Tectonic setting of kimberlites

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A B S T R A C T

Kimberlites can be viewed as time capsules in a global plate tectonic framework. Their distribution illustrates clustering in time and space. Kimberlite ages span the assembly and break-up of a number of supercontinents, such as Rodinia and Gondwana. These supercontinents show time lines with (i) broad periods devoid of kimberlite magmatism corresponding to times of continent stability, and (ii) narrow kimberlite emplacement windows corresponding to times of fundamental plate reorganizations. This episodicity implies that kimberlite emplacement events are intrinsically related to particular stages in the life cycle of supercontinents. The onset of kimberlite magmatism is closely associated with thermal perturbations (thermal insulation, mantle upwelling?) beneath a stagnant or sluggish supercontinent. These perturbations may have caused uplift and the onset of continental break-up through fracture zones propagating into the supercontinent. Subsequent spreading and ocean floor development is marked by apparent cusps and jogs in plate motion paths. Resultant strain is accommodated along trans-lithospheric corridors with episodic uplift and erosion and focused kimberlite melt migration. The corridors are manifest as discontinuities in the lithosphere mantle, measured as geophysical gradients and as changes in mantle lithosphere composition. Within the crust, these corridors are expressed as (a) terrane boundaries, (b) incipient continental rifts, (c) fracture zones, or (d) major dyke swarms. Some kimberlite populations are clustered along parallel sets of corridors widely distributed across a large part of a subcontinent and repeated magmatism is seen within many of the clusters. The association of kimberlite occurrences with discontinuities may be ascribed to favorable conditions for melt production and to resultant melt focusing along high strain zones that contain fractures and faults. Such conditions may be attained during different stages in the evolution of continents: (a) supercontinent formation; (b) incipient rifting (driven by far-field stresses?) and onset of continental break-up; and (c) strain accommodation along the continental continuation of oceanic fracture zones during spreading. Type (c) may show concomitant kimberlite magmatism in separate continents after break-up.

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1. Introduction

Kimberlites are part of a suite of volatile-rich, high-MgO, ultrabasic rocks (kimberlites, sensu lato). These ultrabasic rocks include potentially diamondiferous members such as kimberlites and olivine lamproites and superficially similar but uneconomic rocks such as melnoites and carbonatites (e.g., Mitchell, 1995; Chakhmouradian et al., this issue; Nielsen et al., this issue).

Kimberlite ages span the assembly and break-up of a number of supercontinents from the Neoarchean to the Cenozoic Eras, the younger of which are Rodinia and Gondwana. Kimberlite occurrences are found on all continents, and in a variety of geological settings emplaced as small volcanic pipes, sills or dykes (Fig. 1). Amongst these, the diamondiferous members are generally restricted to cratons, shields or mobile belts and underlain by thick subcontinental lithosphere mantle (SCLM; Clifford, 1966; Janse, 1991).

The lowermost part of the SCLM is “a complex, chemically active zone where depleted mantle lithosphere is injected and metasomatised by small-volume melts sourced from the adjacent fertile, adiabatic, convecting mantle asthenosphere” (O'Reilly and Griffin, 2006). General agreement exists about the source region for the Group 2 kimberlites in South Africa (metasomatised mantle lithosphere peridotite, e.g., Le Roex et al., 2008), but opposing views persist in the case of the Group 1 kimberlites, with models ranging from sub-lithospheric sources (e.g., Nowell et al., 2004; Paton et al., this issue; Pearson et al., 2008; Brey et al., this issue) to deep lithospheric sources (e.g., Le Roex et al., 2003; Becker and Le Roex, 2006).

Differing models have also been proposed for the trigger of kimberlite melt formation, including (a) enhanced mantle plume activity producing hotspot tracks with kimberlite age migration (e.g., Morgan, 1983; Le Roex, 1986; Skinner, 1989; Heaman and Kjarsgaard, 2000), (b) subduction of oceanic lithosphere and partial melting of...
overlying mantle producing traces of deep-seated subduction (e.g., Helmstaedt and Gurney 1984; McCandless 1999), (c) thermal perturbations associated with tectonic events involving lithospheric faults formed or reactivated during break-up of continents with strain localization and melt focusing (e.g., Dawson, 1970; Marsh, 1973; Sykes, 1978; Bailey 1992; White et al., 1995; Jelsma et al., 2004; Moore et al., 2008), or (d) multiple origins (e.g., Heaman et al., 2004).

