A review of the alluvial diamond industry and the gravels of the North West Province, South Africa

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ABSTRACT

The liberalization of the diamond marketing system led to increased diamond prices and this, coupled with the devaluation of the Rand against the US$ during late 2001 and 2002, resulted in a significant increase in onshore alluvial diamond production in South Africa. Inland, alluvial diamond production reached a recent peak of 1.23 million carats in 2003, providing employment for an estimated 25,000 people which then dropped to a disappointing 6,000 people in 2005. The discovery of the Lichtenburg diamond field in 1926 made a huge, short term impact on South Africa's diamond production but this impact was short-lived due to the global decline in diamond sales that resulted from the Great Depression.

In recent years, there have been important advances in the techniques used in the exploration for alluvial diamonds, enhancing the ability to locate new deposits. These include improvements in the remote sensing techniques of aerial photography and satellite image interpretation, as well as various airborne and ground geophysical methods. The extremely low concentrations of diamond in most alluvial deposits and the almost random distribution of the diamonds within the gravels, necessitate the taking of large samples in order to evaluate the commercial potential of a deposit.

In the southern, Schweizer-Reneke diamond field, five ages of diamondiferous gravels occur, ranging from late Cretaceous to Pleistocene. Post-depositional modification has resulted in the formation of colluvial and eluvial "*Rooikoppie*" deposits, which were preferentially mined by the artisanal diggers of the previous century.

The northern Lichtenburg, and eastern Ventersdorp diamond fields are largely underlain by dolomitic horizons that have undergone at least four phases of karst development. Even though several phases of gravel deposition have occurred, the distribution of the diamondiferous gravels is influenced by weathering features in the dolomite and these now occur as pothole-fill, sinuous, discontinuous, narrow, steep-sided alluvial channels or laterally more continuous, yet thin sheet-like gravels, assumed to be younger reworked material. The pot holes (or sinkholes) have formed excellent trap sites for diamonds and enormous quantities of diamonds have been recovered from some of these.

Introduction

The liberalization of the diamond marketing system resulted in higher prices being paid for diamonds and this, coupled with the significant devaluation of the Rand during late 2001 and 2002, offered a window of opportunity for increased alluvial diamond mining in South Africa. As a result, there was a noticeable increase in inland alluvial diamond production, which rose to over 1.0 million carats in 2002 and 1.23 million carats in 2003. In addition, implementation of the Mineral and Petroleum Resources Development Act (MPRDA) in 2004 has freed up additional ground for new entrants. Consequently, it is appropriate to review the present status of knowledge of South Africa's alluvial diamond deposits in order to make high quality information more easily available to entrepreneurs and potential investors alike. This paper concentrates on what were known for many years as the alluvial diamond fields of the western and southwestern Transvaal and which now mostly fall within the North West Province of South Africa (Figure 1).

The discovery of the Lichtenburg alluvial diamond field in 1926 was, at the time, the most significant in South Africa in terms of alluvial diamond production (de Wit, 1996). The >10 million carats recovered dramatically increased the country's and, indeed, the world's diamond production between 1926 and 1930. The rapid decrease of production after 1930 was largely the result of a dramatic decline in global demand for diamond during the Great Depression. Many otherwise viable diggings closed and it is likely that some of these never re-opened. Of those that did re-open, many ceased operations when they reached the water-table. Thus there may be further potential for production in some of the older, abandoned operations. In fact, some of these may not even have reached the most productive, basal gravel horizons, because these were often difficult to access. The artisanal diggers of that time generally exploited the richer, more easily accessible deposits and left what were considered lower, more marginal grade ones. Often in the Southern Field, (Figure 1) only the colluvial and eluvial (*Rooikoppie*) gravels were worked, while the underlying alluvial units

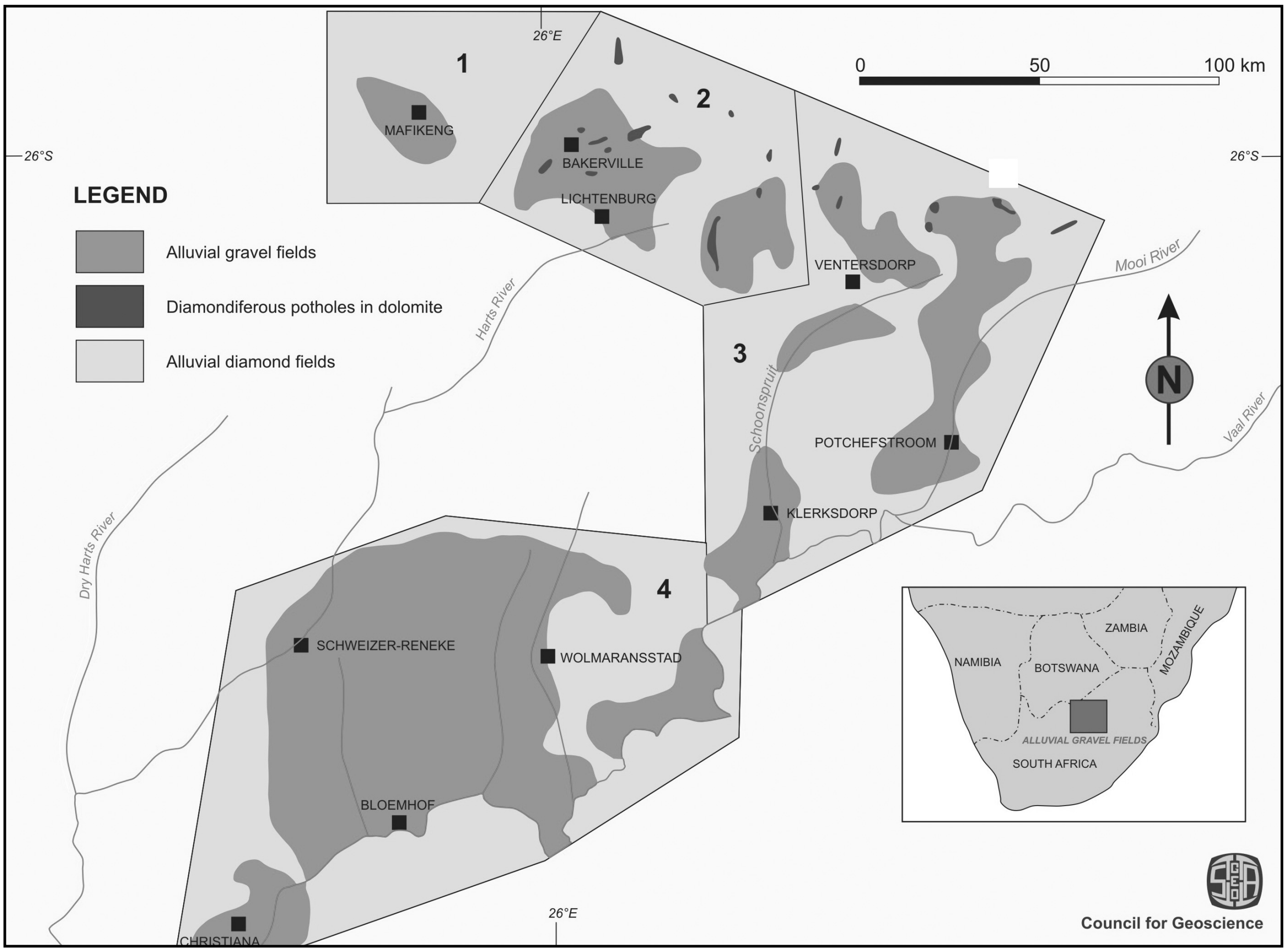


Figure 1. Locality of the North West Province diamondiferous gravel fields. Modified after Marshall (1990a). Area 1 is the Mafikeng-Molopo, or Northwestern Field; Area 2 is the Lichtenburg-Bakerville, or Northern Field; Area 3 is the Ventersdorp-Potchefstroom-Klerksdorp, or Eastern Field and Area 4 is the Christiana-Schweizer-Reneke-Wolmaransstad-Bloemhof, or Southern Field.

went unrecognised and, hence, unmined (Marshall, 1990a). The exploration potential in the underlying alluvial deposits thus remains untested.

