



# The preservation of alluvial diamond deposits in abandoned meanders of the middle-Orange River

by P.G. Gresse\*

## Introduction

The Orange-Vaal River system is known to be the primary secondary source for alluvial diamond deposits in the northern Cape and along the west coast of Namaqualand. The higher order sources for diamonds contained within this system are still not defined entirely to satisfaction, but certainly include kimberlite pipes exposed in the catchment regions of these rivers.

The focus of alluvial diamond mining along the Orange-Vaal system recently changed from the traditional areas in the upper catchment regions—the Barkly West, Christiana, Bloemhof, Wolmaranstad, Schweizer-Reineke region, and the lower regions near the mouth of the Orange River at Baken, Alexander Bay and Oranjemund, to the area between Douglas and Prieska—the so-called mid-Orange region (Figure 1).

## Geomorphological development of the Douglas-Prieska sector of the Orange River

The present Orange River between Douglas and Prieska displays a meandering channel morphology, best developed in areas underlain by the Dwyka Group. The average amplitude of these rather regular modern meanders is about

6 km and the average wavelength is 13 km. Standard deviation from the average is remarkably small (Figure 1). Intensive exploration during the past three years, making use of various exploration tools, has revealed remnants of a similar older meandering system, covered by sand and calcrete, along this section of the river.

## Calcrete caps and land surface evolution

The present Orange River valley in this region is flanked by a steep calcrete-capped escarpment on both sides (Figure 1), situated at between 60–100 m above the present river level, marking the distance of scarp retreat caused by river incision since the formation of the calcrete. The valley width from scarp to scarp measures between 8 and 10 km, and the valley depth is generally some 80 m below the calcrete cap.

Remnants of previous valley floors are preserved as topographic benches on exposed bedrock spurs at specific elevations between the river channel and this scarp face; these benches are capped by even younger, less-indurated calcrete deposits. A much older calcrete cap is found at about 150 m above the riverbed on the north bank where the massive Cretaceous calcrete cap of the Ghaap Plateau is exposed (Figure 1). This scarp is located 10 km or more from the Orange River and marks the distance of scarp retreat due to river incision since the Cretaceous. Distance varies according to bedrock hardness—the scarp retreated far more rapidly on the soft Dwyka sediments between the Asbesberge and the Ghaap se Berg, exposing a large elongated 'basin' of Dwyka Group trending north towards Postmasburg and Finsch (Figure 1).

Calcrete erosion and calcrete scarp retreat reflect repeated land cycle evolution and repeated lowering of base level and river incision due to sea level fluctuations or local tectonic activity along the course of the Orange River.

## Calcrete caps in relation to palaeoterrace preservation

Each successive calcrete surface caps remnant fluvial deposits of different ages preserved at different elevations. The youngest calcrete development appears to have occurred after deposition of the +20 m terraces. A semi-continuous calcrete layer, following surface contours, covers Dwyka bedrock exposed between the upper calcrete and the river

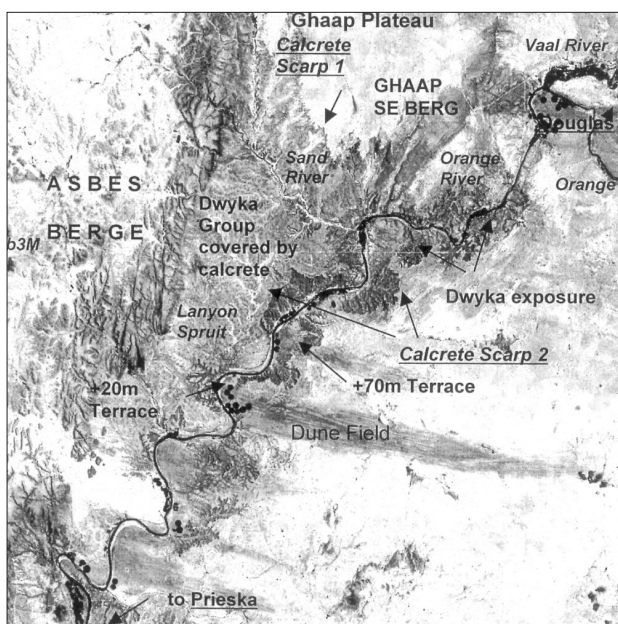


Figure 1—Geomorphological setting of the mid-Orange diamondiferous deposits (+110 m terraces not shown)

\* Trans Hex Group, P.O. Box 723, Parow, 7499.