In this study spatial and temporal data for kimberlites from Southern Africa are compared with the lithosphere anisotropy and surface geological features. We will discuss the setting of kimberlite magmatism within a global tectonic context and outline different tectonic environments in which kimberlite melts are formed, that may help elucidate their origins.

2. Temporal and spatial constraints

Over time, continents show alternating periods set apart either by abundance or scarcity of kimberlite magmatism. Heaman et al. (2003) noted a 110 Ma period of absence of kimberlite activity between 360 Ma and 250 Ma worldwide. In Southern Africa a quiescent period is evident between 500 Ma and 250 Ma, following the assembly of palaeocontinent Gondwana.

Appendix A and Fig. 2 provide an overview of available age data using Southern Africa as an example. The database comprises 195 occurrences representing a wide spectrum of rock types (including 122 kimberlites, 22 melnoites, and 33 carbonatites and syenites), analytical methods (mostly U–Pb zircon and perovskite and Ar–Ar, Rb–Sr and K–Ar mica and whole rock techniques), and precision and accuracy, and is the collective effort of a multitude of researchers during a period of over 30 years. Clustering of ages can be seen during the Mesoproterozoic (1635 Ma, 1330 Ma, 1200 Ma, 1100 Ma), the early Paleozoic (510 Ma, Pan-African), the Mesozoic (240 Ma, 145 Ma, 120 Ma, 85 Ma, 73 Ma), and the Cenozoic (54 Ma and 31 Ma). Some age populations appear to represent a local, short-lived magmatic episode (e.g., 1635 Ma Kuruman event), whereas others are distributed across an entire region (e.g., the Cretaceous 120 Ma and 85 Ma events) and show a wider variation of ages.

Kimberlite preservation depends on the geological environment and on age (younger kimberlites tend to be better preserved compared to older kimberlites, but this is certainly not always the case). This is basically an exhumation and burial account. Over 1 km of erosion off-the-top of a typical kimberlite pipe removes most of the crater- and diatreme-facies components, and therefore lowers the likelihood of discovery. Burial of kimberlites beneath a syn- or post-emplacement sedimentary cover sequence temporarily preserves the kimberlites. Following burial, the kimberlites may (or may not) be re-exhumed during subsequent erosion.

In space, the continents are transected by sets of systematic lineaments or mega-lineaments that are considered to be corridors of
Fig. 3. Distribution of kimberlites in Southern Africa. (a) Digital elevation model (90 m SRTM) with ocean floor bathymetry. Note the blocky rectilinear coastline of the subcontinent. (b) Geological of Southern Africa (Jelsma et al., 2004), with superimposed kimberlite age data (Table 1). (c) Structural elements mapped from geological, geophysical, remotely sensed and elevation data and extent of Permo-Triassic Karoo basins (rift and sag) and recent earthquake locations (source: USGS, 1973-2008, M=1.5).
concentrated, aligned tectonic activity. Fig. 3 shows the distribution of kimberlites in Southern Africa with the major crustal structural elements. These structures occur as lineaments visible on digital elevation models, high resolution satellite (or aerial photo) imagery, and on geophysical datasets or geological maps. They are marked by changes in drainage and vegetation patterns, fault-line valleys or scarps, density of linear photo-anomalies and breaks and displacements of geophysical anomalies (gravity, magnetic, seismic and resistivity features). Many of these lineaments are associated with zones of neo-tectonic faulting (e.g., faulting of escarpments, faulting of dune patterns in Namibia and Botswana, drainage system reorientations, etc.) and current (low magnitude) seismic activity.

