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A conceptual model for kimberlite emplacement by solitary interfacial mega-waves on the core mantle boundary

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Abstract

If convection in the Earth's liquid outer core is disrupted, degrades to turbulence and begins to behave in a chaotic manner, it will destabilize the Earth's magnetic field and provide the seeds for kimberlite melts via turbulent jets of silicate rich core material which invade the lower mantle. These (proto-) melts may then be captured by extreme amplitude solitary nonlinear waves generated through interaction of the outer core surface with the base of the mantle. A pressure differential behind the wave front then provides a mechanism for the captured melt to ascend to the upper mantle and crust so quickly that emplacement may indirectly promote a type of impact fracture cone within the relatively brittle crust. These waves are very rare but of finite probability. The assumption of turbulence transmission between layers is justified using a simple three-layer liquid model. The core derived melts eventually become frozen in place as localised topographic highs in the Mohorovicic discontinuity (Moho), or as deep rooted intrusive events. The intrusion's final composition is a function of melt contamination by two separate sources: the core contaminated mantle base and subducted Archean crust. The mega-wave hypothesis offers a plausible vehicle for early stage emplacement of kimberlite pipes and explains the age association of diamondiferous kimberlites with magnetic reversals and tectonic plate rearrangements.

Keywords: Core; D″ layer; Diamonds; Kimberlite; Rogue waves; Ultra low velocity zone (ULVZ)

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1. Introduction

Kimberlites are one of the main source rocks for diamonds, consequently their occurrences within the Earth's crust have been reasonably well documented. However there is still a lack of consensus on their source and transport to a final state location (Foulger and Natland, 2003; Haggerty, 1999), but now enough pieces of the kimberlite puzzle are available to formulate the first complete picture of the unusual life of a kimberlite melt. The mega-wave model introduced here is an attempt to tie all the existing pieces of the kimberlite story together in a cohesive way by means of some basic assumptions and a simple unifying experiment.

In analogy with the idea underlying the Gaia hypothesis (Lovelock, 2003), we assume the whole Earth as one system behaves in a complex manner; the Earth's solid mantle behaves as a fluid primarily through thermally activated creep over geological time, that there is a small percentage of residual silicate in the core; and that the chaos of interactions

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between eddies and swirls in the outer core will eventually permeate the whole planet in some form (Yamitski, 2001; Larsen et al., 1998). This should in theory allow ferrosilicate melt to escape the core and be captured by nonlinear boundary waves in the mantle (mega-wave model). This is a complex process but there exists an overwhelming amount of indirect evidence to support the idea.

Although mantle convection is not usually chaotic (Turcotte, 1997), nonlinear waves along the mantle base would briefly disrupt mantle convection and any linear wave motion along the top of mantle or related boundaries within. Dalziel (2001) and Dalziel et al., 2000 note the upper and lower thermal boundaries of the mantle appear to have been functionally linked since early in the Earth's history. It is proposed that a mechanism for the formation and emplacement of kimberlite melts arises indirectly from periods of instability in the Earth's magnetic dynamo, seen as magnetic inversions (Glatzmaier and Roberts, 2001, 1997; Johnson et al., 1995; Kirdyashkin et al., 2000) in the geological record, the result of 1/*f* noise which characterises the spontaneous rise of systems to a critical state (Bak et al., 1987). Magnetic reversals and the age of kimberlites appear coupled (Dobretsov and Kirdyashkin, 2000; Larson and Olson, 1991) as shown in Fig. 1. Core derived melts related to these reversals

