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With compliments
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Diamond mega-placers: southern Africa and the Kaapvaal craton in a global context

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Abstract: Diamond mega-placers, defined as ≥ 50 million carats at ≥ 95% gem quality, are known only from along the coast of southwestern Africa, fringing the Kaapvaal craton, where two are recognized. One is associated with the Orange–Vaal dispersal, the other, to the south, has an uncertain origin. Placers are residual when left on the craton, transient when being eroded into the exit drainage, and terminal. Terminal placers, the final depositories of diamonds, have the greatest probability of being a mega-placer. There are four main groups of controls leading to the development of a mega-placer: the craton, the drainage, the nature of the environment at the terminus and the timing.

Cratons, being buoyant, have a tendency to leak diamonds into surrounding basins; however, being incompressible they may have orogens converge onto them resulting in some lost sediment being returned as foreland basin fills. The craton size, its diamond-fertility and the retention of successive kimberlite intrusions that remain available to the final drainage, are significant to mega-placer development.

Maximum potential recovery is achieved when the drainage delivering diamonds to the mega-placer is efficient, not preceded by older major drainages and focuses the supply to a limited area of the terminal placer. There should be sufficient energy in the terminal placer regime to ensure that sediment accompanying the diamonds is removed to areas away from the placer site. All conditions should be near contemporaneous and most were satisfied in the Orange–Vaal Rivers–Kaapvaal system and mega-placers were consequently generated.

Placer diamonds have been mined in India since 300 BC, more than 2000 years before the discovery of the first primary deposit at Kimberley in 1871. However, in contrast to the volume of research on kimberlites, relatively little has been written about alluvial diamonds, particularly in a global context. The volume of diamonds retained in kimberlite pipes diminishes with depth and following erosion, placer deposits are a significant accumulating residue, potentially carrying a record of some of the history of diamond emplacement on a craton.

The bulk of the natural diamonds are currently produced from primary (kimberlitic, lamproitic) sources. For example, on the Kalahari craton of southern Africa the primary diamond production for the year 2003 stands at *c.* 40 × 10^6 carats and the placers on and around this craton yield *c.* 1.5 × 10^6 carats or *c.* 3.8% of the total production. However, placer deposits on or fringing the Kalahari account for >7.5% of the total production value. It follows that placer deposits have to be very large to have any significant impact on total diamond production and they should (and commonly do) have a relatively high value per carat. For this, and other reasons to emerge later, we propose a narrow definition of a diamond mega-placer as being a continuum of linked deposits that are generally the result of a single or continuous process of transportation and deposition and which contain or have contained at least 50 × 10^6 carats, of which >95% are of gem quality.

The largest single deposit (primary or secondary) in terms of volume is the complex at Mbuji-Mayi in the Democratic Republic of Congo (see Table 1). It is now recognized as a highly weathered primary deposit and, as it is not transported, does not qualify as a true placer. In terms of the definition of a mega-placer the only ones so far identified occur along the coast and immediately offshore of southwestern Africa (Fig. 1). This total region has, over the time of its production, yielded more than 120 × 10^6 carats.

Types of placers and conditions for their formation

Three categories of placer deposits are recognized (Fig. 2).

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Table 1. *Statistics for both diamond placer and primary deposits (for source see text)*

Region	Million carats	Value US m$ (production 2001)
Southern Africa	140	633.1
Angola & DRC	120	1124.2
DRC (Mbuji Mayi)	834	–
Central African Republic	20	92.1
W Africa	200	251.9
S America	75	79.2
Others	74	–
TOTAL	1463	
Primary deposits	1500	

Retained: those deposits remaining on the craton and not readily available to the dispersal system;

Transient: those that, during the current cycle of erosion, have been dispersed but have been temporarily stored in or on the margin of the dispersal route; and

Terminal: the final accumulation from the current drainage.

Retained placers

Kimberlites, intruded over a range of time, may disperse their diamonds into deposits remaining on the craton, in some cases for >2.5 Ga, so that they may accumulate there for final release. There are a number of ways in which these secondary deposits may be retained, two of the more significant are in karsts and intra-cratonic basins. (Figs 2–4).

Karsts (including karst surfaces), estimated to occupy 10–20% of the Earth's land area (Palmer 1991), may become areas of substantial diamond retention. Karstification is extensively developed on cratonic cover and adjacent areas where post-Archaean carbonates have been subject to climatic and base level changes since *c.* 2.5 Ga. With diamond-fertile kimberlites being found principally on Archaean cratons there is great potential for long-term diamond

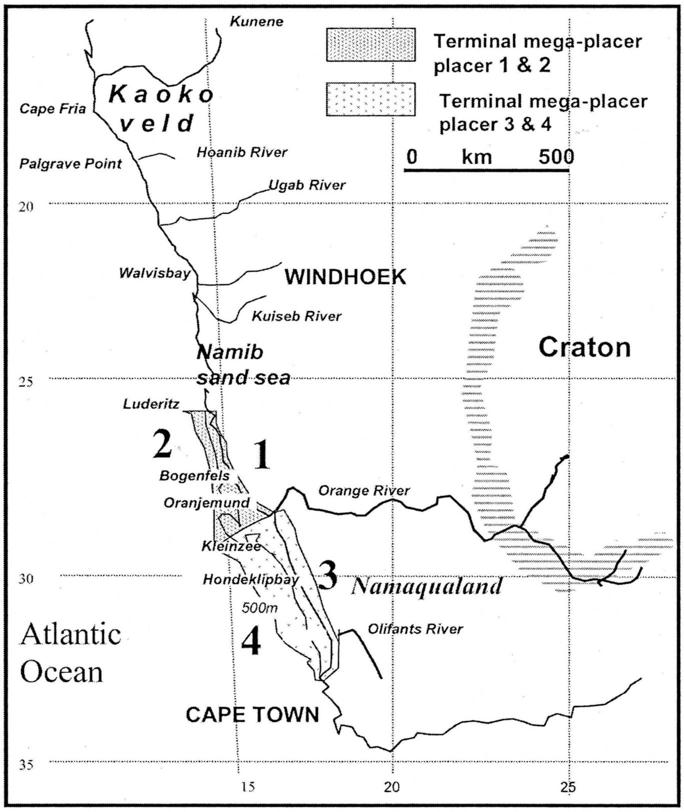


Fig. 1. Distribution of the Namibia–Namaqualand mega-placers, together with the water depths on the shelf.

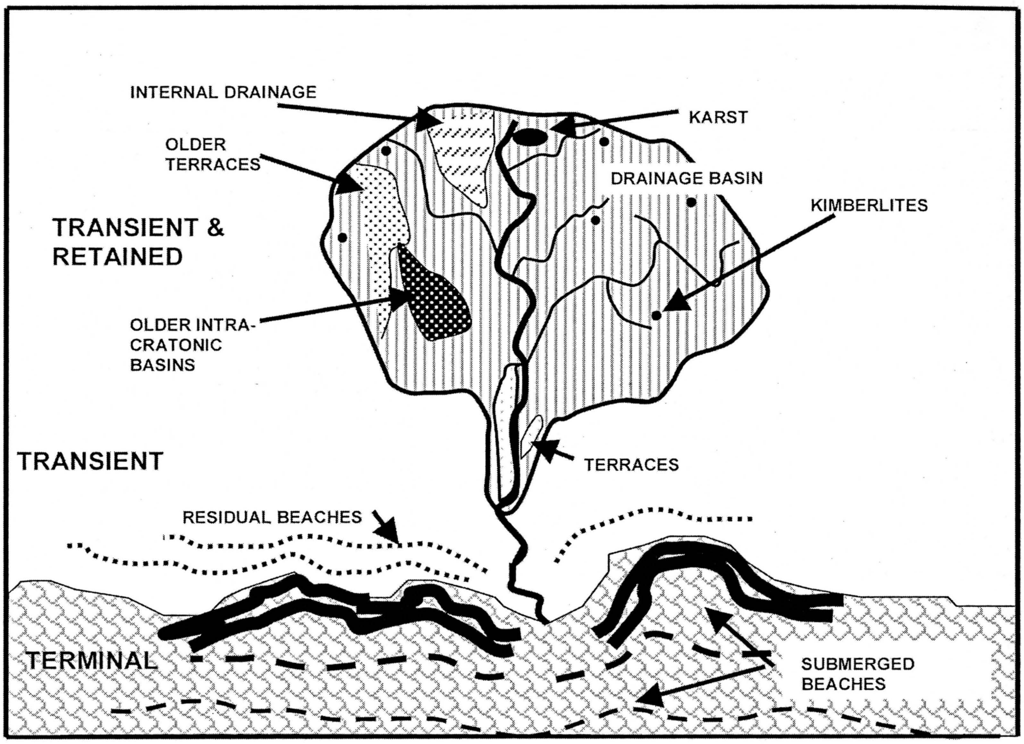


Fig. 2. Types of placers.

retention through subsequent erosion and trapping in and on karsts.

Potential trapping occurs in caves and on the highly irregular karst surfaces, and cavities, hundreds of metres across and tens of metres deep, may run for several kilometres. Cave systems develop both quickly and extensively: extension rates are up to 200–300 m ka^{-1} and flow rates in caves from *c.* 4 m hr^{-1} to 700 m hr^{-1}. The Carboniferous Madison Limestone of South Dakota illustrates the potential for possible volumes generated, where cave density reaches 120 km of passage-way beneath an area of 1.3 km^2 (Bakalowicz *et al.* 1987).

In the Late Archaean–Palaeoproterozoic Chuniespoort and Ghaap Groups (Transvaal Supergroup), the Kaapvaal craton has one of the oldest known regional carbonates in the world, estimated to cover 500 000 km^2 and up to 1700 m thick (Button 1973; Tankard *et al.* 1982). In the North-West Province (formerly Western Transvaal; Fig. 3), more than 12 × 10^6 carats have been recovered from karst surfaces retaining diamond-bearing gravels (du Toit 1951; Stettler *et al.* 1995; de Wit 1996). At least four periods of karstification have affected some of these carbonates and Martini & Kavalieris (1976) suggested that in the Lichtenburg area a palaeo-river system, along with potholes, controlled the distribution of the diamond-bearing gravels (Fig. 3). Some of the gravel lies in potholes and other gravel 'runs' that stand slightly higher than the surrounding land surface. Du Toit (1951) thought that the high standing gravel may originally have been deposited in karst-related depressions but, due to down-wasting of the surrounding carbonates (the 'runs' protecting the carbonate surface from down-wasting), invert to relief. With some of the gravels being Upper Cretaceous in age (Bamford 2000) and with surface reduction rates in karst being recorded elsewhere at 1.5–4.0 m/Ma then this explanation is highly probable.

In places on the craton, and even within the externally draining basin itself, there are areas of internal drainage not yet tapped by the drainage network that are therefore failing to dispense diamonds to the other placer types. Some basins are quite small and temporary, but

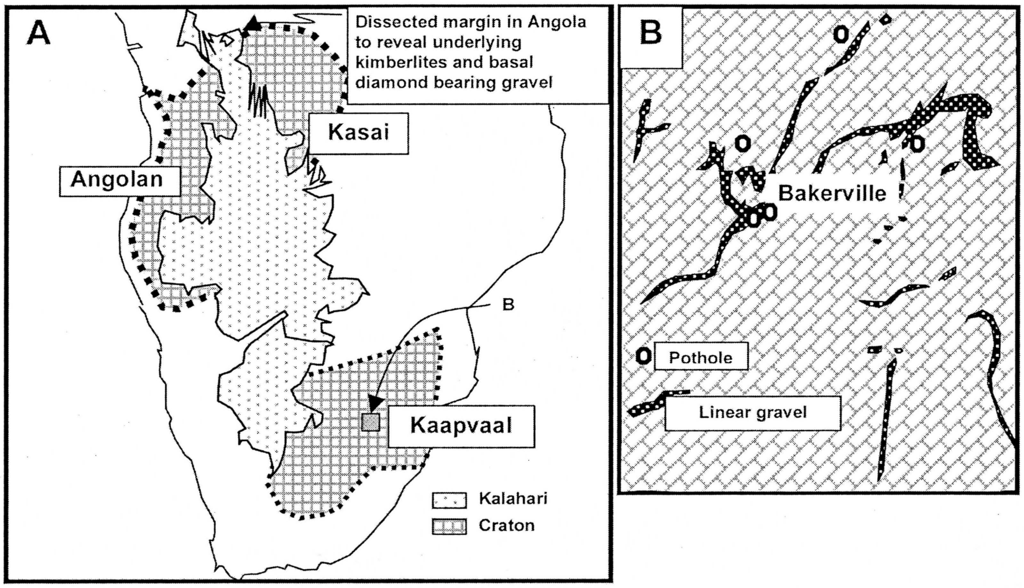


Fig. 3. Examples of residual placers. (**A**) The internal, diamond-bearing, Kalahari basin in relation to the exposed and covered cratons, demonstrating its extent over the Angolan, Kasai, Kaapvaal and Zimbabwe cratons. (**B**) Residual diamond-bearing deposits in the karst topography in the region of Lichtenburg, South Africa (for location see map A) from Stettler *et al.* (1995).

others are large intra-cratonic basins covering thousands of square kilometres. The post-Gondwanan Kalahari basin is still active. It extends widely over southern and central Africa covering a large portion of the Kalahari and adjacent cratons and shields (Fig. 3). This basin has been subject to a number of influences since the break-up of Gondwana in the late Jurassic (Haddon 2000). There are four main depocentres; the sediments, over 300 m thick, begin with coarse basal gravel and terminate in calcrete, aeolian sand and pan sediments, these finer sediments commonly overlapping onto the craton (Haddon 2000).

The potential for diamond retention in this deposit is demonstrated on its northern (Angolan) margin where northerly flowing rivers have dissected a small part of the basin edge in response to the downcutting of the Kasai. Where close to primary sources, the basal gravel of the Calonda Formation and associated younger deposits host high diamond grades (Fig. 4). Continued cut back by large rivers results in dilution of diamond grades unless upgrading is achieved in local scour pools. The life-span of basins of this type is uncertain, but the Kalahari basin may be at least Early Cretaceous in age, thus holding a Mesozoic–Cenozoic record. During this time and during the initial stages of basin opening it would have derived diamonds from the erosion of kimberlites on the basin floor (when underlain by craton, as occurred in Angola). However, as the basin develops, the peripheral drainage may derive diamonds from the surrounding basement. There is also the possibility of post Early Cretaceous kimberlites having been intruded into the sediment fill.

Other sedimentary basins currently developing on or near to cratons in Africa include the Niger, Congo, Taoudenni and possibly Chad (Burke 1996). The extent to which these basins contain diamonds is uncertain and depends on the fertility of the associated cratons, but they are all depocentres into which drainage crossing Archaean crust is or may have been active in the past. Smaller basins near to or on cratons include the Senegal and Volta basins, although the extent to which Hercynian (Mauritanides) and Pan African Rokelides belts have dominated sediment input to all these basins is yet to be determined.