The economic viability of deeper or previously unrecognised gravel units began being evaluated in all the inland alluvial diamond fields during the 1970s, resulting from technological advances in heavy earthmoving machinery, gravel processing and diamond recovery equipment. Later, during 2002, the rapid decline in the value of the Rand against the US$ made lower grade, high volume deposits profitable to mine (de Meillon and Bristow, 2002) and a rapid resurgence of alluvial diamond mining ensued with production reaching 1.23 Million carats in 2003 (Damarupurshad, 2004). The South African Diamond Producers Organisation (SADPO) had a record 1 000 members in 2002, each employing an average of 25 people (Mineweb, 09/11/2004).

The subsequent strengthening of the Rand against the US$ significantly decreased operating margins and hence a better understanding of the controls affecting the deposits was required to locate and exploit these deposits profitably. Such research is additionally warranted, because it has the potential to grow the small-scale mining industry and assist black economic empowerment in South Africa. However, the strong Rand, increased cost of fuel, added costs of complying with new legislation affecting the mining sector and slow pace at which new prospecting and mining rights are being issued, have all contributed to a sharp decline in alluvial diamond production since mid 2004, in spite of increasing diamond prices. SADPO recently announced that its membership had dropped to 164 (Mining News, 2005).

Previous geological investigations

Various theories have been put forward to explain the nature and origin of both the alluvial diamond deposits and, later, kimberlitic occurrences. In 1914, Wagner systematically compiled all available data on both the kimberlitic and alluvial diamond fields known up to that time. Draper (1928) noted the unique dolomitic substratum of the Lichtenburg deposits. Williams (1930) published an account of all the inland and coastal alluvial diamond deposits in southern Africa and expounded his views on the origin of the Lichtenburg deposits. Du Toit (1951) comprehensively described the Lichtenburg field, based on his field work carried out in the 1930s when sporadic diggings were still taking place. Retief (1960) mapped the gravels and gave

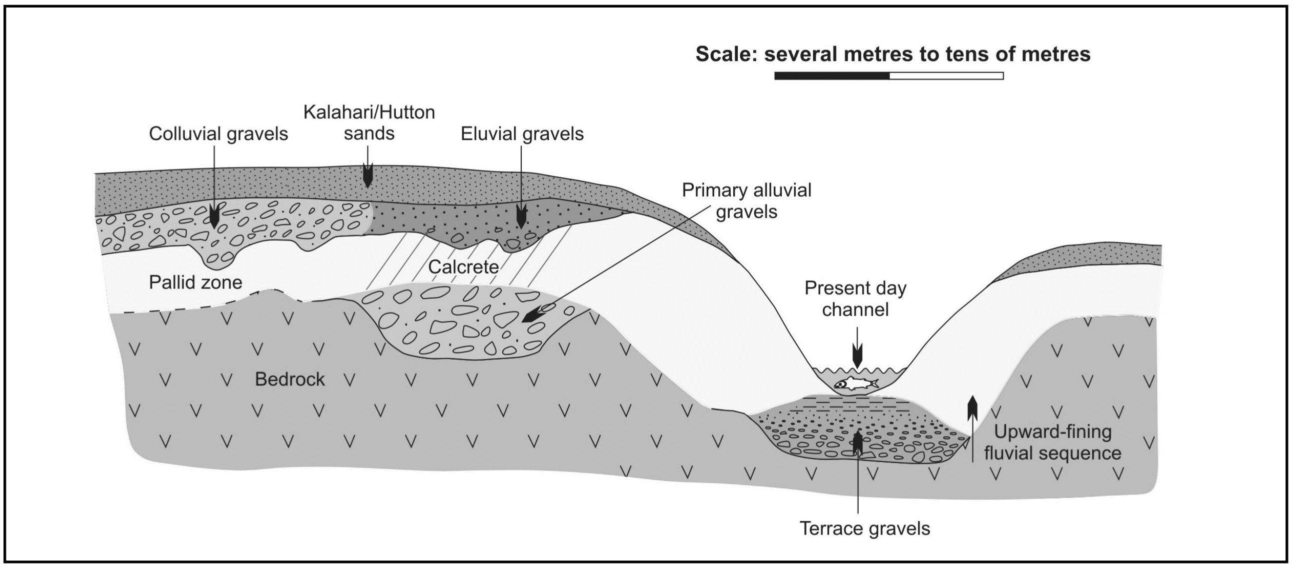


Figure 2. Diagrammatic representation of relationships amongst colluvial, eluvial and alluvial gravels in the Vaal River system (modified after Marshall, 1990a).

comprehensive descriptions of the various runs, both diamondiferous and barren. Davis and Prevost (1978) gave a short summary of the gravels in the Lichtenburg area to accompany their report on the geology of six, 1:50 000 scale, map sheets which they re-mapped. Stettler (1979) studied two areas near Bakerville in detail, with emphasis on geophysical prospecting techniques, as did de Wit (1981). Stratten (1979) attempted to determine the origin of the diamonds by characterizing gravels in terms of clast shape, roundness, and imbrication, from which he inferred palaeo-river flow directions. Marshall (1990a) recognized that the alluvial gravels in the Schweizer-Reneke-Bloemhof area were deposited by north-bank tributaries of the palaeo-Vaal River, and distinguished these from the eluvial and colluvial (*Rooikoppie*) gravels which were derived from the underlying alluvial deposits (Figure 2). She also correlated these gravels with the Cainozoic deposits of the Vaal River. Marshall (1990a; b) and de Wit *et al.,* (1998) provided the most recent insights into the origins of the alluvial diamond fields in the North West Province.

Marshall (1986) estimated that the historic diamond production from these alluvial fields between 1904 and 1984 was some 14.4 million carats which, at 2005 prices, would have an estimated value of some US$ 5 billion. Later de Wit (1996) raised this estimate to in excess of 15 million carats. Accurate records of production of alluvial diamonds post-1996 are not available, but figures of 1 to 1.2 million carats per year are thought likely.

Controls on Diamond deposition and concentration

Bedrock Geology

Much of the North West Province is covered by shale and mudstone of the Ecca Group, with rare exposures of Dwyka Group tillite (SACS, 1980). Where these sedimentary rocks have been removed, Archaean and Proterozoic rocks are exposed (Figure 3). The Ventersdorp Supergroup (primarily the Klipriviersberg Group lavas with lesser Bothaville Formation sediments) form the bedrock to the vast majority of the alluvial deposits. In some areas, both Dwyka and Ecca deposits are preserved under Cainozoic gravels.

