THE CENOZOIC STRATIGRAPHY AND ASSOCIATED HEAVY MINERAL PALAEO-PLACER DEPOSIT ON GEELWAL KAROO: WEST COAST, SOUTH AFRICA.

by

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree. Where use was made of the work of others, it has been duly acknowledged in the text.

L. Elferink **Date:**

ABSTRACT

The farm Geelwal Karoo is situated some 16km north of the Olifants River mouth on the West Coast of South Africa and hosts fluvial, marine and aeolian deposits of post-Gondwana age. The oldest basal fluvial succession, unconformably overlies Proterozoic and Palaeozoic basement rocks and is in turn capped by aeolianite and littoral packages representing two transgressive cycles.

The fluvial channel clay succession is deposited in shallow bedrock-incised channels, has a wedge-shape and is deposited parallel to the present coastline. The flow direction is along the coast and the northward-tapering, angular, poorly sorted basal vein-quartz lag indicates a northward palaeo-flow direction. Less than 1% total heavy minerals (THM) is found in the matrix of these gravel units and the heavy mineral suite is distinguished by zircon, pseudorutile and kyanite. The channel clay unit is dominated by an upper, medium-grained quartzose sand and kaolin clay facies, which shows advanced post-depositional weathering. The fluvial unit is correlated with the channel clay unit of Hondeklip Bay and a Cretaceous age is proposed for the initial channel incision.

The two shallow marine successions have been correlated with the Late Miocene, Early Pleistocene, +30m and +50m packages respectively. These marine sediments were first described by John Pether (1994) in the Hondeklip Bay area and were named according to their transgressive maxima. They are transgressive successions arranged *en echelon* down the coastal bedrock gradient, from oldest and highest to youngest. The offshore environment of the +50m package consists of fine silty sand, which is moderately sorted. The mineral assemblage is dominated by quartz and the average THM is 18%. The inshore environment is distinguished by a single poorly sorted basal cobble lag which shows an overall fining upward succession. The beachface environment is composed of medium to fine-grained sand, which is moderate to well-sorted. Mineral diversity is greatest in the inshore and beachface environments and the average THM for these two units is greater than 35%. The +30m package has been extensively eroded due to its lower erosion and outcrops were sporadic along the coast. The +30m offshore sediments are recognised by fine sediments with high concentrations of glauconite and organic matter. The inshore environment is distinguished by numerous poorly sorted pebble lags with fining upward successions. Both the inshore and beachface units have higher feldspar concentrations than the corresponding +50m units. The average THM for these two units is less than 3%.

The aeolianite unit, which comprises several distinct units, extends over the entire length of the study area and is characterized by calcrete and red bed horizons. Colour variations in the otherwise homogeneous unit are due to heavy mineral enrichment and/or different degrees of *in situ* weathering and cementation. The unit is composed exclusively of fine- to medium-grained sand and the THM concentration averages 9%. This unit is composed of more than one generation of aeolian sand and forms part of an aeolian transport corridor which transported sand from the beach to the interior. The oldest unit has been equated with the Upper Miocene Prospect Hill Formation, whereas the more recent yellow dune sand is equated with the Pleistocene Springfontyn Formation.

At Geelwal Karoo, only the heavy sand placer in the +50m package was deemed to be of any economic significance. The average THM of this placer was calculated to be 40% and some 150 thousand tons of Ti-bearing material can be expected from this succession. This relatively small volume of heavy minerals and extensive cementation however, make this placer a less attractive prospect than the neighbouring Namakwa Sands operation.

OPSOMMING

Die plaas Geelwal Karoo is ongeveer 16km noord van die Olifantsriviermond aan die Weskus van Suid-Afrika geleë en het voorkomste van fluviale, marine en eoliese afsettings van post-Gondwana ouderdom. Die oudste eenheid, ‘n basale fluviale eenheid, oorlê Proterosoiëse en Paleosoiëse plaaslike vloer gesteentes wat op hulle beurt weer bedek word deur eoliese en littorale eenhede verteenwoordigene ven twee transgressiewe siklusse.

Die fluviale kanaalklei-opeenvolging, afgeset in vlak ingesnyde rotsbedding-kanale, is wigvormig en is afgeset parallel aan die huidige kuslyn in ‘n alluviale waaier-afsetting. Die vloeirigting was langs die kus en die noorwaards toespitsende, hoekige, swak gesorteerde basale aar-kwarts bodemgruis dui op ‘n noordwaards palaeo-vloeirigting. Minder as 1% totale swaarminerale (TSM) is gevind in die tussenmassa van hierdie gruis-eenhede en die swaarmineraal reeks word onderskei deur sirkoon, pseudo-rutiel en kianiet. Die kanaalklei eenheid word oorheers deur ‘n boonste, medium-korrelrige kwarts-bevattende sand en kaolien kleifasies was dui op gevorderde verwering na afsetting. Die fluviale eenheid word gekorreleer met die kleikanaal en ‘n Kryt-ouderdom word voorgestel vir die aanvanklike insnyding van die kanaal.

Die twee vlak marine opeenvolgings word gekorreleer met die Laat Mioseen, vroeg Pleistoseen, naamlik die +30m en +50m eenhede onderskeidelik. Die aflandige omgewing van die +50m eenhied bestaan uit matig-gesorteerde, fyn slikkerige sand. Die mineraalversameling word oorheers deur kwarts en die gemiddelde TSM is 18%. Die subgetysone word onderskei deur ‘n enkele swak-gesorteerde gruislaag en is oorwegende opwaarts fynerwordend. Die strandomgewing is goed verteenwordige en bestaan uit matig tot goed-gesorteerde medium- tot fynkorrelrige sand. Die grootste mineraal-diversiteit kom voor in die subgety- en strandomgewings en die gemiddelde TSM vir hierdie eenhede is hoër as 35%.

As gevolg van algemene erosie kom die +30m eenheid sporadies voor. Die aflandige omgeving is herken deur fyn kleierige of slikkerige sedimente met hoe konsentrasies gloukoniet en organiese materiaal. Die subgetysone omgewing is gekenmerk deur verskeie gruislae wat almal opwaarts fynwordend is. Altwee die subgety- en strandomgewings het hoer feldspar konsentrasies as die +50m eenhede. Die gemiddelde THM vir hierdie enhede is minder as 3%.

Die eolitiese eenheid, bestaan uit verskeie duidelik-onderskeibare eenhede, beslaan die totale lengte van die studiegebied en word kenmerk deur uitgebreide kalkreet en rooi-laag horisonne. Kleurverskille in die andersins homogene eenheid kan verklaar word in terme van lae swaarmineraal konsentrasies en/of as gevolg wan verskillende grade van *in situ* verwering en sementering. Die eenheid bestaan uitsluitlik uit fyn- tot medium-korrelrige sand en het ‘n gemiddelde TSM konsentrasie van 9%. Die eenheid bestaan uit meer as een generasie eoliese sand en maak deel uit van ‘n eoliese vervoersisteem wat sand vanaf die strand na die binneland vervoer het. Die oudste sande in hierdie eenheid is gekorreleer met die Laat Mioseen Prospect Hill Formasie terwyl die meer onlangse geelduin sand vergelyk word met die Pleistoseen Springbokfontein Formasie.

By Geelwal Karoo is slegs die +50m eenhede beskou as economies van belang. Die gemiddelde TSM van hierdie swaarmineraal-ertsligaam is bereken op 40% met 'n verwagte 150 duisend ton Ti-draende material van die opeenvolging. Die relatiewe klein volume swaarminerale en uitgebreide sementering het tot gevolg dat dit 'n minder aanloklike proposisie is as die aanliggende Namakwa Sands aanleg.

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1. INTRODUCTION

Geelwal Karoo is situated on the West Coast of the Republic of South Africa, approximately 20km south of the Namakwa Sands, Graauwduinen development (Figure 1.1). Whilst the main economic resource in this area lies offshore in the diamond mining operations, Geelwal Karoo is also host to a heavy mineral placer (Macdonald and Rozendaal, 1995a) on land. The former is exploited by a number of private enterprises which, in turn, operate under the auspices of the Cape Town based company, Trans Hex Group Ltd.

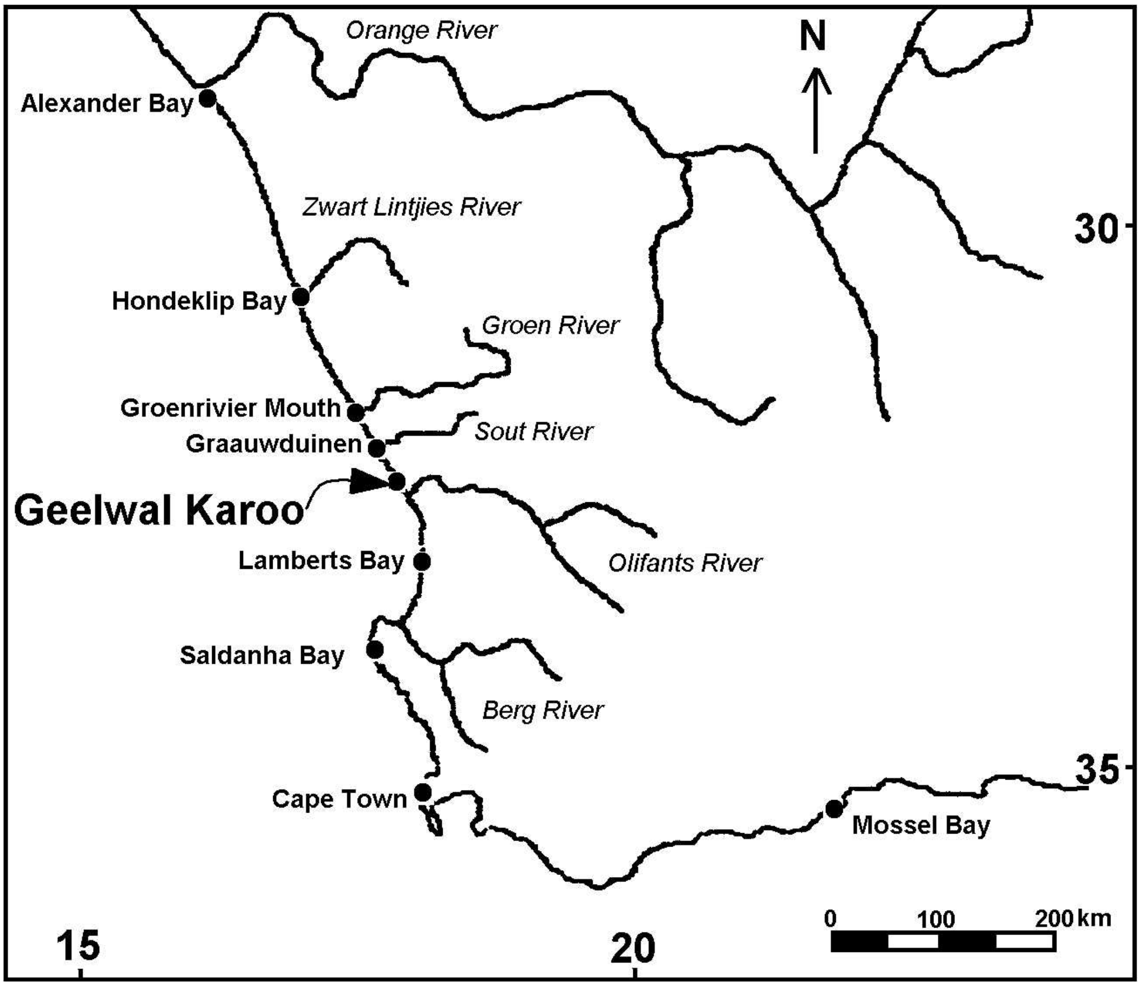


Figure 1.1 The coastline of southwestern Africa, showing the location of the study area.

1.1 Aims and Methods

The aims of this study were to map and describe the Cenozoic sedimentary successions found on the farm Geelwal Karoo. At the start of this study the records of the Cenozoic stratigraphy of this area were non-existent and the aim was therefore to compare these sediments to the rest of the West Coast and to incorporate them into a regional geological model.

The field work for this study was limited to the sedimentary successions found between 10 and 80 meters above sea level (a.s.l.) and included detailed mapping and sampling of the alternating consolidated and unconsolidated gravel, sand and clay layers. At Geelwal Karoo the sediments occur as windows in the recent aeolian sand sheet and these exposures were mapped on a scale of 1:200 as a series of profiles. A lithostratigraphic column incorporating all the field data was made for each of the profiles (Appendix I) and this is summarized in Appendix II.

In the light of the diamond and heavy sand placers found further northwards along the coast, an additional aim of this study was to explore the economic potential of these resources. To allow for comparison with the previous studies on West Coast heavy minerals by Cilliers (1995), Macdonald (1996) and Philander (1999) uniformity was maintained with regard to practical methodology. Consequently grain size analyses, heavy mineral separation and microscope techniques are the same for all these studies, including the present one. This project differs from previous studies in that particle size analyses (sedigraph analysis, supported by XRD) were conducted for the very fine fractions (clays and silts).

1.2 Previous studies

The first descriptions of the palaeontology of the Cenozoic sediments found on land were by Haughton (1931), Carrington and Kensley (1969), and Rogers (1977).

Hendey (1981) matched these observations to sea level fluctuations on a fixed time scale and proposed four late Cenozoic shorelines for the West Coast. These he named according to their elevation above sea level namely; the +90m, +50m, +30m and +20m shorelines. Differences in the physical geography prompted Hendey to divide the West Coast into two regions: i) False Bay to the Olifants River, which he named the Southwestern Cape Coast, and ii) the Olifants to the Orange River Mouth, which he termed the Namaqualand Coast. The Namaqualand Coast is characterised by shorelines which are incised into bedrock and which consequently have a more or less regular north north-west to south south-east trend. These marine terraces are situated at high elevations and in places can reach a maximum of +100m a.s.l.

Using the outcrops he found at Hondeklip Bay, Pether (1986, 1994) redefined Hendey's classification scheme and described the Cenozoic outcrops in terms of marine packages (Figure 1.2).

Using the elevation of the transgressive maximum as a distinguishing characteristic, these packages were named as the +90m package, +50m package, +30m package and +20m package, respectively. These packages are of formation status, but as yet have not been accepted by SACS (1980) and are thus presently included in the Alexander Formation. The ages assigned to the various marine packages have however come under debate and review (Pether, *et al*., 2000). These changes will be discussed in Chapter 4.

Pether's (1994) classification scheme found favour with several authors including Cole and Roberts (1996). Their publication briefly touches on the stratigraphy found on the farm adjacent to Geelwal Karoo, but concentrates on describing the lignite deposits found in the unexposed, fluvial sediments in the area.

Of economic relevance is the work by De Decker (1982, 1986, 1988) in which he discusses the factors influencing the diamond distribution on the inner shelf between the Orange River Mouth and Wreck Point in Namaqualand. His observations are based on high-resolution seismic profiles, which extend from the breaker zone to a depth of -500m below sea level. He gives a general view on the currents, sea level curves and offshore sediments associated with the diamond concessions along the West Coast.

Coetzee (1957) was the first to mention the heavy sand placer found in the dunes of Geelwal Karoo. Palmer (1994) released a publication on the Graauwduinen heavy sand deposit found 20km to the north. A year later Cilliers (1995) completed an M.Sc. thesis on the mineralogy and sedimentolgy of the Graauwduinen deposit. Visser and Toerien (1971), Hammerbeck (1976), Macdonald and Rozendaal (1995a), Macdonald (1996) and Philander (1999) discuss the mineralogy and chemistry of the heavy sand placer found on the present Geelwal Karoo beach.

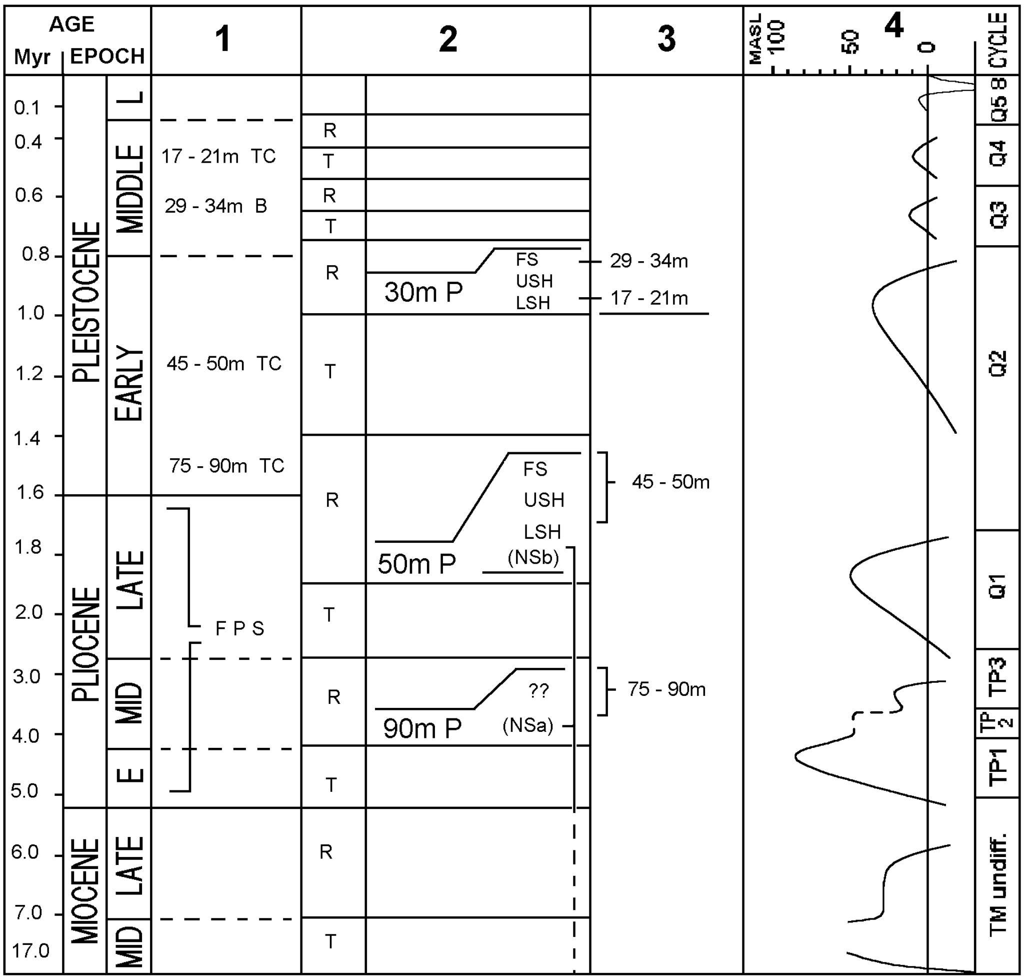


Figure 1.2 West Coast stratigraphy: summary of previous work. *Column 1:* succession after Carrington and Kensley (1969); TC, transgression complex; B, beach; FPS, fossiliferous phosphatic siltstones. *Column 2:* succession after Pether (1986); R, regression; T, transgression; 30m P, 30 metre Complex; 50m P, 50 metre Complex; 90m P, 90 metre Complex; FS, foreshore facies; USH, upper shoreface; LSH, lower shoreface; NSb, 50m Complex nearshore shelf; NSa, 90m Complex nearshore shelf. *Column 3:* correlation between Carrington and Kensley (1969; Col. 1) and Pether (1986; Col. 2). *Column 4*: Neogene and Quaternary sea-level cycles modified from Vail and Hardenbol (1979).