Extensional episodes were common on most cratonic blocks from Late Archaean–Proterozoic times and intra-cratonic basins thus generated may have been repositories for placers or have provided a host cover for diamond-bearing intrusions. They range from poorly explained

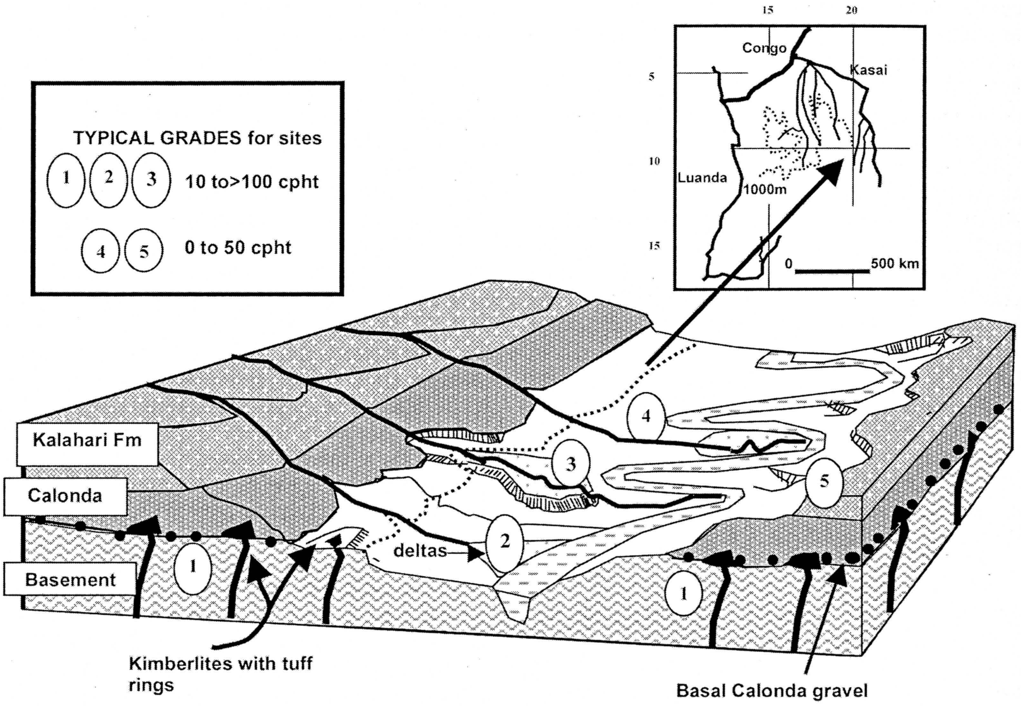


Fig. 4. Residual and transient type placer deposits in the eroded northern edge of the Kalahari basin (and associated kimberlites) in NE Angola (see inset for location). The Calonda Formation, here the base of the Kalahari basin, was deposited by small streams that eroded exposed kimberlites to form a local sheet-like retained placer, 1. 2 is formed by small deltas in the tributary streams to the main channel concentrating diamonds from the Calonda Formation and exposed primaries. Placer 3 occurs in mass-flow deposits, with some fluvial reworking giving exceptional grades; placer 4 occurs in the principal rivers and 5 their terraces. The type 4 deposits often have low grades when being diluted by barren Kalahari sediment.

and long-lived roughly circular depressions such as Hudson Bay and the Williston Basin on the North American shield; Paranaiba on the Central Brazilian shield and Congo, to Triassic to Recent rift-generated basins. The potential of these and related basins to retain diamonds is illustrated on the Kaapvaal craton where placer diamonds have been recovered from Ventersdorp and Witwatersrand Supergroups.

The potential of intra-cratonic and associated basins in preserving kimberlites was recognized by Gold (1984) and clearly applies also to the detritus accumulating from eroded kimberlites (Figs 3, 4 & 12). This potential is revealed when basins have been partially inverted and subsequently truncated, as demonstrated clearly in craton history (for the Kaapvaal see Brandl & de Wit 1997; Cheney & Winter 1995; Cheney 1996) and is seen spectacularly in Angola (Fig. 4).

Transient placers

Transient placers are diamond-bearing sediment piles stored along the dispersal route or within the active drainage basin. The distinction between these and residual placers clearly merge if the drainage density in the drainage basin is low with the result that the removal of sediment is inefficient and diamond bearing sediment remains untouched there for extended periods. In the present Orange River drainage basin, for example, aridification has resulted in low drainage density and run-off and placers have remained in that drainage basin since the Cretaceous.

Transient placers in river terraces have provided some rich placer deposits that depend upon uplift–incision for their formation and stacking. In addition, the attendant rejuvenation is needed to increase the slope and energy in the channel, to effect bedrock incision related trap sites and, in rejuvenated tributaries, to deliver coarse sediment to the main channel which might otherwise comprise fines. Without this coarse sediment load and increase in velocity of flow, hydraulic selection and retention of the diamonds into viable placers may not have occurred.

Fine examples are supplied by the terraces along the Vaal and Orange rivers in southern Africa, and terraces of uncertain age (but almost certainly post-Cretaceous) along the Kwango and other rivers in Angola (in places yielding grades >500 carats per hundred metric tons gravel (cpht)). Other transient deposits occur along the Krishna River in India, the Yuan in China, Smoke Creek in Northern Australia and many deposits in Borneo and South America. All are related to episodes of uplift or other base level changes followed by incision. These deposits, and those removed by erosion, supplement the diamond population of the main channels ensuring a steady supply of diamonds to the terminal placer.

Transient placers, in the form of river terraces, were a source of diamonds probably centuries before the primary deposits were found, as for example in India (Marshall & Baxter-Brown 1995). Since they were first found in South Africa in 1866 at Hopetown, along the Orange River, extensive coarse-grained gravel terraces along both the Vaal and the Orange river upstream of their confluence have yielded more than 3 million carats (de Wit 1996). These transient placers, developed during the evolving drainage, range in age from Cretaceous to Recent (Partridge & Brink 1967; Bamford 2000; de Wit 2004).

On the Lower Orange River, *c.* 100 km inland from its mouth, diamonds have been mined from a sequence of terraces since 1967 and provide essential evidence for the changing nature of diamond supply to the terminal placer over an interval of time (Van Wyk & Pienaar 1986; Jacob *et al.* 1999; Fig. 5). In both Vaal and Orange Rivers, the terraces demonstrate a declining grade and a general increase in diamond size from oldest to youngest (Fig. 6), thought to be the record of a decline in a major input of diamonds fed into the drainage system and ultimately to the terminal placer. This information is an important line of evidence explaining variable grade in the terminal placer and in targetting areas in the offshore environment.

Although all of these placer types have provided rich deposits (a single 'plunge-pool' in the Mbuji-Mayi River has yielded 25 × 10^6 carats (Oosterveld 2003)), none has yet yielded the abundance and quality seen in the only known substantial terminal placers on the SW

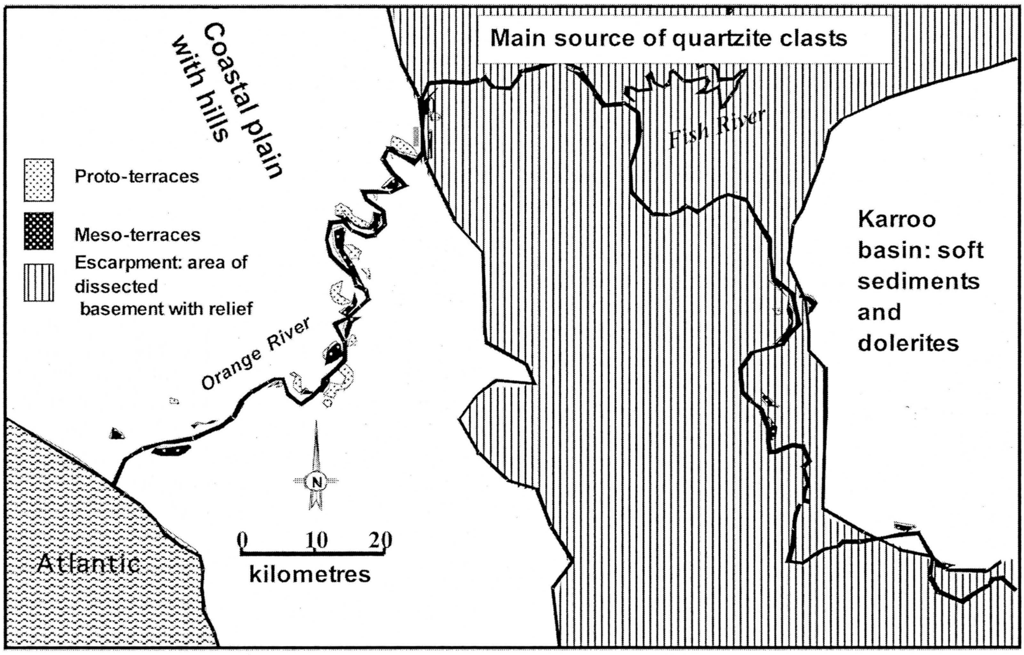
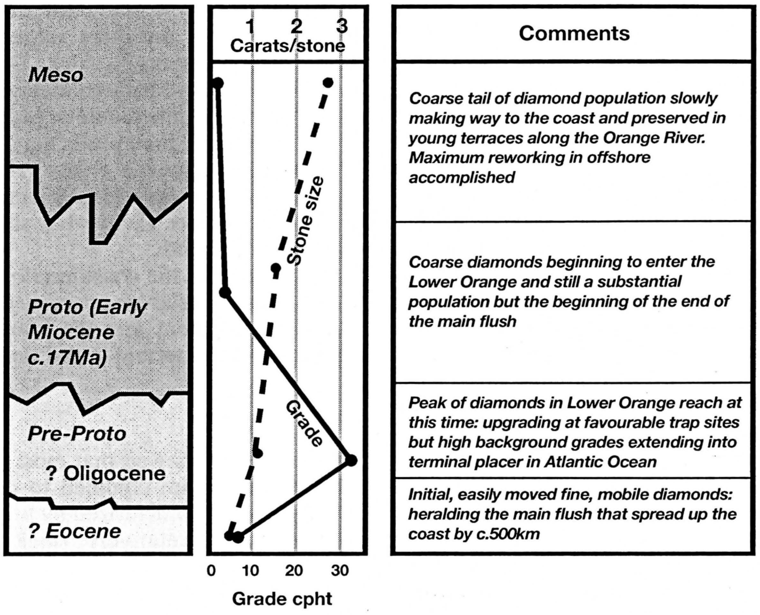


Fig. 5. Distribution of transient placers along the lower Orange River valley. The terraces are particularly common (but not confined to) the river where it has emerged from the area of relief (Jacob *et al.* 1999).



Coarse tail of diamond population slowly making way to the coast and preserved in young terraces along the Orange River. Maximum reworking in offshore accomplished

Coarse diamonds beginning to enter the Lower Orange and still a substantial population but the beginning of the end of the main flush

Peak of diamonds in Lower Orange reach at this time: upgrading at favourable trap sites but high background grades extending into terminal placer in Atlantic Ocean

Initial, easily moved fine, mobile diamonds: heralding the main flush that spread up the coast by c.500km

Fig. 6. Diagrammatic section through the Lower Orange River terraces (Fig. 5) along with the changing grade and diamond size. Cpht, carats per 100 metric tons of gravel; stones refers to diamonds (see Jacob *et al.* 1999).

African coast. The extent to which they and the diamond-bearing kimberlites remain in the drainage basin is a measure of the lack of efficiency of the drainage gathering the diamonds to deliver them finally to the terminal placer. In this respect, the Orange drainage basin, although delivering a mega-placer is, nevertheless, remarkably inefficient as it has left behind some substantial residual placers, and probably the world's greatest reserve of primary diamonds after more than 60 Ma of erosion.

Terminal placers

Terminal placers occur at the extreme end of drainage systems where diamonds and sediments, in a different repository, are subject to further segregation. Processes in the terminal placer need to change successive increments of sediment containing a small population of diamonds into a relatively large, quasi-single population of diamonds hosted in a relatively low volume sediment. The conditions required to achieve this are:

1 The total volume of diamonds transported over a period of time determines the magnitude of the terminal placer. The extent and richness of the craton with respect to both primary and secondary diamond deposits is an essential prerequisite as is the availability of diamonds to the transport system. The diamonds generated need to be retained on the craton for as long as possible so that yields from successive kimberlite intrusions or from re-erosion of earlier placers, accumulate there and become available for their final exit.

2 In order to focus the maximum number of diamonds into the smallest terminal area, the exit drainage needs to be large-scale and single. The greater the drainage area, given that this correlates with a greater proportion of craton, then the greater the abundance of diamonds being transported to the terminal point. However rivers capable of bringing a substantial quantity of diamonds are also likely to have brought down considerable volumes of diluting sediment. Ideally there should be low volumes of diluting sediment in the fluvial delivery and this sediment should be of a grain size capable of trapping diamonds.

3 The terminal area has to have sufficient energy to separate the diamonds from the other entrained sediment as (with respect to 2, above) the greater the drainage area, the greater the sediment load and therefore the environment in the terminal placer has to be correspondingly more energetic to

concentrate the diamonds. There are a number of critical conditions here:

a. The environment into which the diamond-bearing sediment is deposited needs to be sufficiently energetic to segregate diamonds from other sediment and separate gravel out to form the host for diamond retention. This degree of energy, normally found in the marine realm, is determined by the characteristics of both ocean and shelf. Long-period waves acting on a broad, shallow, low-gradient shelf, will, for any one state of sea level, transport and segregate sediment and farm for diamonds. In addition, wind, wave and tidal energy are needed to remove the diluting sediment from the potential placer site.

b. Given that the delivery of diamonds to the terminal placer will take place over a period of time (see Fig. 6), the size of the final placer should be, as near as possible, the sum of all diamonds brought down by the river since its inception. As many increments of diamonds as possible brought down by the river to the terminus should be available for re-concentration there, i.e. not buried by the accompanying or other sediments so as to be sealed off from further concentration. This demands a number of factors including a wide area of shelf with little or no subsidence over the time of placer development so that sea-level changes can repeatedly rework the sediment. As a corollary to this, unwanted sediment, separated from diamonds, needs to be dispersed to areas away from the site of placer development to nearby regions of accumulation where it can be accommodated and more permanently buried.

4 Conditions 1–3 must be united by time. The processes of concentrating the diamonds from the other sediment delivered are not likely to be maintained for any great length of time. It is therefore important that the delivery of diamonds coincides with the time interval over which the optimum conditions for sediment fractionation and disposal are operating in the environment of the terminal placer.

Timing of the whole dispersal and terminal placer development is also highly significant in another sense as the diamonds are to be recovered from loose sediment rather than being locked-up in cemented rock. Diamonds are hard but relatively brittle so that, unlike gold for example, recoverable diamond placers are more likely to be found in deposits that have escaped deep burial, orogenesis or severe cementation. Thus Mesozoic or younger sediments on cratons or their edges are favourable sites for easily recovered diamonds.