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and +20 m deposits alike, and also merges with the older calcrete along the upper rim of the river valley. This calcrete, as well as the +20 m terraces, have been incised by even younger erosion related to lowering of the riverbed from +20 m to its present elevation. No calcrete clasts, indicating reworking of the older calcrete levels, have been observed in fluvial gravels as yet, but should be present. These calcrete caps not only played a significant role in protecting the diamondiferous palaeogravels from 20th century diggers, it also played a role in the preservation of the high elevation terrace gravels from complete erosional removal during each renewed erosion cycle initiated by repeated lowering of the base level.

### The Rooikoppie gravels—origin and setting

All the calcrete caps, as well as the different fluvial terrace deposits, are covered by so-called Rooikoppie gravels. The Rooikoppie gravels represent mobile, multi-cyclic deflation and gravitational deposits sourced from surface scree deposits and/or elevated (inverted) fluvial deposits, and preserved and recycled repeatedly from one successive land surface to the next. Only the most durable silicic clasts (banded iron formation [BIF], quartzite, chert, etc.) survived this deflation recycling, and diamonds are only present where the Rooikoppie gravels recycled older diamondiferous fluvial deposits. Diamondiferous Rooikoppie gravels often overlie barren fluvial deposits and vice versa. Present day gravitational Rooikoppie runs and scree slopes, standing above the oldest preserved fluvial terraces, attest to even older, higher elevation river cycles than any of those observed to date.

### Diamondiferous palaeo-deposits of the Orange River

Palaeochannel depositional packages of the Orange River are preserved at different elevations above the present Orange River bed. Three of these aggradational or depositional cycles, based at +20 m (lower terraces), +60–80 m (upper terraces) and +110 m above the present riverbed, will be discussed (Figure 1). Although all of these are defined by

actual fluvial deposits at one or more locality, the probability of preservation decreases with increasing age and elevation. Diamondiferous Rooikoppie gravel scree slopes higher than the oldest preserved fluvial deposits suggest that even older and higher elevation palaeodeposits were present and have been removed completely by erosion.

Palaeogeographic reconstruction of the Douglas-Prieska sector of the river is based on actual palaeogravel preservation and extrapolations from calcrete-covered benches along the Orange River valley representing remnants of older valley-floor surfaces. Although described here as specific events, based on elevation above present riverbed, the following discussion will show that these events or cycles are linked in some way or another by the process of continuous channel migration and incision.

### The +70 m Orange River Cycle

The most consistent high-level palaeodeposit, and the one on which the geological model for this area was developed, occurs between 60–90 m above river level (Figure 1). These deposits represent palaeomeanders exhibiting a wavelength of approximately 13 km and an amplitude of about 6 km, very similar to that of the modern river. Frequency of occurrence suggests that the known deposits represent the complete palaeochannel profile for this section of the river. The correspondence in palaeo- and modern river morphology, for this cycle, indicates that this sector of the Orange River system remained in relative equilibrium since probably the Miocene. All the preserved meanders at this elevation lie to the south of the present river channel, suggesting that meander cut-off occurred mostly along the northern loops of the meanders. This may be an indication of regional slope to the south or slow, continuous uplift to the north.

These palaeomeanders were defined by means of a combination of aerial photographic and field mapping, airborne magnetic mapping and drilling. The meanders are generally covered entirely by either calcrete or wind-blown sand, or both, but careful mapping has defined points of entry and emergence of palaeochannel deposits from underneath the upper calcrete cap, along the valley scarps. These so-called upper terrace gravel deposits occur at about 1000 m.a.s.l. (+70–60 m above river) and generally slope slightly to the south, away from the Orange River. Both the calcrete cap and the bedrock exhibit this same slope.

