

**THE ALLUVIAL DIAMOND DEPOSITS OF THE LOWER VAAL
RIVER BETWEEN BARKLY WEST AND THE VAAL-HARTS
CONFLUENCE IN THE NORTHERN CAPE PROVINCE,
SOUTH AFRICA**

By

FABRICE GILBERT MATHEYS

B.Sc. (Hons)

Thesis

**submitted in partial fulfilment
of the requirements
for the degree of**

MASTER OF SCIENCE

Department of Geology

Rhodes University

Grahamstown

DECEMBER 1990

ABSTRACT

The alluvial diamond deposits along the Vaal River, between Barkly West and the Vaal-Harts confluence, have been worked for more than one century by thousands of private diggers.

The diamonds are recovered from two sedimentary units of Cenozoic age, the Older Gravels and the Younger Gravels. These rest on a basement of Ventersdorp Supergroup andesites and Karoo Sequence sediments, which have been intruded by Cretaceous kimberlites. The gravels are, in turn, overlain by the Riverton Formation and the Hutton Sand. On a large scale, tectonic setting, geomorphology and palaeoclimate have played a major role in the formation of diamondiferous placers in the area under investigation. A study of the sedimentology of the Younger Gravels was carried out with the aim of acquiring an understanding of the processes responsible for the economic concentration of high quality diamonds. An investigation of facies assemblages, clast composition, clast size, external geometry, particle morphology and palaeocurrent directions led to the conclusion that the Younger Gravels were deposited in a proximal braided stream environment during high discharge.

A small-scale experiment was carried out to test the efficiency of different sedimentological trap sites in concentrating kimberlite indicator minerals. The results show that the concentration of indicator minerals is dependent on the size fraction chosen, bed roughness and gravel calibre. The examination of surface features on pyrope, microilmelite and chrome diopside from kimberlite led to the conclusion that most of these minerals are locally derived.

Diamond grade variations within the Younger Gravels are influenced by a combination of factors, including bed roughness, channel width and sorting process from the source. Alluvial diamond exploration programmes must take into account the tectonic setting, the palaeoclimate, the level of erosion, the stability of the drainage system in the area as well as the presence of local trap sites in the river profile.

It is concluded that the diamonds are the product of a long and complex process of erosion, reworking and concentration and are derived from Cretaceous kimberlites in the area.

ACKNOWLEDGEMENTS

The author wishes to thank the following:

Mr. M.C.J. de Wit, chief geologist, De Beers Consolidated Mines, Ltd., for his considerable guidance and constructive criticisms during the course of this investigation.

Dr. N. Hiller for his helpful comments and time spent on proof reading the draft of the thesis.

Anglo-American Corporation of South Africa and De Beers Consolidated Mines Ltd., for the provision of a grant to finance this study, and the C.S.I.R. for a post-graduate bursary.

The De Beers Geology laboratory in Kimberley for the sorting of the kimberlite indicator minerals.

The Minerals Bureau of South Africa in Johannesburg for providing the diamond production data.

All my friends of the M.Sc. course for their encouragement, help and advice they have given me throughout the year.

My family for their understanding of the long absence from home.

CONTENTS

	PAGE
1. INTRODUCTION	1
1.1 PURPOSE OF STUDY	1
1.2 METHODS OF STUDY	1
1.3 GEOGRAPHICAL SETTING AND CLIMATE	1
1.4 HISTORICAL BACKGROUND	3
2. THE DIFFERENT HOSTROCKS OF DIAMONDS	4
2.1 INTRODUCTION	4
2.2 PRIMARY HOSTROCKS	4
2.3 INTERMEDIATE HOSTROCKS	6
2.4 FLUVIAL, MARINE AND EOLIAN PLACERS	7
3. PRE-CENOZOIC GEOLOGY	8
3.1 INTRODUCTION	8
3.2 VENTERSDORP SUPERGROUP	9
3.3 TRANSVAAL SUPERGROUP	11
3.4 PRE-KAROO INTRUSIONS	12
3.5 KAROO SEQUENCE	12
3.6 KIMBERLITE INTRUSIONS	13
4. CENOZOIC GEOLOGY	14
4.1 INTRODUCTION	14
4.2 THE OLDER GRAVELS	15
4.3 THE YOUNGER GRAVELS	17
4.4 THE RIVERTON FORMATION	18
4.5 THE HUTTON SAND	18
4.6 PALEOSOLS	19

	PAGE
5. GEOMORPHOLOGICAL AND CLIMATIC CONTROLS OF THE DIAMONDS	19
5.1 INTRODUCTION	19
5.2 THE ROLE OF GEOLOGICAL STRUCTURE AND LITHOLOGY	19
5.3 THE ROLE OF VEGETATION AND CLIMATIC CHANGE SINCE THE CRETACEOUS	22
5.4 THE STABILITY OF THE DRAINAGE SYSTEM	24
5.5 RIVER PROFILE AND BEDROCK CHARACTERISTICS ..	25
5.6 CONCLUSIONS	28
6. SEDIMENTOLOGY OF THE YOUNGER GRAVELS	29
6.1 INTRODUCTION	29
6.2 MAPPING OF THE SEDIMENTS	29
6.3 SEDIMENTARY LITHOFACIES	30
6.4 FACIES ASSEMBLAGES	33
6.5 CLAST COMPOSITION	37
6.6 MEAN CLAST SIZE AND SORTING	38
6.7 EXTERNAL GEOMETRY	43
6.8 PARTICLE MORPHOLOGY	45
6.9 PALEOCURRENT DIRECTION	52
6.10 PROVENANCE OF THE GRAVELS	56
6.11 SEDIMENTOLOGICAL MODEL	58
7. THE KIMBERLITIC INDICATOR MINERALS	63
7.1 INTRODUCTION	63
7.2 METHODS	63
7.3 RECOVERY AND DISTANCE OF TRANSPORT	67
7.4 SORTING AND EFFICIENCY OF FLUVIAL "TRAP" SITES	68
7.5 CONCLUSIONS	70

	PAGE
8. THE DIAMONDS	71
8.1 INTRODUCTION	71
8.2 CHARACTERISTICS OF THE DIAMONDS	72
8.3 RELATIONSHIP BETWEEN DIAMOND DISTRIBUTION AND GEOLOGICAL PARAMETERS	72
8.4 ORIGIN OF THE DIAMONDS	77
9. EXPLORATION FOR ALLUVIAL DIAMOND DEPOSITS	80
9.1 INTRODUCTION	80
9.2 REGION SELECTION	81
9.3 RECONNAISSANCE SURVEY	85
9.4 GENERAL PROSPECTING	88
9.5 EVALUATION	89
10. GENERAL CONCLUSIONS	90
REFERENCES	92
PHOTOS	104
APPENDICES	119

LIST OF FIGURES

	PAGE
Figure 1: The Vaal River Basin, with gravel occurrences.	2
Figure 2: Detail of figure 1, showing the main diggings under investigation.	2
Figure 3: Distribution and ages of southern African kimberlites.	5
Figure 4: Pre-Cenozoic geology in the Barkly West area.	10
Figure 5: Age relationships between the different formations in the lower Vaal Basin and comparison with the Lichtenburg and Alexander Bay gravels.	16
Figure 6: Two stages in the evolution of the Vaal River as a result of its capture by the retreating headwaters of a small tributary of the Harts River.	21
Figure 7: Possible reconstruction of some tributaries of the Vaal and Orange Rivers in the late Tertiary.	25
Figure 8: Profile of the Vaal River and bedrock composition between Barkly West and the Vaal-Harts confluence.	26
Figure 9: Mean of the largest boulders	39
Figure 10: Preliminary test of clast size determination methods.	41
Figure 11: Arithmetic mean of 50 clasts (> 26 cm long axis) versus distance of transport.	42
Figure 12: Coefficient of variation of 50 boulders versus distance of transport.	42

Figure 13: Bed thickness versus maximum particle size diagram for the Rietputs Formation C.	44
Figure 14: Clast sphericity versus distance of transport.	46
Figure 15: Zingg diagram (I/L versus S/L).	47
Figure 16: Sneed and Folk diagram (S/L versus L-I/L-S).	48
Figure 17: Roundness versus distance of transport.	50
Figure 18: Paleocurrent directions in the study area.	55
Figure 19: Environmental setting: terrace gravels and steep valley with colluvially derived detritus (A) and depositional model: proximal braided stream deposits (B) for the Younger Gravels.	60
Figure 20: Weight of diamonds versus prices in US dollars (quality VVS1-E, December 1989). The prices per carat rise in steps.	72
Figure 21: Value per carat data (Rand/carat) for the farm Gong-Gong and Delpoortshoop since 1926.	75
Figure 22: World map of significant alluvial diamond deposits.	82

LIST OF TABLES

	PAGE
Table 1: Characteristics of the Older and Younger Gravels.	17
Table 2: Summary of principal geomorphic events in southern Africa since the Mesozoic.	20
Table 3: Classification of lithofacies in the Younger Gravels and their characteristics.	31
Table 4: Comparison of the lithology and morphometry of 200 clasts from the Younger Gravels and Dwyka tillite at Gong-Gong.	47
Table 5: Field description of "trap" sites and selected laboratory processing results for 19 test samples.	64-65
Table 6: Different stages in the laboratory treatment of the samples.	66
Table 7: The largest (more than 100 carats) diamonds recovered in the study area.	73

LIST OF PHOTOS

	PAGE
PHOTO 1: Dolerite koppie rising sharply from the pediment near Schmidtsdrif.	104
PHOTO 2: General view of the Vaal River and its braiding pattern. Gong-Gong falls in mid-distance.	104
PHOTO 3: Typical small-scale digger's rig with washing pan at Longlands.	105
PHOTO 4: Independent licensed diggers still work by the traditional methods (Gong-Gong).	105
PHOTO 5: Striated glaciated pavement on Ventersdorp andesite, after removal of formerly overlying Dwyka tillite.	106
PHOTO 6: Ventersdorp andesite with large amygdales of quartz (1-3 cm) and dissolution features.	106
PHOTO 7: Dolomite of the Transvaal Supergroup forming the Ghaap Escarpment north of Schmidtsdrif.	107
PHOTO 8: Dwyka Tillite (Upper Carboniferous) exhumed by long-continued erosion, together with its glaciated pavements of Ventersdorp andesite (Nooitgedacht).	107
PHOTO 9: Detail of the Dwyka Tillite with pebble to boulder size material (Nooitgedacht).	108
PHOTO 10: Younger Gravels overlying bedrock of Prince Albert Shale (Sydney-on-Vaal).	108

PHOTO 11:	The Gong-Gong Falls (3 m high). The Falls represent a re-excavated feature of a pre-Karoo valley.	109
PHOTO 12:	Uneven bedrock consisting of Ventersdorp lavas with potholes at Gong-Gong.	109
PHOTO 13:	"Giant" pothole (4 m deep) within the Ventersdorp andesite at Gong-Gong.	110
PHOTO 14:	Potholes within the Dwyka Tillite (0.3 to 0.8 m deep).	111
PHOTO 15:	Large boulders of Ventersdorp andesite at Bad Hope (the largest one can reach 1.7 m in length).	112
PHOTO 16:	Well-imbricated clasts of Ventersdorp lava and Prince Albert Shale (lower part) at Longlands (facies Gm).	113
Photo 17:	Trough-stratified cobble-size gravels at Sydney-on-Vaal (facies Gt).	113
PHOTO 18:	Rietputs Formation C gravels overlain by the Riverton Formation (calcretized sand), itself overlain by the Hutton Sand (red sand) at Sydney-on-Vaal.	114
PHOTO 19:	Massive and structureless lenses of gravelly sand (facies Sm) interbedded within the Rietputs C Formation at Sydney-on-Vaal.	115
PHOTO 20:	Openwork gravel layers overlain by matrix-filled layers at Sydney-on-Vaal. There is a clear upward fining.	115
PHOTO 21:	Composition of the gravels.	116
PHOTO 22:	Visual determination of roundness (angular to subrounded).	117

PHOTO 23: Visual determination of roundness (rounded to very well rounded).	117
PHOTO 24: Imbrications (current is from left to right).	118
PHOTO 25: The Dwyka Tillite at Gong-Gong.	118
PHOTO 26: Ventersdorp lava overlain by the Dwyka Tillite forming the bedrock at Gong-Gong.	119
PHOTO 27: A 2 carat diamond recovered in the concentrate at Delportshoop.	119

1. INTRODUCTION

1.1 PURPOSE OF STUDY

The principal aims of this study were the following :

- To review the geomorphological control of the gravel deposits.
- To describe the nature and distribution of the alluvial gravels.
- To determine the environment of deposition and the provenance area of the sediments.
- To compile the recovery of diamonds during this century.
- To acquire an understanding of the sedimentary processes responsible for the economic concentration of high quality diamonds in this area.
- To discuss the previous hypotheses concerning the origin of the diamonds.

1.2 METHODS OF STUDY

The interpretations presented here are based on detailed field investigation carried out from October to December 1989, and re-checked in March 1990. The methods adopted for the collection and processing of the data involved mapping and logging of the sediments, dry-sieve determinations, clast morphology and paleocurrent analysis, and heavy mineral study.

1.3 GEOGRAPHICAL SETTING AND CLIMATE

The spatial context for this thesis is defined as the drainage of the Vaal River between Barkly West and the Vaal-Harts confluence near Delpoortshoop in the northern Cape Province, a distance of 44 km (Fig. 1 and 2).

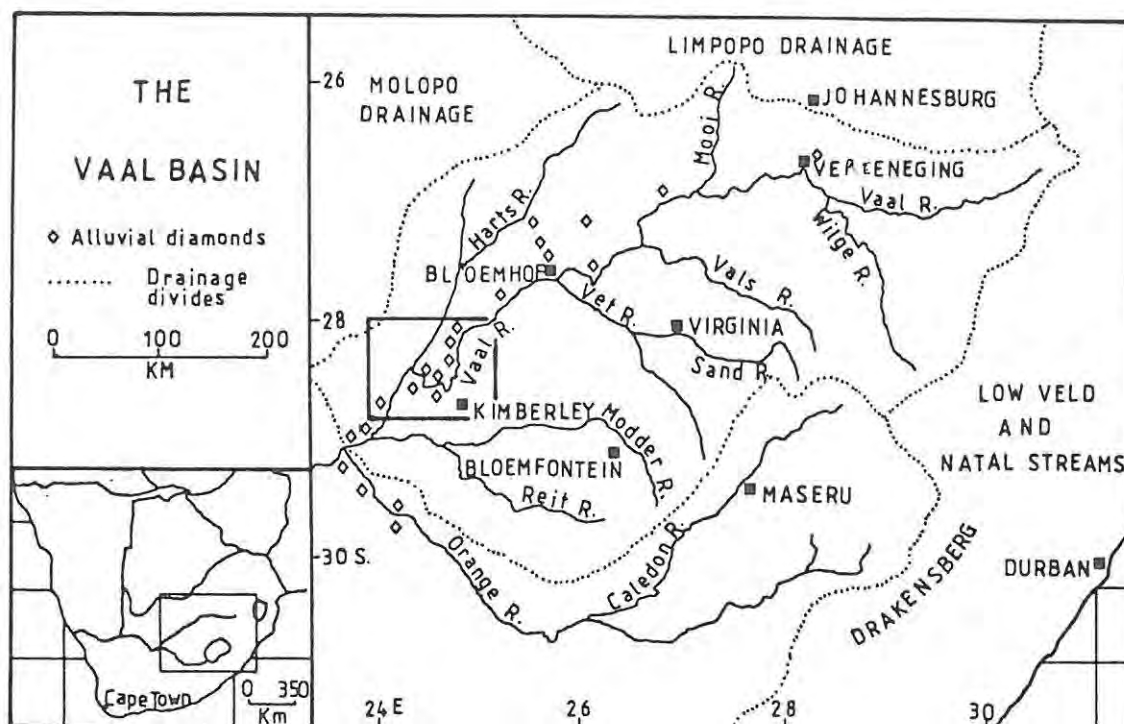


Fig.1 The Vaal River basin, with gravel occurrences (Modified after Helgren, 1979).

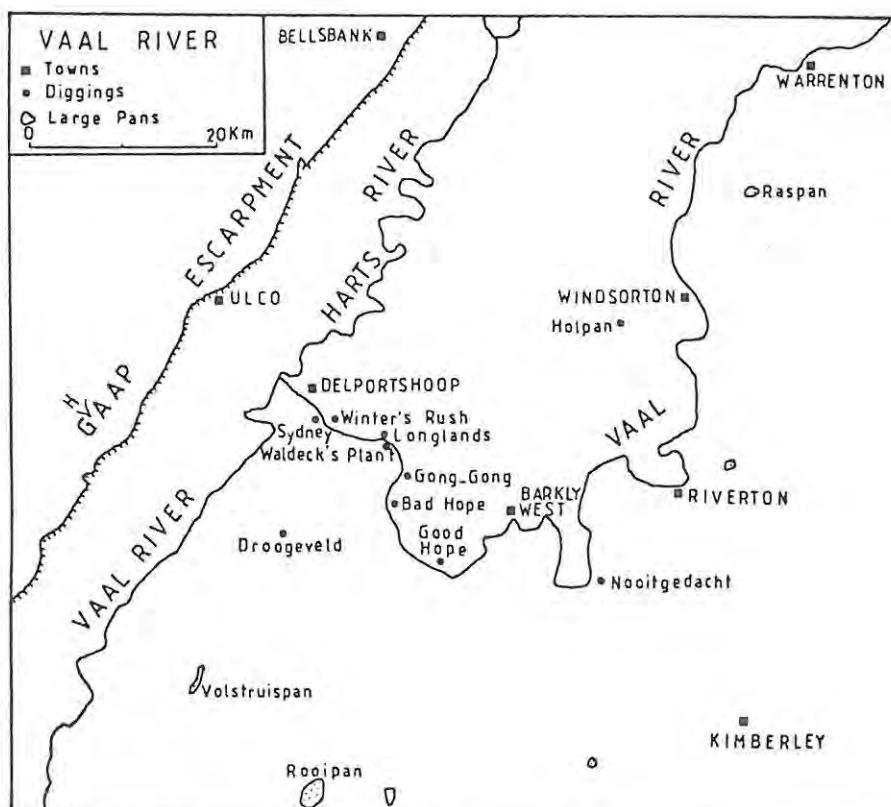


Fig.2 Detail of figure 1, showing the main diggings under investigation.

The basin of the Vaal River drainage system covers an area of about 194 250 km², embracing parts of the northern Cape and southern Transvaal and much of the Orange Free State. Average annual precipitation in the Vaal drainage decreases from 800 mm upstream to 300 mm downstream.

In the northern Cape, the semi-arid landscapes are dominated by broad, low-angle plains, bounded by river valleys or isolated clusters or chains of koppies (Photo 1). The climate is characterised by dry, cool winters, and warm to hot summers. Annual rainfall at Barkly West averages 417 mm, more than half being the product of sporadic thunderstorms during summer months (Helgren, 1979). The rainfall results in a perennially-flowing river but after the summer floods the volume declines steadily until, in its natural state, it became only a narrow stream connecting scattered pools during the dry season (Cooke, 1947). Now, however, conservation schemes have greatly modified the flow and rendered it much more nearly constant (Photo 2).

1.4 HISTORICAL BACKGROUND

Early in 1867, the discovery of a few diamonds along the banks of the Orange River near Hopetown led a small population of diggers to work the wet diggings along the Orange, Vaal, and Hartz Rivers. In 1869, the Star of South Africa, a diamond of 83.5 carats, was found, and precipitated the diggers rush. The first diggings were at Klipdrift (now called Canteen Kopje), Pniel, Hebron, Gong-Gong, Longlands and Sydney on the banks of the Vaal river near Barkly West. Despite the discovery of diamondiferous pipes between 1870 and 1872 at Jagersfontein and Kimberley, searching for alluvial diamonds continued without interruption until today along the section of the Vaal basin which lies between the mouth of the Harts river and Bloemhof.

As in the early times, the exploitation of the diamond-bearing gravels is entirely in the hands of individual diggers, working their own claims (30 ft by 60 ft). Every digger has in the first place to take out a licence which entitles him to dig for and to sell diamonds. The digging operations are of an extremely simple character, involving the removal of an overburden of sand or soil and the excavation of the underlying gravel (Photo 3 and 4). In 1987, the total production from

alluvial diggings in the Barkly West District was 19 745 carats (Axsel, 1988).

2. THE DIFFERENT HOSTROCKS OF DIAMONDS

2.1 INTRODUCTION

Before the discovery of the Jagersfontein kimberlitic pipe in 1870, the only source of diamonds was in river gravels. The early discoveries were made in India (about 800 B.C.), Borneo (sixteenth century), Brazil (1721), and South Africa (1867). Since then, the recognition that other types of deposits may contain diamonds has produced a new perspective in targets for diamond exploration. At the present time, diamonds are found in many parts of the world, and the location of new provinces (e.g. in China, Brazil and north Australia), and new occurrences in established areas (e.g. Kuruman and Venetia, South Africa) highlight that potential exists in new areas. However, the Southern African Province is still one of the most important producers of diamonds in the world and is certainly the first in gem quality output. The association with a cratonic area, the favourable geomorphological environment, and the regional fracture systems may account for this unique situation.

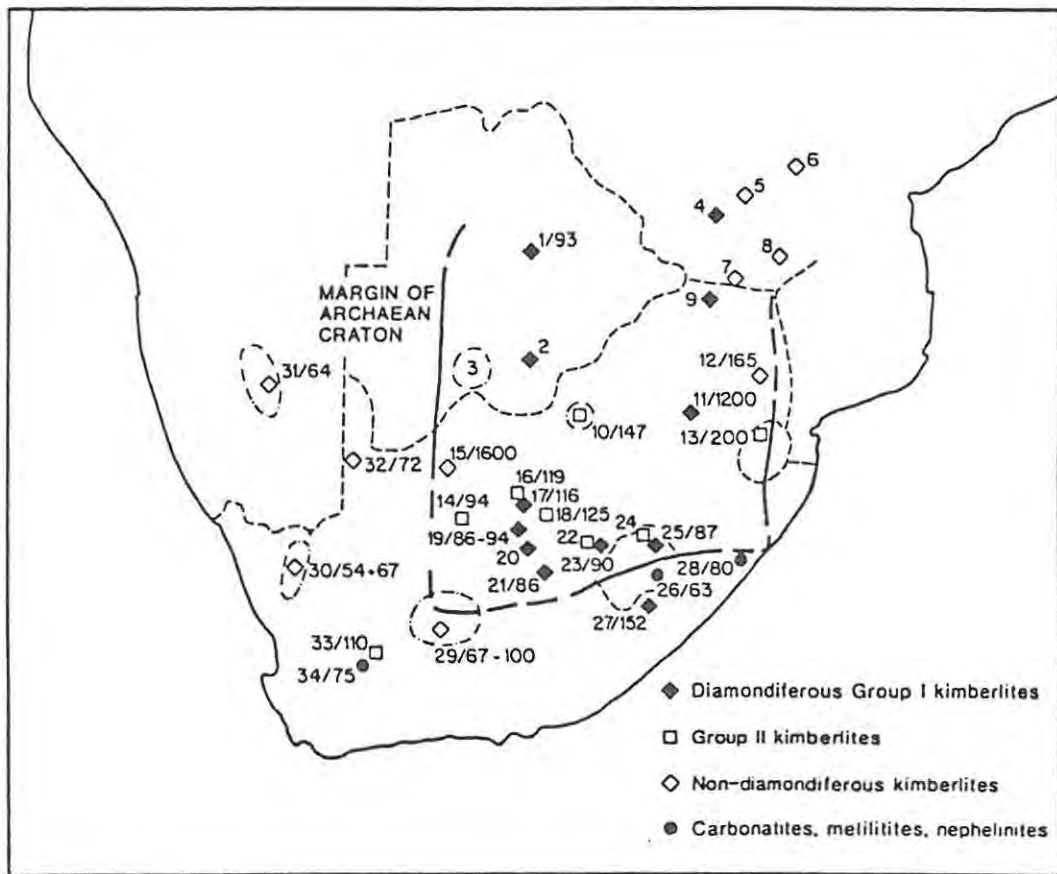
2.2 PRIMARY HOSTROCKS

The primary source rocks of diamond in economic quantities are certain varieties of kimberlites and lamproites. These two varieties of rocks differ in detail with respect to petrology and geochemistry but are broadly related in the sense that they carry a wide variety of upper-mantle derived xenoliths and are apparently generated at deeper levels in the mantle than most other magmas.

Kimberlites are ultrabasic potassic igneous rocks occupying small pipes, sills and dykes. Diamondiferous kimberlites are ubiquitous in regions of the continental crust that are underlain by old cratons (>2.4 Ga) although some non-economic kimberlites have been recognised

within mobile belts (Clifford, 1966; Dawson, 1970).

In southern Africa four kimberlitic intrusive events have been recognized (Dawson, 1989): Kuruman (~ 1.6 Ga), Premier (~ 1.2 Ga), Venetia - Beitbridge (500 Ma), and the Triassic-Cretaceous event (240-60 Ma) (Fig.3). These can be broadly correlated with major orogenesis and intrusion. Moreover, the presence of diamonds in the Witwatersrand conglomerates (De Beers Geol. Dept., 1976) implies that a primary source must have been emplaced before 2.6 Ga. The kimberlites are divided into Groups 1 and 2 on isotopic (Smith, 1983), geochemical



◆ major Group I kimberlites or kimberlite clusters; ○ non-diamondiferous kimberlites; - - - areas of non-diamondiferous kimberlite intrusion; □ Group II kimberlites; ● carbonatites, olivine melilitites and nephelinites. Numbers following strokes are ages of kimberlites, sometimes averaged for a cluster of intrusions.

1. Orapa; 2. Jwaneng; 3. S.W. Botswana; 4. Colossus and Wessels; 5. Clare; 6. Charter; 7. River Ranch; 8. Shingwize; 9. Venetia; 10. Swartruggens; 11. Premier; 12. Dullstroom (Elands-kloof); 13. Dokolwayo; 14. Finsch; 15. Kuruman; 16. Bellsbank; 17. Barkly West (Newlands, Mayeng, Frank Smith); 18. Boshof area (New Elands, Roberts Victor, Blaauwbosch); 19. Kimberley area (Bultfontein, Dutoitspan, De Beers, Wesselton); 20. Koffiefontein; 21. Jagersfontein; 22. Winburg area (Star, Lion Hill); 23. Monastery; 24. Marakabei, Lesotho; 25. Mothae, Lesotho; 26. Melkfontein carbonatite; 27. Mzongwea; 28. Eshowe melilitites; 29. Victoria West (Lushof, Uintjes Berg); 30. Namaqualand (Platbakkies, Brakfontein); 31. Gibeon-Keetmanshoop area, Namibia (Deutsche Erde, Mukorob); 32. Rietfontein; 33. Eendekuil; 34. Sutherland melilitites

Fig.3 Distribution and ages of southern African kimberlites (After Dawson, 1989).

(Smith et al., 1985) and petrological (Skinner, 1989) grounds. Only a small percentage of kimberlites are economic; approximately 1% in South Africa.

The discovery of diamonds within olivine lamproites at Ellendale and Argyle, on the SW and E margins of the Kimberley craton in NW Australia (Atkinson et al., 1984), opened a new field for diamond exploration. Lamproites are K- and Mg-rich igneous rocks which tend to be localized marginal to continental craton cores, in areas that overlie fossil Benioff zones. In contrast, the general occurrence of kimberlites is more towards the interior of continental cratons (Bergman, 1987).

In South Africa, lamproite dykes have been reported at Pniel (Baster's Mine), Postmasburg and Pielansburg and may have some similarities with the Group 2 kimberlites (Smith, 1983; Dawson, 1987).

The possibility of finding diamonds in other mantle-derived igneous rocks must not be excluded. The presence of diamonds has been reported from ophiolite sequences associated with plate margins. Slodkevitch (1983) reported graphite paramorphs after diamond in the layered ultramafic body at Beni Bouchera, Morocco.

2.3 INTERMEDIATE HOSTROCKS

Once diamonds have been released from their primary hostrocks, they can be recycled in any available sedimentary sequences. These sequences are generally associated with continental formations of old platforms and more specifically their coarse facies. Diamond occurrences are found in conglomerates, quartzites, sandstones, arkoses and tillites. These diamondiferous formations may cover very large surfaces. For instance, the alluvial diamond fields that straddle the Zaire/Angola border are essentially derived from the reworking of Cretaceous conglomerates and cover about 60 000 km² (Bardet, 1974). With the exception perhaps of some Brazilian tillites (Tompkins and Gonzaga, 1989), the concentration is rarely sufficiently elevated to be of economic importance. However, the reworking and reconcentration of such poor and diffused mineralization may lead to economically viable placer deposits. Junner (1943), studying the

diamond field of Ghana, noticed that diamonds are even able to undergo metamorphic events that alter the surrounding rock types and to be released to the fluvial system at a later stage.

2.4 FLUVIAL, MARINE AND EOLIAN PLACERS

Placer deposits are formed as a result of the transportation of diamonds from a primary or intermediate host rock, and their concentration within gravels or sand. This ability of diamonds to form placer deposits is due to their high specific gravity, their durability, and their chemical inertness. Most of the world's diamondiferous placer deposits are no older than Cretaceous because older deposits have been destroyed or reworked by subsequent erosion.

Placer diamond deposits can be sub-divided into three main categories:

-**FLUVIAL PLACERS**: these deposits are the result of the deposition of diamonds in paleo-river channels and terraces, as well as present-day river channels and flats. The principal fluvial deposits in South Africa are those in the valleys of the Vaal and Harts rivers between Prieska and Potchefstroom, the deposits on the high plains of the western Transvaal in the Lichtenburg and Ventersdorp Districts, and those of the Lower Orange River in Namaqualand.

-**MARINE PLACERS**: these deposits are found along paleo-marine beaches, onshore and offshore, as well as along present-day beaches. Beach deposits occur on passive continental margins (Mitchell and Garson, 1981), where the predominant influences are appropriate source materials, the fluctuation of sea-level in Quaternary times and the mechanical concentration of heavy minerals by wave and current activity. The only economic occurrence in the world occurs along the Atlantic Coast of South Africa and Namibia from the Olifants River in the south to the Kunene River in the north, a distance of 1600 km .

-**EOLIAN PLACERS**: these deposits are developed in desert regions where the deflation and transport of clastic material by the wind are exceptionally important. Placers developed by eolian activity are rare, well sorted, and occur in the vicinity of a primary or

secondary source. A classical example of this type is the deflation deposits found at the beginning of this century south of Luderitz in the Namibian desert (Merensky, 1909).

Commonly the placer minerals which occur in fluvial and beach environments have undergone several cycles of erosion, transport and deposition. The degree to which diamonds are up-graded will depend largely on topography and climate. Sutherland (1982) emphasized the systematic variation in size and quality of diamonds that result from transport by fluvial and marine processes. This author noticed that the brittleness of diamond and the sorting effect due to transport, both tend to diminish the size of diamond from the source. Moreover, transport tends to increase the quality of the diamonds by removing bort, mechanically weaker diamonds, and cleavage stones, and by entraining preferentially the rounded forms which suffer less weight loss during cutting. The absolute value (dollars per carat) of a diamond population is therefore a balance between the reduction in size and the increase in quality that are complementary of the transport process.

3. PRE-CENOZOIC GEOLOGY

3.1 INTRODUCTION

The geological history of southern Africa extends back 3.8 billion years. Tankard et al. (1982) have recognized five major phases of crustal evolution:

The first phase was a period of Archean crustal development which gave rise to foliated granitoids and gneisses with deformed greenstone relicts of volcanic and sedimentary sequences (e.g. Barbeton Sequence).

In the second stage, extending from the end of the Archean into the mid-Proterozoic, the crystalline basement was buried by sediment and volcanic rocks, represented by the Pongola, Witwatersrand, Ventersdorp, Transvaal-Griqualand West Supergroups and the Waterberg-

Soutpansberg-Matsap red beds. The Bushveld Complex arises from the emplacement of basic magma into the Transvaal Supergroup during the Early Proterozoic.

During the third phase, orogenic activity reworked the older crystalline rocks and their supracrustal cover in the south and west of the subcontinent. The Proterozoic deformation was accompanied by granitoid intrusions produced by partial melting of older crust and by additions from the mantle. Geosynclinal opening and closing of the proto-South Atlantic is recorded along the west coast.

The fourth stage is referred to as the Gondwana Era. During the Early Paleozoic, abortive rifting of Gondwana resulted in the deposition of the Cape Supergroup. This sedimentary phase was followed by continental glaciation, giving rise to widespread subglacial and glaciomarine sedimentation and forming the Dwyka Formation, the basal unit of the Karoo Sequence. Subsequently, the Karoo basin was filled with sediments of the Ecca and Beaufort Groups and the Molteno, Elliot and Clarens Formations. Finally, the sediments were covered by the lavas of the Drakensberg Formation and intruded by dolerite dykes and sills.

Mesozoic fragmentation of Gondwana marks the fifth phase. Many of the subcontinent's kimberlites, carbonatites and other alkaline intrusions were emplaced at this stage of continental uplift and nearby sea-floor spreading. Late Mesozoic and Cenozoic sedimentation was restricted to the margins of the stable subcontinent and depressed areas of the interior.

Phases two (Ventersdorp and Transvaal Supergroups), four (Karoo Sequence) and five (Older and Younger Gravels) are well represented in the area under investigation (Fig. 4).

3.2 VENTERSDORP SUPERGROUP

In the Barkly West District, the Ventersdorp Supergroup is only represented by a basal unit of quartzite overlain by a thick sequence of andesitic lavas interbedded with minor agglomerate. The former is regarded as the equivalent of the Bothaville Formation while the

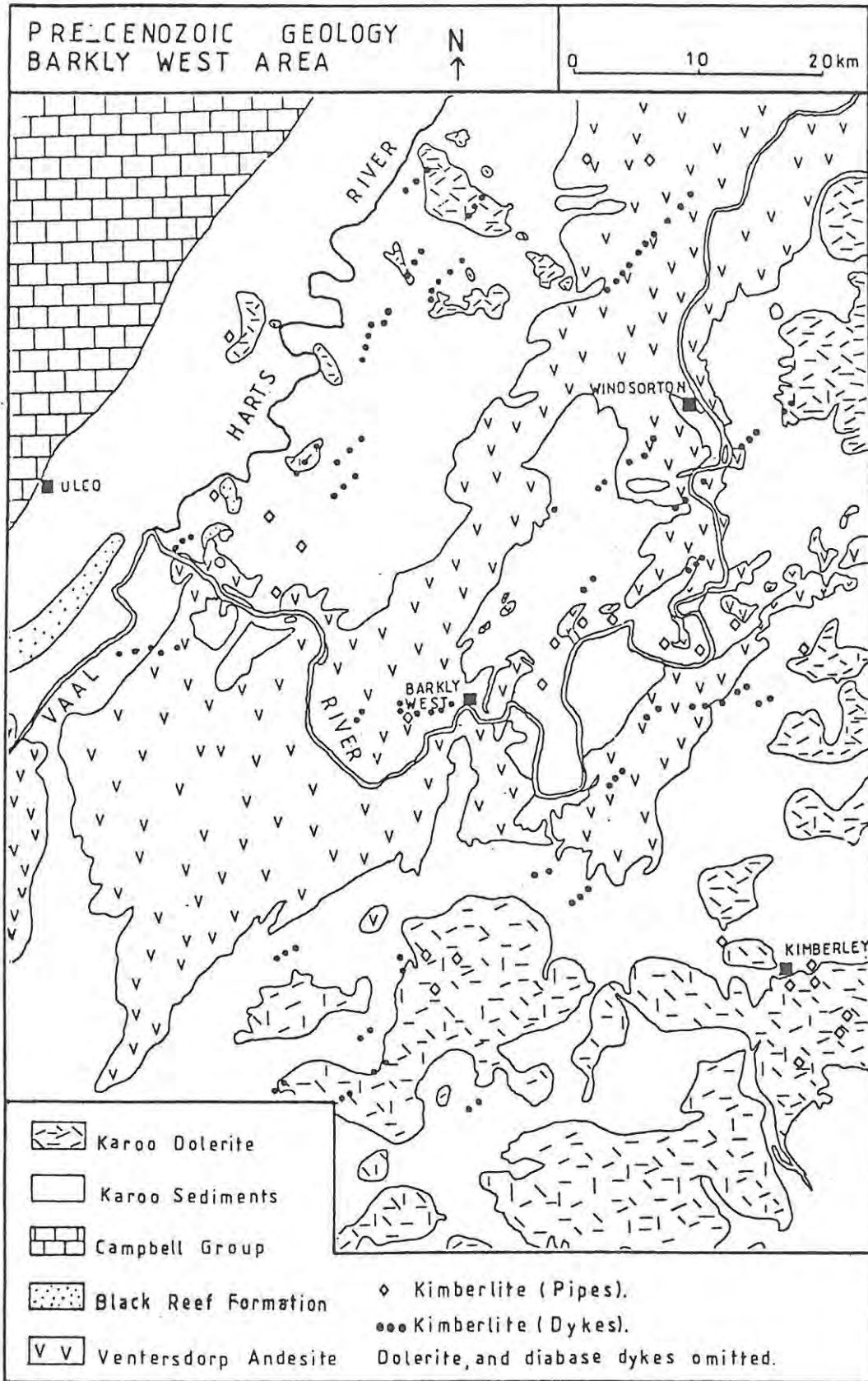


Fig.4 Pre-Cenozoic geology in the Barkly West area (redrawn after the 1/238,000 map of Du Toit (1910) and the 1/50,000 map of the Geological Survey (1978)).

latter is regarded as the equivalent of the Allanridge Formation (SACS, 1980). The succession has a minimum thickness of 1000 m. On the basis of a U/Pb study on zircons, the Ventersdorp Supergroup has been dated at about 2,7 Ga (Armstrong et al., 1990).

The andesites are green to dark-grey fine-grained microcrystalline rocks which are usually altered by chloritisation, epidotisation, uranisation, saussuritisation and calcitisation. The andesitic lavas forming most of the roches moutonnées and striated pavements in the area (Photo 5), show the development of amygdales of quartz, chalcedony, carnelian, agate, jasper, calcite, epidote, chlorite and pyrite (Photo 6). Porphyritic and non-porphyritic zones are present, while pillow lavas are found in a few places.

The Ventersdorp rocks exhibit extensive jointing and variable displacement faulting which trend in a NNW, NNE, and NE directions. Except for outcrops close to or in the river bed, these rocks are covered by a variable thickness of reddish sandy loam or even tufa.

Visser et al. (1976) suggested that the accumulations of andesite took place in broad basins largely under subareal conditions and interpreted them as plateau lavas.

3.3 TRANSVAAL SUPERGROUP

The Transvaal Supergroup lies unconformably on the Ventersdorp Supergroup and is composed of the Black Reef Formation and the overlying Campbell Group. These rocks dip at less than 4° and are at least locally conformable. The Transvaal sedimentation was probably initiated after 2.3 Ga and had ceased by 2.1 Ga (Tankard et al., 1982).

The Black Reef rocks, which have a total thickness of about 100 m, consist predominantly of quartzite and siltstone. Good outcrops are exposed from Delpoortshoop to beyond the confluence with the Orange River.

The Campbell Rand rocks consist of a basal, transitional zone (>200 m) of calcareous quartzite, siltstone and calcarenite shale, followed by

a thick sequence of dolomite, dolomitic limestone and pure limestone (~ 3000 m), overlain by BIF and jaspilite (185 m thick). These sequences form the Ghaap Plateau and are well-exposed along the scarp face (Photo 7).

The depositional setting for the Campbell Group in the region apparently was a shallow epicontinental sea with a coastline retreating to the modern north-west (Tankard et al., 1982).

3.4 PRE-KAROO INTRUSIONS

A series of quartz porphyries, diabases, and pegmatites are intrusive into rocks of the Ventersdorp and Transvaal Supergroups. Pegmatite dykes intrude the Ventersdorp volcanics on high Pniel (South of Barkly West) and a quartz porphyry dyke, following the Dikbosh Fracture, intrudes the Ventersdorp terrane from Barkly West to north of Schmidtsdrif. Diabase dykes are common along the crest of the Ghaap escarpment and trend across some Ventersdorp surfaces.

3.5 KAROO SEQUENCE

Only glacial deposits of the Dwyka Formation, shales of the Prince Albert Formation (base of the Ecca Group) and late Karoo intrusives are represented in the area.

The Dwyka Formation records the migration of Gondwana over the South Pole at the Carboniferous and Permian transition. In the lower Vaal basin, the glacial beds vary in thickness from virtually zero in some places to more than 40 m. The Prince Albert Shale, with a maximum thickness of 90 m, does not outcrop fully in the area.

The glacial beds consist of tillite, banded tillite, boulder shale, conglomerate, carbonate-rich sandstone and varved shale which contains dropstone horizons. The tillite consists of boulder to sand-grade particles set in a muddy matrix (Photos 8 and 9). Lithologies of the largest clasts generally reflect the local, pre-glacial bedrock. The erratics are up to 2 m in diameter and consist mainly of subangular to rounded fragments of the Ventersdorp andesites with minor quartzite,

dolomite, conglomerate, chert, jasper and quartz. Granite, quartz porphyry and syenite also occur in the Nooitgedacht area while the Transvaal Supergroup limestone and dolomite are common in the glacial valleys along the Orange River below Douglas. The matrix contains few clay minerals, but is dominated by silt and clay-sized fragments (Hamilton and Krinsley, 1967). The matrix is a mixture of angular to sub-rounded quartz with secondary feldspars and micas. A few pebbles and many clay and silt-sized microclasts may have lithologies from outside the Vaal basin (Helgren, 1979). The change in deposition from subglacial diamicton to glaciolacustrine or glaciomarine sediment suggests a major inundation of the area and supplies evidence for a rapid, final destruction of the glaciers (Visser and Loock, 1988).

Overlying the glacial beds and partly interdigitating with the varved shale, are the horizontally-bedded Prince Albert Shale (Photo 10). At the base is black carbonaceous shale with several concretion horizons. Mica-rich greenish mudstone and khaki-coloured shale form the largest part of the succession.

Late Karoo dykes and one sill of dolerite are intrusive into rocks of the Dwyka Formation. The dolerite sill has a maximum thickness of about 90 m. Where it is in contact with the Prince Albert Shale, these are altered to lydianite, popular raw material in Stone Age times.

3.6 KIMBERLITE INTRUSIONS

The youngest intrusions in the area are kimberlite pipes and fissures (140 - 70 Ma). Apart from the diamonds and inclusions derived from the mantle in the kimberlite, fragments of Dwyka shale from the wall rock are common in some pipes. Two different fields can be recognized:

The Kimberley field, which contains the famous Kimberley, De Beers, Dutoitspan, Wesselton, and Bultfontein mines, consists of diatreme facies kimberlites whose distribution is controlled by northwest-southeast orientated feeder dykes.

In contrast, the Barkly West field, occurring at the same erosional

surface, consists of a swarm of northeast-southwest trending subparallel feeder dykes. Diamonds in economic quantity have been found in the Jubilee, Newlands, Doornkloof and Frank Smith kimberlites.

4. CENOZOIC GEOLOGY

4.1 INTRODUCTION

The Tertiary record in southern Africa is poorly represented. With the exception of the Central Kalahari Basin and the lacustrine and fluvial sediments, all the extensive deposits occur on the continental margins. The diamondiferous gravels of the Vaal basin give a rare opportunity to study the Cenozoic interior of South Africa.

On account of their economic significance as a source of alluvial diamonds and on scientific grounds as deposits associated with Stone Age implements, these deposits have received considerable attention from various geologists. Du Toit (1910) gave the first comprehensive account of the gravels and described the Vaal River from a physiographic viewpoint. Wagner (1914) described the alluvial deposits as a whole and studied the economic problems of explaining the erratic occurrences of diamonds within the gravels. In 1937, Söhnge and Visser described the river deposits downstream of Vereeniging in some detail and subdivided the succession on the basis of the stone implements contained in the terraces. They grouped the terrace gravels into High-level "Older Gravels", usually red in colour, and low-level "Younger Gravels" in which they distinguished three phases of deposition. Cooke (1947) emphasized the role of geomorphological control and climatic change during the deposition of the gravels, while Van Riet Lowe (1952) attempted to correlate alluvial terrace and cultural changes. New concepts have been described by Partridge and Brink (1967), Butzer et al. (1973) and Helgren (1979). At the present time, there is a general agreement that three different groups of deposits have been laid down by the river during Tertiary and Quaternary times: the Older Gravels, the Younger Gravels and the succeeding Riverton Formation.