It follows from the considerations above that the groups of variables concerned with mega-placer development are: the craton, drainage, conditions at the terminus and timing.

The craton

Clifford (1966) showed that most diamondiferous kimberlites are confined to crustal blocks over 2 Ga old, characterized by low geothermal gradients and relatively thick crust, thus allowing for high pressure at comparatively low temperature and, consequently, generation of diamonds within the stability field in the mid–lower portions of cratonic lithosphere. Nevertheless diamond bearing kimberlites and lamproites have been found in Proterozoic belts (e.g. Western Australia (Atkinson 1986), Buffalo Hills, Alberta (Carlson *et al.* 1998)) although these may be cover to older cratons which might have been beneath them at the time of kimberlite emplacement. There are minor occurrences of small diamonds in regional eclogites, mainly in Phanerozoic belts (Nixon 1995).

Janse & Sheahan (1995) estimated that *c.* 500 of the 5000 kimberlites discovered by the mid 1990s were diamond bearing and there is clearly a wide variation in fertility of pipes within the same craton as there is between cratons (Figs 7 & 8). The combination of the extent, fertility and geological history of the craton are part of the fundamental controls on the development and richness of a mega-placer that it might generate.

Extent

It follows from 'Clifford's rule' (above) that the global availability of diamonds is largely related to the global area of Archaean crust, and continents richly endowed with Archaean blocks have commensurately greater potential for diamond yields and likelihood of producing a mega-placer. Goodwin (1996) has calculated that the total area of Archaean craton is 15.5×10^6 km^2, 43% of which is exposed. About 24% of the total estimated Archaean crust is in North

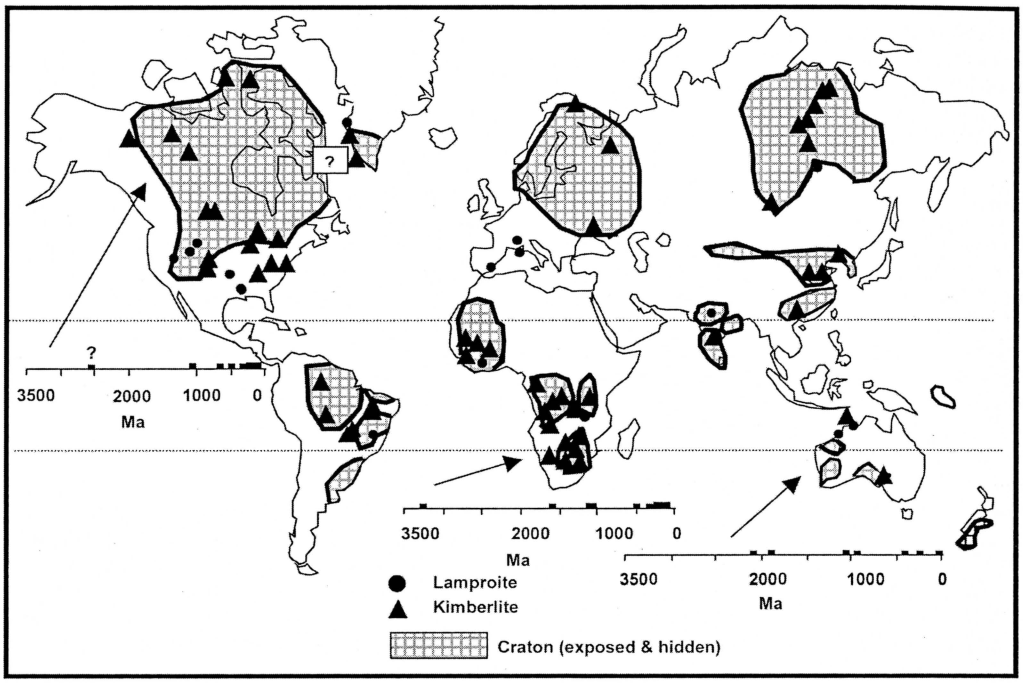
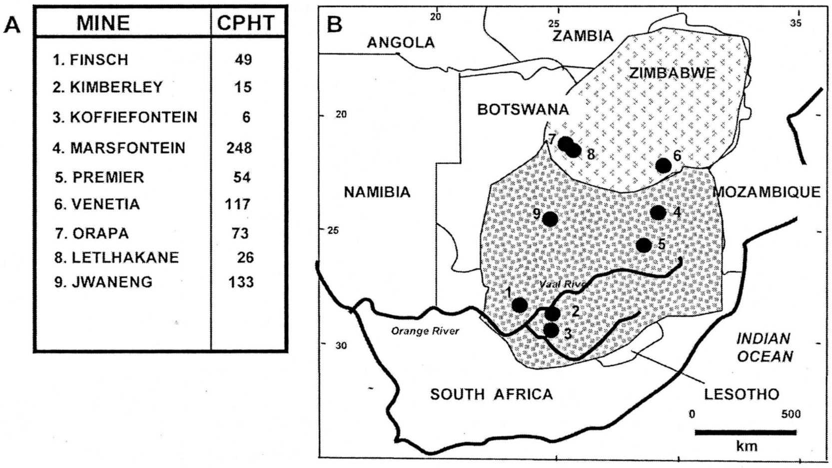


Fig. 7. Distribution of kimberlite/lamproite clusters on the cratons together with their age ranges (largely based on Nixon 1995).


A

MINE	CPHT
1. FINSCH	49
2. KIMBERLEY	15
3. KOFFIEFONTEIN	6
4. MARSFONTEIN	248
5. PREMIER	54
6. VENETIA	117
7. ORAPA	73
8. LETLHAKANE	26
9. JWANENG	133

Fig. 8. (**A**) Variations in diamond grade between kimberlites mined by De Beers on the Kalahari craton, based on production figures for 1998–2003. (**B**) Location of these De Beers primary deposits on the craton (source: De Beers annual reports).

America and Africa with 32% of the exposed Archaean crust in Africa and 27% in North America. Both these continents therefore have potential to yield high volumes of diamonds (Canada is the country with the largest area of Archaean crust (Janse 1993)). However, it is the interactive craton (i.e. including the craton, now partly buried but which has interacted with younger erosion cycles) that is the key influence on volumes of diamonds generated and the extent of that influence has yet to be determined. In the same way, for any continent, a formerly extensive craton may have been detached during continent break-up, possibly leaving or taking with it some of the diamonds dispersed out of the existing pipes.

Fertility

The fertility of cratons with respect to diamonds is determined by the time range over which diamond-bearing kimberlite intrusion has taken place, the abundance of kimberlites intruded at any one time and the grade and purity of the diamonds in the kimberlites. There appears to be growing evidence for world-wide episodes of diamond formation beneath cratonic blocks. Studies by Shirey *et al.* (2002) indicate that diamonds have been available below many cratons, including the Slave and Siberian cratons, since *c.* 3.2–3.4 Ga. Lamprophyres dated at *c.* 2.67 Ga in the Proterozoic Abitibi belt have yielded diamonds (Ayer & Wyman 2003) and diamond-bearing kimberlites and lamporites >1177 Ma (Argyle) and others *c.* 20 Ma (Ellendale) are found off craton with apparently no Archaean rocks nearby (Atkinson 1986).

In both the North American and South African cratons, kimberlites of *c.* 1100 Ma have been dated and alluvial diamonds (implying the existence of primaries at the surface) have been recovered from the Witswatersrand basin, deposited between 3074 Ma and *c.* 2710 Ma (Armstrong *et al.* 1991). The extent to which other cratonic blocks have these older kimberlites is yet to be revealed, but many have suites extending back to *c.* 500–600 Ma and almost all have suites of Permian, Jurassic and Cretaceous diamondiferous kimberlites (Fig. 7).

The relative fertility of cratons is difficult to establish for a number of reasons. Some cratons are poorly known and have a short history of diamond exploration so that many kimberlites may yet be discovered. On others, many of the kimberlites have not been dated and in some it has not been possible to evaluate the grades within pipes. Even within cratons, kimberlites have a wide range of grades not always related to present erosion levels, so signifying a real variation in the original diamond xenocryst population.

Bearing in mind the caveats listed above, current evidence suggests that the Kaapvaal craton is the most fertile in the world. It has a range of ages of kimberlite intrusions and contains some of the richest pipes ever discovered (Figs 7 & 8). In addition, many kimberlites were intruded during each time slice and particularly during the Cretaceous. This high degree of fertility is thought to be partly related to the characteristics of the oceanic lithosphere possibly generated by subduction processes during Archaean and later crustal growth (De Wit *et al.* 1992; Carlson *et al.* 2000). Komatiites from the Kaapvaal craton have, for example, volatiles at >4% (Parman *et al.* 1997) and this volatile content may be a key factor in bringing diamond-bearing rocks to the surface. However, it may not be coincidental that the Kalahari craton is, topographically, the highest of the world's large cratonic blocks and the Aldan craton is, in places also quite high, with elevations in excess of 2000 m.

Geological history

The degree to which diamonds are retained or lost through time and the degrees of concentration through down-weathering are all important factors in deciding the quantity of the diamonds available for final release. The unique characteristics of cratons have some relevance to the loss-retention of diamonds and there are two characteristics of cratons that are particularly significant in this respect.

First, cratons typically have seismically fast roots extending to depths greater than 200–250 km. Samples, in the form of xenoliths in kimberlites, from the top 200 km of lithosphere are peridotites depleted in Ca, Al & Fe resulting in less garnet and a residual peridotite less dense than fertile mantle at the same temperature (Carlson *et al.* 2000). O'Reilly *et al.* (2001) have also calculated that Archaean lithospheric mantle is less dense than younger lithospheric mantle and these calculations are consistent with observed seismic properties. Archaean cratons therefore have a long history of buoyancy, a prediction that is consistent with the fact that stratigraphically younger formations commonly overlap onto them from thicker deposits in deeper basins off their margins (e.g. Bally 1989). For this reason they have, and have had for a considerable time, the potential to leak diamonds to surrounding areas.

Secondly, in addition to buoyancy there is the also the effect of the root or tectosphere (Jordan 1988) in controlling the post-formation history of the craton. The tectosphere is considered to be not only a thermal shield (Nyblade 1999) but is also able to resist delamination and fail to compress in the same way as younger crust (O'Reilly *et al.* 2001). However, cratons may break up by extension, as evidenced by the numerous rift valleys crossing them (Sengor &

Natal'in 2001), some eventually to translate into passive margins on craton dispersal.

Margins of cratonic blocks appear to undergo periods of extension when sediment and some of the diamonds eroded from primary and retained placers is dispersed from the comparatively elevated craton into the basins adjacent to it. However extensional events are frequently followed by compression on the craton margin and as the main craton resists this compression fold belts ride onto it to return sediment that was previously lost (Fig. 9).

In North America, orogens, at least as far back as the Neoproterozoic Grenville, have been thrust onto (in that case) the Superior Province and a number of other orogens have also converged onto the North American craton (Fig. 9A). A similar situation is seen in southern Africa where the Kheis, Namaqua-Natal, Damaran and Cape fold belts all converge onto the Kaapvaal craton (Fig. 9B). These converging fold belts are not only instrumental in sediment return but they are also usually accompanied by foreland basins that migrate toward the interior of the craton as the fold belts advance (Fig. 9C). These basins also have significance for the retention-loss of diamonds.

The foreland basin margin, distal from the fold belt (i.e. interfacing with the craton), receives sediment from the craton and so a potential diamond loss is incurred. In addition, the sediment in the foreland basins offers a host to kimberlite intrusions, as in the western Canada basin and in the Karoo basin of southern Africa. Foreland basin sediment can extend over the larger part of the craton. The Grenville orogen, for example, dispersed sediment 1000s of kilometres to the Slave province in NW Canada (Rainbird *et al.* 1992; Fig. 9A) as did the Franklinian–Caledonian orogen (Patchett *et al.* 2004).

Many foreland basins are marine, so placer deposits may develop along the migrating shorelines at the craton–basin margin during both advance and retreat of the basin edge (Fig. 12C). There is potential, for example, for the development of placers on the NE–SW migrating edge of the foreland basin to the

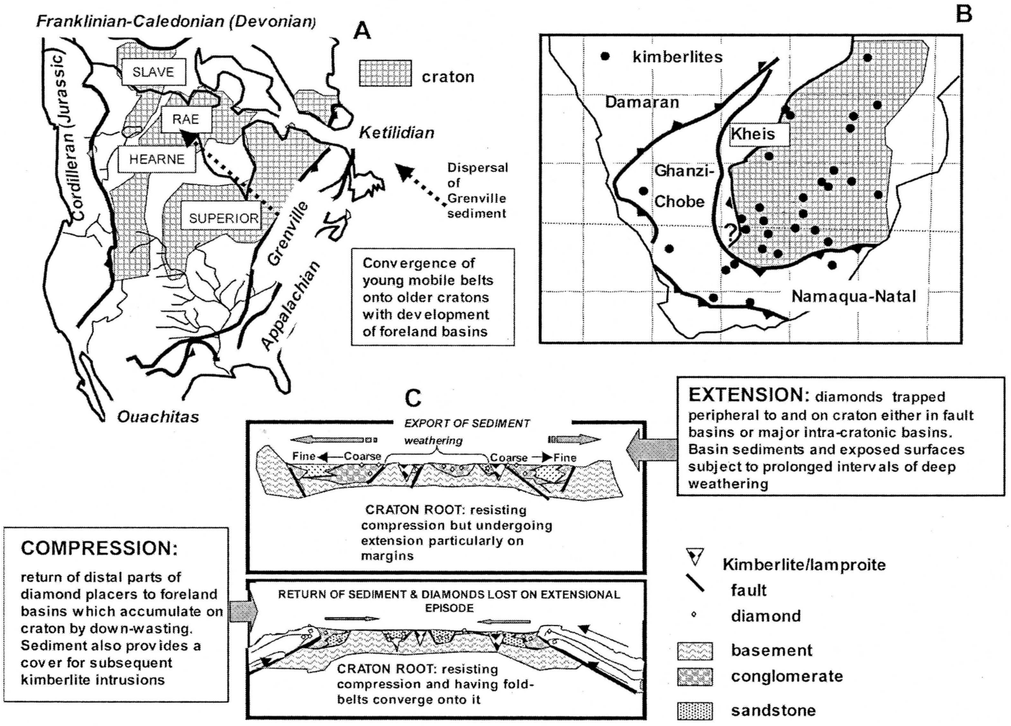


Fig. 9. The convergence of orogens peripheral to the cratons of (**A**) North America and (**B**) South Africa. Most converging orogens are accompanied by foreland basins, which, in the case of the Grenville is known to have dispersed sediment widely over the Canadian shield. (**C**) is a section illustrating some of the processes thought to occur during the extensional–compressional cycle.

Cape fold belt (Behr 1965; Catuneanu *et al.* 1998).