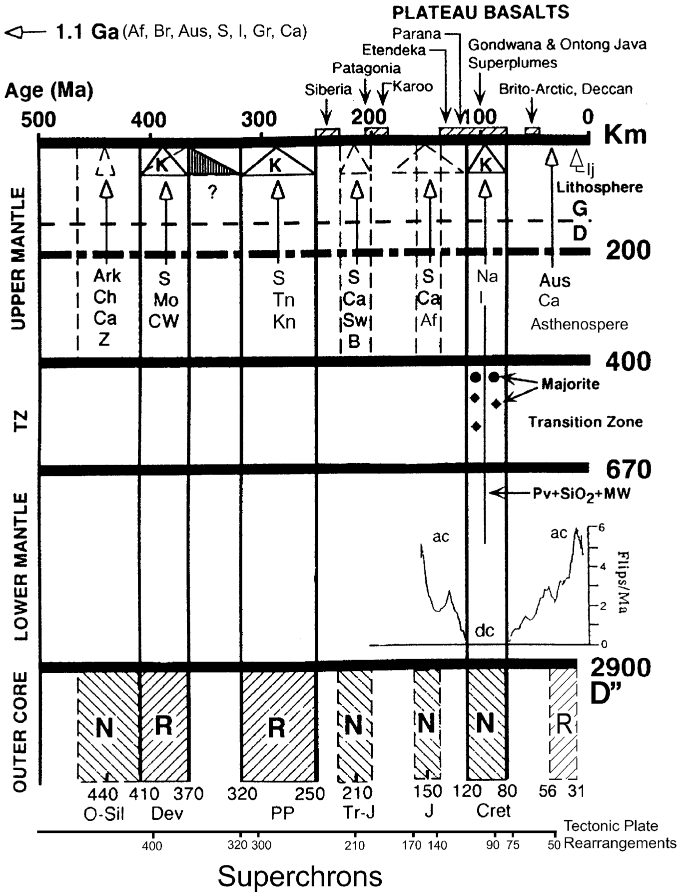

Fig. 1. Orthogonal and schematic cross section of the Earth showing geomagnetic behavior (R: reverse, N: normal) and ages of kimberlite intrusions. Exact polarities seem less important than the change over between reverse and normal behaviour (*proposed* onset of turbulence). Dominant polarities (superchron) are solid lines, shorter periods with a mainly N or R polarity are dashed (subchrons). The flips/Ma curve is a frequency curve for polarity changes as a function of the time interval 5–160 Ma; AC (alternating current), DC (direct current) describe the geodynamo during rapid oscillations and periods acquiescence. Ages of kimberlites are shown in the upper portion of the diagram: Archangelsk (Ark), China (Ch), Canada (Ca), Zimbabwe (z), Siberia (s), Missouri (Mo), Colorado-Wyoming (CW), Tennessee (Tn), Kentucky (Kn), Swazilandland (Sw), Botswana (B), Irian Jaya (Ij), Namibia (Na) and Australia (Aus). The 80–120 Ma event is global. The arrow pointing in the direction of 1.1 Ga is for kimberlites throughout Africa (Af), Australia, Brazil (Br), Siberia, India (I), Greenland (Gr) and Canada. The ordinate is depth, the diamond-graphite stability curve is correctly placed relative to the lithosphere-asthenosphere boundary. Time span is schematic. O–Sil: Ordovician–Silurian; Dev: Devonian; PP: Permian; Tr–J: Triassic–Jurassic; Cret: Cretaceous. Major tectonic plate rearrangements are noted on bottom scale. Figure and caption reproduced from Haggerty (1993) updated and modified.

could be ferried quickly from the core–mantle boundary to the planetary crust via large amplitude solitary nonlinear waves.

Most diamondiferous kimberlites are Mesozoic (65–245 million years bp) in age with minor examples dating from 33 million years bp (Paleocene) back to 3.3 billion years bp (Archean), the older examples perhaps under represented as a function of poor preservation. This age grouping can be indirectly explained by compositional work done on kimberlites over the last 30 years. It has been concluded that the unusual mineral assemblages in kimberlites are a mixture of ultrabasic material (essentially ferromagnesian minerals) and subducted Archean crust (Pearson et al., 1984; Jacob et al., 1994; Schersten et al., 2004). The rock record shows that lithospheric plates were unusually active in the Mesozoic (McCandless, 1997), providing the opportunity to subduct more surface rock (Archean or otherwise). Likewise, during the Archean, terrains were subjected to (proto-)tectonic processes (Burke, 1997; Pollack, 1997). Recycled carbon dioxide (Wallmann, 2001) and biological material in the crust can supplement the carbon available in the lower mantle to form diamonds (Haggerty, 1999).

1.1. The ULVZ separating the core and mantle

A zone exists between the core and mantle which appears to be a mixture of solid and liquid, inferred from seismic data. This zone may represent one of three things. It could be a layer in its own right, which would imply our current understanding of planet accretion is likely flawed as the evolution of such a layer between the core and mantle has never been modelled. The second option is that the zone is part of the core, a kind of lower density layer (crust) of crystalline iron (with or without silicates) on the outside of the core. Thirdly, the zone may be the basal part of the mantle, super heated and contaminated by core leakage, like the water logged underside of a timber floating in the sea. The authors favour a combination of the latter two options as implied by Buffett et al. (2002). The first option would undermine existing ideas regarding the Earth's formation and its subsequent internal structure.

2. Solitary mega (Rogue)-wave and transmitted turbulence model

Any ferrosilicate melt expelled by turbulence from the core is free to be transported to higher elevations as a function of mantle–core boundary interactions and wave phenomena. Interfaces between discrete bodies are common in the environment around us, but more importantly, waves may develop along these interfaces as a function of differential density. For example, atmosphere partitions (Gary, 1999), ocean–atmosphere, liquid–liquid contacts within the sea water column (the result of e.g. salinity variation), solid–liquid interfaces (Hide, 1970) or solid–solid boundaries (Haddow and Jiang, 2000) can give rise to both linear and nonlinear waves in a thick medium. Waves along these interfaces are usually linear until some critical value in controlling variables is forced allowing the waves to degenerate to a nonlinear chop, with the possibility of chaos and spontaneous pulse formation of very high amplitude events like those observed from time to time on the ocean's free surface or on interfaces within the ocean.