Some of these lineaments are lithosphere-scale structural corridors that formed focal areas for magmas and fluids ascending from the mantle. These corridors are manifest as anisotropies associated with gradients in the SCLM, measured by seismic velocity, seismic anisotropy, resistivity, potential field and/or compositional heterogeneities (e.g., Fouch et al., 2000; Jaques and Milligan 2004; Jones and Craven 2004; Snyder et al., 2004; O’Reilly and Griffin 2006). Within the crust, these corridors are expressed as (a) terrane boundaries, (b) incipient continental rifts, (c) fracture zones, either as the continental continuation of oceanic fracture zones or as associated accommodation zones, or (d) major dyke swarms. On a regional scale, the distribution of kimberlites is typically clustered along these trans-lithospheric corridors. An association is apparent between kimberlites and tips or shoulders of rifts, major pre-existing dyke swarms, and bends, step-overs and fault intersections within structural corridors. Many corridors have been repeatedly reactivated over time, suggesting they are through-going fundamental “flaws” within the continental architecture, and “pathways” for kimberlite magmas.

In Southern Africa, a strong association was noted (a) between Jurassic-age kimberlites and ENE–WSW and NNW–SSE trending corridors and (b) between Cretaceous-age kimberlites and NE or NW trending corridors (e.g., Jelsma et al., 2004). Similar lithosphere trends are observed as anisotropies associated with the cratonic keel (James et al., 2001), craton edges and marginal orogenic belts (Fig. 3b), the Permo-Triassic Karoo Rift System (Fig. 3c; Catuneanu et al., 2005) and the Cenozoic East Africa Rift System (Fig. 3c), as well as recent earthquake loci (Fig. 3c; cf. Dirks et al., 2003). Both corridor systems are directly related to the break-up of Gondwana and the continuation of oceanic fracture zones into the African continent. For instance, the Jurassic corridor trends were imprinted on the continent during the separation of West and East Gondwana and the opening of the Somali Basin and the Weddell Sea along NNW–SSE trending fracture zones (such as the Davie Fracture Zone); the Cretaceous corridor trends during the separation of South America and Africa with the opening of the South Atlantic. Similar examples can be found elsewhere. The corridors are expressed by, respectively, the blocky rectilinear outline of segments of the coastline of east Africa (Somalia–Kenya–Tanzania–Mozambique–South Africa) and southwest Africa (Namibia and Angola), visible on digital elevation models. Some of these corridors have older origins, such as the well-described ENE–WSW trending Thabazimbi–Murchison Lineament and Zoetfontein Fault in South Africa, the NE–SW trending Omaruru–Omatako Lineament in Namibia and the NE–SW trending Quilenges–Andulo Fault Zone in Angola.

The ENE–WSW trending Zoetfontein Fault is a high angle fault zone that marks the northern edge of the Kaapvaal Craton and has a history of repeated reactivation since the late Archean and continuing to the present. It controlled deposition of both the Mesoproterozoic Waterberg and Carboniferous–Jurassic Karoo sediments and basalts. The Thabazimbi–Murchison Lineament to the south marks the zone of accretion between the Witwatersrand Block and the Northern Domain of the Kaapvaal Craton and has shown 2700 Ma of episodic
deformation (Good and de Wit, 1997). The Omaruru–Omatako Lineament is a prominent and long-lived NE–SW trending fault zone that has displaced Karoo basalts and members of the Karoo-age Okavango dyke swarm. It controlled deposition of Cretaceous sediments and is still seismically active. The basement-cover basal Cretaceous surface shows a marked step across this structure. Neotectonic activity is indicated by linear depressions and displacement and erosion of dunes. Towards the Atlantic coast the structure is associated with complexes of carbonatites and syenites. The NE–SW trending Quilenges–Andulo Fault Zone in Angola has a strike length of over 400 km between the towns of Quilenges and Andulo and has a width of 90 km (De Boorder 1982). It is a composite set of discontinuous faults that are deep-seated and associated with carbonatites and kimberlites. The fault zone is along strike with the Lucapa “Graben” in northeastern Angola. The latter was active during the Palaeoproterozoic, the Permo-Triassic, the Cretaceous and the Cenozoic (with neotectonic faulting and associated earthquake activity). It can be traced to the southwest to one of the transfer zones of the South Atlantic Ocean (Sykes, 1978).