As cratons, away from the zone of convergence, passively receive the sediment rather than actively subside to accommodate it, much of the foreland basin sediment is lost when the converging mountain mass is eroded down and the basin inverts. At this point any newly intruded kimberlite suites are subject to erosion and if the time of inversion is optimum for both large-scale drainage development and conditions at the river terminus then the potential for mega-placer development is enhanced.

In the Kaapvaal instance, late Neoproterozic–Cambrian sediments of the foreland basin to the Damaran–Gariep fold belts are still preserved (Germs 1995) as are the sediments of the foreland basin to the Palaeozoic Cape fold belt (Catuneanu *et al.* 1998). If the sediment from the earlier of these foreland basins had extended well onto the craton then they would have formed a host to kimberlite intrusions. The timing of kimberlite intrusion in relation to foreland basin development assumes some significance in this respect and two examples are given in Figures 10 & 11.

Drainage

Important prerequisites to the development of a mega-placer are: the accessibility to the final drainage network of diamond-bearing deposits on the craton or its borders, whether primary, transient or retained; the area of drainage basin and the proportion of it which is on-craton; the degree to which older drainage networks have robbed the craton of accumulated diamonds; and the sediment loads and efficiency of the drainage network to release diamonds.

The accessibility of diamonds to the drainage network: the nature of diamond retention

In order to synchronize the time of diamond delivery to the terminus with the optimum conditions for their concentration there, diamonds existing on the craton, primary or secondary, should be available to the drainage network in abundance for a specific time interval. Source areas releasing small quantities of diamonds over a long time-span may fail to yield sufficient for mega-placer development. The range of settings in which diamonds may be retained on the craton and their corresponding ease of access to the drainage are illustrated in Figure 12. Three situations are taken to illustrate this point: primary deposits in cover, pre-assembled placers and down-wasting on planation surfaces.

Primary deposits in cover

Many kimberlites have intruded a cover (often provided by a foreland basin). The rate of its

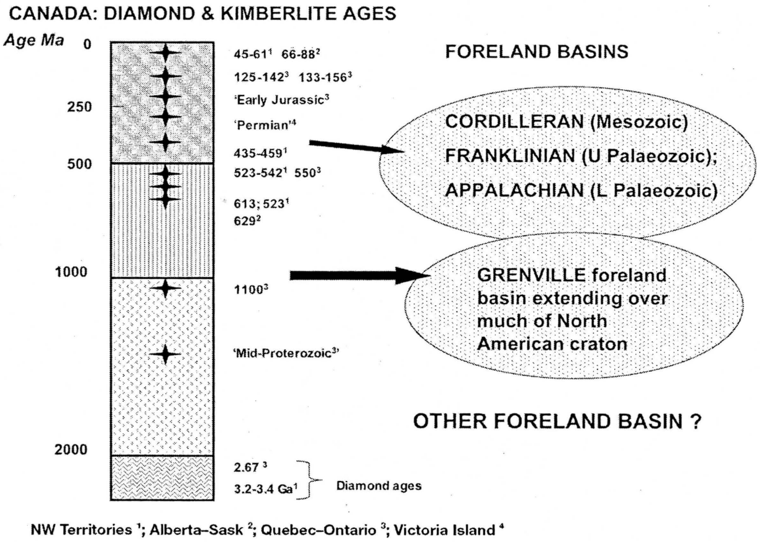


Fig. 10. Distribution of diamond-bearing kimberlites through time for the cratons of the Canadian shield and the presence of foreland basins when there was potential loss of diamond from the craton.

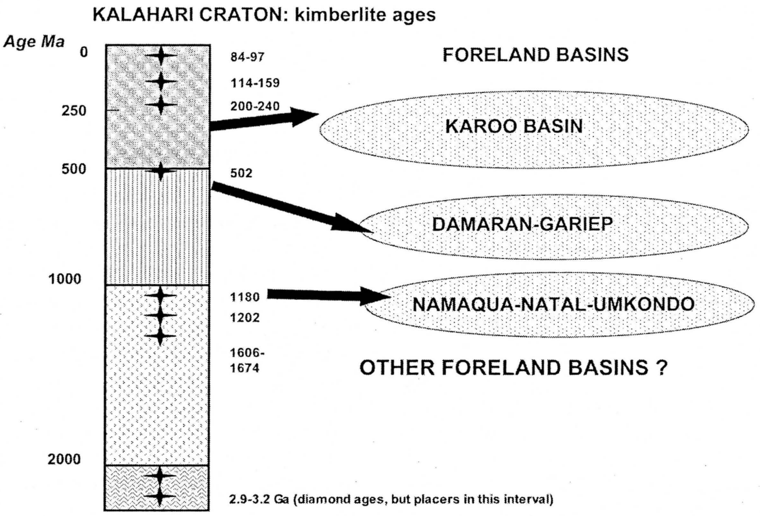


Fig. 11. Distribution of diamond-bearing kimberlites and times of possible leakage, Kalahari Craton.

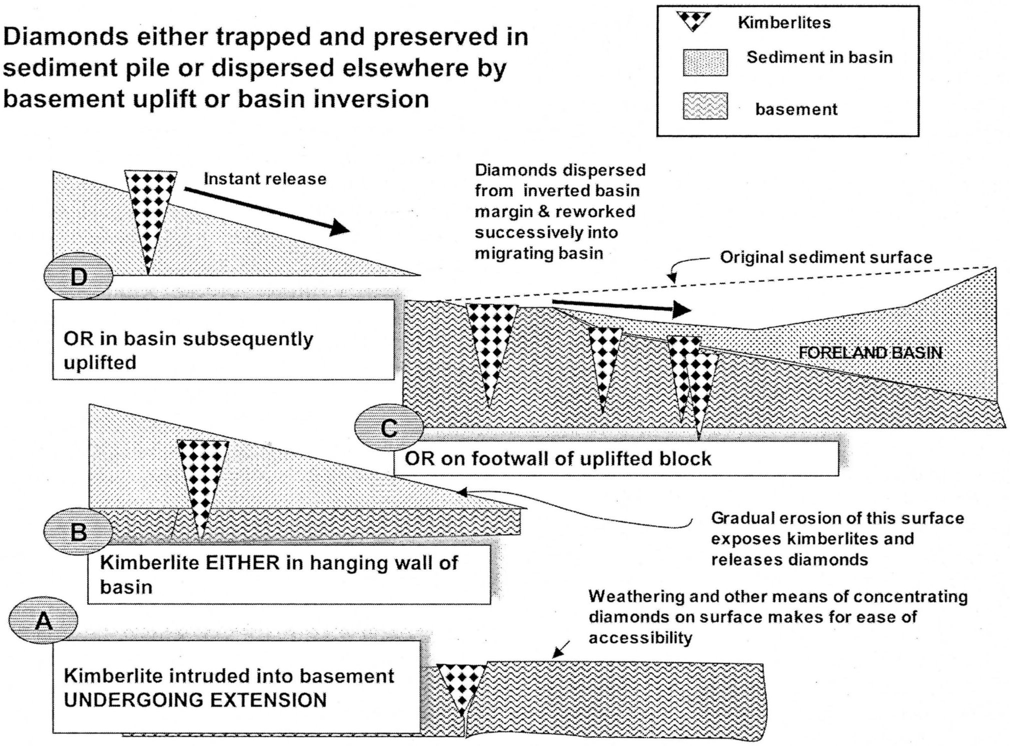


Fig. 12. Means of concentrating and retaining diamonds on cratons. (**A**) Gradual downwasting of the craton surface intruded by kimberlites. (**B**) Kimberlite being intruded into sedimentary cover. (**C**) Diamonds being eroded from uplifted craton for reworking on the margin of a migrating foreland basin. (**D**) Basin sediment uplifted and diamonds dispersed over the craton to find residence elsewhere.

erosion and removal to expose diamond-bearing rocks is important to the delivery time of diamonds to the placers. Exposed kimberlite pipes may continue below the current level of erosion to yield significant quantities of diamonds as the cover continues to be stripped off (Fig. 12). Field & Scott-Smith (1998) estimated kimberlitic breccias and diamond-bearing kimberlitic rocks to extend for more than 2 km below near-surface crater facies. Alternatively, they may be totally buried by sediments. Good examples of both these cases are seen in Angola where a group of northward-flowing tributaries (Luembe, Chiumbe Luachimo, Tchikapa) to the Kasai River are uncovering Early Cretaceous kimberlites buried by the Calonda (Cretaceous) and Kalahari (Cainozoic) Formations even before some had even had their tuff rings eroded away (Figs 4 & 12A,D).

The diamond-bearing kimberlites on the present Kalahari craton exist only because erosion has not yet removed them. In some cases, erosion has been extremely slow and a permanent drainage network has failed to reach them, either because of climate or because of the low rates of erosion caused by the lack of surface relief. Orapa (92 Ma) and Jwaneng (245 Ma) in Botswana probably remained in or near to crater facies for both climatic and relief reasons. Although Jwaneng was intruded into Lower Karoo sediments and has been subject to exhumation, from the regional geology, it is difficult to envisage a long burial–exhumation cycle being involved in the case of Orapa.

Pre-assembled placers

The accessibility of diamonds to the final drainage network of the river generating the terminal mega-placer is greatly enhanced if discrete placer deposits are already gathered within or near to the final drainage network. In North Australia, New South Wales and Borneo, for example, there are several small detached retained and transient placers that would possibly yield larger, concentrated and commercially viable deposits if they were all in reach of a larger drainage network. A variety of sources over a wide area and a dearth of larger drainage networks precludes this possibility.

In marked contrast, abundant commercial diamond placer deposits have existed in the present Orange–Vaal drainage basin since at least Cretaceous times (Stratten 1979; de Wit 1996, 2004; Fig. 17). When this drainage basin was rejuvenated in Tertiary times ample transient and residual placers had already been gathered on the craton, some during a more humid Cretaceous climate, so that whatever the contribution from primary sources, these secondary sources ensured a diamond supply at the right time.

Down-wasting on planation surfaces

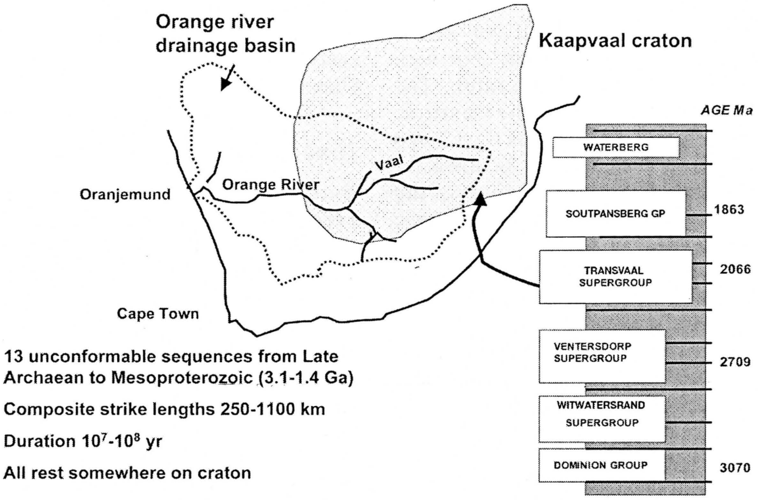
Down-wasting significantly increases the diamond concentration of weathered products by more than ten times the grades of the host gravel (Wagner 1914; Marshall 2004). Cratonic relief has been mildly positive since post Archaean times and many unconformities, weathered surfaces and palaeosols have developed on them, some extending back 3.0 Ga (see Gall 1999 for examples). Down-wasting of this type has taken place over long periods of time on the Kaapvaal craton (for example Cheney & Winter 1995; Fig. 13). Many pre-1 Ga kimberlites may have been eroded and the diamonds held in palaeosols, or upgraded and dispersed into intra-cratonic basins or basins peripheral to the craton.

The drainage basin

Large rivers with high discharges have large drainage basins and any part of the drainage basin not on the craton is potentially contributing sediment but no diamonds to the final placer. Mega-placers should therefore have a high proportion of their drainage basins on the craton or on those fringes that may have diamond-bearing rocks. Another significant factor is the volume of sediment transported by the river system, determined largely by relief and climate. Cratonic blocks, whatever their elevation, tend to have low relief, but the upper reaches of drainage networks crossing a craton may be in marginal fold belts or uplifted blocks with high relief and be tectonically active. These drainage networks may therefore transport a good deal of sediment onto and over the craton to the terminal placer. Three examples are taken to illustrate the significance of this point.

The Lena River drains mainly the Aldan and partly the Anabar cratons in Siberia (Fig. 14A). The total area of exposed craton in this region is 482 500 km^2 and the total drainage basin area for the Lena is 2.5×10^6 km^2 with *c.* 25% on the craton. This leaves 75% of the drainage from off-craton rocks ranging in height from sea level to more than 2900 m above sea level (masl) in the Khrebet and Verkonoyansky Ranges. Although these ranges are comparatively old, sediment loads dispersed into the tributary rivers such as the Aldan are likely to be high.

The Congo River illustrates a different



13 unconformable sequences from Late Archaean to Mesoproterozoic (3.1-1.4 Ga)

Composite strike lengths 250-1100 km

Duration 10^7-10^8 yr

All rest somewhere on craton

Fig. 13. The early history of the Kaapvaal cratons illustrating the numerous unconformites likely to have been accompanied by intensive weathering on exposed craton surfaces (from Cheney & Winter 1995).

