,
17 London, Special Publications, 206, pp. 427-463.
- 18 Hoffman, P.F., 1999. The break-up of Rodinia, birth of Gondwana, true polar wander and the snowball Earth.
19 *Journal of African earth Sciences* 28, 17-33.
- 20 Hoskin, P.W.O., Schaltegger, U., 2003. The Composition of Zircon and Igneous and Metamorphic Petrogenesis.
21 *Reviews in Mineralogy and Geochemistry* 53, 27-62.
- 22 Kalt, A., Hegner, E., Satir, M., 1997. Nd, Sr, and Pb isotopic evidence for diverse lithospheric mantle sources of
23 East African Rift carbonatites. *Tectonophysics* 278, 31-45.
- 24 Kampunzu, A.B., Lubala, R.T., Makutu, M.N., Caron, J.P.H., Rocci, G., Vellutini, P.J., 1985. Alkaline
25 complexes from the interlake region of eastern Zaire and Burundi – An example of anorogenic
26 massifs in the relaxation stage. *Journal of African Earth Sciences* 3, 151-167.

- 1 Kampunzu, A.B., Kramers, J., Tembo, F., 1997. Neoproterozoic alkaline and carbonatite magmatism along the
2 western rift in Central-Eastern Africa: Break-up of Rodinia supercontinent and reconstruction of
3 Gondwana. *Gondwana Research* 1, 155-156.
- 4 Kampunzu, A.B., Kramers, J.D., Makutu, M.N., 1998. Rb-Sr whole rock ages of the Lueshe, Kirumba and
5 Numbi igneous complexes (Kivu, Democratic Republic of Congo) and the break-up of the Rodinia
6 supercontinent. *Journal of African Earth Sciences* 26, 29-36.
- 7 Kampunzu, A.B., Mohr, P., 1991. Magmatic evolution and petrogenesis in the east African Rift System, in:
8 Kampunzu, A.B., Lubala, R.T. (Eds.), *Magmatism in extensional structural settings: The Phanerozoic
9 African plate*. Springer-Verlag, Berlin, pp. 85-136.
- 10 Kontak, D.J., Clark, A.H., 2002. Genesis of the giant, bonanza San Rafael Lode tin deposit, Peru: origin and
11 significance of pervasive alteration. *Economic Geology* 97, 1741–1777.
- 12 Kramm, U., Maravic, H.v., Morteani, G., 1997. Neodymium and Sr isotopic constraints on the petrogenetic
13 relationships between carbonatites and cancrinite syenites from the Lueshe Alkaline Complex, east
14 Zaire. *Journal of African Earth Sciences* 25, 55-76.
- 15 Kröner, A., Cordani, U., 2003. African, southern Indian and South American cratons were not part of the
16 Rodinia supercontinent: evidence from field relationships and geochronology. *Tectonophysics* 375,
17 325-352.
- 18 Le Bas, M.J., 1981. Carbonatite magmas. *Mineralogical Magazine* 44, 133-140.
- 19 Le Bas, M.J., 1984. Nephelinites and carbonatites, in: Fitton, J.G., Upton, B.G.J. (Eds.), *Alkaline Igneous Rocks*,
20 The Geological Society of London, Special Publication, v.30, pp. 53-83
- 21 Le Maitre, R.W., 2002. *A classification of igneous rocks and glossary of terms*. Cambridge University Press, 236
22 p.
- 23 Lehmann, B., Nakai, S., Höhndorf, A., Brinckmann, J., Dulski, P., Hein, U., Masuda, A., 1994. REE
24 mineralization at Gakara, Burundi: Evidence for anomalous upper mantle in the western Rift Valley. *Geochimica
25 et Cosmochimica Acta* 58, 985-992.
- 26 Lenoir, J.L., Liégeois, J.P., Theunissen, K., Klerck, J., 1994. The Palaeoproterozoic Ubendian shear belt in
27 Tanzania: geochronology and structure. *Journal of African Earth Sciences* 19, 169-184.

- 1 Li, Z.X., Bogdanova, S.V., Collins, A.S., Davidson, A., De Waele, B., Ernst, R.E., Fitzsimons, I.C.W., Fuck,
2 R.A., Gladkochub, D.P., Jacobs, J., Karlstrom, K.E., Lu, S., Natapov, L.M., Pease, V., Pisarevsky,
3 S.A., Thrane, K., Vernikovsky, V., 2008. Assembly, configuration, and break-up history of Rodinia:
4 A synthesis. *Precambrian Research* 160, 179-210.
- 5 Maravic, H.v., 1983. Geochemische und petrographische Untersuchungen zur Genese des niobführenden
6 Karbonatit/Cancrcinit-Syenitkomplexes von Lueshe, Kivu. NE Zaïre. Unpublished PhD thesis,
7 Technische Universität Berlin, 330 p.
- 8 Maravic, H.v., Morteani, G., 1980. Petrology and geochemistry of the carbonatite and syenite complex of Lueshe
9 (NE Zaïre). *Lithos* 13, 159-170.
- 10 Maravic, H.v., Morteani, G., Roethe, G., 1989. The cancrinite-syenite/carbonatite complex of Lueshe, Kivu/NE-
11 Zaïre: petrographic and geochemical studies and its economic significance. *Journal of African Earth*
12 *Sciences* 9, 341-355.
- 13 Mbede, E.I., Kampunzu, A.B., Armstrong, R.A., 2004. Neoproterozoic inheritance during Cainozoic rifting in the
14 western and southwestern branches of the East African Rift system: Evidence from carbonatites and
15 alkaline intrusions. International conference "The East African Rift system: Geodynamics, resources,
16 and environment, June 20-24 2004, Addis Ababa (Ethiopia). Abstract book, p. 142.
- 17 McDonough, W.F., 1990. Constraints on the composition of the continental lithospheric mantle. *Earth and*
18 *Planetary Science Letters* 101, 1-18.
- 19 McDonough, W.F., Sun, S.S., Ringwood, A.E., Jagoutz, E., Hofmann, A.W., 1992. Potassium, Rubidium and
20 Cesium in the Earth and Moon and the evolution of the mantle of the Earth. *Geochimica et*
21 *Cosmochimica Acta* 56, 1001-1012.
- 22 Meert, J.G., Van der Voo, R., 1997. The assembly of Gondwana 800– 550 Ma. *Journal of Geodynamics* 23, 223-
23 235.
- 24 Melcher, F., Graupner, T., Gäbler, H.E., Sitnikova, M., Henjes-Kunst, F., Oberthür, T., Gerded, A., Dewaele, S.,
25 2013. Tantalum-(niobium-tin) mineralisation in African pegmatites and rare metal granites:
26 Constraints from Ta-Nb oxide mineralogy, geochemistry and U-Pb geochronology. *Ore Geology*
27 *Reviews*, in press.

- 1 Midende, G. 1984. La carbonatite de Matongo (Burundi). Unpublished PhD thesis, Université Libre de
2 Bruxelles, Bruxelles, 288 p.
- 3 Filippo, S., 1995. Evaluation minéralogique par diffraction des rayons X qualitative et quantitative des
4 gisements latéritiques de niobium de la Lueshe et de Bingo dans le cadre de l'optimisation de la
5 récupération du pyrochlore. Unpublished PhD thesis. Université Catholique de Louvain, Belgium,
6 207p.
- 7 Pisarevsky, S.A., Wingate, M.T.D., Powell, C.McA., Johnson, S.P., Evans, D.A.D., 2003. Models of Rodinia
8 assembly and fragmentation, in: Yoshida, M., Windley, B.F., Dasgupta, S. (Eds.), Proterozoic East
9 Gondwana: Supercontinent Assembly and Break-up. Geological Society of London, Special
10 Publication 206, pp. 35-55.
- 11 Pedrosa-Soares, A.C., Flecha de Alkmim, 2011. How many rifting events preceded the development of the
12 Araçuaí-West Congo orogen? *Geonomos* 19, 244-251.
- 13 Powell, C.McA., Li, Z.X., McElhinny, M.W., Meert, J.G., Park, J.K., 1993. Paleomagnetic constraints on timing
14 of the Neoproterozoic break-up of Rodinia and the Cambrian formation of Gondwana. *Geology* 21,
15 889-892.
- 16 Ray, G., 1974. The structural and metamorphic geology of northern Malawi. *Journal of the Geological Society of*
17 *London* 130, 427-440.
- 18 Romer, R.L., Lehmann, B., 1995. U–Pb columbite-tantalite age of Neoproterozoic Ta–Nb mineralisation in
19 Burundi. *Economic Geology* 90, 2303–2309.
- 20 Simonetti, A., Bell, K., 1994. Isotopic and geochemical investigation of the Chilwa Island carbonatite complex,
21 Malawi: evidence for a depleted mantle source region, liquid immiscibility, and open-system
22 behaviour. *Journal of Petrology* 35, 1597-1621.
- 23 Snelling, N., Hamilton, E., Drysdall, A., Stillman, C., 1964. A review of age determinations from Northern
24 Rhodesia. *Economic Geology*, 59: 961-981.
- 25 Songore T 1991. The Matongo phosphate deposit of Burundi. *Fertilizer Research* 30, 151-153.