Fig. 4 shows the orientation data for major faults as well as the spatial distribution of kimberlites at a local scale (<40 km) and a regional scale (40–250 km) using autocorrelation. Note the marked similarity between fault orientations and the inter- and intra-cluster kimberlite spatial distribution. On a local scale, many of the kimberlites are composites of multiple emplacement stages with dykes commonly acting as precursors to subsequent eruptive events, such as observed at Finsch and Kimberley mines (Barnett and Preece, 2002; Dawson, 1970). Circular pipes are frequently found at the intersection of kimberlite dyke trends and other structures such as dolerite dykes or faults. A key feature however is a frequently found at the intersection of kimberlite dyke trends and other structures such as dolerite dykes or faults. A key feature however is a commonality of orientations is observed within a cluster but also across several clusters (for example, Finsch and Kimberley clusters) within a continental domain and implies a regional tectonic control on kimberlite emplacement. If we assume that the orientation of dykes and elongated pipes best reflects the orientation of maximum compressive stress (e.g. Nakamura, 1977), this orientation may have changed from NE–SW during emplacement of the c. 120 Ma kimberlites to NW–SE to WNW–ESE during emplacement of the c. 85 Ma kimberlites.

The NW–SE to NNW–SSE orientations may relate to the Wegener Stress Anomaly (WSA) described by Andreoli et al. (1996). This anomaly extends over the western parts of Southern Africa and was probably attained in the Mid Cretaceous (ca. 100 Ma). A compilation of stress tensors measured on mines suggests that the NW–SE stress orientation is still currently active (Stacy and Wesseloo, 1998). It is possible that the WSA existed prior to the opening of the South Atlantic, based on coast-parallel mafic dyke orientations (132 Ma False Bay Swarm, Reid et al., 1991), and weakened at various times, such as during the emplacement of the c. 120 Ma kimberlites (Andreoli et al., 1996).

3. Bottom-up or top-down?
The Jurassic–Cretaceous kimberlites in Southern Africa are clustered along sets of parallel lineaments widely distributed across a large part of the subcontinent, with the younger groups found closer towards the continent margins (Fig. 6). The linear distribution in South Africa has been used as an argument for a mantle plume hot spot track (e.g., Skinner 1989). However, similar-age magmatism can be seen over vast areas, such as shown by the 120 Ma and 85 Ma age populations, each covering areas of in excess of 2000 km by 1000 km. Repeated magmatism is observed in many clusters (Appendix A; Fig. 3b), such as Kimberley (119 Ma, 85 Ma), Sutherland (120 Ma, 74 Ma), Klipspringer (148 Ma, 74 Ma), and Luxinga/Alto Cuido (135 Ma, 115 Ma). Parallelism of same-age “kimberlite “tracks” and repeated magmatism at the same sites suggests emplacement along structural discontinuities rather than an association with hotspot tracks. Systematic younging of kimberlites between 70 Ma (E) and 46 Ma (W) in the western part of South Africa and in Namibia probably reflects strain propagation and melt migration along fracture zones, associated with the opening of the South Atlantic Ocean.

Table 1 compares the timing of kimberlite magmatism with major events affecting Gondwana. Kimberlite emplacement age windows coincide with: (i) apparent cusps (variation in direction) and jogs (variation in velocity) in the relative plate motion paths of continents (Africa–Eurasia, Africa–Antarctica), based on a fit of seafloor magnetic anomaly isochrons with oceanic FZ traces and on the construction of apparent polar wander paths from palaeomagnetic data (but note that data points are few and far apart); (ii) stages of uplift and erosion, and the formation of unconformities in the offshore and onshore stratigraphic record documenting episodic tectonic instability (cf. Jelsma and Smith, 2004; Moore et al., 2008); (iii) Large Igneous Province (LIP) manifestation. Marsh (1973) and Hargraves and Onstott (1980) already noted the synchronicity of kimberlite ages and changes in Apparent Polar Wander curves. In Hargraves words, “these

Fig. 4. Fault orientations and kimberlite spatial distribution in Southern Africa. Major faults (N = 818, mapped from Landsat, SRTM) show dominant orientations at 055° and 150° (a), Autocorrelation on kimberlite distributions (irrespective of age, N = 2173) within clusters (0–40 km) shows preferential NW–SE alignment (b) and between clusters (40–250 km) 053°, 078° and 145° trends (c).
relationships suggest that the emplacement of kimberlites may coincide with episodes of changes in the direction of plate motions. Jelsma et al. (2004) and Moore et al. (2008) linked kimberlite magmatism to changes in the direction and velocity of plate motion.