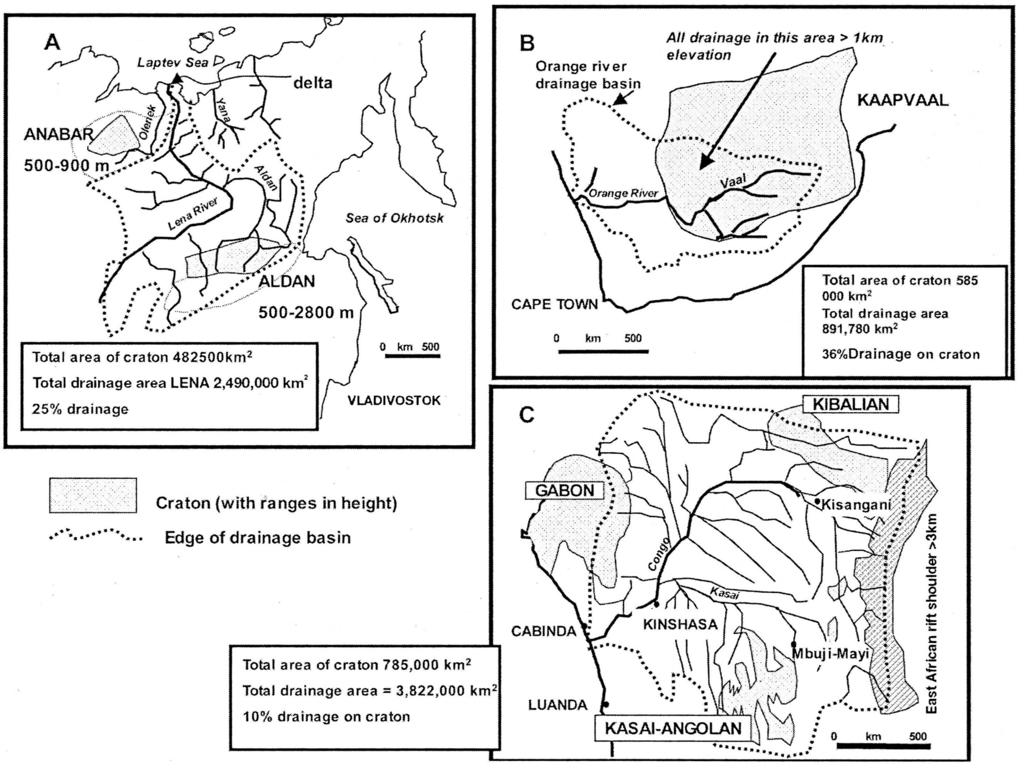


Fig. 14. The relationship between craton area, drainage basin area and the percentage overlap in both for three selected major river systems. (**A**) The Lena River, Siberian craton; fine dotted line marks the subsurface extent of cratons. (**B**) The Orange River, Kaapvaal craton. (**C**) The Congo River, for the Congo craton. The area of the Congo craton is estimated to be 5.7×10^6 km^2 (Goodwin 1996), but is largely covered by the thick sediments of the Congo basin.

situation. The total area of craton is *c.* 785 000 km^2 and the Congo River has a drainage basin area of 3.7 × 10^6 km^2 but with only *c.* 10% draining the exposed craton. The Congo River, initiated only during the Cenozoic (Reyre 1984; Droz *et al.* 1996) crosses the Congo basin which has low relief, but the headwaters (via the Lualaba and Uele) drain sections of the East African rift system where there are some of the highest elevations in Africa at more than 3000 masl. This region has considerable relief, continual uplift, substantial sediment input and is off craton (Fig. 14C).

In marked contrast the Kaapvaal craton has a total area of 585 000 km^2, and is drained by the Orange–Vaal Rivers with a drainage basin area of 891 780 km^2 (Bremner *et al.* 1990), *c.* 36% of which is on craton (Fig. 14B). Although the bulk of the drainage basin lies above 1000 m there is little relief, with the exception of the headwaters in the Drakensberg, where the relief is steep, and elevations reach 3200–3400 m but has little evidence of a high rate of uplift. Sediment off the Drakensberg is dispersed westwards to the Atlantic via the Orange River drainage but also eastward, in short reach rivers, to the Indian Ocean.

Time of drainage development

To release the greatest abundance of diamonds, a regional drainage network covering as wide an area of craton as possible needs to develop at the optimum time. The pool of diamonds retained within the craton and its immediate boundaries will be continually enhanced by repeated additions if newer kimberlites are added to the craton and down-wasting continues. The younger the drainage development the richer the source will be with respect to diamonds: early large-scale drainage networks will potentially take away those accumulated diamonds (Fig. 15).

In the case of North America (Fig. 16), whatever large drainage networks might have existed prior to the Carboniferous, Archer &

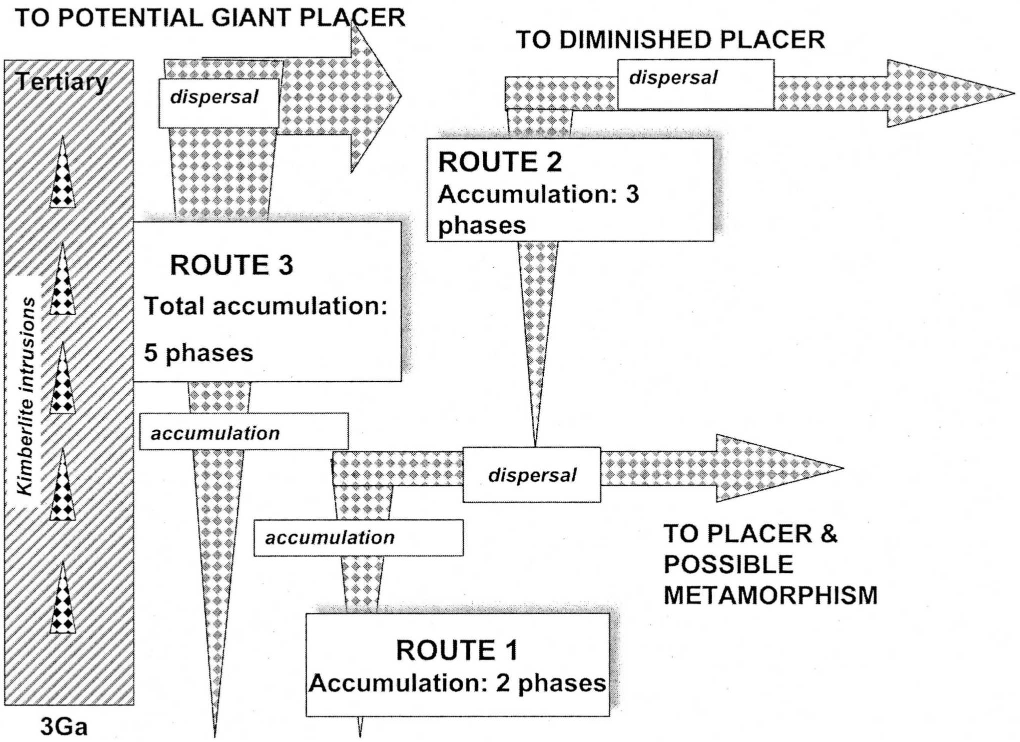


Fig. 15. The importance of retaining diamonds on the craton in order to yield a mega-placer. The left-hand column has five phases of diamond-bearing intrusions. In Route 1 a large-scaled drainage removes the accumulated diamonds from two phases of intrusion; then a subsequent drainage removes the other three in Route 2. Route 3 sees a late-stage drainage having access to the total diamond-bearing phases and is therefore most likely to yield a mega-placer.

Greb (1995) have demonstrated that Amazon-scale drainages, covering much of the Superior province, were certainly present in the Carboniferous deposits of the mid-West. This drainage probably links with the proto-Mississippi flowing into the Illinois basin-embayment (Potter 1978). Sediment from the Slave craton would almost certainly have dispersed into a series of Palaeozoic basins developed along the route of the McKenzie River.

A Cenozoic river supplying sediment to a basin extending from off Baffin Island to the sea off Labrador had an estimated drainage basin covering parts or a great deal of the Superior, Hearne, Nain and Rae cratons (McMillian 1973). Then, finally, in addition to the earlier Proterozoic glaciations, a major glaciation has occurred in the last *c.* 2 Ma. The extent to which these removed kimberlitic material (discussed in greater detail later) is not known but diamonds have been recovered from glacial outwash sediments in the American mid-continent (Gunn 1968) and kimberlite blocks and tracers in glacial deposits on the Canadian shield (e.g. Baker 1982).

In South America, the Guyanas and Guapore–Sao Fransico cratons (the Central Amazonian Province) are divided by the present Amazon drainage and Amazonian Basin which, together with its extension to the SW, is underlain by a series of basins that have existed since at least Silurian times (Colombo & Macabira 1999; Milani & Zalán 1999). Here, and in the North American craton, where at least four major basins developed on or near to craton edges (the Williston basin, Hudson Bay basin, Michigan basin and Illinois basin; Bally 1989), whatever diamonds were contributed to these basins are now buried.

In the case of the Kaapvaal craton there is no evidence yet for a large-scaled drainage prior to the development of the Orange–Vaal River basin with the possible exception of its eastern margin (Moore & Larkin 2001). Neoproterozoic, Ordovician and Permo-Carboniferous ice ages have all been possible agents of diamond loss. The Permo-Carboniferous glaciation on the Kaapvaal and adjacent cratons may have transported sediment as far west as the Parana basin in Brazil and the Colorado basin, west of

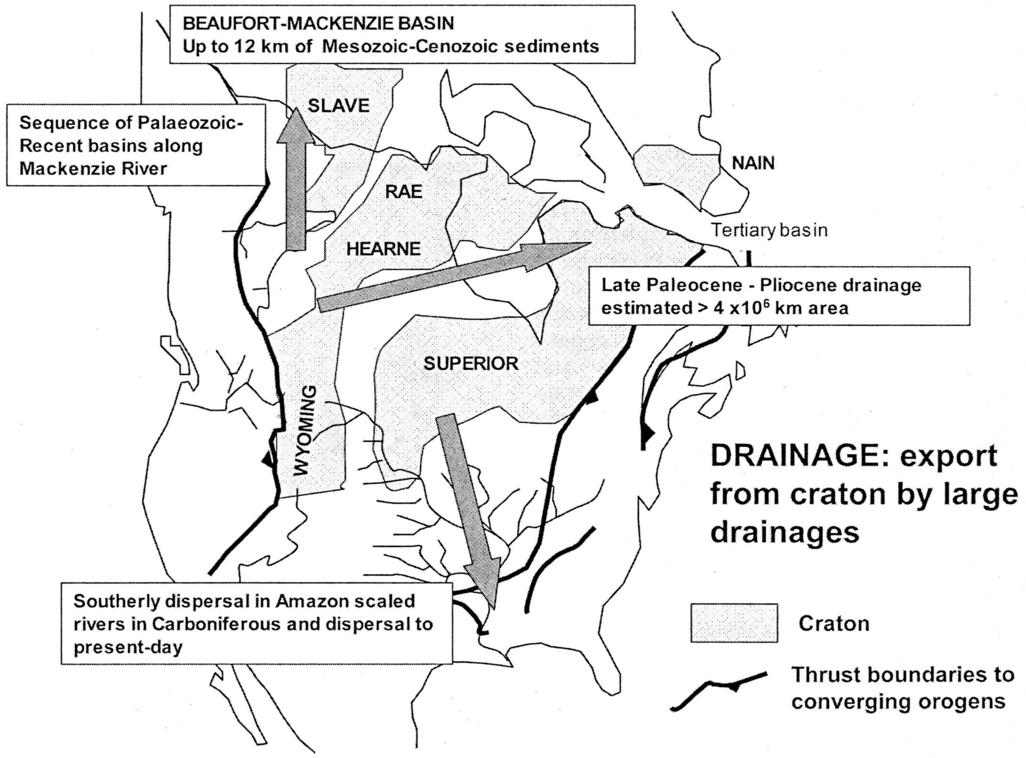


Fig. 16. Large river systems known to have drained parts of the North American cratons and therefore may have removed diamond deposits existing up to the time when the drainage was initiated (see text for sources).

Argentina (Visser 1990; Moore & Moore 2004). In the case of the Kaapvaal, some of that sediment reached the Karoo foreland basin and therefore remained within the subsequently developed Orange River drainage basin.

Sediment loads

Large African rivers have lower sediment loads compared to all others (Milliman & Meade 1983), the result of them draining cratons with relatively low elevation and low relief. Africa, like Australia, also lacks substantial marginal active mountain chains. However the East African rift system, and to a lesser extent the Drakensberg and the Atlas reach more than 3000 masl. In marked contrast to Australia and the Canadian cratons, Africa has very large rivers with equally impressive drainage basins (the Congo being the second largest in the world).

Other cratons with major rivers and very large drainage basins differ from African ones in that the bulk of the discharge and sediment supply comes from adjacent, active uplifted blocks. This unwanted sediment load dilutes the contribution from the craton itself. The Amazon, McKenzie and rivers traversing the cratons in India, for example, already carry a substantial volume of sediment before they cross the cratons.

Although sediment loads are relatively low in African rivers and there are also significant differences between them. The Congo, for example, is sourced in the East African rift flanks; a drainage basin with precipitation of 1000–2000 mm a^{-1} and a sediment discharge of 43×10^6 t a^{-1}, contrasts with the drier, more seasonal Orange River drainage basin. In the latter, the bulk of the drainage basin experiences precipitation of less than 500 mm a^{-1} and a sediment discharge of 17×10^6 t a^{-1}. That state has probably existed for a substantial part of the Cenozoic after the onset of initial aridification began (Ward & Corbett 1990), and at a critical time when the bulk of the diamonds were carried down.

Rejuvenation

Given a constant climate, when base level falls and adjustments are made in the river systems, drainage density increases and more residual placer and kimberlite deposits are brought into the drainage network. In addition, rejuvenation, in providing steeper slopes also increases the energy in the landscape, resulting in both increased transport efficiency and potential for diamond sorting in the rivers. At the same time, incising rivers cut through any soft cover and may expose primaries and bedrock and both the bedrock topography and the clasts yielded from it provide the trapsites for diamonds.

As discussed previously, the presence of kimberlites on any cratonic block, particularly those in crater facies, is a testament to the inefficiency or lack of available time to scour the craton free of its diamonds. Many of the Angolan Cretaceous pipes for example, were buried by small-scale river systems that laid down the Calonda and its equivalent Formations in central Africa. These streams were either grossly inefficient at erosion (possibly because they were infilling a subsiding basin) or had little time to remove the kimberlitic crater facies, in places tuffs, which spread onto the surface (Fig. 4). On a larger scale, the presence of crater facies kimberlites, e.g. Premier (*c.* 1250 Ma), Venetia (530 Ma), and Orapa (*c.* 90 Ma) on the Kalahari craton illustrate a lack of intensive erosion and inefficient removal of diamond-bearing rocks (Fig. 17).

Unusually, coastal uplifted blocks may yield coarse materials to the terminal placer as the river cuts through them before entering the sea.

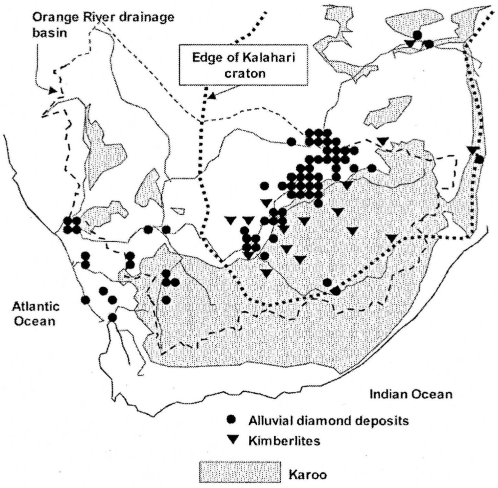


Fig. 17. Distribution of kimberlites and alluvial deposits with respect to the Orange River drainage basin. Kimberlites still yielding diamonds range from *c.* 1200 Ma and workable alluvial (transient) deposits from the Cretaceous. Diamonds have been recovered from Archaean basins, making this drainage near to route three of Figure 15 (based on de Wit 1996).