Although the bulk of the diamondiferous gravels are recent and unconsolidated, the bedrock, over which palaeo-rivers flowed, played a significant role in the concentrating of diamonds. Depending on the resistance of the bedrock to river erosion, traps such as riffles and potholes may develop in the river bed. Such traps more commonly form in Ventersdorp lavas than in the horizontally bedded shales of the Dwyka and Transvaal successions. During deposition, diamonds, being denser and harder than most other river-born sediments, tend to concentrate in depressions in the irregular bedrock. Diamond concentrations in pothole gravels can be up to 100 times those of gravels not associated with such features.

Structural Influence

The structural features developed in the various lithologies include different ages and magnitudes of faults, fractures, and joints. Their patterns and intersections control the location of dykes, and influence the drainage patterns (including the location of pans), as well as the development of numerous karst features (on dolomite). Because the various rock strata exhibit different structural patterns, the drainage courses over them show significant variation.

Geomorphic Evolution

The distribution of alluvial diamond deposits in southern Africa is controlled by the evolution of palaeo-drainage systems. As a result, a thorough understanding of the

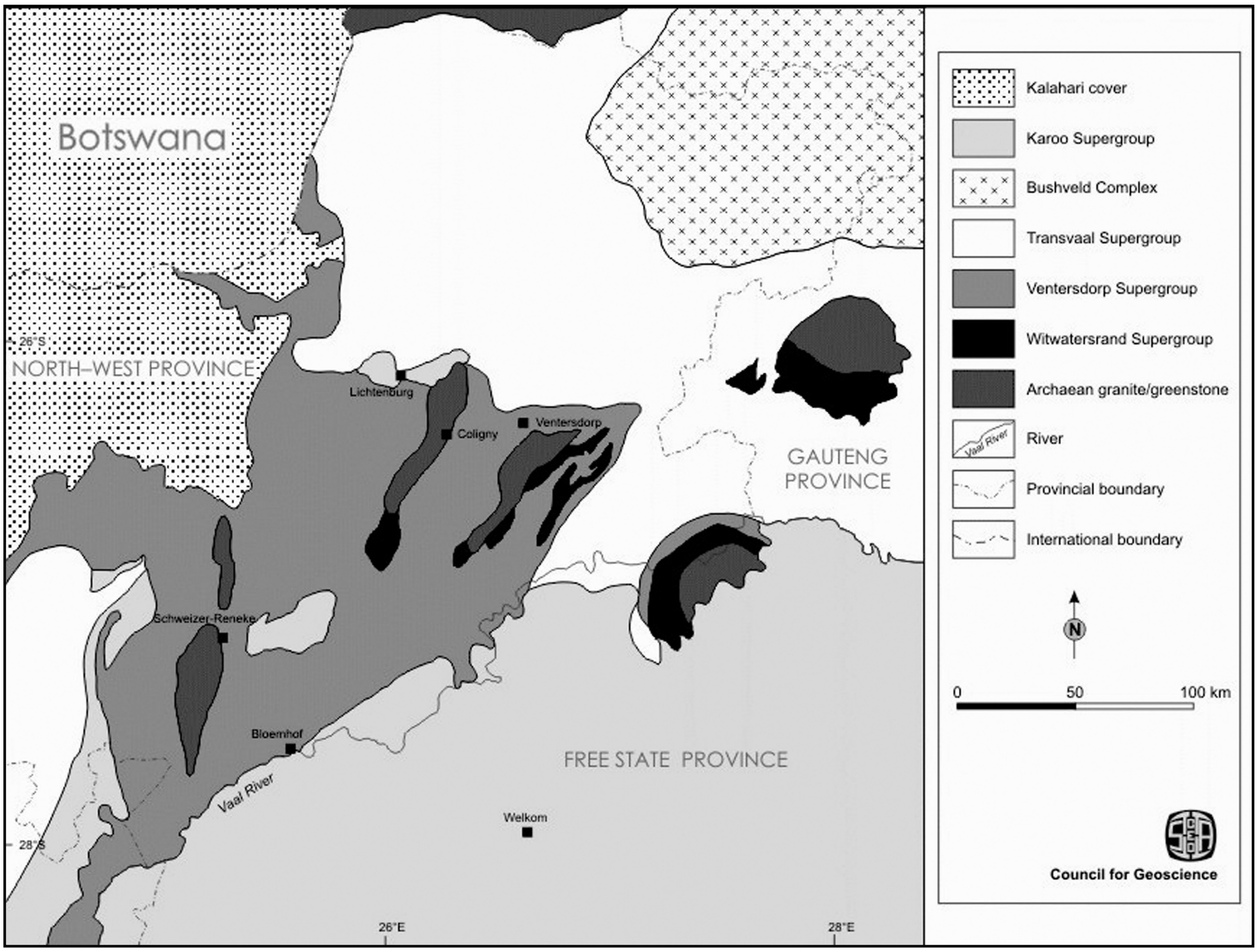


Figure 3. Simplified geological map of part of the North West Province. Information taken from the Council for Geoscience 1:1 000 000 scale Geological Map of South Africa (1997).

geomorphological development of southern Africa greatly facilitates an understanding of diamondiferous gravel deposits, which in turn assists in the exploration for such deposits. The current drainage system is believed to have been initiated shortly after the break up of Gondwana during the Cretaceous (between ~180 Ma in the east and ~130 Ma in the west), and is intimately associated with the geomorphological evolution of the sub-continent. Understanding of King's (1951) "African Surface" and its later evolution was advanced by Partridge and Maud (1987). Burke (1996) studied the geodynamic evolution of the African continent and challenged some aspects of the African Surface paradigm. The most contentious issues of geomorphologic evolution involve the relative timing and amount of uplift which the southern African interior experienced during its post-Cretaceous development. A major unresolved problem remains the cause(s) of the uplift which resulted in the African Swell (Nyblade and Robinson, 1994). Recent seismic geophysical studies strongly suggest that a major mantle upwelling emanating from the core-mantle boundary, is responsible for the uplift (Gurnis *et al.*, 2000; Lithgow-Bertelloni and Silver, 1998).

The origin of the Alluvial Diamonds

The origin of alluvial diamonds remains a hotly debated topic. This is not surprising considering the complexities of the gravel deposits and the apparent absence of obvious kimberlitic sources close enough to gravels to explain both the angular nature of some pebbles and the value distribution of the diamonds. The gravel deposits associated with the present- and palaeo-Vaal River system carry diamonds which are of generally higher quality, suggesting that the poorer quality diamonds have been destroyed during fluvial transport. The bulk of the diamonds recovered from the Lichtenburg area are, conversely, of poor quality, suggesting that they were transported shorter distances. The proponents of a distal source for the North West Province alluvial diamonds include Harger (1909), Stratten (1979), and de Wit (1981). However, Stettler (1979), Marshall (1990a; b) and Mike de Wit (personal communication, 2005) advocate a very proximal source for the diamonds in all of these fields.