The model introduced here arises by sequentially linking existing models from different disciplines together with some basic assumptions and applying the combined result to a complex geological problem. The Earth's interior is simplified to a basic three-layer model (Fig. 2) which provides the backround for further discussion. The model has a number of key components: chaotic instability of convection in the liquid outer core (Glatzmaier and Roberts, 2001) as inferred from magnetic reversals, irregular topography along the core–mantle boundary (Gutenberg discontinuity) (Buffett et al., 2002), rotation of the mantle which convects, but does not rotate in its own right relative to the Earth; the possibility of nonlinear wave effects along boundary layers within a stratified liquid (Rusas and Grue, 2001); and the effects of turbulent layers on adjoining non-turbulence layers (Dohan and Sutherland, 2002).

All these topics have been independently studied by others and now enough information may exist to assemble a larger picture of the Earth's interior processes with specific reference to kimberlites. Everything mentioned above is brought together to form the mega-wave model, which explains the formation and transportation of core derived (proto-) kimberlite melts from the Earth's core to the surface. Each major component in the mega-wave model, representing a single piece of the kimberlite puzzle is introduced and summarized separately.

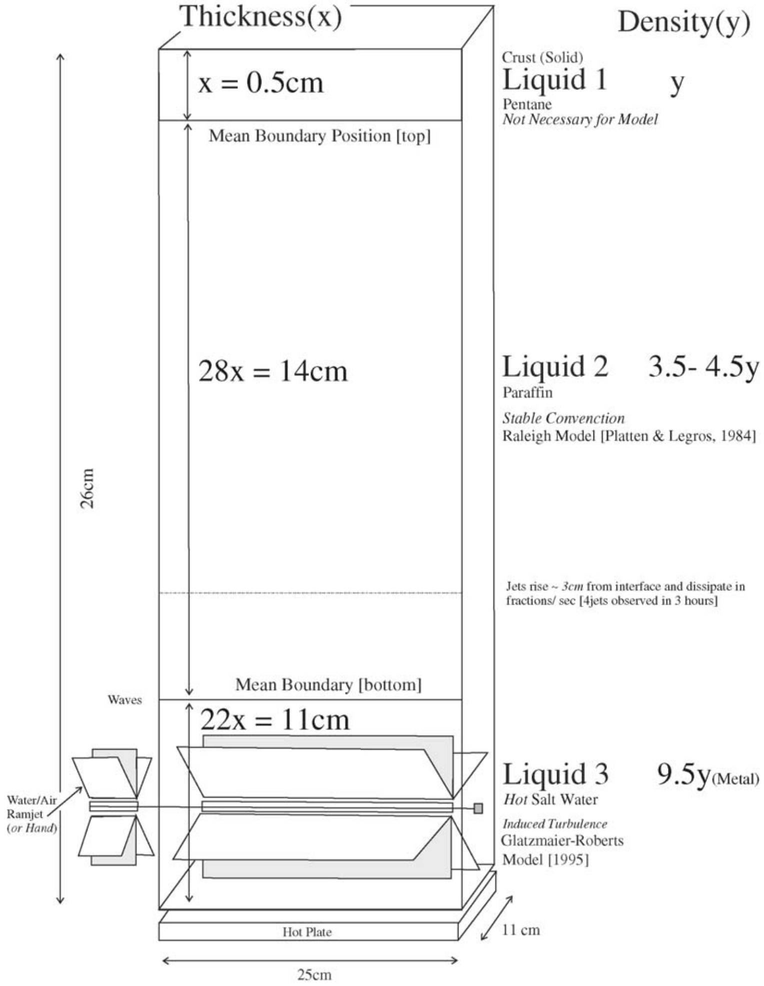

Fig. 2. Three-layer experiment with induced disturbance, after Dohan and Sutherland (2002) as an anology for core derived ferrosilicate jets invading a lower density mantle, the result of turbulence in the liquid outer core. The experiment confirms transmission of nonlinear effects between layers. Waves on boundary layers are primarily a function of density variation. In the case of the Earth's onionskin structure; density is directly related to chemical composition. Turbulence is induced in the basal layer which is heated to simulate a geothermal gradient. Nonlinear waves develop on the boundary between liquids 2 and 3. Turbulent jets of liquid 3 shoot up into liquid 2. Liquid 1: (omitted) pentane, density (ρ) = 0.5 g/l; liquid 2: paraffin, $\rho = 0.87$ g/l (Glatzmaier and Roberts, 1995); liquid 3: salt water, $\rho = 1.3$ g/l (Platten and Legros, 1984). The turbulence wheel fins extends to within 0.5cm of the walls and fluid interface to negate any boundary flow effects.