1.3 Physiographic setting

1.3.1 Climatic evolution

Along the West Coast, there was a dramatic change over time from a warm, pluvial climate in the Late Cretaceous and Middle Miocene to an arid, more inhospitable habitat in the Tertiary and Quaternary (Cole and Roberts, 1996). These observations were confirmed by the pollen grains in the lignite beds in the channel clay formation near Koekenaap (Cole and Roberts, 1996), which support evidence for dense foliage in the Middle Miocene.

At Langebaanweg, Hendey (1981) noted the changes in the fossil record of the onshore marine sediments and concluded that by the Early Pliocene, the tropical forests of the West Coast had given way to grassland and "fynbos", typical of a more temperate climate with winter rainfall. Hendey (*op. cit.*), however, also mentions that the fossils related to the oldest marine incursion, the +90m transgression (Figure 1.2), were associated with cold-water conditions, which he ascribed to an ice age that occurred in the Late Miocene. He further states that the sea temperature started rising as the sea transgressed, so that, by the Late Pliocene - early Pleistocene, the fossils of the +50m and +30m packages reflect warmer water conditions. Pether (1994) went on to suggest that the presence of *Choromytilus meridionalis* in the +30m package, hinted at a colder sea, but that the fossils records of the +50m and +30m packages were too similar, to be able to determine exactly when the sea water became colder.

Colder oceanic conditions and the phenomenon of upwelling have been associated with the gradual drying out of the interior. Parrish and Curtis (1982) indicate that the South Atlantic Anticyclone may have begun to influence the West Coast surface wind pattern during the Late Cretaceous, becoming more established in the Palaeocene. Today the West Coast has a Mediterranean climate with a low, winter rainfall and at Geelwal Karoo the predominant wave incidence is from the SW to S, (CSIR, 1984). Throughout the year, along the West Coast wave heights in excess of 5m occur along the upper shoreface (inshore) and according to De Decker (1988) 95 % of the time the wave conditions of the West Coast are capable of transporting very coarse sand at a depth of 20m. For the other 5% of the time, storm winds from the northwest, with an average speed in excess of 30 knots, prevail (Taljaard, 1972). The resulting waves are able to move medium pebbles and small cobbles. These storms may also result in brief reversals in the Benguela current direction. These short-lived reversals in the current direction aid the diamond mining industry as finer sediments are removed from the near-shore and heavy minerals are thereby concentrated.

Changes in sea level or eustatic cycles, according to Schopf (1980) are the result of one or more of the following phenomena; ice ages, sea-floor spreading and tectonism, isostatic sinking of sedimentary basins, and the drying up or filling up of large basins. Of the four phenomena, ice ages and tectonism appear to have been the most common reason for affecting the Cenozoic eustatic cycles of the West Coast. Sea level curves have proved to be the most important form of gross indicators for correlation purposes. The history of sea level fluctuations in the Cenozoic sedimentary record along the West Coast will be discussed in detail in Chapter 2.

Marine still-stands occupy a very short span in geological time and therefore are not immediately apparent. Marine still-stand implies a lack of fluctuation in mean sea level over time and, by virtue of the greater sorting capacity, they have played a crucial role in the formation of diamond- and heavy sand-bearing deposits along the West Coast.

An important diamond placer-forming still-stand occurred roughly 20 Ma ago (De Decker, 1986) whereas at Geelwal Karoo such a process is evident in the heavy sand placer within the units of the +50m package and on the present beach, (Macdonald and Rozendaal, 1995a).

1.3.2 Coastal morphology

The topography of the coastline at Geelwal Karoo can be seen in Figure 1.3. In the south, the coastline is dominated by a pronounced J-Bay in the region of Cliff Point.

The surface contours of Cliff Point show the development of high sea cliffs, formed out of the more erosion resistant Peninsula Formation. The J-Bay environment has been instrumental in the formation of heavy sand placers in this area and evidence of this can be found in the superimposed foreshore facies of the various marine packages. Also in the Cliff Point area, the fault zone between the different bedrock types appears to have been exploited by an ancient river system and evidence of this can be found in the outcrops of channel clay formation.

1.3.3 Sediment Supply

The catchment of the Olifants River has a total length of 1080km and drains the Winterhoek Mountains in the west and the Skurweberg in the east (Figure 1.4). In the south, the Olifants River branches out into the Doring River. This river is semi-permanent, although its flow can vary considerably. In winter the run-off and flow from the western Karoo escarpment is fast and large quantities of silt may be introduced into the Olifants River. The Olifants catchment area in the north consists mainly of ephemeral rivers, the most important of these being the Hol River.

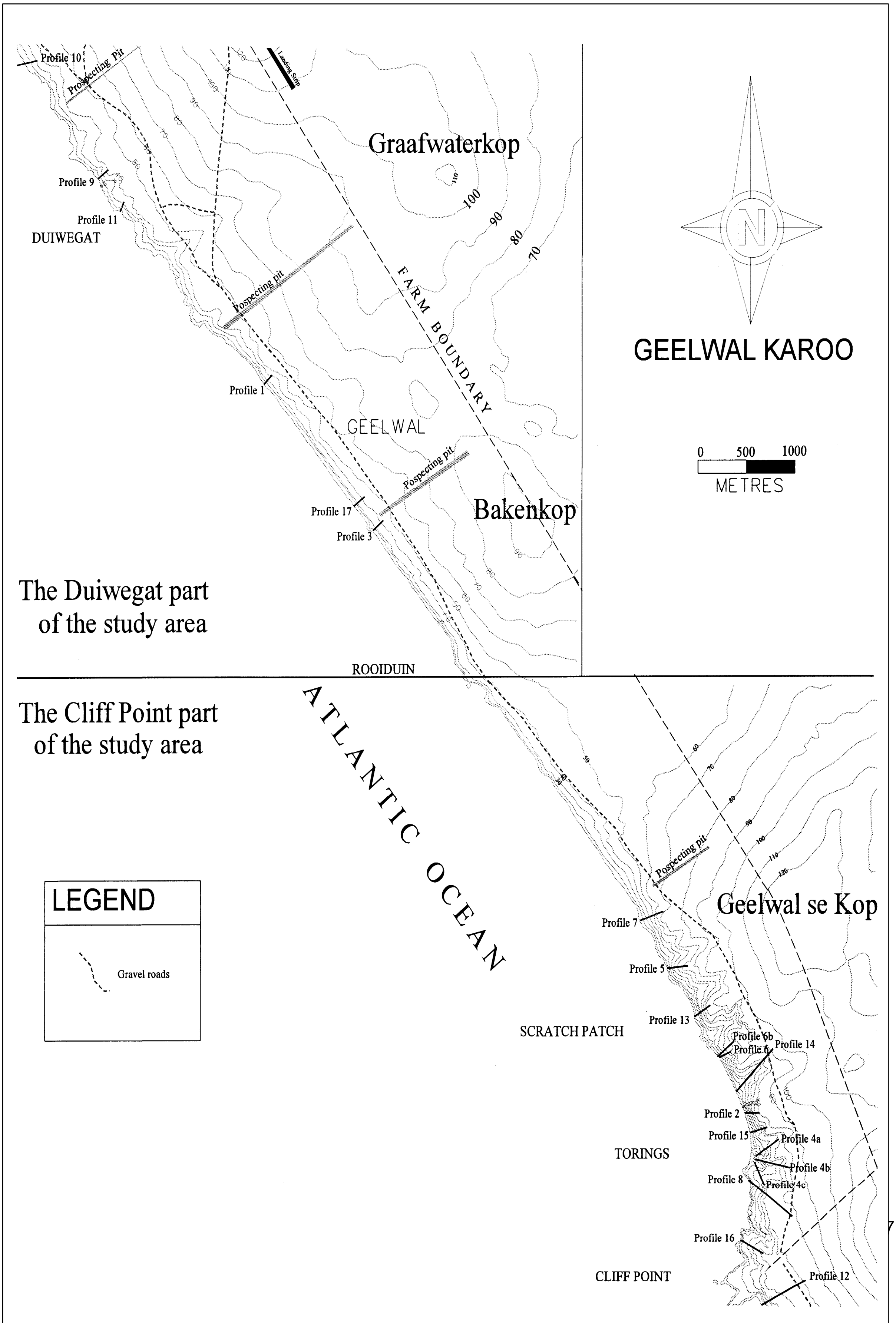

Profile 10
Prospecting Pit
Landing Strip
Graafwaterkop
110
100
90
80
70
Profile 9
Profile 11
DUIWEGAT
Pospecting pit
FARM BOUNDARY
Profile 1
GEELWAL
Pospecting pit
Bakenkop
Profile 17
Profile 3
The Duiwegat part
of the study area
ROOIDUIN
GEELWAL KAROO
0
500
1000
METRES
The Cliff Point part
of the study area
ATLANTIC OCEAN
LEGEND
Gravel roads
Pospecting pit
Geelwal se Kop
Profile 7
Profile 5
Profile 13
SCRATCH PATCH
Profile 6b
Profile 6
Profile 14
Profile 2
Profile 15
Profile 4a
TORINGS
Profile 4b
Profile 8
Profile 4c
Profile 16
CLIFF POINT
Profile 12

Figure 1.3 Topographic map of Geelwal Karoo showing the localities of each of the stratigraphic profiles.

The numerous palaeo-river beds found eroded into the escarpment and coastal lowlands along the West Coast suggest a history, in stark contrast to the present, of active fluvial erosion and sedimentation. The majority of these rivers appear to have been active in the Miocene, when they supplied the continental shelf with vast amounts of terrigenous material.

The fact that the erosion of Krom River is presently seen as being out of proportion to its present size has led numerous authors to propose that in the Palaeogene there was a connection between the Olifants and the Orange/Vaal drainage systems (Dingle and Hendey, 1984, De Wit, 1993). The sediment discharge from the Olifants/Orange River at this time has been estimated to be at a rate of 2 x10^6 m^3 per year. This is considerably lower than the rate seen in the Cretaceous Period.

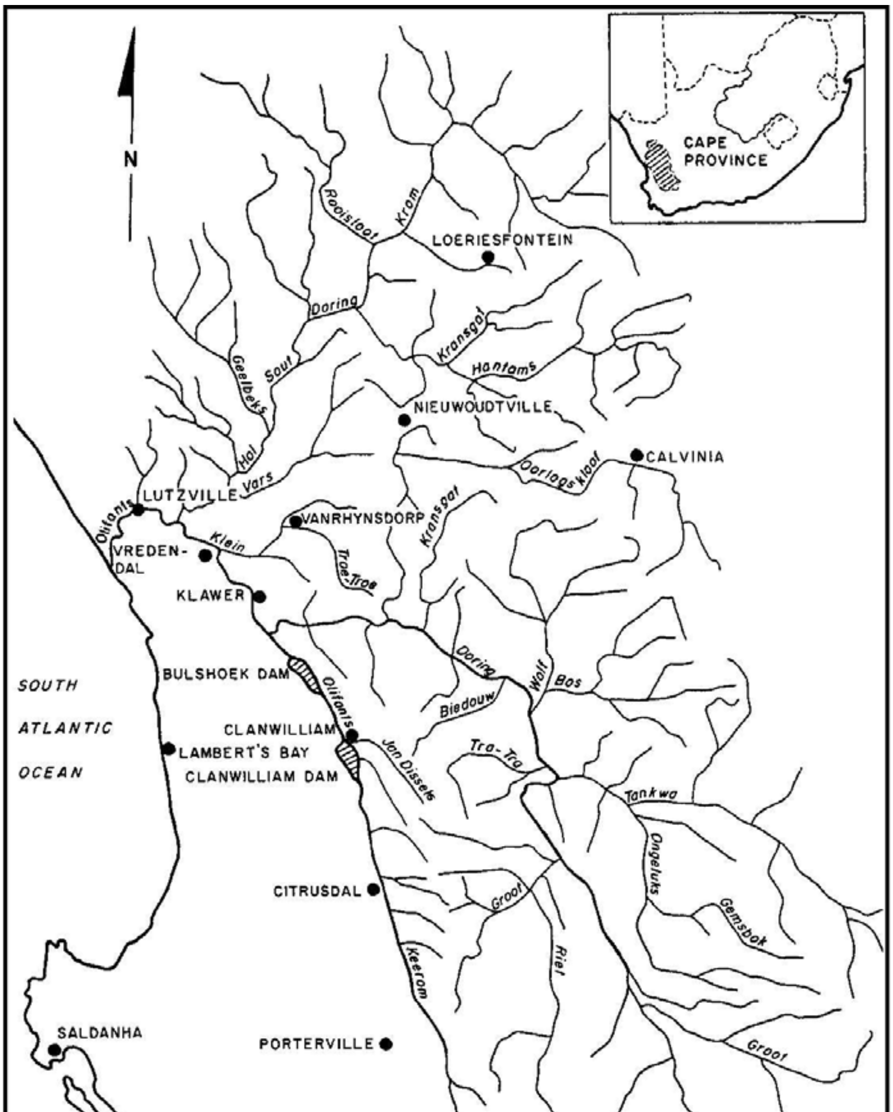


Figure 1.4 The Olifants River catchment area. (CSIR report no 26, 1984)

By the early Tertiary the bulk of the erosion was complete and, coupled with the change to a drier climate, the sediment supply to the continental shelf was drastically reduced. In the Miocene, the main drainage pattern had evolved to form the present Orange and Olifants Rivers (De Decker and Woodborne, 1996).

Evidence for the southward migration of the Olifants River Mouth can be seen in relict gravel terraces found at elevations well above the present river level. One such gravel terrace is found on the northern bank, +27m above the present Olifants River Mouth (CSIR, 1984). Another gravel terrace was found approximately 16km north of the present mouth at an elevation of about +15m above its present level.

Narrowly linked to the evolution of drainage patterns along the West Coast are the changes in provenance reflected in the sediment load of the river systems. During the Cretaceous Period this appears to have been particularly true for the ancient Olifants River which not only played a role in supplying a bedload fraction of sand and gravel but also produced a sediment composition unlike that seen in the Tertiary and Quaternary Periods. The change in the provenance of the Olifants River is reflected in the channel clay formation found at Cliff Point.

By the Late Cretaceous, the link with the Orange/Vaal system was established and erosion of the interior was starting to decrease. Over this period, the sediment load of the Olifants River changed dramatically. About 1400m of the interior had been eroded and introduced to this drainage system (De Decker and Woodborne, 1996). This produced a bedload of argillaceous Karoo gravels and a matrix of heavy minerals and quartz.

2. REGIONAL GEOLOGICAL SETTING

The regional geology of the Geelwal Karoo area is summarised in Figure 2.1 and in the table below.

AGE	DESCRIPTIVE NAMES	STRATIGRAPHIC CLASSIFICATION
<1 Ma	Present beach placer unit, red aeolian sand	Alexander Fm, Witzand Fm
?1 – 3 Ma	+30m package, basal marine gravel unit	+30m package (Alexander Bay Fm)
1 – 2 Ma	Yellow sand unit, aeolianite unit	Springbokfontein Fm
2 – 5 Ma	Palaeoplacer strandline, basal marine gravel unit	+50m package (Alexander Bay Fm)
10 – 12 Ma	Dorbank unit, blood red Aeolian sand unit, aeolianite unit	Prospect Hill Fm
17 – 19 Ma	Dipping marine placer	+90m package (Alexander Bay Fm)
10 – 115 Ma	Cretaceous delta unit, channel infill unit, fluvial unit, alluvial unit, channel clay unit	None
145-190 Ma	Dolerite	Karoo Dolerite Suite
480-460 Ma	Table Mountain Sandstone	Peninsula Fm, Table Mountain Group, Cape Supergroup
780-650Ma	Gariep phyllites, schists and dolomites	Widouw and Atties Fm, Gifberg Group, Gariep Supergroup
1147-1184Ma	Namaqua Metamorphic Complex gneiss	Bushmanland Group, Little Namaqualand Suite, Landplaas Gneiss, Namaqualand Metamorphic Province

Table 2.1 A summary of the stratigraphy of Geelwal Karoo.

2.1 Basement Geology

The oldest outcrops found in the study area belong to the mid-Proterozoic Namaqualand Metamorphic Province (NMP) (Kröner, 1968) and these are found in the Duiwegat area (Figure 2.1). On Geelwal Karoo, the quartz-feldspar biotite Landplaas Gneiss was identified (De Beer *et al.,* 2002). These gneisses form part of the intrusive rocks associated with the Little Namaqualand Suite of the NMP.

The Late Proterozoic Gariep Supergroup features prominently in the basement geology of the West Coast and represents the southern coastal branch of the Damara orogen (Germs and Gresse, 1991; De Beer *et al.*, 2002).