As an alternative to fluviatile models, Harger (1909) suggested that glaciers, which developed during the Dwyka era, carried diamonds in moraines which were deposited, buried and consolidated as tillite. Subsequent uplift of southern Africa resulted in the weathering and erosion of the Dwyka tillite which released both gravel clasts and diamonds into the prevailing drainage systems. Maree (1987) expanded considerably on the Dwyka origin for the southern African alluvial diamonds as have Moore and Moore (2004).

With the exception of Harger (1909), who advocated a Ventersdorp lava origin for the diamonds, most researchers ascribe a kimberlitic source to the diamonds. The majority of the productive kimberlite intrusions in southern Africa are Cretaceous in age (Smith, *et al.*, 1985; Lynn *et al.*, 1998). This argues against the Dwyka glaciation model which requires a pre-Permian age for the diamonds. However, numerous older diamondiferous kimberlite clusters are also known to exist (e.g. Jwaneng (± 250 Ma), Venetia (± 520 Ma), Premier (± 1200 Ma)) or are inferred to have existed (diamonds in >2.7 Ga Witwatersrand Supergroup auriferous reefs). These older deposits may also have contributed to the alluvial diamond budget.

With regard to the Lichtenburg field, de Wit *et al.* (1998) and de Wit (personal communication, 2002/2004/2005)) reported preliminary indications that kimberlitic dykes/fissures may have intruded the dolomitic karst terrane and were subsequently eroded and infilled with gravel, in some cases forming diamondiferous gravel "runs". A zircon grain recovered from highly decomposed ultrabasic, ultramafic material from deep within one of the potholes was dated at ~500 Ma, implying a pre-Karoo age for the possible kimberlite fissure. Further exploration for these potential kimberlite intrusions has been limited due to the low value of the diamonds recovered from the Lichtenburg alluvial deposits as well as the limited expected size of the intrusions that remain after the significant erosion that has taken place since emplacement.

In the Schweizer-Reneke and Bloemhof districts, evidence for a kimberlitic origin of the diamonds is found in the results of the analysis of numerous heavy minerals. For example, analysis of garnets from alluvial diamond diggings on the farm Goudplaats 96 HO in the Schweizer-Reneke district, indicated that 35% were from kimberlitic sources (de Bruin and Kiefer, 2004) and garnets from alluvial diamond workings on the farm Vaalbank 355 HO, north of the Bloemhof Dam, revealed that 67% were from kimberlitic sources (de Bruin, 2005). See also mineral chemical analyses presented by Marshall (1990b).

Diamond exploration techniques

The initial discoveries of alluvial diamonds were made by old fashioned prospecting using keen observation of drainage channels and opening up with a pick and shovel. Shortly after the initial discoveries, most surficial gravels were tested for payability, with the richer runs being exploited immediately.

Marshall and Baxter-Brown (1995) outlined the basic principles of modern, grassroots alluvial diamond exploration. They emphasize that there is no single, universally applicable method of target selection for alluvial diamond deposits. However, a number of exploration techniques are available and include remote sensing, geophysical surveys, drilling/pitting and bulk-sampling (Marshall, 2003).

Remote Sensing Methods

Landsat TM, Aster, RadarSat, DEM, IR-thermal images are all extremely useful for regional interpretation and target generation, but may have limited use in detailed farm scale applications. SPOT images offer better resolution but can be costly for the smaller operator. Aerial photographs are essential for any exploration operation. Black and white photos are easy and cheap to acquire and are useful for mine planning as well as prospecting. Colour photos are even more useful, but since they have to be specially commissioned, they can work out quite expensive for the smaller operator. In dolomitic terrains, colour infra-red photos have proved very useful but again they have to be specially commissioned and are costly. All remote sensing techniques can be extremely useful when combined with geophysical or geological data in one or other of the commercially available exploration/mining software programmes. However, ground verification and mapping are essential.

Geophysical Methods

Whilst carefully selected geophysical techniques provide useful information, it is essential that these surveys are supplemented by some combination of drilling, pitting and trenching, in order to determine the true nature of the anomalies located, as well as to confirm any volumetric estimation. Diamond grade and value can only be determined by completing a bulk-sampling programme.

Gravity

A variety of geophysical techniques have been applied with mixed success to locate and evaluate the extent of alluvial diamond deposits. The most useful methods have been gravity (both ground and airborne) and a variety of electro-magnetic methods. Stettler (1979), de Wit (1981) and Stettler *et al.,* (1995) have shown that ground gravimetrics can be applied to locate potholes and similar features buried beneath sand and soil cover, particularly in dolomitic terrains. More recently the technology to produce airborne gravity surveys has been developed by BHP Billiton (Falcon™) and Bell Geospace (3D Air FTG®). In late 2003 the Air FTG® was used successfully to identify, characterise and map known palaeochannel deposits surrounding the Tirisano Mine, near Ventersdorp (http://www.etruscan.com).

Electro-magnetics

Extensive practical experience in the southern, Schweizer-Reneke Field, has shown that EM31 surveys are particularly effective at locating shallow gravel deposits, especially the "*Rooikoppie*" type gravels. For deeper deposits and those associated with calcretized palaeochannels ERT (electro-resistivity tomography) has also been shown to be effective. One of the advantages of this system is that a pseudosection can be created from the data, giving an approximate picture of the true subsurface resistivity distribution (Loke, 1999). Since ground resistivity is closely related to various geological parameters, resistivity pseudosections can be viewed as approximating geological sections.

Airborne electromagnetics is a technique which increasingly is playing an important role in locating new gravel deposits. It is, however, generally very expensive. The Council for Geoscience of South Africa is currently developing its own, hopefully more affordable system which is scheduled to be ready for use in 2006.

Ground Penetrating Radar (GPR)

GPR is another high resolution method which can be used for imaging the subsurface structure. Resolution is controlled by the wavelength of the propagating electromagnetic wave in the ground and increases with increasing frequency. The depth of investigation increases with decreasing frequency but is accompanied by a decrease in resolution. The depth of investigation ranges from less than a metre in clay rich soils to some 30 m in fresh-water saturated, clay-free sands.

Drilling/Pitting

Depending on the various characteristics of a deposit, auger, percussion and reverse circulation (RC) drilling, can all be useful. In most cases, RC drilling gives a much clearer definition of gravel thicknesses and types, but its higher cost may mitigate against its use. In dolomite terrains, where manganese wad presents a problem, RC drilling is indispensable. In shallow gravels, it is often more cost-effective simply to proceed directly to the pitting phase and complete the entire programme with a small excavator or tractor-loader-backhoe.

Bulk-Sampling

In alluvial deposits, diamonds occur in clusters within natural traps such as gullies, potholes and gravel bars and are unevenly distributed within such trapsites. In addition, the individual diamonds themselves constitute discrete units of varying size and weight and are not evenly or uniformly distributed throughout an alluvial deposit. The clusters are not only randomly distributed in space, but the point density of each cluster is also random (Rombouts, 1987).

Consequently, in order for the estimated diamond grade of a prospect to be reliable, sample sizes need to be relatively large. Due to the nature of the distribution of diamonds throughout a deposit, the grade estimated from any individual sample can vary widely. A single sample provides only a limited amount of information and the conclusions drawn from a single sample are, correspondingly, uncertain.