The terminal placer: the Orange River and related placers

Diamonds in substantial quantities and of exceptional quality are found on the SW African coast and shelf, north and south of the present Orange River mouth. There are two pairs of major diamond accumulates (Fig. 1) both possibly linked to an evolving drainage system related to, or directly the result of, the Orange–Vaal River. The most significant pair consists of gravel beaches and desert deflation deposits along the Namibian coast north of the Orange River, and corresponding submerged equivalents offshore. The second pair comprises gravel beaches and alluvial deposits in onshore Namaqualand and a diminished offshore counterpart. Together these two broad areas have yielded 120 × 10^6 carats, more than 95% of them being gem quality. The Namibian sector has yielded *c.* 80 × 10^6 carats and the Namaqualand *c.* 40 × 10^6 carats to date (Corbett 1996; Oosterveld 2003; Table 1). The additional estimated deposits remaining in Namaqualand bring that total to 50 × 10^6 carats and the past Namibian production plus estimated resources amounts to more than 100 × 10^6 carats, making each area a mega-placer deposit.

The total estimated potential for all four placers is 1.5 × 10^9 carats according to Levinson *et al.* (1992). This estimate, which depends heavily on the estimated thickness of the Karoo cover (and consequently the former height of the kimberlite pipes in South Africa), is disputed and the total diamond count in the southwestern African placers may be only 30% of that value.

Westward draining river systems, including the Orange, Buffels, Groen and Olifants all have terraces along them containing diamonds and each has made a contribution to the terminal placers. There is a well-documented decline in diamond size northward along the coast from the present Orange mouth (Hallam 1964; Sutherland 1982; Schneider & Miller 1992, Figs 18–20). With no or few other likely contributors, the Orange River has been identified as the point source of the diamonds to the coast in this instance.

There is also a northward decline in the diamond size along the Namaqualand coast, beginning at or near to the mouth of the present Olifants River (Rogers *et al.* 1990; Fig. 18). However in this case, there are a number of potential in-put points for diamonds, highlighted by Stevenson & McMillan (2004).

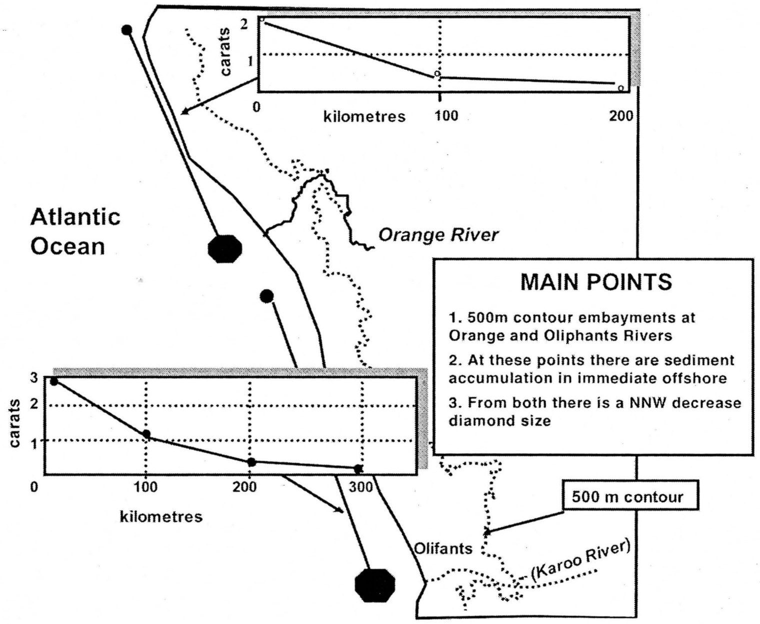
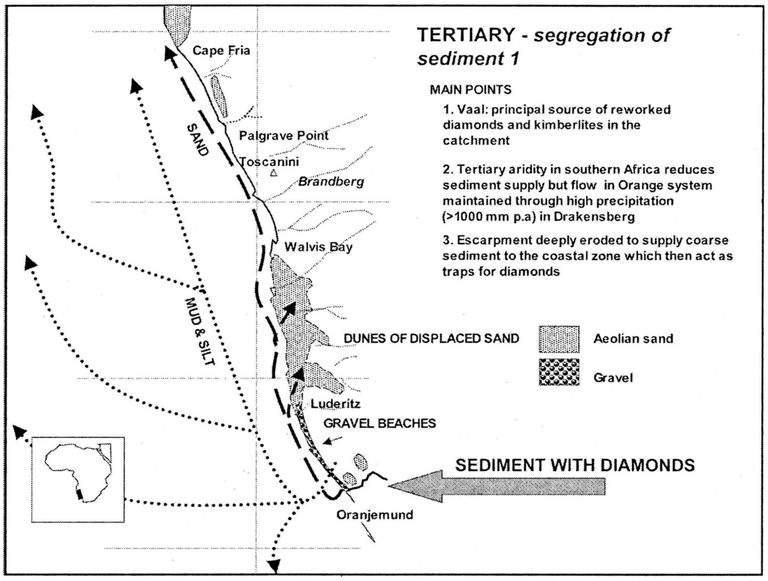


Fig. 18. The variation in diamond size along the SW African coast and some of the evidence for two principal mega-placer systems.



TERTIARY - *segregation of sediment 1*

MAIN POINTS

1. Vaal: principal source of reworked diamonds and kimberlites in the catchment

2. Tertiary aridity in southern Africa reduces sediment supply but flow in Orange system maintained through high precipitation (>1000 mm p.a) in Drakensberg

3. Escarpment deeply eroded to supply coarse sediment to the coastal zone which then act as traps for diamonds

Fig. 19. A reduced sediment input (cf. Fig. 21) enters a neutrally buoyant shelf where there is vigorous coastal energy. The fractionated sediment disperses with fines moving off the immediate shelf, a strong onshore wind returning sand to land along the arid coast and the gravel accreting to the coast immediately up-drift from the river mouth (as it would have done for the various sea-level fluctuations over the broad shallow shelf).

Aspects of the Mesozoic–Recent geological history of the west coast and Orange River drainage basin

The Orange–Vaal drainage is the principal route along which the diamonds have been transported from the interior to the coast (e.g. Hallam 1964). Like many South African rivers, it has all the characteristics of a superimposed meandering river drainage, cutting across the strike of the Neoproterozoic fold belts (Wellington 1958). Offshore of its present mouth and dominating the stratigraphy of the continental shelf lies the Cretaceous Kudu delta of Turonian–Maastrichtian age (*c.* 93–70 Ma; Wickens & McLachlan 1990; Clemson *et al.* 1997; Aizawa *et al.* 2000; Brown *et al.* 1995, Fig. 21 but see Stevenson & McMillan 2004). Ward & Bluck (1997) suggested that the wavelength of the meander loops was consistent with a large river which might have deposited this delta and then in post-Cretaceous time, imposed itself through a Karoo cover onto the local Precambrian basement, retaining an approximate memory for its original meander loop size.

Key exposures at both the river mouth and northwards from it comprise gravel with clasts of, amongst others, agate and chalcedony. These are typical of the Vaal and upper reaches of the Orange drainage with the minerals having a provenance in the Ventersdorp (Archaean) and Drakensberg (Jurassic) lavas. At one locality near Bogenfels, *c.* 150 km north of the present river mouth, a sedimentary sequence containing this distinctive gravel clast assemblage has been dated by its faunas as Eocene (*c.* 43 Ma; Siesser & Salmon 1979; SACS 1980) and this clast assemblage is regarded as the signature of sediments of that age (Kaiser 1926). Agate clasts up to 100 mm in diameter are recorded from these deposits and, close to the current Orange River mouth, are accompanied by quartzite cobbles and small boulders. Their presence implies a considerable change in the slope of the Orange River and its drainage from the one that deposited the fine-grained Kudu delta in the Late Cretaceous.

These Eocene deposits indicate that between *c.* 70 Ma (the estimated final phase of deposition of the fine-grained Kudu delta) and *c.* 43 Ma most or all of the Orange River basin, and by implication most of southern Africa, had been uplifted sufficiently to expose the basement beneath its Karoo cover and access coarse sediment from the eastern margins of its drainage basin. This resulted in the channel becoming steeper and able to transport this substantially coarser sediment. The precise

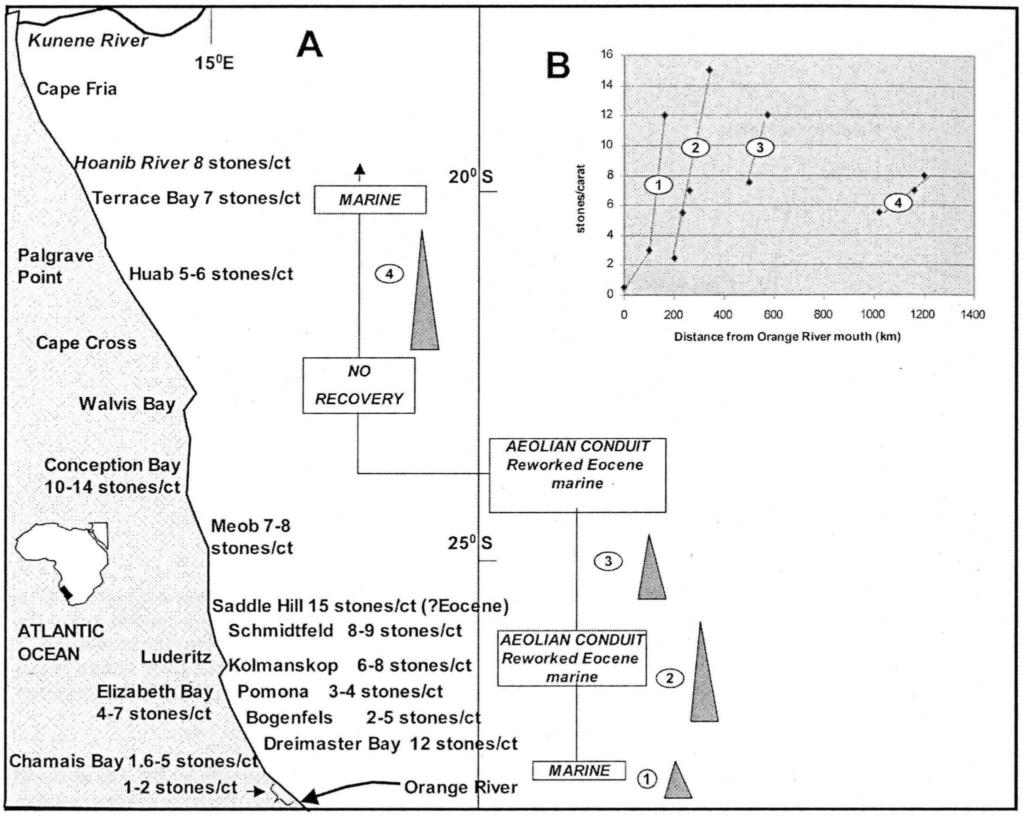


Fig. 20. The changing diamond sizes along the Namibian coast. In **B** the *y*-axis of the graph records the number of diamonds/carat. 1–4 refer to the dispersal units each with a differing rate of diamond-size decline and may reflect both the redistribution processes (such as sheetwash and aeolian influences) as well as differing rates of diamond-size decline for differing periods going back to the Eocene (data from Hallam 1964).

nature and timing of this uplift event has yet to be determined; however, it is partly recorded in a sub-Tertiary unconformity offshore. Aizawa *et al.* (2000) estimated an uplift of *c.* 1000 m on this western margin of SW Africa. The occurrence of a major epeirogenic uplift in this region of southern Africa is supported by the estimated elevation of both undeformed Permo-Carboniferous Dwyka Group shallow marine sediments now at 1200 masl in central Namibia (Martin & Wilczewski 1970) and Permian Ecca beach deposits at similar elevations near Bothaville in South Africa (Behr 1965). This estimate also approximates to the height of the base of the Neoproterozoic–Cambrian Nama Group that crops out *c.* 100 km inland at *c.* 1000 masl and comparatively young uplifts may be partly a reason for the preservation of these exposures.

This uplift event was of great significance in the development of the placer. It rejuvenated an existing river system making it able to cut back into the craton and through any cover to access the diamond-bearing rocks that were widely available there. Concomitantly, in increasing the slope of trunk and contributory streams, coarse sediment (including diamonds) was transported out of the interior and a more vigorous route to the Atlantic was established, resulting in an upgrading in the quality of the transported diamonds.

Through this major uplift, and critically for placer development, the Orange–Vaal becomes a rare example of a river with a drainage area of almost 1 million km^2, with an abundant supply of coarse gravel at its mouth. In cutting through the coastal Neoproterozoic fold belts, the river and its tributaries yielded clasts, up to 5 m in diameter, near to the terminal placer thereby delivering materials for the trapping of the diamonds. It also provided the tools, in the

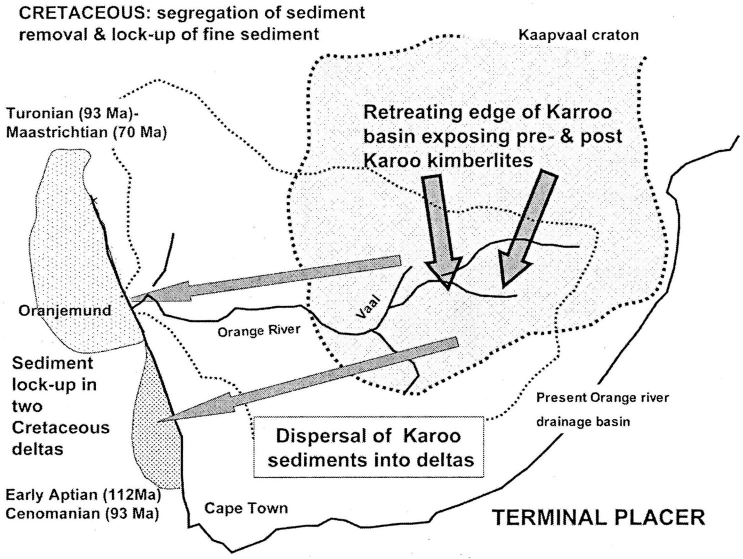


Fig. 21. Soft Karoo cover is easily removed and deposited in two deltas in the offshore. Thus sediment with the potential to dilute the Tertiary placer is disposed of in areas of subsidence and is no longer a contributor to the processes at the terminal placer site. In addition, the latest batch of kimberlites intruded into the craton are exposed to erosion. The rate of sediment yield is thought to have reduced greatly when the river system began its incision into the various basement rocks thus reducing the sediment supply to the terminus. Deltas adapted from Brown *et al.* 1995.

form of durable, large quartzite clasts, derived mainly from Nama Group with which to cut deep potholes into the coastal bedrock platforms (Jacob *et al.* in press) as well as acting as long-lasting hosts for diamond accumulation in the Namibian littoral environments. This Early Tertiary uplift event, in initiating the flush of coarse gravel and accompanying diamonds from the interior craton to the coast, is considered to be the onset of the formation of the Orange River–Namibian mega-placer (Fig. 6).