- 1 Stendal, H., Frei, R., Muhongo, S., Rasmussen, T.M., Mnali, S., Petro, F., Temu, E.B., 2004. Gold potential of
2 the Mpanda Mineral Field, SW Tanzania: evaluation based on geological, lead isotopic and
3 aeromagnetic data. *Journal of African Earth Sciences* 38, 437-447.
- 4 Stracke, A., Bizimis, M., Salters, V.J.M., 2003. Recycling oceanic crust: Quantitative constraints. *Geochemistry,*
5 *Geophysics, Geosystems* 4, DOI: 10.1029/2001GC000223.
- 6 Sun, S.S., 1982. Chemical composition and origin of the Earth's primitive mantle. *Geochimica et Cosmochimica*
7 *Acta* 46, 179–192.
- 8 Tack, L., De Paepe, P., Deutsch, S., Liégeois, J.P., 1984. The alkaline plutonic complex of the Upper Ruvubu
9 (Burundi): geology, age, isotopic geochemistry and implications for the regional geology of the
10 Western rift, in: Klerkx, J., Michot, J. (Eds.), *African Geology*, pp. 91-114.
- 11 Tack, L., Sindayihebura, A., Cimpaye, D., 1992. The Nkoma (SE Burundi) : An episodically reactivated Lower
12 Burundian (Middle Proterozoic) siliciclastic sequence, locally overlain by a Malagarasian (Upper
13 Proterozoic) sedimentary breccias. *IGCP n°255 Newsletter* 4, 31-43.
- 14 Tack, L., Liégeois, J.P., André, L., Navez, J., 1995. The Upper Ruvubu alkaline plutonic complex (Burundi).
15 *Annual Report of the Royal Museum for Central Africa, Tervuren*, p. 9.
- 16 Tack, L., Deblond, A., De Paepe, P., Duchesne, J.C., Liégeois, J.P., 1996. Proterozoic alignments of alkaline
17 plutons revealing lithospheric discontinuities : evidence from Eastern Africa, in: Demaiffe, D. (Ed.),
18 *Petrology and Geochemistry of magmatic suites of rocks in the continental and oceanic crusts. A*
19 *volume dedicated to Professor Jean Michot, Université Libre de Bruxelles, Bruxelles, Belgium*, pp.
20 219-226.
- 21 Tack, L., Wingate, M.T.D., De Waele, B., Meert, J., Belousova, E., Griffin, A., Tahon, A., Fernandez-Alonso,
22 M., 2010. The 1375 Ma “Kibaran event” in Central Africa: prominent emplacement of bimodal
23 magmatism under extensional regime. *Precambrian Research* 180, 63–84.
- 24 Theunissen, K., Lenoir, J.L., Liégeois, J.P., Delvaux, D., Mruma, A., 1992. Empreinte pan-africaine majeure dans
25 la chaîne ubendienne de Tanzanie sud-occidentale : géochronologie U-Pb sur zircon et contexte
26 structural. *Comptes Rendus de l'Académie des Sciences de Paris* 314, 1355-1362.

- 1 Van den Haute, P., 1986. Sphegne fission-track dating of a precambrian alkaline pluton in Burundi (Central
2 Africa). *Terra cognita* 6, p. 165.
- 3 Van Overbeke, A.C., 1996. Le complexe à carbonatite et syénite de la Lueshe (N-Kivu, Zaïre): pétrogenèse des
4 roches ignées et caractérisation géochimique des processus métasomatiques (féritisation).
5 Unpublished PhD thesis. Université Catholique de Louvain, Louvain-la-Neuve, Belgique. 235 p.
- 6 Van Overbeke, A.C., Demaiffe, D., Verkaeren, J., 1996. The syenite-carbonatite complex of Lueshe (NE Zaïre):
7 petrography, geochemistry and Rb-Sr chronology, in Demaiffe, D. (Ed.), *Petrology and
8 Geochemistry of magmatic suites of rocks in the continental and oceanic crusts. A volume dedicated
9 to Professor Jean Michot, Université Libre de Bruxelles, Bruxelles, Belgium*, pp. 355-370.
- 10 Van Wambeke, L., 1977. The Karonge rare earth deposits, Republic of Burundi: new mineralogical and
11 geochemical data and origin of the mineralization. *Mineralium Deposita* 12, 373-380.
- 12 Vellutini, P., Bonhomme, C., Caron, M., Kampunzu, A.B., Lubala, T., 1981. Sur la signification tectonique des
13 complexes alcalins acides de Kahuzi et de Biega (Kivu, Zaïre). *Comptes Rendus de l'Académie des
14 Sciences de Paris* 292, 1027-1029.
- 15 Verwoerd, 1967. The carbonatites of South Africa and South West Africa. *Handbook 6 of the Geological Society
16 of South Africa*, 452 p.
- 17 Villeneuve, M., 1987. Géologie du synclinal de l'Itombwe (Zaïre oriental) et le problème de l'existence d'un
18 sillon plissé pan-africain. *Journal of African Earth Sciences* 6, 869-880.
- 19 Vrana, S., Kachlik, V., Kroner, A., Marheine, D., Seifert, A.V., Zacek, V., Baburek, J., 2004. Ubendian
20 basement and its late Mesoproterozoic and early Neoproterozoic structural and metamorphic overprint
21 in northeastern Zambia. *Journal of African Earth Sciences* 38, 1-21.
- 22 Walemba, K., Master, S., 2005. Neoproterozoic diamictites from the Itombwe Synclinorium, Kivu Province,
23 Democratic Republic of Congo: Palaeoclimatic significance and regional correlations. *Journal of
24 African Earth Sciences* 42, 200-210.
- 25 Woolley, A.R., 2001. Alkaline rocks and carbonatites of the world. Part 3: Africa, Geological Society of
26 London, 372 p.

- 1 Zeh, A., Gerdes, A., 2012. U-Pb and Hf isotope record of detrital zircons from gold-bearing sediments of the
2 Pietersburg Greenstone Belt (South Africa) – Is there a common provenance with the Witwatersrand
3 Basin? *Precambrian Research* 204-205, 46-56.
- 4 Zhao, Z.-F., Zheng, Y.-F., Wei, C.-S., Gong, B., 2004. Temporal relationship between granite cooling and
5 hydrothermal uranium mineralization at Dalongshan in China: a combined radiometric and oxygen
6 isotopic study. *Ore Geology Reviews* 25, 221–236.
- 7 Zindler, A., Hart, S., 1986. Chemical geodynamics. In: *Annual review of earth and planetary sciences*. Vol. 14,
8 pp. 493-571.

10 **Figures and tables captions**

11

12 **Fig. 1.** (A) Carbonatite and alkaline massif occurrences in Africa (redrawn from Woolley, 2001), (B) Alkaline
13 magmatism along the western branch of the East African Rift system (redrawn from Tack et al., 1984 and
14 Kampunzu and Mohr, 1991). The Itombwe “syncline” and Malagarazi basin consist of Neoproterozoic rocks; the
15 Malagarazi Supergroup (Burundi) – formerly known in Tanzania as Bukoba Supergroup – has been renamed
16 Nyamuri Supergroup (Geology and Mineral map of Tanzania, 1:2.000.000, 2008).

17 **Fig. 2.** Geological sketch map of the studied area (modified and redrawn from Tack et al., 1984, and after
18 Fernandez-Alonso et al., 2012), with location of the showings/deposits mentioned in the text. The insert
19 illustrates the location of the drill holes.

20 **Fig. 3.** Photomicrographs of the various Matongo carbonatite facies: (A) coarse-grained sövite I, cut by a vein of
21 “late” hydrothermal calcite (calcite finely admixed with Fe oxides) (sample LT-SI-1), (B) fine-grained sövite II
22 with biotite (sample LT-SII-1), (C) euhedral crystals of aegirine in a sövite II (sample RG 140.280A), (D)
23 richterite needles within a sövite II (sample RG 140.280B), (E) association of ankerite (dark grey on the picture),
24 calcite and iron-stained silica (red on the picture) (sample RG 140.272), (F) fenite comprising K-feldspar and
25 biotite (sample S1/183.5-184.25) and (G) fenite almost exclusively made up of biotite (sample RG 140.279).
26 Scale bars are in cm.

1 **Fig. 4.** The Matongo carbonatites in classification/discrimination ternary diagrams: (A) CaO-Fe₂O₃(t)+MnO-
2 MgO(based on Le Maitre et al., 2002) and (B) Na₂O+K₂O-CaO-MgO+Fe₂O₃(Le Bas, 1981, 1984).

3 **Fig. 5.** Chondrite-normalized REE abundance patterns of the Matongo carbonatite facies. (A) sövite I, (B) sövite
4 II and associated cumulates (comprising clinopyroxene, apatite and amphibole), (C) ferrocarbonatite and “late”
5 hydrothermal calcite, and (D) fenites-silicocarbonatites. Normalization values to the chondrites from Sun (1982)
6 and McDonough (1990).

7 **Fig. 6.** Spidergrams of the Matongo carbonatite facies. (A) sövite I, (B) sövite II and associated cumulates
8 (comprising clinopyroxene, apatite and amphibole), (C) ferrocarbonatite and “late” hydrothermal calcite, and (D)
9 fenites-silicocarbonatites. Normalization values to the primitive mantle from McDonough et al. (1992).

10 **Fig. 7.** Pictures of the Matongo (A and C) and Lueshe (B and D) zircon megacrysts (A and B: backscattered
11 electron images, C and D: cathodoluminescence images): red and white dots represent electron microprobe and
12 LA-MC-ICP-MS analyses, respectively. E and F: concordia plots of LA-MC-ICP-MS U-Pb data, with data
13 point error ellipses at 2σ.

14 **Fig. 8.** Initial εNd-εSr isotopic diagrams for the various Matongo carbonatites (7 samples; Demaiffe, 2008). For
15 comparison, are reported the fields for the sövites from the Lueshe Neoproterozoic carbonatite (DRCongo;
16 Kramm et al., 1997) and for the East African carbonatites (dated between 200 and 0 Ma; Bell and Tilton, 2001).
17 The positions of the main oceanic mantle reservoirs identified by Zindler and Hart (1986) are shown: DM =
18 depleted mantle, BSE = bulk silicate earth, EMI and EMII = enriched mantle I and II, HIMU = high U/Pb
19 domain. Outline of the mantle array (dashed line) is drawn after Stracke et al. (2003) and Bizimis et al. (2003).

20 **Fig. 9.** Schematic diagram comparing the isotopic ages obtained on carbonatites and alkaline complexes (located
21 in Fig. 1B) and the new Matongo and Lueshe zircon U-Pb ages. All these ages are considered together and
22 reinterpreted in the regional geodynamic context. Reference numbering is as follow: (1) This paper; (2) Kramm
23 et al. 1997; (3) Bellon and Pouclet, 1980; (4) Cahen and Snelling, 1966; (5) Kampunzu et al., 1998; (6) Cahen et
24 al., 1979; (7) Tack et al., 1984; (8) Vellutini et al., 1981; (9) Cahen et al., 1975; (10) Demaiffe, 2008; (11)
25 Stendal et al., 2004 ; (12) Brock, 1968 ; (13) Mbede et al., 2004; (14) Ray, 1974; (15) Snelling et al., 1964; (16)
26 Vrana et al., 2004; (17) Van Overbeke, 1996; (18) Van den Haute, 1986; (19) Tack et al., 1995.