In diamondiferous gravel deposits where the average grade is measured in carats per hundred tonnes and where individual stone sizes are in the order of 1 carat per stone, then it is necessary to process many thousands of tonnes of sample material (composited from numerous individual samples) to obtain a statistically meaningful sample grade and representative information relating to diamond size distribution and value. Such large samples, however, also allow for the determination of treatment plant specifications needed in the trial mining phase and what stripping ratios will be economic. In the future, the sizes and number of samples may be dependent on guidelines from the SAMREC code that has been devised by the South African Mineral Resources Evaluation Committee (http://www.saimm.co.za). Until this code is fully operational, however, as a rule of thumb, one would like to see at least a 5% sample for an inferred resource with a preferred minimum of some 50 000 tonnes, bulked from at least 4 or 5 individual samples. Obviously, significantly larger samples would be required for better levels of resource and reserve estimation.

Details of the mining, processing and beneficiation of alluvial diamond deposits, although of enormous practical importance, are outside the scope of this discussion and the interested reader is referred to the Abstract Volume of the "Diamonds: Source to Use (2005)" Symposium, organized by the South African Institute of Mining and Metallurgy (SAIMM).

Detailed descriptions of the geology of the gravel deposits

An alluvial fill is a record of a set of superimposed floodplains, reflecting an interval of net, but not necessarily continuous or homogeneous, deposition along a river valley. Unconformities between alluvial fills record erosional phases when the main stream and its local tributaries incised earlier alluvium and bedrock surfaces, destroying earlier terraces and removing part of that alluvial record, leaving behind limited, and usually transitory, fill on eroded surfaces. All alluvial sequences record many such erosional and depositional phases. The interpretation of complex alluvial fills is difficult because the processes of sediment supply and those of erosion and transport are interrelated, not only to each other, but also to other factors in the wider geomorphic environment. In addition, the processes responsible for a cumulative history of incision and floodplain aggradations have variable magnitude, frequency, spatial location and temporal context. Such changes do not occur with constant intensity through time; may have been accomplished by an assortment of events with variable magnitudes, durations and frequencies; and may not be uniformly distributed across the river valley at any particular time.

The Upper Vaal River System

In the Schweizer-Reneke, Wolmaransstad, Christiana and Bloemhof districts of the North West Province (Figure 1), a sequence of five alluvial units and multiple colluvial and eluvial units have been identified (Table 1).

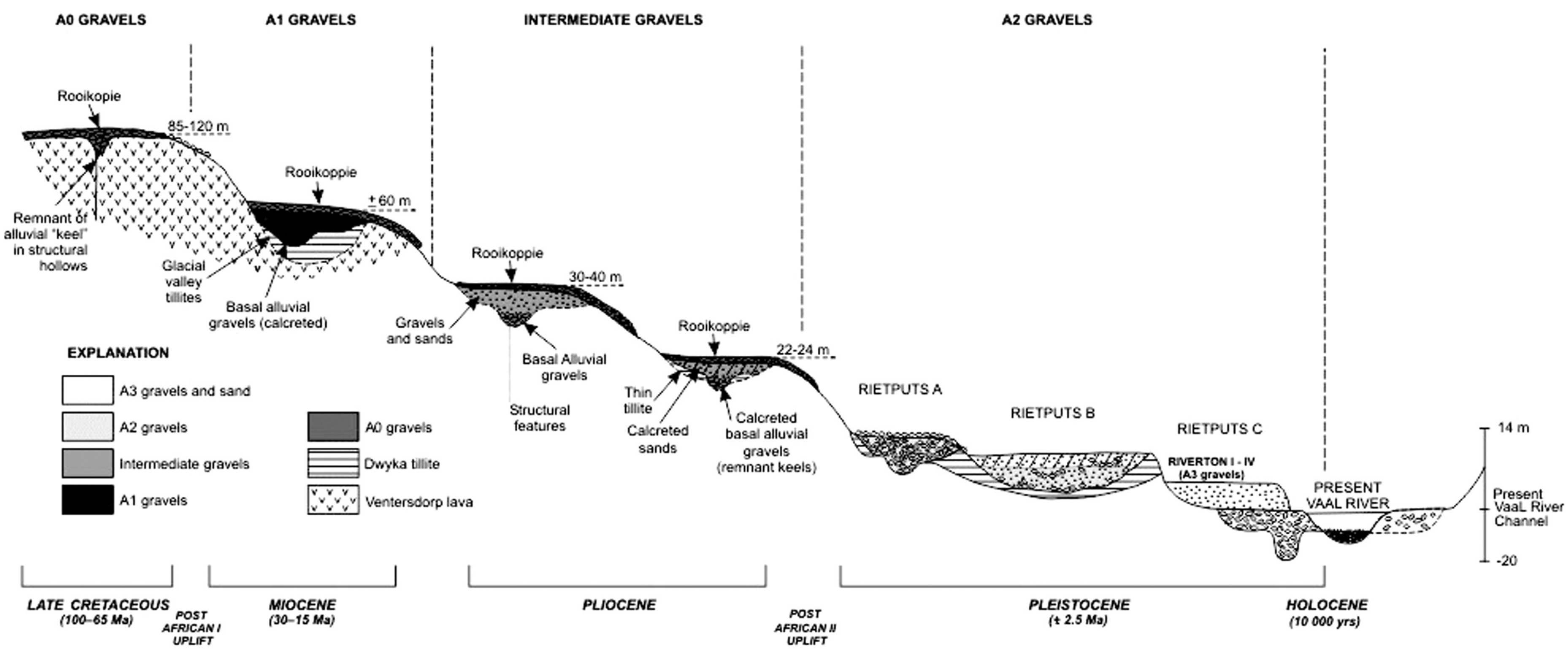


Figure 4. Summary diagram illustrating the various ages of gravels developed along the Vaal River system, as described in more detail in the accompanying text.