A more humid climate in Late Cretaceous times allowed the palaeo-Orange drainage to easily erode into the soft Karoo cover and dispose of it in a relatively short time. This resulted in a low gradient river removing unwanted Karoo cover to a delta (where some, if not most, was sealed from further interaction) and also exposing kimberlites, intruded into that cover, to a more vigorous, rejuvenated Tertiary drainage (Fig. 21).

The Atlantic coast of southern Africa is amongst the most energetic in the world. The coast receives almost continuous southwesterly swell from the South Atlantic storm belt and has, in addition, a dominantly southerly quadrant, coastal wind system created by the south Atlantic anticyclone superimposed on a cold ocean fringing a warm landmass. The swell has the effect of transporting sediment at depth on the shelf and periods of strong onshore winds create local wave energy, particularly effective along the coastal strip. Both swell and locally generated wave orthogonals are oblique to the shore so this energy is converted into a substantial northbound long-shore drift. The arid coastline has limited vegetation to hinder the movement of sand off the coast and onto the land, where it has accumulated in desert sand seas.

In the present coastal regime, 90% of the waves have a height falling within the range 0.75–3.25 m with an average 1.75 m for winter and 1.5 m for summer (Rossouw 1981; de Decker 1988). The coast is subject to long period swell with 53% of the waves having a period over 12 seconds and a height of more than 5 m. Energy from this swell is capable of moving cobble sized gravel, at depths of 15 m (de Decker 1988); submersible dives have also detected wave-generated water movements capable of transporting sediment at 120 m depth.

In addition there are significant ocean currents moving the water mass on the shelf, the most well known and probably most significant of which is the Benguela. The Benguela current has a northward velocity of 288 m/hour; the deeper South Atlantic central water and Atlantic intermediate water currents move south at *c.* 208 m/hour (Bremner & Wills 1993).

Seismic sections reveal that since the post-Cretaceous unconformity, large areas of the shelf, particularly those immediately north and south of the Orange River, have accumulated little sediment and therefore have undergone minor, if any subsidence in that time (Aizawa *et al.* 2000). The present shelf is both wide and shallow (Figs 1, 22) and a substantial proportion of it is under the influence of the vigorous wave and current regimes, factors critical to the ultimate generation of the mega-placer.

The combined effect of the wind–wave system, longshore drift, shallow, neutrally buoyant shelf with little slope and arid coastal climate has been to segregate the sediments by grain size and disperse them into discrete areas of accumulation (Fig. 19). In the Orange River–Namibian coast placer system, gravel is returned to land in the immediate vicinity of the river mouth, where, under the influence of the strong longshore drift it migrates northward, mainly in the intertidal and nearshore subtidal zone, for a distance over 200 km. The sand also moves mainly along the coast in a narrow, usually less than 3 km wide, subtidal zone (Corbett 1996) and northwards, sand beaches replace gravel, possibly continuing northward for *c.* 1000 km. Sand, transported on-shore from the offshore conveyor, is trapped in J-shaped bays, where wave refraction, in transporting sand around headlands, deposits large volumes onto relatively quiet beaches. Given the long period waves, sand build-up on the beaches would be potentially high but from there it is rapidly transferred onto the land by strong onshore winds and carried in fast moving barchans (up to 100 m a^{-1}; Corbett 1996) to join the main Namib Sand Sea (Rogers 1977; Lancaster & Ollier 1983; Lancaster 2000).

In this highly energetic regime, the mud fraction is dispersed into the marine water column and moves offshore. Although it may settle on the floor temporarily (Bremner &

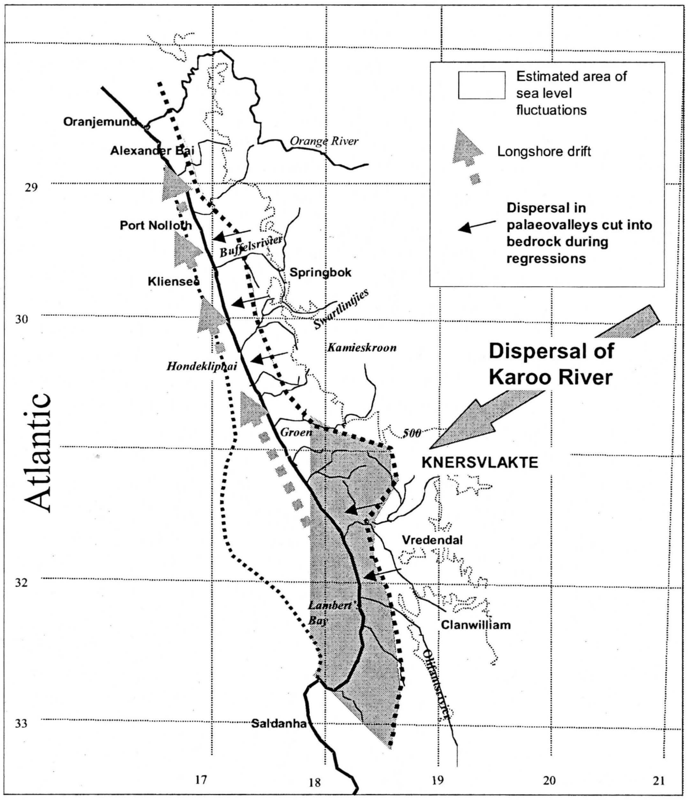


Fig. 22. The area covered by possible sea-level fluctuations and the areal distribution of diamonds over the shelf and bordering land for the Namaqualand mega-placer.

Willis 1993) the mud generally finds a more permanent residence on the continental slope (Aizawa *et al.* 2000), and in subsiding parts of the shelf to the north (Holtar & Frosberg 2000) or to a lesser extent to the south of the Orange River mouth. This fractionation of the sediment is highly significant for placer development as the coarser diamonds move with the gravel fraction and are preserved, relatively free of other diluting sediment, in gravel beaches and their associated wave-cut platforms.

The exposures at the river mouth and to the north, near Buntfeldschuh show that the incision of the Orange drainage basin, the delivery of coarse clasts, the wind system, longshore drift and little subsidence on the shelf have all been operating to some degree since at least the Middle Eocene (*c.* 43 Ma). Sections dated as Eocene expose shoreface and possible sand–gravel beaches, and a section with strong Eocene clast type signature at Buntfeldschuh also has dunes with northeasterly dipping cross-bedded strata indicative of an onshore southerly wind system at that time (Corbett 1993). The critical point is that these conditions, effecting the diamond removal from the interior and their concentration on the contemporary shorelines, were all established within the same time frame.

The Namibian mega-placer

The Namibian mega-placer onshore is a relatively thin strip of continuous beach and related deposits, *c.* 3 km wide, near the Orange River mouth tapering northwards to intermittent pocket gravel or raised beach deposits less than 300 m wide. The most economically significant sector of this placer lies between the Orange River mouth and Chameis Bay, a distance of *c.* 110 km. However, the total length of the dispersal system is possibly more than 1000 km as small diamonds have been recovered north from the Orange River mouth at Hoanib on the Skeleton Coast (Fig. 20). Here chalcedony and small agate pebbles occur, that are known to have a provenance in the Orange River drainage basin and to be associated with diamonds both there and nearer the mouth of the Orange River.

The placer is at its most complete and continuous near the Orange River mouth, where it comprises a sequence of coarse gravel beaches stacked from old in the east and young to the west. The oldest preserved beach at +10 to +30 masl is Late Pliocene; they decline in height through the Pleistocene to a Mid-Holocene beach at *c.* +2 masl (see Pether *et al.* 2000). Farther north, preservation of the older (higher) beaches is fragmentary.

The southern beaches, exposed in mine workings and sample trenches, also reveal a sequence of beach types, with spits and barrier beaches in the south, replaced by barrier beaches, linear and finally pocket beaches in the north. Each beach type, and the subenvironments that make them, have a variable potential for retaining diamonds (Spaggiari *et al.* in press). These beaches and the often competent, potholed, Neoproterozoic footwall on which they rest are the essential trap-sites holding the littoral diamond population (Hallam 1964; Apollus 1995; Jacob *et al.* in press). The beach gravel ranges up to boulder size and is dominantly Nama quartzite brought down by the Orange River in the south, augmented by local bedrock in the north.

The transient terrace placers along the lower Orange River, for some 100 km inland, contain diamond grades (measured in carats/hundred tonnes, cpht) and stone sizes (recorded in carats/stone, cts/stone) varying spatially along the channel length and through time (Fig. 6). The oldest diamond-bearing deposits in the lower Orange valley, close to the mouth, have an Eocene clast signature that, together with their marine counterparts preserved onshore further north, demonstrate a low grade (<0.5 cpht) and low stone size (<0.4 cts/stone) deposit. By contrast the next youngest fluvial deposits (estimated to be *c.* 25 Ma, and locally referred to as the Pre-Proto Orange suite) have grades up to 35 cpht and an average diamond size of 2 cts/stone. Early Miocene (*c.* 17 Ma) age terraces (Corvinus & Hendy 1978; SACS 1980; Pickford & Senut 2003; Bamford 2003) of Arries Drift Gravel Formation, locally called Proto-Orange deposits, have grades of *c.* 1–5 cpht and a stone size of 1–2 cts/stone. The topographically lowest terraces, known as the Meso Orange deposits (? Plio-Pleistocene) have <0.5 cpht but with a stone size up to 3 cts/stone (Fig. 6). From these data we conclude that there was an early flush of fine diamonds in the Eocene followed by a main flush recorded in pre-Proto terrace remnants (?Late Oligocene) and thereafter a declining population with the largest diamonds accumulating in the youngest deposits. This conclusion is supported by the increasing density of a clast population through time, beginning with siliceous clasts (Eocene), through epidote rich (pre-Proto) and banded iron formation (Meso).

As the bulk of the Namibian mega-placer comprises littoral gravel deposits of Late Pliocene–Holocene age, it was not supplied directly with diamonds from the Orange River. The immediate source for these deposits was older beaches that had accumulated off the Orange River mouth since the Eocene and which were reworked into the Late Cenozoic–Holocene beaches. Some intraclasts of marine conglomerate recovered from the Late Cenozoic–Holocene beaches contain a Miocene fauna and support this conclusion. In order to be accessible to reworking onto these Late Cenozoic–Holocene beaches, sufficient of the former deposits must have been exposed or not buried too deeply. At the same time, the older regimes needed to have been vigorous enough to remove unwanted sediment and concentrate both diamonds and the host boulder and cobble-bearing gravel, as occurs off the present Orange River mouth (Murray *et al.* 1970; Corbett & Burrell 2001).

Diamond-bearing beaches, much like the present ones, are likely to have existed since the Eocene: the time of significant diamond release from the craton. Subsequently there have been numerous changes in sea-level with a highstand at *c.* 170 masl (Eocene) and a low stand at *c.* 120 m below sea-level in the Pleistocene (ignoring the potentially lower, controversial Oligocene low-stand). To this we can add wave base, calculated by de Decker (1988) to be *c.* 30 m, but thought to be more than 60 m from submersible dives. Thus the whole width of the shelf possibly down to 200 m may have been within wave base at some time during the last 60 Ma. As the shelf and coastal strip have not undergone any substantial subsidence since the Early Tertiary, this fairly extensive shallow region, *c.* 150 km wide to 200 m below sea-level and tapering north to *c.* 30 km wide at Walvis Bay, would have been raked by marine processes. Consequently the diamond-bearing sediment brought down by the Orange River since the Eocene has been available for concentration and reworking at innumerable intervals over this extensive shelf.

Today, divers working at depths *c.* 20 m record northward moving gravel ('travel gravel') sometimes highly enriched in diamonds. This moving gravel probably derived its diamonds from pre-existing deposits, possibly of beach-type, and may be an illustration of one of the mechanisms by which the diamond population migrated along the coast over the past *c.* 45 Ma. In addition to contributions to the current coastal placer from the offshore there was almost certainly a diamond contribution from onshore deposits laid down during earlier high stands. Sheetwash action and small ephemeral streams are known to redistribute diamonds from older high stand beaches in the northern areas of the Sperrgebiet (Kaiser 1926).

Any diamonds transported by the Cretaceous rivers, in spite of their fine grain size, are also likely to have been concentrated and maintained on this shelf. The post-Late Cretaceous unconformity truncated the deposits of the proximal Kudu delta so subjecting that sediment to the rigorous reworking on the neutrally buoyant Tertiary shelf.

In Namibia, the coastal placer deposit is a complex one with many indirect sources for its diamonds. However, each increment of diamond-bearing gravel deposited during earlier sea-levels was probably influenced by a similar longshore drift system and each probably retained a northerly clast and diamond-size decline. All subsequent deposits inherited and modified this decline to some degree. The potential of seaward and landward sources for the diamonds are abundantly clear and this is considered in more detail with respect to the Namaqualand mega-placer. This complexity may be an underlying reason for the irregular nature of the diamond-size decline along the coast (Fig. 20).

Since the pioneering work of Sammy Collins in 1960s (reported in Williams, 1996) it has been recognized that the broad continental shelf off the West coast of Namibia contains diamond bearing gravel (Murray *et al.* 1970). Submersible dives carried out recently, together with sophisticated side-scan sonar surveys have successfully identified patches of gravel beach in this offshore region (Corbett & Burrell 2001). This area, located *c.* 100 km north and south of the Orange River mouth has now yielded more than 3 million carats of gem quality diamonds and is regarded as an extension of the onshore placer.

The richness of the Tertiary terraces on the lower Orange River implies the widespread availability of diamonds in the source. There are numerous diamond-bearing kimberlites presently exposed, with a range of ages, within the Orange River drainage basin (Figs 8 & 17) and they stand as an obvious source either making a direct contribution to the drainage or indirect contribution (via terraces, etc.). The contribution of the Late Cretaceous Kimberley primary source cluster is evident in the +10 carat octahedral diamonds of Cape Yellow colour in the lower Orange transient and Namibian terminal placers. However, Van Wyk & Pienaar (1986), Maree (1987); Moore & Moore (2004) are amongst many who see earlier sedimentary formations, particularly the Dwyka Group as a probable source or even the main source for the diamonds to the terminal coastal placers.

The Dwyka includes a period of glaciation extensively covering the Kalahari craton and those kimberlites older than it would have been liable to erosion at this time. Episodes of Dwyka glaciation extend from Early Carboniferous (Streel & Theron 1999) through *c.* 300–302 Ma (Bangert *et al.* 2000) into Permian. Although it is impossible to estimate the abundance of diamond-bearing kimberlites intruded in pre-Dwyka times, Premier (*c.* 1202 Ma), Colossus (*c.* 502 Ma), the Kuruman Group (*c.* 1606 Ma) and Venetia (535–505 Ma) are examples of what may have been more widespread kimberlitic intrusions. These are clearly potential diamond sources to the Dwyka diamictites (Moore & Moore 2004).

On the Kaapvaal craton, many of these older kimberlites still retain either crater or near crater facies, some of which are richly diamond bearing (Fig. 8). This clearly indicates that the Dwyka glaciation was not entirely effective in removing diamond-bearing kimberlite. A substantial volume of diamond-bearing kimberlite was left in post-Dwyka times with the potential to add to the later Karoo and abundant Cretaceous kimberlites, many of which were available to the Orange River drainage from post-Gondwana times onwards.