### Geological model based on the +70 m cycle

Drill sections and geological modelling indicate that the sloping surfaces mentioned above represent the original slope across which palaeomeanders of the Orange River migrated, the so-called meander migration surface (MMS). The MMS (Figures 2 and 3) terminates in the last channel position before cut-off and abandonment and is flanked to the south by a steep cut-bank exposing Dwyka bedrock. The abandoned channel on average lies about 3 km south of the northern edge of the preserved terrace deposit and at an elevation of between 20–40 m above river elevation.

Assuming a mid-Miocene age for the +70 m deposits (high sea-level stand at, say, 8 Ma) and an early to mid-Pliocene age (high sea-level stand at, say, 4 Ma) for the +20 m deposits, which equals the elevation of some of the abandoned meanders, a meander (channel) migration rate of

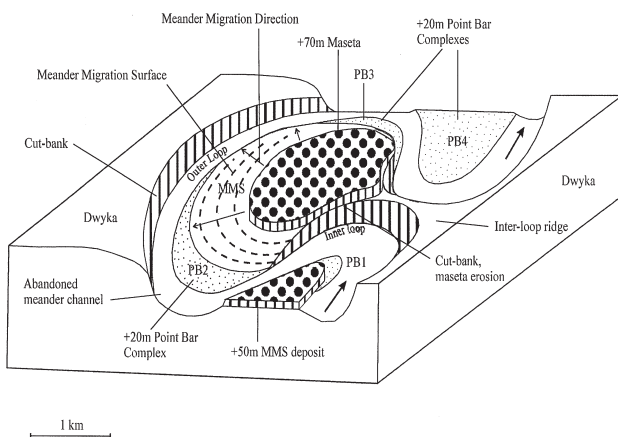


Figure 2—Schematic model for palaeomeander development, mid-Orange River sector. PB—Point Bar complex; PB1–4 denotes downstream sequence of development; MMS—Meander Migration Surface

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0,1 cm/year is indicated. Assuming the same time span, the 40 m difference in elevation between upper and lower terrace, or upper and lower end of the MMS, indicates an approximate channel incision rate into Dwyka bedrock of 0.001 cm/year.

The preserved portion of one continuous meander cycle therefore comprises of a central hub, or Maseta, containing a massive, channelized or laterally accreted succession of fluvial gravel and sand, a sloping meander migration surface (MMS) containing a dipping, interbedded, laterally accreted gravel-sand succession, an abandoned channel, filled with fluvial sand and longitudinal gravel bars, and an interloop ridge, representing the bedrock ridge that separated the converging loops before break-through and meander cut-off (Figures 2 and 3).

These features represent the classical model for palaeomeander deposits along the mid-Orange River and have been observed repeatedly in paleogeographic reconstructions from surface maps, drill data and high-resolution airborne magnetic data. The magnetic data reflects BIF-content of the sediments and therefore, apart from showing Rooikoppie gravel deposits on the surface, also serves to map out primary gravel and sand bodies. The method is particularly effective along this sector of the river, which is underlain by the Dwyka Group, providing a 'low-noise' background magnetic signature.

A feature of this model is that it postulates semi-continuous deposition per cycle, possibly spanning a period of up to 4 Ma in some cases, and depositing fluvial sediments continuously at a range of elevations differing by up to 40 m, thus covering MMS surfaces with large laterally accreted, diachronous deposits. All these features are exposed in exploration and mining activities along the mid-Orange River and really negates the traditional concepts of upper and lower terraces, as many of these deposits are genetically linked through continuous cycles of migration and incision. There are, however, distinct levels or cycles of more pronounced sediment deposition, as mentioned, which are probably linked to specific regional geological events such as sea-level fluctuation, crustal tectonics and climatic changes, which influenced river gradient, incision rate, down-flow and bed-load discharge.