Kimberlite age data for “Laurasia” and West Gondwana are shown in Fig. 7. Members within each of these supercontinents (e.g. Southern Africa and South America in West Gondwana) show similar age peaks, reflecting a common history, but different peaks are visible when members across the two supercontinents are compared. For instance, the 370 Ma reconstruction shows continent break-up and associated kimberlite magmatism affecting Siberia, and continent stability and lack of kimberlite magmatism in Southern Africa and South America. In North America Jurassic kimberlite magmatism follows the break-up of Pangea with the opening of the Atlantic and the eruption of the Central Atlantic Magmatic Province at 200 Ma. In Southern Africa, kimberlite magmatism follows (1) the break-up of West and East Gondwana with the opening of the Weddell Sea and Somali Basin and the eruption of the Karoo–Ferrar basalts at 180 Ma, (2) the break-up of South America and Africa with the opening of the South Atlantic and the eruption of the Parana–Etendeka basalts at 135 Ma. Kimberlite magmatism is marked by a number of distinct peaks. At 135–115 Ma, seafloor spreading in the South Atlantic causes rifting of Africa and South America and is accompanied by a major peak in kimberlite magmatism. The subsequent peak at 95–80 Ma is marked by concomitant magmatism in Southern Africa and South America, after continental break-up, and heralds major plate reorganization.

The temporal association between Large Igneous Province magmatism (the Karoo–Ferrar Province at 180 Ma, the Parana–Etendeka Province at 135 Ma and perhaps the Reunion Province at 85 Ma) and the coinciding and subsequent main pulses of kimberlite magmatism (180–145 Ma, 135–115 Ma, 95–80 Ma) is significant. Sears (2001) proposed that the stalled Gondwana supercontinent “drove its own break-up by insulating the underlying mantle, causing thermal expansion, and uplift, fracturing and associated LIP magmatism”. Using compilations of data from xenoliths and xenocrysts, Bell et al. (2003) and Griffin et al. (2000) presented evidence for a protracted thinning and heating event during the Jurassic that affected Southern Africa. Geochemical imaging of the SCLM by Kobussen et al. (2008) has demonstrated marked changes between time slice sections for the Group 2 kimberlites (143–117 Ma, listing their age grouping) and the Group 1 kimberlites (108–74 Ma, ibid.) across the SW Kaapvaal craton boundary. The work shows that the SCLM was heated and chemically refertilised by infiltrating asthenosphere-derived melts, thinning the SCLM layer in the order of 40 km. The authors attribute this event to changes in the stress field associated with the opening of the South Atlantic Ocean, or to mantle upwelling. The regional extent of this thermal event is poorly constrained. Seismic tomography (James et al., 2001 — Kaapvaal Seismic Program) showed no pervasive thermal erosion of the mantle root beneath the interior parts of the Kaapvaal Craton.

4. Discussion

Experimental modeling by O’Neill et al. (2005) helps to explain some of the observations and interpretations, in particular the importance of discontinuities in the lithosphere mantle and the role of plate motions in creating or reactivating discontinuities. The authors modeled sub-lithospheric melt production and showed that the geometry of the continental keel plays a critical part in determining both location and extent of partial melting as well as time-dependent thermal perturbations in particular in proximity to craton margins and gradients of the lithosphere–asthenosphere boundary. Beneath thick cratonic lithosphere a thermal upwelling or mantle plume will only produce a small volume of melt, unless volatiles are introduced to the system. Significant volumes are only generated once hot upwelling material has advected around the thick
root zone into regions of thinner lithosphere. The modeling showed the importance of large stress gradients on craton boundaries and other lithospheric discontinuities in localizing strain and focusing (kimberlite) melt migration in these areas.

The association of kimberlite occurrences with trans-lithosphere discontinuities may be ascribed to favorable conditions for melt production as a result of thermal perturbations (thermal insulation, mantle upwelling?) and to resultant melt focusing along networks of faults. Such conditions may be attained during different stages in the evolution of continents (Fig. 8).