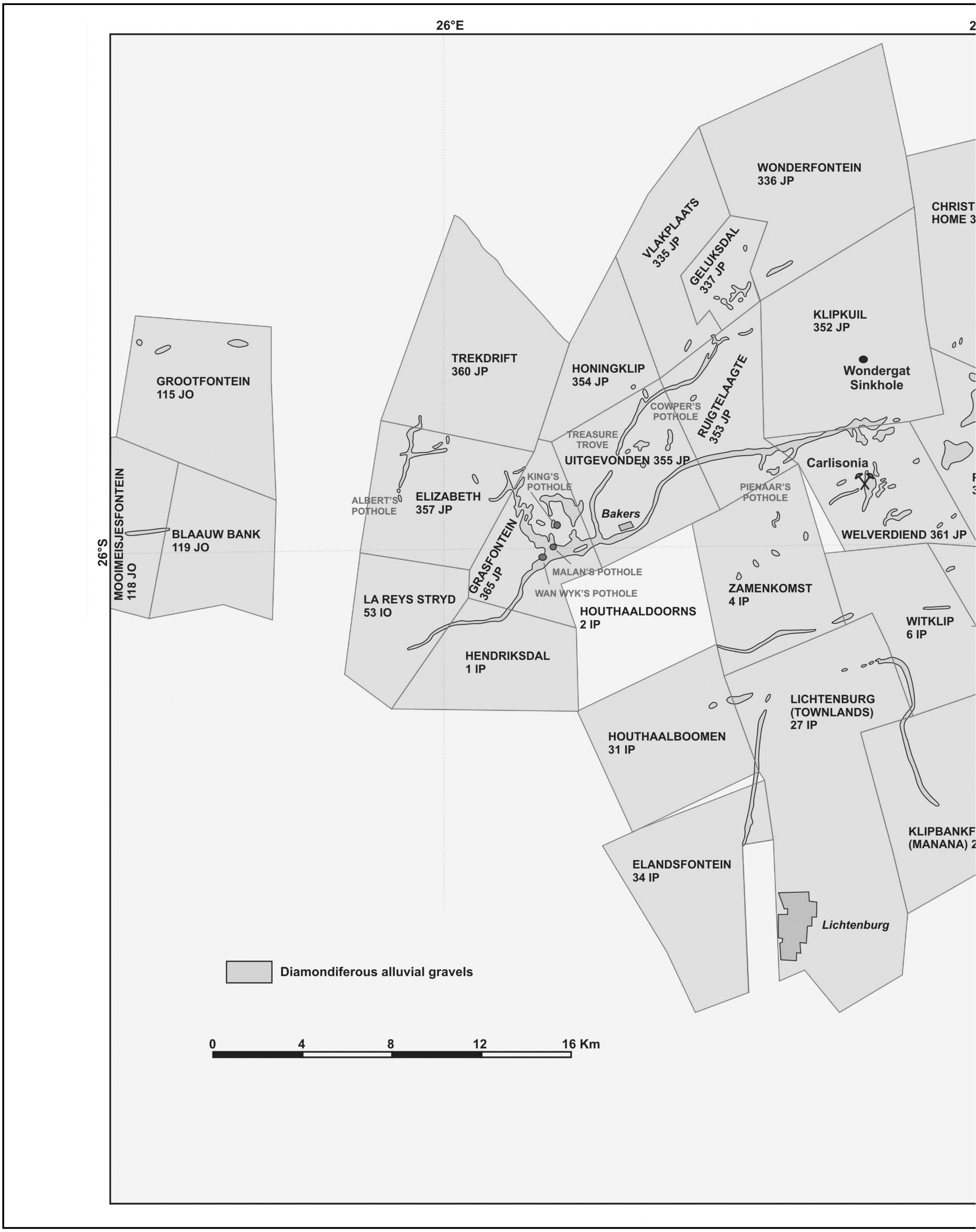
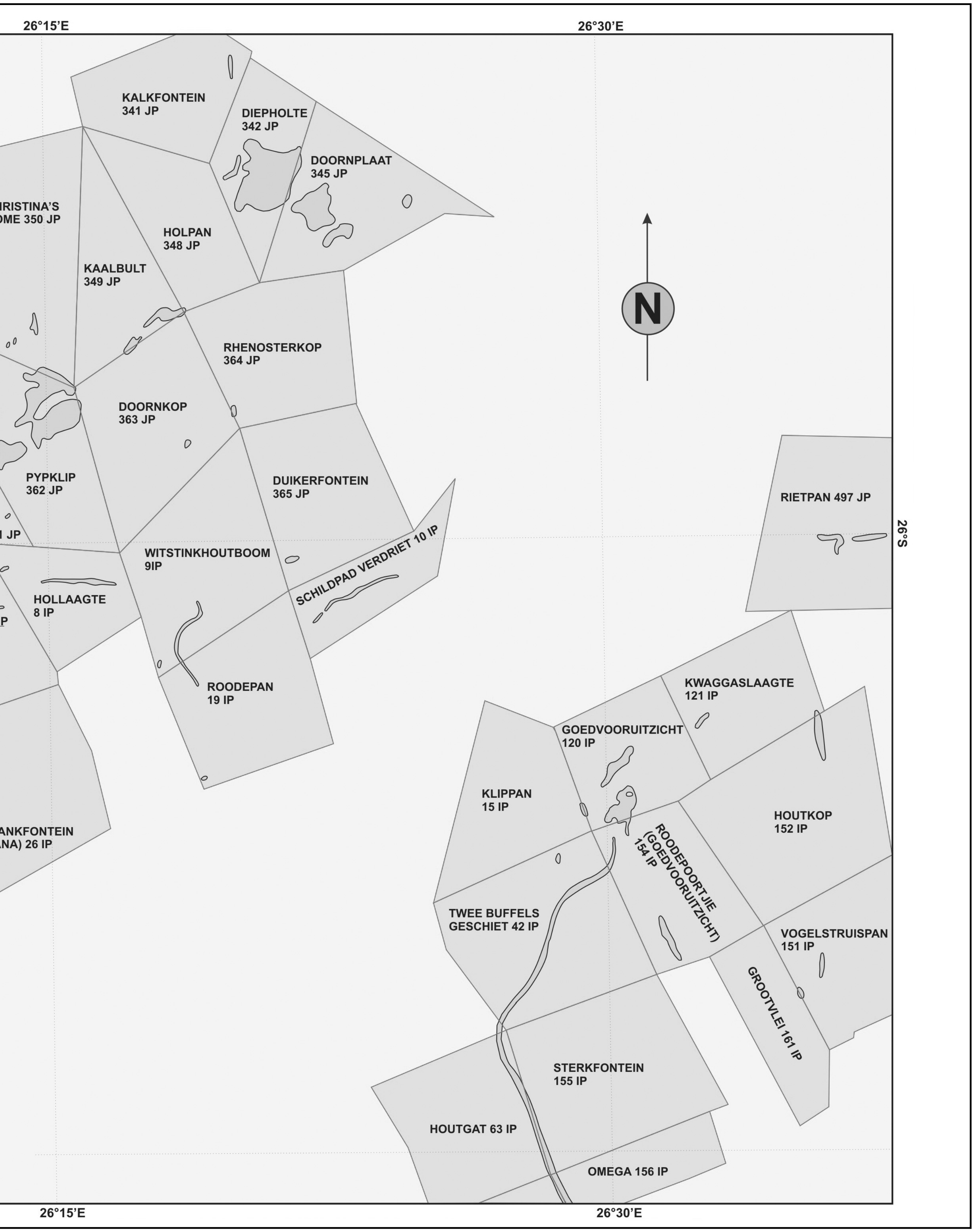


Figure 5. Plan showing the known diamondiferous alluvial gravels around Lichtenburg, modified after Du Toit (1951).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ROODEPAN 19 IP
KWAGGASLAAGTE 121 IP
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KLIPPAN 15 IP
ANKFONTEIN
ANA) 26 IP
HOUTKOP 152 IP
ROODEPOORTJIE (GOEDVOORUITZICHT) 154 IP
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Table 1. Simplified stratigraphy of the Vaal River Gravels (Modified after SACS, 1980; de Wit *et al.*, 2000).