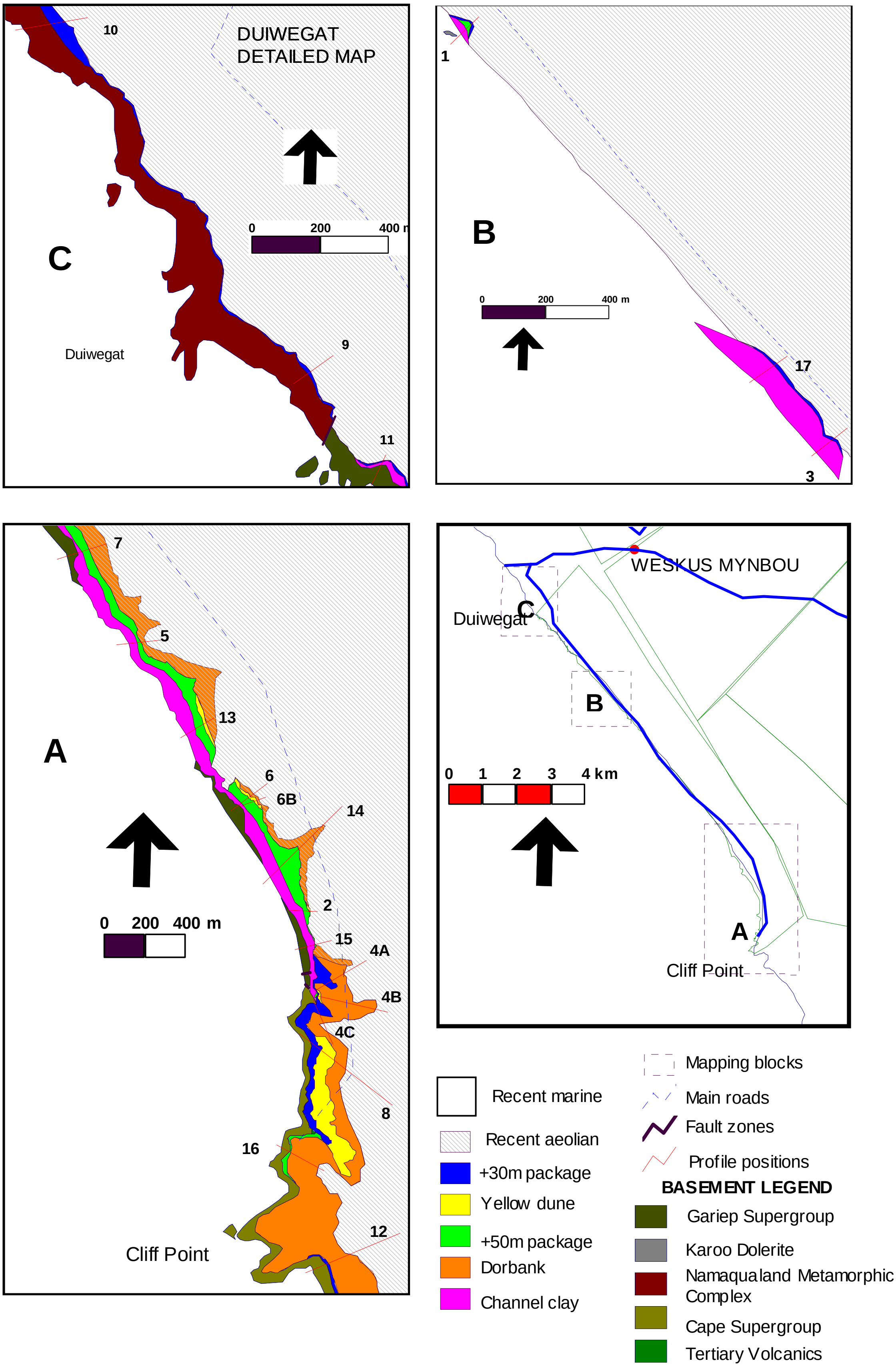


Figure 2.1 The regional geology of Geelwal Karoo. The best exposure of the Cenozoic geology coincides with the position of the profiles.

At Geelwal Karoo the Widouw and Atties Formations (Figure 2.1) have been identified (De Beer *et al.*, 2002) and these are seen to represent deeper-water facies of a pull-apart basin formed in response to the faulting related to a transtensional rift margin. The Widouw Fm is represented by a series of dolomites and phylittes whereas the Atties Fm consists of the quartzites found near Duiwegat.

At Cliff Point, the Peninsula Formation of the Ordovician / Silurian Table Mountain Group is found overlying the Gariep Supergroup (Tankard *et al*., 1982, Macdonald and Rozendaal, 1995a; De Beer *et al.*, 2002, Figure 2.1; Photograph 2.1). These massive orthoquartzite outcrops are characterised by an easterly dip of 16^{o} and are almost completely white, except for a black manganese capping.

Photograph 2.1 The c. 20m high sea cliffs formed by the Table Mountain Group seen here dipping to the east (Photograph looking south).

Two EW-trending dolerite dykes occur at Geelwal Karoo and can be equated with the Karoo Dolerite Suite associated with the Drakensberg lavas and thus are part of the first phase of igneous activity of the Early Jurassic (Gresse, 1992; Photograph 2.2).

During the Late Cretaceous, erosion and sea level fluctuations were coupled with continental uplift (Hawthorne, 1975). This period is regarded as a time of maximum sediment supply and although smaller contributions where made by the Berg and Olifants rivers, the main bulk of Mesozoic sediments was contributed by the Orange River (Siesser *et al.*, 1974; Rogers, 1977; Dingle et al., 1983).

Photograph 2.2 Dolerite dyke cropping out on the beach near Duiwegat. 15cm long pen for scale.

Complete records of Upper Cretaceous stratigraphy are recorded from offshore boreholes only whereas outcrops of Cretaceous sediments on land are limited to two localities (Dingle *et al*., 1983). The first outcrop is found at Bogenfels (south of Lüderitz in Namibia) and consists of an assemblage of marine fossil shells of Cenomanian age (SACS, 1980). The other outcrop is found at Kangnas, which is situated 140km inland of the Orange River Mouth and contains dinosaur bones embedded in the sediments (crater facies) of a melilite intrusion (De Wit *et al.,* 1992). Pether (1996) first introduced the fluvial, basal kaolinitic deposits of Hondeklip Bay and he dated the first channel incision as being Early Cretaceous (Rogers et.al., 1990).

2.2 Cenozoic Geology

Tertiary deposits along the western continental margin occur both as shelf and slope deposits where they reach thickness of 1.5 km thick (Dingle *et al*., 1983). On land, they form vast but thin coastal-parallel lenses, which stretch the length of the margin (Cole and Roberts, 1996).

During the Palaeogene Period, tectonic movement of the African subcontinent was such that it resulted in the development of shorelines along the West Coast at elevations well above and below present-day sea level (De Decker and Woodborne, 1996). Due to subsequent erosion, outcrops of Palaeocene sediments have not yet been documented onshore for the continental margin of southern Africa (Dingle *et al*., 1983).

An Eocene transgression, which Hendey (1981) attributes to downwarping, effectively drowned the southwestern Cape and marked the start of Tertiary sedimentation along the Western margin. In Namaqualand, onland Eocene outcrops have been documented at Kamaggas on the Buffels River (37km west of Springbok) and at Quaggaskop, 26km north of Vanrhynsdorp (Dingle *et al*., 1983). Beach gravels containing shark-teeth characterise the sediments of the latter two outcrops and the ages of these outcrops is still under debate, (Ward, J.D., pers. comm., 2003). Eocene sediments found offshore are in the form of glauconitic clays and quartzitic limestones (Siesser *et al*., 1974).

The Eocene transgressive phase was followed by a period of major regression and erosion in the Oligocene (Dingle *et al*., 1983). De Decker and Woodborne (1996) claim that during this regression, a maximum of -500m was reached and that the wave action that accompanied this regressive cycle, played a major role in bringing diamonds to the present shelf break. The low rate of shelf subsidence of the Mid-Tertiary combined with active erosion, resulted in low quantities of terrigenous input to the continental shelf. As a result there was a net loss of Cretaceous and Palaeocene sediment from the deep-sea basins (Dingle, 1992). During this period of erosion, incisions were made into the sedimentary units of the proto-Cape Canyon by the western extension of the Olifants River and most of the proximal portion of the Cape Canyon was subaerially exposed (De Decker and Woodborne, 1996).

Three igneous events are found in the Paleogene Period on the western margin (Dingle *et al*., 1983). Davis (1977) identified a Late Palaeocene kimberlite plug in the south of Namaqualand. Kröner (1973) identifies an Early Oligocene Period of phonolite lavas in the Klinghart Mountains of Namibia as well as an olivine melilite plug in the south of Namaqualand, which he assigns to the Late Eocene. Along the West Coast, a Late Eocene/ Early Oligocene alkaline volcanism appears to be concentrated in small local centres of olivine melilites, phonolites, and trachybasalts. According to Moore (1979) the melilites are non-diamondiferous. Dingle *et al*. (1983) made the observation that the younger intrusions lie progressively closer to the West Coast. At Geelwal Karoo, evidence of Tertiary volcanic activity was found in a road section at Cliff Point (Photograph 2.3).

Although subsequent Miocene and Pliocene transgressions deposited thin, shallow water facies on the continental shelf, the bulk of the Neogene sediments were deposited on the continental slope (Dingle, 1992). These sediments are well represented in shallow marine deposits, characterized by local high-energy environments with a low terrigenous input.

Photo 2.3 An outcrop of volcanic rocks at Cliff Point (De Beer *et al.*, 2002), estimated to be of Oligocene age.

The periods of major regression and erosion which were started in the Oligocene persisted into the Miocene; the sea level reached several hundreds of meters below its present level (De Decker and Woodborne, 1996). Oligocene deposits were reworked into Miocene and younger successions, with the result that the diamonds were distributed in the gravels of the littoral zone (Dingle *et al*., 1983). A temporary still-stand may have compounded the severity of the erosion at this time (De Decker and Woodborne*, op. cit.*).

In the Early Miocene, evidence has been found at Kleinzee that the sea level transgressed to a maximum of +90m (*Pether et al*, 2000). This transgression resulted in the large-scale erosion of the Cenozoic successions found offshore and produced a record of deep marine, outer shelf sediments. The marine transgression brought about major changes in the environment and Hendey (1981) saw this as the time for the development of limestone and calcretes.

Exposures of sediments resulting from this transgression have been found in the Varswater and Elandsfontyn formations at Langenbaanweg, south of the study area. The Varswater Formation disconformably overlies the Elandsfontyn Formation (Cole and Roberts, 1996) in the Saldanha-Varswater embayment area and is distinguished by its phosphate-bearing marine sands (Dingle *et al*., 1983).

The sediments of this formation can be divided into non- or poorly phosphatic estuarine sand units and a succession of fluviatile sands and minor clays (Cole and Roberts, 1996). The fossil material of this unit indicates a Late Miocene age. At Saldanha, Quaternary river-channel sediments and aeolian sands overlie the Varswater Formation (Dingle *et al*., 1983).

The Neogene saw the deposition along the Namaqualand coast of three extensive marine formations containing warm water mollusc assemblages (Pether *et al.*, 2000). These packages are parasequences that are genetically defined, each being related to a cycle of marine transgression and regression. Each package has been named after its respective transgressive maximum, the oldest of which is the +90m package. Subsequent +50m and then +30m packages are arranged *en echelon* down the coastal bedrock gradient. Each package comprises marine sediments deposited during regressive progradation seawards from the maximum elevation reached by the transgression (Pether *et al*., *op cit*).

Although there is evidence to suggest the accumulation of more than two nearshore successions, the sea rarely transgressed its present level in the Quaternary (De Decker and Woodborne, 1996). Few remnants of Quaternary shorelines have been found and Pether (1994) hints at the presence of a +20m transgression at Hondeklip. Offshore along the West Coast evidence of a marine regression to –120m was found. It is believed that this was a response to the ice age recorded at 20 000 years (De Decker and Woodborne, 1996).

The Recent geology inland of the West Coast includes an aeolian component, which for the purposes of this study has been equated with the youngest member of the Sandveld Group, the Witzand Formation (Pether *et al*., 2000). The marine component of the Recent sedimentary record is found on the present beach and is host to a modern day heavy sand placer (Macdonald and Rozendaal, 1995a;1995b).

3. SEDIMENTOLOGY, STRATIGRAPHY AND MINERALOGY OF THE GEELWAL KAROO CENOZOIC SUCCESSION

The focus of this thesis lies on the sedimentary successions between +5 and +80m above the present beach and which unconformably overlie the Proterozoic and Paleozoic basement rocks. Five sedimentary units have been identified at Geelwal Karoo. The distribution of these units is presented in Figures 2.1, with a longitudinal section shown in Figure 3.1.

Figure 3.2 summarises the spatial relationship of the various units occurring on Geelwal Karoo relative to their height above present sea level. A chrono-stratigraphic succession is developed in Chapter 4. In this chapter each unit will be discussed in terms of its physical and textural appearance, sedimentary characteristics and mineralogy. Emphasis will be placed on those criteria which aid in identifying the depositional environment of the unit.

3.1 Channel clay unit

3.1.1 Occurrence, characteristics and stratigraphy

The channel clay unit is a fluvial succession deposited in shallow bedrock-incised channels (Photograph 3.1). It is the oldest unconsolidated sedimentary succession found at Geelwal Karoo and is overlain by the more recent sedimentary units.

This unit has been subjected to extensive erosion and its preservation in the sedimentary record at Geelwal Karoo can be attributed to the differential erosion seen in the basement rocks. The best exposures of the channel clay unit are associated with the occurrence of the down-faulted (lower-lying) phyllites and dolomites of the Gariep Supergroup.

In the geological profile presented in Figure 3.1, the channel clay unit occurs between profile 11 and profile 4B, a distance of approximately 11km.

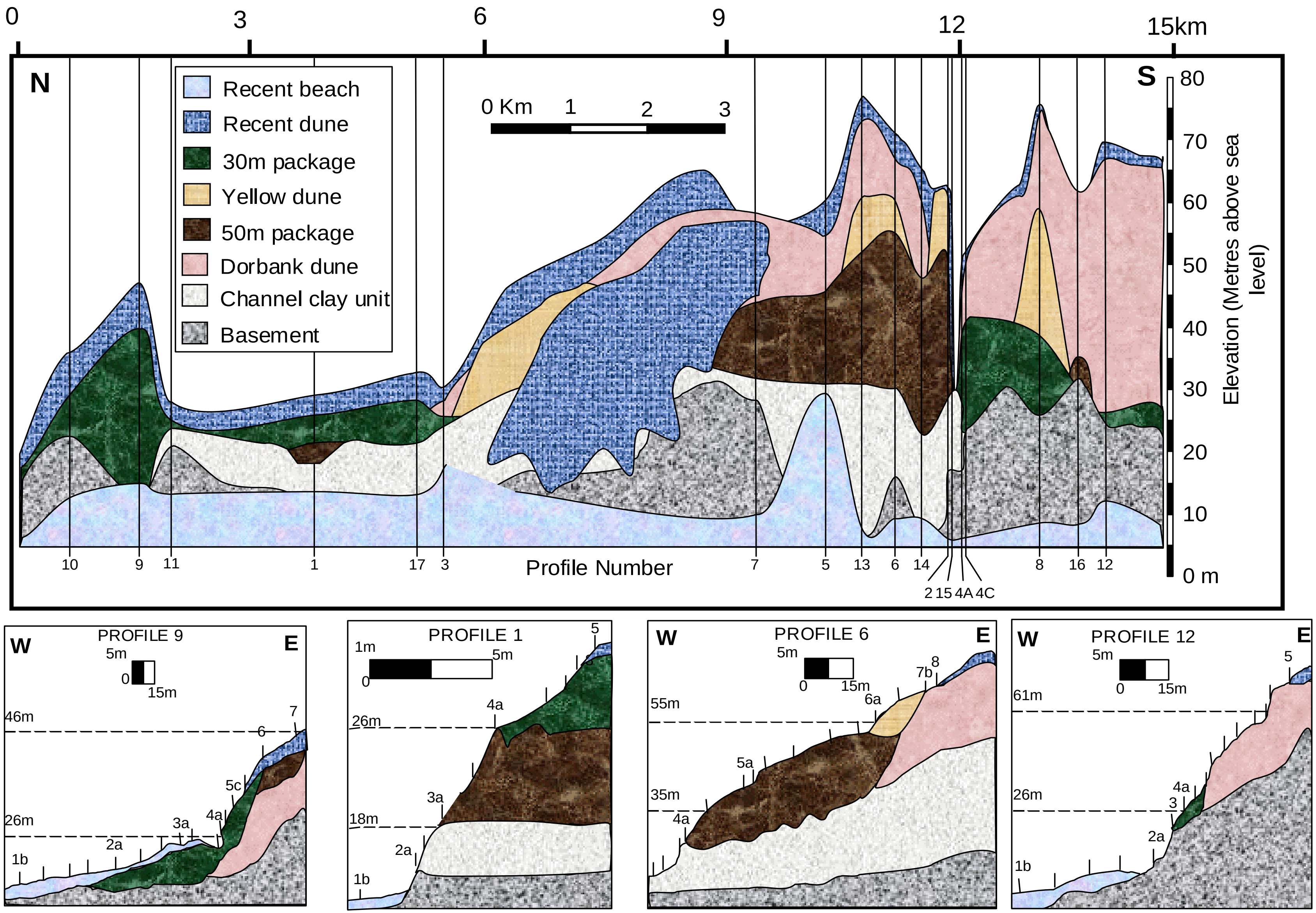


Figure 3.1 Cross section through the Cenozoic geology at Geelwal Karoo to show the spatial relationships of the various sedimentary units. The relationships were extrapolated between the profiles and the mapping in these areas is therefore schematic.