Their ages have been approximated through external correlation of the included fossils and artifacts (Fig. 5). Overlying these deposits are the Hutton Sands and a variety of paleosols.

4.2 THE OLDER GRAVELS

The Older Gravels are fluvial and colluvial rudaceous deposits occurring at, or very near, the surface. The main characteristics of these deposits are given in Table 1. The Older Gravels have been intensively worked by the diggers and at the present time they appear in small clusters of low mounds of carefully sorted gravels. Cooke (1947) pointed out that the Older Gravels are found at progressively lower elevations nearer the river, spread out laterally over as much as 10 km. However, terraces are preserved at different surface elevations at different localities (Helgren, 1979).

Two categories of Older Gravels have been recognised: primary and derived (Söhnge et al., 1937; Cooke 1947). The lowermost primary gravels ("Basal Older Gravels" of Cooke, 1947) are confined to the terrace remnants and consist of in-situ, calcified alluvial deposits, with appreciable quantities of subangular andesite and minor proportions of resistant minerals. They are poorly sorted, coarse-pebble to boulder-grade materials. The derived gravels (also called "Redistributed Older Gravels", "Red Older Gravels", and "Potato Gravels") occur on terraces and slopes and are well sorted and well rounded in the coarse-pebble grade. These gravels contain chalcedony, agate, quartz, and quartzite with a surface staining of iron oxide. They have been interpreted as weathered and colluvially reworked residues of the primary gravels (Cooke, 1947; Helgren, 1979).

It may be mentioned that the diamond diggers did not work the primary gravels and ceased operations as soon as they encountered andesite boulders in any great quantity. This can be explained if we consider the derived gravels as a concentrate of the primary gravels.

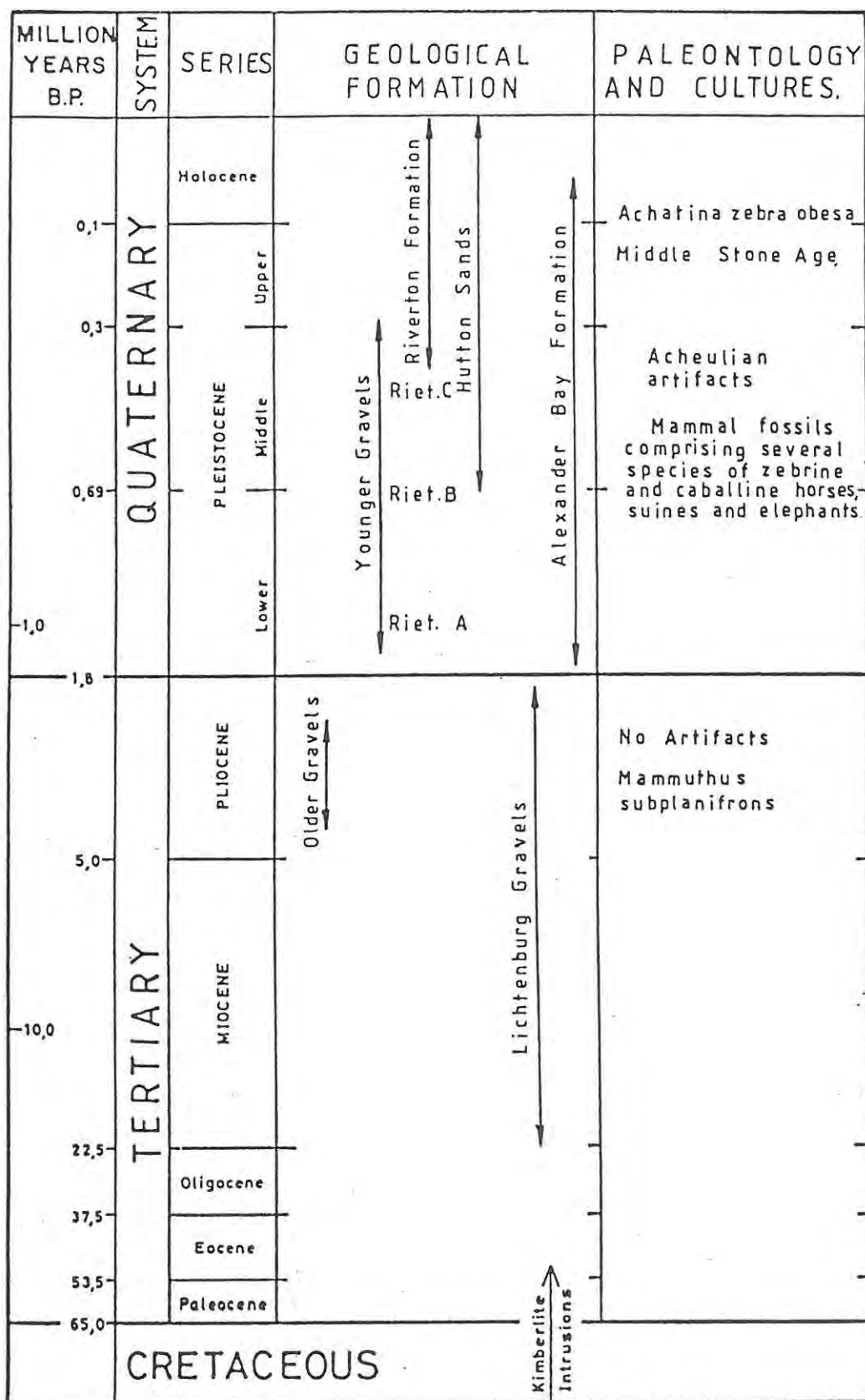


Fig.5 Age relationships between the different formations in the Lower Vaal basin and comparison with the Lichtenburg and Alexander Bay gravels (compiled after Partridge and Brink (1967); Butzer et al.(1973) and Helgren (1979)).

	Older Gravels	Younger gravels
Relative elevations	20 to 90 m above modern flood level.	-18 to 23 m below/above the present flood level.
Gravel composition	Quartz, chalcedony, chert, agate, jasper, quartzite, silicified wood, banded ironstone, lydianite except for the primary gravels which contain a large quantities of Ventersdorp andesite.	Ventersdorp andesite with minor shale, dolerite, quartz chalcedony, agate, jasper, chert, quartzite, banded ironstone and breccia.
Thickness	Generally 1.5 m or less, locally greater than 3 meters.	2 to 10 m, locally greater than 15 meters.
Clast size	Pebble to cobble-grade conglomerate.	Cobble to boulder-grade conglomerates.
Roundness	Rounded to well-rounded, except for the primary gravels with locally derived subangular rocks.	Sub-rounded to well-rounded.
Paleontologic and artifact record	Possible Mammuthus subplanifrons. No artifacts.	Mammalian fossils. Acheulian artifacts.

Table 1 : Characteristics of the Older and Younger Gravels (compiled and modified after Butzer et al. (1973) and Helgren (1979)).

4.3 THE YOUNGER GRAVELS

The Younger Gravels are as coarse as, or coarser than the Older Gravels, and are lithologically similar to the primary Older Gravels (Table 1). These deposits are located on or near the modern river bed. They are composed of three distinct depositional units designated as the Rietputs Formation A, B, and C (Helgren, 1979). Episodes of erosion and pedogenesis intervene between these units. In places there are three terraces (e.g. Windsorton-Riverview Estates); in others only two (e.g. Winter's Rush); while along certain stretches of the river there is only one terrace. The greatest recorded height of these Younger Gravels above the present stream is about 23 metres (at Gong-Gong) and the greatest depth below the river bed drops as low as 18 meters (also at Gong-Gong), a depth that is due to the filling of potholes in bed rock (Van Riet Lowe, 1937). The remains of Mastodon, Hippopotamus and Equus from a 70-foot terrace at Waldeck's Plant suggest that the gravels are of lower Pleistocene age.

4.4 THE RIVERTON FORMATION

The Riverton Formation consists of late Pleistocene to Holocene deposits dominated by sand and silt. They usually occur disconformably above the Younger Gravels or as separate units near the present river bed. Butzer et al. (1973) have recognized five different units near Riverton-on-Vaal (designated from oldest to youngest 1, 2, 3, 4, 5). They suggest that an appreciable part of the sand component was derived either from existing eolian deposits by colluvial action or by direct eolian sedimentation over permanent streams and standing waters.

4.5 THE HUTTON SANDS

The Hutton Sands (also called Red Sands) consist of clayey to silty sands, dominated by medium to fine-grained, well-sorted and rounded quartz. The red colour is produced by iron-oxide coatings on the sand grains. They appear for the first time during aggradation of the Rietputs Formation B (Helgren, 1979). Sand depths sometimes exceed 12 m, but 1 to 5 m depths are most common. They are distributed primarily to the south and east of the modern Vaal channel. Three different hypotheses have been proposed to explain the provenance of these deposits:

- The first explanation sees the Hutton Sands coming from the Kalahari basin after multiple episodes of eolian transport during an arid phase in the Quaternary (Mayer, 1986).
- The second hypothesis suggests that the Hutton Sands were derived from oxisols which developed in the southern Transvaal and northern Orange Free State during a more humid period (Helgren, 1979).
- The third hypothesis implies a local origin through weathering and erosion of Ventersdorp andesite and/or Dwyka sediment (Helgren, 1979).

4.6 PALEOSOLS

Different types of paleosols have been recognized in the lower Vaal basin:

- Calcretes cementing the primary or reworked gravels.
- Silcrete duricrusts in some exposures of the Younger Gravels.
- Ferro-manganese oxide horizons in many gravel exposures as well as eolian deposits.
- Localised vertisols, primarily in Riverton sediments.

5. GEOMORPHOLOGICAL AND CLIMATIC CONTROLS OF THE DIAMONDS

5.1 INTRODUCTION

For southern Africa, Partridge and Maud (1987) recognized seven major geomorphic events since the Mesozoic (Table 2). This section discusses some particular aspects of this evolution with special emphasis on the consequences for the concentration of diamonds in the lower Vaal basin.

5.2 THE ROLE OF GEOLOGICAL STRUCTURE AND LITHOLOGY

Three structural-lithologic factors may have influenced the deposition of the Vaal terrace gravels, namely tectonic movement, knickpoint retreat, and river capture.

Tectonic movement along the Griqualand-Transvaal axis during the late Tertiary and early Pleistocene has been proposed as a prime cause of the accelerated lateral shifting of the Vaal River towards the south-east and the formation of the Older Gravels terraces (Mayer, 1973). However, this hypothesis is not available for the Younger Gravels in the study area since the paleocurrent directions (see section 6.9)

Event	Geomorphic manifestation	Offshore sedimentation	Age
Climatic oscillations and glacio-eustatic sea-level changes (most pronounced during middle and late Pleistocene).	Low-level marine benches, coastal dune deposits, river terraces, Kalahari sands.	Accumulation of cones off mouths of major rivers. Widespread erosion elsewhere following development of near-shore current circulations. Renewed sedimentation in deep ocean basins.	Late Pliocene to Holocene
Post-African II cycle of major valley incision, especially in southeastern coastal hinterland.	Incision of coastal gorges, downcutting and formation of higher terraces along interior rivers, formation of Post-African II erosion surface (with planation restricted to eastern Lowveld region).		
Major uplift (up to 900 m in eastern marginal areas)	Asymmetrical uplift of the subcontinent and major westward tilting of previous landsurfaces of interior, with monoclinal warping along southern and eastern coastal margins.		Late Pliocene (~2,5 Ma)
Post-African I cycle of erosion.	Development of imperfectly planed Post-African I erosion surface. Major deposition in Kalahari Basin.	Renewed sedimentation giving rise to Uloa Fm. (southeastern coast), upper Alexandria Fm. (southern coast), Bredasdorp Fm. (southern and western coasts) and Elandsfontyn and Varswater Fms. (western coast). Major resurgence of sedimentation in deep ocean basins.	Early mid-Miocene to late Pliocene
Moderate uplift of 150-300 m.	Slight westward tilting of African surface with limited coastal monoclinal warping. Subsidence of Bushveld Basin.		End of early Miocene (~18 Ma)
African cycle of erosion (polycyclic).	Advanced planation throughout subcontinent. Surface at two levels above and below Great Escarpment. Development of deep-weathered laterite and silcrete profiles. Development of Kalahari basin with concomitant onset of sedimentation towards end of Cretaceous	Widespread epeirogenic sedimentation in several pulses, as exemplified by offshore Alphard Fm., Mzinene and St Lucia Fms. of southeastern coast and lower Alexandria Fm. of southern coast. General slowing of shelf sedimentation from end-Cretaceous, culminating in major Oligocene unconformity.	Late Jurassic/early Cretaceous to end of early Miocene
Break up of Gondwanaland through rift faulting.	Initiation of Great Escarpment owing to high absolute elevation of southern African portion of Gondwanaland. Deposition of Enon Conglomerate Fm.	Rapid, localized taphrogenic sedimentation producing <i>inter alia</i> Uitenhage Group of southern coast.	Late Jurassic/early Cretaceous

Table 2 Summary of principal geomorphic events in southern Africa since the Mesozoic (After Partridge and Maud, 1987).

show that the Vaal River was flowing in a north-east to north-west direction. Moreover, the aerial photography, together with the field evidence, does not show any indications of significant tectonic deformation in the Barkly West area during the Cenozoic.

The steep reaches of the Vaal valley between Barkly West and Delpoortshoop, are exhumed resistant units of the Ventersdorp lava. The valley was filled with comparatively soft Dwyka sediments, which were selectively removed during Cenozoic exhumation. The harder rocks may

have formed irregularities in the stream profile, and stream incision may have been retarded at such points. However, such local base levels, or nickpoints, would have developed in poorly-resistant Dwyka sediments and would therefore have been quite ephemeral. Other resistant units such as dolerite dykes are absent along the study portion of the Vaal channel. The formation of nickpoints has probably played only a minor role in the formation of the terrace gravels.

Cooke (1947) proposed that the early Vaal River was captured by a former tributary of the Harts River (Fig.6). Several features, indeed, favour this hypothesis:

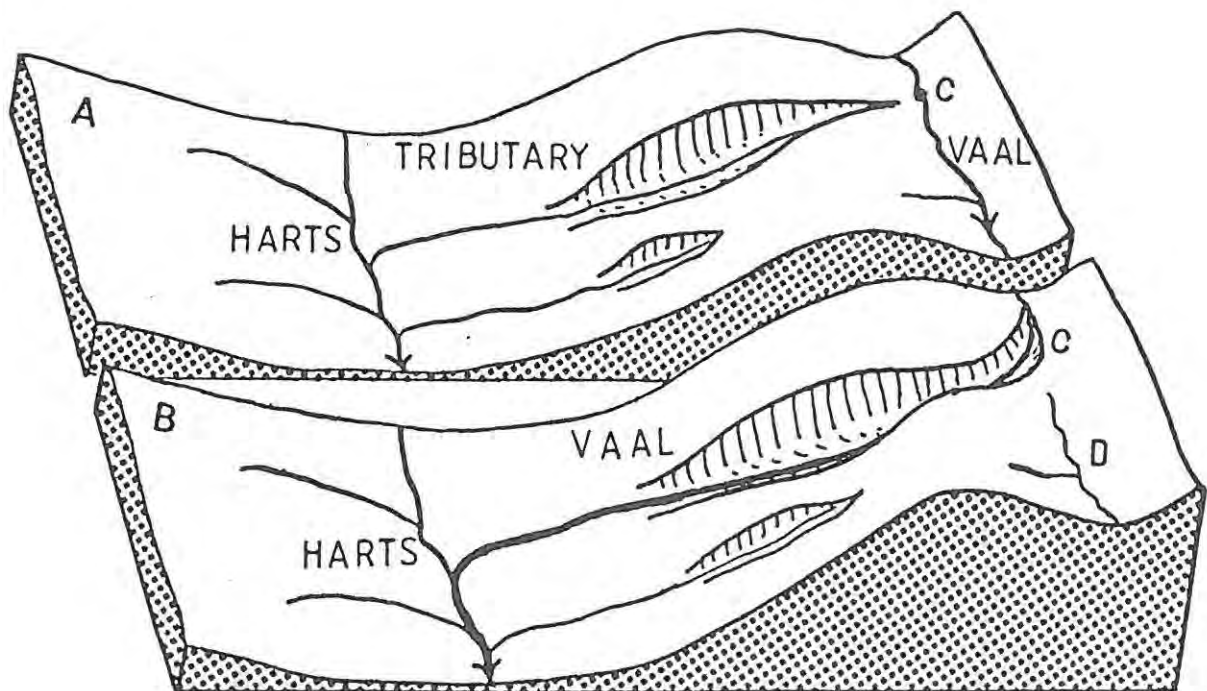


Fig.6 Two stages in the evolution of the Vaal River as a result of its capture by the retreating headwaters of a small tributary of the Harts River (C: Elbow of capture; D: Abandoned Droogeveld channel).

- The course of the Vaal River between Good Hope and the Vaal-Harts confluence is shifted by approximately 35 km to the north-west from where it continues its former south-westerly direction.

- The relatively steep "barrier" gorge between Barkly West and the Vaal-Harts confluence may be due partly to river capture and partly to the initial profile of the pre-Karoo valley. In the proposed model the pre-Karoo valley was re-excavated first of all by the tributary of the Harts River and subsequently by the Vaal River itself.
- The abandoned channel of the lower portion of the Vaal was apparently flowing from Pniel towards Schmidtsdrift along a course now represented by the Droogeveld gravels. However, the Droogeveld channel in its present form represents the result of subsequent colluvial redistribution of the abandoned deposits.

Of all the above mentioned processes, only river capture and the initial profile of the pre-Karoo valley have played a major role in the gravel deposition by increasing the gradient of the river, and providing the high energy conditions for the concentration of the diamonds. However, river capture involves one single event which does not explain the cyclic appearance of gravel terraces.

5.3 THE ROLE OF VEGETATION AND CLIMATIC CHANGE SINCE THE CRETACEOUS

World-wide, Tertiary climates show a progressive decline in temperature. Cretaceous mean annual air temperatures were 10-15° higher than at present (Frakes, 1979), with tropical-subtropical conditions extending to at least 45° either side of the Equator (Hallam, 1981).

Coetzee (1978) has classified the Eocene to Oligocene (and probably the Late Cretaceous and Paleocene) southern continental floras as temperate to subtropical forest of Podocarpaceae, Nothofagus, Proteaceae, and ferns. A period of humid tropical or subtropical climate has been postulated by Glass (1977) in pre-Middle Miocene (possibly late Eocene or Oligocene) to account for the saprolite profiles that occur extensively in the SW Cape over granite (up to 60 m thick) and Malmesbury Group (up to 80 m thick).

The very different Cretaceous vegetation (i.e., the absence of

angiosperms) and climatic framework in southern Africa (Coetzee et al., 1983; Tyson 1986) provide the favourable conditions for high rates of erosion and sediment yield (Noble, 1965; Storey et al., 1964). During the Upper Cretaceous and much of the Tertiary, high rainfall and high temperatures induced an extensive and deep chemical weathering of the bedrock. The chemical denudation and mass solutional loss produce an enrichment in resistant minerals. The combination of this in-situ enrichment with the removal in suspension of the greater part of the fine particles of the regolith upon mechanical erosion results in particularly favourable conditions for placer development (Sutherland, 1985).

Evidence in southern Africa points to cooler and progressively more arid conditions during the Late Cenozoic (Dingle et al., 1983). Aridification of Namibia, Botswana, and the northern Cape Province was initiated in late Miocene times and intensified into the Pleistocene (Siesser, 1978; Dingle et al., 1983). As stressed by Meadows (1988), however, with the onset of more arid climate, we must recognize important climatic oscillations. From studies of the Alexanderfontein Pan near Kimberley, Butzer et al. (1973b) have shown that annual rainfall was approximately double the present 400 mm average during the latter part of the last glacial period (about 15 000 BP). Partridge (1990) stressed the fact that if the annual rainfall were to double that of today (i.e. to about 850 mm), the mean annual discharge would be approximately 17 times the present mean volume and would result in a marked increase in surface runoff. This author emphasized that fluctuations in total rainfall are more significant than infrequent large flood discharge for fluvial erosion in semi-arid areas. On the basis of detailed sedimentological studies, Helgren (1979) inclined to a climatic interpretation for the presence of terraces along the Vaal River. Thus regional climatic changes, with incision during long episodes of persistently high discharge, seem to offer the best explanation for the formation of the Vaal terrace gravels.

The onshore Tertiary is characterized by the development of indurated horizons such as calcium-rich calcrete, silica-rich silcrete and iron-rich ferricrete. Calcretes, by far the most frequent surface veneers in the lower Vaal basin, are most characteristic of warm areas with limited precipitation (typically 400 to 600 mm/year), and tend to

develop preferentially on low angle surfaces (about 2° or less). The calcrete consists of white cryptocrystalline to crystalline calcite with additional silica cement, unweathered shale fragments, and quartz sand. It involves the cementation and/or replacement of soil, rock or sediment by introduction of vadose carbonate.

The calcretes form resistant crusts that protect the surrounding rocks from further denudation. At the present time, the kimberlites and the alluvial diamond deposits are concealed by calcrete and Quaternary sediments and there is little released or reworked into the present drainage system. This may explain not only the absence of diamonds in the immediate surroundings of the kimberlite (the alluvial diamonds nearest to Kimberley are found at Nooitgedacht, 25 km away), but also the fact that the diggers prefer to recover diamonds from the terraces lying 5-15 meters above the present-day river, which are richer than from the river itself. Alluvial diamonds have been derived predominantly in an earlier period of lesser aridity.

5.4 THE STABILITY OF THE DRAINAGE SYSTEM

Since the Miocene, southern Africa has undergone asymmetrical uplift, ranging from about 1150 m near the eastern margin to 250 m near the western margin. Taking this movement into account, absolute elevations on the pre-rifting surface would have ranged from about 2350 m at Letseng Le Terai in the Lesotho Highlands to around 1800 m at Kimberley (Partridge and Maud, 1987). This feature suggests that prior to rifting, the predominant direction of the drainage was to the west.

Another argument in favour of this hypothesis is given by the analysis of sediments in the southern Atlantic which indicates that the Orange Basin was the main depocentre for sedimentation since continental break-up between southern Africa and South America in Lower Cretaceous times (Dingle and Hendey, 1984).

A number of the larger rivers (e.g. Orange, Vaal, and Limpopo) are thought to have been evolving since at least the Cretaceous (Dardis et al., 1988) and it is probable that diamonds have been carried by the Vaal River since that time. Mayer (1973) suggests that the Vaal River downstream of Bloemhof had a fairly high transporting capacity during

the late Tertiary because of the supply by the palaeo-Harts River (Fig. 7).

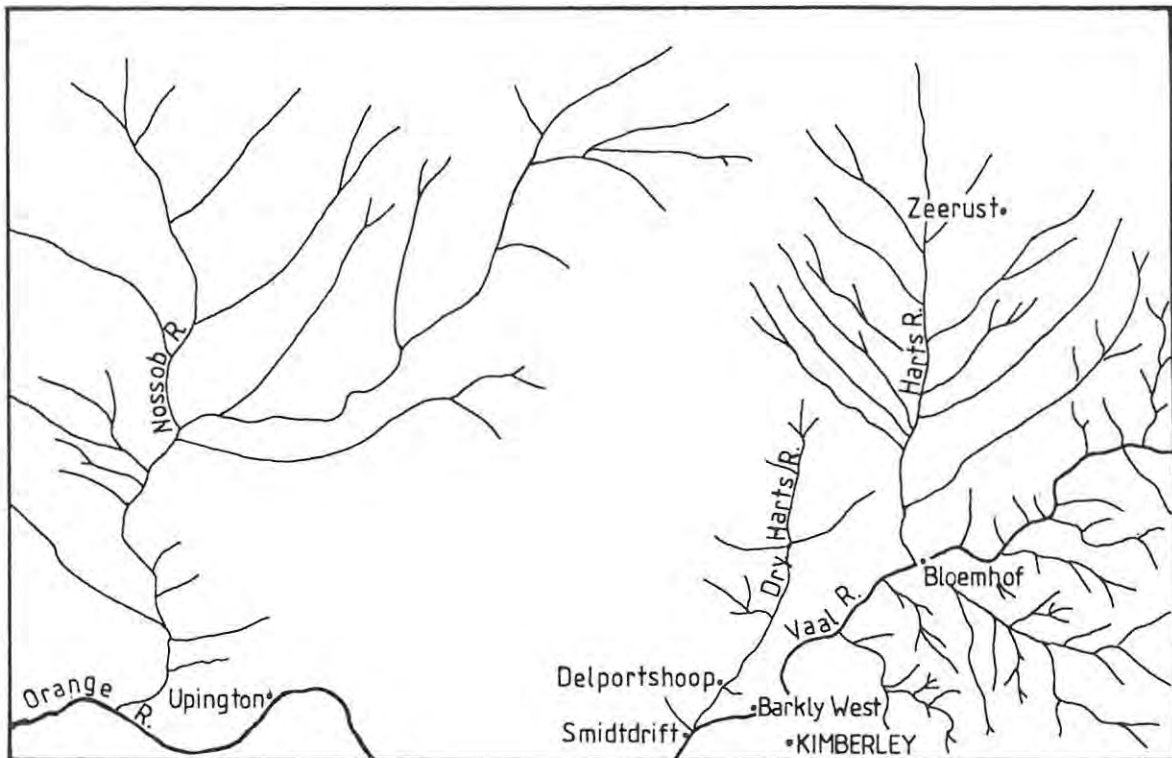


Fig. 7 Possible reconstruction of some tributaries of the Vaal and Orange Rivers in the late Tertiary (redrawn after Mayer, 1973).

An important aspect of the Dwyka glaciation is the great impact on the drainage system made by the successive ice sheets. In the Griqualand-West area the Transvaal ice sheet flowing to the south-west induced the formation of deep glacial valleys in the surrounding rocks. Du Toit (1910) emphasized that the morphology of the present-day river system has been profoundly influenced by the Dwyka glaciation and advocated that some portions of the Harts and Vaal Rivers may have re-excavated a pre-existing glacial valley.

5.5 RIVER PROFILE AND BEDROCK CHARACTERISTICS

A study of the profile of the Vaal River (Fig. 8) reveals that the gradient is only 0.28 m/km between Windsorton and Barkly West, a distance of 68 km. Upstream of Barkly West, the Vaal is a deep meandering channel. Between Barkly West and Gong-Gong, the Vaal drops

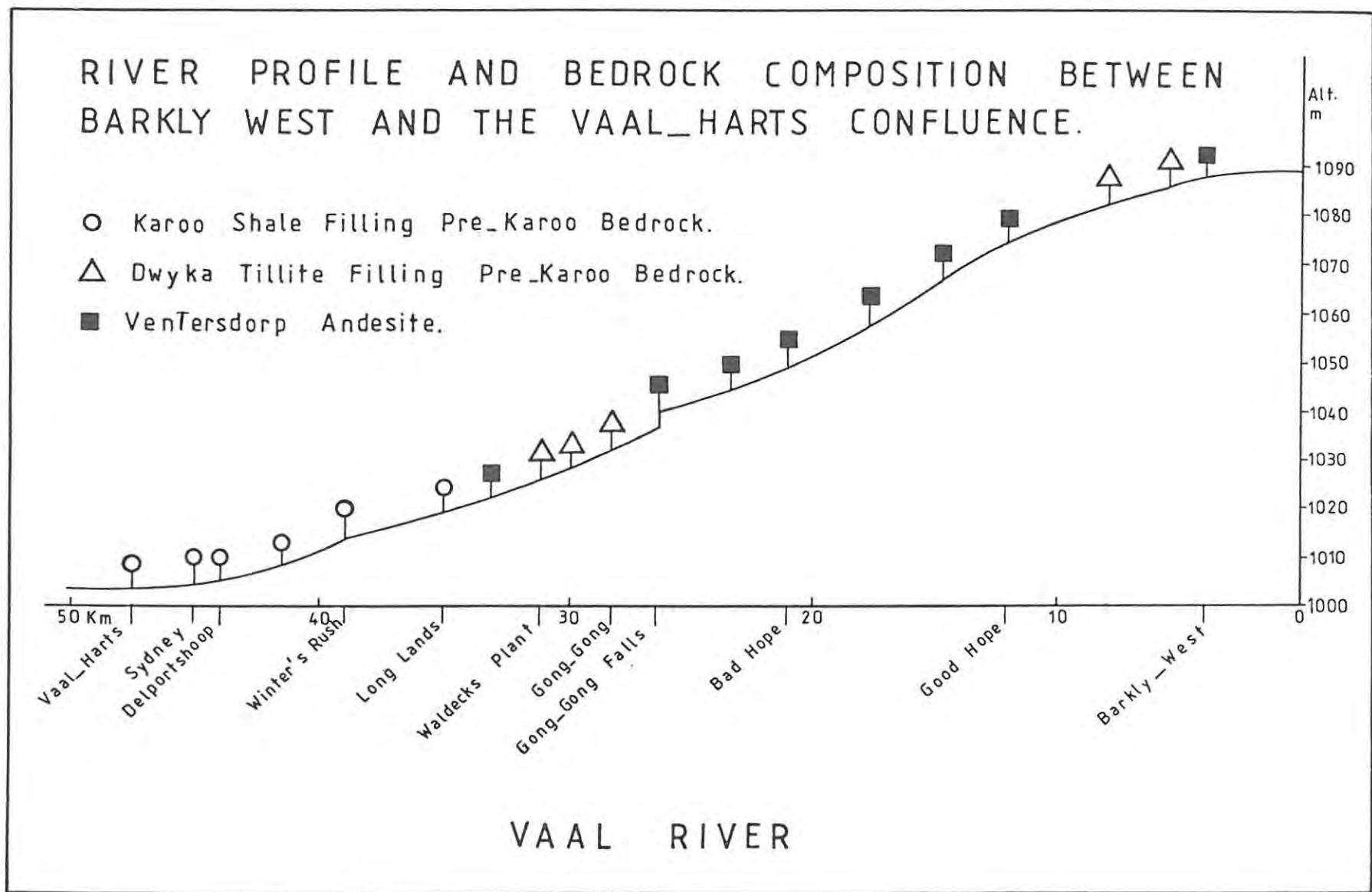


Fig.8 Profile of the Vaal River and bedrock composition between Barkly West and the Vaal-Harts confluence.

sharply by 55 m after only 24 km (gradient 2.29 m/km) in a steep and narrow valley interrupted by the Gong-Gong Falls (Photo 11). The gradient becomes a little bit lower (1.49 m/km) between Gong-Gong and the Vaal-Harts confluence (19.4 km), where the Vaal has a braided pattern. The streams are generally wide and shallow with nearly straight channel system. Between the Vaal-Harts confluence and Schmidtsdrif (53 km), the river falls by 14 m only (gradient 0.26 m/km), re-establishing its meandering pattern. This is in accordance with the view of Leopold and Wolman (1957) who noticed that for a given bankfull discharge, braiding is favoured by high slopes and meandering by lower slopes.

From Barkly West to Winter's Rush, the basement geology encountered over much of the river profile is the dark grey Ventersdorp andesitic lava. Locally, it contains amygdales of quartz and chalcedony which are generally 1 to 3 cm in diameter but may reach 20 cm in length. Striations, grooves, polished surfaces, as well as whale-back structures can be found on some andesite surfaces (e.g. station 8 at Gong-Gong; see map at the end of this thesis). The Ventersdorp lava is generally deeply incised and forms good channels. At Bad Hope, Gong-Gong and Waldeck's Plant the bedrock is very uneven and irregular, reflecting the high energy environment (Photo 12). Potholes, which are typically 0.3 to 1.5 m deep, are often present. Some potholes, however, are much deeper, reaching 4 m or more (Photo 13). The potholes were probably formed in recent times by the Vaal River itself. An alternative hypothesis is that they could be pre-existing features formed by glacio-fluvial processes during Dwyka times but the absence of potholes within glaciated pavements in the area (e.g. Nooitgedacht) tends to corroborate the first hypothesis.

Further rock-types found along this section of the river are represented by remnants of Dwyka tillite. Good exposures can be found at Gong-Gong (station 8) and Waldeck's Plant (station 12). These are typically preserved in the lower parts of the channels and one can assume that they were much more extensive previously. Potholes are also developed within the tillite but these are generally 0.3 to 0.8 m deep (Photo 14).

The Prince Albert Shale forms the paleochannel bottom between Delportshoop and the Vaal-Harts confluence indicating less incision

than is encountered upstream towards Bad Hope and Gong-Gong where the bedrock is commonly the Ventersdorp lavas. Isolated patches of Prince Albert shale overlying the Dwyka tillite or the Ventersdorp andesite are also abundant between Longlands and Winter's Rush. The horizontally bedded shale is slightly undulated. During the investigation, only one pothole (40 cm deep) has been encountered within the Prince Albert shale (station 33).

5.6 CONCLUSIONS

- The capture of the Vaal River by a tributary of the Harts River, together with the exhumation of the pre-Karoo valley, increased the gradient of the river giving the favourable conditions for the formation of placers downstream of Barkly West.
- Climatic change was the most important factor for the formation of the diamondiferous terrace deposits.
- Most of the diamonds from kimberlites in the Kimberley area have been released during late Cretaceous to early Tertiary times when the climate was more humid and the area at 1800 m altitude.
- At the present time, the kimberlites and the alluvial diamond deposits are typically sealed by calcrete or covered by Quaternary sediments and there is little release or reworking of diamonds to the present drainage.
- Braiding was favoured by the slight decrease in the gradient after the Gong-Gong falls, and the widening of the valley.

6. SEDIMENTOLOGY OF THE YOUNGER GRAVELS

6.1 INTRODUCTION

This section focuses on three interrelated objectives:

- The first objective was to map the different lithologic units by photo interpretation and field survey.
- The second was to provide a detailed sedimentological study at 40 different stations along the Vaal course.
- The third was to provide a genetic model for the gravels as a whole.

Because of the extreme scarcity of emplaced exposures of the Older Gravels, the study was concentrated mainly on the Younger Gravels. The absence of fossils has also hampered stratigraphic correlation and the interpretation of facies changes.

6.2 MAPPING OF THE SEDIMENTS

The Cenozoic map (1/50,000) of the study area is given at the end of this thesis. This map was modified from the existing map (1/50,000) of the Geological Survey and the 40 stations used in the sedimentological investigation are plotted on it.

Terrace elevations and characteristics vary greatly between Barkly West and the Vaal-Harts confluence. Moreover, the deposits have been intensively mined and many of the lower terraces have been destroyed by local diggers. It must also be emphasized that the Younger Gravels are not always terrace deposits in the true sense of this term, but abandoned channel deposits. This is the case at Gong-Gong where three parallel channels have been recognized. Despite these reservations, the Younger Gravels can be broadly subdivided into three successive terraces:

- A lowermost terrace lies 3-5 m above the present bed of the Vaal River, and typically consists of Rietputs Formation C. The width of this terrace never exceeds 50 m.
- A second terrace is present 8-12 m above the bed of the Vaal River and consists of Rietputs Formation B. The width of this terrace varies between 40 and 70 m.
- A third terrace, 17-22 m above the present bed of the Vaal River, contains Rietputs Formation A.

The Younger Gravels are overlain by calcretized sands of the Riverton Formation which are, in turn, succeeded by the Hutton Sands.

In the sedimentological investigation (clast size, external geometry and particle morphology), the sampling was carried out in the lowermost terrace, lying 3 to 5 m above the river bed, in order to have reliable information concerning the downstream trends.

6.3 SEDIMENTARY LITHOFACIES

The study section of the Vaal River can be defined as a braided river. The term "braided" is used here for multi-channel water courses of low sinuosity, a definition discussed in more detail elsewhere (e.g. Miall, 1982).

Braided alluvial deposits can be divided into three types on the basis of their dominant lithology: gravel, sand, and silt. Within these lithotypes further facies can be recognized, chiefly on a combination of lithology and sedimentary structures.

The principal types of sedimentary structure together with relative abundances are listed in Table 3. The facies were defined according to the scheme devised by Miall (1977, 1978) for the modern braided-stream environment. However, the calcretisation of the sandy units tends to destroy the sedimentary structures and makes identification of the lithofacies difficult. Therefore, in cases where the type of stratification could not be identified confidently, the letter "u" is used, for example Su, denoting calcretised sands with undifferentiated

FACIES CODE	LITHOLOGY	% ABUNDANCE	BASES	GRADING	SEDIMENTARY STRUCTURES	INTERPRETATION
Gm	Clast-supported matrix-filled gravel	82.8	Flat slightly scoured	None or crude normal	Imbrication or crude horizontal bedding	Channel lag or longitudinal bar deposits
Gms	Matrix-supported gravel	11.4	Flat slightly scoured	None	None	Waning flow deposits
Gt	Clast-supported matrix-filled gravel	2.7	Scoured	None	Trough crossbeds	Minor channel fills
Gp	Clast-supported matrix-filled gravel	0.5	Flat	None	Planar crossbeds	Linguoid bars
Sm	Pebbly coarse sand	2.2	Flat	None or crude normal	Crude horizontal bedding	Rapid channel sedimentation
Sh	Sand, medium to very coarse may be pebbly	0.3	Flat	None	Horizontal lamination, parting or streaming lineation	Planar bed flow
St	Sand, medium to very coarse may be pebbly	< 0.1	Flat	None	Trough crossbeds	Dunes
Sp	Sand, medium to very coarse may be pebbly	< 0.1	Flat	None	Planar crossbeds	Linguoid, transverse bars, sand wave

Table 3 Classification of lithofacies in the Younger Gravels and their characteristics.

stratification. Moreover, certain massive sand units do not display any internal structure. The facies code Sm (massive sand) was used for this type of deposit which is interpreted as rapid channel sedimentation.

Facies Gm (Appendix 1) consists of clast-supported gravels showing imbrication or poorly defined horizontal bedding. Clast support indicates energetic aqueous transport that deposits gravel on the bed while sand is still carried in suspension (Rust, 1979). When flow velocity decreases, sand infiltrates the spaces between the larger particles. The flat stratification is sometimes due to

alternations of beds of different clast size. Poorly stratified, massive gravels with clast imbrication have been commonly interpreted as channel lag and longitudinal bar development (Rust, 1972; Miall, 1977). Channel lag deposits are formed around bars by the coarsest gravels. These are likely to be strongly imbricated where clasts are flattened. Longitudinal bars are initiated as diffuse sheets during, or immediately after, flood stage (Ramos et al., 1983). Leopold and Wolman (1957) proposed that longitudinal bars are formed by deposition of the coarsest bedload fractions in mid-channel. Subsequent growth takes place by addition of finer sediment on top of and downstream of the bar nucleus, which may rise above water, and become vegetated. Their surfaces may be convex upward, slightly inclined, or virtually flat (Smith, 1980).

Facies Gms (Appendix 1a, 1d and 1i) is poorly sorted, matrix-supported, structureless deposits that have undergone little or no reworking by stream water. Matrix support indicates aqueous transport, but at a lower energy level in which sand and gravel particles are deposited together (Rust, 1979). Rust (1978) interpreted this facies as a debris flow deposit. According to Bull (1964) debris flows are favoured by steep slope, an abundance of clastic debris and a high discharge of water. These conditions are commonly encountered in arid or semi-arid environments, where long, dry periods, during which abundant clastic detritus is generated by mechanical weathering, are punctuated by flash floods, and there is insufficient vegetative protection to inhibit run-off. These kinds of deposits usually extend only a few kilometres from a mountainous source area into the alluvial plain, and are most typical of alluvial fans (Bull, 1977; Rust, 1979).

Facies Gt (Appendix 1h) consists of trough-crossbedded gravel of varying clast size which suggests formation under upper or lower flow regime, plane-bed conditions. They form broad, shallow channels which commonly cut into each other both laterally and vertically. Miall (1977) suggests that this facies represents minor channel fills which are similar to scour hollows described in the Donjek River by Williams and Rust (1969). According to these authors the scours are related to lee face erosional hollows of advancing dunes and bars.

Facies Gp (Appendix 1f), planar cross-bedded gravel, was very rarely encountered in the study area and occurs only in solitary sets. Miall

(1977) suggests that this facies is generated by the migration of linguoid bars during flood stage. Linguoid bars may develop in the same channel as longitudinal bars only under conditions of reduced sediment and water discharge. An alternative interpretation by Eynon and Walker (1974) is that this facies represents the product of delta-like growth from an eroded bar remnant into a relatively deep outwash channel.

Facies St (**Appendix 1h**), trough cross-bedded sand, is interpreted to have its origin in migrating dune fields. The grain size is generally pebbly coarse sand.

Facies Sh (**Appendix 1a and 1h**), horizontally-bedded sand, may be laminated to massive, very fine to coarse-grained with scattered pebbles. Parting lineation may be well developed, as are very small-scale ripple marks. This facies can occur under two different conditions: in shallow water and during flood stage (Miall, 1977). Beds of this facies have flat bases or are moulded over the beds underneath. Their tops have generally been scoured.

Facies Sp (**Appendix 1e**), planar cross-bedded sand, was found very rarely and can contain gravel. This facies is interpreted to have formed in migrating sand waves and sand bars.

6.4 FACIES ASSEMBLAGES

6.4.1 Bad Hope, Gong-Gong and Waldeck's Plant

Between Barkly West and the Gong-Gong falls, several little prospects have been intensively mined by the diggers. At Bad Hope (station 1), the gravels are lying 18 m above the river bed. The cobble/boulder material is rounded and coated by iron oxide. Subangular clasts of Ventersdorp lava have been colluvially mixed with the gravels. Facies studies were not possible because of the lack of emplaced outcrops. However, the deposits are of interest because they carry the largest boulders seen in the study area, some of them reaching 1.7 m in diameter (**Photo 15**).

The typical sequence at Gong-Gong and Waldeck's Plant consists of a

clearly differentiated basal coarse member (facies Gm and Gms) overlain by a sand member (Su) belonging to the Riverton Formation. Gravel thickness varies from 2.5 - 4 m. The gravels are crudely stratified, cobble/boulder-supported, weakly imbricated and very poorly sorted (full range of grain size is present from silt to large boulders). Clast size is variable both vertically and horizontally but shows no consistent trend. The clasts are sub-rounded to well-rounded with thin calcrete coatings. However, a subangular component (<3%) is present, presumably reflecting fragments derived from nearby slopes. Locally, iron oxide infilled the top of the gravel. Gradually, facies Gms may appear upwards due to a more abundant matrix and a lack of imbrication. In a single channel, the coarsest load is carried along the deepest portion of the channel where competency is greatest. Much of it accumulates as a lag in scour pools. Lenses of well-sorted, medium to coarse sand are also present in some places (Facies Sh). These are thin (maximum 3 cm) and never exceed 2 m in length. They may represent remnants of sandy units eroded during high floods. The gravels are texturally immature in terms of grading and sorting, but texturally mature in terms of roundness.

The matrix consists of coarse grey sand to gravelly sand which is generally calcretised. The matrix is predominantly composed of quartz.

The presence of discontinuous bedforms in addition to the disorganized texture and scoured base suggests that this gravel was deposited by channelized, sediment-laden gravelly flows, which contained a large amount of suspended sand.

The gravels are overlain by a massive calcretised sand unit which is 2 - 4 m thick (facies Su, Riverton Formation) infilled by red sand at the top. The sand contains features typical of overbank deposits, such as root traces and calcrete nodules. The base of the sandy units is commonly marked by fine gravels consistent with overbank scour and-fill process during extreme flood. The transition between the underlying gravel and the sand is abrupt and in places slightly erosive. This is followed by about 1 m of Hutton Sand.

Potholes are filled with well-rounded pebbles/cobbles of andesite and finer gravel of resistant material.

6.4.2 Longlands to Winters Rush

Rietputs Formation A, B, and C are well exposed in this area.