Type A — Supercontinent formation. Emplacement of kimberlites follows the assembly of continental fragments into a supercontinent (such as Rodinia or Gondwana). Examples include 1100 Ma kimberlites in Zimbabwe (Mwenezi cluster) and India (Narayanpet and Wajrakarur clusters) and 520 Ma kimberlites in Southern Africa (Venetia, The Oaks, Sese, Colossus, Uitkomst clusters). In Southern Africa, the 1100 Ma kimberlite event may be linked to the emplacement of the Umkondo LIP (Hanson et al., 1998), following accretionary events along the southern and eastern margins of the Kaapvaal Craton within the Namaqua–Natal orogenic belt. In India, a similar association may be made between concomitant kimberlite magmatism, a thermal anomaly beneath the eastern Dharwar Craton and tectonic events that took place along the eastern margin of the Dharwar Craton with the Eastern Ghat Mobile Belt. The 520 Ma kimberlites in Southern Africa define a broad ENE–WSW trending lineament that parallels the Pan-African age Damaran Orogenic Belt to the north. In all examples given, these events may be linked to the formation of large-scale mantle thermal anomalies following orogenic events, perhaps as a result of late-stage thermal relaxation following collision, with thermal equilibration and resultant partial melting of (sub?) lithospheric mantle and with kimberlite melt migration within the lithosphere focused along reactivated pre-existing structures.

Type B — Incipient rifting. Following a period of supercontinent stability, thermal insulation of the lithosphere beneath a stagnant or sluggish supercontinent or the impact of a hot spot or plume impinging on a supercontinent leads to uplift and the onset of continental break-up. During the initial stages of break-up, a network of rifts and fault zones is formed as a result of extensional or transtensional stresses that propagated into the supercontinent. The Karoo and East Africa Rift Systems in Africa in many places reactivate pre-existing discontinuities. Examples of associated magmatism include kimberlites within the Jwaneng cluster (244 Ma; Smith, 1983) in Botswana, emplaced along a major NE–SW trending Karoo fault zone that forms an accommodation structure between the Zoetfontein Lineament and the Thabazimbi–Murchison Lineament. The Kapamba cluster (240 Ma; Phillips, 1986) in Zambia was emplaced...
Table 1
Time-event chart for Southern Africa.

<table>
<thead>
<tr>
<th>Time (Ma)</th>
<th>Kimberlites “sensu lato”</th>
<th>Events</th>
<th>Plate vector cusps</th>
<th>Sediments unconformities</th>
<th>Hotspot manifestation thermal perturbation</th>
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<tr>
<td>180 Ma</td>
<td>?</td>
<td>Karoo–Ferrar LIP (183 Ma), onset spreading Somali sea (180 Ma?)</td>
<td>183 Ma (180 Ma)</td>
<td>183 Ma: Bouvet (Karoo–Ferrar)</td>
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<tr>
<td>145 Ma</td>
<td>148–141 Ma</td>
<td>West and East Gondwana separate (145 Ma)</td>
<td>145 Ma</td>
<td>Onshore (142 Ma)</td>
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<td>132 Ma</td>
<td></td>
<td>Etendeke–Pasa LIP (137–133 Ma), opening of South Atlantic (133–120 Ma)</td>
<td>135 Ma</td>
<td>Onshore (135 Ma)</td>
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<td>120 Ma</td>
<td>135–115 Ma</td>
<td>Africa and South America, India and Antarctica separate (120 Ma)</td>
<td>128 Ma</td>
<td>5 Atl (127–124 Ma)</td>
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<td></td>
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<td>Development of Central Africa Cretaceous Rift System (118 Ma)</td>
<td>121 Ma</td>
<td>6 Atl (120–118 Ma) and onshore (120 Ma)</td>
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<td>102 Ma</td>
<td>103–101 Ma</td>
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<td>13 Atl (112 Ma) onshore (101 Ma)</td>
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<td>92 Ma</td>
<td>95–83 Ma</td>
<td>India and Madagascar separate</td>
<td>84 Ma</td>
<td>15 Atl (94–91 Ma)</td>
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<td>84 Ma</td>
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<td>16 Atl (86–84 Ma) and onshore (84 Ma)</td>
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<td>72 Ma</td>
<td>76–70 Ma</td>
<td>India and Seychelles separate</td>
<td>65 Ma</td>
<td>85 Ma: Marion, St Helena, 90°East, Comores, Reunion</td>
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<td>65 Ma</td>
<td>65–59 Ma</td>
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<td>Onshore (66 Ma)</td>
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<td>52 Ma</td>
<td>56–50 Ma</td>
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<td>Offshore (54–43 Ma)</td>
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<td>37 Ma</td>
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<td>Offshore (40–37 Ma) and onshore (37 Ma)</td>
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<td>Appendix A</td>
<td>Jelsma et al., 2004</td>
<td>Fairhead and Wilson, 2004; Eagles and König, 2008</td>
<td>McMillan and Dale, 2002; Fairhead and Wilson, 2004</td>
<td><a href="http://www.mantleplumes.com">http://www.mantleplumes.com</a></td>
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within the NE–SW trending Luangwa Rift, at the intersection with a NW–SE trending fault zone. The Kundelungu kimberlites in the DRC (32 Ma; Batumike et al., 2008) are located at the tip of the NE–SW trending Lake Mweru–Luapula graben, which is the southwestern extension of one of the branches of the East Africa Rift System. Individual kimberlites were emplaced at the intersection of NE–SW and NNW–SSE faults. Along the proto-Indian Ocean and proto-Atlantic Ocean margins, continental break-up is associated with thermal