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- 1 **Table 1.** Major element contents (in wt. %) of samples from the Matongo carbonatites.
- 2 **Table 2.** REE contents (ppm) La_N/Yb_N ratios, ΣREE and tetrad effect of samples from the Matongo carbonatites.
- 3 **Table 3.** Trace elements (in ppm) of samples from the Matongo carbonatite.
- 4 **Table 4.** Representative electron probe microanalyses of zircon megacrysts from Lueshe and Matongo
- 5 **Table 5.** Representative U-Th-Pb analyses of zircon megacrysts from Lueshe and Matongo
- 6 **Table 6.** Sr and Nd isotopic data of samples from the Matongo carbonatites (Demaiffe, 2008).
- 7 -----
- 8 **Supplementary data.** Representative microprobe analyses (elements in wt. %) of carbonates (A),
- 9 clinopyroxenes, amphiboles (B), feldspars and phyllosilicates (C) from the Matongo carbonatites.

10

11

Sample	Description	Si O ₂	Al ₂ O ₃	Fe ₂ O 3(tot)	Mn O	Mg O	Ca O	Na 2O	K ₂ O	TiO 2	P ₂ O ₅	LOI	Su m
LT-SI-1 RG140.276-S7/62- 63m	sövite I	0.0	0.0		0.6		54.	0.0	0.0	0.0	0.0	#N.	79.7
		9	1	0.03	86	0.4	13	3	1	01	1	A.	7
	Sövite I	0.0	0.0		0.6		55.	0.0	0.0	0.0	0.0	#N.	80.9
Gi3-ITS4/84-87m	sövite II	8	1	0.03	82	0.5	16	2	1	01	1	A.	7
		0.8	4.8		0.2	0.4	51.	0.0	0.0	0.0	1.4	38.	99.0
	8	8	1.14	5	9	72	8	3	1	2	16	6	
LT-SII-1	sövite II	2.4			0.1	0.4	50.	0.4	0.0	0.0	0.6	34.	80.7
		2	0.7	1.33	34	7	99	1	4	14	2	64	6
RG 140.273	sövite II	0.9	0.2		0.2	0.1	56.	0.0	0.1	0.0	0.4	34.	84.7
		3	6	2.21	21	1	92	8	5	08	1	12	1
Gi2-S3/147	sövite II	10.	0.9		0.1	2.2	42.	1.4	0.4	0.3	3.7	22.	81.3
		27	6	4.48	31	6	9	7	8	77	7	5	3
Gi12-S5/121.5m	sövite II with apatite	1.3	0.0		0.2	0.7	48.		0.0	0.0	10.	36.	99.1
		2	1	1.36	3	5	57	0.2	7	4	45	19	9
LT-cum-1 RG 140.280A- S5/121-121.60m	sövite II with apatite and px		1.7		0.1	3.4	31.	2.8	1.1	0.3	2.4	24.	97.5
		23	7	11.37	83	4	39	5	7	77	6	99	4
Gi1-S2/171-172m	sövite II with apatite and px	28.	1.3		0.0	2.4	25.	5.3	0.2	0.3	10.	9.0	98.1
		74	5	16.65	88	4	57	7	9	39	39	8	1
Gi10-S6/155-156m	sövite II with apatite and px	6.4	0.6		0.1	0.6	42.	0.2	0.4	0.1	3.3	40.	98.5
		6	8	3.27	7	2	82	8	4	0	6	39	9
Gi11-S8/56m RG 140.280B- S5/121-121.60m	sövite II with apatite and px	6.2	0.5		0.1	0.6	42.	0.5	0.3	0.1	4.7	38.	98.7
		8	4	4.27	6	1	74	9	4	1	9	30	3
Gi11-S8/56m RG 140.280B- S5/121-121.60m	px and apatite cumulate	21.	3.2		0.0	1.7	34.	0.8	2.3	0.4	9.9	15.	100.
		48	2	10.40	9	4	48	1	6	0	6	61	55
Gi16-S3/121m	ferrocarbonatite	16.	0.6		0.0	1.2	38.		0.4	0.1	19.	5.0	89.4
		18	1	7.76	61	9	03	3.4	3	65	29	2	4
LT-CJ-1 RG 140.272- ITS5/60m	ferrocarbonatite	7.7	2.2		0.2	3.1	29.	0.6	0.0	0.4	0.2	32.	54.0
		2	8	9.46	1	7	68	5	9	7	8	58	1
Gi17-S7/91-95	"late" hydrothermal carbonatite	2.3	1.2		0.2	0.6	50.	0.0	0.3	0.0	3.9	28.	83.7
		1	1	2.19	68	8	49	5	4	37	1	38	3
Gi5-ITS3/291	kfs-fenite	9.3	2.8		1.0	2.4	44.	0.0	0.8	0.3	0.2	38.	85.6
		9	2	4.11	45	9	62	3	9	89	4	33	8
Gi14-ITS4/150	kfs-fenite	0.9	0.2		0.6	2.4	50.	0.0	0.1	0.0	0.0	11.	82.9
		1	6	1.22	19	7	24	3	2	32	3	03	7
Gi15-S5/104-106	bt-fenite	51.	14.		0.0	0.0	10.	0.7	12.	0.0	0.1	16.	99.5
		78	5	0.67	64	9	67	1	24	27	1	49	4
S1/183.5-184.25	Kfs-bt-fenite	32.	9.3		0.4	0.3	25.	0.9	7.1	0.0	0.1	13.	88.8
		06	5	2.14	78	7	39	5	5	2	5	21	9
S1/183.5-184.25	Kfs-bt-fenite	35.	16.		0.0	4.6	13.	4.4	3.5	1.9	0.1	6.5	
		26	55	7.9	98	4	19	7	4	72	4	6	98.3
		55.	16.		0.1	0.4	6.0	0.9	12.	0.1	0.6	#N.	100.
		04	79	2.32	05	1	6	1	56	76	3	A.	4

Sample	Description	L a	C e	P r	N d	S m	E u	G d	T b	D y	H o	E r	Y b	L u	La _N /Y _b N	Eu */E u	Su mR EE	Tetrad effect (La _N *Sm _N)/(Ce _N *Nd N)
LT-SI-1	sövite I	0.6	1.1	0.18	0.8	0.3	0.06	0.2	0.1	0.2	0.1	0.1	0.1	0.04	4.05	0.71	3.88	1.6
RG140.276	Sövite I	1.4	1.9	0.37	1.7	0.8	0.17	0.7	0.1	0.5	0.1	0.3	0.3	0.05	3.15	0.68	8.39	2.8
Gi3-ITS4/84-87m	sövite II	1.4	2.7		1.0	1.2	3.2		0.9				1.0	0.2	67.1	1.47	539	0.5
LT-SII-1	sövite II	1.5	2.5	2.5	8.6	1.2	3.9	9.7	0.9	4.3	0.8	2.2	1.9	0.2	55.5	0.89	552	0.7
RG 140.273	sövite II	2.1	1.3	1.4	1.1	0.4	2.0	7.2	0.7	3.2	0.6	1.6	1.5	0.2	58.1	0.84	461	0.7
Gi2-S3/147	sövite II	3.2	4.1	4.5	5.7	2.2	5.7	5.9	1.5	6.3	1.7	2.7	1.8	0.6	89.0	0.91	907	0.6
Gi12-S5/121.5m	sövite II with apatite	1.8	3.6		1.3	1.6	4.2		1.2				2.1	0.3	58.8	1.46	707	0.5
LT-cum-1	sövite II with apatite and px	1.4	0.3	2.1	7.6	1.1	6.6	6.5	0.8	3.7	0.6	1.6	1.3	0.2	59.3	0.92	442	0.6
RG 140.280 A	sövite II with apatite and px	2.3	4.4	8.2	7.1	2.4	6.6	1.6	1.5	6.3	1.1	2.8	2.1	0.3	76.9	0.89	950	0.6
Gi1-S2/171-172m	sövite II with apatite and px	1.0	0.7		6.0	0.1	5.7		1.1				1.7	0.8	80.2	1.49	807	0.5
Gi10-S6/155-156m	sövite II with apatite and px	1.2	3.6		9.7	1.2	3.4		1.0				1.8	0.2	49.0	1.49	509	0.5
Gi11-S8/56m	px and apatite cumulate	1.7	2.2		1.1	1.4	8.3		1.1				2.1	0.2	94.2	1.47	638	0.5
RG 140.280 B	sövite II with apatite and amph.	1.5	1.9	2.2	6.6	3.3	8.9	2.7	1.8	7.1	1.6	2.6	1.6	0.4	175.3	0.86	1550	0.6
Gi16-S3/121m	ferrocarbonatite	1.4	2.9		1.1	1.4	3.8		1.0				1.5		64.5	1.48	568	0.5
LT-CJ-1	ferrocarbonatite	2.2	4.6	8.8	6.3	3.9	6.8	1.8	1.9	8.6	1.5	4.1	3.1	0.4	63.7	0.86	1047	0.7
RG 140.272	ferrocarbonatite "late"	2.6	2.9	7.9	3.5	6.7	6.7	5.4	0.7	3.9	0.8	2.3	2.5	0.4	16.9	0.82	225	1.0
Gi17-S7/91-95	hydrothermal carbonatite	1.3	2.8	2.8	6.2	0.7	7.5	2.5	0.1	5.5	0.2	7.4	5.8	0.7	3.66	0.85	396	2.3
Gi5-ITS3/291	kfs-fenite	3.8	2.2	1.9	9.1	2.4	6.7	2.1	0.2	1.2	0.0	0.7	0.7	0.1	37.0	0.89	134	0.6
Gi14-ITS4/150	kfs-fenite	1.8	1.3	3.9	9.1	4.1	4.7	1.4	1.6	8.2	1.8	5.5	5.4	0.0	25.4	0.96	681	0.8
Gi15-S5/104-106	bt-fenite	4.5	1.1	4.5	5.6	8.3	2.5	5.7	0.7	2.7	0.0	1.4	0.1	0.5	45.9	0.97	259	0.6
S1/183.5-184.25	Kfs-bt-fenite	5.4	0.1	1.7	2.4	6.4	6.5	4.2	0.6	2.9	0.0	1.5	1.1	0.2	36.9	0.92	234	0.6
<i>Normalization values used</i>		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				

<i>in REE diagrams - chondrite</i>	3	8	1	6	2	0	2	0	3	0	2	2	0
<i>concentrations of Sun</i>	1	1	2	0	0	7	6	5	2	7	1	1	3
<i>(1982) and McDonough</i>													
<i>(1990)</i>													