### The +20 m Orange River Cycle

Deposits of the +20 m cycle occur even more widespread than the +70 m deposits along the present banks of the Orange

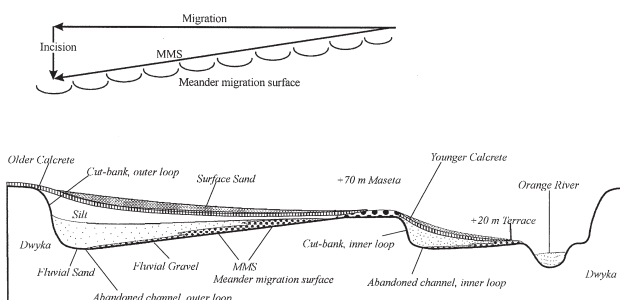


Figure 3—Schematic cross-section showing salient features of abandoned meander deposits in the mid-Orange region

River (Figure 1) and display a much more complex internal morphology as deduced from airborne magnetic data and drill sections. Magnetic mapping, reflecting the attitude and internal configuration of fluvial deposits as a factor of their banded iron formation content, and hence gravel content, show up to four different mutually discordant gravel deposits within any one terrace. This is a clear reflection of continuous channel migration, switching, and loop migration within a relatively wide, alluvium-filled flood plain causing continuous erosion and recycling of alluvium. This probably reflects an extended period of sea-level and/or tectonic stability causing low river gradient and a choked valley, followed by rapid incision and abandonment of meander-alluvium at the +20 m elevation.

### The +110 m Orange River Cycle

Deposits of the +110 m cycle are very limited and are only preserved at two places along the river. They reflect similar depositional environments as the +70 m deposits.

### Composition and source of the palaeo-Orange River gravels

Significant differences in the composition of the sediments in these three cycles reflect their provenance and show a direct correlation with diamond grade. The compositions of the gravels and sands of the +110 m and +20 m cycles is distinct from the +70 m cycle in that they show a much higher Drakensberg basalt and zeolitic sand content and hence a much higher sediment contribution from the Orange River *per se*, as opposed to the Vaal River. The dominance of an 'Orange River' source usually reflects negatively on diamond grade, partly because of a dilution factor through the introduction of a larger sand component, and partly because of a lack of source for diamonds.

Sediments of the +70 m cycle are diachronous, as explained above, and display a gradation from older gravel types dominated by Vaal River-type lithologies to younger or lower elevation gravel types dominated by Orange River-type lithologies, similar to the +20 m deposits, which often represent the end of the cycle.

Vaal River-type lithologies exhibit a predominance of Ventersdorp lava clasts and a high percentage of red agate and banded iron formation (BIF), although the latter is not necessarily a Vaal River contribution, as discussed below.

Thick (3-9 m), chaotic, channel-fill or point-bar, pebble, cobble and boulder gravels of this cycle contain between 30-70% of banded iron formation clasts from a point in the Orange River some 40 km west of Douglas, the so-called BIF-line. These clasts are derived from outcrops of banded iron formation in the Asbesberge to the north and west

### The Banded Iron Formation (BIF) factor

The point and timing of BIF introduction into the Orange River deposits are significant as they appear to have contributed substantially to, and also forced, increased bedload deposition downstream from the point of introduction, as a result of added bulk and specific gravity (SG). The added bulk and SG of the bedload provided an increased trapping and blocking mechanism reflected as higher than normal diamond grades in these deposits.

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BIF was introduced into the system in large amounts some time after deposition of the +110 m cycle, through two main point sources, the Sand River and Lanyon Spruit, two tributaries draining the large catchment between the Orange River and the Ghaap Plateau scarp-break to the north (Figure 1). Interpretation of the timing and distance of scarp retreat of the differently-aged calcrete caps, as described earlier, suggests that this catchment basin filled up with BIF debris and scree during the +110m 'aggradational' event, which reflected as deceleration of erosion in the catchment areas. A significant lowering of base level at the end of the +110 m cycle, caused abandonment of that cycle and rapid river incision. The resultant new erosion cycle 'pulled the plug' on the choked catchment basin to the north, causing a sudden influx of BIF-load from the Sand River confluence downstream, and triggering a localized depositional plume or lobe of BIF-rich gravels in the ensuing +70 m cycle downstream from the point source entry points.

## Diamond concentration mechanisms

The primary source of diamonds trapped in palaeogravels of the Orange River were liberated from kimberlites and intermediate secondary sources like eluvial, fluvial and glacial deposits in the catchment regions of the Vaal and Orange rivers. These diamonds were deposited along the course of the river in favourable trap sites, either in bedrock-traps or in point-bar complexes and within-channel bars, particularly in meanders, scour pools and areas of divergent flow. The model presented here shows that the Orange River system evolved cyclically through various depositional and erosional events and that most of the documented development occurred in close proximity to the present course of the river and show clear morphological similarities to the present river pattern.