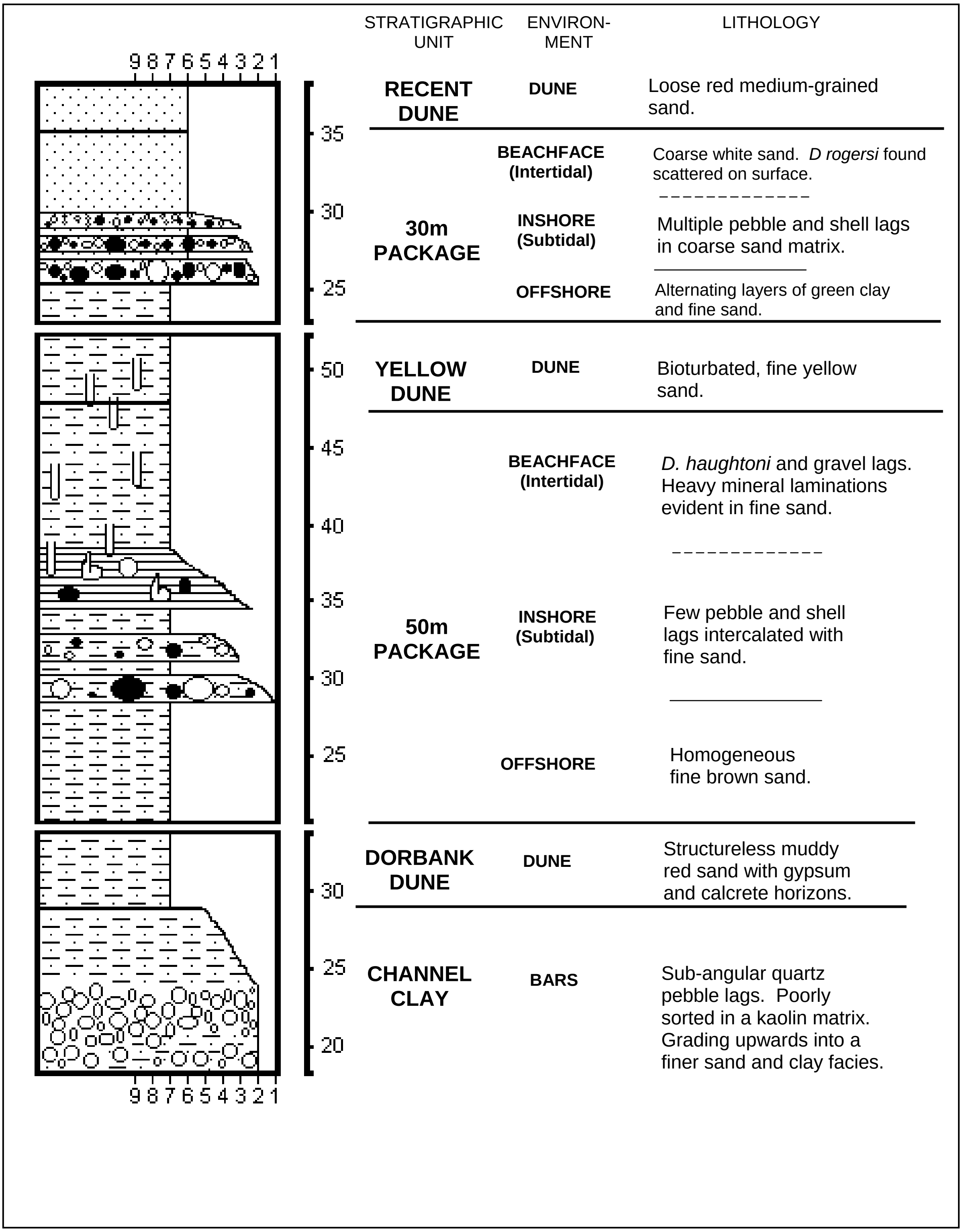
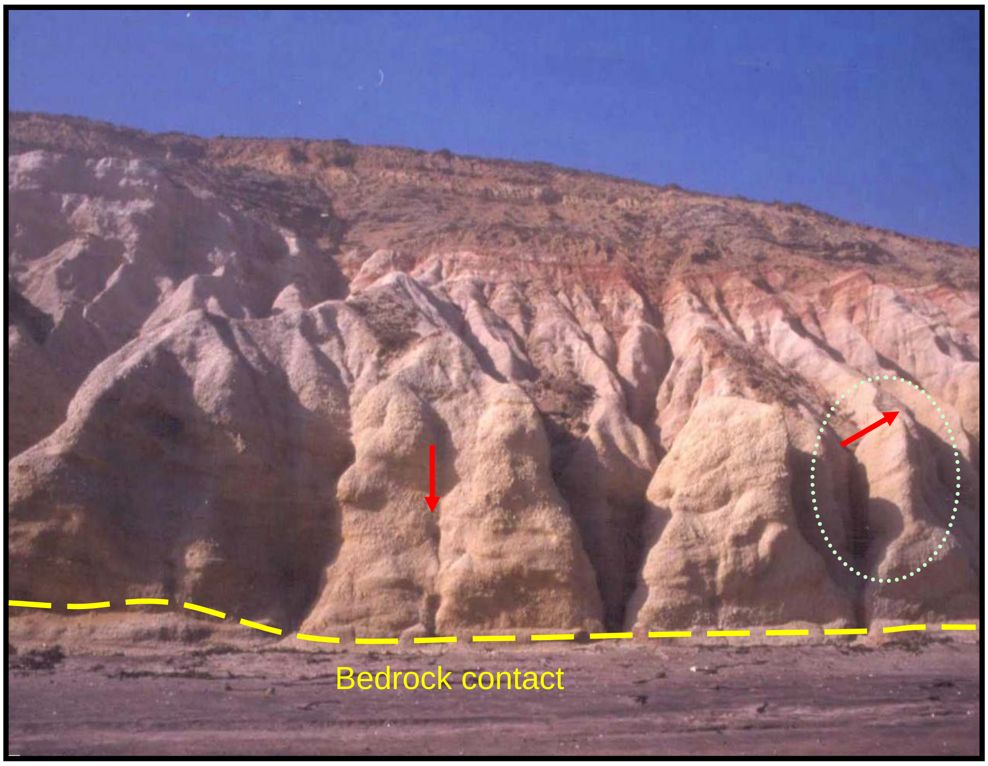


Figure 3.2 Stratigraphic column of the Cenozoic geology at Geelwal Karoo

The channel clay unit is wedge-shaped, reaching a maximum thickness of 23m in the south and tapering to 3m in the north. The unit was intercepted by boreholes drilled 2km inland from the coast (Cole and Roberts, 1996) and there are no other records to indicate the course of this channel inland.

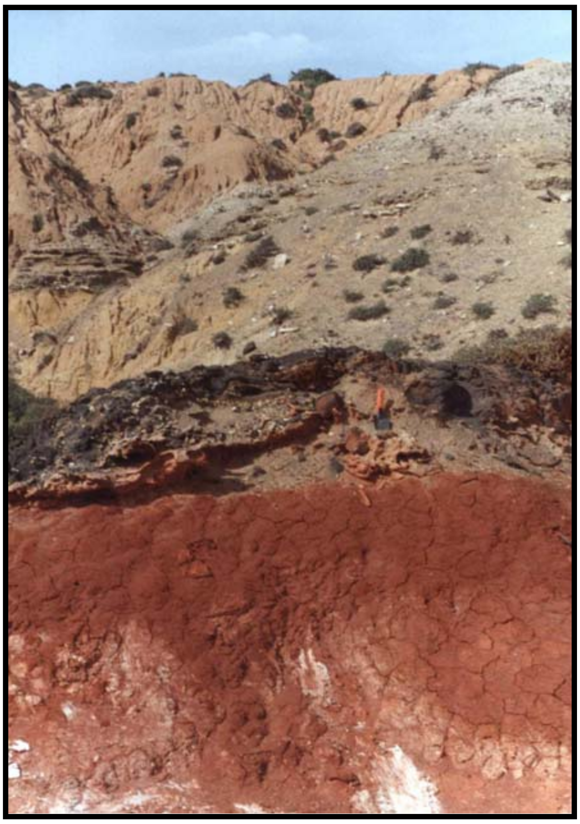
Furthermore, the angular nature of the clasts in this unit suggests that the channel unit did not extend very far inland and is therefore testimony to the proximal nature of this fluvial deposit.



Photograph 3.1 The channel clay unit at the base of profile 13. The upper contact with the grey-black +50m package is clearly visible and the bedrock contact is denoted by the yellow, dashed line. An example of slumping is seen in the circle and the arrows show how the flow direction has been affected. The height of embankment is approximately 60 metres.

The colour of the sand within the channel clay unit is distinctive and varies from pure white at the top to very pale orange at the base. Isolated patches of iron staining were observed within the clay units, as well as occasional yellow laminations (Photograph 3.2). The latter was identified as remnant organic material when there was a violent reaction when treated with hydrogen peroxide. No other evidence of fossil material was found in this unit.

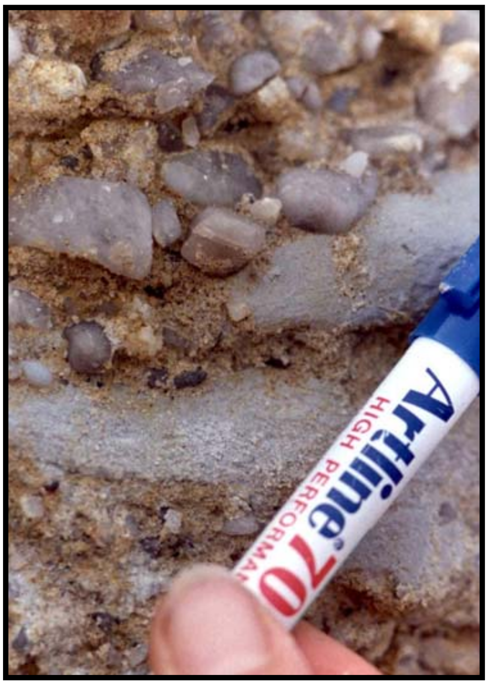
In the field, this unit characteristically lacks uniformity or lateral continuity and consequently, could only be broadly divided into two units; a basal coarse and an upper fine unit (Addendum I, Table 1.4).



Photograph 3.2 An example of the highly localized and superficial discolouration of the channel clay unit. The red stain is the result of iron being leached from overlying ferricrete boulders of the +50m package.

Although the gravel lags are found throughout the channel clay unit, they tend to be concentrated in the basal part. The gravel lags consist of a chaotic accumulation of sub-angular to sub-rounded vein quartz pebbles and small cobbles in a matrix of coarse sand. Traces of other lithologies (feldspathic, granitic and gneissic rock fragments) were noted in the matrix of these gravel lags, but these were rare and due to extensive kaolinization of both the basement and sedimentary units, are present as isolated clay lenses (Photograph 3.3).

The gravel lags of the channel clay unit typically lack any signs of bedding although some exposures show a strong seaward (westward) dip of up to 20^{o} (Photograph 3.4). Evidence of both matrix- and clast-supported gravel lenses were found and the lags are poorly sorted. The quartz clasts within the gravel lags become more rounded and better-sorted northwards, along the coast.



Photograph 3.3 A clay lens within the quartz pebble lag of the channel clay unit at profile 1. The clay is all that remains of the other lithologies within the channel clay unit. The pebbles in this profile show a greater degree of rounding than in the south of the study area.

Photograph 3.4 Gravel lens occurring within the channel clay unit. The gravel lens appears to be dipping towards the northwest (see red arrow), is poorly sorted and shows no obvious imbrication.

The coarse basal gravel unit reaches a maximum thickness of 10m in the south (Addendum I, Table 1.4) and tapers to the north where it eventually ends at profile 13. In the study area beyond profile 13 only the upper fine unit of the channel clay unit is represented. A geological model of this phenomenon is developed in Chapter 4.

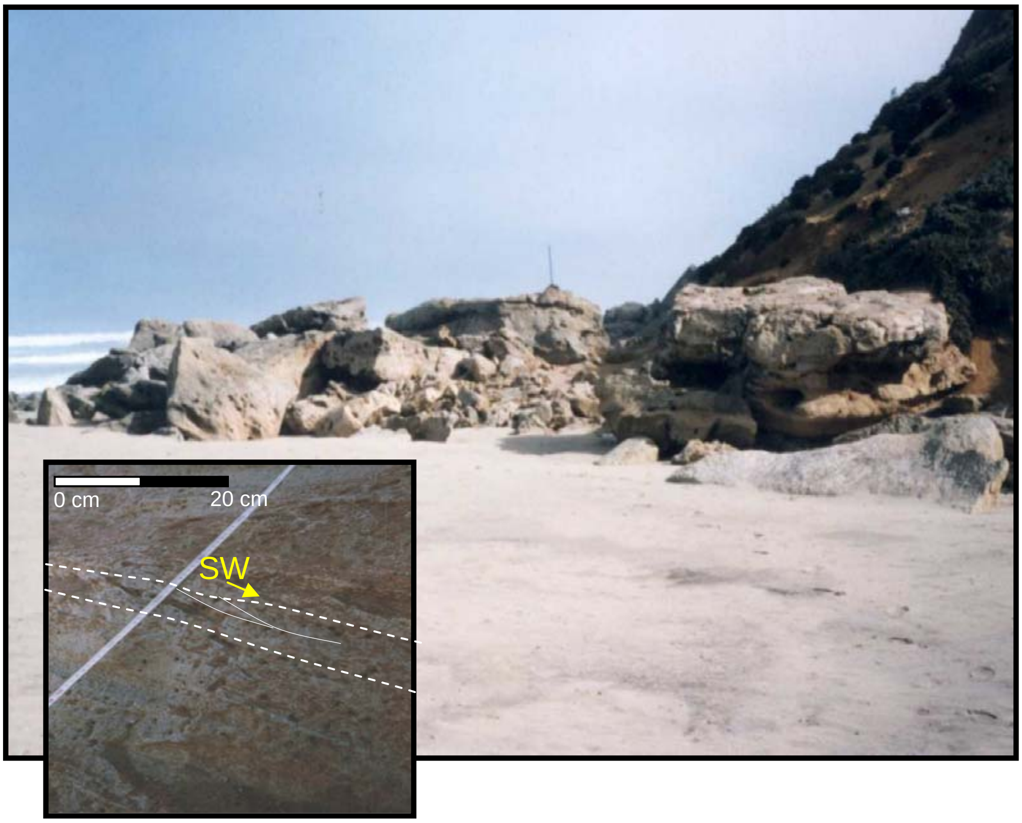
The upper, finer part of the channel clay unit dominates the succession and consists of a structureless, predominantly arenaceous facies of medium-grained sand and clay. Sporadic quartz gravel lag were noted. The top 5 metres of the unit has been cemented by secondary silica and in places bedding was found preserved (Photograph 3.5). In the places where there is no cementing, this part of the channel clay unit is often associated with the occurrence of large-scale slumping. The upper fine unit reaches a maximum thickness of 11m (profile 13) and the top contact with the marine and aeolian units is estimated to be in the region of 32m a.s.l.

3.1.2 Sedimentology

Texturally the channel clay unit represents a wide range of sample types, which plot as a more or less even distribution on the gravel and sand continuum (Figure 3.3.). Due to the method of the particle size analysis, the clay fraction is not accurately represented in this figure. Cementation further precluded sampling in some of the profile sites and the data in this section is therefore strongly biased towards representing the basal coarse unit of the channel clay unit.

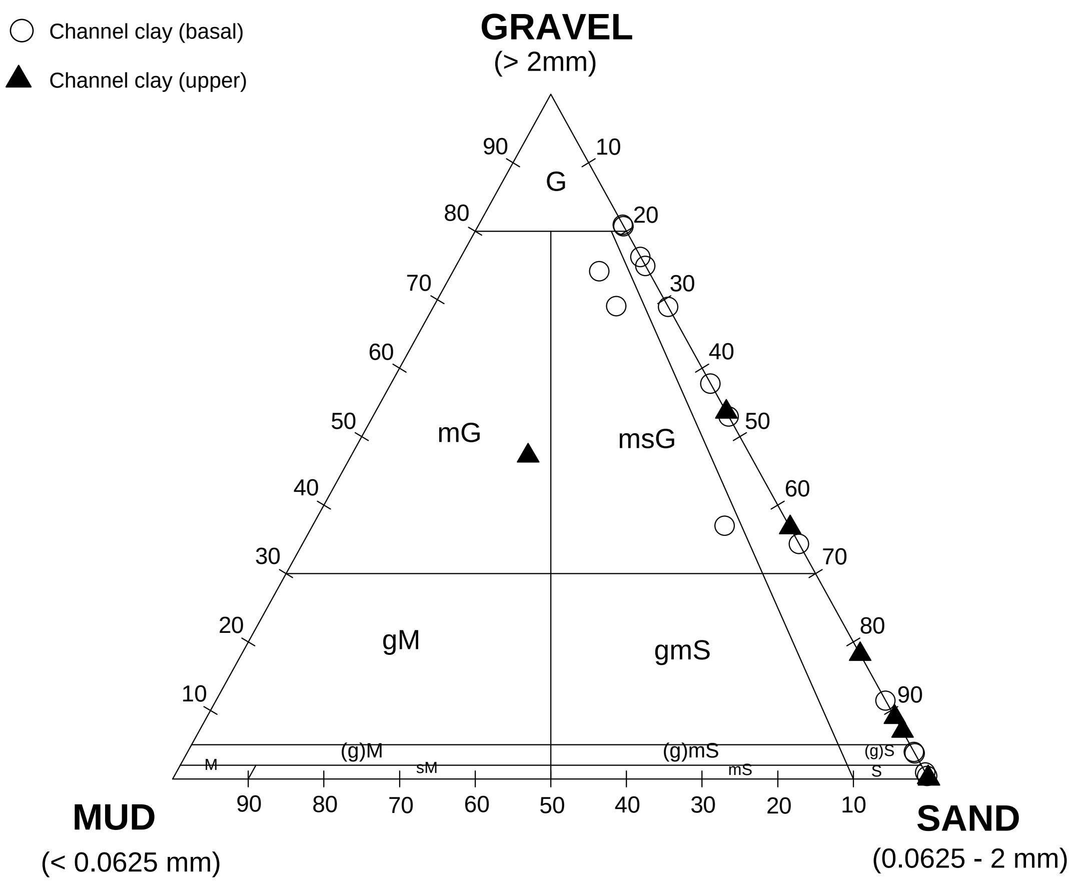
In the basal coarse unit, a large percentage of the samples are concentrated near the coarser gravel end member (samples are either very coarse sand- or granule-bearing). The particle size analysis of these samples produced histograms that were either bimodal or polymodal. They consistently showed a positive skewness (Appendix 2, Figure 1) and the sorting ranged from well to very poor. Field observations showed that the basal coarse unit had the largest clasts and this was often associated with poor sorting.

According to Schopf (1980), the poor sorting, positive skewness and polymodal distributions are expected in fluvial systems as transportation is very uneven from season to season (multiple channel fill) and the size-frequency distribution often includes both coarse (introduced during flooding) and fine (accumulate in dry seasons) material. In the basal gravel lag, more than one erosional cycle has been preserved. The relatively poor sorting in these lags suggests rapid sedimentation over a short period of time.



Photograph 3.5 Silcrete blocks from the upper part of the channel clay unit found on the present beach at the base of profile 5. The cross-bedding is visible in the inset photograph taken of an *in situ* outcrop at profile 17.

In general, the sorting in fluvial samples is poorer than that seen in beach samples (Schopf, 1980) and this is true for Geelwal Karoo. According to Visher (1969), the suspension population of fluvial samples can make up to 20% of the total distribution and the truncation between suspension and saltation in fluvial samples is generally between 2.75 and 3.5 phi. The saltation population ranges between 1.75 and 2.5 phi and has a slope of between 60 and 65 degrees. Only one sample, sample 47 (Appendix 2, Figure 2) shows the latter fluvial characteristics whereas the vast majority of the channel clay samples appear to be atypical. In most of the samples, the coarser saltation and traction fractions appear to dominate and there is no clear truncation between saltation and suspension fractions. If the bedload is present in the channel clay samples it is generally coarser than 1 phi and this is in keeping with Visher's (1969) observations on the fluvial environment. In conclusion it must be said that the Visher diagrams of the channel clay unit were not conclusive as to the depositional environment and the fluvial nature of the sediments had to be deduced from the field observations. Visher diagrams are best used for the details at specific sample sites (whether it is a bar tail or halfway between bar tail and its head) once the sedimentary environment has been deduced.



G = gravel
sG = sandy gravel
msG = muddy sandy gravel
mG = muddy gravel
gS = gravelly sand
gmS = gravelly muddy sand
gM = gravelly mud

(g)S = slightly gravelly sand
(g)mS = slightly gravelly muddy sand
(g)M = slightly gravelly mud
S = sand
mS = muddy sand
sM = sandy mud
M = mud

Figure 3.3 Textural classification of the channel clay unit (basal coarse unit, n=16 and fine upper unit, n=8).