Rietputs A consists of massive, clast-supported, pebble/cobble gravels in a matrix of reddish coarse sand (facies Gm). The gravels are well-sorted and show a crude horizontal stratification discernable through changes in grain size. High-angle planar cross-stratification occurs at the margins of some bars (facies Gp). Discontinuous sandy interbeds also occur. These consists of coarse sand (facies Sm, Sh) and are 2-3 cm thick.

After a period of incision, Rietputs B was aggraded. This consists of a massive calcretised gravel with weak imbrication (Facies Gm). In vertical sequence individual units may be distinguished by the scour or interruption surfaces between them, and in some places by thin gravelly sand sheets (< 3 cm) (Facies Sm). This proves that the gravel does not represent a single depositional event.

The last period of channel deposition is represented by Rietputs C, which consists of well-imbricated, cobble/boulder material in a coarse sandy matrix (Photo 16). Compared with the upstream exposures, the gravels are better sorted and finer grained. They extend from the river channel to the lowermost terrace, and represent channel infill/lag deposits which were deposited under high energy conditions and aggraded rapidly. The gravels are 2 - 4 m thick, lying directly on shale or tillite. Lenses of pebble-sized clasts are sometimes present at the top of the gravel. These represent periods of waning flood deposition or areas isolated from the main flood. The upper part of the gravels preserved a rubefied paleosol.

The gravels are overlain by a calcretised gravelly sand (Su) which gradationally changes to a laterised zone (1-2 m thick). Calcretisation may be due to percolation of Ca-rich solutions along lines of weakness formed or enlarged through the wedging of deep-rooting vegetation.

6.4.3 Delportshoop and Sydney

The Rietputs Formation C, which is 3 - 10 m thick, consists of

calcretised, medium to well-sorted and weakly imbricated cobble/boulder material set in a coarse sandy matrix (facies Gm). Clast-supported gravel is the dominant lithotype and is abundant in the large active channels. The gravels are poorly stratified and packing improves towards the bedrock. The average clasts are 15 - 25 cm across at Sydney and 20 - 40 cm across at Delpportshoop. Facies Gms is more frequent than in the upstream deposits. Trough and planar cross-stratified gravels are more frequent (Photo 17). The gravels are preserved beneath a thick (1 - 7 m) sequence of alluvial/colluvial sand and silt which belong to the Riverton Formation (facies Su) (Photo 18).

At Delpportshoop, the gravels tend to be well channelised and have a braided pattern. Thicker strata imply deeper channelised flow or a strongly channelised flood. In the deeper parts of the channel, the pebbles are coated with calcrete. These white pebbles were preferentially followed by the diggers. The clasts are well-rounded but medium-sorted.

At Sydney, Rietputs C contains gravelly to coarse sandy lenses that are generally massive and structureless (facies Sm) (Photo 19). Only in a few places can lamination (Sh) and trough crossbedding (St) with some planar crossbedding (Sp) be observed. The lenses occur 1.0 - 2.5 m above the bedrock. They are intercalated within facies Gm and are typically 10 - 40 cm thick and 5 - 30 m in lateral extent. The tops of many lenses are erosionally truncated. The preservation of such deposits is an indicator of declining discharge and discontinuous accretion. Thin strata of well-laminated sand typically result from rapidly shifting, shallow braided channels, or from shallow flow on the tops of braid bars (Miall, 1982). A possible explanation is that the sandy units were deposited at the downstream end of a point bar except during very high flow, when gravel was swept over the whole bar. Near the river (station 40), some bars contain openwork gravel layers and matrix-filled layers alternating in a cyclical fashion (Photo 20). Openwork gravel was deposited during high flow when most of the sand was carried in suspension. During ebb flow, the sand infilled pores near the surface but was unable to reach the earlier-deposited gravel beneath. Smith (1974) suggested that alternations of matrix-filled and open-work layers record normal fluctuations of discharge. The gravels can be labelled more mature than in the upstream deposits

in view of the degree of sorting of the framework components.

Matrix colour varies from white-grey where calcretised to red-brown in the capping horizons which are infilled by the Hutton Sand or with ferromanganese and limonitic cement. Below the water table, the matrix is generally olive grey to green.

6.5 CLAST COMPOSITION

6.5.1 Purpose

The aims of this investigation were:

- To determine the various clast types and their relative proportions in the Younger Gravels.
- To determine downstream variation, if any, of clast composition.

6.5.2 Methods and results

Clast assemblages were determined at the 40 stations which are plotted on the map by recording the composition of at least 50 clasts (>4 cm) at each locality. The clasts were chosen randomly by tracing a horizontal line on the gravel wall.

The results show that the gravels are mainly polymictic with clast composition consisting of andesite, shale, quartzite, quartz, chalcedony, chert, jasper, carnelion, banded ironstone, breccia, dolomite, and dolerite (Photo 21). Except for material directly derived from the immediate surrounding rocks (e.g. shale and quartzite), very few changes in composition occur within the Younger Gravels.

In the boulder/cobble sized material, andesite derived from the Ventersdorp Supergroup represents more than 95% of the clasts. The lavas are dark grey to light green in colour and three different varieties have been recognized:

- Amygdaloidal and porphyritic andesitic lavas. The amygdales, which

are generally 0.2 – 3 cm in diameter are composed predominantly of quartz and chalcedony with minor jaspers, carnelions, agates and pyrite. Very small phenocrysts (< 5 mm) of orthoclase, plagioclase and pyroxene are also present. Dissolution features are often present. In thin section the lavas are strongly altered to a mixture of chlorite, sericite, saussurite, epidote and clay minerals.

- Dark grey massive andesite without phenocrysts.
- Light green andesite. In thin section this shows a very intensive epidotization (variety pistachite).

From Longlands to the Vaal-Harts confluence, the gravel may locally contain scattered boulders or cobbles of shale which are mostly confined near the bedrock. A number of cleavage planes are present in the shale so these clasts could not have survived for a long time in the high energy current. Thus, they are thought to have been derived directly from the underlying bedrock. The other constituents consist of quartzite, breccia, dolomite and banded ironstone. Pebbles and granules consist of andesite, fragments of shale, quartz, chert, agate, jasper, chalcedony, lydianite, banded ironstone and quartzite.

The matrix consists of about 90 % detrital quartz with minor feldspar, sericite and heavy minerals. In thin section the quartz occurs as sub-angular to rounded grains.

6.6 MEAN CLAST SIZE AND SORTING

6.6.1 Purpose

The aims of the investigation of clast size were the following:

- To determine a mean longitudinal clast size and sorting variation pattern for possible correlation with diamond values.
- To obtain information about processes of sedimentation.

For regional studies, two different methods can be used to obtain mean clast size for coarse gravel (Lindholm, 1987). The faster technique is that of ignoring the smaller size fraction and determining a mean for a specified number of the largest boulders in the population. An alternative method is to determine an arithmetic mean of a minimum number of clasts of a specified range of size. Both methods were used in this investigation.

6.6.2 Mean of the largest boulders

The mean of the coarse fraction of the clast population was determined by measuring the long axes of the 25 largest boulders occurring in a stratigraphic section with arbitrary surface area of 2 m (base) x 70 m of gravel, and using the 10 largest values to calculate the arithmetic mean. Figure 9 shows the results of the investigation. The origin has been taken 500 meters upstream of station 1 (see map).

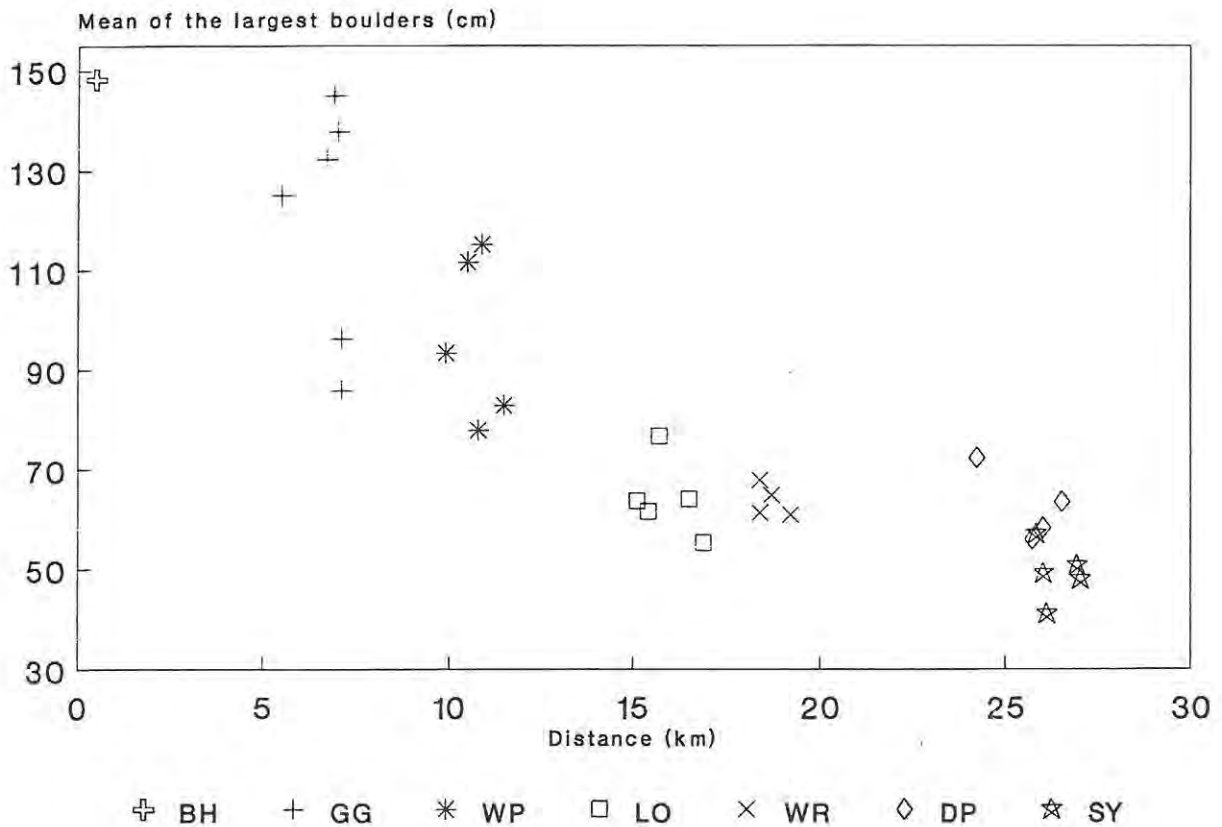


Fig. 9 Mean of the largest boulders (BH = Bad Hope; GG = Gong-Gong; WP = Waldeck's Plant; LO = Longlands; WR = Winter's Rush; DP = Delpportshoop; SY = Sydney-on-Vaal).

Mean maximum particle size is controlled by different variants such as availability of particle sizes, current competence and slope. The maximum particle size is an indication of the agent's competence at a particular point. However, maximum particle size is taken from the coarsest member of the sequence, and for that reason is not related to stream competence but to the maximum stream competence during a long period of gravel deposition.

The results display a gradual decrease in mean clast size in a downstream direction. The boulders at Good Hope are the largest seen in the study area, some of them reaching 170 cm in length. According to Smith (1980), downstream decrease in sediment size is axiomatic for rivers in general, occurring more quickly for rapidly aggrading systems. The coarse nature of the gravel reflects the high-energy environment of deposition. The downstream fining may be due to a decrease in energy and competency of the transporting agent.

6.6.3 Mean of a specified range of size

To determine the minimum number of clast sizes to be measured in order to obtain meaningful parameters, preliminary tests were carried out. The mean size and standard deviation were determined for 25, 50, 75, 100, clasts with a minimum long axes of 26 cm (boulder size material) and the results^{were} plotted graphically (Fig. 10). From the graphs it can be seen that there is little variation in the parameters after 50 measurements. Thus, the mean size and standard deviation were calculated for each station by taking 50 measurements of long axes (L) directly in the field.

For each of the 29 localities investigated, the mean size, standard deviation, and coefficient of variation were calculated using the moments method (Blatt et al., 1980). The following formulae were applied to calculate parameters:

$$\text{Arithmetic mean:} \quad \bar{x} = \sum x_i / n$$

$$\text{Standard deviation:} \quad s = \sqrt{\sum (x_i - \bar{x})^2 / n - 1}$$

where \bar{x} is the long axis of the clast and n the number of measurements.

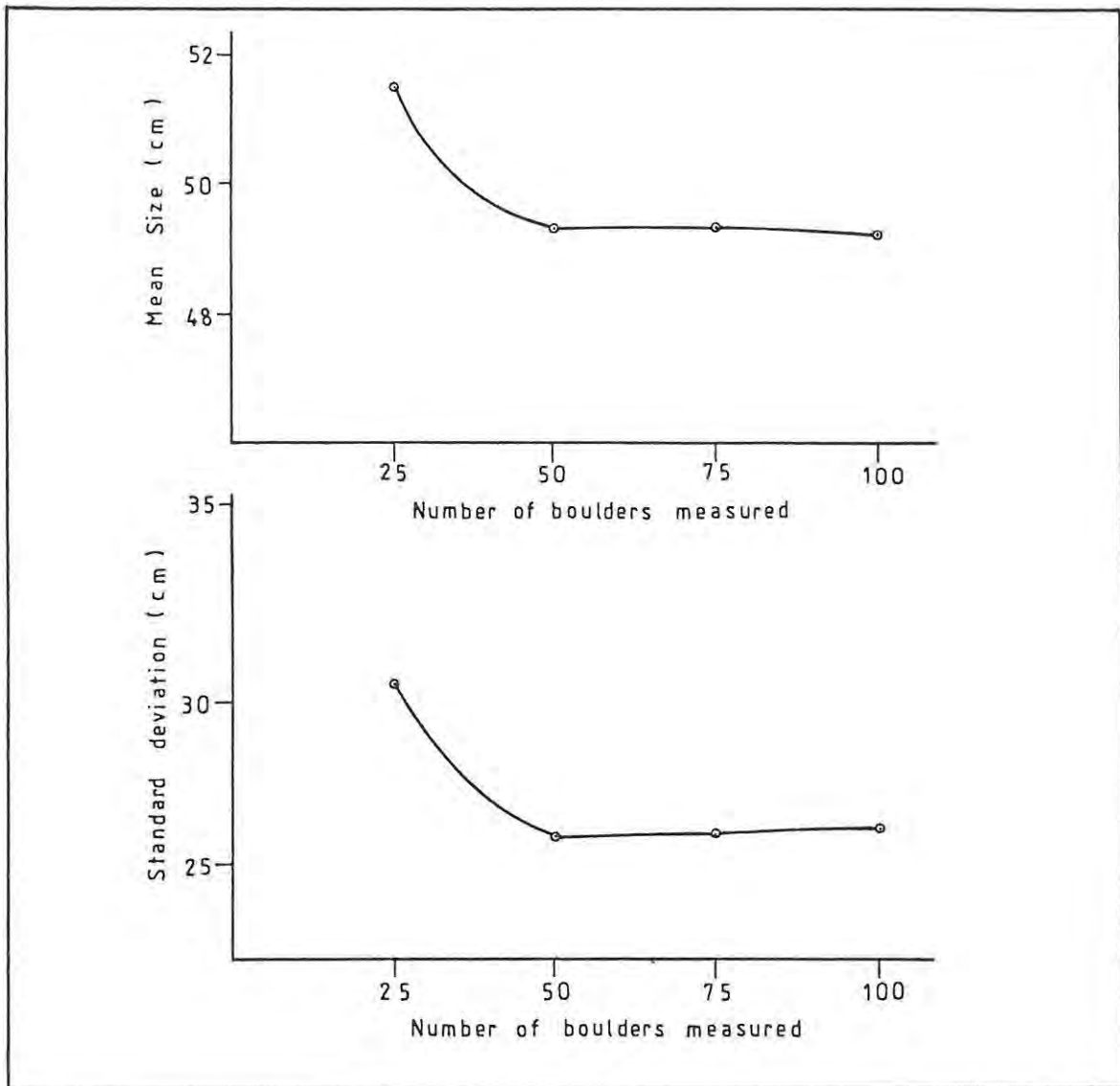


Fig.10 Preliminary test of clast size determination methods.

The standard deviation is of little direct value to express sorting because it can not be used to compare samples with a different mean diameter. To avoid this problem, Lindholm (1987) suggests use of the coefficient of variation (C.V.) which is defined as the standard deviation divided by the mean.

The results (Fig. 11 and 12) show a progressive decrease in mean clast size with a corresponding increase in sorting in a downstream direction. This feature may be explained by progressive sorting where proximal flows had less time to achieve a balance between load and competence. The data also tend to suggest that there is suppression of coarse material, and particularly the very coarse. A

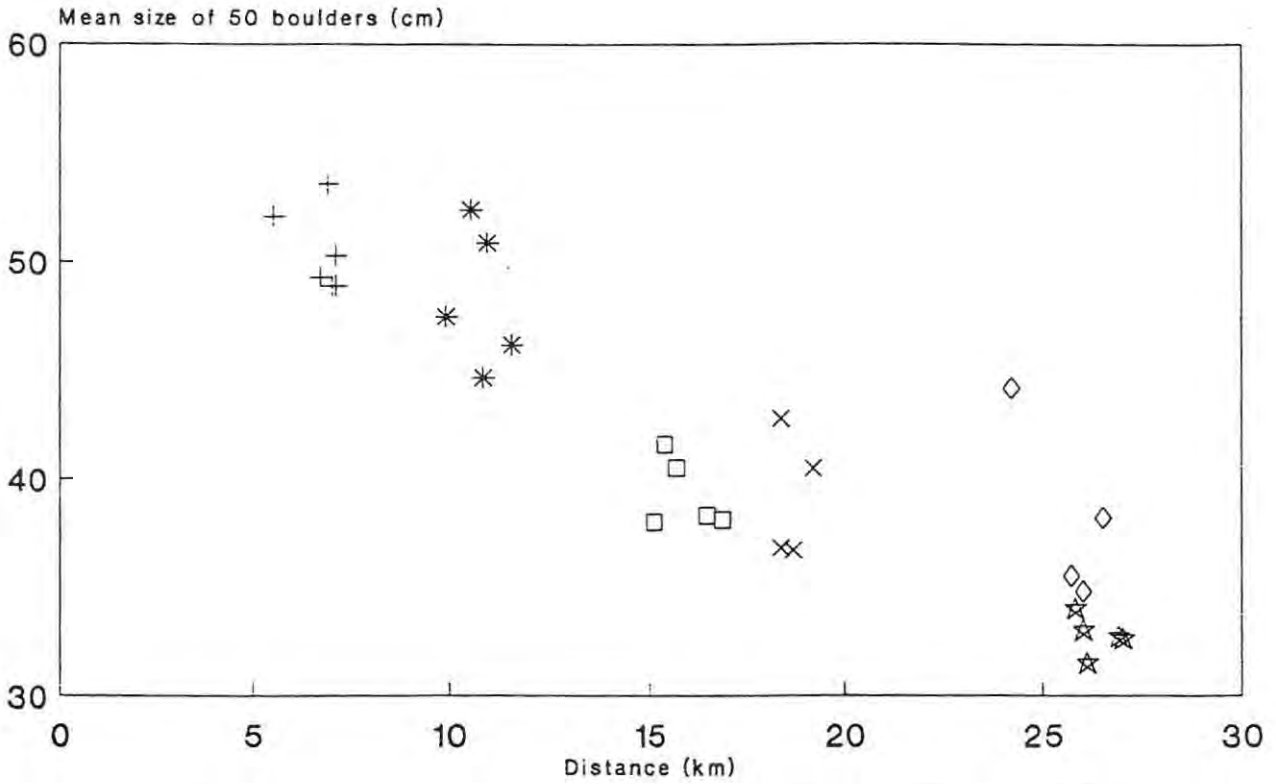
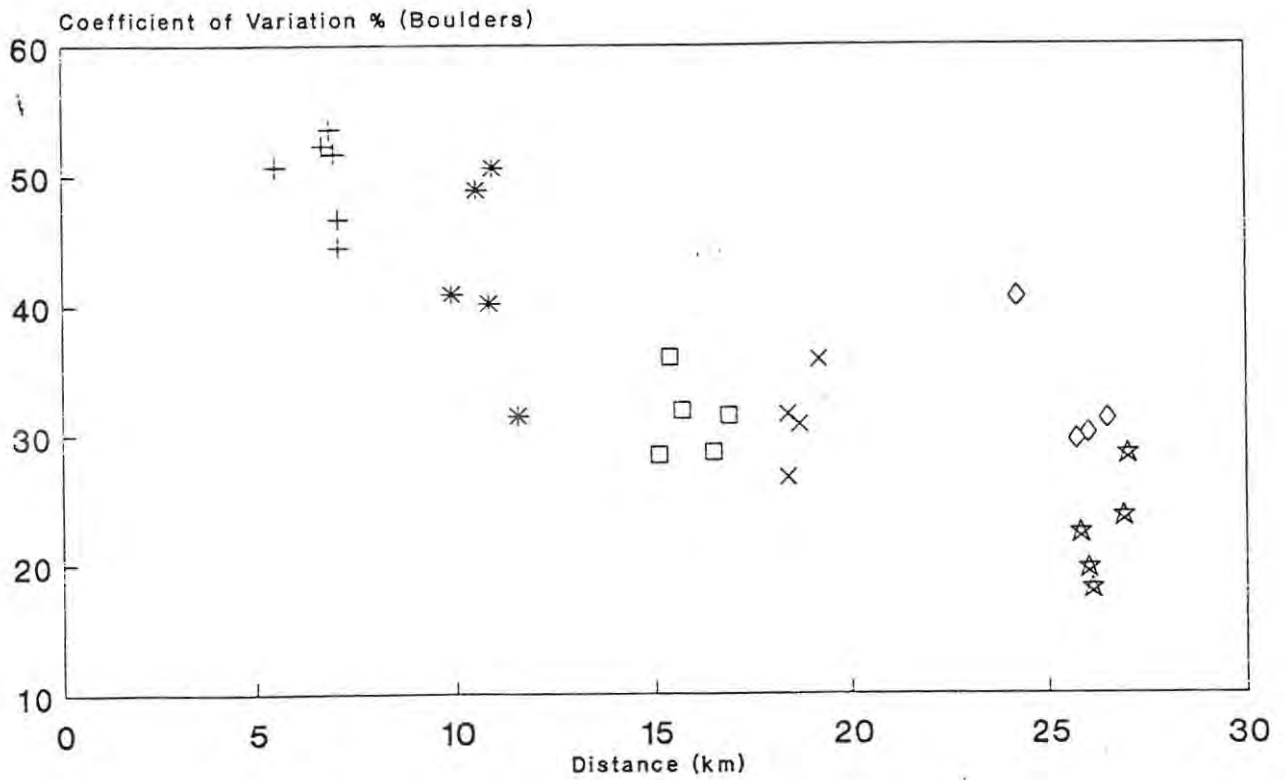


Fig. 11 Arithmetic mean of 50 clasts (≥ 26 cm long axis) versus distance of transport.



+ GG * WP □ LO x WR ◇ DP ☆ SY

Fig. 12 Coefficient of variation of 50 boulders versus distance of transport. Same legend than Fig. 9.

possible explanation is that the coarser clasts moved by surface creep tend to lag behind. Subsidiary, the downstream fining may be ascribed to particle abrasion and breakage although these processes must have been negligible over a so short distance. With reference to source, these gravels are assumed to be in the order from proximal (Gong-Gong) to more distal (Sydney-on-Vaal).

An exception to this trend is given at station 31 where coarse subangular boulders of quartzite derived from the immediate surroundings have been mixed with the gravels. In such station, the variation in grain size provides little or no help in the reconstruction of the processes of deposition.

6.7 EXTERNAL GEOMETRY

6.7.1 Purpose

The aims of the study of the external geometry of the Younger Gravels were the following:

- To identify any trend in the thickness of the gravel .
- To determine correlation, if any, between bed thickness and maximum particle size.
- To gain some idea about the processes of sedimentation.

6.7.2 Methods and results

The thickness of the gravels was measured at the same places as maximum particle size occurred, at 29 different stations.

The results show that the thickness of the Younger Gravels varies from 1.7 m to just over 10 m. There is no downstream trend in the variation of thickness, the thickest deposits having been found at Sydney-on-Vaal (stations 34 and 36). Moreover, thickness of any single deposit varies significantly due to the irregular nature of the bedrock surface.

Correlation of bed thickness with maximum clast size is thought to reflect the positive relationship between competence and size of flow (Bluck, 1967; Larsen and Steel, 1978). Maximum particle size versus bed thickness is plotted on Figure 13, which shows that there is no correlation between the two. The conclusions are two fold:

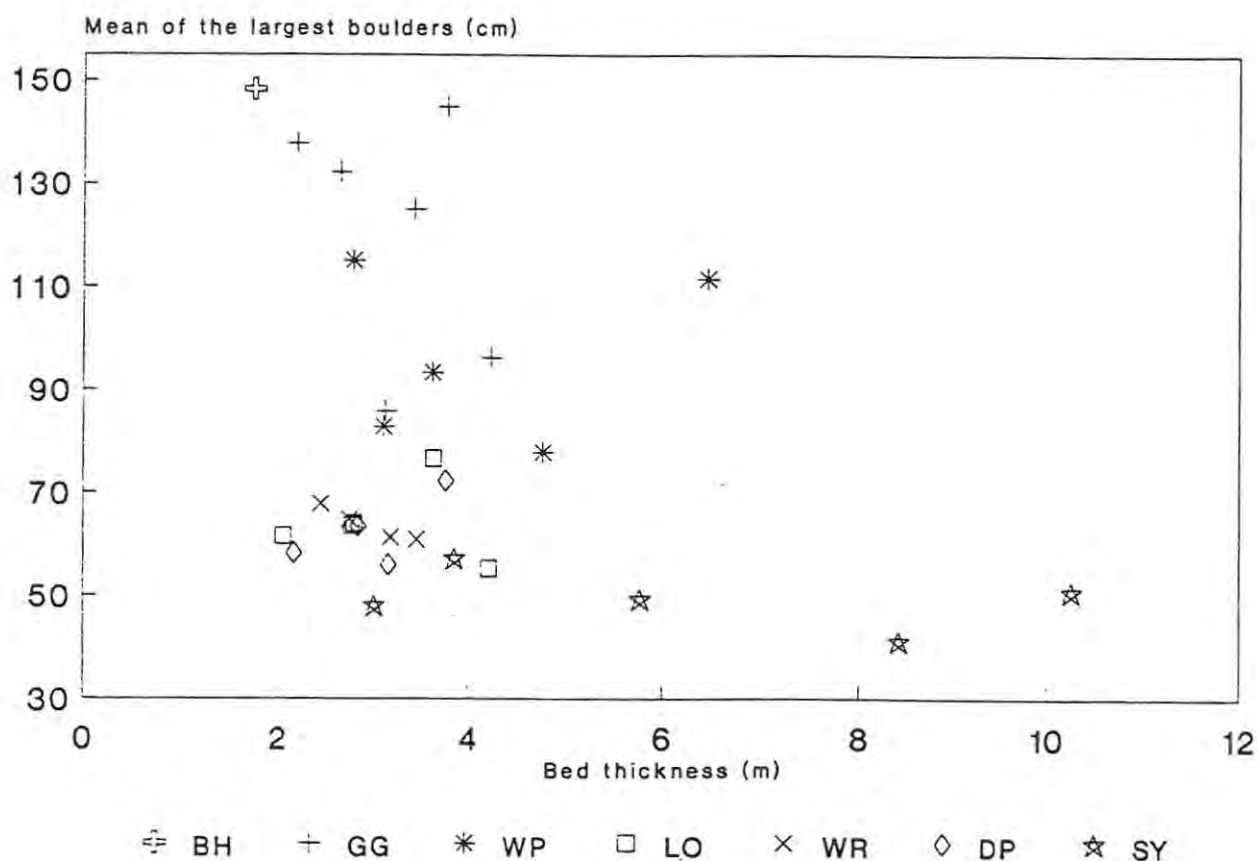


Fig. 13 Bed thickness versus maximum particle size diagram for the Rietputs Formation C. There is no size/thickness correlation.

- The materials of the gravel were derived from the erosion and reworking of previously deposited beds since the thickness of the eroded gravel bears little, or no relation to discharge. The lack of correlation can also be ascribed to subsequent erosion since the Riverton Formation unconformably overlies the Younger Gravels.
- An alternative interpretation is that the lateral variation of thickness is due to scouring during deposition, and an uneven pre-depositional bedrock surface.

6.8 PARTICLE MORPHOLOGY

6.8.1 General

Three factors determine the morphology of sedimentary particles:

- Their initial morphology inherited from the source rock, which is itself a function of jointing, cleavage, composition and climate.
- The chemical corrosion and mechanical alteration, including both abrasion and fracturing during sediment transport.
- Hydraulic sorting during transport and deposition.

Four different aspects of grain shape were used for this study: sphericity, form, roundness and surface textures.

6.8.2 Sphericity

Sphericity values describe how closely a grain approximates to a sphere. This property is a complex function of lithology, clast size, and distance of transport.

Various formulae have been proposed to describe this parameter but the maximum projection sphericity, as introduced by Sneed and Folk (1958), is favoured here because it relates better to the behavior of a grain in a fluid since it compares the grain's maximum projection area to that of the projection area of a sphere of equal volume. This states that:

$$\psi_p = (S^2/LI)^{1/3}$$

where L, I, and S are the long, intermediate and short axes, respectively. Because sphericity and form are strongly controlled by particle composition and clast size, Sneed and Folk (1958) recommended comparison of particles of the same lithology and collection of equal numbers of clasts in a narrow class size.

At each of the 20 stations, a set of 60 clasts of Ventersdorp andesite was collected by taking all clasts with long axes in the size range of

12.0 to 20.0 cm (cobble). The three axes of each cobble were measured with vernier calipers. The greatest care was taken not to measure broken clasts as they would tend to give misleading results. For each sample the arithmetic mean and the standard deviation have been computed.

The results are the following (Fig. 14):

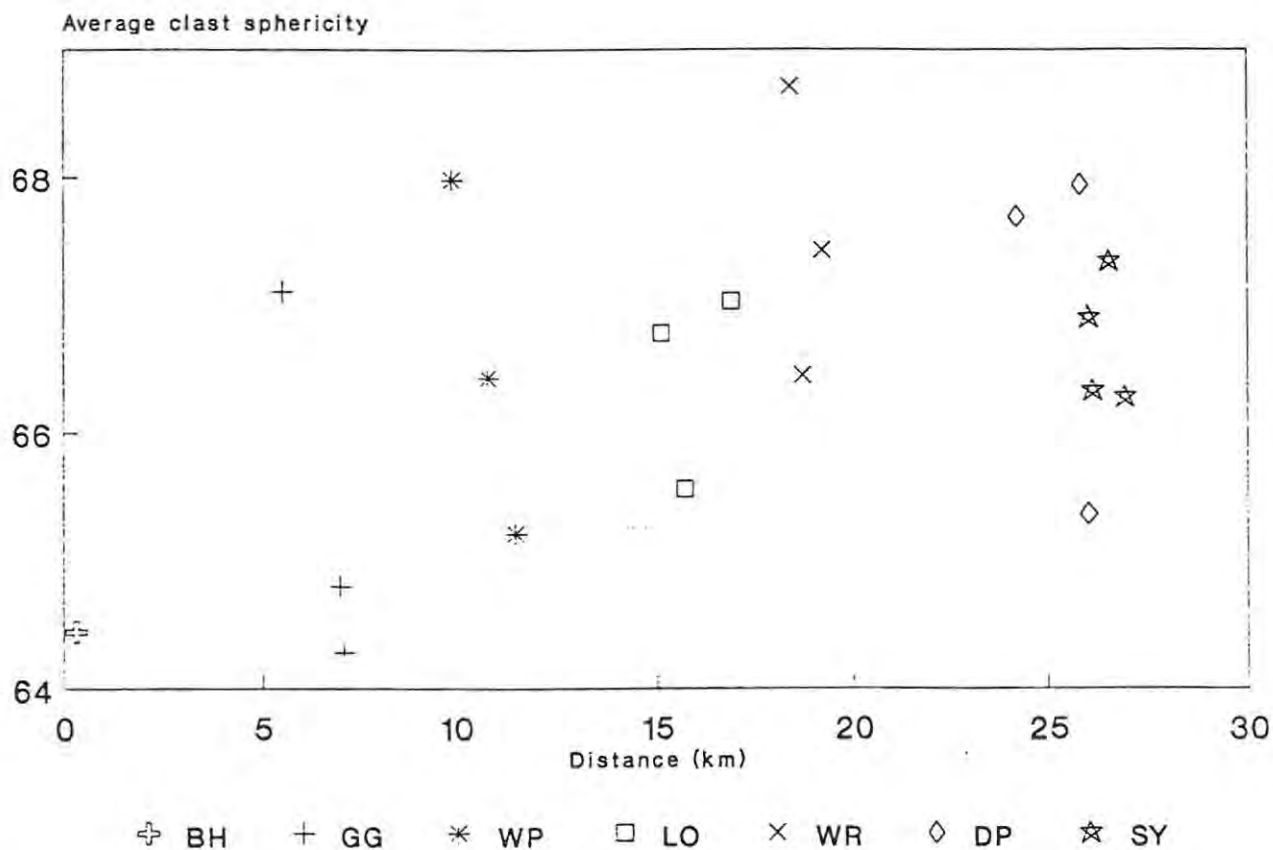


Fig. 14 Clast sphericity versus distance of transport.

- Mean sphericity values vary between 64 and 69.
- There is no downstream trend in the variation of the sphericity parameter.
- The variation in sphericity is more a function of local environment than the result of selective sorting in a downstream direction. For example, lower sphericity values were found in the well-channelised and lower part of the stream where the clasts tend to be flatter, than in poorly-channelised and the upper parts of the gravels where sphericity tends to increase.

6.8.3 Form

Particle form is generally defined by two axial ratios, I/L and S/I (Zingg, 1935). The indices are used to construct a diagram which is divided into four fields, defining four main shape classes: oblate, equant, bladed, and prolate. Equant particles have highest sphericity, but oblate, bladed and prolate particles may all have the same sphericity values. It might be expected, however, that these different shapes would behave differently; for example, prolate particles might roll much more easily than oblate or bladed particles.

Sneed and Folk (1958) proposed combining the two indices S/L and L-I/L-S on a triangular diagram. The diagram is divided into a number of shape fields which depict the ideal shapes of grains of different sphericity.

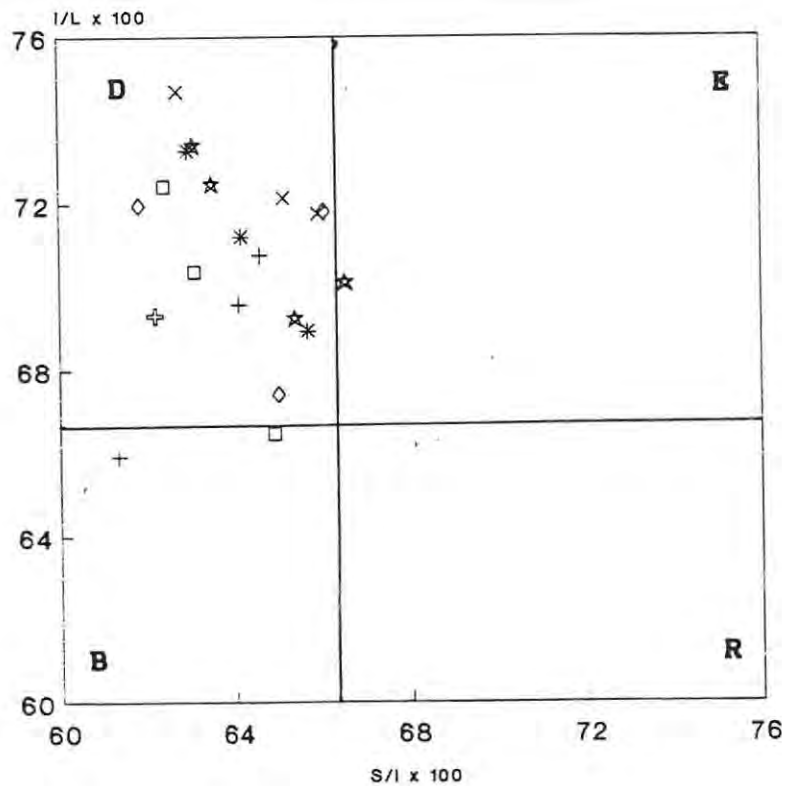


Fig. 15 Zingg diagram. Axial ratios (I/L and S/I) are based on length of long (L), intermediate (I) and short (S) axes. Four major shape categories are indicated as D discoidal, E equant, B bladed and R rod-shaped.

The same method employed in the investigation of sphericity was used here. The results are the following:

- At each locality, the individual clasts were found to be highly variable in form and covered the four fields of the Zingg diagram.
- In the Zingg diagram, most of the mean clasts for each station fall in the oblate field only a few falling in the bladed field (Fig. 15).
- In the Sneed and Folk diagram, the clasts fall in the bladed field (Fig. 16).

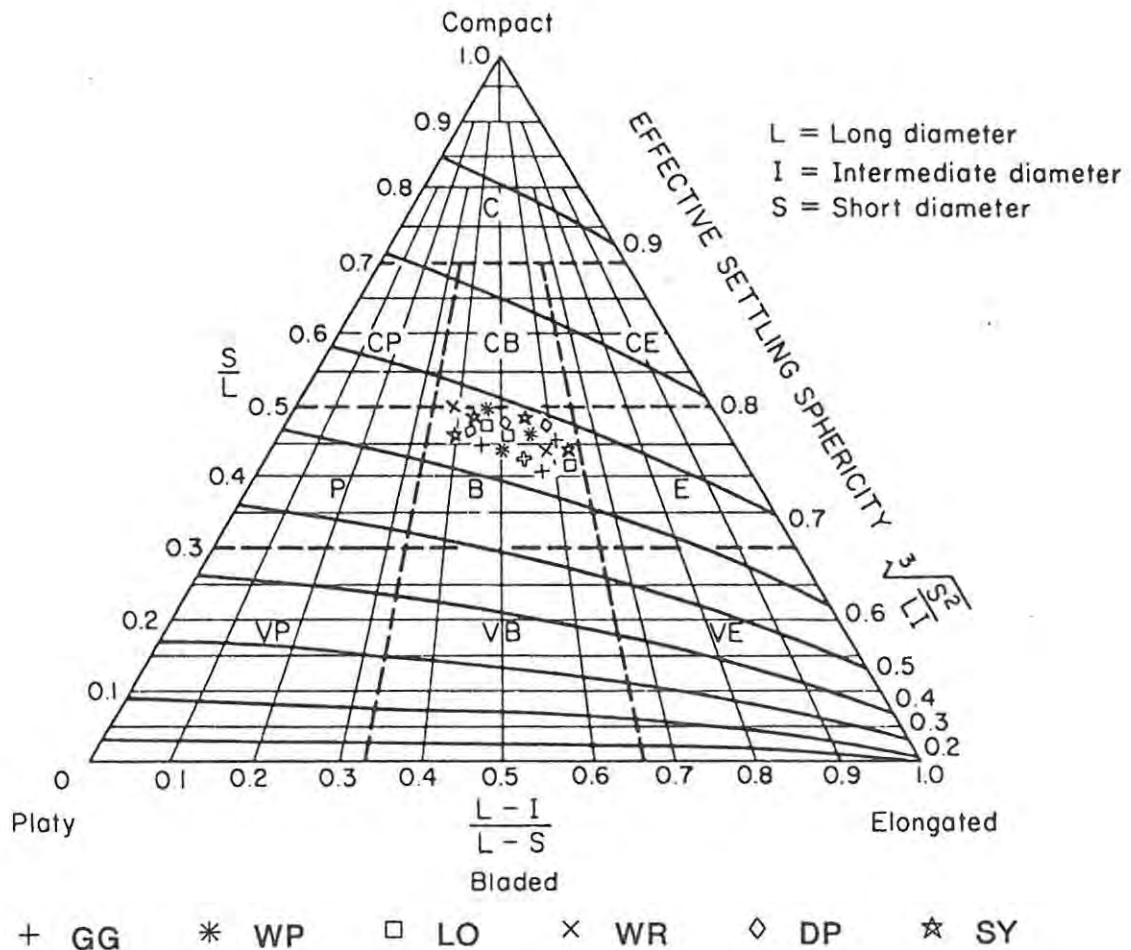


Fig. 16 Sneed and Folk diagram. Ten form classes are defined by heavy dashed lines and designated by the following initials: C, compact; CP, Compact-Platy; CB, Compact-Bladed; CE, Compact-Elongate; P, Platy; E, Elongate; VP, Very Platy; VB, Very Bladed; VE, Very Elongate.

- As for sphericity, there is no downstream trend and the form of the clasts is only controlled by local factors such as changing current velocity .
- The absence of downstream change in particle sphericity and form may be an indication that the original fragments supplied to the gravels were already the product of the erosion and reworking of previously deposited clasts. Morphologically mature, the shape of these particles did not change perceptibly during their last transport cycle within the Younger Gravels.

6.8.4 Roundness

The roundness of andesite clasts was measured to gain some idea of the paleoenvironment, the distance the pebbles had travelled and the provenance of this material.

Roundness refers to the sharpness of the corners and edges of the grain. This morphologic aspect may be expressed as the ratio of the mean radius of curvature of the grain corners to the radius of the largest inscribed circle (Wadell, 1932).

The disintegration of the parent material releases particles whose roundness increases with the distance of travel. Apparently rounding is a good index to the maturity of a sediment. The effects of abrasion are cumulative so that the roundness acquired in an early cycle of transport may be inherited and added to in a later stage of transport. In contrast to shape and sphericity, numerous studies show that pebble roundness increases rapidly during fluvial transport (Pettijohn, 1975; Folk, 1980).

Direct measurement of roundness is so difficult and tedious that it was necessary to work by visual comparison with charted standards. This procedure is relatively fast and good enough for general descriptions. It should be noted, however, that this method is subjective, with accuracy and precision often poor (Folk, 1972). In order to avoid this problem as far as possible, the following precautions were taken into account:

- The standard image method was adopted by placing the roundness of each clast into one of six groups (Photos 22 and 23). On this scale, nearly all natural grains can be described by roundness values ranging from 15 (perfectly angular) to 85 (perfectly rounded).
- At each of the 20 stations where roundness was taken, 60 clasts of Ventersdorp andesite were used, clast size ranging from 12 to 20 cm. To avoid day-to-day error by the same operator because of change in mood, weather or other imponderables giving "high-roundness" or "low-roundness" days, each 60 clast suite was divided into three subsamples of 20 clasts, so that each single locality has been measured on three separate days and the numerical mean calculated.
- Each subsample of 20 clasts was tested twice. In any case, the discrepancy was found to be less than two percent.