In the range of deposits described here, and within the context of the model presented, diamonds were first deposited in point-bar complexes in the inner bends of palaeo-meanders at an elevation of +110 m above the present river. This cycle matured and, after meander abandonment, rejuvenation of erosion due to lowering of base level, valley-scarp retreat recycled the +110 m palaeodeposits back into the next active fluvial system, the +70 m cycle.

Within this cycle diamond concentrations are dependent on the timing of erosional removal of high grade, diamondiferous deposits from +110 m gravel remains, i.e. early or late preservation within the younger cycle, and location within the nearest major trap site, i.e. the first point-bar complex, scour or obstruction in the river downstream from the point of derivation of the recycled material. In this way the oldest diamondiferous gravels deposited by the Orange River have been recycled and redeposited repeatedly through time, down to the lowest level gravels as preserved today.

The grade and geographical spread of points of concentration of each cycle depend on the grade distribution within the previous cycle and the amount of dilution introduced by the new cycle, be it gravel or sand from the Orange or Vaal river catchment areas, or recycled Rooikoppie gravels from the valley slopes. A series of potential target deposits have therefore been defined in successive cycles, stepping down the elevation and time scale, from the oldest high-grade deposits down to the present riverbed, based on elevation, age and composition of each successive cycle.

## Neotectonics and diamond distribution

Ore thickness and bedrock contour maps based on grid drilling and airborne magnetic data reflect a range of bedrock features that appear as dykes and bedrock steps or bedrock ridges within the alluvial diamond deposits. These features are important as they may form trap sites and hence cause grade enhancement. Where exposed in mining blocks, most of these features have been proved to reflect low-angle faults, often conjugate pairs, and are often associated with dolerite dykes or sills. Thrust or normal displacement on these structures is in the order of 1 to 3 m and they clearly post-date the gravel deposits as basement (Dwyka Group) slices have been thrust over gravel in some cases. Some thrusts are associated with repeated reactivation of movement surfaces along dolerite dyke contacts, in which case they did form obstructions and/or trap sites in the river where some movement occurred prior to gravel deposition. Significant grade increases are encountered in the proximity of these trap sites.

Neotectonic movement in post-Miocene times, as observed here, is probably a reflection of crustal adjustments and space problems generated by Cenozoic crustal warping. These structures affected drainage patterns and the general geomorphological development of southern Africa as described by various authors in the past (De Wit, 1999; Moore and Larkin, 2001; Moore and Blenkinsop, 2002).

## Summary and conclusion

Alluvial diamond deposits along the mid-Orange River sector reflect cyclical development and preservation through a series of palaeomeander events preserved at different elevations above the present riverbed. The internal structure and morphology of these deposits have been delineated by means of grid drilling and high-resolution airborne magnetic surveys, the latter a reflection of their high banded iron formation content, and enable reconstruction of various palaeomeander cycles.

The cyclical development of the Orange River system reflects phased incision interspersed with periods of alluvial plain deposition. Due to repeated recycling from one cycle to the next, the distribution and grade of diamond deposits associated with these cycles are interdependent, reflecting the morphology of each previous cycle. Deposits also show either grade increase or decrease, depending on the volume and composition of bedload in transit during each particular event, which in turn reflect on source, climate and crustal/sea level stability.

## References

- DE WIT, M.C.J. Post-Gondwana drainage and the development of diamond placers in western South Africa. *Economic Geology*, vol. 94, 1999. pp. 721-740.
- MOORE, A.E. and LARKIN, P.A. Drainage evolution in south-central Africa since the breakup of Gondwana. *South African Journal of Geology*, vol. 104, 2001. pp. 47-68.
- MOORE, A.E. and BLENKINSOP, T. The role of mantle plumes in the development of continental-scale drainage patterns: The southern African example revisited. *South African Journal of Geology*, vol. 105, 2002. pp. 353-360. ◆