The absence of marine or lacustrine fossils and signs of bioturbation in the channel clay unit appears to point to a fluvial rather than marine-dominated depositional environment, although the Visher diagram of sample 101 seems to indicate a river estuary environment. Initially, the poor sorting, the steep dip and angular nature of the gravels layers seem to suggest a strong gravity-flow component to this deposit. The similarity between the Visher diagrams of samples 103, 87 and 105 with turbidity current environments seem to provide further evidence for a mass flow component.

Further investigation, however, revealed clearly incised channels in the bedrock (rather than uniform basal erosion) and this together with the poor sorting (as opposed to the very poor sorting) within the coarse fraction of the basal gravel bar provided evidence for a fluvial rather than a gravity-flow driven system. Futhermore, the basal gravel lags show distinct aggradation; large pebble clasts are found on the basement contact and these grade upwards into a succession of smaller pebbles disseminated in a matrix of fine sand and clay.

The concentration of the quartz gravel lags appears to decline above +19.5m a.s.l. and this elevation was chosen to mark the transition (Addendum I, Table 1.4.) between the basal coarse and upper fine units of the channel clay unit. Sedimentary features such as intraformational layers of clay and cross-bedding were observed in the upper, cemented portion of the channel clay unit. Both features could suggest subsequent marine reworking of the fluvial succession, but the evidence is not conclusive. (The cross-bedding was in the silicified portion of the unit and it was not possible to obtain a 3D view to establish the presence of herringbone cross-bedding). The sharp erosional contact in Photograph 3.4, is typical of the traction currents in operation within a fluvial system. Sample 106 matched the Visher diagrams of a plunge zone in a marine environment and given the confirmed fluvial nature of the channel clay unit, this result would seem to indicate a degree of contamination by the overlying marine sediment.

In the Friedman *et al*. (1992) scatter plot, some of the samples of this unit plot in the area characterized by a unidirectional flow pattern (Figure 3.4). This is in keeping with the observation that the unit has a fluvial origin.

A grain size analysis of both bedrock and channel samples done by means of a Sedigraph yielded the cumulative frequency curves shown in Figure 3.5. This figure shows that no clear distinction can be made between the bedrock and sediment samples. This fact together with the observation that the clay is sometimes found in the form of pockets or lenses rather than layers suggests that the presence of the clay is the result of post-depositional weathering rather than sedimentation. The post-depositional kaolinization of this unit is discussed in detail in Chapter 4.

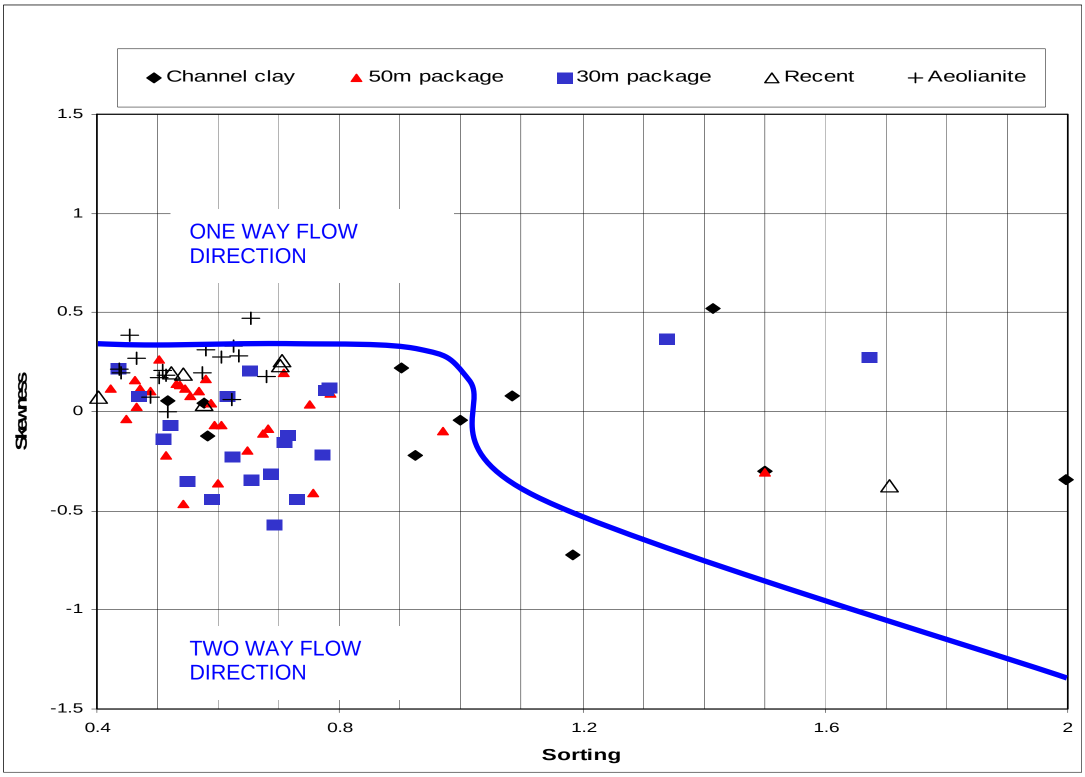


Figure 3.4 Friedman scatter plot of all samples taken at Geelwal Karoo. (After Friedman *et al.*, 1992)

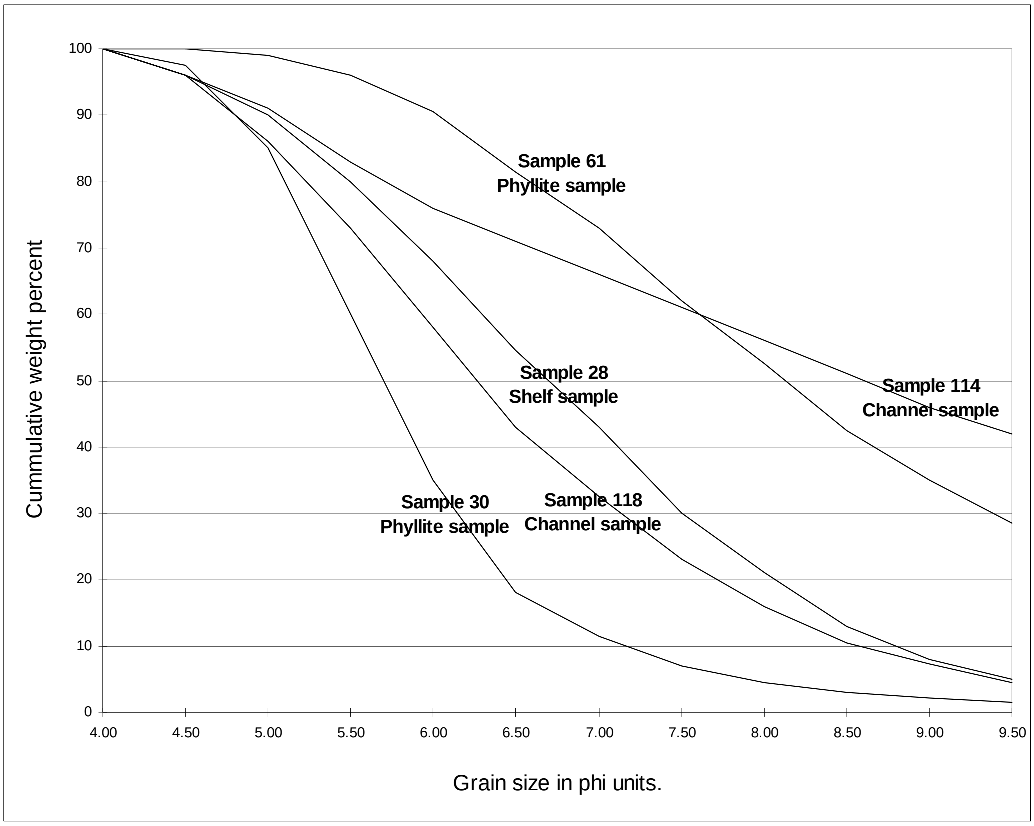


Figure 3.5 Cumulative-frequency curves for particles smaller than 4 phi in the channel clay samples.

3.1.3 Mineralogy

The matrix of the channel clay samples (sand fraction) is distinctly monomineralic quartz and the grains are sub-angular to sub-rounded. These quartz grains are characteristically white or clear in colour. Peculiar to the channel clay unit were gneissic rock fragments which were more noticeable near Duiwegat, close to the Gariep Supergroup and Namaqualand Metamorphic Complex contact.

Trace amounts of heavy minerals, mica and banded-iron formation rock fragments were found in the matrix but this amounted to as little as 1% of the total sample. Despite the low THM percentage, the point counting data of the heavy mineral assemblage of this unit showed the greatest mineral diversity. The results are presented in Table 3.1 and Table 3.2.

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Table 3.1: A summary of the point-count data of the heavy mineral fraction of all the sedimentary units. Data presented as an average percentage of the total heavy fraction.

Unit	Channel clay	Aeolianite	50m package	30m package	Recent
Rutile	6	1	2	7	3
Zircon	11	1	1	2	3
Garnet	9	16	8	11	26
Augite	10	16	9	8	9
Hornblende	0	1	6	1	1
Weathered grains	9	15	14	10	11
Tourmaline	2	1	2	0	1
Kyanite	4	0	1	0	0
Monazite	0	0	0	0	0
Staurolite	0	0	0	1	0
Ilmenite	10	7	13	19	9
Hydrated ilmenite	7	4	11	12	4
Leucoxene	6	2	2	7	2
Other opaque minerals	2	2	3	3	4
Magnetite	0	0	29	0	0
Chromite	1	0	1	0	0
Pseudorutile	7	1	5	5	0
Glauconite	0	0	33	1	0
Rock fragments	2	11	9	7	7
Carbonates	1	0	14	0	2
Total % heavy minerals	**88**	80	62	96	83
Feldspar	**0**	1	11	0	1
Quartz	**12**	19	17	4	16
Grand total all minerals	**100**	100	72	100	100
%THM of whole rock	**1.08**	9.53	35.31	4.92	9.49
% Ti-mineral only	**41.00**	19.00	42.15	51.94	20.40
%Ti-minerals THM for whole sample	**0.39**	1.63	12.16	4.11	3.14
% Non-opaque heavies	50	38	31	35	44
% Opaque heavies	26	15	40	42	19
% Other heavies	12	27	18	19	20

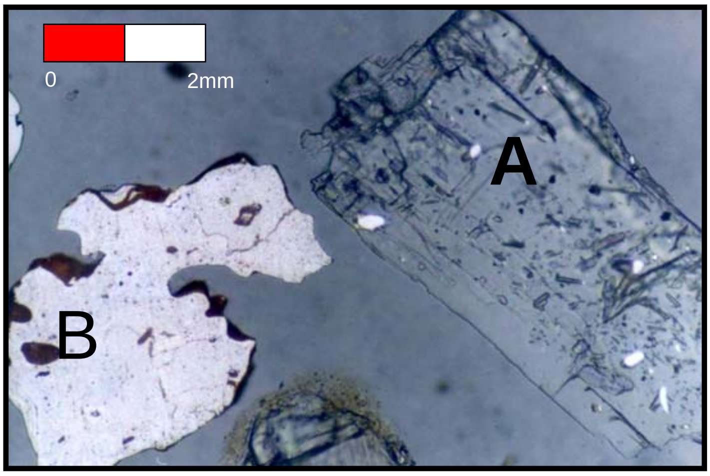
The relative abundance of zircon, tourmaline, pseudorutile and the presence of kyanite grains (non-opaque minerals) distinguish this unit (Photograph 3.6) from the aeolian and marine successions. There were no obvious differences between the heavy mineral assemblage of the upper fine and basal coarse units of the channel clay unit (Appendix 3, Figure 2a.)

The presence of pseudorutile and leucoxene is a result of the high degree of *in situ* weathering of the channel clay unit. The ilmenite and hematite grains have an average size of 0.2mm and are sub-angular. These grains are smaller than those found in the marine units and this also suggests a greater degree of *in situ* weathering. The zircon grains in the channel clay unit were well rounded and averaged 0.19mm in size (Photograph 3.7).

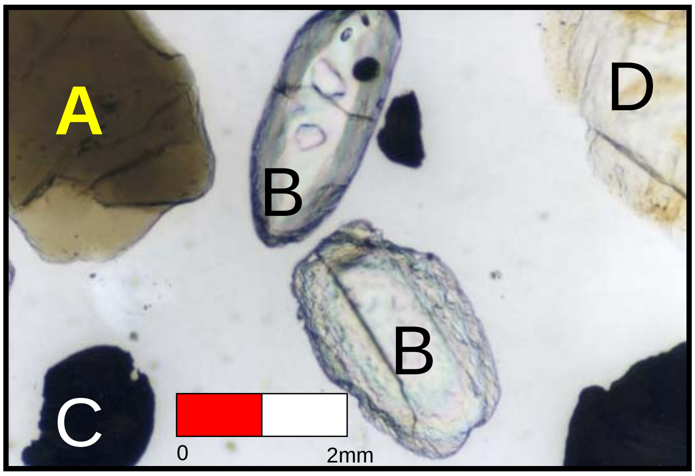
Table 3.2: Point-count data for the heavy mineral fraction of the channel clay unit. Data presented as a percentage of the total heavy fraction.

Sample number	**117a**	**113**	**117b**	**117c**	**8b**	**82**	**9b**	**118**	**83**	**115**	**47**	**Average**
Facies	Basal	Basal	Basal	Basal	Basal	Basal	Basal	Basal	Basal	Upper	Upper	
Sampling elevation	8.10	9.10	13.40	14.50	15.00	16.10	16.40	18.00	19.00	20.50	31.53	
Distance (km)	10.50	9.50	10.50	10.50	3.50	10.50	3.50	10.50	10.50	9.50	9.00	
Rutile	5	7	6	3	10	16	5	2	4	9	3	6
Zircon	9	9	12	7	11	11	3	10	3	21	6	9
Garnet	8	11	8	9	2	8	1	4	9	10	14	8
Augite	2	3	7	8	4	10	2	12	17	15	11	8
Hornblende	0	1	1	1	2	0	0	0	1	0	0	1
Weathered grains	10	24	11	2	13	1	12	2	16	2	13	10
Tourmaline	1	3	2	2	2	1	0	1	2	1	2	2
Kyanite	1	4	1	1	0	0	46	0	0	1	2	5
Monazite	0	1	0	0	0	0	0	0	0	0	0	0
Staurolite	0	0	1	1	0	0	3	0	0	0	0	1
Ilmenite	16	8	11	11	4	24	2	2	10	8	13	10
Hydrated ilmenite	3	8	9	11	0	9	0	5	9	8	6	6
Leucoxene	12	2	7	9	14	7	5	18	12	4	3	8
Other opaque minerals	2	3	4	4	0	2	1	1	3	1	2	2
Magnetite	0	0	1	0	0	0	0	0	0	0	1	0
Chromite	0	0	0	0	0	0	0	0	0	0	2	0
Pseudorutile	7	0	8	14	24	0	10	20	7	4	2	9
Glauconite	0	0	0	1	1	0	2	0	0	0	1	0
Rock fragments	1	7	1	1	2	0	2	2	1	3	2	2
Carbonates	0	0	3	1	0	1	0	1	0	2	0	1
Total % heavy minerals	**79**	**91**	**93**	**86**	**92**	**93**	**92**	**82**	**95**	**91**	**83**	**89**
Feldspar	0	0	0	0	0	0	0	0	0	0	0	**0**
Quartz	21	9	7	14	8	7	8	18	5	9	17	**11**
Grand total all minerals	100	100	100	100	100	100	100	100	100	100	100	**100**
%THM of whole rock	0.46	1.19	0.77	2.91	0.06	0.65	8.00	0.10	1.05	0.92	0.04	**1**
% Ti-mineral only	55	28	44	55	58	62	24	58	44	37	32	**45**
%Ti-minerals of THM for whole sample	0.25	0.33	0.34	1.61	0.03	0.40	1.89	0.06	0.46	0.34	0.01	**0.52**

The ZTR index of Hubert (1962) is the combined percentage of zircon, tourmaline and rutile (ZTR) among the transparent heavy minerals, omitting micas and authigenic species, and is used to determine the chemical maturity of heavy mineral suites. The channel clay samples (Appendix 3, Table 2) have the highest ZTR index (average 17). The samples of this unit can therefore be considered chemically more immature than the other marine and aeolian sediments at Geelwal (closer to the arkoses). The feldspar component of these samples is thought to have been weathered to the kaolin matrix of the unit.



Photograph 3.6 Kyanite (A) and pseudorutile (B) found in the heavy mineral fraction of the channel clay unit. The blue colour and step-like (110 and 010) cleavage features identify kyanite. Pseudorutile is identified by deep red internal reflections, seen in the halo around the grain in the photograph. (Sample 9b; 200x magnification; oil immersion; reflected light).



Photograph 3.7 Hornblende (A), zircon (B), ilmenite (C), and quartz (D) grains found in the heavy mineral fraction of the channel clay unit. Note the small size of the ilmenite grain and that the quartz grains show a degree of contamination in the heavy mineral separation. (Sample 113; 200x magnification; oil immersion; transmitted light)

3.1.4 Alteration

The channel clay unit shows advanced pedogenesis and this is visible in the extensive kaolinization and compaction (Photograph 3.8). The *in situ* kaolinization extends into the bedrock, making the contact between bedrock and sediment difficult to distinguish. Furthermore as a result of the compaction and the associated dipping layers, it was difficult to determine a flow direction for the sediments.

Photograph 3.8 An example of compaction and its affect on the channel clay unit. Compaction and the associated de-watering results in synsedimentary faulting of the bedrock and these faults have affected (through the steeply dipping fluvial layers) the overlying channel clay sediments (Collinson and Thompspon, 1989).

The XRD technique used in this study did not allow for the conclusive identification of the clay minerals. It is however, interesting to note that when the diffractograms of the channel clay unit (Figure 3.6) are compared to those of the basement (Figure 3.7) there is little difference between the two and they give the same kaolin signature.

The extensive silcrete capping in the channel clay unit is also the result of ground water action. According to Passarge (1904) and Botha (2000), silcretes may form in the upper component of a fluvial channel, which is subjected to periods of flooding. These wet periods are associated with a lowering in the groundwater pH and the calcium carbonate within the soil profile is dissolved, and then replaced with silica. The silcrete capping in the channel clay unit is the product of a moist climate and appears to predate the incipient aridity of the West Coast.