The results (Fig.17) show the following features:

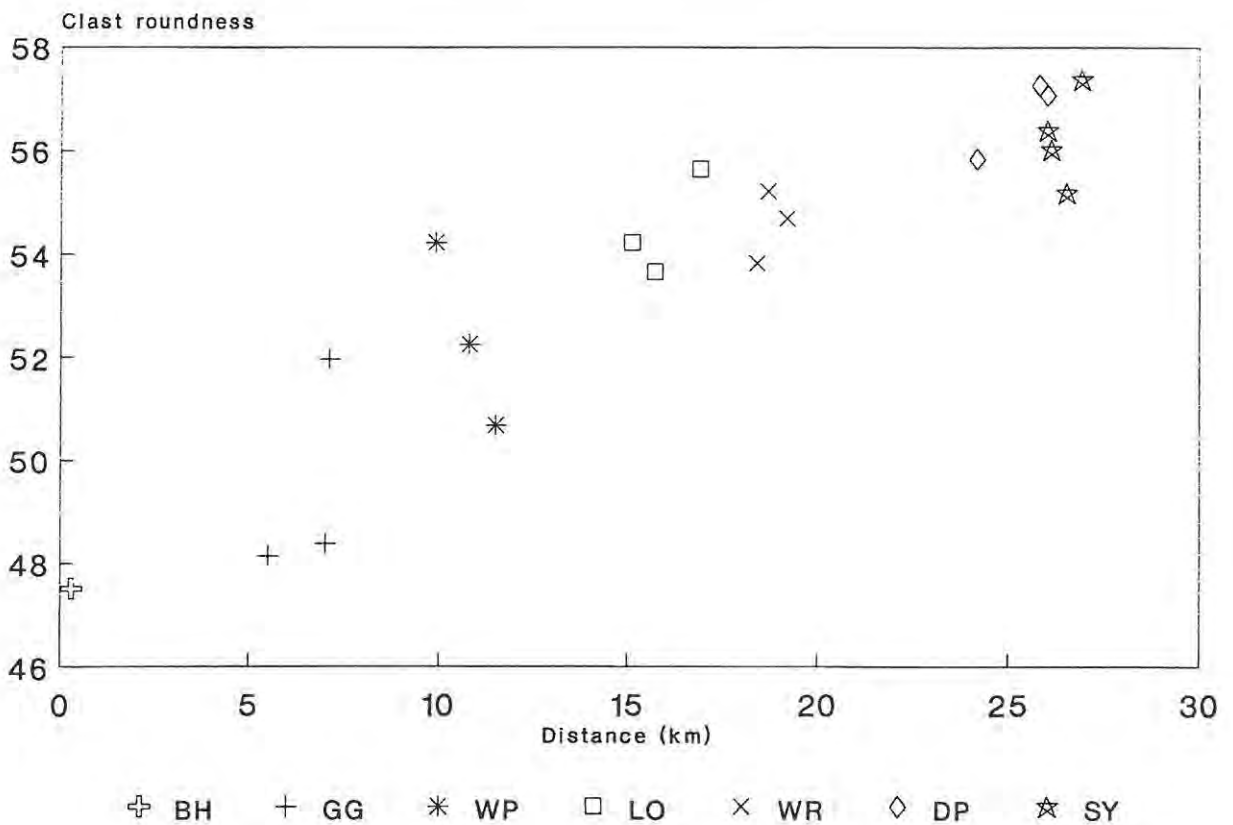


Fig.17 Roundness versus distance of transport.

- The roundness of clasts varies from subrounded to well-rounded. At Bad Hope, however, about 8 % of the clasts were subangular. These are thought to be derived directly from the surrounding andesite basement without reworking.
- The average roundness was, for all the stations, in the range of rounded clasts.
- There is a slight increase in roundness in a downstream direction. Clast roundness at Gong-Gong has an average of 49.5 while at Delportshoop the average is 56.7.

6.8.5 Surface texture

Several surface textures are noteworthy:

- At Gong-Gong and Waldeck's Plant, andesite clasts within the gravels present sometimes some striations. Striated gravels are indicative of ice action. The striations are thought to disappear very rapidly by abrasion and consequently these clasts must have been derived from a local Dwyka tillite source.
- Pebbles of quartz may show features like pitting and frosting. In high velocity flows, quartz particles collide with each other, making impact scars.
- Banded ironstones show a polished surface.
- When andesite clasts are in contact, some of them show characteristic dissolution marks, where part of one clast has been pressed into another.
- Also worthy of mention are a small percentage (<2%) of broken clasts, with spalled corners, which are thought to be indicative of exceptionally high-velocity currents (Pettijohn, 1975).

6.9 PALEOCURRENT DIRECTION

6.9.1 General

Paleocurrent measurements are an important step in the reconstruction of the paleogeographic record of an area. Not only do they indicate the direction of flow when the gravel were deposited, but they can also give information concerning the main sources supplying the gravel. Three different parameters were taken into account for this study: imbrication, cross-bedding and ancient stream direction defined by the diggers' excavations.

6.9.2 Methods

a. Imbrication: The overlapping, shingling effect of clasts in gravels and conglomerates has been commonly described as imbrication (Photo 24). This feature results from the combination of gravity and current action. In coarse fluvial gravels there is a distinct upstream dip of the clasts. The orientation of clast axes can be specified by two angles, azimuth and inclination. Imbrication is a good paleocurrent indicator which can be measured wherever the gravel is found in-situ. The main disadvantage is that this method is slow and time consuming. Moreover, the relations of clast orientation to flow direction are sometimes complex and the following points must be taken into account to obtain reliable information:

- Observation of modern fluvial systems indicates that the long axes of clasts may either lie parallel or perpendicular to stream direction (Potter and Pettijohn, 1977). In the study area, about 67% (out of 200 counts) of the clasts were parallel to the flow direction, with the a-axis dipping upstream at about 30° or less. This feature confirms previous observations that clasts parallel to the flow direction are found in rivers with a steep slope (Pettijohn, 1975) and in high energy currents (Leeder, 1982). Isotropic fabrics (facies Gms) usually result if deposition is very rapid, as in the deposits of densely charged turbidity currents (Leeder, 1982).
- Clasts with a ratio of long axis to intermediate axis of approximately 2:1 or more were measured preferentially.

- A total of 26 stations was chosen over the entire area in accordance with accessibility, good exposure and in order to cover the whole area. The number of measurements required to estimate mean current direction at a given outcrop increases with the directional variability of the gravel fabric. Stratten (1979) advised taking a minimum of 49 readings but the actual number taken at each station was generally 50. Over the whole area a total of 1285 clasts were used in the paleocurrent studies.
- The azimuth and dip of the long axis of clasts were measured using a standard Zeiss compass. This was set to correct automatically for magnetic declination. The experimental error of this compass was about 2 degrees.
- The vector mean (\bar{x}), vector magnitude and the magnitude of the resultant vector in terms of percent from a frequency distribution of azimuth were calculated for ungrouped data using the following formulae:

$$V = \sum_{i=1}^n \cos x_i$$

$$W = \sum_{i=1}^n \sin x_i$$

$$\bar{x} = \text{arc tan } W/V$$

$$R = (V^2 + W^2)^{1/2}$$

$$L = (R/n) \cdot 100$$

where x_i is the azimuth of the i th measurement, \bar{x} is the azimuth of the resultant vector, n the total number of observations, R the magnitude or length of the resultant vector, and L is the magnitude of the resultant vector in terms of per cent. The magnitude of the vector is a measure of the concentration of the azimuth; the greater L the greater the concentration. At each locality the paleocurrent was indicated as being strongly unimodal with a very low variance. Appendix 2 gives the results of the computation and compares the arithmetic^{mean} with the vector mean.

b. Cross bedding: The paucity of cross bedding structures within the gravels limits the amount of paleocurrent measurements obtainable by this method. Trough cross beds were, however, calculated at station 35 where the gravels become finer. The direction indicated was very similar to the imbrication results.

c. Diggers' excavations: By following the diamond occurrences, the diggers defined clearly the course the stream took. The diggers' excavations, however, only give the lineation of flow and not the direction. This, used in conjunction with the imbrication of the gravels, is a useful method for determining the ancient stream direction.

6.9.3 Results

The paleocurrent directions for the entire area are plotted on a map to gain an overall impression of the ancient drainage pattern (Fig. 18). The measurements indicate the direction in which sedimentary materials were being moved at the time of deposition, but this direction may be only indirectly related to the position of the ultimate sources of the detrital materials. The following features are noteworthy:

- The general direction of flow within the Younger Gravels varies from north-west to north-east. Within the Older Gravels, only the record of the diggers' excavations was studied because of the lack of good exposures. This indicates a north-west to south-west lineation.
- At Gong-Gong, three parallel channels indicate a flow direction towards the north-east.
- The general pattern of the current directions is complex and suggests that the gravels have been deposited by a braided river.

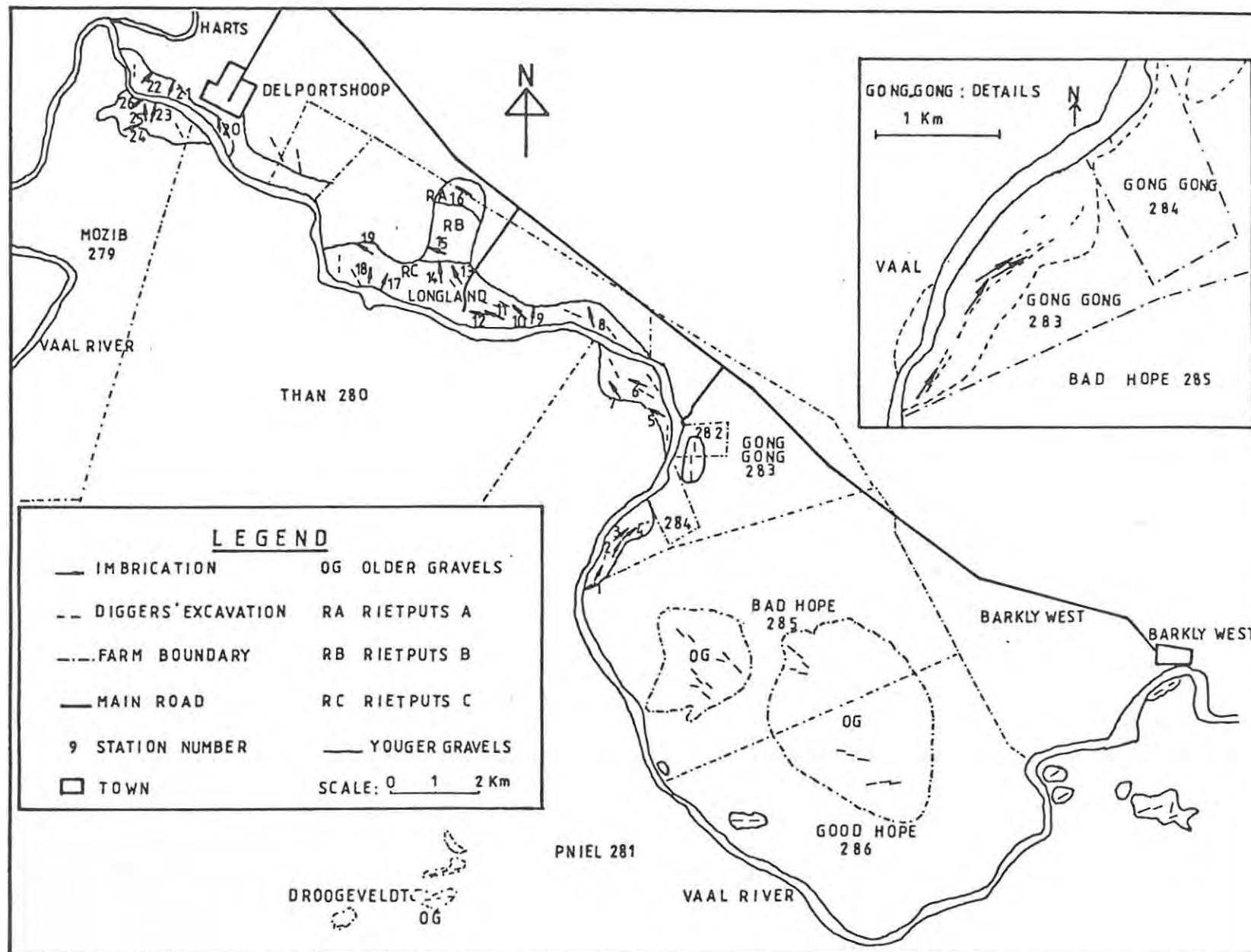


Fig. 18 Paleocurrent directions in the study area.

6.10 PROVENANCE OF THE GRAVELS

Five different sources may have supplied the Younger Gravels:

- a. As regards the source of the boulder and pebble-size material, a local origin is supported by the author. Upstream of Barkly West, the low gradient of the Vaal river does not favour the transport of very coarse material, even during high discharge. The break in slope after Barkly West increases the velocity of the current giving the right conditions for erosion of the country rocks and bedload transport of boulder-size material during flash floods. In terms of roundness, however, most of the clasts can be classified as sub-mature to mature (sub-rounded to well-rounded), a feature which, at first sight, is in contradiction with the transport over so short a distance. The most reasonable explanation is that the Younger Gravels were supplied by colluvially derived Ventersdorp andesite from hillslopes. The weathering and the colluvial reworking of the andesite clasts produced readily decomposed sub-rounded clasts which may have supplied an important proportion of the Younger Gravels.
- b. Dwyka tillite that once filled the valley floor between Barkly West and the Vaal-Hartz confluence may also have supplied the Younger Gravels. Table 4 compares the lithology and morphometry of 200 clasts from the Younger Gravel and tillite at Gong-Gong. The result shows that the clasts from the alluvial and glacial deposits are very similar, having comparable lithology and shape (Photo 25). The only notable difference is better rounding and larger clast size in the fluvial deposits. An important part of the Ventersdorp andesitic clasts, as well as pebbles of banded ironstone breccia and dolomite derived from the Transvaal Supergroup, could have been introduced into the gravel deposits via tillite. The Dwyka tillite is enriched in resistant minerals (quartz, agate, chert, chalcedony etc.) which may have supplied the gravels. Between Barkly West and the Vaal-Hartz confluence, the bedrock and valley-side tillite were eroded and fluvially resorted on the valley bottom (Photo 26).
- c. The granule to pebble-grade particles of quartz, agates, chalcedony, chert, jasper and quartzite may also have been produced by erosion

Table 4: Comparison of the lithology and morphometry of 200 clasts from the Younger Gravels and Dwyka tillite at Gong-Gong.

	YOUNGER GRAVELS	TILLITE
Composition	96 % of Ventersdorp andesite with minor quartz, agate, chalcedony, banded ironstone.	92 % of Ventersdorp andesite with minor banded ironstone, agate, quartz, quartzite.
Mean size (> 4 cm) of apparent long axis	15.9 cm.	9.7 cm.
Mean roundness	42.0	39.4

of various Precambrian rocks in the Vaal basin. Quartz, chalcedony and agate may have derived directly from the amygdales of Ventersdorp lavas.

d. A third source for coarse-grade clasts is locally derived shale of the Prince Albert Formation and quartzite belonging to the Black Reef Formation. The shales generally reflect directly the bedrock underlying the gravels while subangular to subrounded quartzites, which is more abundant in the Delpøortshoop area, is thought to derived from the country rocks.

e. The last source of material supplying the Younger Gravels is colluvial erosion of the Derived Older Gravels nearby. Most of the resistant material (quartz, chalcedony, agate etc.) in the Younger Gravels was probably introduced to the Lower Vaal system through denudation of adjoining hillslopes, and not necessarily as gravel surges introduced from the upstream drainage or derived from active dissection of the pre-Karoo bedrock. The Older Gravels themselves may have derived from the Dwyka tillite or from the erosion of Precambrian rocks such as the Ventersdorp andesite.

6.11 SEDIMENTOLOGICAL MODEL

6.11.1 Summary of the sedimentological investigation

In order to construct a 3-dimensional model for the Younger Gravels, the following points must be highlighted:

- **Lithofacies:** The lithofacies found in the Younger Gravels are characteristic of a braided stream environment with Gm and Gms predominant. The former is interpreted as channel-lag and longitudinal bar deposits while the latter represents waning stage of deposition when the matrix and the gravels were deposited together. Gt, Gp, and sandy facies represent less than 5% of all the Younger Gravels deposits.
- **Lithofacies distribution:** Facies Gm is generally overlain by facies Gms or Su (Riverton Formation). There is a gradual downstream increase of sandy facies within the sequences (about 5% at Sydney), and an increase of sand in the matrix. This change reflects a gradual decrease in the particle size/water depth ratio as stream competence decreases downstream. The presence of a single cycle of deposition in most outcrops is interpreted to be mainly the result of erosion and reworking of previously deposited gravels.
- **Clast composition:** The gravels consist dominantly of cobbles/boulders of Ventersdorp lava with minor shale, quartzite, banded ironstone, and agate. The matrix is made of quartz and resistant minerals. Very few changes in composition occur from one outcrop to another.
- **Mean clast size and sorting:** There is a gradual decrease in mean clast size in a downstream direction indicating a decrease in the transportational energy. Based upon the sorting of the clast population, the gravels can be classified as proximal (Gong-Gong) to more distal (Sydney-on-Vaal). The coarse nature of the gravel implies a high energy environment.
- **External geometry:** There is no downstream trend in the variation of thickness of the gravels and no correlation between bed thickness and maximum particle size. These features are attributed to erosion

and reworking of previously deposited material, scouring during deposition, subsequent erosion of the gravel, and an uneven pre-depositional bedrock.

- **Particle morphology:** There is a slight increase in roundness in a downstream direction. In terms of roundness, the gravels can be qualified as mature.
- **Palaeocurrent directions:** The river was flowing in a north-west to north-east direction. The pattern is typical of a braided stream system.
- **Provenance of the gravels:** A local origin for the gravels is supported. The most important sources supplying the gravels are thought to be colluvially derived clasts and resistant minerals from hillslopes, as well as the Dwyka tillite which were eroded from the bedrock and valley-sides and redeposited on the valley bottom. Other sources comprise shale and quartzite derived from the country rocks as well as resistant minerals produced by erosion of various Precambrian rocks in the Vaal Basin.

6.11.2 Environmental setting and depositional model for the Younger Gravels.

The Younger Gravels are situated downstream of the lower end of the gorge which the Vaal river has cut through the andesite after passing Barkly West. The high gradient between Barkly West and the Vaal-Hartz confluence favoured high current velocities. The semi-arid climate was characterized by irregular but intense rainfall during the summer season and limited interception by a sparse vegetation cover. Rock weathering was dominated by mechanical breakdown rather than chemical processes, and large proportions of bedload-calibre material were thus available for transport. Flash floods produced a relatively high density fluid in which heavy particles were more easily transported. The ephemeral nature of the fluvial activity, together with the high sediment load, led to poorly-sorted gravels.

The following features suggest that the gravels were deposited in braided *streams* during high discharge (Fig. 19):

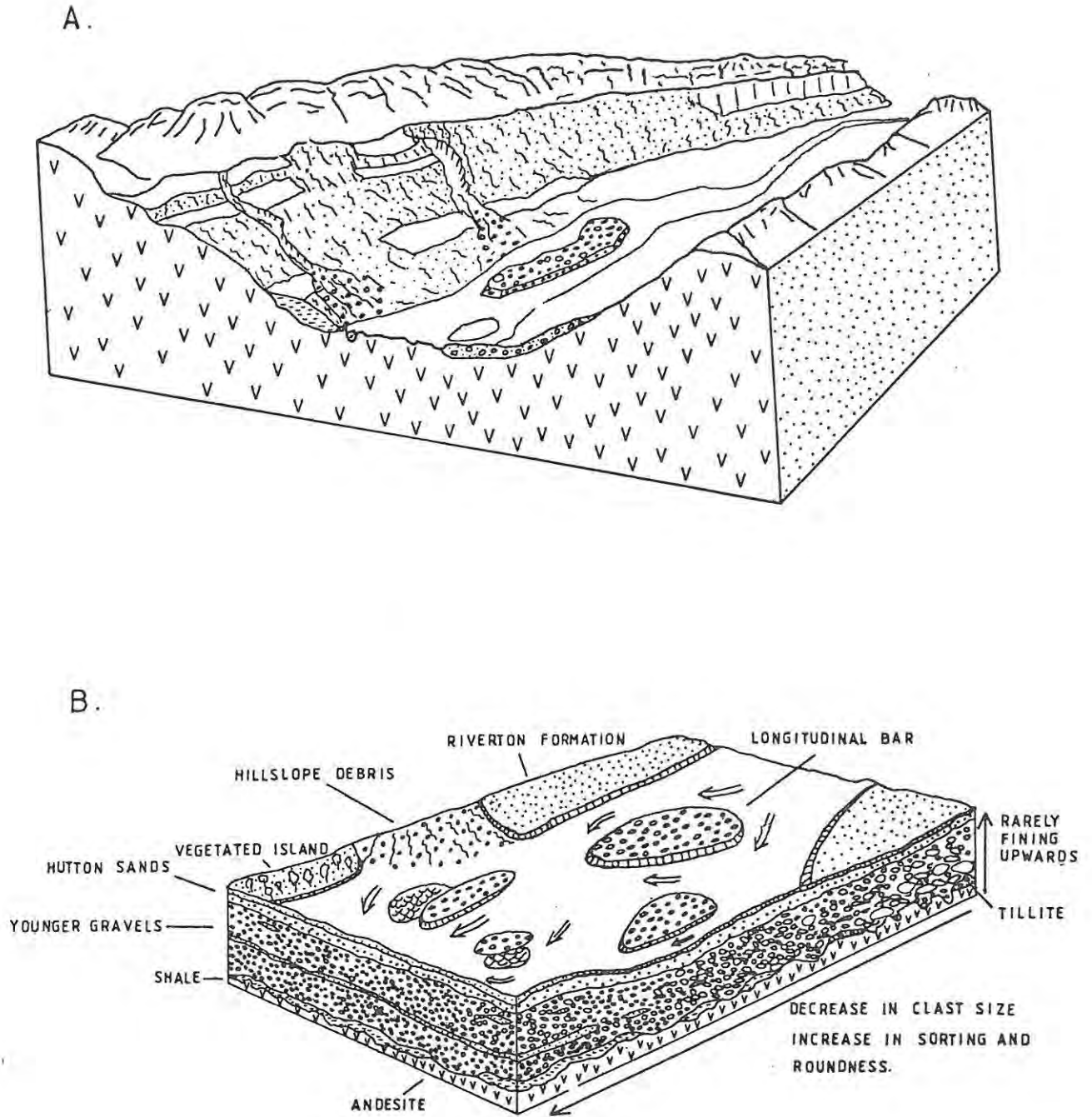


Fig. 19 Environmental setting: terrace gravels and steep valley with colluvially derived detritus (A) and depositional model: proximal braided stream deposits (B) for the Younger Gravels.

- The coarse nature of the gravel and the lack of well defined beds.
- The vague to distinct stratification and widespread clast imbrication, with dominantly a-axis parallel to the flow.
- The evidence of scouring and channelised flow conditions.

Because of their relatively steep slope and abundant coarse bedload, the proximal reaches in the area tend to be of low-sinuosity, multiple-channel type. Braiding occurred when flow strength in the stream became insufficient to move the sediment load and water discharge in the channel, resulting in modification in the stream bed through either deposition (bars emergence) or scouring (channels). The result was sorting as the stream left behind those sizes of the load which it was incompetent to transport.

The lack of fan-shaped accumulation, the dominance of Gm facies, and the one-dimensional pattern favoured the idea that the gravels were deposited by a proximal braided river rather than an alluvial fan. The confined valley played a major role by allowing multiple reworking of the gravels and subsequent concentration of the diamonds. Alluvial fan processes would have probably been less effective in upgrading the diamonds.

About 80% of facies Gm lacks fining upwards sequences, suggesting a predominant deposition by channel-lag processes. The remaining occurrences were formed by longitudinal bar processes. The dominance of clast-supported framework, usually with well-developed imbrication, is more typical of bedload rather than debris flow transportation. In debris flow beds commonly display a significant positive correlation between their thickness and maximum clast size (Nemec and Steel, 1984), a feature which is lacking in the Younger Gravels. This characteristic corroborates Rust's (1979) observation that debris flows are rarely preserved in braided river deposits because the consistent aqueous flow is likely to rework them before consolidation.

The highest energy current and the coarsest bedload were confined to channels. However, gravel was not necessary limited to channels, but the bedload could spread out on proximal overbank surfaces, if stream power was high enough. The braiding pattern was favoured by rapid and

large discharge fluctuations, steep slope, an abundance of clastic debris, insufficient vegetative protection, and local stream incompetence. The massive to crudely-stratified gravels are interpreted as the result of deposition from either hyperconcentrated flood flow or stream flow with very high sediment concentration and high current velocity. In gravel-bed proximal channels, facies Gm dominates with relatively few other facies (e.g. Gong-Gong). Channel-lag deposits and longitudinal bars are very coarse while sand deposits are rare. In very proximal channels, sand is transported in suspension and little is deposited except as gravel matrix. Locally, thin sandy interbeds (< 3 cm) represent remnants of sedimentation during waning flow stage. Farther downstream, sand becomes more abundant in the bedload, and massive sandy interbeds (10 to 40 cm thick at Sydney), although representing less than 5% of all the deposits, become more common. A few planar cross-bedded and trough cross-bedded units are sometimes present within the gravel. These features suggest a downstream decrease in the energy of the flow and the transition from a proximal to more distal environment.

At first sight, the scarcity of fine sand, silt and clay material may be surprising since the gravel deposits were partly formed by erosion of Dwyka tillite of which the matrix is rich in these materials. This feature is probably due to their non-deposition rather than their absence in the environment. Sand grains require less initial energy than cohesive mud, particles to be brought into suspension but will settle out more rapidly than mud which has lower settling velocity. Braided streams may transport considerable amounts of suspended load, but deposit very little of it (Miall, 1981). During low flow, fine particles can be deposited in local depressions or on bar surfaces but preservation potential is very low.

The ⁿYounger Gravels show similarities with the Scott-type depositional environment of Miall (1977, 1978) which represents a proximal river in a braided stream environment. Similarities include dominant facies Gm with minor facies Gt, Gp, and Sp deposited during waning flow.

The contact between the Younger Gravels and the Riverton Formation is erosional, indicating rapid change in the energy of the stream. The Riverton Formation may represent deposition in abandoned channels.

7. THE KIMBERLITIC INDICATOR MINERALS

7.1. INTRODUCTION

This section describes a small-scale experiment carried out to:

- gain an idea about the composition of the kimberlitic minerals and the distance they have travelled.
- study the effect of sorting of kimberlitic minerals in three different size fractions in a braided stream environment.
- test the efficiency of fluvial "trap" sites to concentrate kimberlite indicator minerals for possible correlation with diamonds.

The kimberlitic indicator minerals, rather than other heavy minerals, were studied preferentially because they are more likely to reflect the post-Cretaceous history of deposition.

7.2 METHODS

7.2.1 Collection of samples

Nineteen test samples were collected from a variety of sedimentological "trap" sites between the Gong-Gong falls and the Vaal-Harts confluence, a distance of 24 km. One sample has been collected in a pothole near the Gong-Gong falls, ten samples in the Younger Gravels, seven samples in the Riverton Formation and one sample in the Hutton Sand. The initial samples were each equivalent to at least 20 litres in volume, and comprised particles < 2 mm in diameter screened on site. The characteristics of the sediment and position relative to the bedrock profile were recorded. Observations were made of packing and sorting characteristics, the proportion of gravel to sand and silt, the degree of calcretization, the relationship of the site to bedrock, and location details with respect to the type of formation. Field description of all sedimentological sites are summarized in Table 5.

Table 5 Field descriptions of "trap" sites and selected laboratory processing results for 19 test samples.

SN	F	Description	% BP	x	CV	HCl	ID	D	FC	BC	TGA	TIL	TCD	TSP	TGR	GR	Final
1	GG	Pothole, 70 cm deep, 25 cm in diameter, 50 m from the Gong-Gong falls. Very tightly packed cobble/pebble-size material in a matrix of very coarse sand. Sample material removed from the deepest part of the pothole.	85	1.06	41	0	1.44	5	1936 1686 429	41 24 12	2 3 1	51 60 36		3	53 63 40	1 4 9	Excellent Good Moderate
2	GG	Strongly calcretized sand (Riverton Formation), coarse greyish sand with rare granules (facies Su), sample material collected from the lower part near the top of the Younger Gravels.	2	0.91	44	3	1.27	15	1012 1510 878	4 3 1		2 1		1	2 1 1	9 16 17	Moderate Very poor Very poor
3	GG	Similar to site for sample 2, but sample material removed from 1 m above the Younger Gravels.	2	0.77	56	3	1.25	17	919 1662 834	2 2 4		1 40			1 40	11 - 9	Poor Negative Moderate
4	WP	Tightly packed, cobble/boulder-size (boulder may reach 80 cm in length) poorly-sorted gravel (Rietputs C Formation). Calcretized coarse sandy matrix reddish in color. Bedrock not reached during excavation. Sample material removed from the coarsest bedload.	80	0.80	55	2	1.22	18	1122 1094 822	30 11 6	2 3	5 62 67	1	2	7 68 67	4 2 4	Good Good Good
5	WP	Strongly calcretized grey sand (Riverton Formation), coarse sand with rare granule (facies Su), sample material collected 50 cm above the Younger Gravels (same site as sample 4).	3	0.71	66	4	1.26	16	876 779 482	6 3 1		1 5 82		11	1 5 93	11 12 3	Poor Poor Good
6	WP	Very tightly packed, cobble/boulder-size (boulders may reach 1.2 m in length) poorly-sorted gravel (Rietputs C Formation). Coarse grey sandy matrix. Bedrock reached and sample material collected 0 to 30 cm above it from the coarsest bedload.	85	0.74	70	1	1.42	7	1562 1232 594	20 8 5		10 54 21		3 9	10 57 30	3 6 12	Good Good Moderate
7	WP	Brown-yellow sand (Riverton Formation) 2 m above the Vaal river. Medium-size sand. No calcretization.	0	0.43	78	2	1.42	7	58 77 353	1 1 1						- - -	Negative Negative Negative
8	LH	Clast-supported, cobble-size material with minor boulders (45 cm in length maximum), well-sorted gravels (Rietputs B Formation). Strongly calcretized coarse sandy matrix. Bedrock not reached during excavation. Sample material removed 1.5 m below the Riverton Formation.	65	0.65	68	3	1.38	11	690 701 531	4 2 2		4 23 14		1	4 27 16	7 9 13	Moderate Moderate Poor
9	LH	Strongly calcretized, coarse greyish sand (Riverton Formation, facies Su). Sample material collected 10 cm above the Younger Gravels (same site as sample 8).	2	0.73	67	4	1.35	12	60 54 60	1 1 1		1			2 2	- 13 16	Negative Very poor Very poor

Abbreviations: SN sample number; F farm names: (GG=Gong-Gong; WP=Waldeck's Plant; LH=Last Hope; LO=Longlands; WR=Winter's Rush; DP=Delportshoop; SY=Sydney on Vaal); % BP in situ estimate of percentage of gravel (including boulders) as opposed to sand in trap site; x average grain size; CV coefficient of variation grain size; HCl reaction with HCl 10 % (0=none; 1=slight; 2=moderate; 3=strong; 4=very strong); ID initial density (kg/l); D index for ID (initially

most dense 1, least dense 19); FC field concentrate in g (after second acidification); BC tetrabromoethane concentrate (g); TGA total number of garnet grains recovered (1 number= +1 mm; 2 number= +0.5 mm; 3 number= +0.3 mm); TIL idem for ilmenite; TCD idem for chrome diopside; TSP idem for spinel; TGR idem for total grains recovered; GR index for TGR (greatest number of grains recovered 1); Final trap site ratings based on total number of grains recovered in each class size.

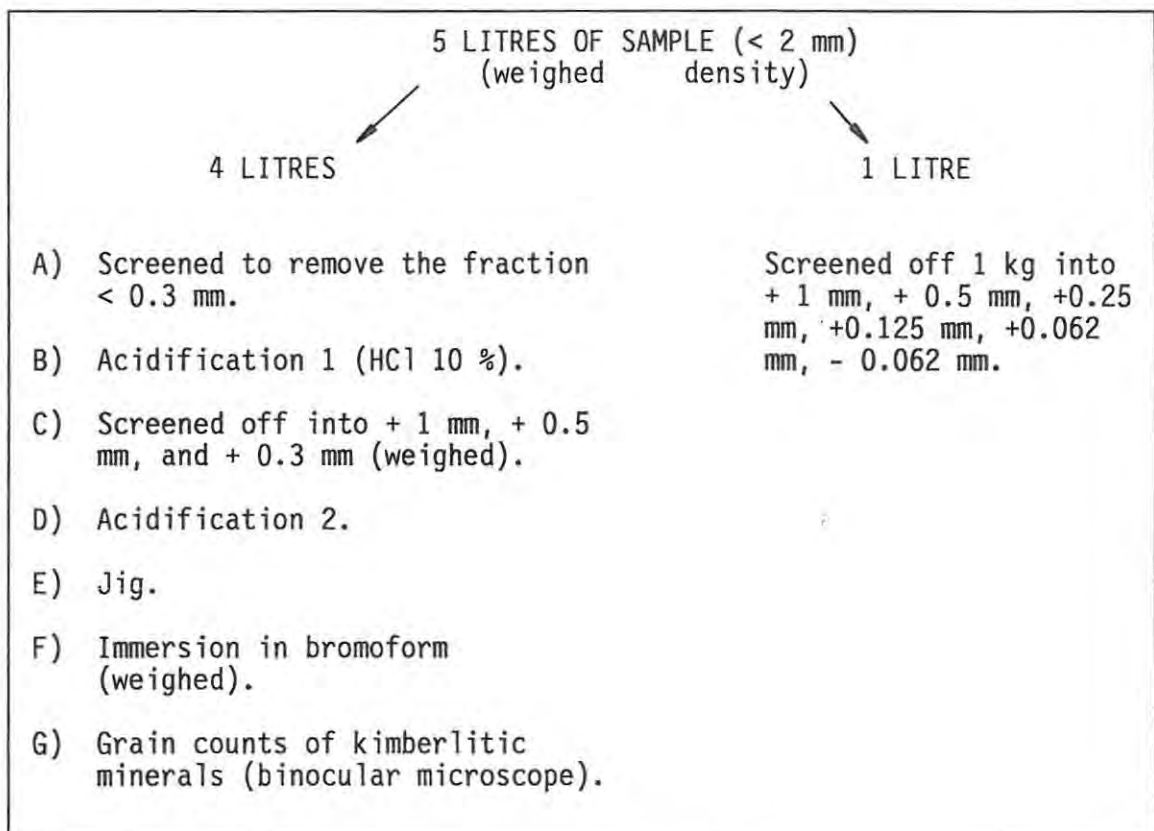
Table 5 (CONTINUED). Field descriptions of "trap" sites and selected laboratory processing results for 19 test samples.

SN	F	Description	% BP	x	CV	HCl	ID	D	FC	BC	TGA	TIL	TCD	TSP	TGR	GR	Final
10	LO	Clast-supported, cobble/boulder-size material (boulder may reach 50 cm in length) medium-sorted gravel (Rietputs C Formation). Calcretized coarse sandy matrix. Bedrock reached during excavation and sample material removed 0 to 30 cm above it from the coarsest bedload.	70	0.75	64	2	1.33	13	489	16	1	10			11	2	Good
									923	2	1	33	1	35	8	Moderate	
									625	2		47		47	6	Moderate	
11	LO	Strongly calcretized, coarse greyish sand (Riverton Formation, facies Su). Sample material remove 70 cm above the Younger Gravels (same site as sample 10).	2	0.88	55	3	1.21	19	313	1						-	Negative
									320	1		2		2	13	Very poor	
									136	1		4		4	15	Poor	
12	WR	Clast-supported, cobble/boulder-size material (boulders may reach 55 cm in length) medium-sorted gravel (Rietputs C Formation). Calcretized very coarse sandy matrix. Bedrock not reached during excavation. Sample material collected from the coarsest bedload.	65	1.27	31	4	1.59	1	725	6		1			-1	11	Poor
									34	3		20	1	21	10	Moderate	
									603	1		52	2	54	5	Good	
13	DP	Clast-supported, cobble/boulder-size material (boulders may reach 60 cm in length) medium-sorted gravel (Rietputs C Formation). Calcretized coarse sandy matrix. Bedrock reached during excavation and sample material removed 0 to 30 cm above it from the coarsest bedload.	70	0.66	61	1	1.50	3	1572	15		4			4	7	Moderate
									1225	8	5	58		63	4	Good	
									1226	13	2	44	1	47	6	Moderate	
14	DP	Same site than for sample 13 but sample material removed 1.5 m above the bedrock.	70	0.68	64	2	1.33	13	373	10	2	4			6	5	Good
									643	3	1	51		52	7	Good	
									524	4		28	6	34	11	Moderate	
15	SY	Matrix-to clast-supported, cobble-size material with minor boulder (40 cm in length maximum), well-sorted gravel (Rietputs C Formation). Coarse sandy matrix. Bedrock not reached during excavation and sample material collected 70 cm below the Riverton Formation.	60	0.68	55	1	1.47	4	606	15	2	3			5	6	Good
									372	7	2	95	6	103	1	Excellent	
									796	11		77	45	122	2	Excellent	
16	SY	Massive coarse granuly sand (about 20 % of granule-size material). Consist of a lens in the Younger Gravels (facies Sm). Sample material removed 1.2 m above the bedrock (same site as sample 15).	30	0.79	48	0	1.41	9	874	4		2			2	9	Moderate
									2804	6		13		13	11	Poor	
									1091	7	3	37	6	46	8	Moderate	
17	SY	Massive red medium-sized sand (Hutton Sand, facies Sm). Sample material removed 50 cm above the Riverton Formation (same site as sample 15).	0	0.39	62	1	1.41	9	36	1						-	Negative
									65	1		1		1	16	Very poor	
									371	1		1		1	17	Very poor	
18	SY	Clast-supported, cobble-size material with minor boulders (40 cm in length maximum), well-sorted gravel (Rietputs C Formation). Coarse sandy matrix. Bedrock not reached during excavation and sample collected 2.2 m below the Riverton Formation.	60	0.52	67	1	1.55	2	512	11	1				1	11	Poor
									2071	6	2	62	3	67	3	Good	
									1880	12	4	120	18	142	1	Excellent	
19	SY	Strongly calcretized coarse greyish sand (Riverton Formation, facies Su). Sample removed 10 cm above the Younger Gravels (same site as sample 18).	2	0.71	72	3	1.44	6	169	1						-	Negative
									127	1		2		2	13	Very poor	
									131	1		5		5	14	Poor	
									43649	368	45	1316	1	119	1481		

7.2.2 Laboratory processing

All samples were reduced by an identical sequence of processes to their heavy mineral components of specific gravity > 2.95. Five litres of sample material (< 2 mm) were first weighed, using a Mettler balance (accuracy +/- 0.005 kg), in order to monitor relative primary sample density (Table 6). One litre of each sample was separated and of this, one kilogramme was used for screening in order to have an idea of the mean size, coefficient of variation and the different fractions constituting the sediment (Table 5, Appendix 3). The other four litres were screened to remove the fraction smaller than 0.3 mm (the cut-off at 0.3 mm was dictated by the practical limit of reliable recognition of kimberlitic minerals under a binocular microscope). All samples were acidified a first time (HCl 10 %) in order to dissolve broadly the calcrete, and the degree of reaction was monitored (Table 5). After drying, the samples were separated into three fractions by screening (+1 mm, +0.5 mm and +0.3 mm) and weighed (Table 5). A second acidification was carried out in order to dissolve the remnant of calcrete. Each sample was then passed over a jig and dried. The

Table 6 Different stages in the laboratory treatment of the samples.



resultant three heavy fractions were concentrated further by immersion in bromoform of specific gravity 2.9. The concentrate was weighed after being washed in acetone and dried, using a Sartorius electronic balance (accuracy ± 0.0001 g). The three bromoform "sink" fractions of each sample were sorted in De Beers Geology Laboratory for kimberlitic indicator minerals (garnet, ilmenite and chrome diopside) on a grain by grain basis using a binocular microscope. The number of indicator mineral grains in each sample is shown in Table 5. The trap site ratings, also shown in Table 5 have been computed according to the total kimberlitic grains recovered.

7.3 RECOVERY AND DISTANCE OF TRANSPORT

A total of 1362 kimberlitic mineral grains (1316 ilmenites, 45 garnets and 1 chrome diopside) were recovered in the sediments.

According to Atkinson (1989), under warm climates and marked seasonal rainfall, indicator minerals travel from 20 km or more (for 0.4 mm diameter grains) to only 1-2 km (for 1.0 mm diameter grains). It must be emphasized, however, that under flash flood conditions, the kimberlitic minerals may suffer much less mechanical attrition than in other kinds of transport processes. McCandless (1990), for example, showed experimentally that the presence of fine-grained material in a gravel can significantly hinder the wear of kimberlitic minerals, even when much larger clasts comprise 50% of the sediment. He suggested that the fine-grained component cushions the xenocryst minerals from contact with other clasts by increasing the overall viscosity of the sediment charge. This factor must be taken into account when interpreting the distance kimberlitic minerals have travelled.

Ilmenite is by far the most abundant kimberlitic mineral in the study area (96.6 % of all grains). This feature reflects that ilmenite, unlike chrome diopside, and to a lesser extent garnet, is extremely stable, and appears to be unaffected by weathering processes in kimberlite (Garvie, 1981). About 22 % of ilmenite grains showed remnants of the original surface (ROS), suggesting a local origin. The remainder may have been derived from further away from the study area.

Garnet represents 3.3 % of the kimberlitic grains, 93 % of them

showing remnants of original structure (e.g. sculptured surfaces consisting of combinations of rounded hillocks and etch pits formed by resorption process during kimberlite emplacement). This feature suggests a local origin for the garnet. The total absence of kelyphite on garnet (ROK) in the study area suggests that this texture has been destroyed by in-situ weathering after the emplacement of the kimberlite. The kelyphite is considered to be the result of an isochemical reaction between olivine and garnet (Reid and Dawson, 1972).

Only one grain of chrome diopside was recovered from the sedimentary analysis. This is not surprising, since it is well known that, under arid and tropical climates, chrome diopside is rapidly decomposed by in-situ chemical weathering, and does not survive long mechanical transport. For example, Mosig (1980) noted for South Australian kimberlite, that chrome diopside was not recovered more than 3 km from its source. The preservation of the original surface suggests a local derivation from the nearby kimberlite sill, and transportation under flood conditions.

7.4 SORTING AND EFFICIENCY OF FLUVIAL "TRAP" SITES

The data (Table 5) suggest that the best bromoform concentrate (BC) occurs in the pothole (sample 1) and in the coarser facies (sample 4 and 6). The concentration of kimberlitic grains generally occurs in the gravel facies, although sand facies may occasionally contain appreciable number of indicators in the +0.3 mm fraction (e.g. sample 5). The data tend also to suggest that the deepest part of the main channel carries the best concentration in the +1 mm fraction (samples 6 and 10) while flood level areas seem least favourable. The reason for kimberlitic minerals to be more abundant in the deeper parts of the river bed may be due partly to natural jiggling and sagging processes (Osovetskii, 1984) but also because of the constricted channel width. Moreover, the coarser light clast framework provides an environment conducive for interstitial entrapment of heavy minerals (Reid and Frostick, 1985). The last depositional unit of the Riverton Formation (sample 7) and the Hutton Sand (sample 17) are extremely poor in kimberlitic minerals.

Muggeridge (1989) suggests that the coarser the gravel environment, the greater the velocity required to mobilize the lighter minerals and thus concentrate heavy minerals amongst the gravel. According to him, to have good potential for concentrating kimberlitic minerals the sediment should be clast-supported, poorly-sorted and tightly packed. The present study tempers this assumption and shows that the concentration of indicator minerals in gravel facies is strongly dependant on the size fraction chosen.

The clast-supported, tightly-packed, cobble/boulder-size gravels carry high concentrations of kimberlitic minerals in the +1 mm fraction (samples 4, 6 and 10) but only moderate concentrations in the + 0.3 mm fraction. On the contrary, the well-sorted, matrix-rich, cobble-size gravels contain very high concentrations of kimberlitic minerals in the +0.3 mm and +0.5 mm but moderate concentrations in the +1 mm (samples 15 and 18). This feature may reflect a difference in the transport process. For the +1 mm fraction, the major sorting and concentrating processes take place on the bed rather than higher up in the flow. The preferential entrainment of the lighter particles leaves behind a lag of heavy minerals in the deeper parts of the channels. The uneven nature of the bedrock at Gong-Gong and Waldeck's Plant has probably enhanced this sorting process. The +0.3 mm fraction is preferentially transported in suspension during flash floods and deposited in the matrix of the gravel during waning flow. The high concentration of kimberlitic minerals in the +0.3 mm and +0.5 mm at Sydney-on-Vaal tends also to suggest that there is a progressive sorting of the finer fraction of the heavy minerals in a downstream direction. During flash floods, the velocity of the current and turbulence in the stream become too strong and flush out the finer heavy particles towards more distal environments.