2.1. Core turbulence and polar magnetic reversals

When a higher density fluid is placed over a lower density fluid an unstable condition exists and the fluids will tend to change places. Lower density ferrosilicates gradually segregating to the outside of the liquid core below the denser mantle would be an example of this unstable condition priming any pockets of this silicate rich core material to move out into mantle. However a perturbation is required in order to initiate the instability. This could take the form of turbulence in the liquid metal core. Glatzmaier and Roberts (2001) have shown than core convection can destabilize, the result of chaotic interactions within the liquid core which sometimes result in magnetic reversals. The forcing factor for this turbulence is thought to be gravitational effects of the sun and moon in conjunction with accelerated rotation of an inhomogeneous inner core (Buffett, 1997).

The core is thought to be largely Fe–Ni–S–O with minor silicate which together form a fined grained mixture of metal and silicate around the core directly below the D″ layer (Bouhifd and Jephcoat, 2003). Ferrosilicate melt expunged from the core as jets of turbulent material may fractionate into an a iron rich part and a silicate rich part

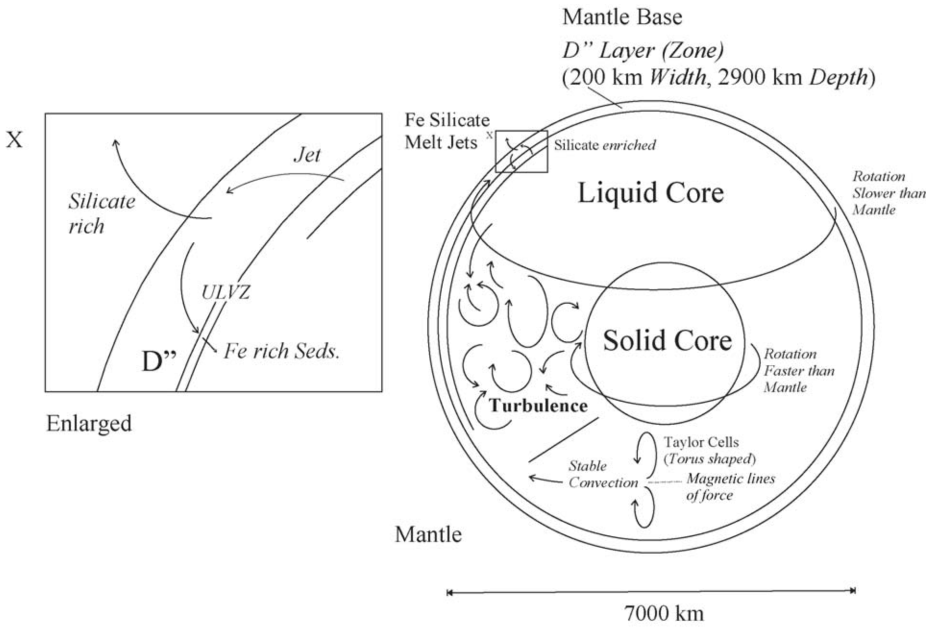

Fig. 3. Core turbulence and the expulsion of ferrosilicate melt from the liquid core as liquid jets.

(Dubrovinsky et al., 2003), as suggested by Buffett et al. (2002; Eqn. (1)):

$$(\mathrm{Mg}_y,\ \mathrm{Fe}_{1-y})\,\mathrm{SiO} + 3(1-y)\mathrm{Fe} \rightarrow y\mathrm{MgSiO}_3 + (1-y)\mathrm{FeSi} + 3(1-y)\mathrm{FeO} \qquad (1)$$

with only the silicate rich part (with elevated FeO) escaping the core permanently to undergo additional mantle contamination during its rise to the Earth's crust. The iron rich part settles back to the core as crystalline iron sediments within the D$''$ layer to be reabsorbed by the liquid core, giving the core temporary topography and offering an explanation for the Earth's axial wobble (Buffett et al., 2002).

Dohan and Sutherland (2002) have shown that jets of turbulent liquid shoot out from a higher density turbulent layer into adjacent lower density non-turbulent layers in a stratified liquid model. In the case of a turbulent core, these jets penetrate the lower mantle, and represent potential kimberlite melts (Fig. 3). Experimental work also shows, decoupled nonlinear waves should develop on the layer boundary between the core and mantle at two scales: the scale of the turbulent jets and the scale of the experimental tank (Dohan and Sutherland, 2002; Daville, 1999); in the case of the mega-wave model, the scale of the liquid core perhaps. These jets into the mantle may then create waves themselves or be captured behind mega-waves forced by core topography. The jet's initial escape after the onset of fully developed turbulence, from the core through the capping ULVZ, wave size or frequency probably accounts for a large portion of the 25–50 million years lag time between magnetic inversions and kimberlite emplacement in the Earth's crust (Fig. 1).