ACCEPTED MANUSCRIPT

Sample	R	B	T	U	N	T	K	L	C	P	P	S	N	Z	H	S	E	T	G	T	D	Y	H	E	Y	L
LT-SI-1	2	8	0.6	0.1	0.1	0.0	0.0	0.6	1.1	5	0.18	2.99	0.28	2.14	0.04	0.03	0.06	0.00	0.02	0.01	0.02	4	0.1	0.1	0.1	0.04
RG14 0.276	2	10	1.8	0.1	1	0.1	0.0	1.4	1.9	5	0.37	1.53	1.71	0.12	0.08	0.07	0.10	0.00	0.07	0.01	0.05	5	0.1	0.3	0.3	0.05
Gi3-ITS4/84-87m	1.0	8.1	1.0	0.5	1.0	6.2	0.0	1.4	2.7			2.5	1.0		1.6	3.1	0.0		0.9	1					1.7	0.4
LT-SII-1	<2	7.3	1.9	0.5	8.0	0.4	0.0	1.5	2.5	5	2.5	8.0	8.8	0.9	0.1	3.1	0.0	9.7	0.9	4.3	2.5	0.8	2.8	1.2	1.9	0.28
RG 140.2 73	3	9.2	0.4	0.2	1.0	0.1	0.0	1.9	2.1	5	2.14	3.81	7.6	0.2	0.9	2.8	0.0	7.0	2.2	0.7	3.2	1.6	0.6	1.6	1.5	0.23
Gi2-S3/14 7	2.2	5.6	1.1	0.7	8.8	4.9	0.2	2.3	4.1	6	4.45	9.57	4.9	0.4	0.1	5.7	0.1	5.9	1.5	6.3	3.0	1	2.7	1.8	1.2	0.26
Gi12-S5/12 1.5m	<4	5.8			1.0	0.4	0.0	1.8	3.6			6.5	1.3		1.5	4.2	0.0		1.2						2.1	0.3
LT-cum-1	7.0	3.9	3.6	2.7	5.5	5.0	0.7	1.4	2.3	5	2.1	5.6	7.6	2.4	1.0	2.6	0.1	6.5	0.8	3.7	1.7	0.6	1.6	1.3	1.2	0.22
RG 140.2 80A	4	1.6	1.8	1.4	1.6	3.4	0.7	2.3	4.3	2.3	4.8	3.8	3.7	2.3	2.3	6.1	0.1	1.6	1.5	6.3	2.8	1	2.8	2.1	2.3	0.33
Gi1-S2/17 1-172m	2.2	5.5	2.8	1.3	3.1	5.3	0.6	2.1	4.0			2.3	1.6		2.3	5.0	0.0		0.7						1.7	0.2
Gi10-S6/15 5-156m	1.4	9.5	1.6	5.4	4.7	4.0	0.2	1.3	2.6			4.1	9.7		1.2	3.4	0.0		2.4		5				1.8	0.26
Gi11-S8/56 m		2.8	4.4	2.4	4.4	2.4	1.4	1.7	3.2			1.9	1.1		1.3	3.8	0.1		1						1.2	0.1
RG 140.2 80B	7.1	3.0	2.4	3.8	8.6	6.2	0.2	4.1	7.1	7	7.6	9.5	6.3	4.9	4.8	8.9	0.0	2.2	1.8	7	3.1	1.1	2.6	1.6	1.6	0.24
Gi16-S3/12 1m		7.8	4.8	5.7	5.3	0.5	1.5	4.5	2.1			3.0	1.2		1.4	3.9	0.2		1.0						1.5	
LT-CJ-1	2.0	2.0	2.3	0.7	4.5	0.1	0.2	2.9	4.6	1.8	4.8	8.4	6.3	3.2	0.6	2.9	0.0	1.7	1.9	8.6	4.5	1.5	4.5	3.1	3.1	0.49
RG 140.2 72	1.1	4.4	5.0	1.4	7.4	1.9	0.5	2.2	2.9	2	7.5	5.8	3.5	5.4	0.8	6.7	1.0	5.4	0.7	0.7	3.9	2.7	0.8	2.3	2.5	0.41

Gi17-S7/91-95	1	7	2	0	4	1	0	0	3	7	3	1	1	7	0	5	1	0	7	1	3	9	3	6	5	0	8	7
Gi5-ITS3/291	2	1	1	1	4	5	7	3	6	6	6	1	1	2	1	2	0	0	2	0	1	7	0	0	0	0	1	1
Gi14-ITS4/150	1	1	1	4	0	1	4	1	3	3	3	4	9	2	0	1	4	0	1	1	8	4	1	5	5	7	7	0
Gi15-S5/104-106	1	1	1	0	5	7	2	5	1	1	1	2	5	2	4	8	2	0	5	0	2	9	0	1	0	1	1	0
S1/183.5-184.25	2	2	7	7	8	9	5	4	0	8	1	6	2	1	0	6	6	0	4	0	2	1	0	1	1	1	2	
<i>Normalization values used in spidergrams - primitive mantle concentrations of McDonough et al. (1992)</i>	0	6	0	0	0	0	0	0	1	0	0	2	1	1	0	0	0	0	0	0	4	0	0	0	0	0	0	
	6	9	0	0	7	0	3	6	7	1	2	1	1	3	4	1	2	5	0	6	5	1	4	4	4	0	0	
	3	8	8	2	1	4	0	8	7	8	7	1	2	0	4	5	1	4	9	7	5	4	3	9	6	6	8	
	5	9	5	1	3	1	1	7	5	5	6	5	2	9	4	4	7	4	9	4	5	9	8	3	8	8	8	

Matongo (RGM 9672)										Lueshe (RGM 9673)										
Grain	1	1	2	3	4	6	6	9	10	1	1	2	3	4	4	6	7	9	10	
Analysis	2	17	20	27	35	47	51	63	67	4	8	25	40	45	48	56	61	69	76	
CL brightness	no	bri	bri	no	bri	no	no	no	no	bri	no	no	no	no	bri	no	no	no	no	me
wt%																				diu
SiO ₂	33.18	.78	33.05	33.01	.89	.88	30.39	.11	.96	33.05	32.01	32.79	28.12	30.41	32.91	.66	.66	.40	32.71	
ZrO ₂	66.45	.68	67.19	66.23	.31	.35	61.96	.82	.53	65.02	65.03	64.64	57.10	61.58	65.87	.19	.37	.77	65.71	
HfO ₂	0.53	0.67	0.60	0.71	0.67	0.62	0.66	0.36	0.70	0.40	0.62	0.80	0.70	0.41	1.25	0.43	0.69	0.59	0.63	
ThO ₂	0.137	<d>	<d>	0.087	<d>	0.098	0.309	13.60	27.00	<d>	17.01	1.151	1.198	0.699	<d>	46.03	42.09	25.07	0.35	
UO ₂	0.059	<d>	<d>	0.043	<d>	0.041	0.084	0.046	0.06	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	0.00	
PbO	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	0.00	
P ₂ O ₅	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	<d>	0.120	<d>	<d>	<d>	<d>	<d>	0.00	
TiO ₂	<d>	<d>	<d>	<d>	<d>	<d>	0.345	<d>	<d>	<d>	<d>	<d>	0.52	0.22	<d>	<d>	<d>	<d>	0.00	
Al ₂ O ₃	<d>	<d>	<d>	<d>	<d>	<d>	0.356	<d>	<d>	<d>	<d>	<d>	0.854	0.411	<d>	<d>	<d>	<d>	0.00	
CaO	0.031	<d>	<d>	<d>	<d>	<d>	0.539	<d>	0.057	<d>	<d>	<d>	1.362	0.740	<d>	<d>	<d>	0.00		
MnO	<d>	<d>	<d>	<d>	<d>	<d>	0.133	<d>	<d>	<d>	<d>	<d>	0.237	0.084	<d>	<d>	<d>	0.00		
FeO	<d>	<d>	<d>	<d>	<d>	<d>	0.715	<d>	0.059	<d>	<d>	31.04	0.668	0.761	<d>	<d>	<d>	0.00		
total	0.39	.13	0.85	0.08	.88	.99	95.31	.48	.64	.64	.699	99.20	91.01	95.32	0.04	4.04	5.05	2.02	99.58	
Cations per formula units																				
Si	1.009	1.009	1.002	1.007	1.000	1.000	0.981	1.013	1.010	1.000	1.008	1.013	0.954	0.981	1.007	1.000	1.007	1.002	1.006	
Zr	0.985	0.985	0.993	0.986	0.989	0.989	0.975	0.982	0.980	0.986	0.985	0.974	0.945	0.969	0.983	0.983	0.983	0.991	0.985	
Hf	0.005	0.006	0.005	0.006	0.006	0.005	0.006	0.003	0.006	0.003	0.005	0.005	0.007	0.004	0.011	0.004	0.006	0.005	0.006	
Th	0.001		0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.008	0.009	0.005	0.003	0.003	0.002	0.004	0.004	
U	0.000		0.000	0.000	0.000	0.000	0.001	0.000	0.000									0.000	0.000	
Pb																			0.000	
P													0.003						0.000	
Ti							0.004						0.017	0.005					0.000	
Al							0.014						0.034	0.016					0.000	
Ca	0.000						0.000	0.000					0.000	0.000					0.000	

	01						19	00				50	26						
								2											
Mn							0.0	04				0.0	0.0					0	0
							0.0	00			0.0	0.0	0.0						
Fe							19	2			01	19	21					0	0
		2.		2.	2.		2.	2.	2.	2.					2.	2.	2.		
total	2.0	00	2.0	2.0	00	00	2.0	00	00	00	00	2.0	2.0	2.0	2.0	00	00	00	2.0
	01	0	00	00	0	0	24	0	2	0	0	00	45	28	00	0	0	0	00