The pothole carries at least five times more kimberlitic minerals in the +1 mm fraction (53 grains) than any other sample but is not particularly enriched in the +0.3 mm fraction (40 grains) compared with other gravel facies. A possible explanation is that the longer a pothole is active the higher the relative resistant mineral concentration becomes as a result of the abrasion of the softer detritus until they reach a critical size, after which they are washed out of the pothole.

The data show also that there is no relationships between the initial density of the sample and the concentration in kimberlitic minerals. For example, sample 4 which is one of the least dense, carries good concentrations of indicator minerals. The same seems true for the mean grain size and coefficient of variation, although finer and poorly sorted sand seems particularly unfavourable (sample 7 and 17).

7.5 CONCLUSIONS

The following features are noteworthy:

- Ilmenites are by far the most abundant kimberlitic indicator minerals in the study area. Their surface textures suggest a double origin: one of local derivation from kimberlitic dykes in the Barkly West District and the other from a more distant source.
- Proximal, poorly-sorted, boulder/cobble-size gravels contain high concentrations of kimberlitic minerals in the +1 mm fraction, while more distal, well-sorted, cobble-size gravels carry better concentrations of kimberlitic minerals in the 0.3 mm and 0.5 mm fractions. The proximal gravels contain better concentrations near the bedrock, whileⁱⁿ the distal gravels^{they} are distributed more regularly in the gravels.
- The pothole is a particularly favourable trap site for kimberlitic minerals in the +1 mm fraction.

Studies of much larger sample population are required if these are to be substantiated.

8 THE DIAMONDS

8.1 INTRODUCTION

It is widely accepted that diamond (> 1 mm in diameter) is a xenocryst in kimberlite and lamproite and that the magmas, which gave rise to these rocks, transported diamond from 150-200 km depth. Chemically, diamond is carbon in an exceptionally pure form. The only foreign element commonly present is nitrogen, which may amount to as much as 0.5 wt % (Sellschopp et al., 1980). Any other foreign elements will be only parts in a million. Diamond is chemically inert in the surficial environment, and hydrofluoric acid can be used to clean its surfaces.

The lattice of diamond is exceptionally strong, which results in its extreme hardness (10 on the Mohs scale) and resistance to deformation. An important property of diamond is its extreme resistance to abrasion: sapphire wears 5000 times more readily than diamond and spinel about 20,000 times (Bruton, 1981). Diamonds can survive several cycles of reworking and deposition. They are able to undergo the extreme conditions existing in a high energy environment such as flash flood. However, diamond is brittle and will shatter if submitted to impact.

Diamond is not particularly dense, its specific gravity ranging from 3.514 to 3.518 (except carbonado which may have a specific gravity as low as 2.9 depending on the impurities it contains). However, diamond behaves like heavier minerals such as ilmenite (specific gravity 4.5-5) because of its hydrophobic nature which makes it extremely slippery in a liquid environment (Rouffaer, 1988).

Diamond value is determined by its classification as industrial or gem quality. Industrial diamond value is determined on such factors as weight, hardness, impact resistance and grain angularity. Gem diamond value is based mainly on weight (number of carats), colour, clarity and the possibility of cutting without losing too much weight. It is noteworthy that the price per carat of gem quality diamonds will increase very rapidly with increase of the weight of the stone (Fig. 20).

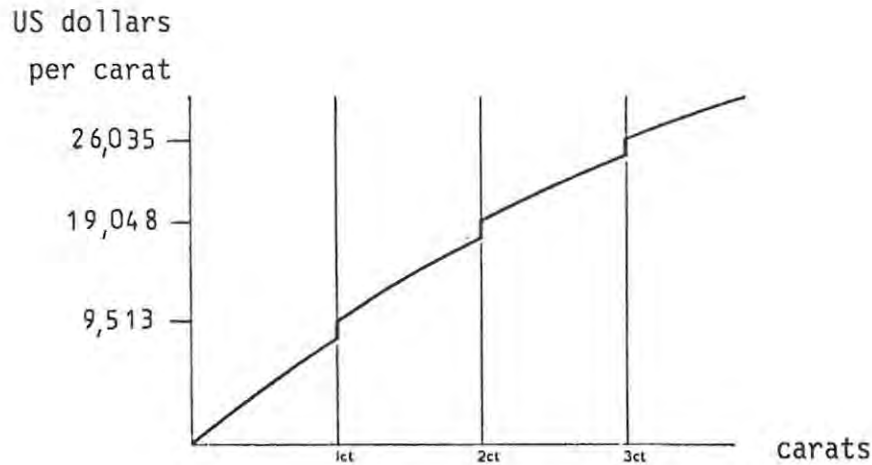


Fig. 20 Weight of diamonds versus prices in US dollars (quality VVS1-E, December 1989). The prices per carat rise in steps.

8.2 CHARACTERISTICS OF THE DIAMONDS

Little information is available concerning the individual characteristics of the diamonds. According to Wagner (1914), the diamonds of the Vaal River show a great variety of shape, size and colour. Broken stones are the most common. Octahedra, rhombododecahedra and macles are also frequent. Octahedral and hexoctahedral habit predominate among the larger sizes, while among the smaller diamonds dodecahedral crystals are generally in evidence. Cracked stones are very rare because of their destruction in the violent processes of river action. A considerable proportion of the alluvial diamonds shows signs of wear (edges and corners abraded). A few bort are also found. A high proportion of diamonds of all size ranges is colourless or slightly yellowish (Photo 27). Brown, green, pink and yellow coloured stones make up the remainder.

8.3 RELATIONSHIP BETWEEN DIAMOND DISTRIBUTION AND GEOLOGICAL PARAMETERS

The diamonds in the Lower Vaal Basin have been worked by thousands of private diggers for more than a century and the reconstruction of their distribution may appear a difficult task. However, three sources of information are available: the previous literature, the compilation

of production data, and the present-day diggings.

8.3.1 Previous literature

On the whole, the alluvial diamonds in the lower Vaal River were markedly superior in quality to the average product of the kimberlitic occurrences. In 1912, for instance, the price per carat for the alluvial diamonds in Griqualand West was three times higher than the price per carat given for diamonds of the De Beers kimberlite (Wagner, 1914). Several large stones have been discovered in the alluvial gravels (Table 7). It is noteworthy that five of the biggest

Table 7 The largest (more than 100 carats) diamonds recovered in the study area (Compiled after Wagner, 1914; Beet and Terpend, 1917; Williams, 1932).

Year	Carats	Farm	Name of the diamond
1872	288 3/4	Waldeck's Plant	Stewart
1891	205 1/2	Good Hope	Litkie
1907	121 1/2	Gong-Gong	Otto Bergstroom
1908	337	Delpoortshoop	Bob Gove
1911	206 1/2	Niekerk's Rush ¹	Fineberg-Jones
1913	272 1/2	Niekerk's Rush	-
1913	269 1/2	Longlands	Harry Young
1916	192 1/2	Gong-Gong	Dan Campbell
1921	381	Gong-Gong	The Arc
1924	135 1/2	Gong-Gong	-
1924	110 1/2	Gong-Gong	-
1928	282	Good Hope	-

stones were found at Gong-Gong. This probably reflects the favourable bed roughness of this area. Wagner (1914) noted that the diamond diggers were particularly interested in gravels with "bantams". "Bantams" (from the Dutch term "bandom" meaning "band around") refers to a very well-rounded, banded metamorphic pebble containing about fifty percent or more of spessartine, the rest being quartz, chlorite and andalusite (Wagner, 1914). Its association with the diamond in the

1. Niekerk's Rush is situated on the opposite bank from Longlands.

gravel is due principally to its specific gravity, which varies between 3.2 and 3.4. The term has, however, been extended to pebbles of any heavy rock or mineral like banded ironstone, hematite and corundum, and may be taken as synonymous with accompagnator minerals.

8.3.2 Compilation of production data

Methods : Annual production data have been compiled for seven farms (Appendix 4). The production figures have been collected mainly from the archives of the Barkly West Museum (1926 to 1931) and from the Minerals Bureau of South Africa in Johannesburg (1936 to 1964 and 1984 to 1988). The diamond production is recorded as total carats, and pound (pre-1961) or rand values per month, per farm. Pre-1961 pound values have been converted to rands using the conversion of £1 = R2. Inflation indices and the current fluctuation of the Rand-Pound exchange rates have not been accounted for. No information concerning the size, value or type of individual stones is recorded in the registers. The grade and spatial distribution of the diamonds is also unknown.

Results : Consideration of the production data shows distinct differences within the diamondiferous alluvial gravels from Good Hope to the Vaal-Harts confluence. The diamond values of the Good Hope and Bad Hope Farms are difficult to interpret in terms of relationships with the sedimentology because they were derived from both the Older and Younger Gravels.

In order to gain an overall impression of the variation in value from farm to farm, the value per carat has been plotted in Figure 21. This shows that there is a tendency towards diminution of value per carat of the diamonds in a downstream direction. The diamonds emanating from the Gong-Gong farm have the highest average value per carat. On the contrary, the diamonds in the Delpportshoop and Sydney farms show a lower average value per carat. Over a so short distance, one can make the hypothesis that the quality of the diamonds did not increase with the distance of transport and that the controlling factor was an average decrease of the diamond size. The author believes that this diminution in size of the diamonds in a downstream direction was probably controlled by two factors:

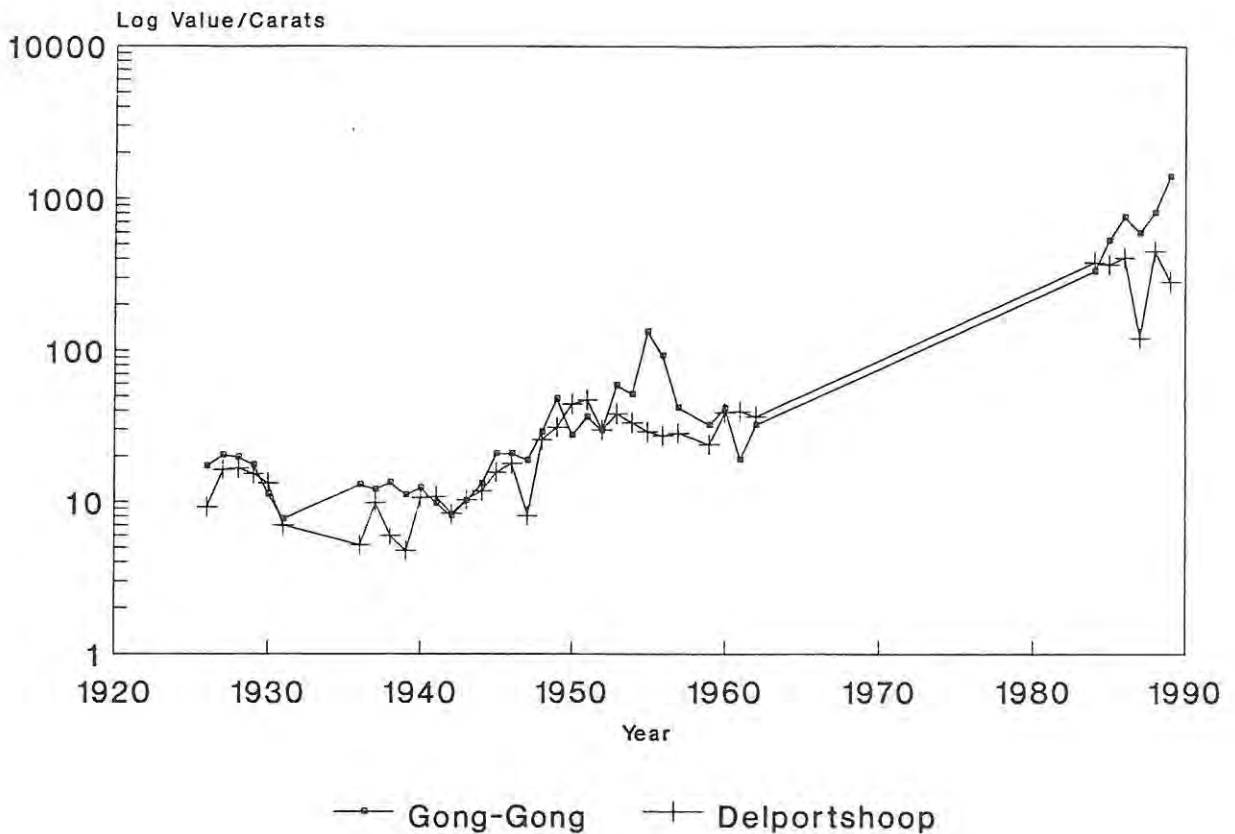


Fig. 21 Value per carat (Rand/carats) for the farms Gong-Gong and Delportshoop since 1926.

a) Irregularities in the bedrock and well-channelized part of the river played a major role. Potholes and natural riffles have a large local trapping influence, which tends to complicate the level of predictability in respect of diamond accumulation and size distribution. These features are particularly abundant in the Gong-Gong area and this may account for the high value per carat on this farm.

b) The diminution in stream velocity downstream, which is reflected by the average diminution in size of the clasts, involved a sorting effect in size of the diamonds. The smaller diamonds were transported farther because less energy is required for their mobilization.

8.3.3 The present-day diggings

The Younger Gravels that remain today are still actively mined for diamonds. According to Helgren (1979) yields are apparently less than 1 carat per 30 tons. The diggers' pits range in size from the traditional 15 x 15 yard "claim" to larger units where eight or more claims have been combined. Nearly all the diggers move erratically from one site to another, following their intuition.

Diamondiferous pay-ore is usually difficult to distinguish from barren gravel. Features such as colour of the pebbles (e.g white gravels at Delpportshoop), eventually proved to be false indicators due to the fact that the coloration is a secondary characteristic associated with pal eo-watertables. In the old times, the diggers recovered the diamonds by digging galleries in the gravels, following the "run" and correcting continuously the direction. This method being extremely dangerous and involving the rapid despoliation of the diamond deposits, the present-day diggers must excavate the all overburden in order to recover the diamonds. Several diggers were using the old galleries as a tool to orientate their diggings.

The experience gained by the author concerning the distribution of the diamonds is reviewed here:

- The single most important factor contributing to the concentration of the diamonds is the presence of bedrock irregularities. Potholes are undoubtedly the best trap site for diamonds. They generally contain large stones. Riffles, crevices and basins are also excellent trap sites. The abundance of these features at Gong-Gong may account for the high production on this farm.
- The diamonds are generally found in a high energy environment. There is a positive correlation between the size of the clasts and the size of the diamonds. Higher grade deposits have large boulder-size material and are poorly sorted. A similar relationship has been noted by several authors elsewhere in South Africa (Van Wyk and Pienaar, 1986; Rouffaer, 1988; Marshall, 1988). However, this relationship seems to be area specific, and the occurrence of significant proportions of barren samples even in coarse gravels means that gravel calibre is only to be taken as indicative of,

rather than predictive of, grade.

- The diamonds are generally found in well-channelized parts of the river. Where the channels are very large and the clasts relatively small, the gravels contain uneconomic quantities of small-size diamonds (e.g. station 35 at Sydney-on-Vaal).
- Due to its higher relative density and to the process of entrainment sorting, relatively high diamond grades and larger stones are often found close to bedrock. However, the diggers often work the entire gravels because small size stones are generally present. This suggests that the smaller diamonds were transported in suspension in a high density fluid and deposited during waning flow as part of a matrix which filtered into the pores of the gravel framework.
- During recovery the presence of large quantities of heavy minerals in the concentrate augurs well for the concentration of diamonds.

8.4 ORIGIN OF THE DIAMONDS

8.4.1 Introduction

Two main *hypothesis* have been proposed as a possible explanation for the origin of the diamonds in the gravel of the lower Vaal Basin. The first hypothesis suggests that the diamonds are derived from pre-Karoo kimberlites via the Dwyka tillites (Harger, 1909). The second hypothesis suggests a direct derivation from Cretaceous kimberlites (Wagner, 1914). The origin of the diamonds is difficult to ascertain because of the exceptional abundance of possible sources in the area. However, some reasonable speculations can be entertained.

8.4.2 The diamonds derived from the Dwyka tillites.

The Dwyka tillite has been suggested by Harger (1909) as a possible source for the alluvial diamond deposits. This author points out that the diamond-bearing gravel generally occur in areas where the Ventersdorp andesite is associated with the overlying Dwyka tillite. He suggests that tillite may locally contain low-grade diamonds that can be reworked by post-glacial rivers into economically

valuable placers. Rouffaer (1988) also emphasized that the Dwyka tillite is locally diamondiferous (e.g. at Bosluispan and Somabula Forest) and advocated that the grinding action of the moving ice together with the dissolution of chemically unstable minerals by intrastratal solutions, resulted in a tremendous reduction in volume and reconcentration of the resistant minerals. He suggested that the diamonds contained in Tertiary and Quaternary placers that occur offshore on the continental shelf of South Africa and Namibia have been derived from the dissection and reworking of low concentration of diamonds in the Dwyka tillite .

The gravels are partly derived from the tillite and the implication is that the diamonds may be as well. However, the author does not favour a derivation of the diamonds via tillites in the study area for the following reasons:

- Subglacial meltwater created a highly effective sluicing system and would have left lucrative pay zones along meltwater-cut channels on bedrock benches, in intraformational gravels in lodgement till and in "lee-side" down-ice of bedrock highs. However, enriched zones of diamonds have never been found in the tillites.
- According to Rouffaer (1988), the transport of diamonds by ice action results in scratching of the diamonds. To the author's knowledge, such scratching has never been described from the Vaal River diamonds.
- The presence of diamonds in a piece of Dwyka tillite has never been observed in the study area.

8.4.3 The diamonds derived from Cretaceous kimberlites.

Wagner (1914) emphasized that the diamonds of the lower Vaal River show many similarities with the diamonds of local kimberlitic pipes. According to him, a large number of stones clearly were derived from the primary deposits of the Kimberley and Barkly West District.

The following features support this hypothesis:

An investigation of the depth of formation of kimberlite sills,

supplemented by geochemical and diagenetic studies of sedimentary rocks of the Karoo Sequence, suggests that the amount of erosion which has taken place in the Kimberley area since the emplacement of the kimberlites (about 90 Ma ago) has been approximately 1400 m, a net rate of 15.6 m/Ma (Hawthorne, 1975). According to Marshall (1985), the Big Hole of the Kimberley pipe yielded after 44 years of mining, 14.5 million carats. Mining terminated at a depth of 1098 m. Gurney (1989) stresses that many kimberlite pipes and dykes show little or no decrease in grade over considerable vertical depths. Thus, one can broadly estimate that 18.5 million carats have been released by weathering since the emplacement of the Big Hole kimberlite. During this erosion, in excess of 50 Mcar of diamonds had been released from the five kimberlite outcrop areas at Kimberley, and became widely dispersed in the surrounding areas. This is five times the estimation made by Sutherland (1985) concerning the entire recovery of alluvial diamonds in the Vaal River basin.

Both from records of offshore sedimentation (Dingle and Hendey, 1984) and from onshore evidence (Partridge and Maud, 1987), there is indication that the major part of the erosion occurred in the period immediately following rifting (Cretaceous). This is partly due to the high level of the interior of South Africa and partly to the more humid climate during that period. By end-Cretaceous to early Tertiary times, the subcontinent had been reduced to a vast peneplain punctuated at infrequent intervals by koppies and high-lying massifs. The amount of erosion was of the order of 1650 m in parts of the Harrismith area and about 1200m in the Kimberley area (Partridge and Maud, 1987). At the end of this cycle, elevations in the interior were of the order of 500-700 m above sea level (Partridge and Maud, 1987). Thus it is probable that an important part of the diamonds from kimberlites in the Kimberley area was released during late Cretaceous and early Tertiary times.

The effect of various erosional cycles of transport and reworking was to concentrate the more resistant minerals. Poorer quality diamonds such as bort, diamonds with inclusions or cracks, and cleavage stones were destroyed preferentially, increasing continuously the average diamond quality. The longer the duration of this process (in space and time) the better was the quality of the diamonds.

In the final stage, older sediments acted as the main source for the diamonds of the Younger Gravels. The diamonds were colluvially derived from hillslopes because of the high gradient which facilitates their reworking. The most likely source to have supplied the Younger Gravels is the derived Older Gravels.

9 EXPLORATION FOR ALLUVIAL DIAMOND DEPOSITS

9.1 INTRODUCTION

The search for alluvial diamond deposits has often been considered simply a matter of luck. Exploration was conducted by skilled prospectors wildcatting erratically and choosing sites largely on intuition. When the returns were too low, the prospect was abandoned and prospecting was resumed elsewhere. This method often led to the premature despoilation of the placer. Only for a few decades, have scientific methods of stream sediment analysis and geomorphic studies been applied.

There is an important difference between searching for diamonds in kimberlites and in alluvial deposits. In the first case, soil and stream sediments are sampled with the purpose of finding the so-called indicator minerals such as pyrope garnet, micro-ilmenite, chromite, chrome diopside and micro-diamonds. In favourable areas, the indicator minerals can be traced back to the kimberlitic source. In the second case, diamond is searched for directly in the alluvium. Alluvial diamond deposits can be completely devoid of indicator minerals.

Although recent explorations have been mostly directed towards the search for primary hostrocks which are more likely to offer long-life mines, exploration for alluvial diamond deposits offers scope for several reasons:

- Diamondiferous alluvial deposits may be economic at a much lower grade than the primary hostrock deposits because of their generally better diamond quality and their incoherent matrix.

- The increased price of diamonds in the last decade has made exploitation of low grade and more-difficult-to-mine deposits economical.
- The relatively low capital expenditure on exploration, mining and dressing, makes the placer deposit an attractive exploration target, even if, relative to primary deposits, *it has* an appreciably smaller content of useful minerals.

The exploration programme can be aimed at finding new deposits; in other cases it involves locating new channels for testing in already-known drainage system. The following sections aim to give guidelines which can be used in the exploration programme.

9.2 REGION SELECTION

The first step in the exploration programme is the choice of a geomorphic situation conducive to the genesis of fluvial diamond deposits. Creation of mental pictures of the setting of diamondiferous placers, before they are discovered, is the most challenging part of the discovery process. Such models must not become rigid and inflexible, but must be subject to continual improvement to allow changes in direction. The following factors must be taken into consideration: a favourable tectonic setting for the formation of alluvial diamond deposits, the paleoclimatic history of the area, the record of erosion over ^asignificant time scale, and the stability of the drainage basin.

Favourable tectonic settings for diamondiferous kimberlites are old cratons (>2.5 Ga), while diamondiferous lamproites are generally located in circumcratonic, early Proterozoic belts. The secondary dispersions tend to be superimposed on the primary pattern and are closely associated with stable continental cratons (Fig. 22). Consequently, cratonic areas will be the top priority prospecting areas. It would be unwise, however, to confine alluvial diamond exploration entirely to the cratonic area. Diamonds can travel for a long time and over great distances. They can survive sedimentary recycling many times. The presence of small quantities of diamonds far from cratonic area is therefore not at all surprising (e.g. Thailand).

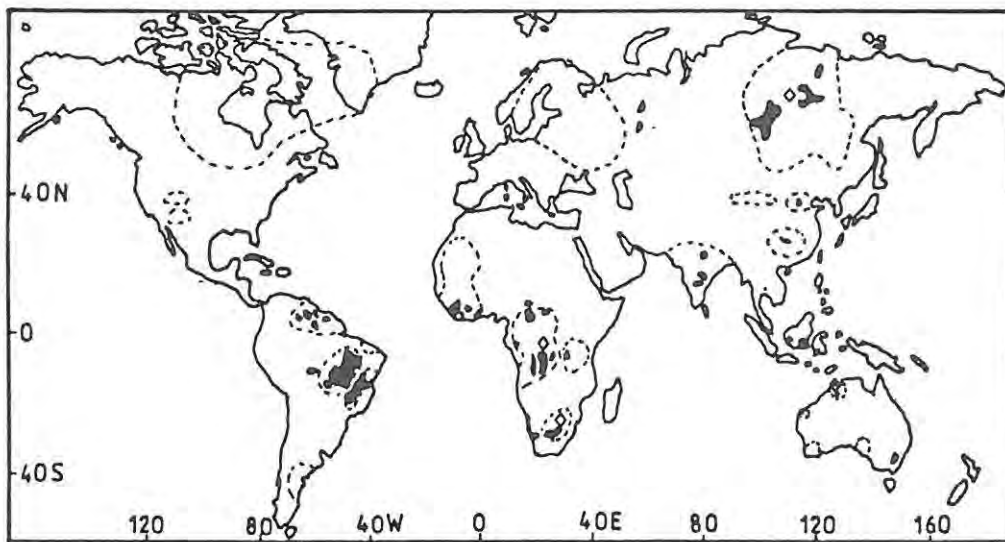


Fig. 22 World map of significant alluvial diamond deposits (solid black). Dashed lines represent cratonic areas (modified after Sutherland, 1985).

It must also be emphasized that many alluvial diamond fields have never been related to a primary source. Examples include most of the alluvial diamond fields in Brazil, which are thought to be derived from lower Proterozoic to Quaternary sedimentary layers (Tompkins and Gonzaga, 1989), and the diamond fields of Ghana, in which the provenance of the diamonds is related to the reworking of Lower Proterozoic/Archaean greywackes (Applin, 1972). According to Bardet (1973), the Cretaceous period was very favourable for the formation of alluvial placers because of the abundance of kimberlite intrusions and the more humid climate. Many present-day placers may have been derived from the destruction and reconcentration of these deposits.

The possibility of finding economic concentrations of diamonds in lithified conglomerate analogous to the Witwatersrand braided stream deposits must not be excluded. Such deposits could provide low-grade but long-life mining targets. Mitchell and Garson (1981) point out that the characteristic features of these sedimentary basins are that they contain thick successions of dominantly shallow-water terrigenous sediment and rest unconformably on a basement of metamorphosed continental rocks. They suggest that many of the basins formed in intracontinental rift-related settings, while others are possibly

remnants of successions deposited in depressions either between, or on the flanks of intracontinental swells and their associated grabens. Preservation potential for such deposits will be found within Archaean or early Proterozoic cratons which have not suffered subsequent rifting, fragmentation and collisional orogenies. Another potentially viable exploration target could be a coarser equivalent of the diamondiferous sandstone at the base of the Elliot Formation in north-east Swaziland (Turner and Minter, 1985). Diamond grade in the sandstone ranges from 2 - 6 car./t. with stone weight averaging 0.008 carat. Here also, the palaeoenvironment was a braided stream system.

The palaeoclimatic history of a region controls the dominant landforming processes that may favour or preclude diamond enrichments. Figure 22 shows that except for the Siberian, Ural and South African placers, the majority of alluvial diamond deposits are found in humid tropical areas.

In humid tropical climate, chemical weathering causes breakdown of the less resistant components in alluvium, with consequent upgrading of the diamond content (Hall *et al.*, 1985; Thomas *et al.*, 1985). Mining activity has probably already worked out most of the colluvial and shallow fluvial deposits of humid tropical regions. However, lack of the requisite technology precludes mining in channels deeper than 4-5 m. New exploration targets should be concentrated in areas of provenance having history of deep weathering and high relief. In such circumstances, significant placers may have been formed and covered by later, barren sediments.

In semi-arid and arid climate, fluvial processes may be more effective in transporting heavy minerals than in reworking and concentrating them to a level of economic interest (Sutherland, 1985). However, preservation of fluvial terraces formed during a more humid climate may prove a prime target for diamond exploration. Arid and semi-arid areas are more difficult to investigate for diamonds, because of the scarcity of mineral concentrations in present-day rivers and the obscuring cover of desert sands and calcrete. Under such conditions, many diamond fields could remain to be discovered in abandoned palaeochannels.

Cold, non-glacial climatic regions (e.g. Siberia) are characterized by

a thin "active" soil layer and limited vegetation cover. Weathering is dominated by mechanical processes with little formation of silt and clay (Sutherland, 1985). A brief period of highly concentrated fluvial activity, during seasonal snow melt, favours multiple reworking of the diamonds. Rich placer deposits may be formed where the periglacial fluvial system has intersected earlier sediments formed during milder climatic conditions (Prokopchuk, 1967).

Humid temperate, glacial or very arid climates are not favourable for the formation of placer deposits (Sutherland, 1985).

The extent of erosion of the primary hostrock governs the amount of diamonds released to the drainage system. The level of erosion can be broadly estimated by applying the model of the depth of sill intrusion (Mudge, 1968), the model of the depth of kimberlite pipe intrusion (Hawthorne, 1975) and by correlation with offshore sedimentation (Dingle *et al.*, 1983). Cratonic areas which have experienced a major uplift during the last 100 Ma must be a primary target in the exploration programme. Particularly favourable conditions are created when cratonic areas are tilted so that diamonds are transported in one direction rather than being dispersed in many directions when ^{the} area is simply uplifted. Rapid sedimentation of coarse material in areas of cratonic downwarp or during periods of marine on-lap is of further significance for placer formation (Sutherland, 1985). Such sediments frequently contain low-grade diamond concentrations over very large areas. Examples include the Precambrian Roraima Formation on the Guyanan Shield in northern South America (Bardet, 1977), the Jurassic sediments of western Siberia (Prokopchuk, 1974) and the Cretaceous Kwango Series of Angola and Zaire (Fieremans 1955, 1961). Subsequent uplift of such sedimentary covers results in their erosion and the reconcentration of the diamonds, often at a considerable distance from the primary sources. Cratonic areas which have been intermittently eroded by glaciation and repeatedly intruded by diamondiferous kimberlites are particularly favourable for the concentration of diamonds. In Brazil, for example, Tompkins and Gonzaga (1989) have shown that the major events related to diamond transport and concentration are associated with three different glaciations.

The stability of the drainage system will control whether the diamonds have been spread widely in the landscape or whether they have been

transported in one direction for a long period. Carefull interpretation of geographical maps and remote sensing images (Landsat and panchromatic aerial photographs) may provide useful data about the ancient drainage patterns, river capture and abandoned terraces. Buried channels may sometimes be identified from changes in vegetation along the course of underground streams or from thermal scanning (Mc Donald, 1983). Such investigations of the watershed stability can save large sums spent in sampling too early without understanding of the processes of diamond transport and deposition.

Unfortunately, geological considerations are not the only criteria to be considered in selection of a favourable area. **Taxation and political factors** often act as significant deterrents or incentives to new exploration programmes and mining operations.

9.3 RECONNAISSANCE SURVEY

The objective of the reconnaissance phase is to locate a maximum of anomalies worth examining in a later phase.

The first step is the recognition of zones where diamonds are likely to be concentrated by mechanical processes (rock barriers, change of slopes, terraces in semi-arid areas etc.). Target selection can be rapidly obtained by using air-photos, satellite images and geological maps in conjunction with previous geological reports and surveys. Goosens (1980) suggested that the best approach for large areas is to prepare a preliminary topographic map with contour levels and drainage patterns, and then superimpose the information from remote sensing.

Panning stream sediments has been used for exploration for hundreds of years. This method is still of great value when used by a person experienced in alluviation processes. Diamonds necessitate higher volumes of sample than other minerals due to their low and random concentration with very rich concentrations locally (the so-called nugget effect). For example, if one considers a gravel grade of 0.1 ct/m³ (according to Helgren (1978), this value is already higher than the grade found in the Younger Gravels), in which the stones have an average weight of 0.50 ct, giving two stones for one carat. Statistically, to find one stone it is necessary to treat 5 m³ of

gravel. Prospecting samples of 1 m³ would have:

- 81.87% chance of finding 0 stone;
- 16.37% chance of finding 1 stone;
- 1.64% chance of finding 2 stones;
- 0.001% chance of finding 3 stones.

As a rule of thumb, the more a gravel is reworked, the more diamonds are concentrated, allowing for easier detection. The initial reconnaissance samples took place in the main rivers and subsequent sampling proceeded upstream. Pitting and small diameter drilling have the advantage of mobility, so that the ground can be covered more rapidly than by bulk sampling. The following criteria are important:

- Sampling must be carried out at the optimal concentration points for diamonds: potholes or gravel-filled depressions in the stream bed, the plunge pool near the base of waterfalls, riffles, crevices, rock barriers, basal gravel accumulation and boulder bars. In a meandering river valley heavy minerals tend to be concentrated at point bars and chute bars.
- Samples are preferentially taken upstream from a confluence. In order to provide an average sample of the deposit, it is best to take two or three samples at intervals of a few metres (Chaussier and Morer, 1981). Spacing between samples is approximately 1 km in accordance with the geology of the region.
- A change of slope is a clear first-order control of the diamond deposition, the best concentration lying just downstream of the higher gradient. River drainage with marked seasonal rainfall is favourable for multiple reworking and upgrading of the diamonds.
- The abundance of the so-called accompanying minerals (e.g. corundum, staurolite, zircon etc.) in the sample give an idea of the concentration of heavy minerals at a particular point of the river and may be locally a good indicator of the presence of diamonds.

In favourable cases, the presence of large quantity of large-sized particles of kimberlite-derived ilmenite and pyrope garnet minerals may also indicate good concentrating conditions for alluvial diamond

deposits (Lord, 1976).

Microdiamonds (diamonds less than 0.5 mm size) in the alluvial and sedimentary record will become increasingly important exploration guides. The crystal size and quality can provide valuable information about the dispersion and concentration processes around a source (Gregory and White, 1988).

The relationships between the nature of the bedrock and the concentration of diamonds is often a determinant factor. The presence of bedrock irregularities is a primary factor controlling diamond concentration. In the Central African Republic, Bardet (1973) noticed that better concentration of diamonds occurred on argillite rather than on sandstone while Sutherland (1984a) points out that potholes occur preferentially at joint intersections on sandstones. In South Africa, potholes seem better developed in massive rocks such as granite and andesite than schist. Limestone and dolomite are particularly favourable (e.g. Lichtenburg deposits).

There is a fundamental difference between exploration in humid tropical and semi-arid climate:

The humid tropical climate is dominated by chemical weathering and deep bedrock decomposition which results in relatively thin surface accumulations of the most resistant minerals, principally well-sorted quartz (Applin, 1976). Active stream beds are enriched in diamonds as a result of the intense reworking processes. The gravels lie on weathered bedrock decomposed to a soft clayey material. Caution must be exercised in sampling this weathered bedrock which may conceal valuable concentrations of diamonds. The tropical alluvium is soft, loose and waterlogged.

Semi-arid weathering is dominated by mechanical rather than chemical break-down of rock, resulting in thick accumulation of polymictic gravel. Recent river deposits are generally poor in diamonds, but remnants of earlier river terraces of principally Tertiary age are the main diamond hosts. The diamonds are generally better concentrated in the coarser and poorly-sorted gravel. However, the upper terraces may have reconcentrated the diamonds by surficial and colluvial processes. In this case, the well-sorted gravel will be the more

enriched in diamonds (e.g. derived Older Gravels in the lower Vaal Basin). The bedrock is hard and creviced, with best diamond values occurring in potholes. Alluvial fans and floodplains may result in little concentration, with grade tailing off rapidly downstream (e.g. Argyle). A relatively narrow valley and high gradient are more favourable. Semi-arid gravels are often calcretised and hard. Where deposits are covered by wind-blown sand and calcrete, the use of a single channel refraction seismograph with hammer impact may give valuable information about the thickness and relative coarseness of alluvial layers above the bedrock. This method is quick and inexpensive.

In exploration a total recovery of the diamonds is essential. The loss of a single stone during the reconnaissance phase could jeopardize the entire survey. This security problem has been largely discussed by Applin (1976).

9.4 GENERAL PROSPECTING

The objectives are to make a broad determination of the extent and tenor of the mineralized deposit and to gain an understanding of the genesis of the placer that can be used as a control for further sampling.

Any encouraging results obtained from the reconnaissance stage should be followed up with detailed **sedimentological work**. Quantitative data regarding the stratigraphy, geometry, composition and paleocurrent directions are necessary in order to develop a predictive model of facies variation and provenance of the clasts.

Pitting, trenching and large diameter drilling to take samples near the bedrock and mineralized horizons will give a first estimation of the diamond content of the sediments. A successful method used in Sierra Leone for sampling buried gravels to a depth of 12 m is to employ a triple boom Poclain excavator equipped with a clamshell grab about 1 m in diameter (Gregory and White, 1988).

Use of high resolution **geophysical techniques** may prove useful to delineate buried targets. Seismic refraction, electrical logging,

resistivity and magnetic techniques are occasionally of value. Davis et al. (1987) recommend the use of ground probing radar (GPR) in conjunction with seismic surveying. Ground probing radar can be used to obtain a high resolution map of the bedrock and soil strata to 30 m depth in coarse grained materials. Seismic refraction methods can map stratigraphy to much greater depths but with lower resolution than the radar method. A precise knowledge of bedrock topography and subsurface stratigraphy greatly improves effective placing of test boreholes and pits.

Important factors having a bearing upon decision-making at the prospecting stage are availability of water for mining and treatment, climatic conditions, access roads, infrastructure and thickness of the overburden.

9.5 EVALUATION

The evaluation phase is directed towards locating and delineating ore reserves, plus calculation of the in situ worth of the gravels. The problem of estimating the grade of diamond placers is notoriously complex owing to the uneven distribution of the diamonds in the deposit, the high unit value and the very low concentration. For example, Applin (1972) points out that the operating cut-off grade in Sierra Leone is about 35 times lower than in Ghana. Sutherland (1984 b) showed that the majority of economic alluvial diamond deposits fall in the 0.1-10 st/m³ and that at least 5,000 carats are needed for valuation. To be effective, sample quantity must be large, which may involve the excavation and treatment of several hundred to several thousand tonnes of material.

Applin (1972) noticed that there is a tendency to undervalue during prospecting. In Ghana and Sierra Leone mining recoveries were 110% and 130%, respectively, above quantities estimated by prospecting. This has been attributed to the presence of pay-patches of much higher grade than the deposit average and to errors in the determination of volume. Diamond size distributions are close to log-normal in alluvial deposits (Sichel, 1972) and specific statistical techniques have been devised for grade and revenue calculation (Oosterveld, 1972; Phillips, 1974 and Oosterveld et al., 1987). For an important mining company

targets will obviously require large reserves but since diamond recovery techniques are relatively simple, some operations can be planned by gradual expansion from bulk sampling, to pilot plant, to full scale.

10 CONCLUSIONS

A combination of favourable circumstances has led to the formation of lucrative alluvial diamond deposits downstream of Barkly West. The controlling factors range over a wide variety of scales:

On a large scale, tectonic setting and palaeoclimate have played a critical role. The cratonic area and the favourable deep fissure pattern controlled the abundance of kimberlite intrusions in the area. The more humid climate during late Cretaceous to early Tertiary times provided the right conditions for rapid erosion of the kimberlites and the release of the diamonds. During late Tertiary to Quaternary times, climatic variations probably played a major role in the cyclic downcutting of the Vaal River and subsequent deposition of the terrace gravels. The diamondiferous placer formation was favoured by prolonged sediment reworking causing heavy minerals concentration, while transporting other sediments downstream.

On an intermediate scale, the break in slope in the river profile after Barkly West provided the high energy conditions for the concentration of diamonds. Braiding was favoured by the slight decrease in the gradient after the Gong-Gong falls. The clasts were colluvially derived from hillslope or eroded from the bedrock.

On a small scale, bedrock irregularities were the most important factor controlling the deposition of the diamonds. Features such as potholes, bedrock depressions and riffles provided potential sites for diamond pay streaks. Channel widening and bedrock contact were primary features for the concentration of the diamonds. Spatial variation in diamond grade was controlled by gravel calibre which was itself dependent on the energy of the flow.

The model proposed for the origin of the diamonds in the lower Vaal Basin involves a long and complex process of erosion, reworking and concentration. Most of the diamonds were released from Cretaceous kimberlites during late Cretaceous to early Tertiary times when the climate was more humid and the area at 1800 m altitude. The multiple reworking of the diamonds continuously increased their quality by destroying diamonds with flaws and inclusions. In the final stage, the diamonds were colluvially derived from hill-slopes and re-concentrated in the Younger Gravels. The more likely final source is the derived Older Gravels.

Undoubtedly, exploration programmes will increasingly focus on isolated areas with lack of exposed alluvial sediments and thicker surficial overburden. Future exploration will increasingly focus on low grade but long-term mining deposits.

It is hoped that the facts elucidated in the course of this thesis and the suggestions that have been advanced as to the origin of the alluvial diamonds in the Barkly West District will form a basis for further detailed work.

REFERENCES

- APPLIN K.E.S., 1972: Sampling of alluvial diamond deposits in West Africa. Trans. Instn. Min. Metall. (Sect. A: Min. industry), 81, A62-77.
- APPLIN K.E.S., 1976: Exploration for alluvial diamond deposits. In: A short course on placers, exploration and mining, University of Nevada, USA.
- ARMSTRONG R.A., RETIEF E., COMPSTON W. & WILLIAMS I.S., 1990: Geochronological constraints on the evolution of the Witwatersrand Basin, as deduced from single zircon U/Pb ion microprobe studies. Abstracts Geocongress 90. Geol. Soc. S. Afr., Cape Town, 24-27.
- ATKINSON W.J., 1989: Diamond exploration philosophy, practise and promises: a review. In: Kimberlites and related rocks, Vol. 2, Geol. Soc. Austr. Special Publ. n° 14, 1075-1107.
- ATKINSON W.J., SMITH C.B. & BOXER G.L., 1984: The discovery and geology of the Argyle diamond deposits, Kimberley, Western Australia. Proc. Australas. Inst. Min. Metall. Ann. Conf., Darwin, Aug. 1984, 141-149.
- AXSEL K., 1988: Operating diamond mines in the Republic of South Africa, 1988. Department of mineral and energy affairs, minerals bureau, directory D 7188, 28pp.
- BARDET M.G., 1973: Géologie du diamant. Première partie: Généralités. Mémoires du B.R.G.M. No. 83, 235pp.
- BARDET M.G., 1974: Géologie du diamant. Deuxième partie: Gisements de diamants d'Afrique. Mémoires du B.R.G.M. No 83, 229pp.
- BARDET M.G., 1977: Géologie du diamant. Troisième partie: Gisement de diamants d'Asie, d'Amérique, d'Europe et d'Australasie. Mémoires du B.R.G.M. No 83, B.R.G.M. ed., Paris, 169pp.
- BEET G. & TERPEND T.L., 1917: The romance and reality of the Vaal diamond diggings. Diamond Fields Advertiser. Limited Kimberley, 118 pp.

- BERGMAN S.C., 1987: Lamproites and other potassium rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. In: Alkaline igneous rocks. Geol.Soc.Spec.Publ.n^o 30, Fitton J.G. and Upton B.G.J ed., Blackwell Scientific Publications, 103-190.
- BLATT H., MIDDLETON G. & MURRAY R., 1980: Origin of sedimentary rocks. Englewood Cliffs, N.J., Prentice-Hall, Inc., 782 pp.
- BLUCK B.J., 1967: Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: A study in the significance of bedding. Scott. J. Geol., Vol. 3 (2), 139-167.
- BRUTON E., 1978: Diamonds. 2nd ed., N.A.G. Press LTD, London ECIV 7 QA, 532 pp.
- BULL W.B., 1964: Alluvial fans and near-surface subsidence in western Fresno County, California: U.S. Geol. Survey, Prof. Paper 437-A.
- BULL W.B., 1977: The alluvial fan environment, Progr Phys. Geogr., Vol.1, 222-270.
- BUTZER K.W., HELGREN D.M., FOCK G.J. & STUCKENRATH R., 1973: Alluvial terraces of the lower Vaal River, South Africa: A reappraisal and reinvestigation. Jour. Geol., Vol. 81, 341-362.
- CHAUSSIER J.B & MORER J., 1981: Manuel du prospecteur minier, Bureau de recherches géologiques et minières. Manuel et méthodes n^o 2, 273pp, Orléans.
- CLIFFORD T.N., 1966: Tectono-metallogenic units and metallogenic provinces of Africa. Earth Plan. Sci. Lett. 1, 421-434.
- COETZEE J.A., 1978: Late Cainozoic palaeoenvironments of southern Africa. In E.M. Van zinderen Bakker (ed.), Antarctic glacial history and world palaeoenvironments, Rotterdam: Balkama, 115-127.