2.2. Topography of the core and extreme amplitude waves

Nonlinear waves of large amplitude are observed in the world's oceans. These may result from wave combination, focusing of wave energy like triple jumping on a trampoline, constructive interference or topographic relief on the ocean floor, with the deep ocean usually being treated as a medium of infinite depth. The authors apply this idea to the Earth's mantle on the assumption that the mantle behaves as a fluid over geological time scales with possible weak magnetorheological (MR) fluid characteristics (Rosensweig et al., 1999) directly related to iron content, an idea supported by the fact that the pseudo-cyclic breakup and formation of supercontinents corresponds with magnetic reversals and phases of kimberlite emplacement in the Phanerozoic rock record (Fig. 1). Such increases in plate tectonic activity would seem a natural response to a more fluid like mantle which could in turn be directly related to any brief hiatus in the Earth's magnetic field as a function of MR properties (Scotese, 2001; Dalziel, 2001).

Reduced viscosity at the base of mantle due to heat conduction away from the core (Glatzmaier et al., 1999) depending on iron present and mantle inhomogeneities (Dubrovinsky et al., 2003; Glatzmaier et al., 1999) would also be significant. Joining these ideas with that of an uneven surface on the core–mantle boundary, the result of contamination of a mantle by liquid core jets or pockets of silicate rich liquid core in an unstable arrangement with the denser overlying mantle sets the stage for the formation of nonlinear waves. Both the former (uneven surface and unstable density arrangement) would result in the formation of iron (with or without silicate) crystal aggregates on the outside of the core (Haddow and Jiang, 2000) giving rise to its temporary relief.

In order for the silicate enriched core derived melt fraction to be sucked up behind a wave front requires mantle rotation relative to the core. The mantle however, does not rotate as an ocean current would over the rough ocean floor, but the liquid core does rotate relatively slowly (Glatzmaier and Roberts, 1996; Vidale et al., 2000) generating a torque against the mantle which shears horizontally (Panning and Romanowicz, 2004). So continuing the ocean analogy, the ocean remains still and the ocean floor rotates under it, producing the net effect of a rotating ocean or, as in the mega-wave model, the rotating mantle. This will provide the necessary forcing to generate extreme amplitude waves on the core–mantle boundary primarily as a function of the D″ layer ULVZ (core surface) topography (Garnero, 2004). Energy is also siphoned into the mega-wave from the adjacent turbulent layer and other wave interactions. Its amplitude increases until the surrounding waves are drained of energy.

These mega-waves (Haver, 2000; Lawton, 2001) which grow rapidly to great size (amplitude) and disappear in an exponential manner are consistent with a Pareto (hyperbolic) distribution of wave amplitudes (Falk et al., 1994; Reiss and Thomas, 1997; Mandelbrot, 1983) rather than with a Rayleigh distribution (favoured for oceanographic studies), which seems to under-estimate the chances of very large amplitude events (Street, 2000). It has been noted (Haver, 2000) that in general, interfacial waves are noticeably larger than their free surface equivalents. On the core–mantle boundary a wave would initially require enough energy to exceed approximately 140 Gpa pressure, although this would decrease at the wave head as the wave grew in amplitude. Equations used to generate experimental nonlinear waves include Schrödinger's nonlinear equation (Osborne et al., 2000) and the Korteweg–deVries equations (Trulsen et al., 2000; Slunyaev et al., 2002). Mega-waves, although a rare phenomenon (White and Fornberg, 1998), harness great energy for a limited time. They are the indirect result of chaotic system behaviour in the outer core inevitably forcing wave motion along sharp chemical composition discontinuities such as the Earth's core–mantle (Gutenberg) and crust–mantle (Moho) boundaries (Larkin et al., 1997; d'Acremont et al., 2002) in sequence away from equilibrium, allowing the formation of random nonlinear mega-waves.

Primary metallic melts expelled from the turbulent core, initially contaminated by the ULVZ, may extend further into the mantle by exploiting the pressure differential behind a mega-wave front and move rapidly towards the Earth's surface combining with subducted Archean crust along the way to produce the final kimberlite melt composition (Fig. 4) seen in the rock record. The mega-wave model does not require melt pooling at layer boundaries, however direct ascent may be complicated by mantle convection trajectories. Nonlinear phenomena would also be possible along deformable boundaries such as the top of the mantle and the lower–upper mantle contact (Lyubimov and Shklyaev, 2002). Although the type of deformation around these wave fronts will depend on material properties of the country rock, a pressure and structural vacuum would be created behind the wave front (Erofeev and Fridlender, 2002; Garanin et al., 2001).