*, metamict
area

	207 P b ^a (c ps)	U b (p p m)	P b ^b (p p m)	T h b U	206 P bc (%)	206 Pb _d U	± 2 s (%)	207 P b ^d U	± 2 s (%)	208 P b U	± 2 s (%)	207 Pb _d U	± 2 s (%)	r h o e	20 P b U	± 2 s (M a U	20 Z P b U	± 2 s (M a U	20 P b ₂₃ U	± 2 s (M a U	20 Z P b ₂₀ U	± 2 s (M a U	c o n c. f (%)	
sp ot AS 96 73																								
A0	27 60 5	1 2 7	8 8 8	1 8 8	0. 06	0. 07	1 7	1. 6	2 2	0. 04	1 7	0. 52	1 3	0	7 9	1 3	7 9	1 2	8 6	1 3	7 2	1 8	2 8	0 1
A0	35 00 6	1 5 8	1 3 0	2 2 0	0. 07	0. 99	1 7	1. 4	2 1	0. 04	1 6	0. 55	1 1	0	7 8	1 3	7 8	1 1	8 5	1 3	7 2	1 9	2 3	9 9
A0	15 46 7	6 0 8	2 0 0	8 7 14	0. 14	0. 32	1 8	1. 6	2 4	0. 04	1 6	0. 56	1 5	0	8 6	1 4	8 3	1 4	8 8	1 3	7 4	1 9	3 5	0 1
A0	12 16 8	5 6 1	9 2 6	4 7 0	0. 09	0. 13	1 8	1. 5	2 5	0. 04	1 8	0. 51	1 7	0	7 9	1 3	7 9	1 4	8 8	1 3	7 0	1 8	3 6	0 2
A0	16 32 9	7 1 4	2 2 0	9 0 0	0. 18	0. 24	1 8	1. 0	2 4	0. 04	1 7	0. 57	1 4	0	8 5	1 7	8 2	1 4	8 3	1 3	7 4	1 8	2 0	0 0
A1	23 55 0	1 1 5	9 2 4	2 4 4	0. 16	0. 83	1 9	1. 1	2 4	0. 04	1 9	0. 56	1 4	0	7 8	1 4	7 2	1 3	7 9	1 5	7 9	1 9	3 4	9 8
A1	13 56 1	6 4 5	4 0 0	6 5 14	0. 14	0. 99	2 0	1. 7	2 5	0. 04	1 9	0. 53	1 7	0	7 8	1 5	7 7	1 4	8 9	1 4	7 9	1 8	3 6	0 0
A1	13 12 2	5 9 14	1 6 0	1 0 5	0. 10	0. 41	1 8	1. 4	2 0	0. 04	1 7	0. 56	0 9	0	8 0	1 4	8 7	1 1	7 5	1 7	7 1	1 9	1 5	0 2
A1	16 82 3	7 5 14	2 1 0	5 0 5	0. 05	0. 36	1 8	1. 6	2 0	0. 03	1 7	0. 54	0 8	0	8 1	1 8	8 4	1 3	7 3	1 1	7 1	1 8	1 9	0 2
A1	36 52 4	1 6 0	1 5 4	2 0 6	0. 11	0. 27	1 8	1. 0	2 2	0. 03	1 9	0. 55	1 3	0	8 0	1 3	8 3	1 1	7 2	1 2	7 8	1 3	2 7	0 1
A1	25 93 5	1 1 3	1 0 9	2 0 4	0. 18	0. 04	1 8	1. 6	2 3	0. 03	1 9	0. 54	1 3	0	7 9	1 3	7 9	1 3	7 9	1 3	7 9	1 8	3 1	0 0
A1	80 66 6	3 2 1	5 8 6	4 0 9	0. 05	0. 30	2 8	1. 2	2 9	0. 04	2 1	0. 55	0 7	0	8 0	2 5	8 5	1 1	7 9	1 2	7 6	1 9	1 3	0 2
A1	32 68 7	1 5 4	2 2 0	4 0 2	0. 10	0. 17	1 7	1. 9	2 1	0. 03	1 9	0. 56	1 2	0	7 8	1 3	7 7	1 2	7 9	1 2	7 9	1 9	2 5	0 0
Lueshe (RGM 9673)	51 11 8	2 3 6	2 0 4	2 0 4	0. 09	0. 13	1 8	1. 3	2 1	0. 04	1 6	0. 55	1 1	0	8 6	1 3	8 2	1 2	7 8	1 2	7 8	1 9	1 3	0 2

^b U and Pb content and Th/U ratio were calculated relative to GJ-1 reference zircon.

^c percentage of the common Pb on the ²⁰⁶Pb.

b.d. = below detection limit.

^d corrected for background, within-run Pb/U fractionation (in case of ²⁰⁶Pb/²³⁸U) and common Pb using Stacy and Kramers (1975) model Pb composition and subsequently normalised to GJ-1 (ID-TIMS value/measured value), ²⁰⁷Pb/²³⁵U calculated using $\frac{^{207}\text{Pb}/^{206}\text{Pb}}{(^{238}\text{U}/^{206}\text{Pb} * 1/137.88)}$

^e rho is the $\frac{^{206}\text{Pb}/^{238}\text{U}}{^{207}\text{Pb}/^{235}\text{U}}$ error correlation coefficient.

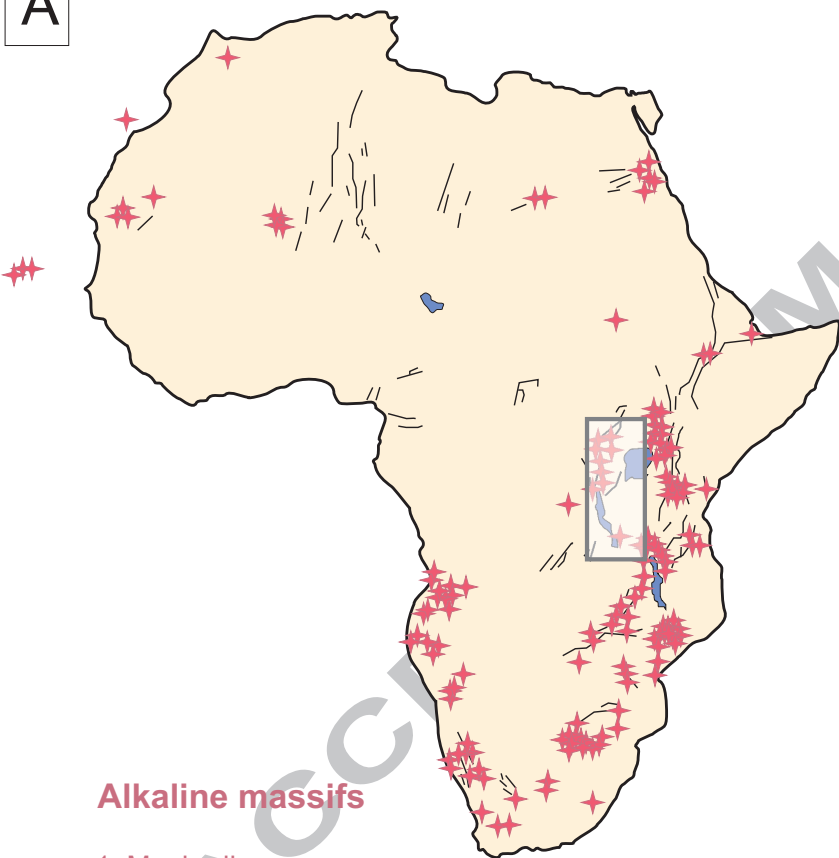
^f degree of concordance = $\frac{^{206}\text{Pb}/^{238}\text{U} \text{ age}}{^{207}\text{Pb}/^{206}\text{Pb} \text{ age}} \times 100$

^g Accuracy and reproducibility was checked by analyses of Plesovice zircon and Ice River perovskite.

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Sample	Description	$^{87}\text{Rb}/^{86}\text{Rb}$	$^{87}\text{Sr}/^{86}\text{Sr}$ (i)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$ d(i)	$\epsilon\text{Nd}(i)$
Matongo carbonatite (Demaiiffe, 2008)							
Gi3-ITS4/84-87m	sövite II	0.0016	0.70314	0.0784	0.512273	0.511913	5.2
Gi2-S3/147	sövite II	0.0134	0.70311	0.0802	0.512233	0.511865	3.1
Gi12-S5/121.5m	sövite II with apatite	0.0001	0.70306	#N.A.	#N.A.	#N.A.	#N.A.
Gi1-S2/171-172m	sövite II with apatite and px	0.0071	0.70294	0.0725	0.512273	0.511940	4.6
Gi10-S6/155-156m	sövite II with apatite and px	0.0024	0.70357	#N.A.	#N.A.	#N.A.	#N.A.
Gi11-S8/56m	px and apatite cumulate	0.0061	0.70344	0.0733	0.512052	0.511716	0.2
Gi16-S3/121m	ferrocarbonatite "late" hydrothermal	0.0066	0.70321	0.0790	0.512205	0.511843	2.7
Gi17-S7/91-95	carbonatite	0.0268	0.71425	0.8398	0.513487	0.509634	-44.0
Gi5-ITS3/291	kfs-fenite	0.4031	0.70280	#N.A.	#N.A.	#N.A.	#N.A.
Gi14-ITS4/150	kfs-fenite	0.0938	0.70350	#N.A.	#N.A.	#N.A.	#N.A.
Gi15-S5/104-106	bt-fenite	0.2747	0.70400	0.0932	0.512303	0.511875	3.3