- COETZEE J.A., SCHOLTZ A. & DEACON H.J., 1983: Palynological studies and vegetation history of the Fynbos. In Deacon H.J., Henday Q.B. & Lambrechts J.J.N. (eds.), Fynbos palaeoecology: a preliminary synthesis, South African National Scientific Programmes Report 75 156-73.
- COOKE H.B.S., 1947: The development of the Vaal River and its deposits. Geol. Soc. S. Afr. Trans., Vol.46, 243-260.
- DARDIS G.F, BECKEDAHL H.R. & STONE A.W., 1988: Fluvial systems. In: The geomorphology of southern Africa, Moon B.P. ed., 30-56.
- DAVIS J.L., ANNAN, A.P. & VAUGHAN C., 1987: Placer exploration using radar and seismic methods. CIM Bulletin, Vol. 80, n° 898, 67-72.
- DAWSON J.B., 1970: The structural setting of African kimberlite magmatism. In: Clifford T.N. & Gass I.G. eds, African magmatism and tectonics, Oliver & Boyd, Edinburgh, 321-335.
- DAWSON J.B., 1987: The kimberlite clan: relationships to olivine lamproites and implications for upper-mantle metasomatism. In: Fitton J.G. & Upton B.J.G. eds, Alkaline Igneous Rocks. Geol. Soc. Lond. Spec. Publ. n° 30, 95-102.
- DAWSON J.B., 1989: Geographic and time distribution of kimberlites and lamproites: relationships to tectonic processes. In: Kimberlites and related rocks, Vol. 1, Geol. Soc. Austr. Special Publ. n° 14, 323-342.
- DE BEERS GEOL. DEPT., 1976: Diamonds. In: Mineral resources of the Republic of South Africa, C.B. Coetzee ed., 17-30.
- DINGLE R.V., SIESSER W.G. & NEWTON A.R., 1983: Mesozoic and Tertiary geology of southern Africa. A.A. Balkema, Rotterdam, 375pp.
- DINGLE R.V. & HENDEY Q.B., 1984: Late Mesozoic and Tertiary sediment supply to the eastern Cape Basin (S.E. Atlantic) and palaeo-drainage systems in southwestern Africa. Mar. Geol., Vol.56, 13-26.
- DU TOIT A.L., 1910: The evolution of the river system of Griqualand West. Trans. Roy. Soc. S. Afr., Vol.1, Part 2, 347-362.

- EYNON G. & WALKER R.G., 1974: Facies relationships in Pleistocene outwash gravels, southern Ontario: a model for bar growth in braided rivers. *Sedimentology*, Vol. 21, 43-70.
- FIEREMANS C., 1955: Etude géologique préliminaire des conglomérats diamantifères d'âge Mésozoïque au Kasai. *Mém. Inst. géol. Louvain*, 19, 224-293.
- FIEREMANS C., 1961: Origine et répartition de la minéralisation diamantifère au Kasai occidental (Congo) et dans le nord-est de la Lunda (Angola). *Bull. Soc. Belg. Géol.*, 70, 89-95.
- FOLK R.L., 1972: Experimental error in pebble roundness, determination by the modified Wentworth method. *Jour. Sed. Petrol.*, Vol. 42, 973-974.
- FOLK R.L., 1980: *Petrology of sedimentary rocks*. Austin, Tex.: Hemphill, 182 pp.
- FRAKES L.A., 1979: *Climates throughout geologic time*. Amsterdam, Elsevier, 384 pp.
- GARVIE O.G., 1981: The surface texture on pyrope, picroilmenite and chrome diopside from kimberlite. MSc. Thesis, Univ. of Capetown, 132 pp.
- GLASS J., 1977: Deep weathering of the southwestern Cape granite and Malmesbury Group: palaeoclimatic implications. *Tech. Rept. Joint Geol. Surv. Univ. Cape Town Mar. Geol. Prog.*, Vol. 9, 118-135.
- GOOSENS P.J., 1980: Programming modern mineral exploration survey, a field geology-oriented approach, *Memoires of the Institute of Geology, University of Louvain, Belgium*.
- GREGORY G.P. & WHITE D.R., 1989: Collection and treatment of diamond exploration samples. In: *Kimberlites and related rocks*, Vol. 2, GSA Special Publ. n° 14, 1123-1134.
- GURNEY J.J., 1989: Diamonds. In: *Kimberlites and related rocks*, Vol. 2, GSA Special Publ. n° 14, 935-965.

- HALL A.M., THOMAS M.F. & THORP M.B., 1985: Late Quaternary alluvial placer development in the humid tropics: the case of the Birim Diamond Placer, Ghana. *J. geol. Soc. London*, Vol. 142, 777-787.
- HALLAM A., 1981: Facies interpretation and the stratigraphic record, San Francisco, Freeman, 291pp.
- HAMILTON W. & KRINSLEY D., 1967: Upper Paleozoic glacial deposits of South Africa and southern Australia. *Geol. Soc. Amer. Bull.*, Vol. 78, 783-800.
- HARGER H.S., 1909: The occurrence of diamonds in Dwyka conglomerate and amygdaloidal lavas; and the origin of Vaal River diamonds. *Trans. Geol. Soc. S. Afr.*, Vol. 12, 139-158.
- HAWTHORNE J.B., 1975: Model of a kimberlite pipe. In: Ahrens L.H., Dawson J.B., Duncan A.R. and Erlank A.J., Eds., *Physics and Chemistry of the earth*, Pergamon, Oxford, Vol. 9, 1-15.
- HELGREN D.M., 1979: Rivers of diamonds: an alluvial history of the lower Vaal Basin, South Africa. The University of Chicago, Department of Geography, Research paper n°185, 399pp.
- JUNNER N.R., 1943: The diamond deposits of the Gold Coast with notes on other diamond deposits in West Africa. *Gold Coast Geol. Survey Bull.* 12, 54pp.
- LARSEN V. and STEEL R.J., 1978: The sedimentary history of a debris flow-dominated alluvial fan - a study of textural inversion. *Sedimentology*, Vol. 25, 37-59.
- LEEDER M.R., 1982: *Sedimentology process and product*. London: Allen & Unwin, 344 pp.
- LEOPOLD L.B. & WOLMAN M.G., 1957: River channel patterns, braided, meandering and straight. *U.S. Geol. Surv. Prof Paper.* 282-B.
- LINDHOLM R.C., 1987: *A practical approach to sedimentology*. London, Allen & Unwin, eds., 276 pp.

- LORD J.F., 1976: Placer mining evaluation, methods and applications. In: Placer exploration and mining short course, Mackay School of Mines, Nevada.
- MACDONALD E.H., 1983: Alluvial mining. Chapman and Hall, London, 508pp.
- MARSHALL T.R., 1988: The diamondiferous gravel deposits of the Bamboespruit, southwestern Transvaal, South Africa. In: Geomorphological studies in southern Africa, Dardis G.F. & Moon B.P., eds., A.A. Balkema/Rotterdam/Brookfield, 495-505.
- MARSHALL T.R., 1989: The alluvial diamond fields of the western Transvaal, South Africa: origin of diamonds and gravels. In: Kimberlites and related rocks, Vol. 2, GSA Special Publ. n^o 14, 1204-1214.
- MAYER J.J., 1973: Morphotectonic development of the Harts River valley in relation with the Griqualand-Transvaal axis and the Vaal and Molopo Rivers. Trans. Geol. Soc. S. Afr., Vol. 76, 183-194.
- MAYER J.J., 1986: Differential erosion of possible Kalahari aeolian deposits along the Vaal-Orange drainage basin and the upper reaches of the Harts River. Trans. Geol. Soc. S. Afr., Vol.89, 401-407.
- MCCANDLESS T.E., 1990: Kimberlite xenocryst wear in high-energy fluvial systems: experimental studies. J. Geoch. Expl., Vol. 37, 323-331.
- MEADOWS M.E., 1988: Landforms and Quaternary climatic change. In: The geomorphology of southern Africa. Moon B.P. & Dardis G.F. eds., 296-316.
- MERENSKY H., 1909: The diamond deposits of Luderitzland German SW Africa Trans. Geol. Soc. S. Afr., Vol. 12, 13-23.
- MIALL A.D., 1977: A review of the braided river depositional environment, Earth Science Reviews, Vol. 13, 1-62.
- MIALL A.D., 1978: Lithofacies types and vertical profile models in braided river deposits: a summary. In A. D. Miall ed., Fluvial Sedimentology, Can. Soc. Petrol. Geol. Mem. 5, 597-604.

- MIALL A.D., 1981: Analysis of fluvial depositional systems. AAPG Education Course Note Series, 75pp.
- MITCHELL A.H.G. & GARSON M.S., 1981: Mineral deposit and global tectonic settings. Academic Press, London 405pp.
- MOSIG R.W., 1980: Morphology of indicator minerals as a guide to proximity of source. In: Glover J.E. and Groves D.I. eds, Kimberlites and diamonds, Geol. Dept./Univ. Ext., Univ. W.A., Pub n° 5.
- MUDGE M.R., 1968: Depth control of some concordant intrusions. Bull. Geol. Soc. Amer., 79, 315-332.
- MUGGERIDGE M.T., 1989: The efficiency of fluvial trap sites in concentrating kimberlitic indicator minerals: an experimental sampling survey. In: Kimberlites and related rocks, Vol. 2, Geol. Soc. Austr. Special Publ. n° 14, 1154-1168.
- NEMEC W. & STEEL R.J.: Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: Koster E.H. & Steel R.J., eds., Sedimentology of gravels and conglomerates. Canadian Soc. of Petroleum Geologists, Memoir 10, 1-31.
- NOBLE E.L., 1965: Sediment reduction through watershed rehabilitation, U.S. Dept. of Agriculture, miscellaneous publication 970, 114-123.
- OOSTERVELD M.M., 1972: Ore reserve estimation and depletion planning for a beach diamond deposit. Proc. A.P.C.O.M., Symp., Johannesburg, 65-71.
- OOSTERVELD M.M., CAMPBELL D. & HAZELL K.R., 1987: Geology related to statistical evaluation parameters for a diamondiferous beach deposit. A.P.C.O.M. 87. Proceedings on the 20th International Symposium on the Application of Computers and Mathematics in the Mineral Industries. Vol. 3: Geostatistics. Johannesburg, SAIMM, 129-136.
- OSOVESTKII B.M., 1984: Accumulation of heavy minerals in coarse-clastic alluvia. Lithol. Mineral. Res., Vol. 18, 330-337. (Transl. from Lithologiya. I. Poleznye Iskopaemye 1983, Vol. 4, 17-25.

- PARTRIDGE T.C. & BRINK A.B.A., 1967: Gravels and terraces of the lower Vaal River Basin. *S. Afr. Geog. Jour.*, Vol. 49, 21-38.
- PARTRIDGE T.C. and MAUD R.R., 1987: Geomorphic evolution of southern Africa since the Mesozoic. *S. Afr. J. Geol.*, Vol.90 (2), 179-208.
- PARTRIDGE T.C., 1990: Symposium on the geomorphology and management of semi-arid lands. Pre-Symposium field excursion guidebook. Organised by the Dept. of Geogr. and Envir. Studies, Univ. of Bophuthatswana in conjunction with the southern Afr. Ass. of Geomorphologists. 47 pp.
- PETTIJOHN F.J., 1975: *Sedimentary rocks*, 3rd edn., New-York: Harper & Row, 628 pp.
- PHILLIPS R., 1974: A method for estimating the grade of diamond deposits. In: *Geol. Min. Metall. sampling*. Ed. by M.J. Jones, the Inst. of Min. Metall., 20-25.
- POTTER P.E. & PETTIJOHN F.J., 1977: *Paleocurrents and basin analysis*; second corrected and updated edition, Springer-Verlag, New-York, 425pp.
- PROKOPCHUK B.I., 1967: Some of the factors in distribution of diamond in channel placer deposits. *Int. Geol. Rev.*, 9, 1171-1176.
- PROKOPCHUK B.I., 1974: The types of primary sources of diamonds and their role in forming diamond placers of different genetic types, *Soviet Geol. Geophys.*, 15, 64-68.
- RAMOS A. & SOPENA A., 1983: Gravel bars in low sinuosity streams (Permian and Triassic, central Spain). In: Collinson J.D. & Lewin J., eds., *Modern and Ancient Fluvial Systems: International Association of Sedimentologists Special Publication 6*, 301-312.
- REID A.M. & DAWSON J.B., 1972: Olivine-garnet reaction in peridotites from Tanzania. *Lithos*, Vol. 5, 115-124.
- REID I. & FROSTICK L.E., 1985: Role of settling, entrainment and dispersive equivalence and of interstice trapping in placer formation. *J. Geol. Soc. London*, Vol. 142, 739-746.

- ROUFFAER E.J.H.F., 1988: On the origin of alluvial diamonds along the Atlantic coast of South Africa and South West Africa. Ph. D Thesis, Université Catholique de Louvain, 125pp.
- RUST B.R., 1972: Structure and process in a braided river. *Sedimentology*, Vol.18, 221-246.
- RUST B.R., 1978: Depositional models for braided alluvium. In: A.D. Miall ed., *Fluvial Sedimentology*, Can. Soc. Petrol. Geol. Mem. 5, 605-625.
- RUST B.R., 1979: Facies models 2. Coarse alluvial deposits, in R.G. Walker ed., *Facies models*, Geoscience Canada Reprint Series 1, 9-21.
- SACS (The South African Committee for stratigraphy), 1980: Stratigraphy of South Africa, Handbook 8. Part 1: Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia and the Republics of Bophuthatswana, Transkei and Venda. Dept. of Mineral and Energy Affairs. Geological Survey, p. 125.
- SELLSCHOPP J.P.F., MADIBA C.C.P. & ANNEGARN H.J., 1980: Light volatiles in diamond: physical interpretation and genetic significance. *Nucl. Inst. Methods*, Vol. 168, 529-534.
- SICHEL H.S., 1972: Statistical valuation of diamondiferous deposits. *J. S. Afr. Inst. Min. Metall.*, Vol. 73, 235-243.
- SIESSER W.G., 1978: Aridification of the Namib desert: evidence from ocean cores. In: van Zinderen Bakker E.M. (ed.), *Antarctic glacial history and world palaeoenvironments*, Balkema, Rotterdam, 105-113.
- SKINNER E.M.W., 1989: Contrasting Group 1 and Group 2 kimberlite petrology: towards a genetic model for kimberlites. In: *Kimberlites and related rocks*, Vol. 1, Geol. Soc. Austr. Special Publ. n° 14, 528-544.
- SLODKEVITCH V.V., 1983: Graphite paramorphs after diamond. *Int. Geol. Rev.*, Vol. 23, 497-514.

- SMITH C.B., 1983: Pb, Sr and Nd isotopic evidence for sources of southern African Cretaceous kimberlites. *Nature*, Vol. 304 (5921), 51-54.
- SMITH C.B., GURNEY J.J., SKINNER E.M.W., CLEMENT, C.R. & EBRAHIM N., 1985: Geochemical character of southern African kimberlites. A new approach based on isotopic constraints. *Trans. Geol. Soc. S. Afr.*, Vol. 88 (2), 267-280.
- SMITH N.D., 1974: Sedimentology and bar formation in the upper Kicking Horse River, a braided outwash stream: *Jour. Geol.*, Vol. 81, 205-223.
- SMITH N.D., 1980: A short course on braided river systems. Section 1, Course Notes. Department of Geology, Rhodes University, Grahamstown, 55pp.
- SNEED E.D. & FOLK R.L., 1958: Pebbles in the Lower Colorado River, Texas, a study in particle morphogenesis. *Jour. Geol.*, Vol. 66, 114-150.
- SÖHNGE P.G., VISSER D.J.L. & VAN RIET LOWE C., 1937: The geology and archeology of the Vaal River Basin. *Geol. Surv. S. Afr. Mem.* 35, pts 1 and 2, 184pp.
- STOREY H.C., Hobbs R.L. and Rosa J.M., 1964: Hydrology of forest and range lands. In: Chow, V.T. (ed.), *Handbook of Applied Hydrology*, McGraw-Hill, New-York.
- STRATTEN T., 1979: The origin of the diamondiferous alluvial gravels in the Southwestern Transvaal. *Geokongress 77: Geol. Soc. S. Afr. Spec. Publ.* 5, 219-228.
- SUTHERLAND D.G., 1982: The transport and sorting of diamonds by fluvial and marine processes. *Econ. Geol.*, Vol. 77, 1613-1620.
- SUTHERLAND D.G., 1984(a): Geomorphology and mineral exploration: some examples from exploration for diamondiferous placer deposits. *Z. Geomorph. N. F. Suppl. Bd.* 51, 1-14.
- SUTHERLAND D.G., 1984(b): Method of establishing the minimum sample size for sampling alluvial diamond deposits. *Trans. Instn. Min. Metall.*, Vol. 93, 355-358.

- SUTHERLAND D.G., 1985: Geomorphological controls on the distribution of placer deposits. *J. Geol. Soc. London*, Vol. 142, 727-737.
- TANKARD A.J., JACKSON M.P.A., ERIKSSON K.A., HOBDAY D.K., HUNTER D.R. & MINTER W.E.L., 1982: *Crustal evolution of Southern Africa*. Springer-Verlag, New York, Heidelberg, Berlin; 523pp.
- THOMAS M.F., THORP M.B. & TEEUW R.M., 1985: Palaeogeomorphology and the occurrence of diamondiferous placer deposits in Koidu, Sierra Leone. *J. geol. Soc. London*, Vol. 142, 789-802pp.
- TOMPKINS L.A. & GONZAGA G.M., 1989: Diamonds in Brazil and a proposed model for the origin and distribution of diamonds in the Coromandel Region, Minas Gerais, Brazil. *Econ. Geol.*, Vol. 84, 591-602.
- TURNER B.R. & MINTER W.E., 1985: Diamond-bearing upper Karoo fluvial sediments in NE Swaziland. *J. geol. Soc. London*, Vol. 142, 765-776.
- TYSON P.D., 1986: *Climatic change and variability in southern Africa*, Oxford University Press, Cape Town.
- VAN RIET LOWE C., 1952: The Vaal River chronology: an up-to-date summary: *S. Afr. Archeol. Bull.*, Vol. 7, 135-149.
- VAN WYK J.P. & PIENAAR L.F., 1986: Diamondiferous gravels of the lower Orange River, Namaqualand. In: Anhaeusser C.R. & Maske S., eds., *Mineral Deposits of Southern Africa*, *Geol. Soc. S. Afr.*, Johannesburg, Vol. 2, 2309-2321.
- VISSER J.N.J., GROBLER N.J., JOUBERT C.W., POTGIETER C.D., POTGIETER G.J.A., Mc LAREN C.H. & LIEBENBERG J., 1976: The Ventersdorp Group between Taung and Britstown, Northern Cape Province. *Ann. Geol. Surv. S. Afr.*, Vol. II, 15-28.
- VISSER J.N.J. & LOOCK J.C., 1988: Sedimentary facies of the Dwyka Formation associated with the Nooitgedacht glacial pavement, Barkly West District. *S. Afr. J. Geol.*, Vol.91, 38-48.

WADELL H., 1932: Volume, shape and roundness of rock-particles. Jour. Geol., Vol. 40, 443-451.

WAGNER P.A., 1914: The diamond fields of southern Africa. Reprint 1973, Struik, Cape Town, 355pp.

WILLIAMS A.F., 1932: The genesis of the diamonds. London, Bouverie House, 636pp.

WILLIAMS P.F. & RUST B.R., 1969: The sedimentology of a braided river, J. Sediment. Petrol., Vol. 39, 649-679.

ZINGG T., 1935: Beiträge zur Schotteranalyse, Schweiz. min. pet. Mitt., Vol. 15, 39-140.

PHOTOS



PHOTO 1 : Dolerite koppie rising sharply from the pediment near Schmidtsdrif.



PHOTO 2 : General view of the Vaal River and its braiding pattern. Gong-Gong falls in mid-distance (view is upstream).



PHOTO 3 : Typical, small-scale digger's rig with washing pan at Longlands.



PHOTO 4 : Independant licensed diggers still work by the traditional methods (Gong-Gong).



PHOTO 5 : Striated glaciated pavement on Ventersdorp andesite, after removal of formerly overlying Dwyka tillite. Three different striation vectors are present (Farm Nooitgedacht).



PHOTO 6 : Ventersdorp andesite with large amygdales of quartz (1-3 cm) and dissolution features



PHOTO 7 : Dolomite of the Campbell Group forming the Ghaap Escarpment north of Schmidtsdrif.



PHOTO 8 : Dwyka Tillite (Upper Carboniferous) exhumed by long-continued erosion, together with its glaciated pavements of Ventersdorp andesite (Nooitgedacht).



PHOTO 9 : Detail of the Dwyka Tillite with pebble to boulder size material (Nooitgedacht).

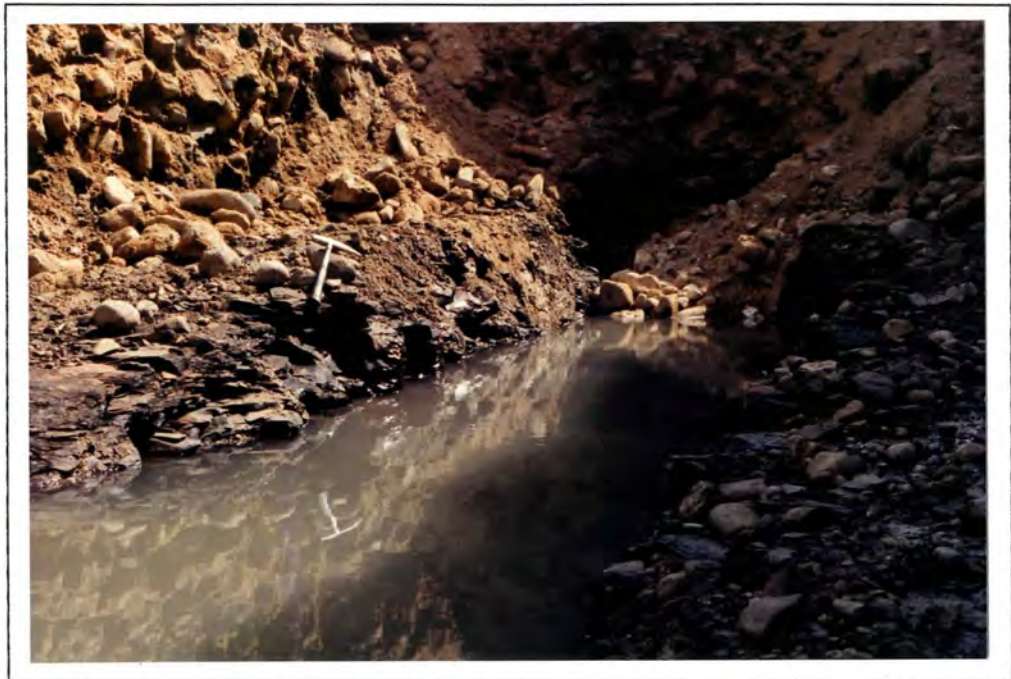


PHOTO 10 : Younger Gravels overlying bedrock of Prince Albert shale (Sydney-on-Vaal).



PHOTO 11 : The Gong-Gong Falls (3 m high). The Falls represent a re-excavated feature of a pre-Karoo valley.



PHOTO 12 : Uneven bedrock consisting of Ventersdorp lavas with potholes at Gong-Gong.



PHOTO 13 : "Giant" pothole (4 m deep) within the Ventersdorp andesite at Gong-Gong.



PHOTO 14 : Potholes within the Dwyka Tillite (0.3 to 0.8 m deep).



PHOTO 15 : Large boulders of Ventersdorp andesite at *Bad Hope*
(the largest one can reach 1.7 m in length).



PHOTO 16 : Well-imbricated clasts of Ventersdorp lava and Prince Albert Shale (lower part) at Longlands (facies Gm).



PHOTO 17 : Trough-stratified cobble-size gravels at Sydney-on-Vaal (facies Gt).



PHOTO 18 : Rietputs Formation C gravel overlain by the Riverton Formation (calcretized sand), itself overlain by the Hutton Sand (red sand) at Sydney-on-Vaal.



PHOTO 19 : Massive and structureless lenses of gravelly sand (facies Sm) interbedded within the Rietputs C Formation at Sydney-on-Vaal.



PHOTO 20 : Openwork gravel layers overlain by matrix-filled layers at Sydney-on-Vaal. There is a clear upward fining.



PHOTO 21 : Composition of the gravels. The boulder/cobble-size material consists of Ventersdorp andesite; the pebble-size material is dominated by the Ventersdorp andesite, quartz and jasper while the calcretized matrix consists predominantly of quartz.



PHOTO 22 : Visual determination of roundness. From left to right angular grains (15-25), subangular (25-35) and subrounded (35-49) (Based on Lindholm, 1987).



PHOTO 23 : Visual determination of roundness. From left to right: rounded (49-60), well rounded (60-75) and very well rounded (75-85).



PHOTO 24 : Imbrications (current is from left to right).



PHOTO 25 : The Dwyka Tillite at Gong-Gong. The clasts are mainly composed of Ventersdorp andesite.



PHOTO 26 : Ventersdorp lava overlain by the Dwyka Tillite (left) forming the bedrock at Gong-Gong. The tillite may have partly supplied the Younger Gravels.

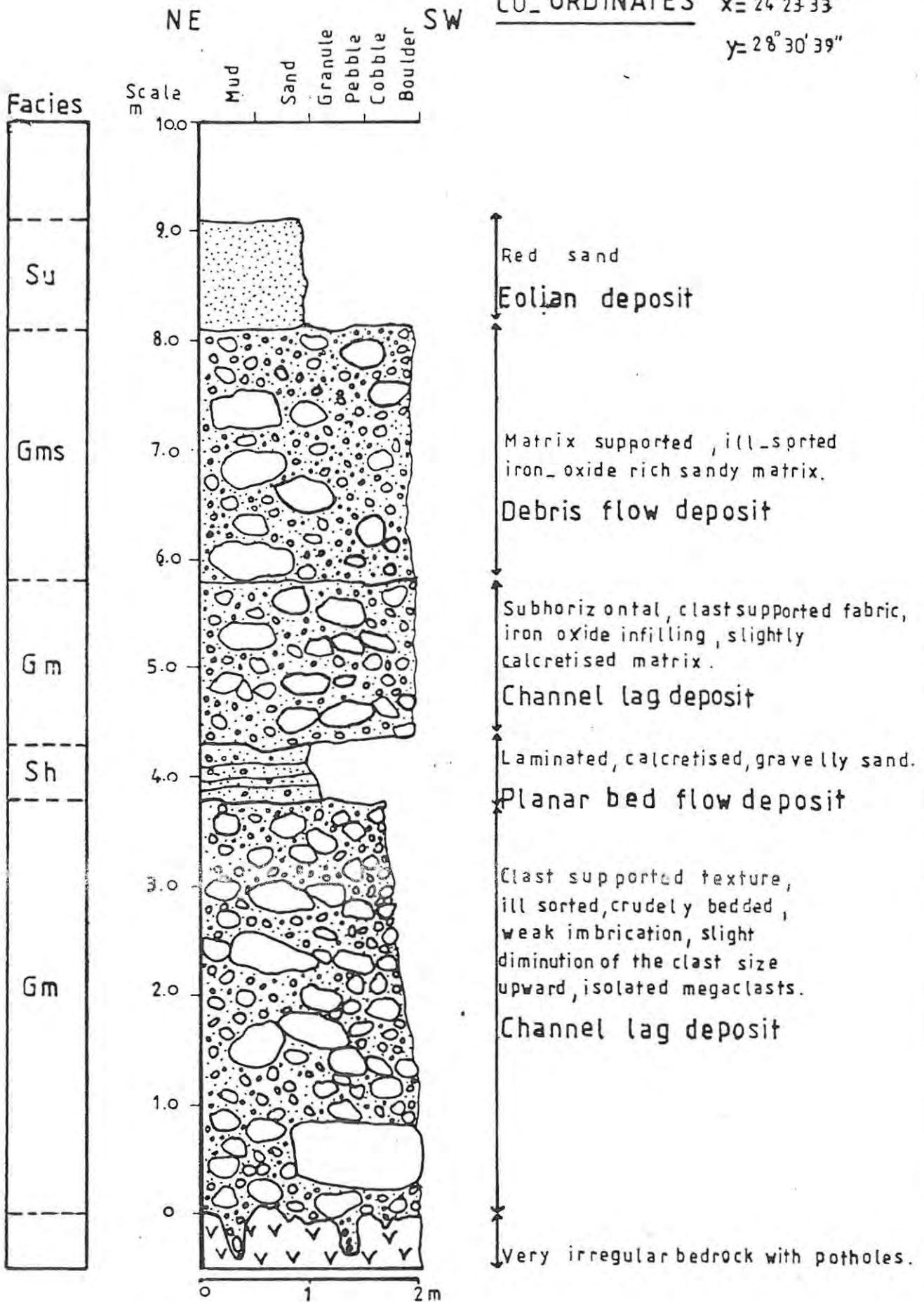


PHOTO 27 : A 2 carat diamond recovered in the concentrate at Delportshoop.

APPENDIX 1a

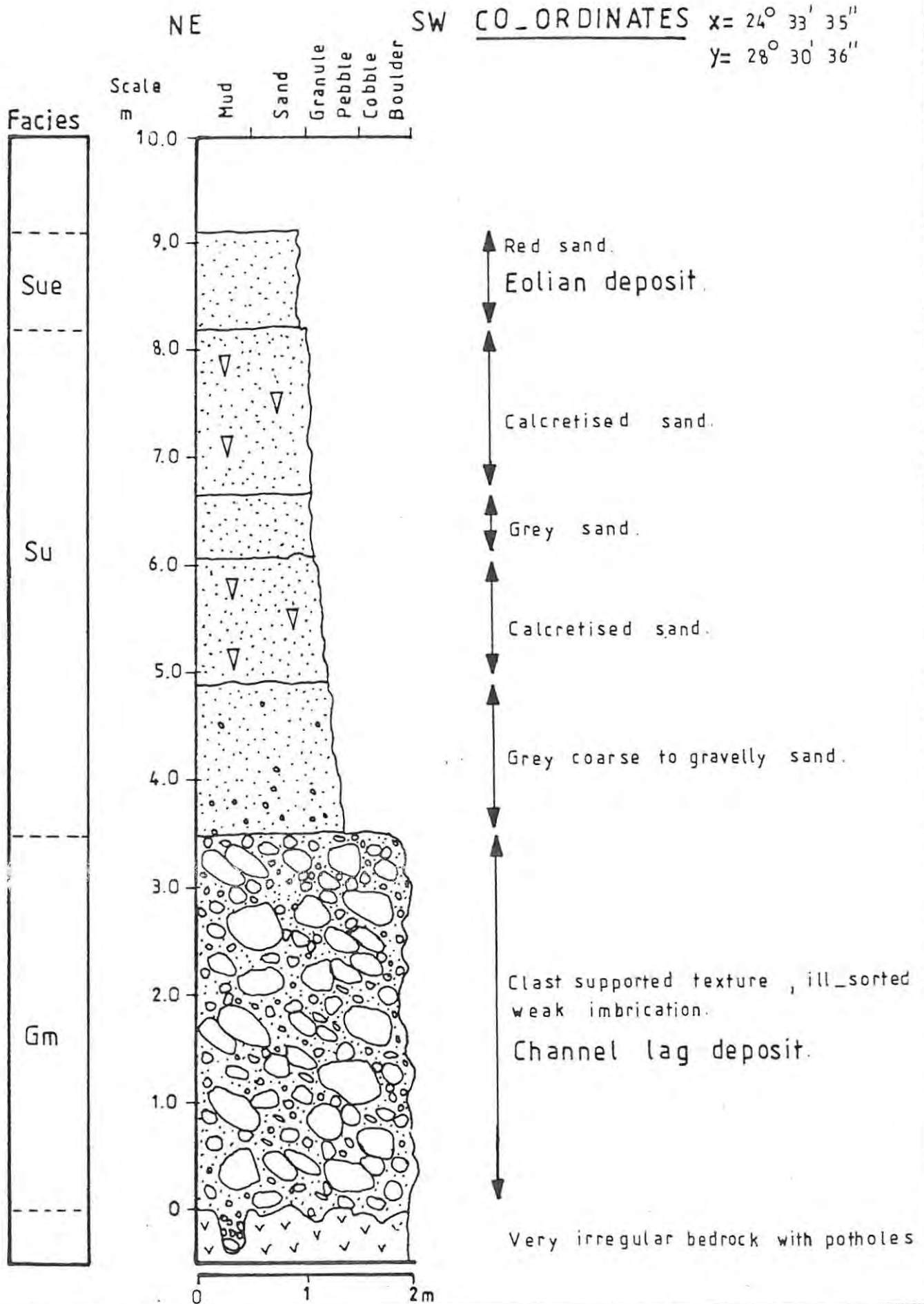
STRATIGRAPHIC PROFILE : GONG - GONG 283.

CO_ORDINATES x = 24° 23' 33"
y = 28° 30' 39"



APPENDIX 1b

STRATIGRAPHIC PROFILE: GONG_GONG 283.



APPENDIX 1c

STRATIGRAPHIC PROFILE: GONG_GONG 283

NE SW

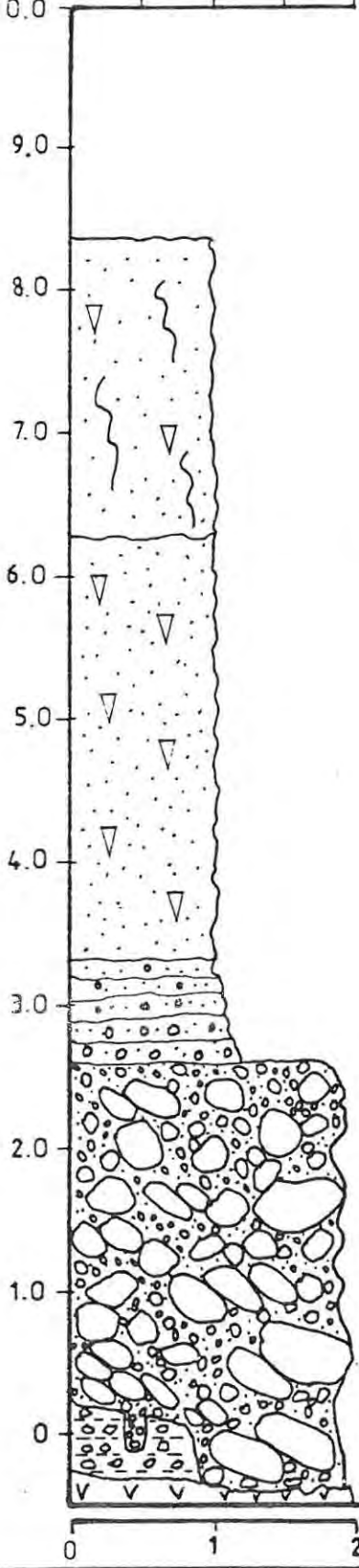
CO_ORDINATES x = 24° 23' 38"

y = 28° 30' 33"

Facies

Scale
m

Mud Sand Granule Pebble Cobble Boulder



Calcretised sand, iron oxide.

Strongly calcretised sand.

Laminated, coarse to gravelly sand, fining upward.

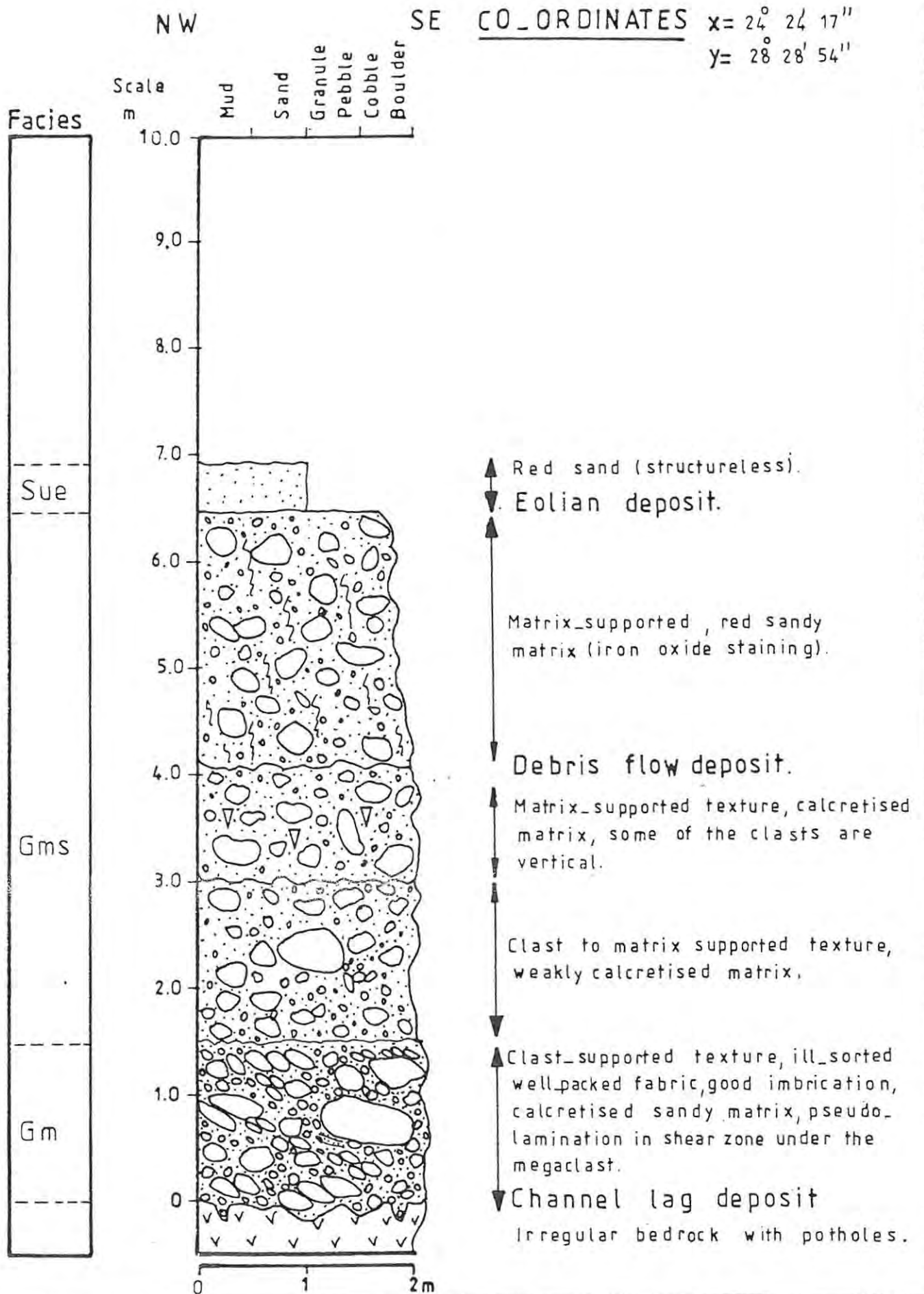
Waning flow deposit

Clast supported texture, ill-sorted, well imbricated clast.

Channel lag deposit

Bedrock: Ventersdorp lavas overlain by Dwyka tillite, potholes.