Mesozoic–Cainozoic Deposits	
Upper Pleistocene	A3 Gravels (River alluvial gravels) *(Riverton Gravels)*
Middle Pleistocene	A2 Gravels (Terrace alluvial gravels) *(Rietputs A, B & C Gravels)*
Pliocene	Intermediate Gravels (alluvial and derived deposits) *(Proksch Koppie & Wedburg Gravels)*
Miocene	**Extensive Calcretization**
	A1 Gravel (Primary alluvial gravels and derived (eluvial) deposits) *(Holpan Gravels)*
Upper Cretaceous	A0 Gravels (Oldest alluvial gravels and derived (colluvial) deposits) *(Nooitgedacht Gravels)*

A0 Gravels
The oldest A0 gravels are believed to represent a late Cretaceous to early Tertiary drainage net that flowed generally southwards to the Vaal River during the African cycle of landscape erosion (de Wit, 1996; Bamford, 2000; de Wit *et al.*, 2000). They are generally shallow, covered only by 1 to 2 m of windblown Kalahari sand and Recent soil. Where the alluvial (channel) component is better preserved, it is composed of any number of oxidised, upward-fining successions. Because the landscape was lowered by weathering and deflation resulting from more than one episode of post-Cretaceous uplift or sea-level lowering (Partridge and Maud, 1987), the alluvial gravels were eroded and spread out on the surrounding surface to form thin (usually less than 0.5 m), laterally extensive (often covering many square kilometres in extent) deposits formed or modified by colluvial or hill-slope processes (Botha and Partridge, 2000). These derived deposits are best preserved as matrix-supported gravels in pockets within deeply weathered Ventersdorp lavas, where the palaeosurface has produced pseudo-karst features by laterization processes (Marshall, 1990a). Such gravels are known locally as *Rooikoppie Gravel* (Marshall, 2004) due to their generally reddish colour and location (Figure 4) on elevated terraces (up to 50 m above the present stream levels).

Very few *in-situ* alluvial channels have survived post-Cretaceous uplift and the resulting erosion and those that have occur only as remnant patches under the more extensive, derived (colluvial) gravels. Consequently palaeodrainage reconstructions are extremely difficult, if not impossible. The lithofacies and architecture of the A0 Alluvial deposits, along with the associated laterization, reflect the more humid late Cretaceous climates during which they are thought to have been deposited (Miall, 1996; Tyson and Partridge, 2000).

A1 Gravels
The African cycle of erosion ended by uplift around the beginning of the Miocene (Partridge and Maud, 2000), when pre-existing A0 deposits were incised and, in places, reworked on the A1 braidplain (Figure 4). As a result of intense calcretization during the arid Miocene (de Wit, 1993; de Wit and Bamford, 1993), derived eluvial deposits often overlie the A1 alluvial gravels. These gravels are also termed *Rooikoppie Gravels* by the local diggers as they are shallow or outcropping deposits, although quite different in both origin and form from the derived gravels associated with the earlier A0 deposits. The derived gravels, formed by eluvial processes, are preserved in solution hollows (*makondos*) in the hardpan calcrete which frequently caps the underlying gravels and are similar to those described from the lower Vaal River basin (Partridge and Brink, 1967, Marshall, 2004).

Intermediate Gravels
The intermediate gravels occur some 20 to 40 m above, and up to 2 km from, the present river levels. They are mostly eluvial deposits overlying thin alluvial deposits with little or no depth extent, and have generally been worked out by the artisanal diggers.

A2 Gravels
These are found along the length of the numerous dry spruits in the area and are locally termed *"spruit gruis"*. They consist generally of a basal diamondiferous gravel up to 2 m thick (deposited on an uneven floor of Ventersdorp lava), overlain by up to 20 m of upward-fining alluvium and capped by 1 to 3 m of black cotton soil. The entire sequence is cemented by immature calcrete. These deposits are the upstream equivalents of the Rietputs A, B, and C Formation gravels, described by Helgren (1979) from the middle Vaal River.

A3 Gravels
The A3 gravels are less than 0.5 m thick and occur beneath 7 to 20 m of upward-fining gravels, sands, and muds. They are composed mostly of fine-grained units and are not generally commercially mineable. They are presumed to be the equivalent of the Riverton (1 to 4) Formation deposits (Helgren, 1979).

Lichtenburg
The origin and processes which led to the deposition and concentration of diamondiferous gravels in the Lichtenburg field (Figure 5) remain debatable with regard to the roles of glaciation and karstification. Stettler (1979) viewed these gravels as simple river deposits where the river courses were influenced by karst features and dykes, and the gravel provenance stems from glacial sources. Based on the large number of kimberlitic garnets found at, for example, Pienaar's Pothole on the farm Ruigtelaagte 353 JP, he originally postulated that the diamonds originated from as yet undiscovered kimberlitic sources. On the other hand, de Wit and others propose that the gravels may come from eskers.

Gravel Stratigraphy

In the Lichtenburg area, the majority of the diamond-bearing gravel units occur as:

(1) pothole-fill;

(2) as sinuous, discontinuous, narrow, steep-sided alluvial channels, locally termed runs (Stettler, 1979); or

(3) as laterally more continuous, yet thin sheet-like gravels, assumed to be younger reworked material (Figure 5; Wilson *et al*., 2005).

Generally the walls of the runs are formed by kaolinised, brecciated, chert and dolomite, or solid dolomite. The channels usually occur as vertically walled troughs incised into the dolomite. In certain runs, small chert blades, at times in a boxwork form (similar to those that develop in phreatic caves), have been observed on the chert walls. Their presence suggests that there has been minimal abrasion of the sidewalls of the open karst areas during gravel deposition and that the gravels have most likely been dumped into the cavities (as would happen during collapse), rather than deposited during transportation by a stream. The potholes in and adjacent to the runs show varying morphologies ranging from collapse- to subsidence- dolines, yamas (perpendicular or oblique shafts leading to caves at depth), wells, lapies (solution channels) and buttresses.

Sinkholes

According to early studies (*e.g.* du Toit, 1951), the gravels in some of the deeper potholes appear to have a fourfold subdivision (Figure 6):

- Basal layer (pale or white gravels, grits and clays)
- Lower productive gravels (red gravels)
- Intermediate unproductive zone (brown clay or sandy layer)
- Upper productive gravels (grey gravels).

Runs or Channels

In the runs, the upper gravels usually lie unconformably above the lower gravels without the intervening clay layer, although such clays may be present in small lenses. Stettler (1979) described a gravel run as comprising a central channel of massive, well-packed gravel with a soil or clay matrix, bounded on both sides by loose rubble consisting of angular chert fragments, red-brown soil and sporadic rounded pebbles. There is a noticeable lack of definable, horizontal layering, bedding or sorting in both the upper and lower gravels. The contact between the central gravel and the marginal rubble is sharp, but not always erosional. In general the gravels are very coarse and material of pebble-to-boulder grade is common. All gradations exist from extremely well-rounded to angular chert fragments.

Sheet Gravels

Sheet gravels (generally <1 m thick) commonly flank the runs and may mark the continuation of a run between isolated patches of alluvial deposits. Numerous ages of these reworked sheet-like gravels are known to exist; the older deposits are usually economically viable, while the younger sheet gravels are often poorly mineralised, or patchy, at best.

Chert, derived from the Malmani Group, constitutes a major portion of the pebbles found in the gravel deposits. Quartzite pebbles, as well as less abundant shale and petrified wood clasts have most likely been derived from the Pretoria Group to the north and from nearby deposits of Ecca and Dwyka tillite respectively. Agates usually occur in large concentrations, but are sporadically distributed. Although they do occur in some shallow alluvial gravel deposits, agates tend to be concentrated in the lower gravels.