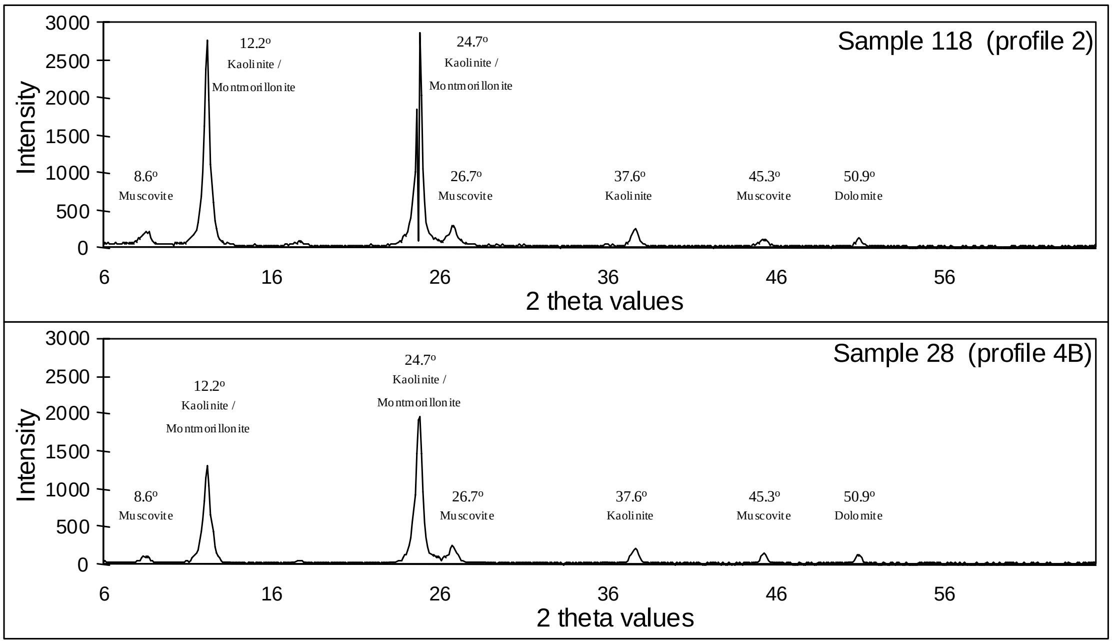


Figure 3.6 XRD diffractograms of selected clay samples from the channel clay unit. These diagrams show clear peaks for kaolinite and muscovite, whereas the peaks for dolomite, quartz and montmorillonite are less distinct. (XRD: Cu radiation, 40mA, 40 kV, window = 100, scan rate = 1 deg/min)

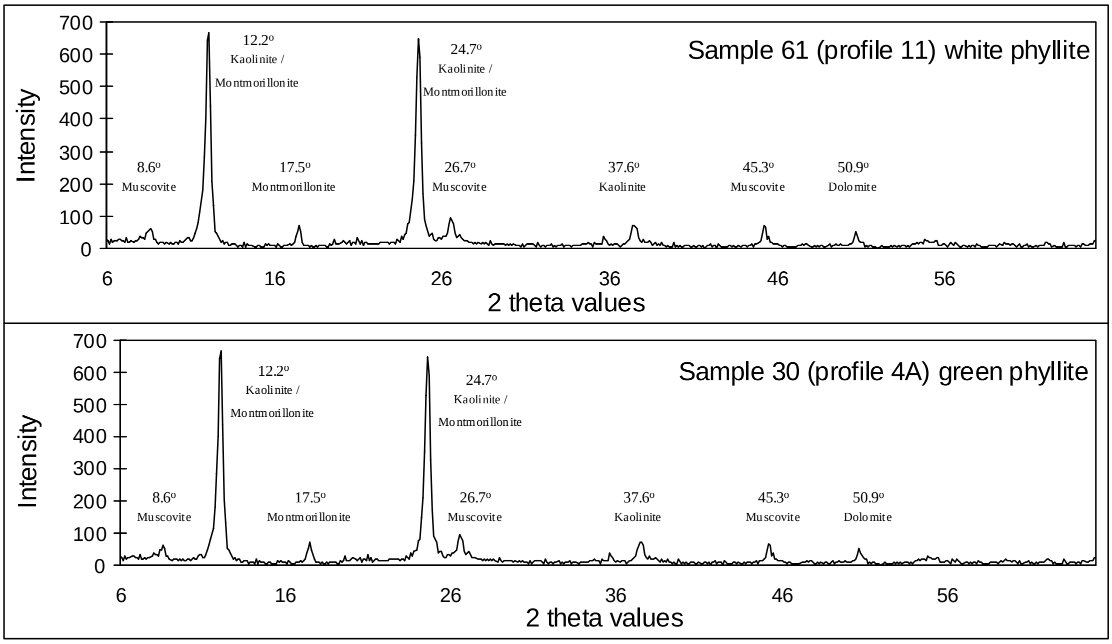


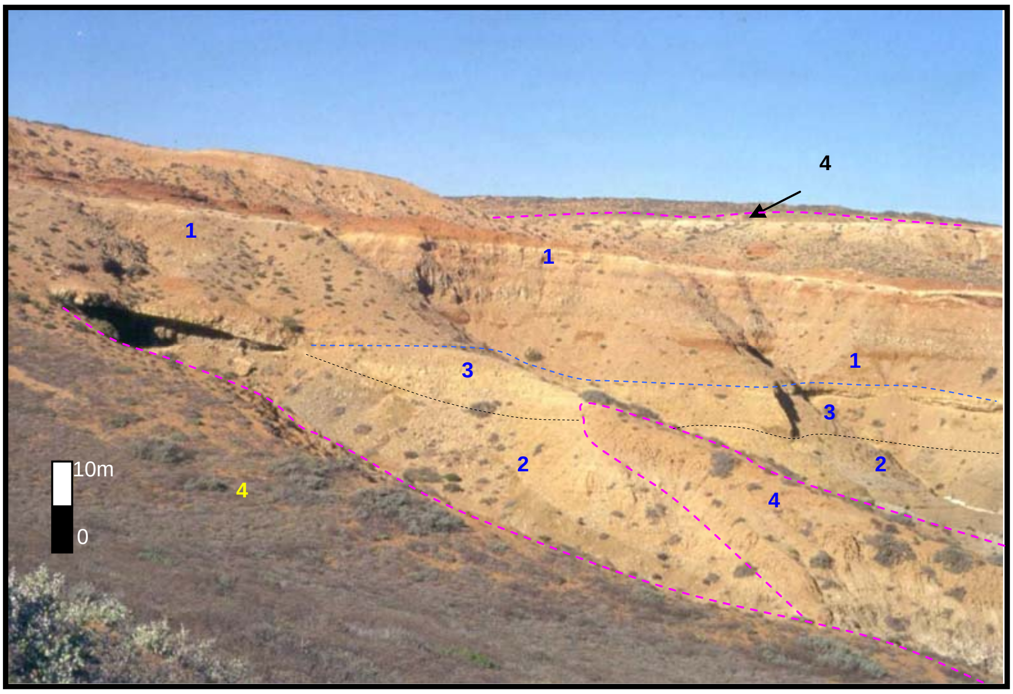
Figure 3.7 XRD diffractograms of clay samples from the Gariep Supergroup outcrops at Geelwal Karoo. A: white phyllite, B: blue phyllite. (XRD: Cu radiation, 40mA, 40 kV, window = 100, scan rate = 1 deg/min)

3.2 Aeolianite

3.2.1 Occurrence, characteristics and stratigraphy

The aeolianite at Geelwal Karoo consists of two distinct units; a yellow dune belt in direct contact with the backshore zone of the +50m package and a more extensive, light brown "dorbank" dune belt which outcrops above the yellow dune sand.

The dorbank unit (Figure 3.2) extends the entire length of the study area and reaches a maximum elevation of approximately 75m a.s.l. in profile 13 and 8. It has an average elevation of 61m a.s.l. and when compared to the other sedimentary successions found at Geelwal Karoo, it is relatively thick with an average thickness of 16m. The colour of this unit is distinctive and ranges from dark yellow through orange to light brown (Photograph 3.9). The aeolianite is overlain by the Recent (Holocene) aeolian sand and can be distinguished from the latter by the presence of numerous calcrete horizons and red beds.



Photograph 3.9 A panoramic photograph illustrating the extent of the aeolianite. The gradational contact with the underlying +50m package sediments and the numerous calcrete horizons are also visible in this photograph. 1) Dorbank unit, 2) +50m package nearshore sediments 3) yellow dune unit 4) Recent dune sands.

In places there are striking colour differences at the contact between the dorbank and yellow dune belt, but the relationship between the two dune types is not that clear. The contact between the two dune series is often gradational and this is largely due to biological activity (numerous trace fossils) and ground water action (seen in the calcrete horizons and red beds).

Furthermore, both dune belts are overlain by a third Holocene dune belt which, due to its red colour and the fact that it is composed largely of reworked dorbank sand, can easily be mistaken for *in situ* dorbank sand. In Photograph 3.9 it is shown that the dorbank is overlain by the sediments associated with the +50m marine transgression.

The dorbank unit appears homogeneous except for heavy mineral-enriched zones, which resulted in a subtle colour change from light brown to greyish orange. In the dorbank dune belt evidence of termites was found (photograph 3.10).

Photo 3.10 Example of a calcified termite mound commonly found preserved in the aeolianite.

The second dune belt in the aeolianite unit is the yellow dune belt and it is in direct contact with the backshore zone of the +50m package (Photograph 3.26). Exposure of the yellow dune belt is limited to the south and particularly the area around profile 6 and the colour of this dune belt is dark yellowish orange. In the single exposure found of the contact between yellow dune and dorbank units, the contact appears to be gradational. Evidence of large-scale sinuous bedforms in the dune belt could be traced on the contact with the marine sediments in the “Torings” area but, in general, the bedding in this aeolianite unit is masked by the presence of the post-depositional calcrete horizons.

In the yellow dune belt, a tortoise shell and trace fossils in the form of burrows and rhizoliths were found. Both had been calcified by subsequent groundwater seepage. The burrows and rhizoliths of the dune belt were smaller and appeared more intricate than those found associated with the intertidal zone of the +50m package.

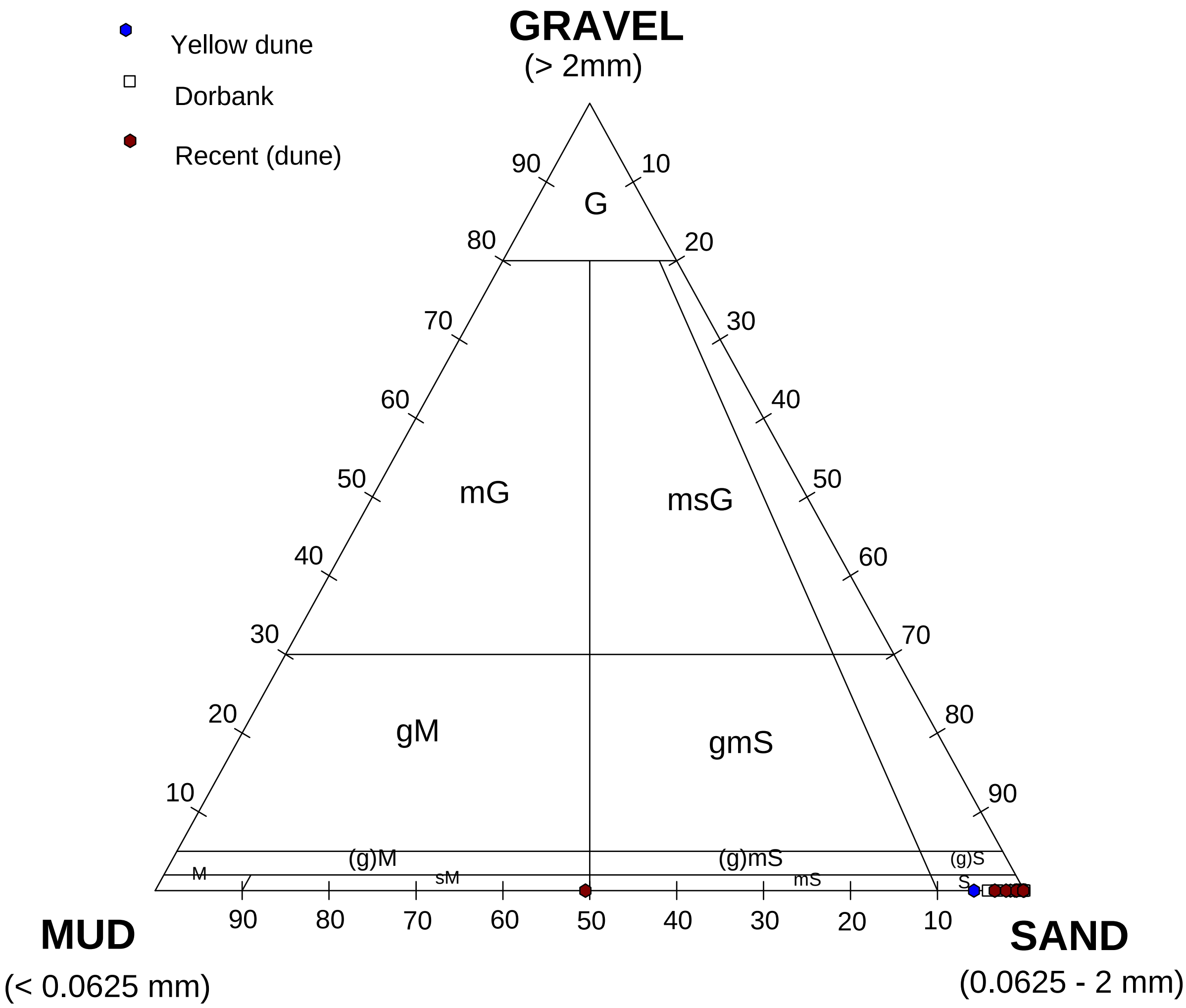
3.2.2 Sedimentology

Except for the field relationships, no significant differences were noted between any of the aeolian units at Geelwal. The dorbank and yellow dune units are composed mainly of sand (Figure 3.8). These dune sands show characteristics that are typical dune sands as listed by Visher, 1969. There is a single large (up to 90% of the graph) saltation population on the cumulative frequency diagram and the saltation population has a slope of 50 degrees (well sorted) and ranges between 2 and 3 phi, (Appendix 2, Figure 4).

The size of the suspension load in dune sand can be related to the proximity of the source of fine clastics (Visher, 1969) and the positive skewness becomes more pronounced as the dunes move inland from the sea. This is because the dunes start to accumulate finer particles and this causes a gradual flattening of the size-frequency curve, (Schopf, 1980). At Geelwal Karoo, in samples 94, 32, 42 and 40, this is not the case. The dominant fine suspension fraction in these samples is seen to be the result of post-depositional weathering rather than being an indication of a more distal setting. In addition, breaking up and disaggregating the calcrete cementation during sample preparation added finer sediment to the samples.

Most of the aeolianite samples showed a relatively well developed coarse traction load which according to Visher (1969) should be very small (less than 2%) or non-existent in dune sands. The presence of this coarser fraction in the Geelwal Karoo samples can be attributed to high wind speeds and the close proximity of the marine environment. If the coarse fraction is present in dune sand, Visher (1969) concludes that it is usually very poorly sorted. This is true for the Geewal Karoo samples where the slope of the saltation fractions is not more than 45 degrees (Addendum 3, Figure 3.4).

A study on the Tsondab Sandstone Formation along the West coast of Namibia revealed no changes in the dominant wind regimes from the Early Miocene to the present (Kocurek *et al.,* 1999). By inference it is assumed that at Geelwal Karoo the dominant wind direction for the aeolianite was also SW with an occasional change to an easterly direction in the winter months. The Friedman scatter plot (Figure 3.4) confirms that the aeolianite is the product of a bi-directional flow regime.



G = gravel
sG = sandy gravel
msG = muddy sandy gravel
mG = muddy gravel
gS = gravelly sand
gmS = gravelly muddy sand
gM = gravelly mud
(g)S = slightly gravelly sand
(g)mS = slightly gravelly muddy sand
(g)M = slightly gravelly mud
S = sand
mS = muddy sand
sM = sandy mud
M = mud

Figure 3.8 **Textural classification of samples in the aeolianite.**

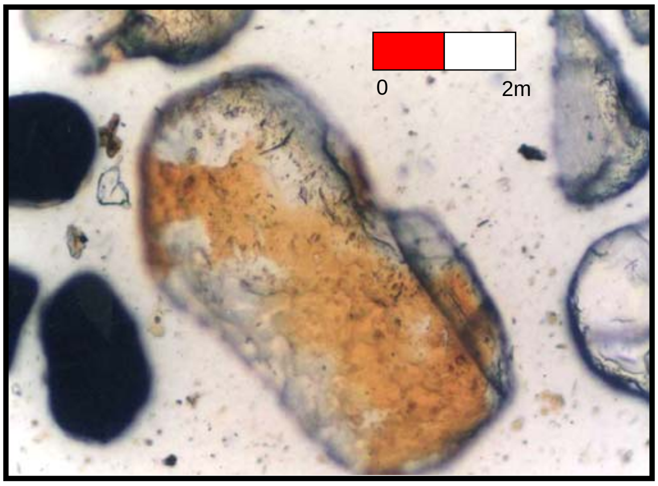
3.2.3 Mineralogy

Although quartz dominates the mineral assemblage in the aeolianite (dorbank and yellow dune units) there is also minor concentrations of rock fragments, ore minerals and altered ferro-silicate grains. It must however be noted that the iron coating on the grains made point counting of the minerals in this unit difficult despite having been washed with acetic acid (Photograph 3.11). The quartz grains had a sub-rounded to rounded shape.

A detailed study of the heavy mineral assemblage (Table 3.1 and Table 3.3) revealed that the aeolianites had more rock fragments (10%) and weathered grains ("other" heavy minerals) than the fluvial and marine units. The ZTR index for the aeolianite had the lowest value (average 4, Appendix 3, Table 2) which suggests that these sediments are chemically the most mature at Geelwal Karoo which is in keeping with the theory that they are the product of more than one erosional and depositional cycle.

In the dorbank unit specifically, the THM% concentration averaged 8 and this unit could be distinguished from the yellow dune unit by the presence of rutile and zircon in the heavy mineral assemblage (Appendix 3, Figure 2b).

The yellow dune unit averaged a THM concentration of 11% and the high heavy mineral concentrations can be explained by the close proximity of the provenance, the +50m package, heavy sand placer. The yellow dune unit had more rock fragments and augite grains than the dorbank unit (Table 3.3). The rock fragments are the result of the erosion of the numerous pebble lags seen in the +50m inshore unit.