On the core–mantle boundary, the transportation window these mega-waves provide for (proto-)kimberlite melts would begin to build slowly and grow faster as they approach the surface probably accelerating to well in excess of the estimated average emplacement velocity of 300 m/s for kimberlite pipes (Head and Wilson, 2002). However the melt will probably do the reverse and slow down in ascent due to a relatively less fluid upper mantle (increased ratio of Mg/Fe content). In the course of the (proto-)kimberlite melts rise to the crust, diamonds previously formed in the lower mantle can be incorporated into the rising melt as xenocrysts (Foulger and Natland, 2003).

2.3. *Final state of core derived melts*

A mega-wave striking the base of the lithosphere will result in a fracture cone of extensional structures arising from the wave peak, like an impact cone (French, 1998). This process may be aided by inelastic behaviour of the kimberlite which occurs at >1 Gpa impact stress (Willmott et al., 2004), except the impact has come from within the Earth. This connects the wave via pipes to higher crustal levels, creating an overall shape of one small cone sitting on top of a bigger cone, with both meeting at their apexes, the cone on top being upside down giving rise to the characteristic funnel shaped breccias seen in many kimberlite pipe complexes (Fig. 5). If the wave has enough energy, fractures

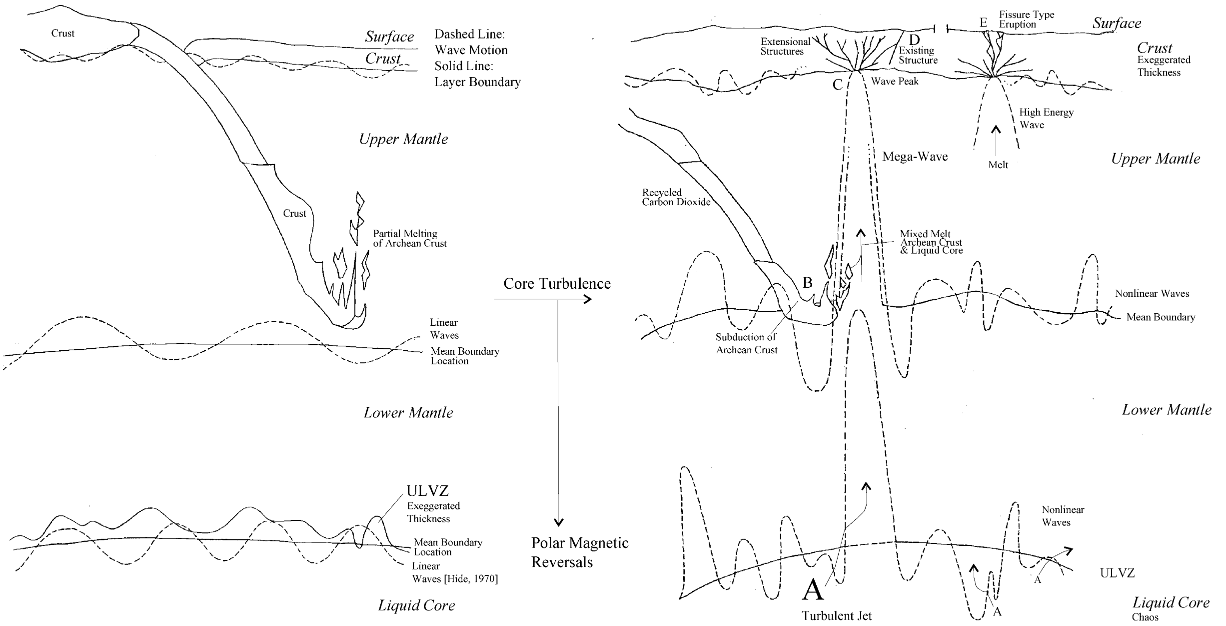

Fig. 4. Emergence of a mega-wave on a discontinuity. Amplitude continues to increase until energy is drained from surrounding waves or it breaks. The overall effect is to press the mantle–crust boundary to the Earth's planetary surface momentarily. Order of events: (A) chaos develops in liquid core, turbulent jets invade mantle and linear interfacial waves become nonlinear; (B) melts mix: subducted Archean crust and primary iron silicate core melt; (C) peak of wave front; (D) intersection with near surface structures or propagation of fracture cone and release of pressure; (E) eruption (optional). Collapse of secondary cone, near surface processes and development of a final state (Fig. 5).

may extend to the Earth's surface resulting in a fissure type eruption. But assuming eruptions do not usually occur, degassing as the melt rises behind the wave front is like opening a Champaign bottle into the fracture cone above the wave peak which results in the final stage of brecciated emplacement (for breccia types see: Taylor and Pollard, 1993). The resulting effects if a waves amplitude were to exceed the critical convective amplitude of Hoyler (1979) or develop a Kelvin–Helmholtz instability (Suji and Nagata, 1973) from excess shearing between the upper and lower layers and break is beyond the scope of this paper.