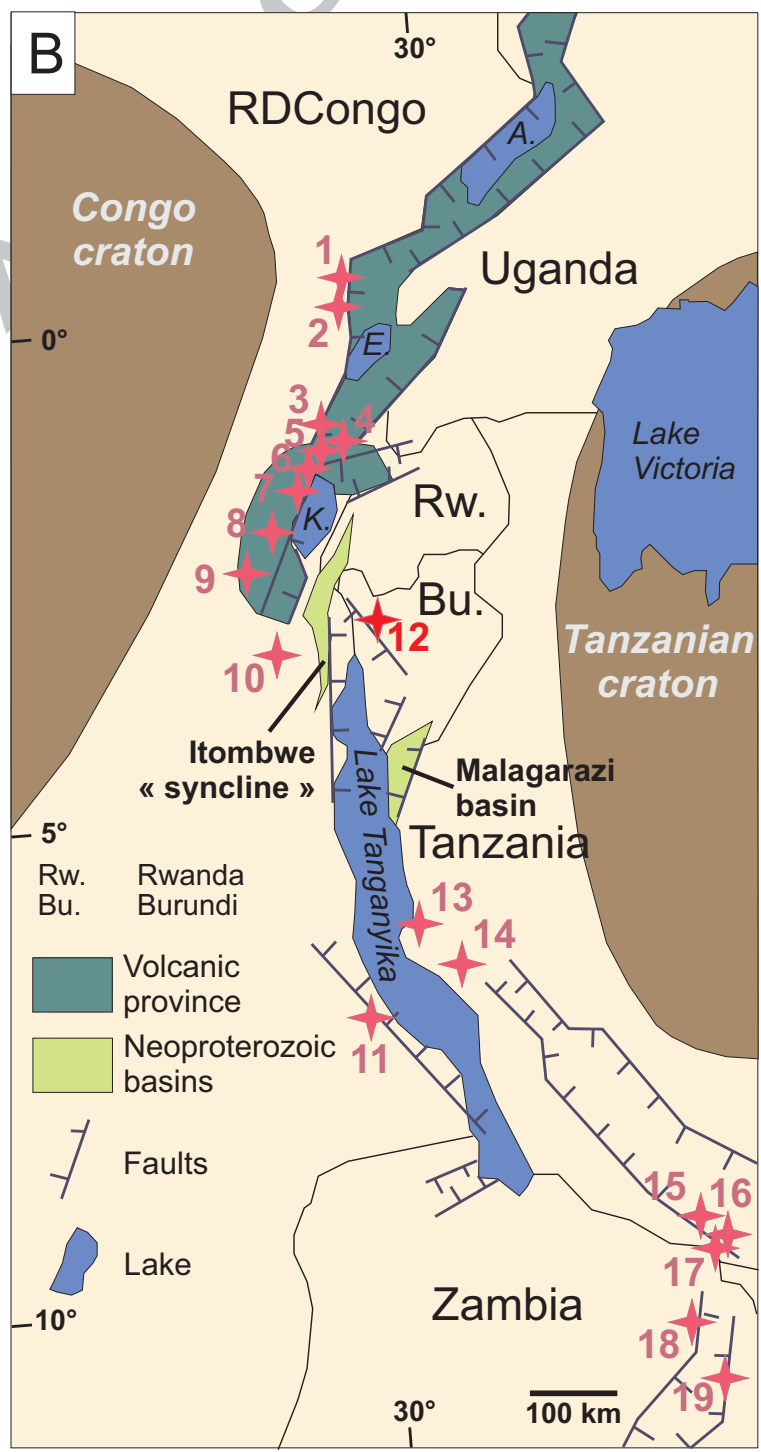
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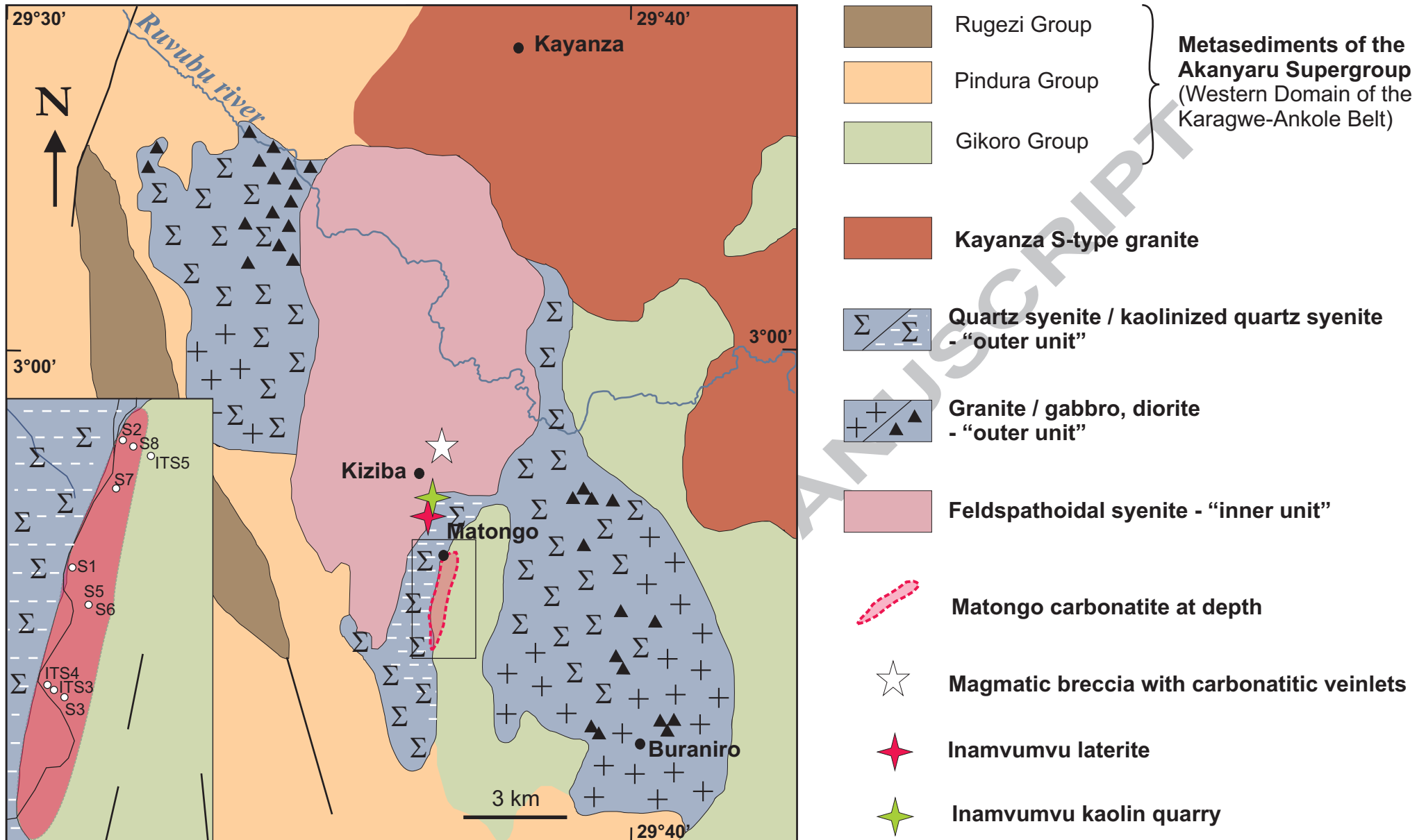


Alkaline massifs

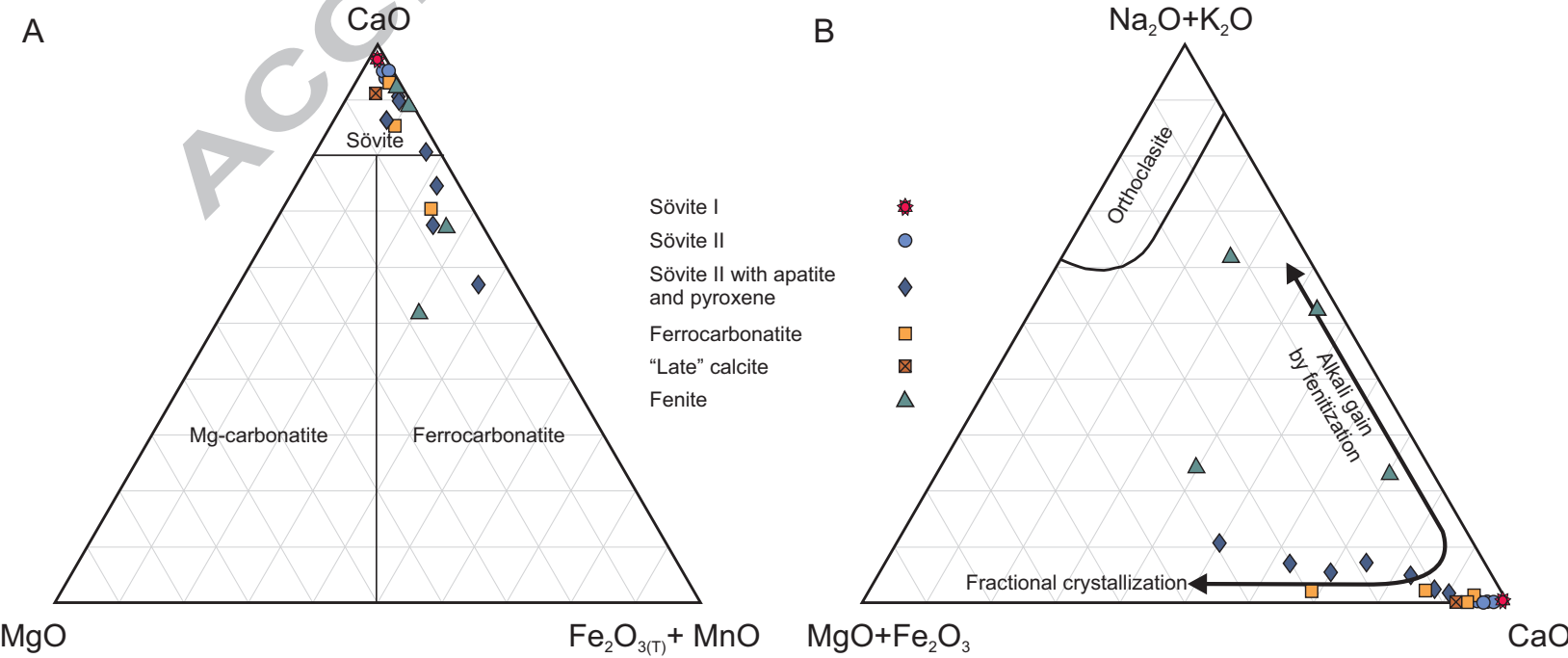
- | | |
|----------------------|--------------------------|
| 1. Monbadio | 11. Kalolo-Lusaka |
| 2. Bingo - Mont Home | 12. Upper Ruvubu-Matongo |
| 3. Lueshe | 13. Lugusu |
| 4. Kirumba | 14. Sangu-Ikola |
| 5. Bishusha | 15. Mbozi |
| 6. Rusongati | 16. Nachendezwaya Hill |
| 7. Numbi | 17. Songwe-Ilomba Hill |
| 8. Kahuzi | 18. Nkombwa Hill |
| 9. Biega | 19. Mivula |
| 10. Miki | |