Assuming there was cover to these kimberlites at the time of glaciation, their preservation may be the result of their being relatively soft and often found in hollows. Studies of glacial erosion have demonstrated that glaciers moving over regionally flat terrane, as large tracts of the Kaapvaal craton would have been in Permo-Carboniferous times, are unlikely to have cut deeply into bedrock (unlike glaciers in valleys). Hence, in NW Canada, which has undergone a recent glaciation, many kimberlites are preserved high in crater facies with graded lapilli-tuffs (Leckie *et al.* 1997; Carlson *et al.* 1998; Field & Scott-Smith 1998) although some may have had a pre-glacial cover of variable thickness.

The distribution of placers along the edge of the Karoo (Dwyka) outcrop (Fig. 17) suggests that they may be related to the southeasterly retreat of this outcrop and the consequent down-wasting and concentration of the contained diamonds. In this case not all the diamonds need to have come from the Dwyka: as already discussed there is the potential for all marine Karoo deposits to have shorelines and thus related placers (e.g. Behr 1965).

As the erosion of these Karoo sediments is likely to have commenced in post-Gondwana times, it is possible that an extensive drainage developed on the craton during this wetter period (which built substantial deltas on the Atlantic coast). This may therefore have been the beginning of the period of transient placer build-up both on the craton and adjacent areas prior to the uplift which resulted in the rejuvenation and incision of the Orange–Vaal Rivers and their tributaries. Diamond-bearing gravels dating back to at least to the Cretaceous and located well into the drainage basin (de Wit *et al.* 2000; Bamford 2000), may be remnants of this earlier phase of concentration with sources in pre- and post-Karoo kimberlites as well as the Dwyka Group sediments.

The major concentration of residual and transient placers along the Vaal River and in other drainage areas to the immediate north (Fig. 17) have yielded more than 16 million carats with average stone sizes often greater than 0.5 carats/stone and with maximum reaching 511 carats (de Wit 1996). The spatial and temporal range of these deposits and the heterogeneous diamond populations highlights the range of potential sources for these diamonds, the Dwyka being a possible one.

With respect to the source of Orange River diamonds this leaves two points to consider. First, many diamond-bearing kimberlites were intruded post-Dwyka and a number of these are in the Orange River catchment. Second, pre-Dwyka kimberlites still carry diamonds, thus remaining a potential source for the whole of post-Dwyka times.

The Namaqualand mega-placer

The post-Gondwana geological history of the Namaqualand mega-placer is less well understood than its Namibian counterpart, resulting in some diversity of opinion over its origin. Dingle & Hendy (1984), along with earlier writers, proposed that the present Olifants-Sout drainage marks the Atlantic mouth of an earlier drainage network that included the Orange–Vaal systems. De Wit (1999), extending the case for this Cretaceous outfall, naming this earlier drainage the Karoo River.

The evidence for the existence of a major river mouth in this southern Namaqualand is based on the following:

1 The presence of a deltaic sequence near to the present Olifants mouth (Dingle *et al.* 1983; Brown *et al.* 1995) of Early Aptian–Cenomanian age (112–93 Ma; Fig. 21).
2 A considerable deflection in the coastal escarpment at the Olifants-Sout exit (Fig. 18).
3 Lines of pans that may trace old drainage

routes (Dingle & Hendy 1984; de Wit 1999) and

4 A substantial volume of sand in both the coastal strip and immediately inland, with zircon ages 2.7 Ga–130 Ma (Rosendaal *et al.* 2002), and which could have a provenance partly in Upper Karoo sediments eroded after the break-up of West Gondwana.

The current total drainage area of the streams originating in the escarpment and delivering sediment to the Namaqualand offshore is 30 000 km^2 and for the Karoo River drainage basins is estimated to be 68 400 km^2 (Dingle & Hendy 1984). This compares with 953 200 km^2 for the Orange River, with some evidence that the drainage basin of the latter has changed little since Late Cretaceous (Ward & Bluck 1997).

Seismic sections (Brown *et al.* 1995) are interpreted as a record of a wave-dominated delta with strike-aligned barriers deposited on highstands, and prograding wedges with incised valleys on lowstands. This interpretation is consistent with the absence of characteristic signatures of a major prograding delta (as seen, for example at the Kudu–Orange River delta). In addition, in the younger Kudu–Orange delta (Turonian–Maastrichtian 93–70 Ma), there is a record of dunes building to the NE (Wickens & McLachlan 1990). A similar northeasterly airflow is recorded in the Jurassic Etjo sandstone (Mountney & Howell 2000); the Lower Cretaceous sandstones of the Huab basin (Jerram *et al.* 2000) and the supposed Eocene deposits at Buntfeldschuh (Corbett 1993). It follows that there is every possibility that the sedimentary complex offshore from the Olifants River was deposited under a wave regime and northerly longshore drift similar to, but perhaps less vigorous, than the present one, thus skewing the sedimentary pile to the NNW (Fig. 21). On this basis the Karoo River is seen as a possible source for diamonds in the Namaqualand deposits.

The channels crossing the contemporary Cretaceous alluvial plain were interpreted as lowstand features re-activating possible existing channels in the escarpment by Brown *et al.* (1995). However, Stevenson & McMillan (2004) suggested that these channels that originated in the escarpment, were the principal routes for sediment building the shelf and therefore assigned the principal sediment source to relatively small-headed rivers now seen crossing the coastal plain. If they are the principal sediment source then it is possible that they also delivered diamonds to the coast. These rivers, themselves not tapping the craton, are required to have derived diamonds from secondary deposits such as the Dwyka Group which covered some of this region.

The total recovered diamonds from the Namaqualand placer up to 1996 was *c.* 42 × 10^6 carats (Oosterveld 2003) but since then, and with unexploited reserves, is >50 × 10^6 and, as with the Namibian placer the diamond population is more than 95% gem quality. Initially discovered in 1926 (Carstens 1962), the placer deposit consists of a compound of beaches, small fluvial channels and weathered gravel of uncertain origin. Diamond grades are highly variable, with some of the highest grades (>200 cpht) in small river channel deposits found in shallow, incised, bedrock valleys and remnant marine basal lag-gravels of Miocene affinity (Pether *et al.* 2000). The deposits have a similar age range to those of the Orange River-derived deposits of Namibia, the oldest dated being Oligocene and the youngest being Mid-Holocene. Remnants of Cretaceous channels onshore (Rogers *et al.* 1990) have yielded no diamonds but diamondiferous gravels are associated with silcretes of possible Late Cretaceous–Early Tertiary age.

As with the Namibian mega-placer, there is a decline in the size of diamonds when traced north from a point near the present Olifants River mouth (Rogers *et al.* 1990; Fig. 18) and, as with the Namibian placer, grades are quite variable along this path of size decline depending upon the local conditions at the time of placer development. Far less numerous than in offshore Namibia, diamonds have also been recovered from the offshore where they are trapped in gravel pockets around ridges of partly lithified, tilted Cretaceous sediment (Kuhns 1995).

There are two possible views on the origin of this placer: that the diamonds are directly derived from rocks formerly covering the coastal plain up to the escarpment and, presumably, were eroded during an assumed scarp retreat. The conduits in this instance are the short reach rivers and the Groen, Swartlintjies and Buffels (Fig. 22) may be the present expressions of them (Stevenson & McMillan 2004). The other sees the interior as the source and the Karoo River as the principal conduit delivering diamonds to the coast for redistribution by reworking.

These two interpretations lead to significantly different view of the source of the diamonds, the origin of the Namaqualand placer and also of the distribution of diamonds in this part of Africa before they were brought to the coast. If the bulk of the sediment came through the Karoo River at the present Olifants mouth, then there is potential for deriving them from a substantial area of the interior, part of which would have contained all primary sources older than and including Group 2 type kimberlites (110–150 Ma). Because of the switch in offshore depocentres at *c.* 95 Ma Kimberley and related Group 1 kimberlites would be excluded.

If they are derived from the small rivers draining the area west of the escarpment then the total potential drainage is small. Given that Namaqualand has yielded *c.* 42 × 10^6 (up to 1996) carats from a drainage area of *c.* 30 000 km^2, then the source would have yielded 1200 carats km^2 (whatever its thickness). The Orange basin with 953 200 km^2 has yielded >80 × 10^6 carats (up to 1996) at *c.* 84.4 carats km^2. The Orange basin contains many diamond-bearing kimberlites (including the Kimberly and related clusters), whereas the Namaqualand has no known diamondiferous primaries and in both cases the volumes of diamonds in the offshore are as yet unknown.

In Namaqualand, if the diamonds are derived from the region of the coastal plain to the escarpment, then their source was in a pre-existing Karoo (and particularly the Dwyka) cover or, alternatively, an older sedimentary package such as the Neoproterozic Nama or Gariep rocks now preserved in parts of the escarpment. In order to yield the volumes of diamonds so far recovered, both these deposits would need to have been very rich, indeed far richer in diamonds than previously considered and as such would open up new areas of potential placers which exploration, to date, has failed to find.

The northward diamond size decline would be accounted for if they were transported to the coast by the Cretaceous Karoo River and dispersed northwards under a southerly wind system. Emplacement of the diamonds into structurally controlled, small-scale bedrock channels in the Mesoproterozoic Namaqua gneisses, aligned subparallel and sometimes normal to the vector of size decline, would have occurred during the regional Early–Mid Tertiary uplift. There, small channel systems are interpreted to have redistributed older (Cretaceous and possibly Eocene) diamond-bearing units emplaced formerly in higher coastlines closer to the escarpment. Such a process, although not as pronounced, has been identified in the Orange placer, particularly north of Chameis Bay.

If, on the other hand, the diamonds are derived from the escarpment and related deposits then their northward size decline would either be a reflection of the parent deposit or a response to the longshore drift. In this latter case the size decline would be, with additions of a range of diamond sizes along its length, poorly defined and difficult to achieve if the diamonds were retained within valleys. Moreover, the distal part of the placer would have a diamond distribution with a large spread of sizes.

Conclusions

Taking the mega-placers in Nambia and the Namaqualand as examples, several conditions are required for their formation.

1. The drained craton must be of considerable size, fertile with respect to diamonds and both primary and secondary deposits should be available to the drainage in order to maximize the supply of diamonds. This availability is enhanced if transient placers have already been assembled along the final exit routes.
2. The drainage basin must cover a large proportion of the craton not only to recover the maximum number of diamonds but also to reduce the supply of potentially diluting sediment. Drainage from an uplift adjacent to the craton either by the presence of a destructive plate margin or an incipient rift–passive margin could swamp the potential placer with diluting sediment.
3. There needs to be limited or at best one point of exit for diamonds so that a substantial outfall focuses the delivery to a restricted area.
4. Cratons should have accumulated diamonds over a considerable length of time by deep weathering and recycling within the craton and its immediate boundaries and there should have been few or no previous large-scale drainage systems or glaciations to disperse the diamonds into smaller placers in older deposits.
5. In order to remove the accumulated diamonds efficiently and completely off the craton, the drainage should have sufficient slope and density and, through incision, be able to reach buried residual and primary deposits so as to release them into the drainage network. This is best achieved by regional uplift and preferably through the rejuvenation of a pre-existing river system (to ensure a single or few outlets to the terminal placer). The volume of residual

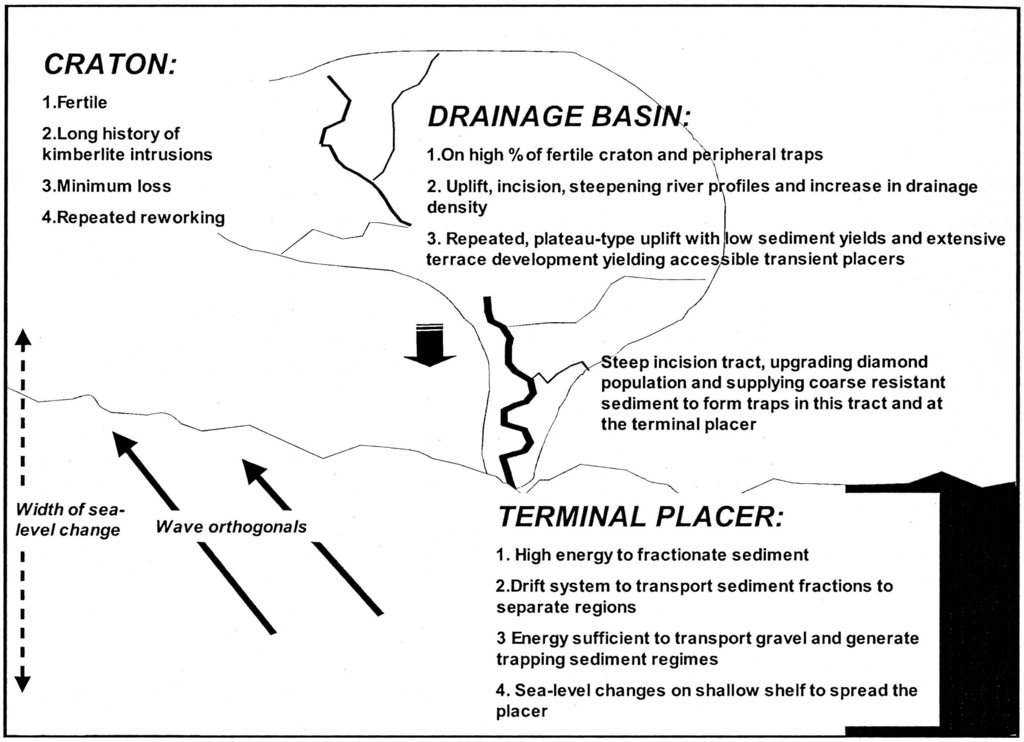


Fig. 23. Summary of the requirements needed to form a diamond mega-placer.

placers and the abundance of diamond-bearing pipes left on the craton is a measure of the inefficiency of the drainage.

6 The drainage should have operated for sufficient time for the drainage network to expand over the surface and cut deeply into it in order to deplete the craton of its diamonds.

7 With respect to this African terminal placer certain critically timed conditions are necessary:
   - The removal of the Karoo cover in Cretaceous times and its deposition into subsiding basins where it was no longer a potential dilutor to the placer;
   - The incision of a pre-existing drainage (essentially Cretaceous) to access the newly exposed primary and the already gathered secondary diamond deposits in the Tertiary;
   - The development of a high-energy coastal regime with a unidirectional wind over a neutrally buoyant, shallow shelf off-the-mouth of the delivery system, during the same time interval and;
   - that time interval has been of sufficient length to allow a mega-placer to build up.

8 The final dispersal of the diamonds should be relatively young and in largely unlithified deposits so that they can be mined with relative ease.

9 Terminal mega-placer deposits are most likely to have developed along marine coastlines where sufficient energy is need to segregate the grain sizes and concentrate the diamonds.

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