Fig. 7. Kimberlite age data for “Laurasia” (top) and West Gondwana (bottom) with continent reconstructions at 370 Ma and 170 Ma (Torsvik and Cocks, 2003).
eroded mantle lithosphere, and the emplacement of Large Igneous Provinces such as the Karoo–Ferrar Province at 180 Ma (Jourdan et al., 2003), the Central Atlantic Magmatic Province (Hames et al., 2003) at 200 Ma and the Paraná–Etendeka Province at 135 Ma (Erlank et al., 1984). During uplift, the core of the supercontinent, including the cratons, undergoes extensional strain. Pre-existing lithospheric discontinuities are reactivated extending into cratonic domains and shields as fracture zones. Related to this stage are the 135–115 Ma kimberlite populations that include Finsch in South Africa and Catoca in Angola.

Type C — Tectonic triggers. Spreading is in progress and plate motion paths are marked by cusps (variation in direction) and jogs (variation in velocity). Changes in the plate motion may have caused shearing of sub-lithospheric ridges with strain accommodation along lithospheric discontinuities, in this case in particular the continental continuation of oceanic fracture zones. Kimberlites that may be related to this stage are the 95–80 Ma kimberlite populations that include Orapa in Botswana (93 Ma), Kimberley in South Africa (85 Ma) and Kao in Lesotho (89 Ma). Of note is the connected 80 Ma kimberlite populations that include Finsch in South Africa and Catoca in Angola.

5. Conclusions

Kimberlites can be viewed as time capsules in a global plate tectonic framework. They record tectonic events in a changing world, marking stages in the evolution of continents and are collectively key pieces in palaeocontinent reconstructions. The trigger for kimberlite magmatism appears to be related to thermal perturbations (thermal insulation, mantle upwelling?) beneath a stagnant or sluggish supercontinent and associated tectonic change — stress change induced within the continental plate because of supercontinent fragmentation or supercontinent assembly.

Many kimberlites are associated with trans-lithospheric structural corridors. Large stress gradients develop at lithospheric discontinuities during tectonic events leading to strain localization. This would have caused localized decompression melting near the base of the SLM (cf. Vaughan and Scarrow, 2003) or merely focused melt migration paths following the impingement of a coinciding thermal anomaly at the lithosphere–asthenosphere boundary (O’Neill et al., 2005). In contrast, periods devoid of kimberlite magmatism correspond to times of supercontinent stability (a sluggish Gondwana at 500–250 Ma), or apparently smooth plate motion paths.

The three tectonic stages, (a) supercontinent formation, (b) incipient rifting and break-up and (c) tectonic triggers represent specific stages in the evolution of any supercontinent. We have given examples of kimberlites that can be related to Gondwana break-up, but other examples can be provided for other continents.

Variable endowment across continental regions may be related to (a) the chemical composition and physical state of potential kimberlite source areas, (b) a required minimum size of continents to be able to cause effective insulation of the underlying mantle and deflect root zone destructive melt volumes, (c) the size and root geometry of continental (and cratonic) lithosphere in determining melt production (O’Neill et al., 2005), (d) the presence and orientation of anisotropies within continents in localizing strain and kimberlite melt migration and, interlinked, (e) tectonic change.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.lithos.2009.06.030.

References