3. Synthesis and discussion

Modelling done by the authors confirmed experiments performed by Dohan and Sutherland (2002), suggesting kimberlites may indeed be a window to the Earth's core as noted by Haggerty (1993). Subduction of Archean crust and the simultaneous development of a mega-wave along the core–mantle discontinuity provides a plausible vehicle for the emplacement of diamond bearing kimberlite pipes within the crust, depending on where exactly the mega-wave driver develops, if a core jet is sucked into the wave, the composition of the Archean part of the source melt which mixes with the primary ferrosilicate material derived from the liquid core and local inhomogeneities in mantle composition. Melt contamination by Archean crust also implies active Archean plate tectonics. The turbulent jets from the outer core which penetrate the lower mantle provide the seeds for kimberlite melts.

These melts may not immediately be picked up by a mega-wave leaving them free for a time to mix with the mantle. In reverse, if the melts derived from turbulent jets of liquid core are picked up by mega-waves promptly, they could date fossil polar magnetic inversions. The proposed mega-wave model is theoretical and not built strictly on existing evidence in the geological record unlike existing data-driven models (Head and Wilson, 2002; Griffin et al., 1999). These latter models explain the detailed features of preserved pipes (Fig. 5), but do not properly address questions regarding the early stages of emplacement or initial triggers. The principal pieces of the early emplacement puzzle had been partly assembled by others (Dobretsov and Vernikovsky, 2001; Haggerty, 1993) and only required the turbulent core jets and nonlinear wave carrier to complete a model for kimberlites as core plumes based on the theory of nonlinear boundary mega-waves forced by core topography and an adjacent turbulent layer.

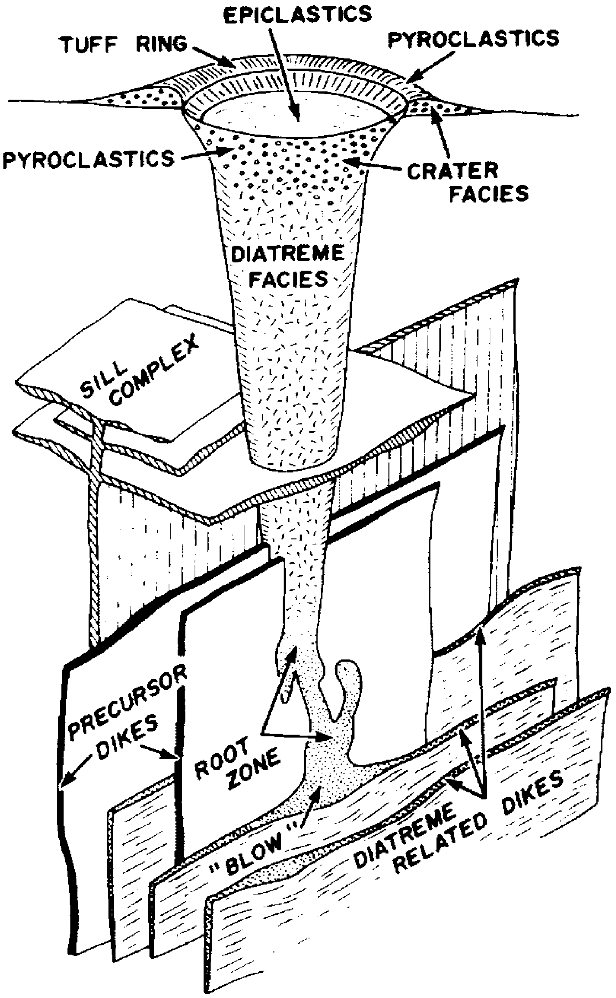

Fig. 5. Kimberlite pipe near surface processes and features. Reproduced from Head and Wilson (2002).

These core plumes, which are one off type events without feeder tails, are somewhat unrelated to mantle plumes which seem to tap fluid at the base of the mantle (D″ layer) rather than being drained directly from the core (Scherstenet al., 2004). Shallow versions also known to exist are likely a function of mantle cooling and the space which develops between shells of mantle rind and the slightly more fluid mantle interior which pulls away from the harder outer shell through shrinkage to begin creating another relatively solid surface below (Kerr Richard, 2003; Clemens and Mawer, 1992; Goleby et al., 1994) like any body cooling from the outside inwards.