Photograph 3.11 Coated garnet grain from the aeolianite. The coatings on the mineral grains made the initial microscope studies unreliable and certain of the samples had to be treated with acetic acid before the mineralogy could be determined. (Sample 39; heavy fraction mount; 200x magnification; oil immersion; transmitted light; uncrossed nicols)

Table 3.3: The point count data for the heavy mineral fraction of the aeolianite. Data presented as a percentage of the total heavy mineral fraction.

Sample number	**69**	**68**	**76**	**39**	**81**	**4**	**77**	**78**	**Average**
Facies	Dorbank	Dorbank	Dorbank	Dorbank	Dorbank	Yellow dune	Yellow du	Yellow dune	
Sampling elevation	40.87	44.67	60.32	70.88	73.08	53.78	54.22	58.55	
Distance (km)	12.00	12.00	9.50	11.50	9.50	10.00	9.50	9.50	
Rutile	1	1	0	0	8	0	0	0	1
Zircon	3	2	1	1	6	1	0	0	2
Garnet	37	23	17	8	24	12	7	11	17
Augite	12	27	4	9	8	10	24	26	15
Hornblende	0	2	2	1	1	1	1	1	1
Weathered grains	9	18	24	34	1	21	1	18	16
Tourmaline	3	1	1	1	3	0	1	1	1
Kyanite	0	0	0	0	0	0	0	0	0
Monazite	0	0	0	0	0	0	0	0	0
Staurolite	1	0	0	0	0	0	1	0	0
Ilmenite	6	4	6	3	18	13	4	5	7
Hydrated ilmenite	8	1	6	2	9	5	2	2	4
Leucoxene	3	2	2	3	5	2	2	1	2
Other opaque minerals	2	1	3	1	6	2	0	0	2
Magnetite	0	0	0	0	0	1	0	0	0
Chromite	0	0	0	0	0	0	0	0	0
Pseudorutile	0	0	2	2	0	2	0	0	1
Glauconite	0	0	0	0	0	0	0	0	0
Rock fragments	7	8	11	9	2	8	25	10	10
Carbonates	1	0	0	0	0	0	0	0	0
Total heavy minerals	**93**	**91**	**79**	**74**	**90**	**77**	**71**	**75**	**81**
Feldspar	0	0	1	2	0	1	0	3	1
Quartz	7	9	20	25	10	22	29	22	18
Grand total all minerals	100	100	100	100	100	100	100	100	100
%THM of whole rock	4.29	5.90	16.26	8.22	3.89	8.56	12.04	13.43	9
% Ti-mineral only	19	8	21	14	44	28	12	10	20
%Ti-minerals of THM for whole sample	0.83	0.48	3.36	1.15	1.71	2.44	1.42	1.38	1.60

3.2.4 Alteration

In the aeolianite unit evidence of groundwater action was found in the form of numerous calcrete horizons. Calcretes are formed from almost any material of almost any consistency. The carbonate precipitates in response to changes to the groundwater within the regolith and can result in *in situ* cementation and/or replacement of a pre-existing material (Netterberg, 1980). In southern Africa, calcrete formation is most common west of 27^{o}E longitude and south of 17^{o}S latitude and can be classified based on their chemical structure and succession of development (Netterberg, *op. cit.*)

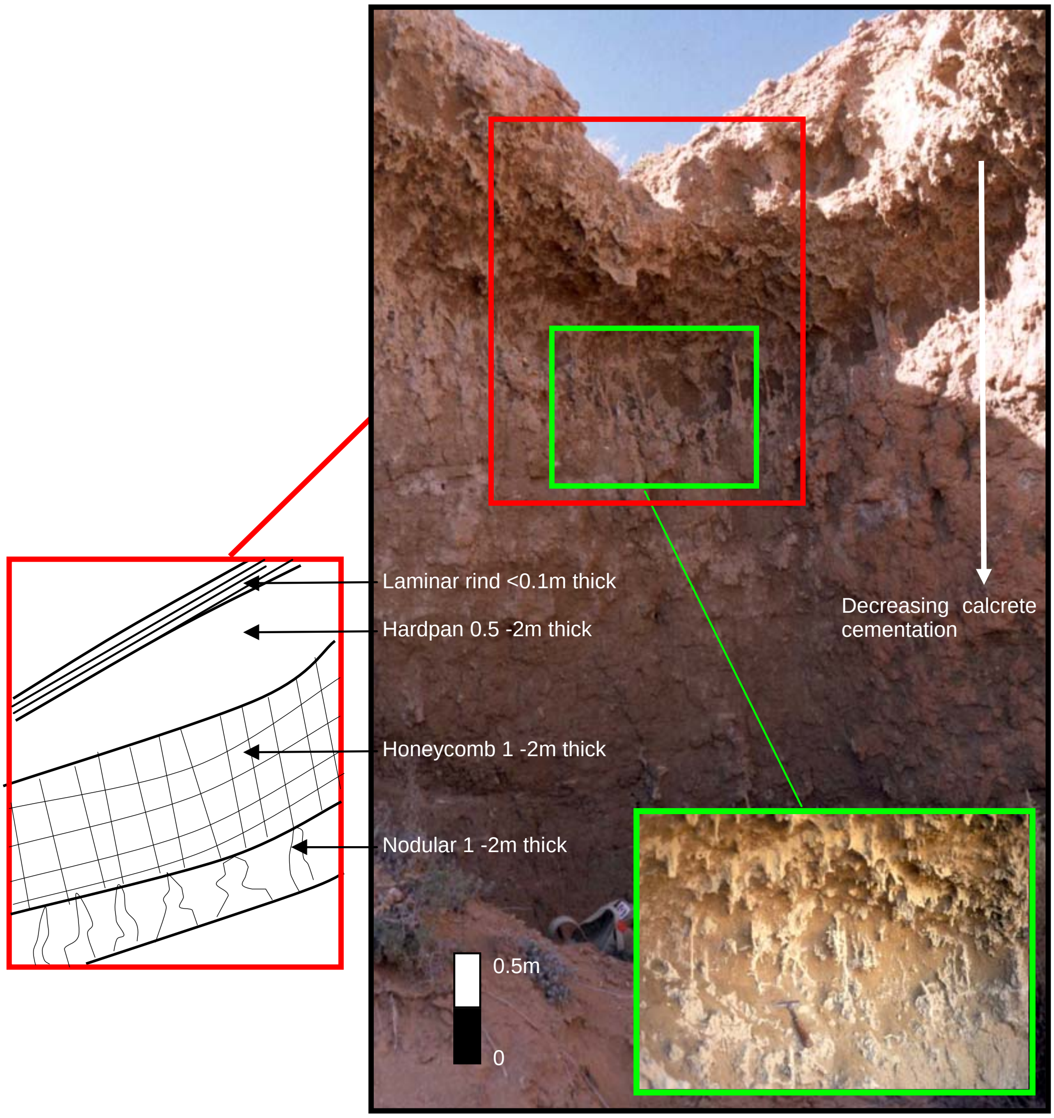
The calcrete cements are often chemically complex, having more than one mineral or clay component (Berner, 1980). Calcrete is common along coastlines and the precipitation of carbonate is dependent on factors such as temperature, pressure, pH, PCO_2 and ionic concentration. Cementation of $CaCO_3$ near the surface is restricted to grain boundaries, which is largely the result of differences in ionic concentrations and evaporation. Two main calcrete types were recorded in the vicinity of the study area: i) a pedogenic calcrete and ii) a lacustrine / pan calcrete that would represent ephemeral water bodies in the ancient dunefield.

Photograph 3.12 represents pedogenic calcrete cementation that is common at Geelwal Karoo. The photograph shows the hardpan-honeycomb-nodular calcrete cementation profile (Netterberg, 1980; Ward, 1987). Pedogenic calcrete is formed by the downward leaching of $CaCO_3$ from the upper soil horizons by percolating waters which carry it in solution lower down in the soil profile where it is then precipitated. The precipitation of calcrete is most concentrated near the surface and it gradually gets less dense down the profile (Ward, op.cit.). At the surface calcrete cementation is typically composed of a laminar rind which grades downwards into a hardpan-type calcrete surface. Deeper down in the soil profile, the calcrete cementation takes the form of a honeycomb fabric and with increasing depth eventually becomes nodular. Under a microscope this type of cementation showed detrital grains embedded in a calcrete matrix (it can either be matrix or clast-supported depending on the distance from the source). The iron coating on the quartz grains within these calcrete layers at Geelwal Karoo is minimal and this suggests that the grains were preserved in a calcrete horizon prior to iron staining.

The second type of calcrete cementation is a massive, unstratified carbonate lenses (Photograph 3.13) within the aeolianite. These are the result of ephemeral water bodies or pans situated in interdune slacks (Ward, 1987). This type of cementation is usually found further inland and consequently was not found at Geelwal Karoo. The association of red beds with evaporites is common as both are formed under conditions of low relative humidity (Berner, 1980). The dorbank of the aeolianite shows advanced red bed formation. In the formation of red beds, iron is leached from ilmenite or other iron-bearing minerals in the surficial zone and is re-precipitated deeper down as iron-hydroxide cement (limonite) on the surfaces of grains (Photograph 3.12). This process has given the quartz grains in the aeolianite their distinctive yellow or red colour.

It has also helped to cement the unit and the cementation observed is believed to be similar to the iron carbonate described by Pether et al. (2000). Closer inspection of the cemented faces also reveals a coating of manganese oxide, which precipitates on the surface in response to the effects of sun and moisture.

The red bed and calcrete horizon formation appears to be absent in the yellow dune belt. The numerous calcified trace fossils however suggest that there has been a degree of calcification within this unit but not to the same extent as the dorbank.



Photograph 3.12 Pedogenic calcrete exposed in the aeolianite, profile 2.

Photograph 3.13 Calcrete horizons found inland at Graauwduinen, site A. These calcretes appear to be the result of subaerial exposure resulting in the formation of evaporites.

3.3 The +50m package

3.3.1 Occurrence, characteristics and stratigraphy

The lateral extent of the +50m package can be seen in Figure 3.1. Three major marine sub-environments namely; offshore, inshore, beachface and backbeach units were identified in the +50m package (Figure 3.9). A yellow dune belt was found overlying the +50m package.

The offshore environment (continental offshore, shoaling and breaker zones) is noted in isolated outcrops at profiles 14, 1 and 4b where it overlies the channel clay unit. At Kleinzee, the offshore was identified as a layer of shelly, structureless, bioturbated green, pebbly, muddy sand which was found locally, beneath the gravel layers (Pether, 1994) and which sometimes contains authigenic phosphorite.

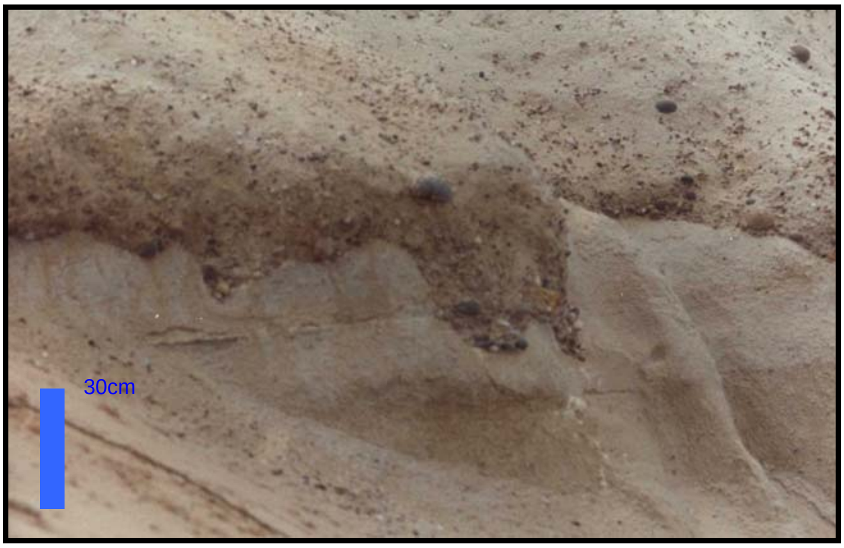
Photograph 3.14 Offshore of the +50m package in profile 1. The basal contact with the channel clay unit is at the base of the scale. The scale is 0.5m long. The offshore in this profile showed no cementing and no bedding.

Unlike Kleinzee, the offshore of the +50m package at Geelwal Karoo is fine-grained, a brownish-yellow colour (Photograph 3.14) and does not appear to be associated with layers of authigenic phosphorite. The sorting of the offshore unit is moderate and it is comprised of fine silty sand, which typically lacks any sign of bedding. It has a sharp basal erosional contact with the channel clay unit and this is only visible in profiles 1 and 14. In profiles 1 and 4, the offshore crops out at a low elevation (25m a.s.l.) and as a consequence is overlain by the inshore of the +30m package (Photograph 3.15). The offshore zone is only slightly cemented and has an average thickness of 6m.

The inshore environment (breaker and surf zones) of the +50m package is distinguished by a prominent basal gravel lag, which forms a sharp erosional contact with the channel clay unit (Photograph 3.16), the offshore zone (+50m package) or the basement. Although this gravel lag would appear to occur along the entire length of the study area, differences in the elevation have required that it be divided into two separate stratigraphic units (Addendum 1, Table 1.2).

The inshore exposures with elevations lower than 31m a.s.l. were assigned to the +30m package, whereas those with elevations above 31m were grouped with the +50m package. On further inspection, subtle differences in the sediment characteristics of the gravel layers were noted. The +50m gravel lag is usually limited to a single layer and on average contains larger clasts. Exposure of the +50m package inshore is concentrated in the central part of the study area (Figure 3.1) and therefore covers a distance of approximately 4km. The inshore of the +50m package has an average thickness of 7m (Addendum 1, Table 1.3).

No apparent difference was noted between the clast assemblages of the +50m and +30m packages and the clasts of both units are all well rounded and are either discoidal or spherical in shape. Quartzites pebbles and cobbles are believed to have been derived from the neighbouring Cape Supergroup, whereas the riebeckite and jasper clasts can be traced back to the Griquatown Group (Asbestos Hill Formation) of the Transvaal Supergroup, John Ward (pers.comm.).



30m
Package

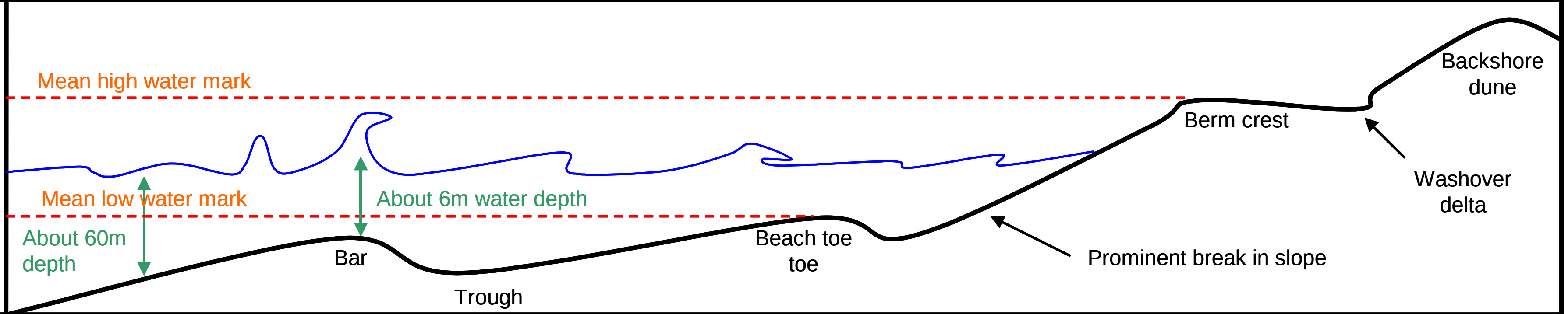
50m
Package

Photograph 3.15 Offshore of the +50m package (below) and the sharp erosional contact formed with the inshore (top) of the +30m package seen in profile 1.

ENVIRON MENT	SHOREFACE		BEACHFACE	BACKBEACH
	Lower shoreface	Inner (upper) shoreface		
MORPHO LOGY	OFFSHORE	INSHORE (Nearshore)	FORESHORE	BACKSHORE

DYNAMIC ZONE	Deep Water or continental shelf	Shoaling	Breaker	Surf (subtidal)	Swash (intertidal)	

PROFILE



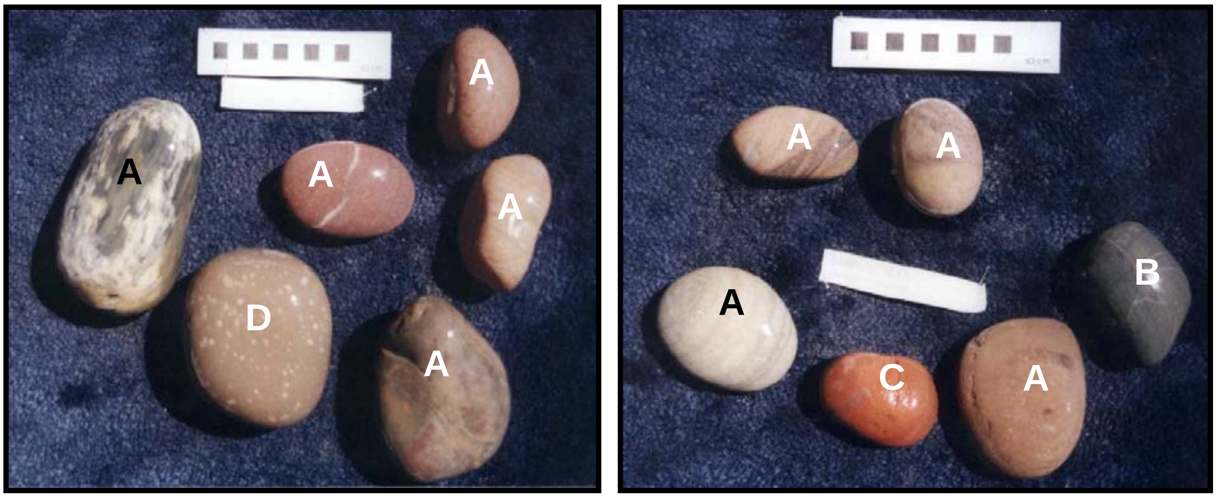
WATER MOTION	Oscillatory waves	Waves of translation (bores); longshore currents; seaward return flow; rip currents	Swash; backwash	
SEDIMENT SIZE TRENDS	COARSER →	← COARSER	← COARSER	← COARSER
ACTION	Accretion	Erosion Transportation	Erosion Accretion and erosion	Accretion
FEATURES	Storm-generated sand beds of laminated and bioturbated facies prevail, possibly with mud / silt interbeds deposited during fair-weather periods	Ephemeral fields of symmetrical and asymmetrical ripples (and possibly dunes) often wiped out during storms and replaced by storm-deposited facies such as laminated and bioturbated facies. The extent of bioturbation varies but tends to decrease landwards.	Parallel lamination and single set cross-bedding.	