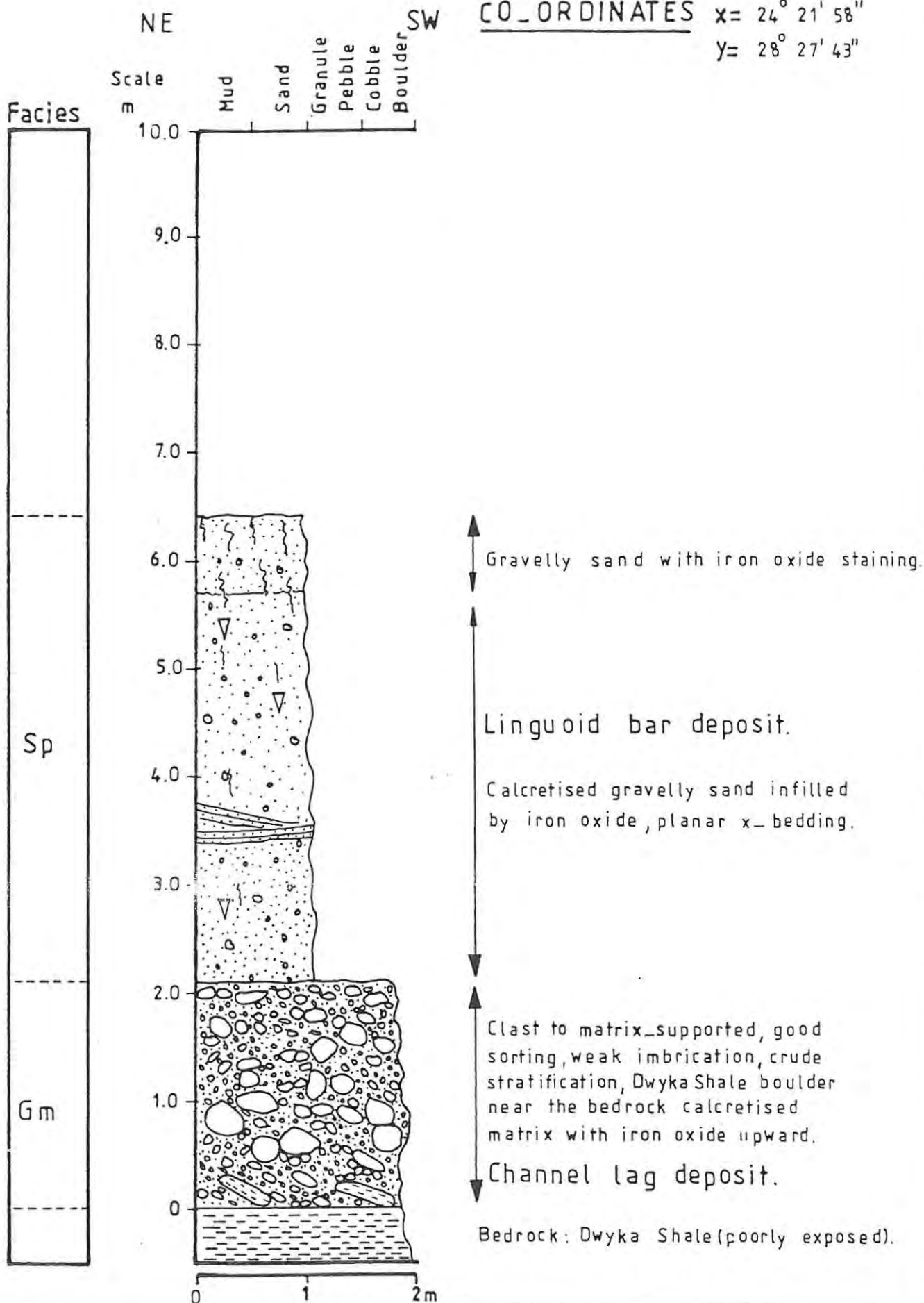
STRATIGRAPHIC PROFILE: WALDECK'S PLANT



APPENDIX 1e

STRATIGRAPHIC PROFILE: LONGLANDS

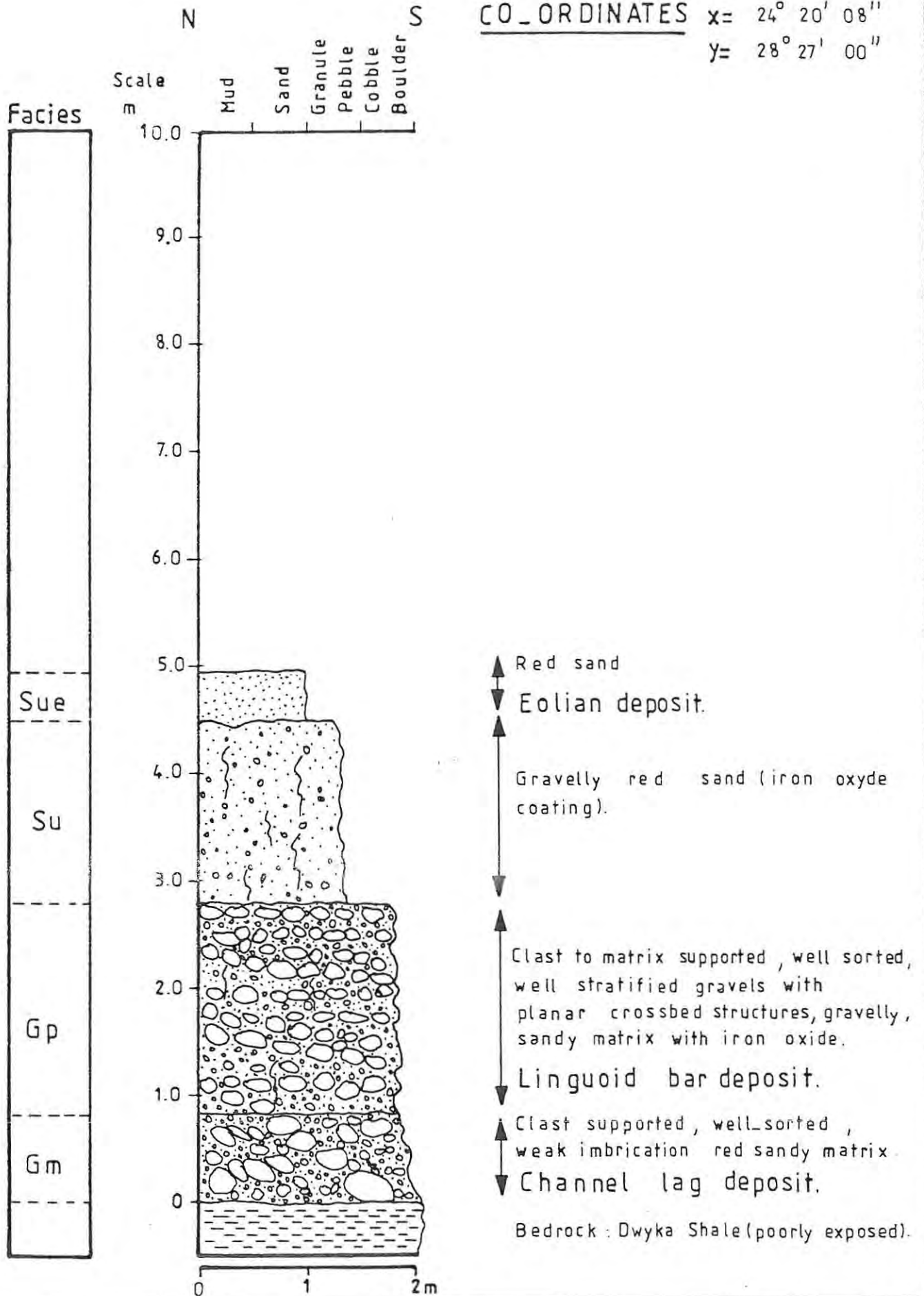
CO_ORDINATES x= 24° 21' 58"
y= 28° 27' 43"



APPENDIX 1f

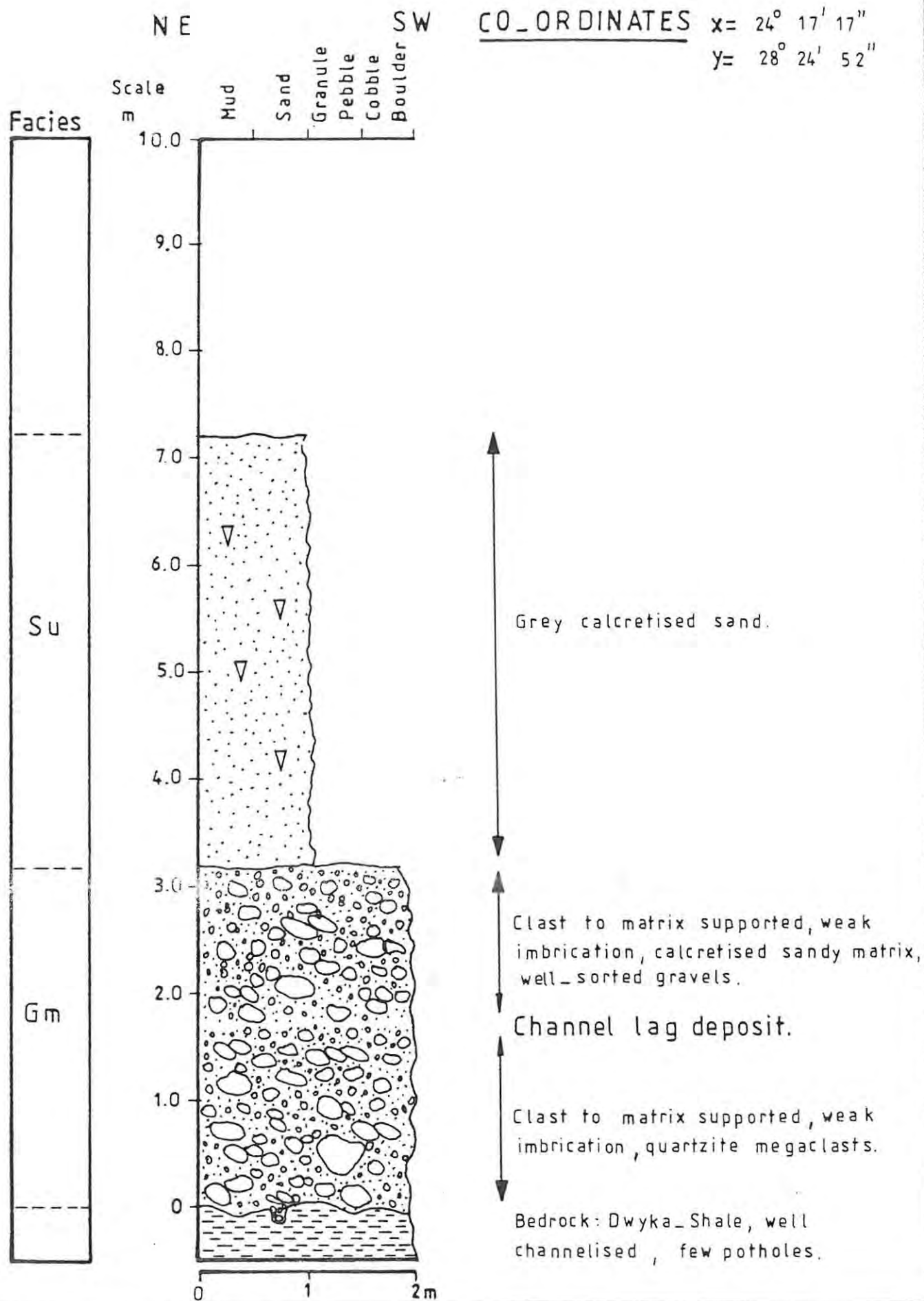
STRATIGRAPHIC PROFILE: WINTER'S RUSH

CO_ORDINATES x= 24° 20' 08"
y= 28° 27' 00"

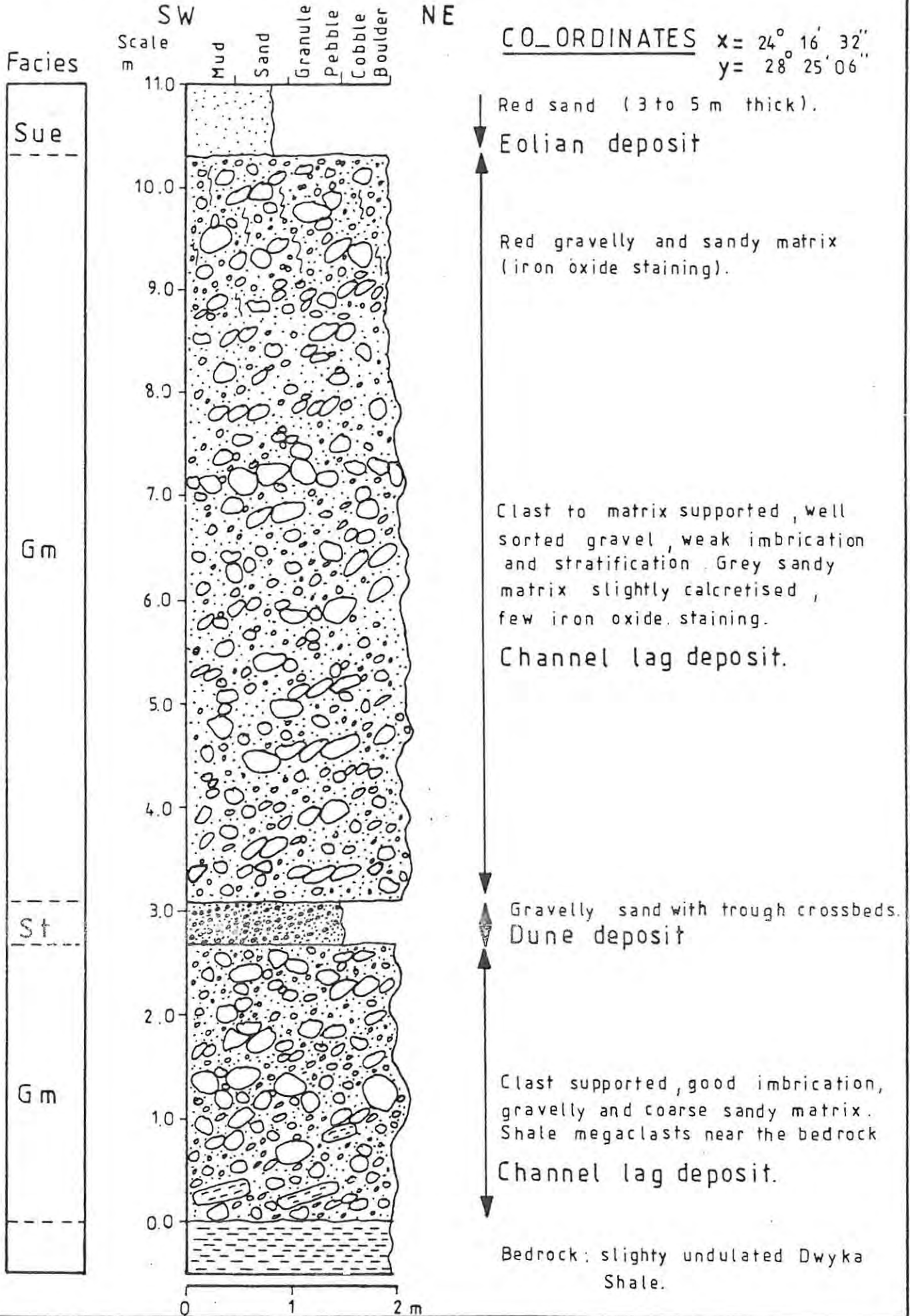


APPENDIX 1g

STRATIGRAPHIC PROFILE: DELPORTSHOOP

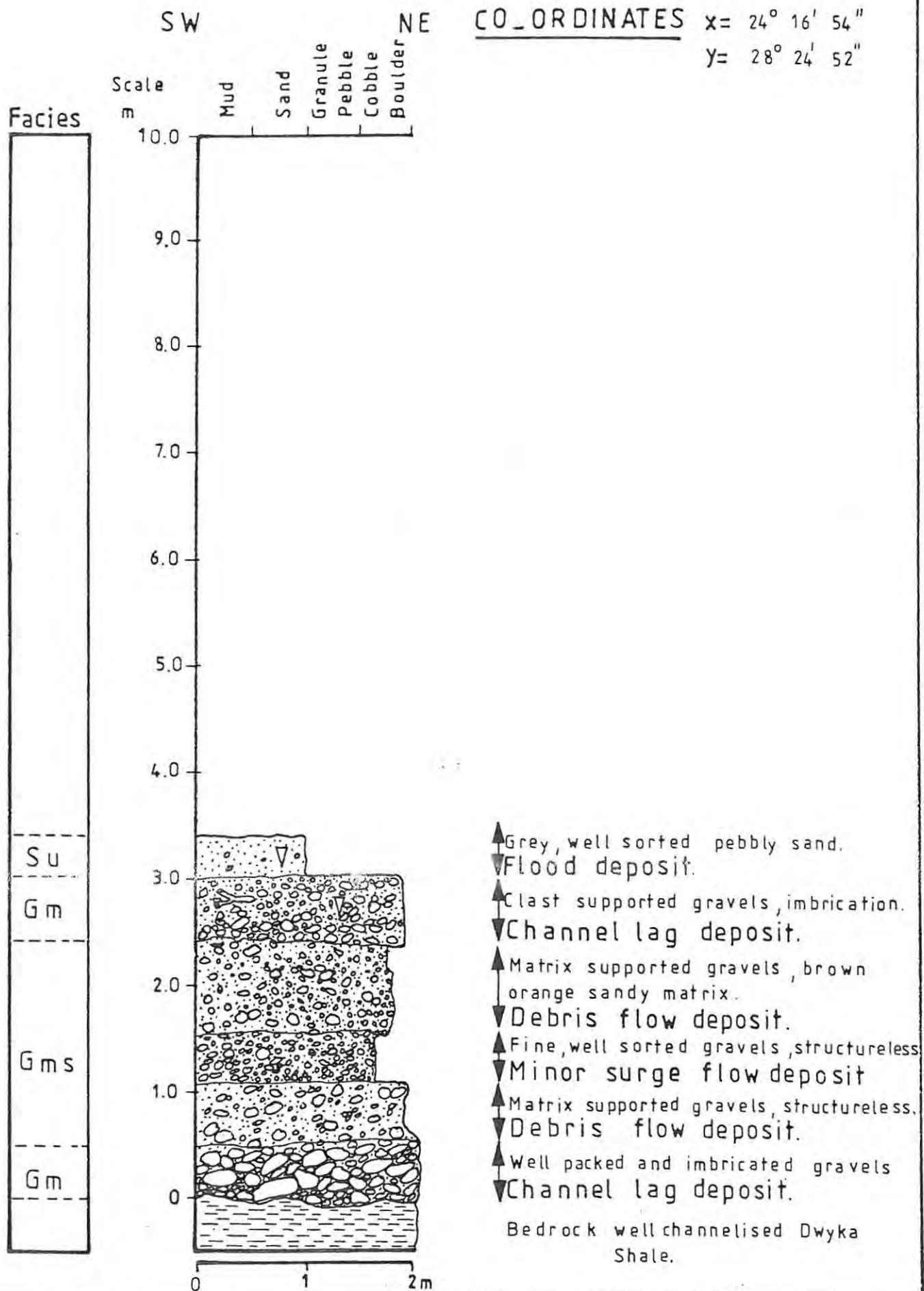


STRATIGRAPHIC PROFILE: SYDNEY- ON- VAAL



APPENDIX 1i

STRATIGRAPHIC PROFILE: SYDNEY_ON_VAAL



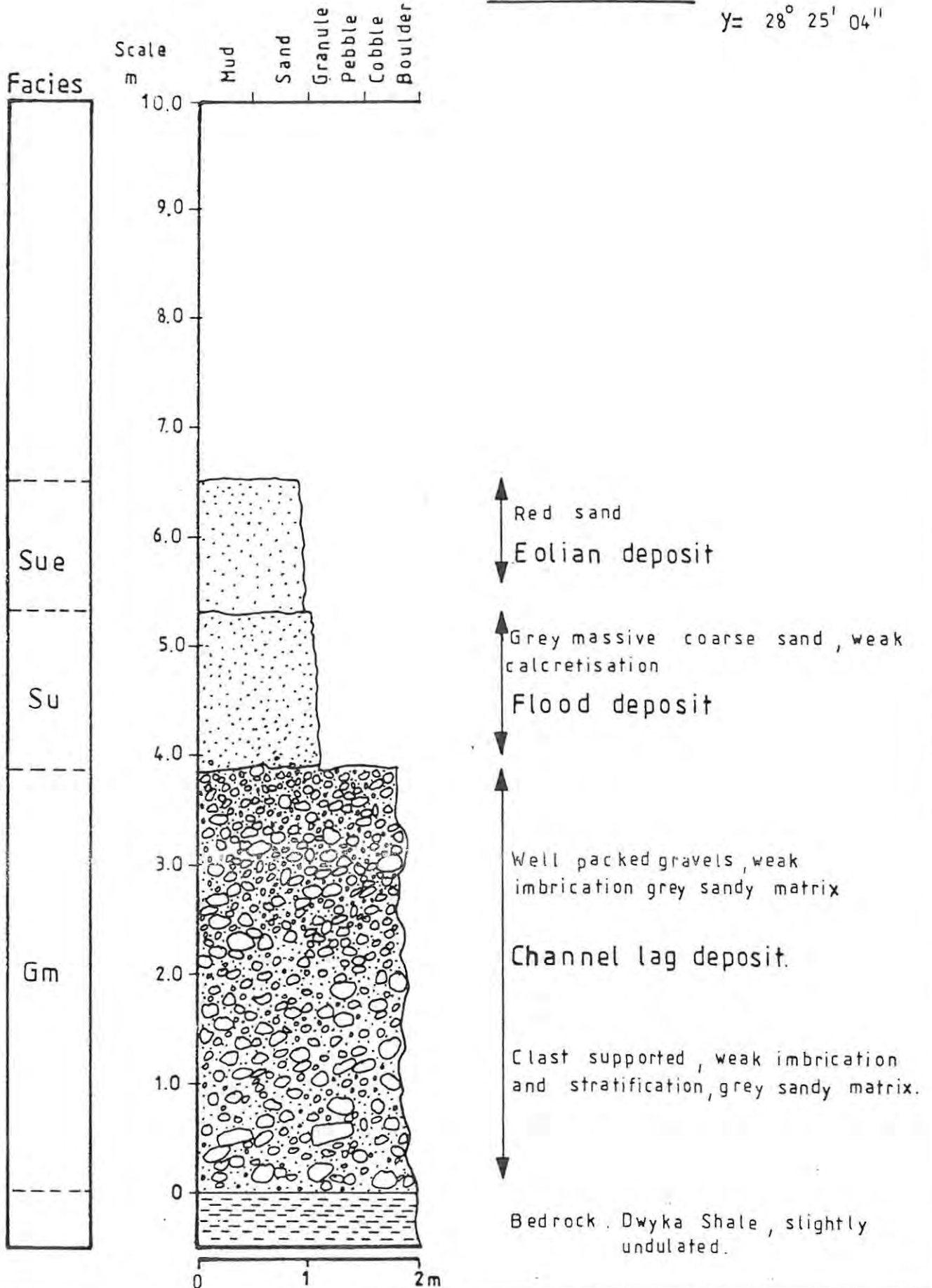
APPENDIX 1j

STRATIGRAPHIC PROFILE: SYDNEY_ON_VAAL

SW

NE

CO_ORDINATES x= 24° 16' 54"
y= 28° 25' 04"



Scale
m

Mud Sand Granule Pebble Cobble Boulder

Facies

10.0

9.0

8.0

7.0

6.0

Sue

5.0

Su

4.0

3.0

2.0

Gm

1.0

0

0 1 2m

Red sand

Eolian deposit

Grey massive coarse sand, weak
calcretisation

Flood deposit

Well packed gravels, weak
imbrication grey sandy matrix

Channel lag deposit.

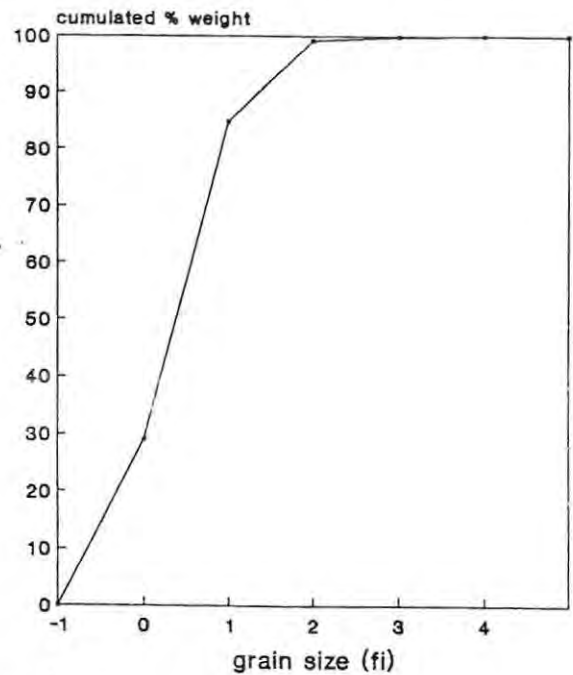
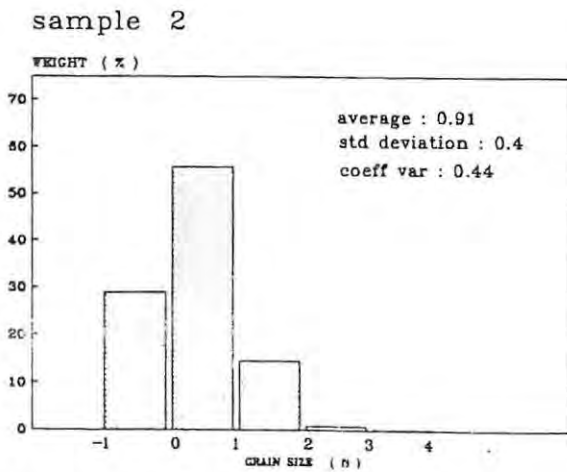
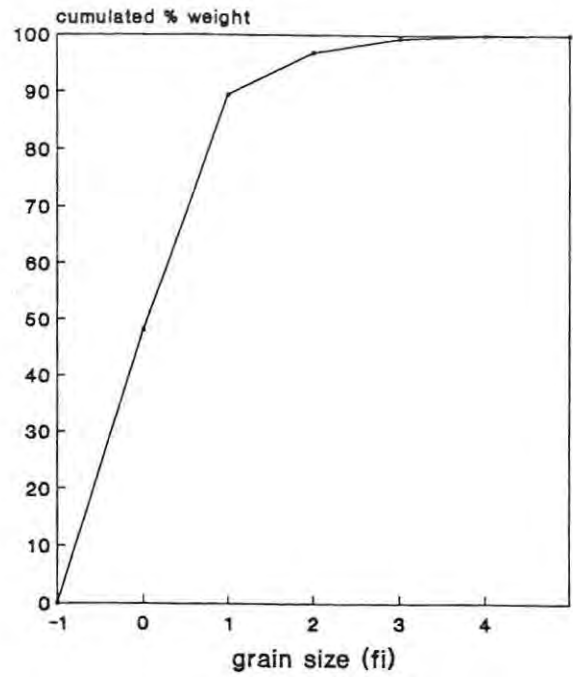
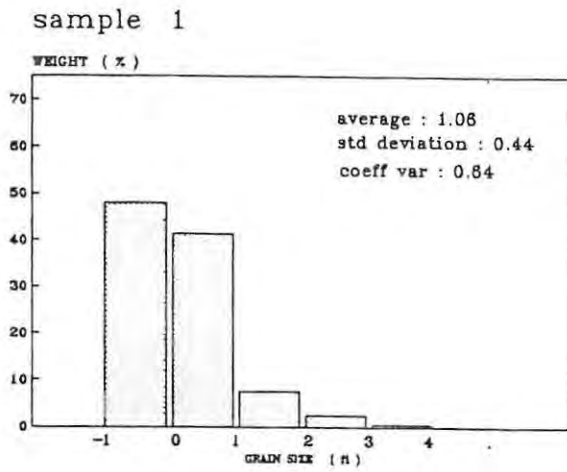
Clast supported, weak imbrication
and stratification, grey sandy matrix.

Bedrock. Dwyka Shale, slightly
undulated.

APPENDIX 2: PALEOCURRENT DIRECTION DATA

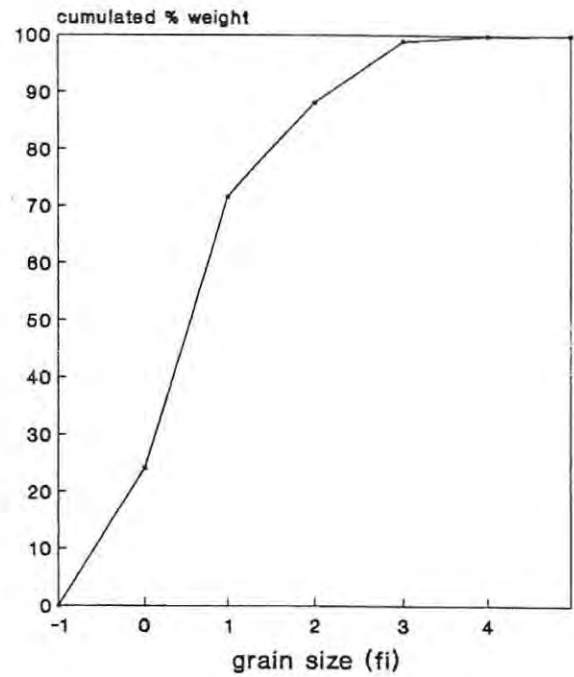
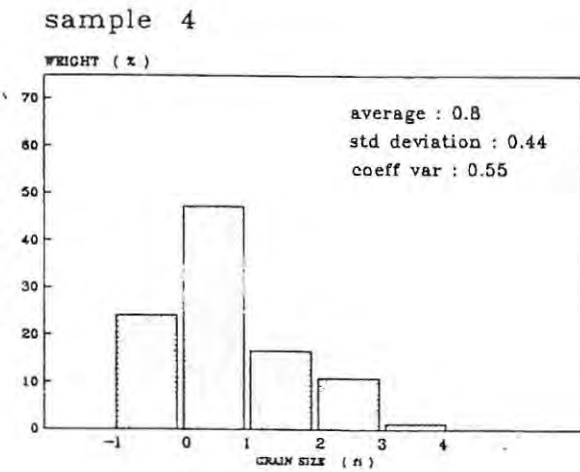
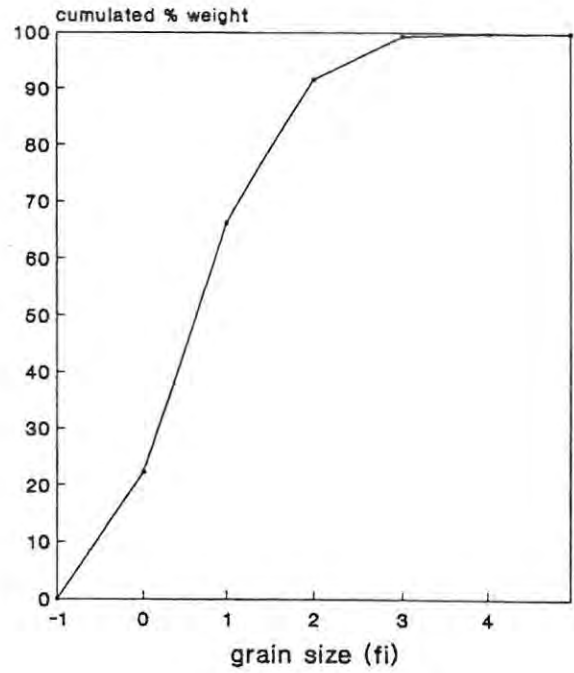
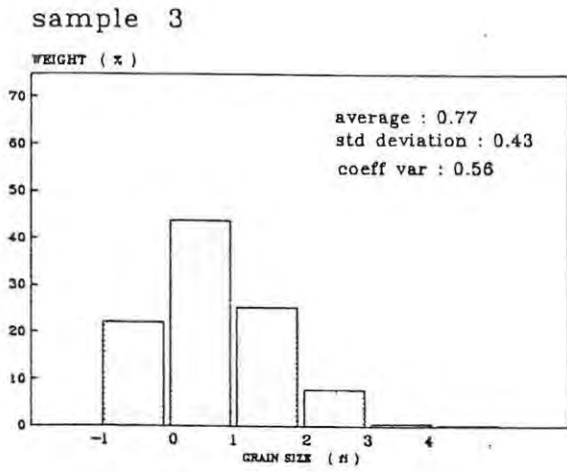
Station	V	W	x	R	L	Number of readings
1	29.33	18.73	32.56	34.80	69.60	50
2	29.12	21.12	35.94	35.97	71.94	50
3	19.80	32.57	58.70	38.12	76.24	50
4	19.59	35.83	61.33	40.83	81.66	50
5	11.75	-23.11	-63.05	25.93	51.86	50
6	10.83	-23.36	-65.13	25.75	51.49	50
7	16.18	-9.70	-30.94	18.87	37.73	50
8	34.79	-9.53	-15.32	36.04	72.15	50
9	22.45	3.07	7.78	22.66	45.31	50
10	21.42	-16.77	-38.06	27.21	66.36	41
11	20.86	-38.09	-61.29	43.42	86.83	50
12	3.17	-30.37	-84.04	30.37	60.75	50
13	15.26	-8.22	-28.32	17.33	34.67	50
14	45.32	-4.57	-5.76	45.55	91.10	50
15	8.23	-23.04	-70.34	24.46	48.92	50
16	13.96	-23.15	-58.91	27.03	54.07	50
17	38.33	14.79	21.09	41.08	82.16	50
18	36.97	2.81	4.34	37.08	74.15	50
19	14.95	-24.23	-58.32	28.47	56.93	50
20	24.51	-0.95	-2.22	24.53	49.05	50
21	30.15	12.47	22.47	32.62	65.25	50
22	14.39	12.11	40.08	18.81	55.33	44
23	35.99	9.45	14.71	37.21	74.43	50
24	10.62	28.48	69.56	30.40	60.79	50
25	20.11	-1.82	-5.18	20.19	40.38	50
26	18.33	20.89	48.74	27.79	55.58	50

APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION.



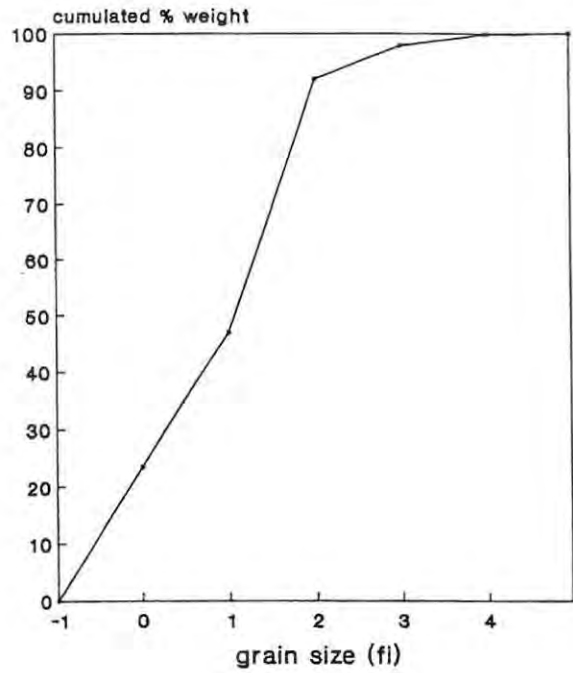
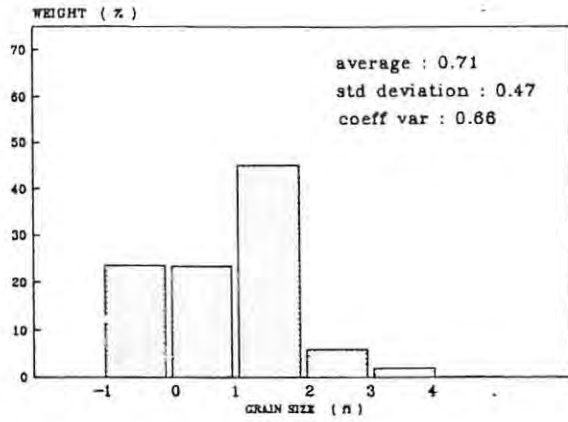
(average and standard deviation in mm)

APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

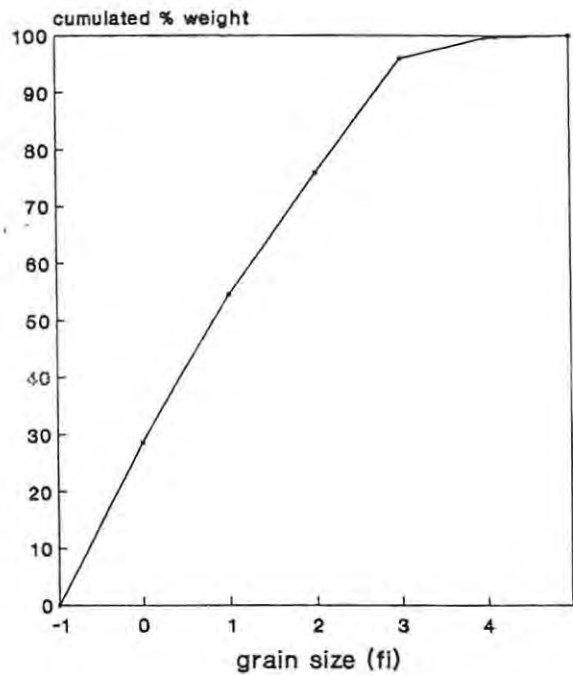
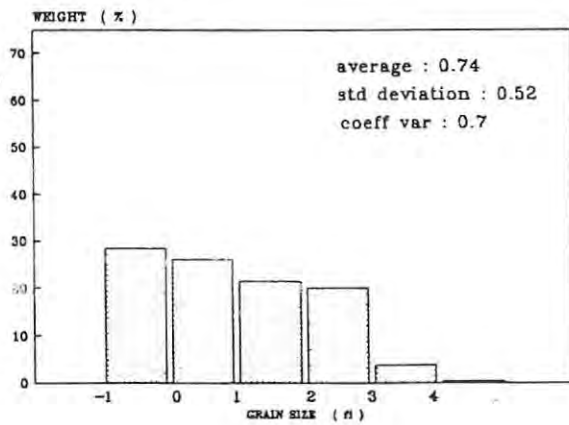


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

sample 5

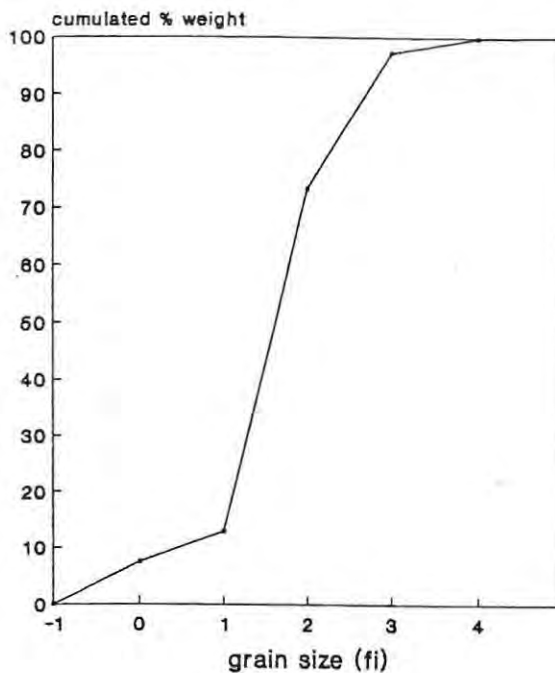
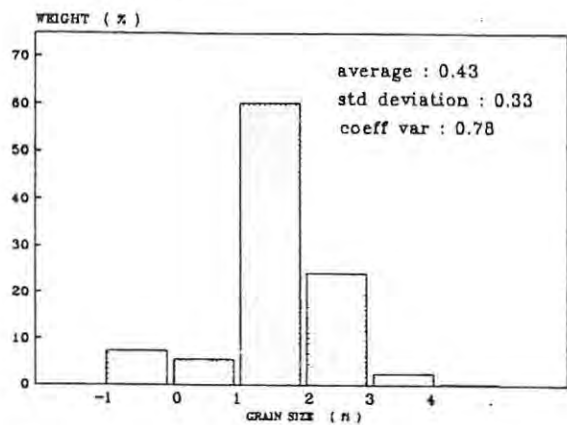


sample 6

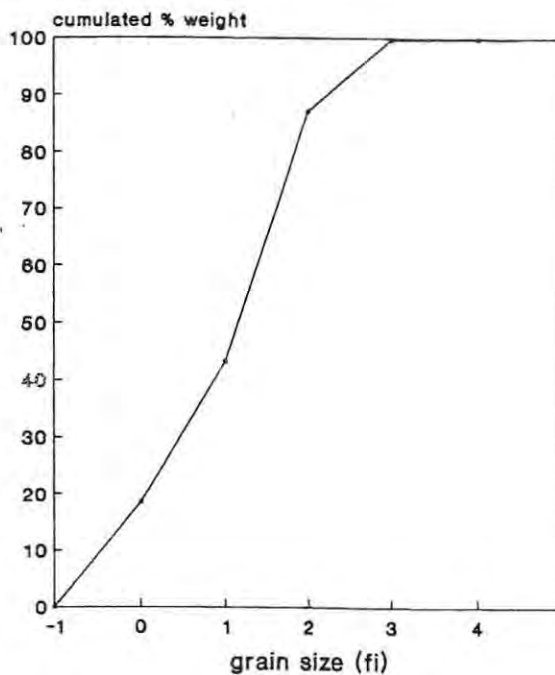
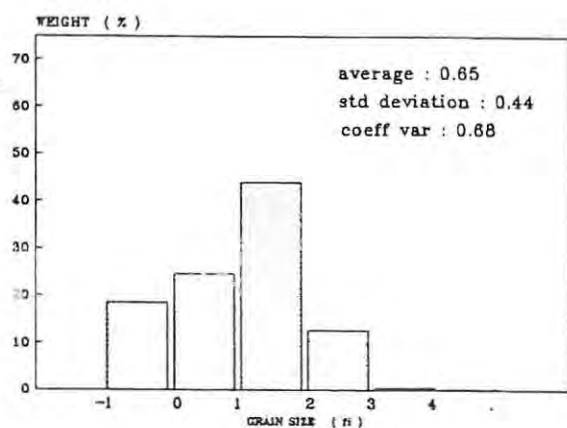


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

sample 7

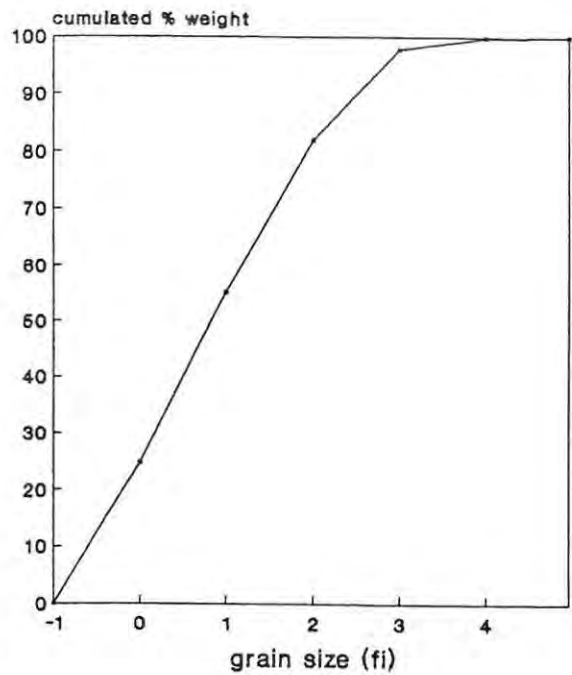
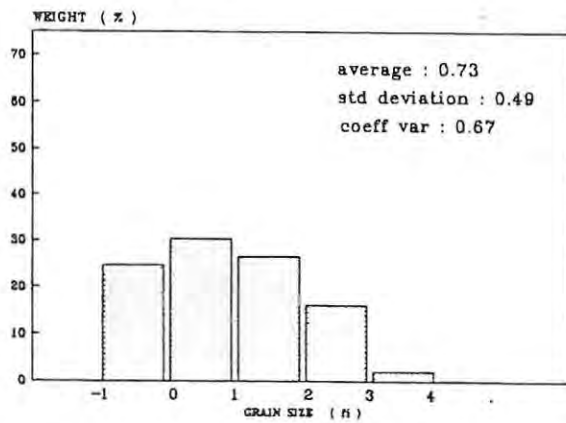


sample 8

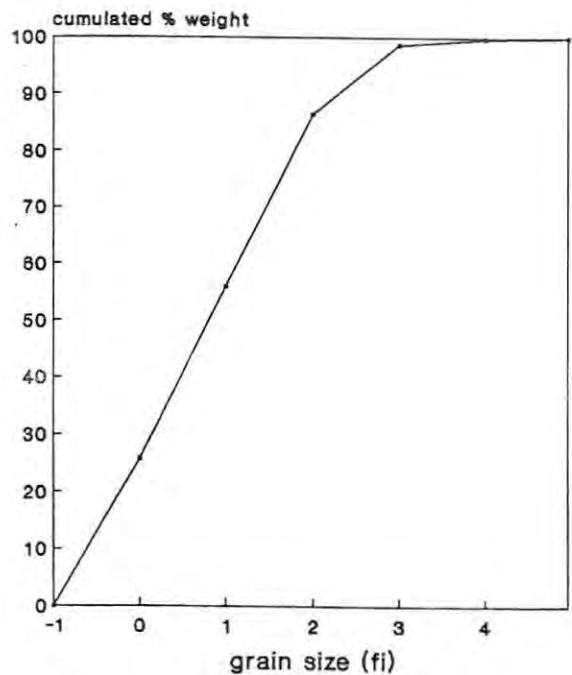
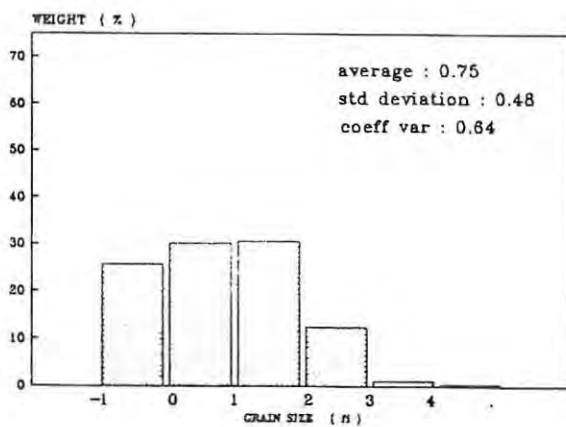


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

sample 9

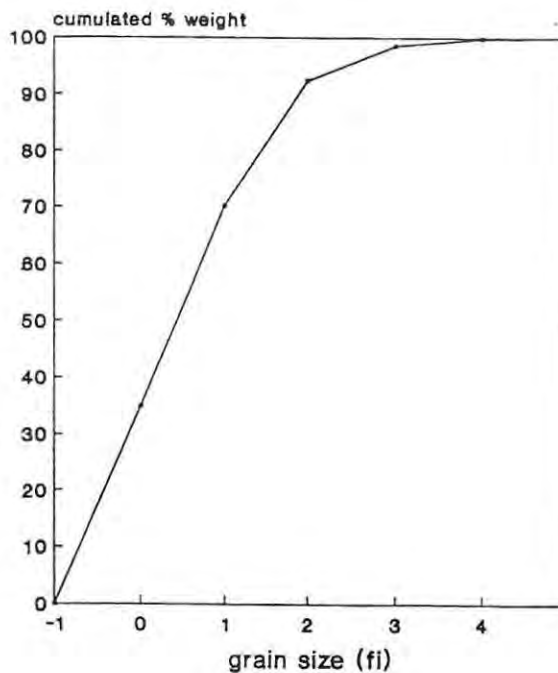
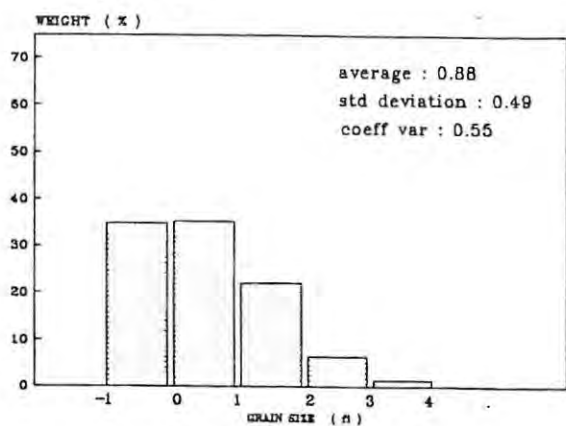


sample 10

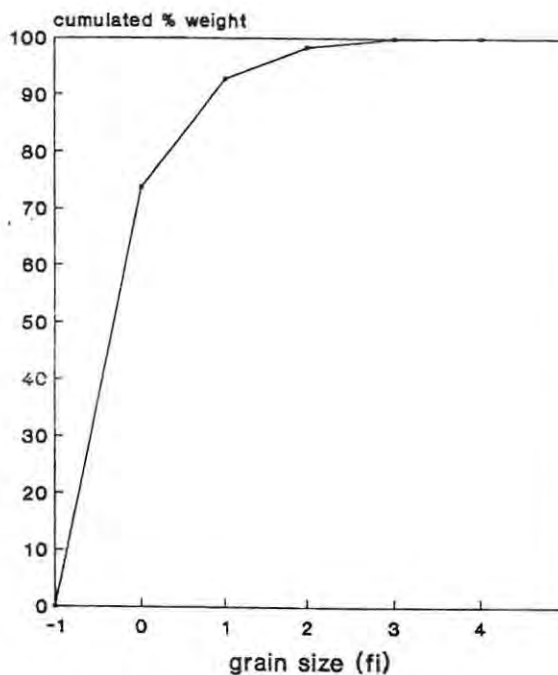
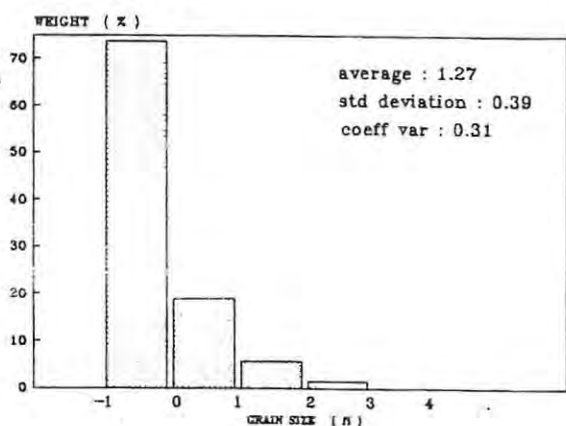