The mega-wave model applied to kimberlites is consistent with existing information regarding the Earth's interior and if it is confirmed, there would be clear economic implications. Diamond exploration potential would be maximized in rock units pre-dating specific magnetic reversals and interpreted to have formed in the vicinity of subduction zones capable of subducting Archean crust. The exact location of any kimberlite pipe is related to the subsurface intersection of the subducted Archean crust (a function of subduction dynamics: speed and angle of plate descent) with the rising wave front. These areas should also have well developed extensional fault complexes, narrowly post-dating the reversal event. If an upside down fracture cone does develop from the wave's impact with the base of the crust, kimberlite pipes should always be found in clusters. Their apparent association with thick lithosphere may be related to wave energy dissipation in conjunction with the spatial location of subducted Archean crust. The sooner the wave encounters the crust the better, otherwise it may not have enough impact to open cracks in the crustal base necessary to tap off the kimberlite from the wave head. The exploration model is summarised below by a set of symbolic coupled linear Eqs. (2–5), where f denotes different functions and y is related as $f(\mathrm{Target}_{\mathrm{Scale}})$ to a subduction zone (modern or ancient) capable of subducting Archean crust:

$$T_K = f(\mathrm{KHost}) \quad \mathrm{KHost}_{\mathrm{Age}} = K_{\mathrm{Age}} + (\text{approximately})\, 50\ \text{million years}, \quad \mathrm{KHost} \neq K_{x,y,z} \tag{2}$$

$$K_{x,y,z} = f(x) \quad \mathrm{Age}_{\text{selected inversion event}} > x_{\mathrm{Age}} > \mathrm{Age}_{(\text{selected inversion event}+1)} \tag{3}$$

$$x = f(y) \tag{4}$$

$$y = f(z) \quad \mathrm{Age}_{\text{selected inversion event}} > z_{\mathrm{Age}} > \mathrm{Age}_{(\text{selected inversion event}+1)} \tag{5}$$

where T_K is the target kimberlite host rock; x the extensional fault complexes, a function of rock unit(s) the structures are developed in.

Unknown rock unit(s), which do not have to have surface exposure: K is the target kimberlite; KHost the *youngest* rock unit cross cut by K; y the rock unit(s) extensional fault complexes are developed in; z is the rock unit(s) of age within selected inversion event pair window.

Selected inversions are a N–R, R–N pair or vice versa, target generation is directly related to selected inversion event; (inversion event + 1) is the next youngerst inversion relative to selected inversion.

A simplified model for general orientation will focus on rock units formed (at surface) around subduction margins active during break-up—formation of supercontinents seen in the geological record and exploring progressively further away from these. Paying special attention to proximal relic Archean crust and extensive fault complexes narrowly post-dating the relevant rock units. If mega-waves are a real component of kimberlite emplacement, then there should be potential for diamond bearing pipes on any differentiated (core, mantle, crust) planets, but polygonal plate tectonics i.e. the chemistry of Archean rocks from the planetary crust and surface carbon might also be critical through feedback.

3.1. Future work

Currently, the only piece of relevant information that contradicts the Megawave model is based on work done by Schersten et al. (2004) regarding the ratios of tungsten isotopes in mantle rock samples. They find no evidence for core contributions to the mantle or kimberlites, however in the words of Hauri (2004), there remains tantalizing clues that the story may not be this simple. One such clue has arisen from work done by Nowell et al. (2004) and Blichert-Toft and Albarede (1997) on the Hf–Nd isotope characteristics of Kimberlites. It is proposed that kimberlites tap a magma reservoir deep in the earth which is separate from the mantle and apparently unsampled by any measured terrestrial volcanic rocks (Nowell et al., 2004).

Validating key assumptions underlying the mega-wave idea is important; although this may be easier said than done. It will involve determining if the mantle behaves as a fluid (rheologically) or solid over geological time scales. On time scales where it is possible to make observations, the mantle is a solid, but this information is probably not helpful for long-term processes. Interpretation of seismic velocities is currently the only way of probing the preceding question, but making decisions on mantle behaviour over hundreds of millions of years requires seismic shots which would take an equivalent amount of time to pass through a solid earth, which is not possible. Another idea difficult to test is whether the solid mantle shows any MR fluid characteristics, becoming more fluid in the absence of a magnetic field which would be of significance during the change over period in an inversion event.

But if we proceed on the premise that the mega-wave idea may be plausible, we can look for signs that will support the hypothesis such as accurate monitoring of the positions of the core–mantle and mantle–crust boundaries over time, this should determine if wave motion is a real phenomenon within the Earth. Ultra-deep drilling below the kimberlite root zone would show if a pipe is in fact one small cone sitting on top of a much larger frozen wave (over observable time scales), with the angles of bounding structures intersecting at the wave crest. Identification of isolated iron rich silicate melts within the mantle and mapping their movement would also offer support to the mega-wave hypothesis. Computational fluid dynamics will hold the keys to wave mechanics.

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