Analyses of the clays and clay-matrix material in most potholes indicate that they contain kaolin and a

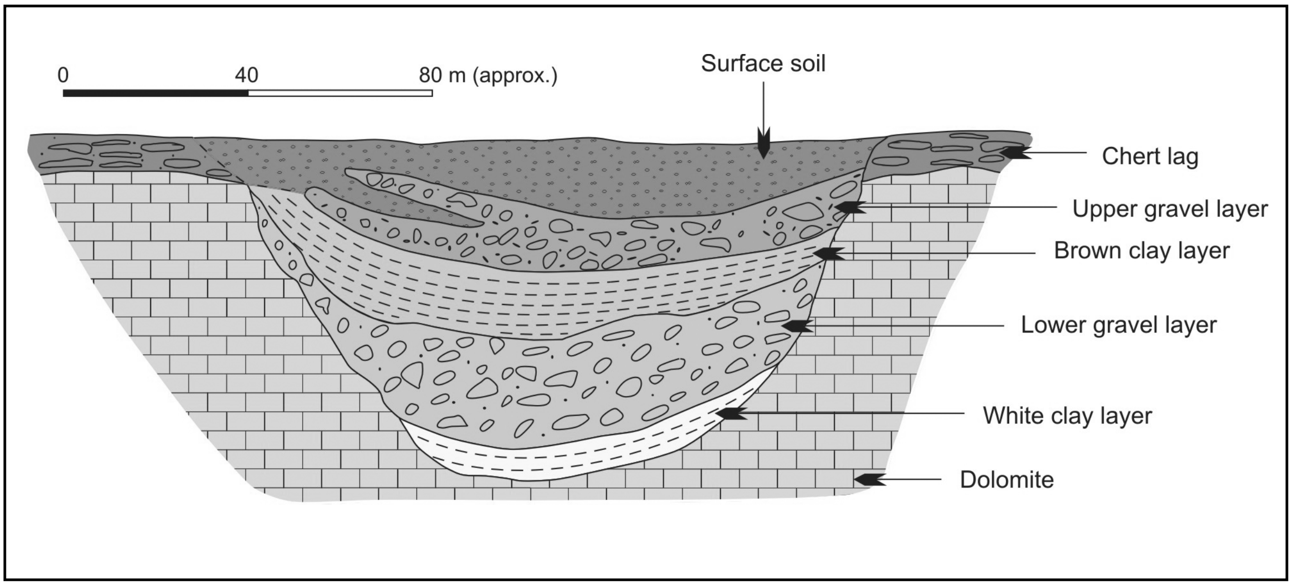

Figure 6. Sketch cross-section through Pienaar's Pothole on the farm Ruigtelaagte 353 JP in the Lichtenburg diamond field (after Williams, 1930).

high percentage of iron-oxide, reminiscent of bauxite. However, clay compositions suggest an ultramafic protolith in King's Pothole (de Wit, personal communication, 2003), suggesting the presence of kimberlitic source material in this case.

Ventersdorp Area

Gravel Stratigraphy

In the Ventersdorp area, numerous phases of gravel deposition have taken place, resulting in a complex stratigraphy of alluvial gravels and interbedded clays (Marshall, 1990b). Due to the karstic nature of the dolomitic terrain, the majority of the diamond-bearing gravel units occur primarily as sinuous, discontinuous, narrow, steep-sided alluvial channels, locally termed runs, along which potholes may occur (typically at structural or lithological intersections) and overlain by laterally more continuous, yet thin, sheet-like deflation gravels, assumed to be younger reworked material. The majority of the diamonds have been recovered from potholes, indicating that they have been an exceptionally effective trapping mechanism.

In profiles exposed in both old diggings and excavations for current operations, the general stratigraphy of these deposits is:

Deflation gravels

Approximately 1 m of sporadically developed, highly manganiferous "float" gravel of variable thickness, from a few centimetres to > 1.5 m. Deflation or sheet gravels usually occur in the vicinity of the original alluvials, commonly flanking the runs and may mark the continuation of a run between isolated patches of alluvial deposits. Numerous ages of these reworked gravels are known to exist; the older deposits are usually economic while the younger sheet gravels are often poorly mineralised or patchy, at best;

Black Gravels

Upper 2 m to 5 m of the Mixed Gravel package, intensely lateritised, normally constituted of large boulders and pebbles of quartzite, chert and chert breccia as well as vein quartz. These gravels contain high concentrations of Mn and Fe oxides;

Red/yellow gravels: Cobble-boulder gravel that is more oxidised at the surface, becoming more yellow with depth. The oxidised red gravels appear to contain more clay than the lower gravels. These gravels are the primary mining target, they may be interbedded with clay (sand) layers, and show a large variation of boulder size. They can be red in colour when oxidised;

Cherty gravels

Along the walls and bedrock, the gravels contain higher proportions of angular cherty clasts with an abundance of very large chert boulders close to the bedrock floor.

Summary

This study was undertaken to assess and verify the information available on the alluvial diamond fields of the North West Province in order to stimulate further interest and investment in this sector of the mining industry. The liberalization of the diamond marketing system led to increased diamond prices and this, coupled with the devaluation of the Rand against the US$ during late 2001 and 2002, resulted in a significant increase in onshore alluvial diamond production in South Africa.

Though the discovery of the Lichtenburg diamond field in 1926, made a huge impact on South Africa's diamond production, it was short-lived due to the effects of the Great Depression. Many, otherwise viable diamond operations were forced to close and some of these never re-opened. The depth of many of the early workings was limited by the lack of heavy equipment and, in some instances not all the mineralised horizons were identified and exploited. As a result it is possible that there remains some potential for commercial alluvial diamond mining in this area. The successful development of the Tirisano Mine in the Ventersdorp area, adds credence to this assertion.

These diamond fields are largely underlain by dolomites that have undergone at least four phases of karst development. Even though several phases of gravel deposition have occurred, the distribution of the diamondiferous gravels is influenced by weathering features in the dolomite and these now occur as pothole-fill, or as sinuous, discontinuous, narrow, steep-sided alluvial channels, or as laterally more continuous, yet thin sheet-like gravels, assumed to be younger reworked material. Pot holes (or sinkholes) have formed excellent trap sites for diamonds and enormous quantities of diamonds have been recovered from some of these.

There is a growing body of evidence which indicates that kimberlitic dykes may have intruded the dolomitic country rock in the Lichtenburg area and have been deeply eroded, leaving channels which were subsequently filled by diamondiferous gravels, forming some of the mineralized "runs" in the area.

Research in the southern diamond field has defined and classified five ages of alluvial gravels (ranging from late Cretaceous to the Pleistocene). The primary alluvial gravels have been modified post-deposition, by eluvial and colluvial processes, forming the ubiquitous "*Rooikoppie*" deposits. The alluvial diamonds associated with the gravel deposits in the Christiana, Schweizer-Reneke, Wolmaransstad and Bloemhof districts are generally of high quality, as a result of the presence of larger stones (50 to 200 ct).

In recent years there have been important advances in the techniques used for the exploration of alluvial diamond deposits. In addition to the traditional aerial photography, a number of different varieties of high resolution satellite images are readily available and, along with digital elevation models, have proved useful in delineating regional targets. Various airborne and ground geophysical techniques have been used to great advantage in the defining of individual targets.

The extremely low concentrations of diamond present in most alluvial deposits and the almost random distribution of the diamonds within the gravels, necessitate very large samples in order that the grade and quality of the diamonds can be meaningfully evaluated and commercial viability established.

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