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

sample 11

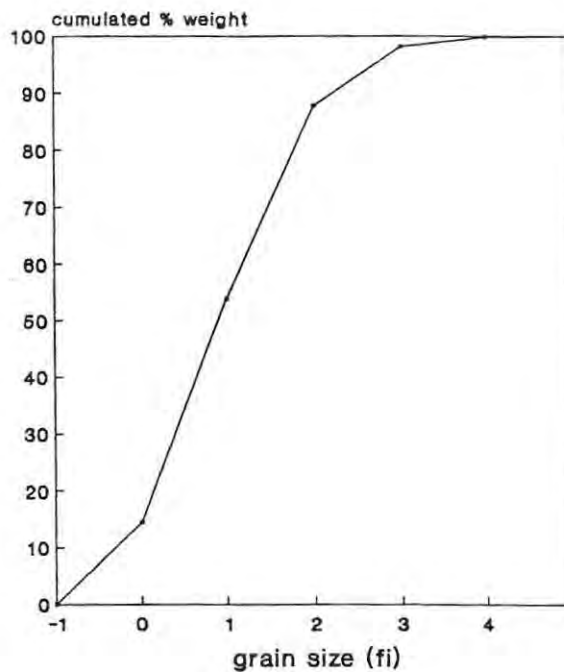
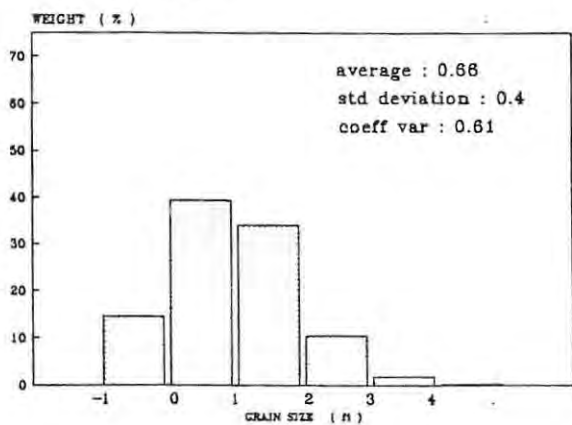


sample 12

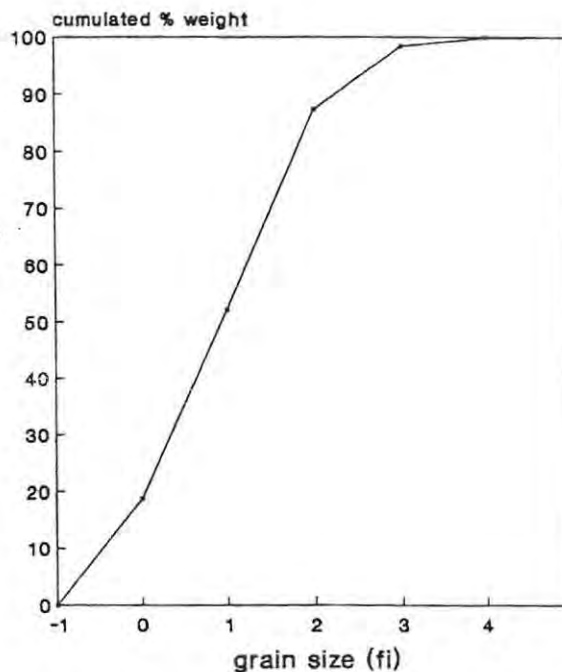
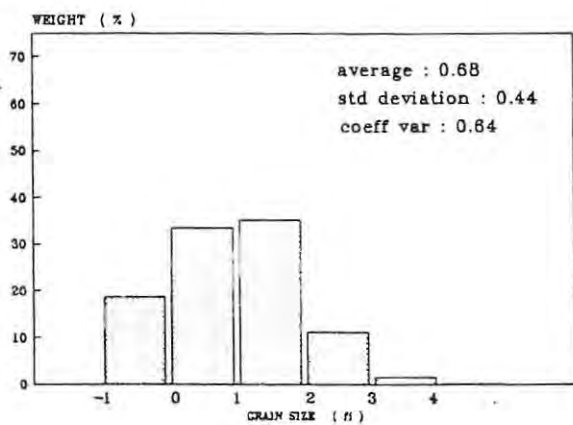


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

sample 13

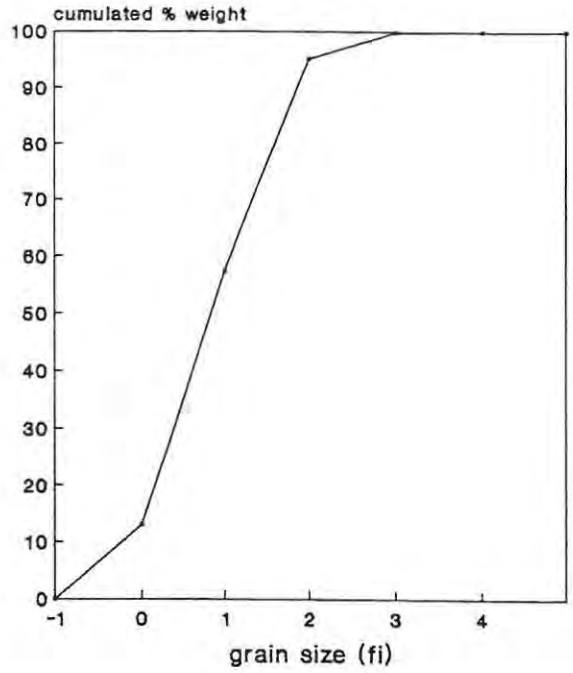
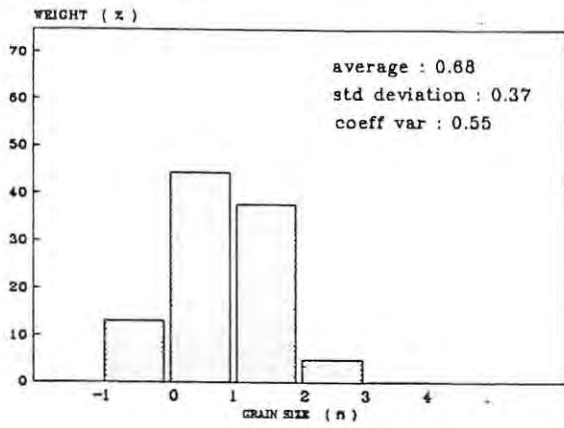


sample 14

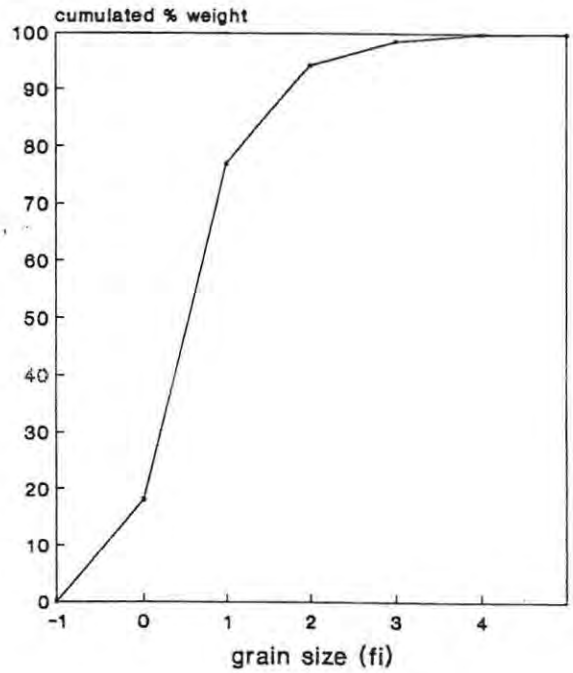
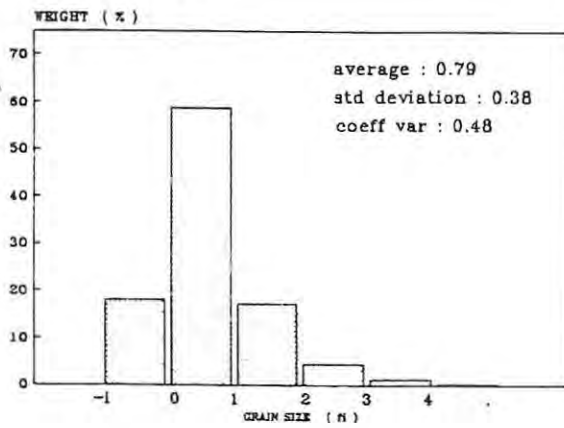


APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).

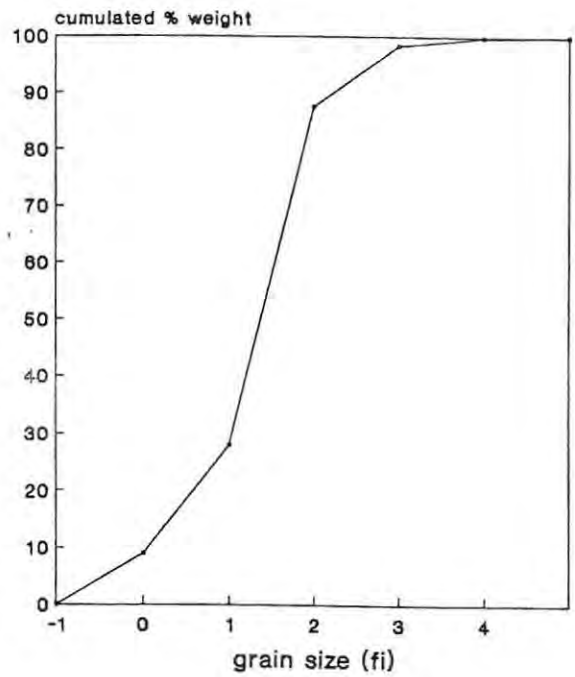
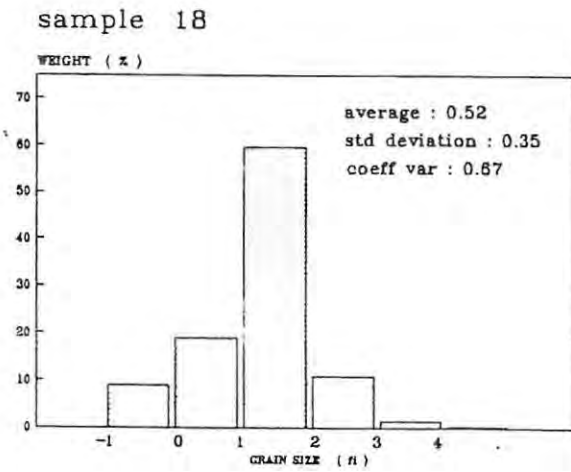
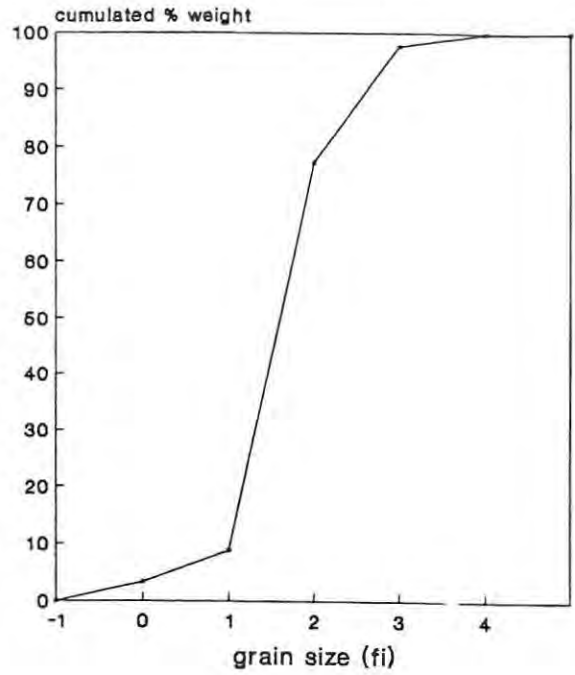
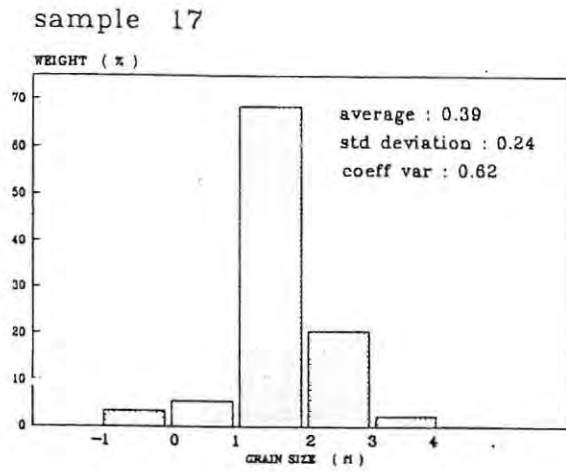
sample 15



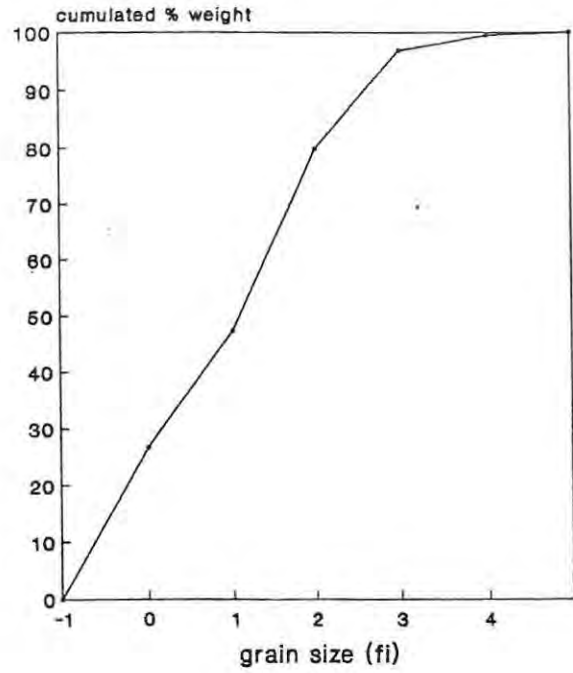
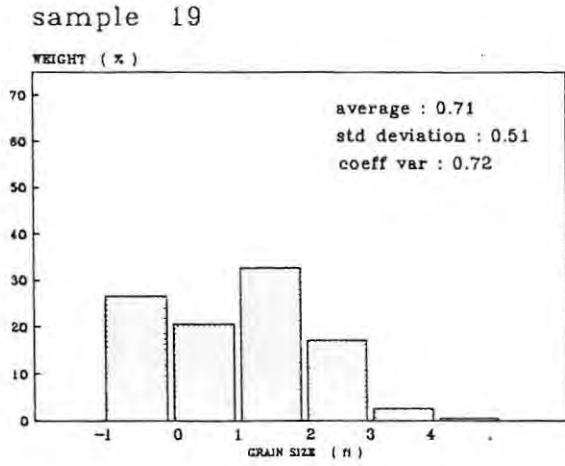
sample 16



APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION (CONTINUED).



APPENDIX 3: HISTOGRAM AND CUMULATED FREQUENCY OF GRAIN SIZE DISTRIBUTION
(CONTINUED).



APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA.

Publication MFA/0745
 Farm Good Hope (7283), B.W. District

Year	Carats	Value	Value/carats
1926	2446.25	37520	15.338
1927	1675.50	15158	9.047
1928	773.75	14025	18.126
1929	1333.00	17970	13.481
1930	1004.50	7348	7.315
1931	575.50	4797	8.335
1936	4813.00	60702	12.612
1937	3003.75	48122	16.021
1938	805.50	6108	7.583
1939	565.25	3180	5.626
1940	815.25	7206	8.839
1941	345.25	2414	6.992
1942	195.00	1120	5.744
1943	127.25	1342	10.546
1944	148.75	1016	6.830
1945	181.50	2106	11.603
1946	118.25	1428	12.076
1947	194.25	4606	23.712
1948	1115.00	41492	37.213
1949	683.75	19482	28.493
1950	567.50	20580	36.264
1951	215.25	7720	35.865
1952	57.50	1352	23.513
1953	70.00	1000	14.286
1954	52.00	974	18.731
1955	4.25	24	5.647
1956	30.00	1064	35.467
1957	7.75	78	10.065
1959	90.50	2188	24.177
1960	42.25	574	13.586
1961	212.00	3532	16.660
1962	109.00	1391	12.762
1963	62.25	1012	16.257
1964	253.25	8224	32.474
1984	19.19	3015	157.113
1985	10.57	9879	934.626
1986	96.58	68300	707.186
1987	3.35	3085	920.896
1988	8.47	7235	854.191
1989	65.87	33520	508.881
	22897.78	471899	20.609

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/0745
 Farm Badhope (7099), B.W. District

Year	Carats	Value	Value/Carats
1926	49.75	717	14.406
1927	19.25	110	5.714
1928	127.50	2854	22.388
1929	387.50	7616	19.655
1930	468.50	9329	19.913
1931	73.00	331	4.529
1936	67.25	686	10.201
1937	241.75	2370	9.804
1938	26.00	142	5.462
1939	43.00	498	11.581
1940	42.00	232	5.524
1941	142.50	1270	8.912
1942	89.00	704	7.910
1943	105.00	1362	12.971
1944	59.75	602	10.075
1945	114.75	1364	11.887
1946	120.50	478	3.967
1947	261.75	5476	20.921
1948	172.00	7602	44.198
1949	263.50	11322	42.968
1950	93.25	2824	30.284
1951	631.25	34554	54.739
1952	204.75	7010	34.237
1953	226.00	6138	27.159
1954	27.00	706	26.148
1955	1.00	10	10.000
1956	71.50	1744	24.392
1957	18.00	162	9.000
1959	2.50	54	21.600
1961	5.50	52	9.455
1962	124.75	7345	58.878
1963	215.75	15770	73.094
1964	258.00	25267	97.934
1984	16.80	1200	71.429
1985	35.57	15485	435.339
1986	169.75	222100	1308.395
1987	248.75	367445	1477.166
1988	60.25	63500	1053.942
1989	57.63	41350	717.508
	5342.25	867781	162.437

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/0823 and 0826
Farm Gong Gong (48 and B), B.W. District

Year	Carats	Value	Value/carats
1926	1521.00	26171	17.207
1927	1722.00	35041	20.349
1928	309.50	6071	19.615
1929	1345.25	23504	17.472
1930	1141.75	12809	11.219
1931	1032.75	7951	7.699
1936	2919.50	37968	13.005
1937	1477.75	17910	12.120
1938	1657.00	22104	13.340
1939	3773.00	41848	11.091
1940	2267.75	28126	12.403
1941	762.00	7454	9.782
1942	435.25	3526	8.101
1943	463.50	4702	10.145
1944	369.75	4886	13.214
1945	407.75	8494	20.831
1946	327.50	6814	20.806
1947	523.25	9856	18.836
1948	407.50	11828	29.026
1949	278.25	13318	47.863
1950	319.00	8794	27.567
1951	167.25	6084	36.377
1952	122.50	3640	29.714
1953	1886.25	110972	58.832
1954	2623.50	134990	51.454
1955	102.00	13630	133.628
1956	77.75	7237	93.080
1957	318.00	13362	42.019
1959	614.00	19908	32.424
1960	286.75	11912	41.541
1961	110.75	2106	19.016
1962	103.25	3344	32.387
1984	828.90	275330	332.163
1985	778.82	411789	528.735
1986	972.55	729922	750.524
1987	353.43	210390	595.281
1988	1061.50	858210	808.488
1989	365.25	506775	1387.474
	34233.45	3658776	106.877

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/0020

Farm Waldeck's Plant (7296), B.W. District

Year	Carats	Value	Value/Carats
1926	5172.00	98267	19.000
1927	3293.50	58581	17.787
1928	908.50	19925	21.931
1929	3719.25	74737	20.095
1930	3549.50	53910	15.188
1931	1509.75	16448	10.895
1936	3114.50	43690	14.028
1937	2143.25	19680	9.182
1938	2423.50	19940	8.228
1939	1890.75	17212	9.103
1940	937.75	9206	9.817
1941	442.50	3796	8.579
1942	447.25	4190	9.368
1943	339.75	6124	18.025
1944	266.00	3922	14.744
1945	177.00	3280	18.531
1946	514.25	9782	19.022
1947	534.00	15688	29.378
1950	709.00	25142	35.461
1951	390.50	12140	31.088
1952	282.50	6904	24.439
1953	241.00	6776	28.116
1954	187.75	3860	20.559
1955	443.25	10806	24.379
1956	437.00	11784	26.966
1957	401.25	16292	40.603
1959	746.50	23742	31.804
1960	619.50	19554	31.564
1961	660.25	30080	45.559
1962	438.50	11638	26.541
1963	595.00	34730	58.370
1964	760.50	60557	79.628
1984	535.56	154285	288.082
1985	1489.64	451944	303.391
1986	1531.32	910384	594.509
1987	1239.95	782940	631.429
1988	746.39	490250	656.828
1989	569.22	497495	873.994
	44407.58	4039681	90.968

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/6888
 Farm Long Lands (7290), B.W. District

Year	Carats	Value	Value/Carats
1926	1957.75	30597	15.629
1927	690.00	9221	13.364
1928	1458.00	27908	19.142
1929	1375.25	22196	16.139
1930	1150.00	11806	10.266
1931	514.00	2833	5.511
1936	3161.75	33830	10.700
1937	2199.75	26602	12.093
1938	1443.50	15980	11.070
1939	1057.25	10860	10.272
1940	1384.75	15724	11.355
1941	1191.75	17690	14.844
1942	673.25	7152	10.623
1943	627.00	10432	16.638
1944	703.50	10474	14.888
1945	558.25	10778	19.307
1946	615.75	17260	28.031
1947	991.25	19468	19.640
1948	795.50	33040	41.534
1949	419.75	9472	22.566
1950	529.00	17160	32.439
1951	496.25	14636	29.493
1952	380.00	11560	30.674
1953	145.00	6528	45.021
1954	753.25	32718	43.436
1955	314.25	12210	38.854
1956	443.00	19352	43.684
1957	578.25	29788	51.514
1959	325.50	10518	32.313
1960	551.75	28920	52.415
1961	447.25	19196	42.920
1962	358.50	10872	30.326
1963	407.75	22493	55.164
1964	222.00	19714	88.802
1984	1083.54	383671	354.090
1985	1176.49	440847	374.714
1986	1203.60	821280	682.353
1987	1120.49	555926	496.145
1988	592.17	267949	452.487
1989	1135.03	287593	253.379
	35231.07	3356254	95.264

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/1031

Farm Wintersrush (7298), B.W. District

Year	Carats	Value	Value/Carats
1926	741.50	11732	15.822
1927	440.75	6538	14.833
1928	181.75	3682	20.261
1929	346.25	5223	15.083
1930	371.00	3833	10.332
1931	189.00	1161	6.144
1936	747.00	11522	15.424
1937	739.00	9980	13.505
1938	128.75	1046	8.124
1939	147.50	984	6.671
1940	290.75	4098	14.095
1941	92.25	848	9.192
1942	1933.50	19014	9.834
1943	721.50	9484	13.145
1944	1215.25	14644	12.050
1945	926.00	18894	20.404
1946	970.25	25388	26.167
1947	499.00	9130	18.297
1948	208.25	5852	28.101
1949	145.50	3288	22.598
1950	66.50	2732	41.083
1951	77.00	1798	23.351
1952	86.00	1730	20.116
1953	54.25	752	13.862
1954	98.50	2252	22.863
1956	81.50	6128	75.190
1957	266.00	18604	69.940
1959	638.75	26800	41.957
1960	1490.75	53036	35.577
1961	1193.00	43746	36.669
1962	272.50	6679	24.510
1963	85.25	4506	52.856
1964	333.00	25724	77.249
1984	36.40	21456	589.451
1985	66.94	13025	194.577
1986	83.06	33385	401.938
1987	52.02	16205	311.515
1988	277.70	369555	1330.771
1989	259.37	431745	1664.591
	16553.24	1246199	75.284

APPENDIX 4: ANNUAL DIAMOND PRODUCTION DATA (CONTINUED).

Publication MFA/0823

Farm Delports' Hope (7280), B.W. District

Year	Carats	Value	Value/Carats
1926	1611.75	14907	9.249
1927	706.50	11561	16.364
1928	1657.75	27614	16.658
1929	4419.50	67524	15.279
1930	2790.00	37069	13.286
1931	1207.75	8479	7.021
1936	1923.00	10030	5.216
1937	803.75	7900	9.829
1938	408.00	2450	6.005
1939	240.50	1146	4.765
1940	695.75	7396	10.630
1941	277.00	3000	10.830
1942	186.75	1574	8.428
1943	94.00	974	10.362
1944	156.00	1834	11.756
1945	148.25	2326	15.690
1946	367.25	6564	17.873
1947	86.75	702	8.092
1948	77.50	1992	25.703
1949	217.00	6772	31.207
1950	238.00	10514	44.177
1951	478.00	22486	47.042
1952	242.75	7262	29.916
1953	523.75	20004	38.194
1954	458.75	15256	33.256
1955	132.50	3870	29.208
1956	247.25	6756	27.325
1957	163.25	4660	28.545
1959	173.25	4150	23.954
1960	122.25	4758	38.920
1961	351.00	13867	39.507
1962	447.50	16422	36.697
1963	695.00	25044	36.035
1964	614.75	44569	72.499
1984	530.07	201520	380.176
1985	990.36	365280	368.836
1986	815.57	331641	406.637
1987	2517.34	301992	119.965
1988	698.07	314910	451.115
1989	248.82	705810	283.663
	28762.23	2007356	69.791

LEGEND



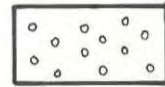
Hutton Sands



Surface limestone



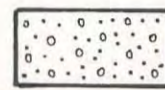
Riverton Formation



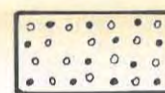
Rietputs C



Rietputs B



Rietputs A



Older Gravels



Farm boundary



Main road



Scarp



Proksh Koppie Platform

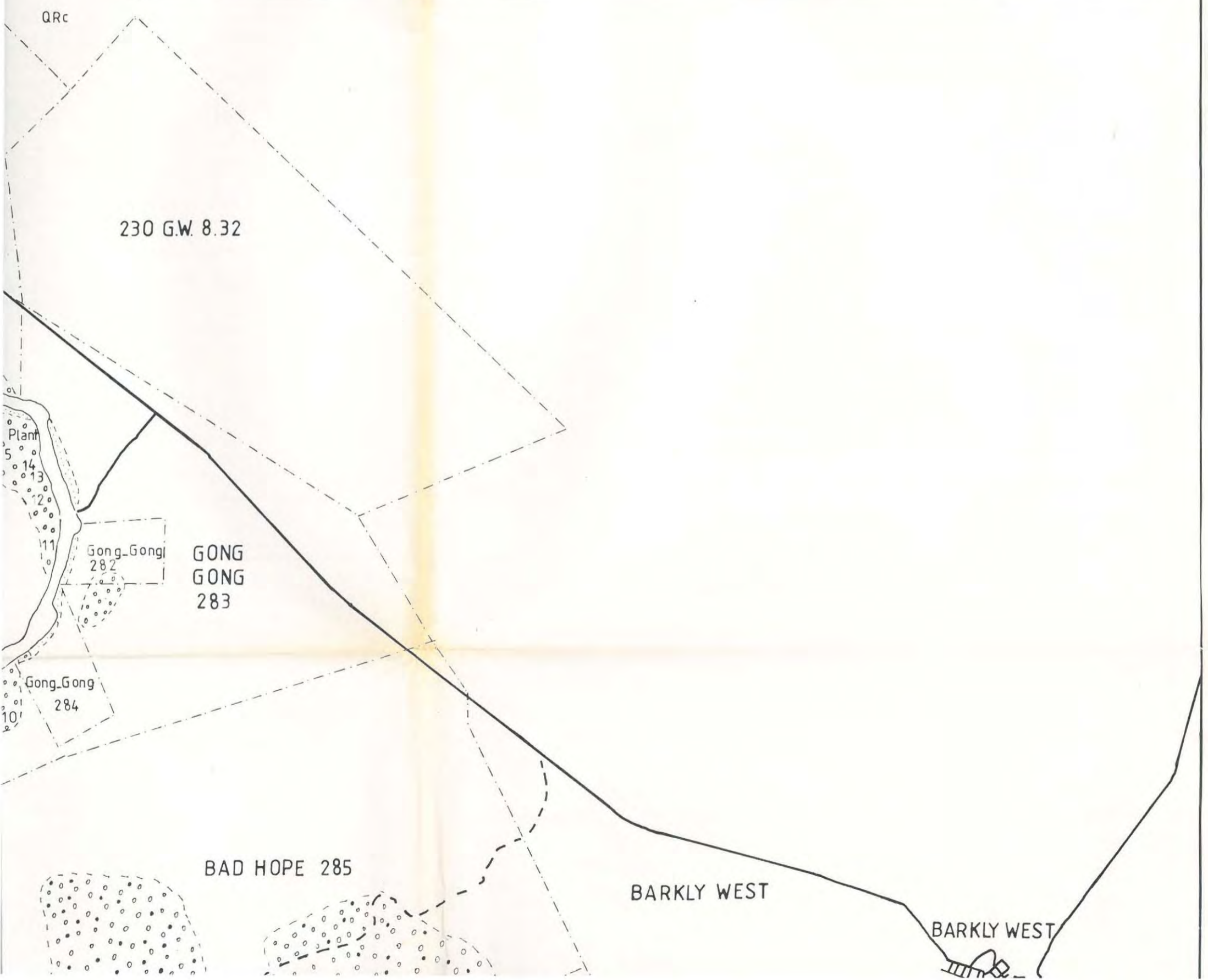


Town

17

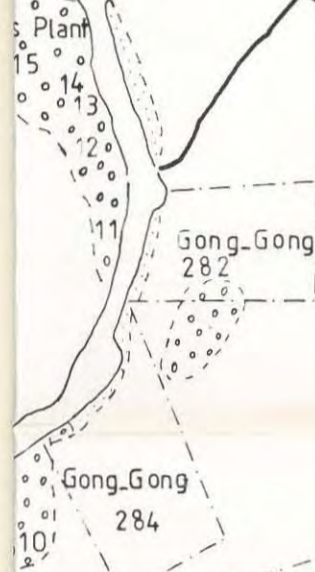
Station number

SCALE: 1:50.000



QRc

230 G.W. 8.32



GONG
GONG
283

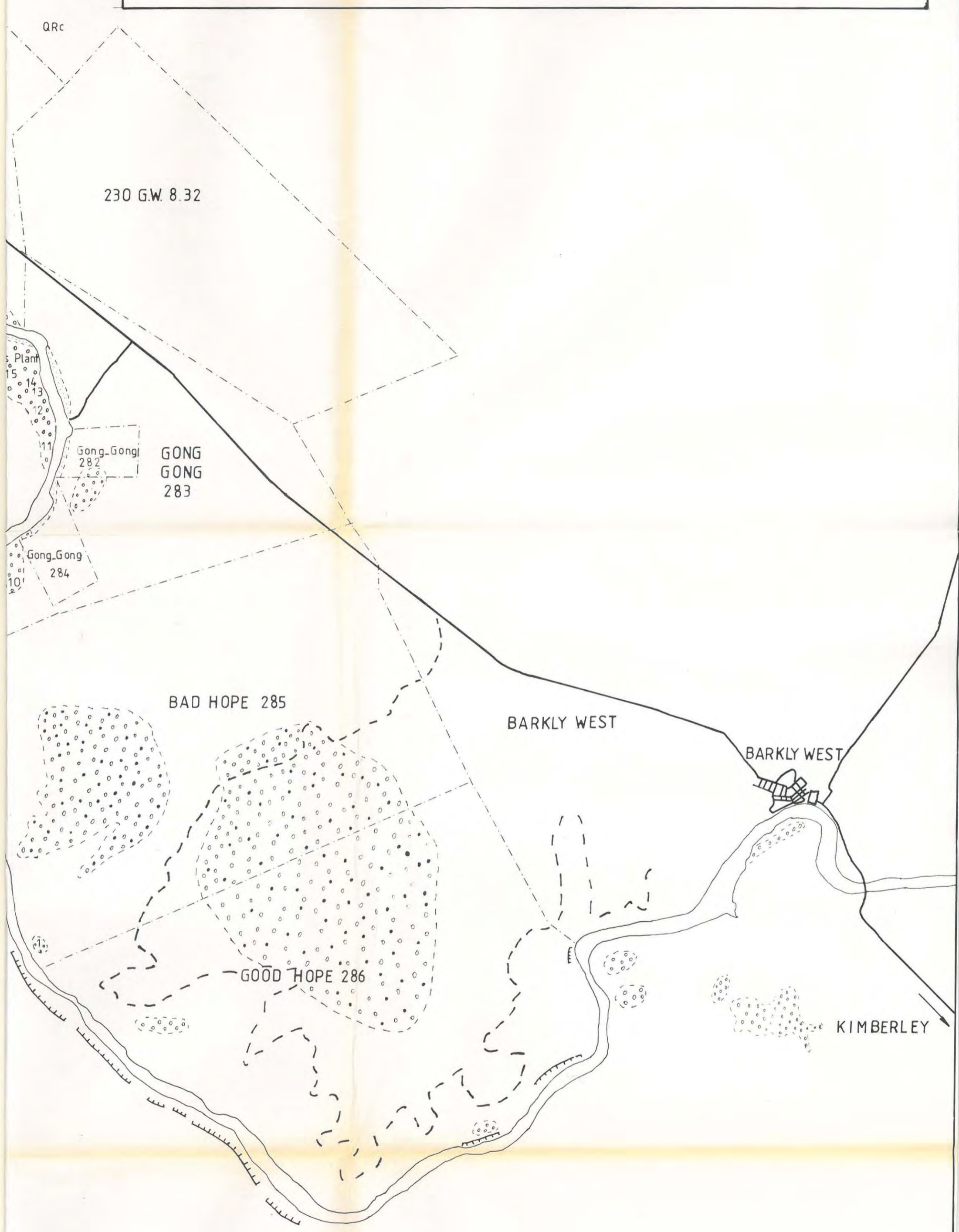
BAD HOPE 285

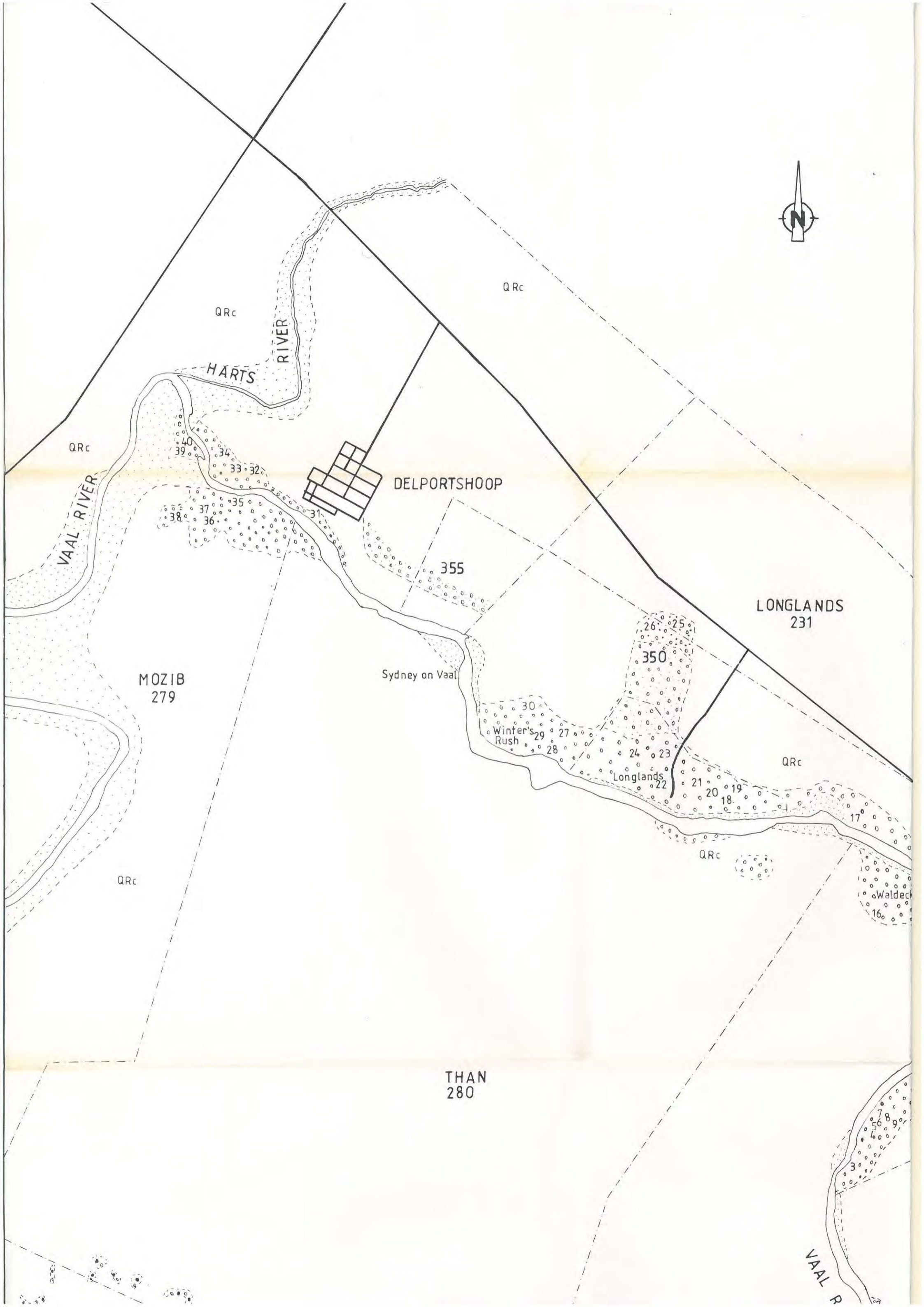
BARKLY WEST

BARKLY WEST

GOOD HOPE 286

KIMBERLEY





QRc

QRc

QRc

DELPORSHOOP

355

LONGLANDS
231

MOZIB
279

Sydney on Vaal

350

Winter's
Rush

QRc

Longlands

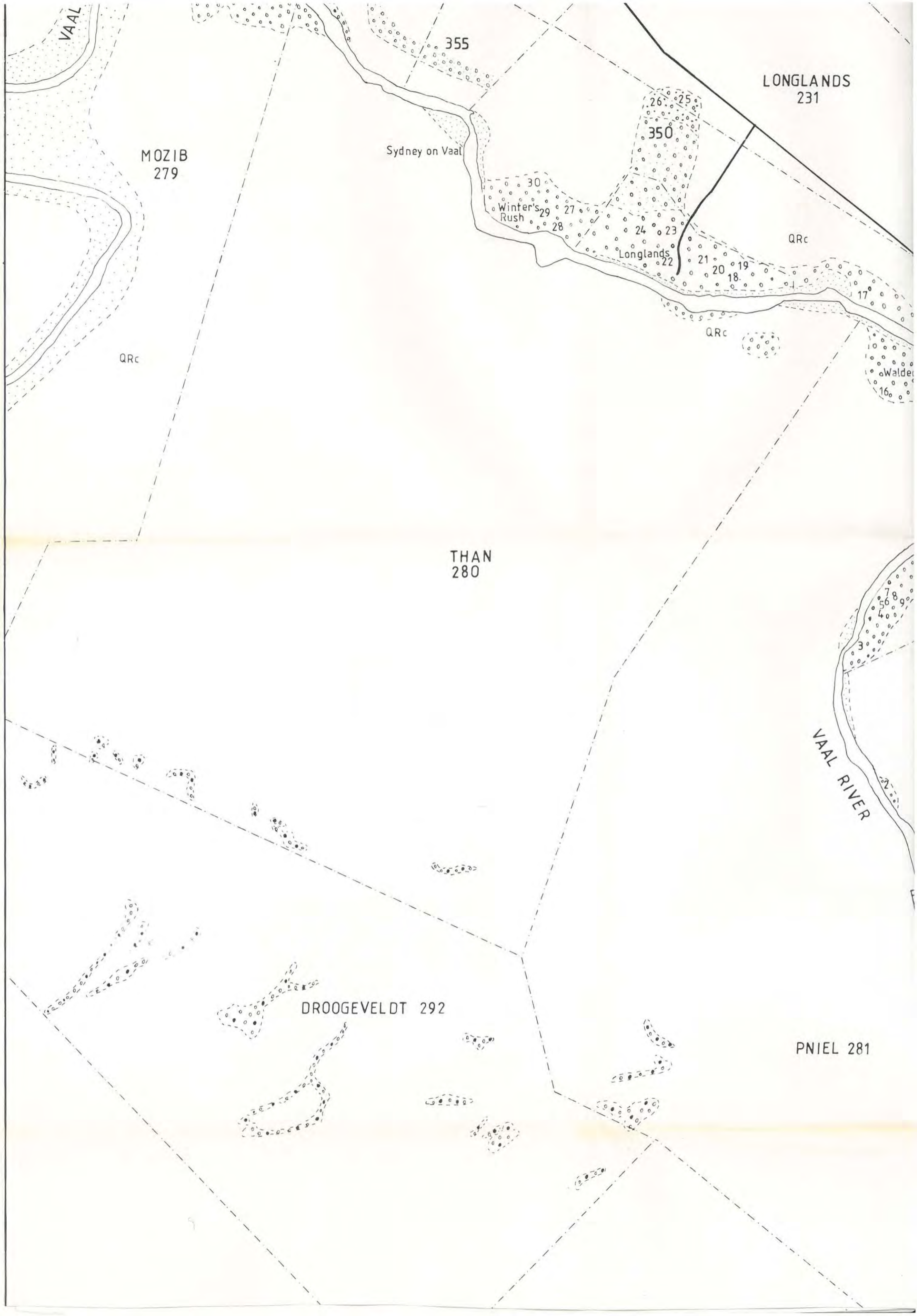
QRc

Waldeck
16

QRc

THAN
280

VAAL R



VAAL

MOZIB
279

Sydney on Vaal

355

LONGLANDS
231

350

Winter's
Rush

QRc

Longlands

QRc

QRc

Walder

THAN
280

VAAL RIVER

DROOGEVELDT 292

PNIEL 281