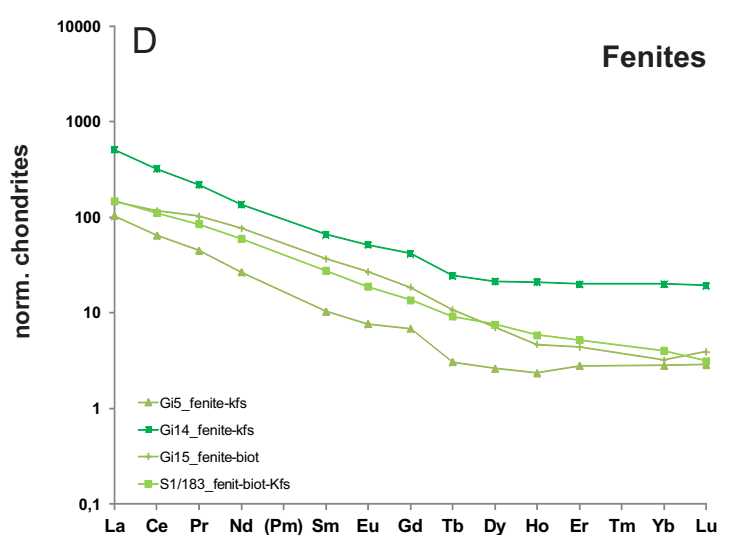
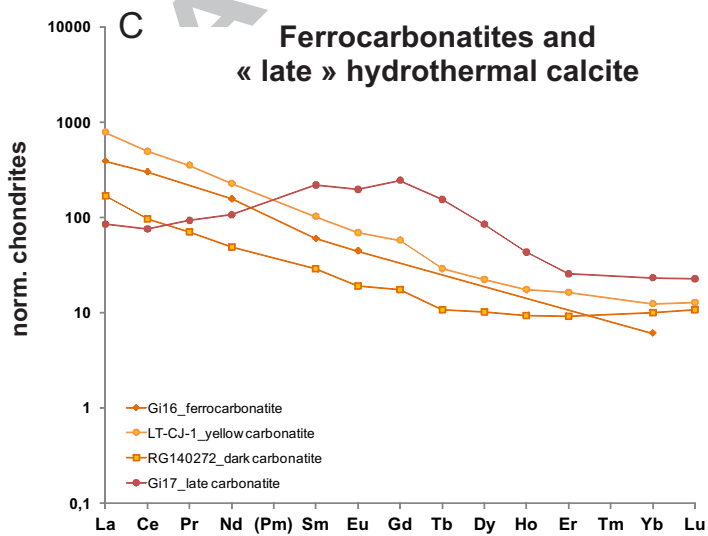
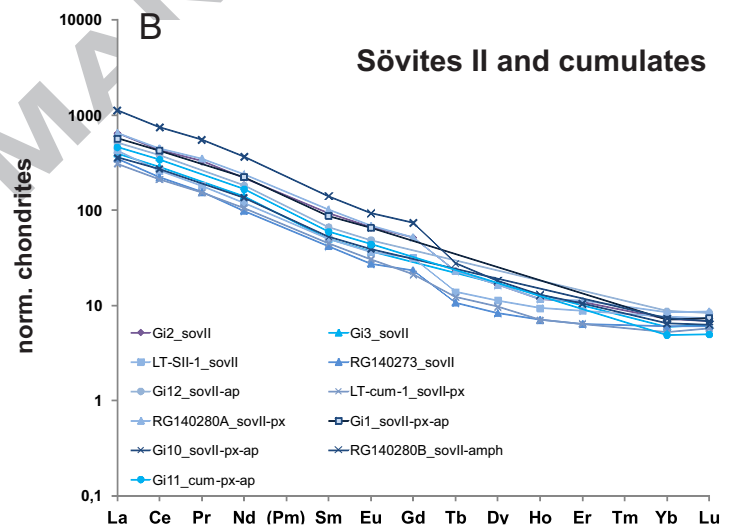
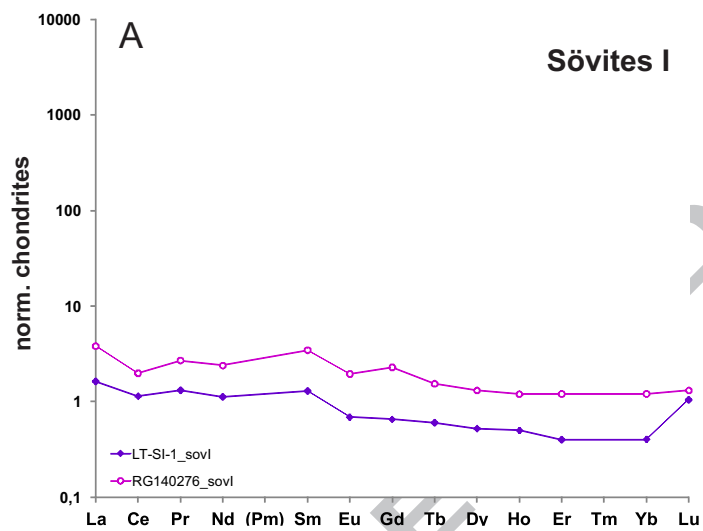
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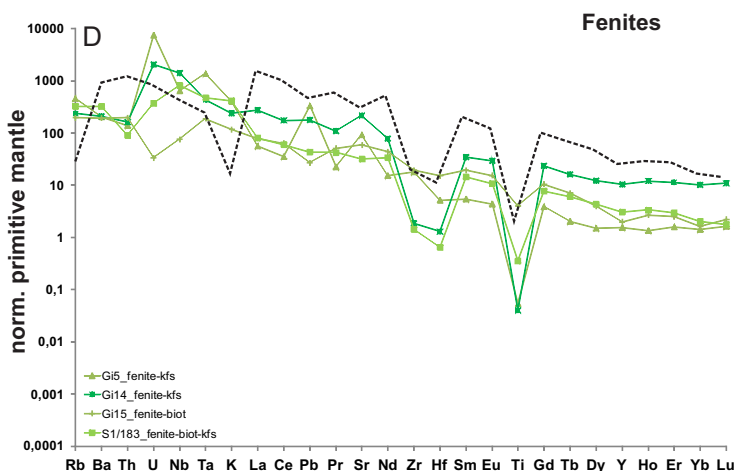
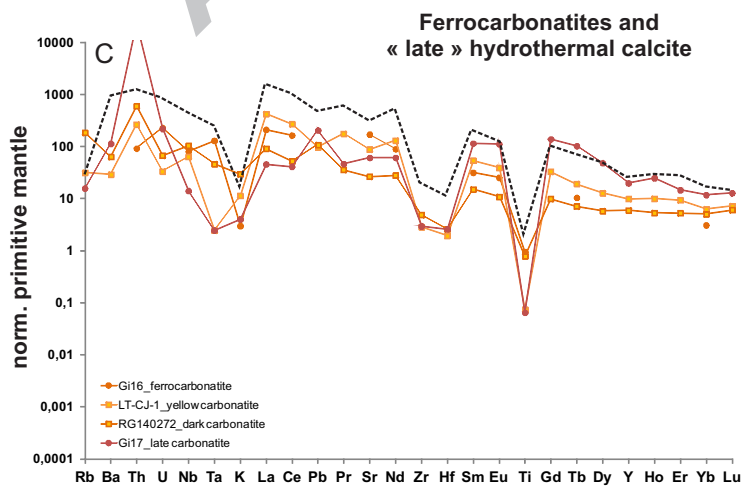
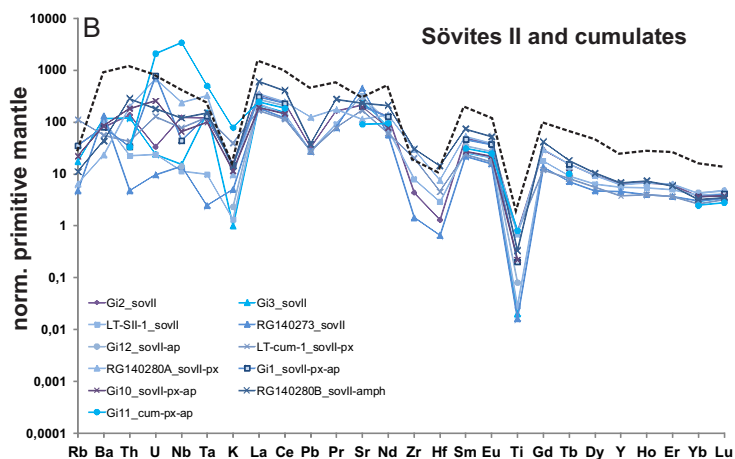
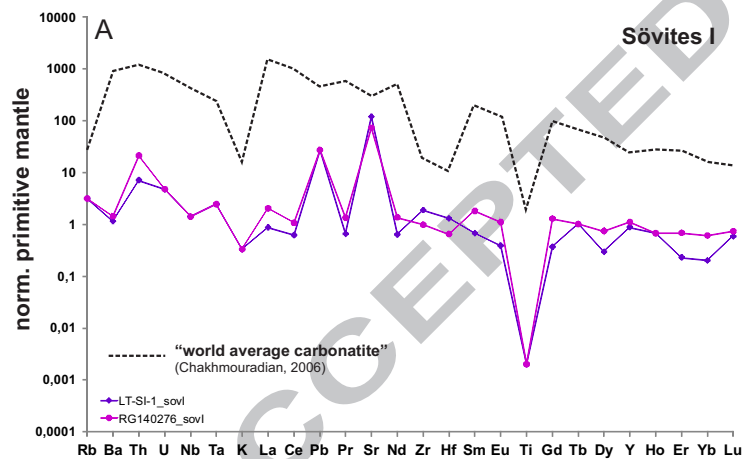


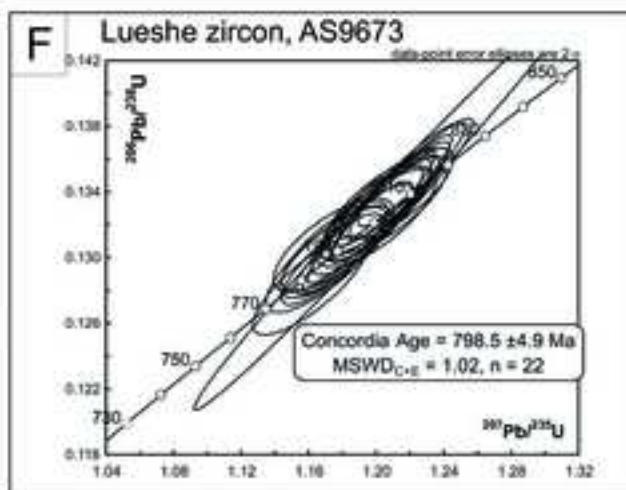
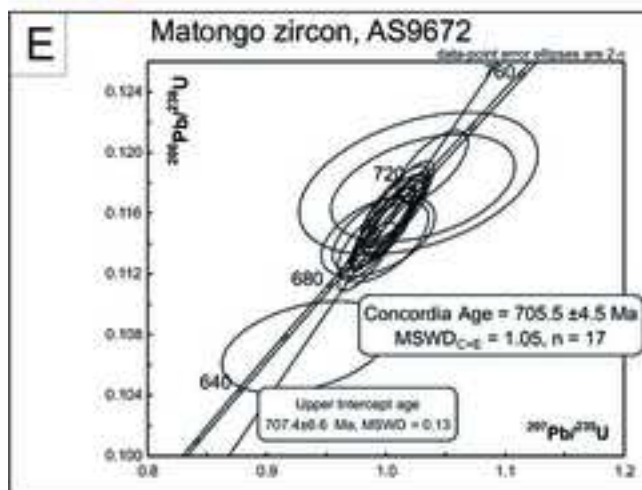
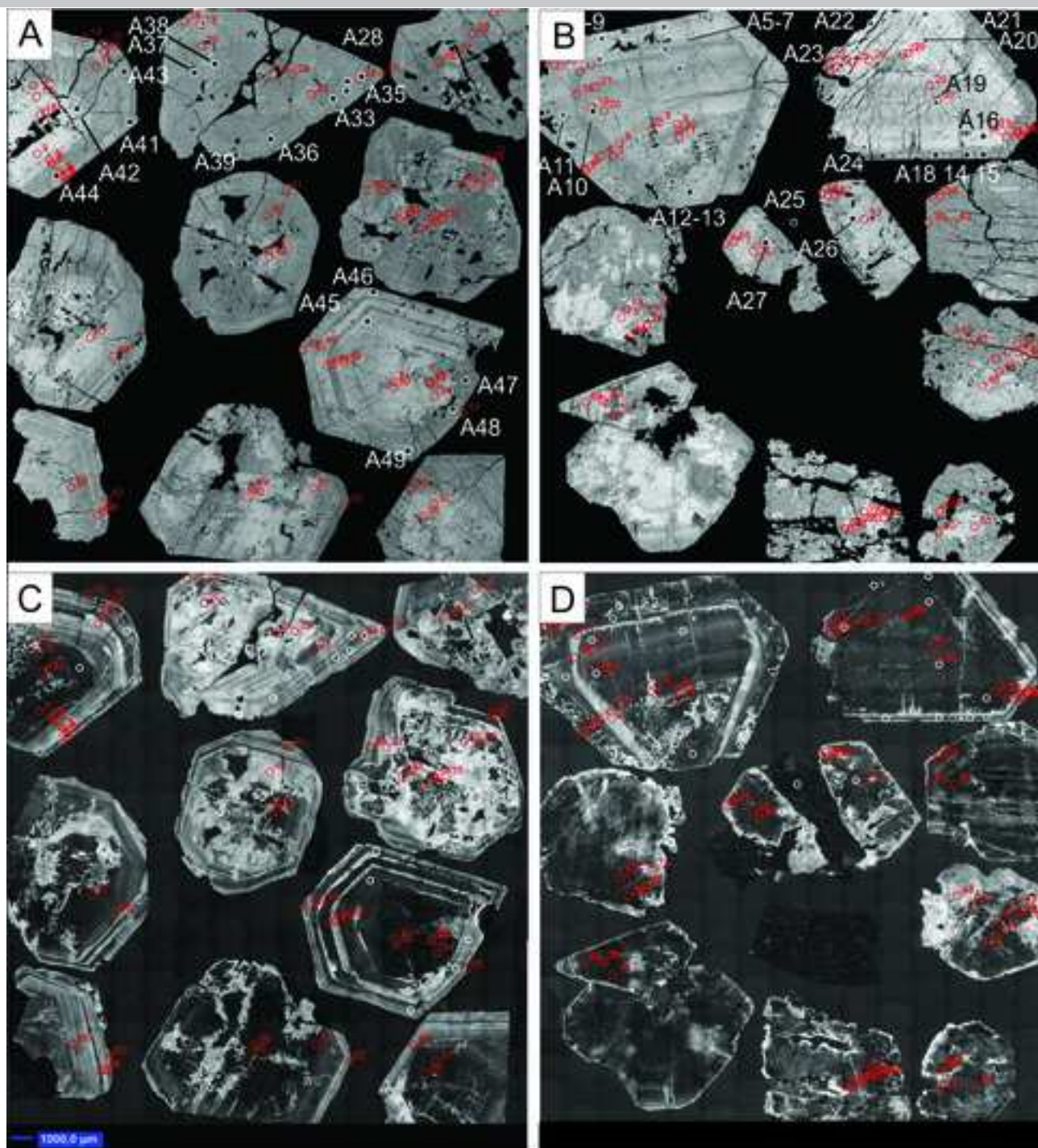


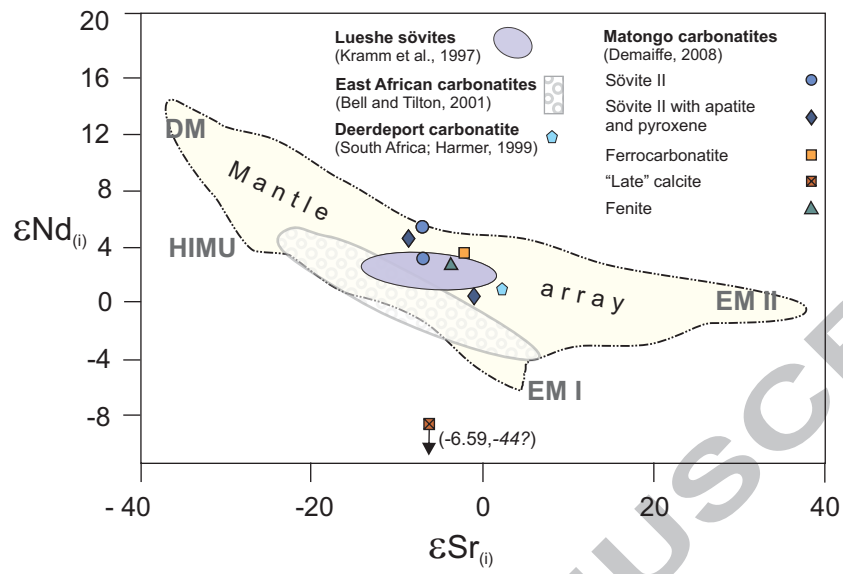


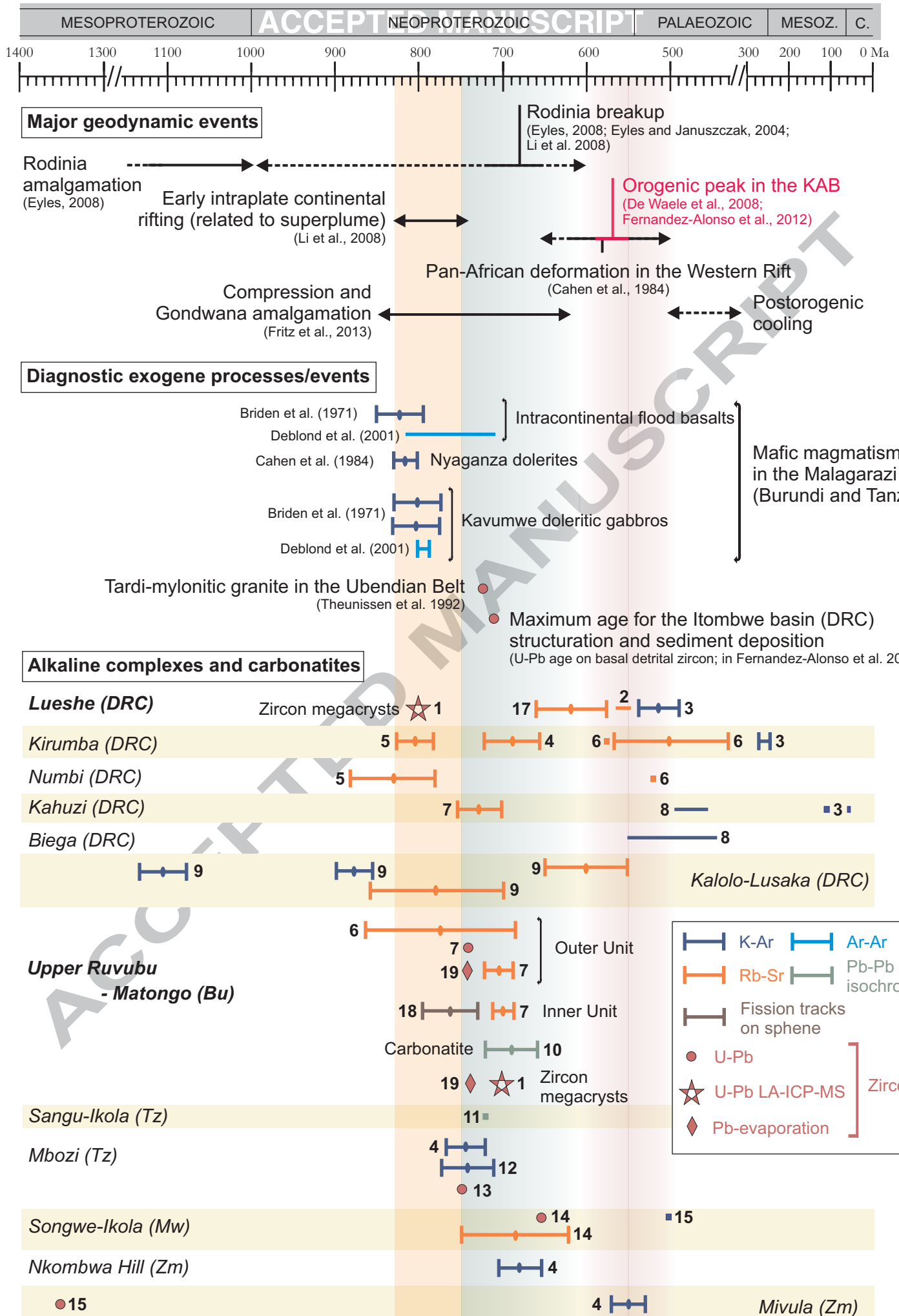












- This study focuses on a Neoproterozoic carbonatite in Burundi, Central Africa
- Petrographic and geochemical data allow determining several carbonatite facies
- LA-ICP-MS U-Pb ages have been performed on zircons from the carbonatitic system
- These ages could suggest that the carbonatite emplacement related to the Rodinia breakup

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