Figure 3.9: Schematic illustration of the major beach-face sub-environments, processes and facies. (Modified after Millad, 2004)

Photograph 3.16: The inshore of the +50m package in profile 7. The lower erosional contact with the white channel clay formation is clearly visible. The basal gravel lag is characterised by well rounded clasts with poor sorting. Scale is 15cm long.

The quartz-porphyry cobbles are derived from the Cenozoic, Biesjesfontein Suite (De Beer et al., 2002). Some examples of the cobbles, pebbles and granules that are found in the inshore of the +50m package are shown in Photographs 3.17 and 3.18. The gravel clasts in the inshore of the +50m package appear larger than those found in the +30m package and can be best described as a cobble/pebble lag. The cobble fraction of these gravel lags is made up of local material found in the form of silcrete, ferricrete, phosphorite and gneiss clasts. The larger clasts in the +50m package indicate an older marine succession rather than a higher energy environment. (The same clasts are present in the +30m package but because they have had an extra million or so years to abrade and they are thus smaller).

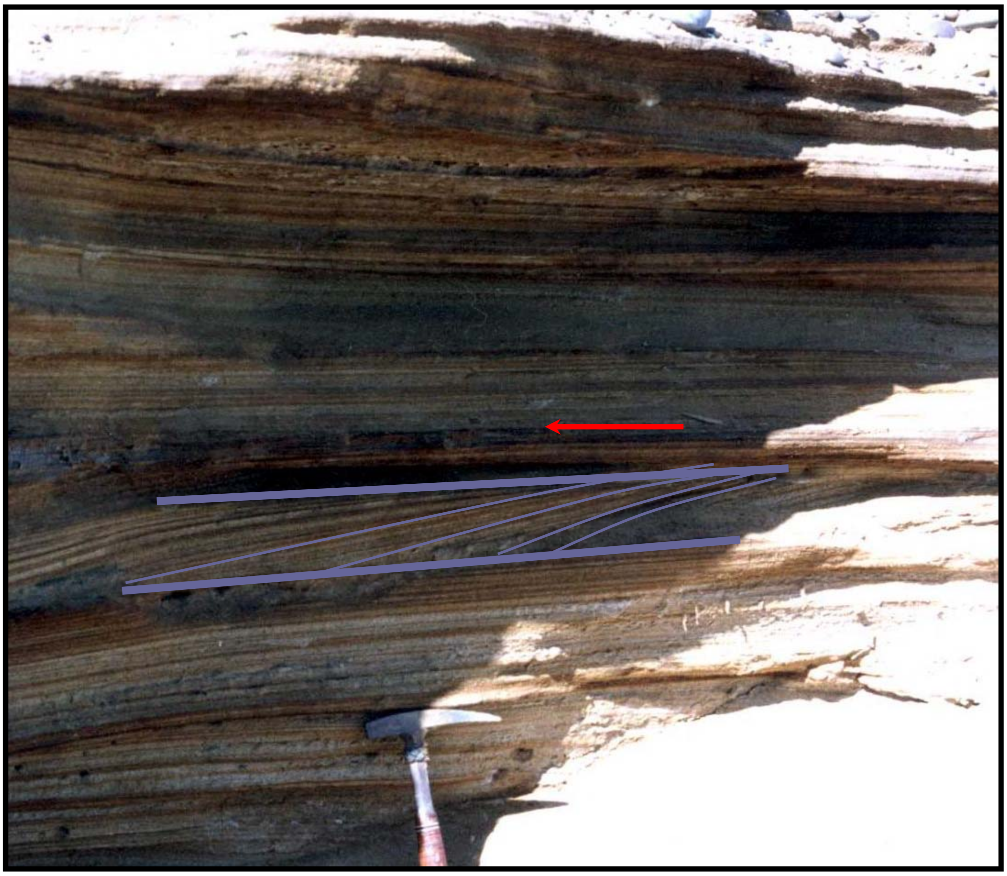
The hummocky cross-stratification in Photograph 3.19 is identified by: 1) "Fanning of truncation surfaces laterally into conformable successions of laminae"; and 2) A "tendency for convex-up sets of laminae to be succeeded upward by concave-up sets" (Southard, 1999). Such patterns are formed in conditions of relatively strong oscillatory-flow regimes. At Geelwal Karoo this stratification is not common and was found below the storm lag deposits and is therefore seen to be the product of a deeper water regime formed in the offshore.



Photograph 3.17 A selection of clasts collected from the inshore of the +50m package. Clasts as follows: (A) Quartzite; (B) Riebeckite; (C) Jasper; (D) Porphyry.

Photograph 3.18 Ferricrete blocks included in the inshore of the +50m package (profile 7). These blocks appear to be locally derived from an older marine terrace, which has subsequently been reworked into the +50m package.

The sorting in the +50m inshore gravel lag (Photograph 3.16) is generally poor and cross-stratification is evident in the sandier upper portions of the unit. There is a gradational contact with the overlying beachface environment and the transition is usually associated with an increase in the visible heavy mineral concentration (Photograph 3.19).



Photograph 3.19 Hummocky cross-stratification is enhanced by the presence of heavy minerals in the inshore of the +50m package (the red arrow indicates a SW flow direction). This photograph was taken in the vicinity of Torings. Geological hammer for scale.

The position of a low angle coquina bed of *Donax* shells (Photograph 3.20) in the inshore record has come under debate. Originally the shell lags were associated with the backshore facies and were seen to be similar to the mussel shell banks, which collect as wash over fans on the modern beachface. The steeply dipping strata under the shell lag (Photograph 3.20) are not characteristic for the beachface environment and are more common in the inshore, where they are the result of migrating sandbars. Furthermore the coquina beds are not well sorted and often interbedded with the occasional pebble and sand layer (shell lags found exposed on the current beachface are very well sorted). The *Donax* shell lags have therefore been transported to the inshore unit and these planar stratified shell lags truncate the steeply dipping sand bar layers. This sharp contact is a result of an increase in the energy within the flow regime and the change can be related to the onset of storm conditions.

Photograph 3.20: The shell lags in the +50m package are the result of storms. Evident below the lag is a sand unit of the subtidal facies (A) in which the seaward dipping foresets of a migrating sand bar are preserved. The geological hammer is for scale.

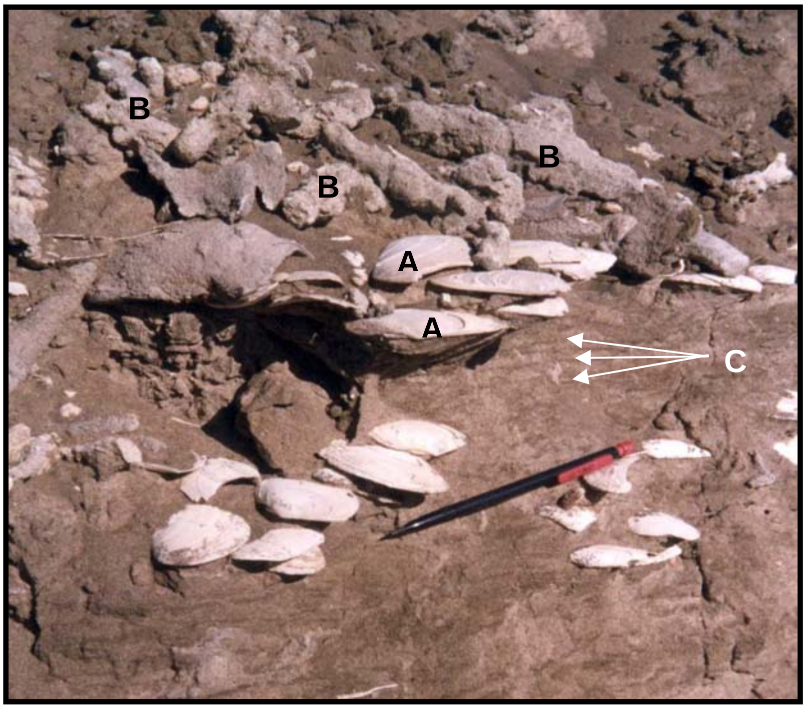
The inshore unit of the +50m package is overlain by the beachface (intertidal or foreshore zone) and it is well represented at Geelwal Karoo (Photograph 3.21). It was assumed that the tidal range of about 1.8m has remained constant during the Cenozoic and this value was used as the thickness for the foreshore and an approximate contact position calculated in the mapping data of Appendix 1. The contact between foreshore and backshore is gradational and difficult to find. At Geelwal Karoo, the beachface and backbeach environments (foreshore and backshore) has an average thickness of ~9m and the average elevation of the bottom contact with the inshore was 38m a.s.l.. The +50m beachface was recorded for a distance of approximately 4km.

The beachface is composed of medium to fine-grained sand, which is moderately to well sorted. South of the “Torings” area the +50m beachface is predominantly quartz-rich with a dark yellow-orange to grey-orange colour. In the remainder of the study area, however, the beach is characterised by high concentrations of heavy minerals (more than 15%) and has a characteristic greyish brown to dark olive green colour (Photograph 3.22).

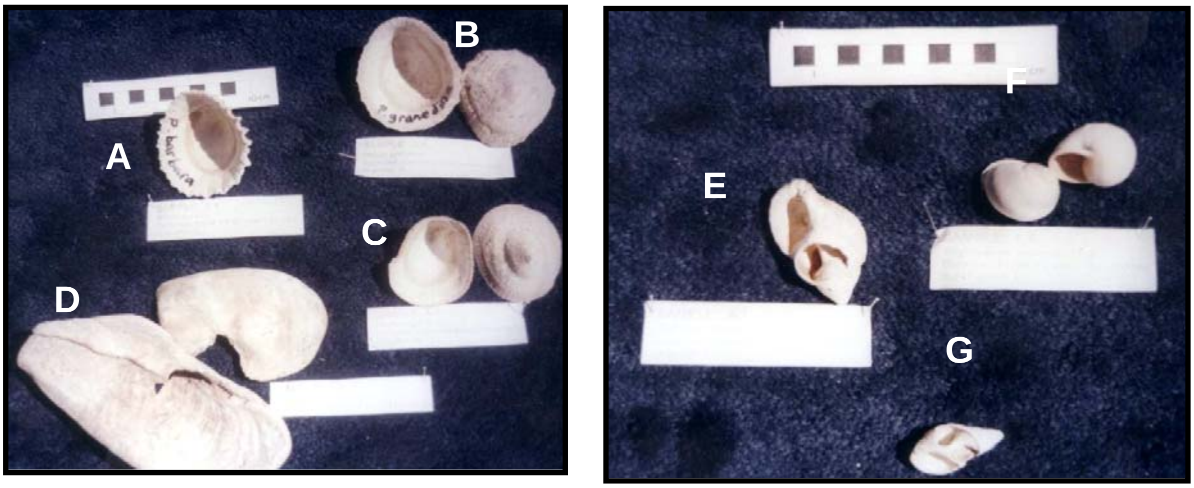
Photograph 3.21 The beachface (A) of the +50m package in profile 2. Evident is the white, channel clay unit (B), the gravel-rich inshore (C) and the gradational contact (D) with the backbeach environment.

The +50m beachface is characterised by the sporadic occurrence of the zone fossil, *Donax haughtoni* (Photograph 3.22). No *in situ* shells were found and in the foreshore zone, particularly in the heavy mineral enriched areas, the sand is well cemented and this has led to the preservation of sedimentary features such as heavy mineral laminations and trace fossil burrows. Towards the top of the beach, the lamination and cementation decrease, as the foreshore grades into the backshore.

Fossil shells in the form of *Patella sp.* and oysters shells, as well as numerous trace fossils (Photograph 3.23, 3.24 and 3.25) were found in the beach of the +50m package. Although the shells confirm the marine nature of the environment, the trace fossils indicate the presence of both marine and terrestrial species and with the receding shoreline, terrestrial influences were superimposed on the marine fossil record. The trace fossil burrows persisted into the backshore and these were found together with remnants of a tortoise shell (profile 6). The latter confirmed the terrestrial nature of the upper part of the placer sand and thereby indicate the start of the backbeach environment of the +50m package. The terrestrial tubes were often associated with a darker centre and were more robust than the marine counterparts. The backshore unit is overlain by the yellow dune belt of the aeolianite unit (Photograph 3.26).

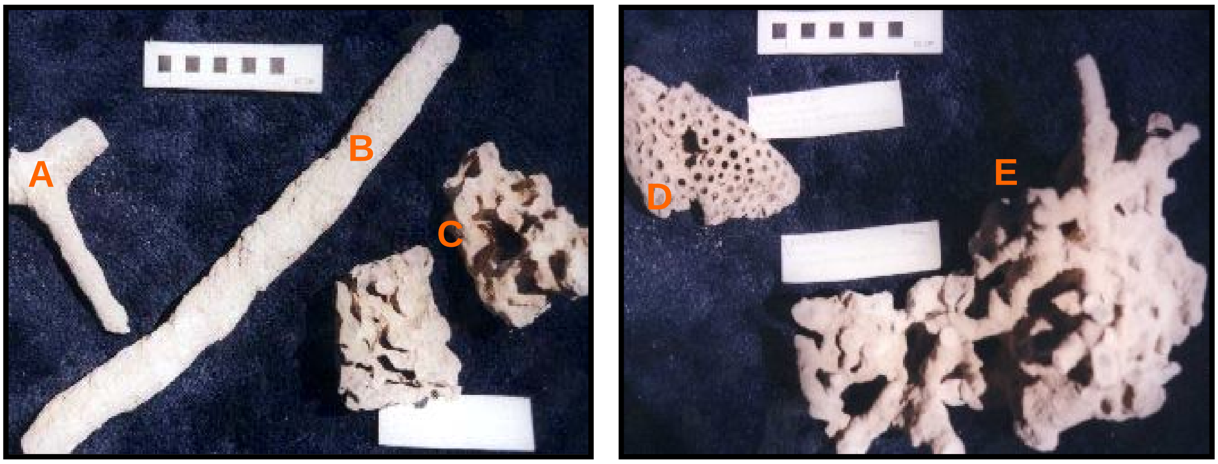


Photograph 3.22 A close-up picture of *Donax haughtoni* shell lag found in the beachface of the +50m package (A). Shell are clearly not articulated and therefore not *in situ*. Also evident are the calcified trace fossil burrows (B) and the heavy mineral laminations (C).

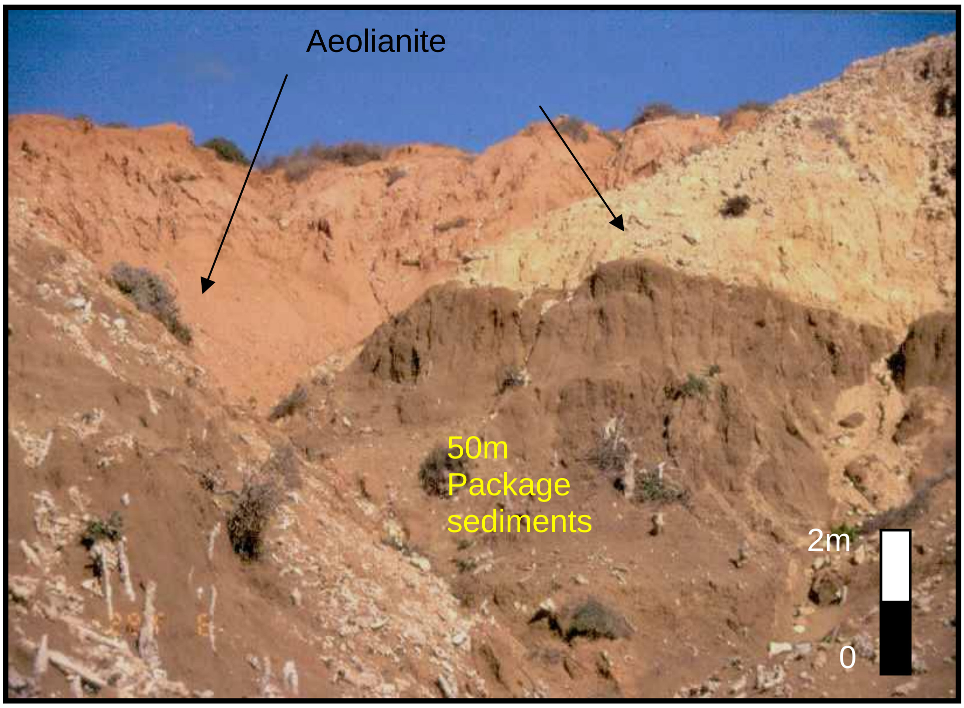


Photograph 3.23 Fossils shells found in the beachface of the +50m package. (A) *Patella barbara* (B) *Patella granatina* (C) *Patella argenvillei* (D) *Crassostrea margaritacea* (E) *Argobuccinum pustulosum* (F) *Trigonephrus globulus* (a species of terrestrial snail still found in the dunes today.) (G) Unidentified

Photograph 3.24 The trace fossils found in +50m package are found in distinct horizons and have been preserved as a result of ground water movement.



Photograph 3.25 Trace fossil burrows collected from the beachface of the +50m package. (A) *Thalassinoides;* (B) *Ophiomorpha;* (C) Termite burrows found in the aeolianite. (D) *Gunnarea capensis* (a modern marine invertebrate). (E) Rhizoliths collected from the beach of the +50m package.



Photograph 3.26 The outcrop of the aeolianite in profile 6. In the foreground is the black heavy mineral-enriched sand of the foreshore of the +50m package, which is overlain by the yellow dune belt of the aeolianite.

3.3.2. Sedimentology

The offshore sediments of the +50m package are dominated by mud and sand (Figure 3.10). A grain size analysis of the samples collected from this unit show histograms with two or more modes. They are negatively skewed (Appendix 2, Table 3). There are no definitive characteristics for the sediments of this environment but generally fine sediments are found on the offshore (deeper water) whereas the outer part (closest the coast) has coarser material (Schopf, 1980). The samples at Geelwal Karoo were mostly fine sand, which was moderately well to well sorted and this would suggest that they represent the offshore environment.

According to Visher (1969) the bedload of the offshore is usually poorly sorted and the truncation is generally finer than 2 phi, which can be seen in samples 10 and 10b (Appendix 2, Figure 6). The size of the saltation population ranges from 1 to 1.5 phi, whereas the suspension populations (up to 80% of the distribution), besides being well sorted, have truncation sizes finer than 3.5 phi. This is not seen in the samples at Geelwal Karoo, but more sampling would be required to confirm this.

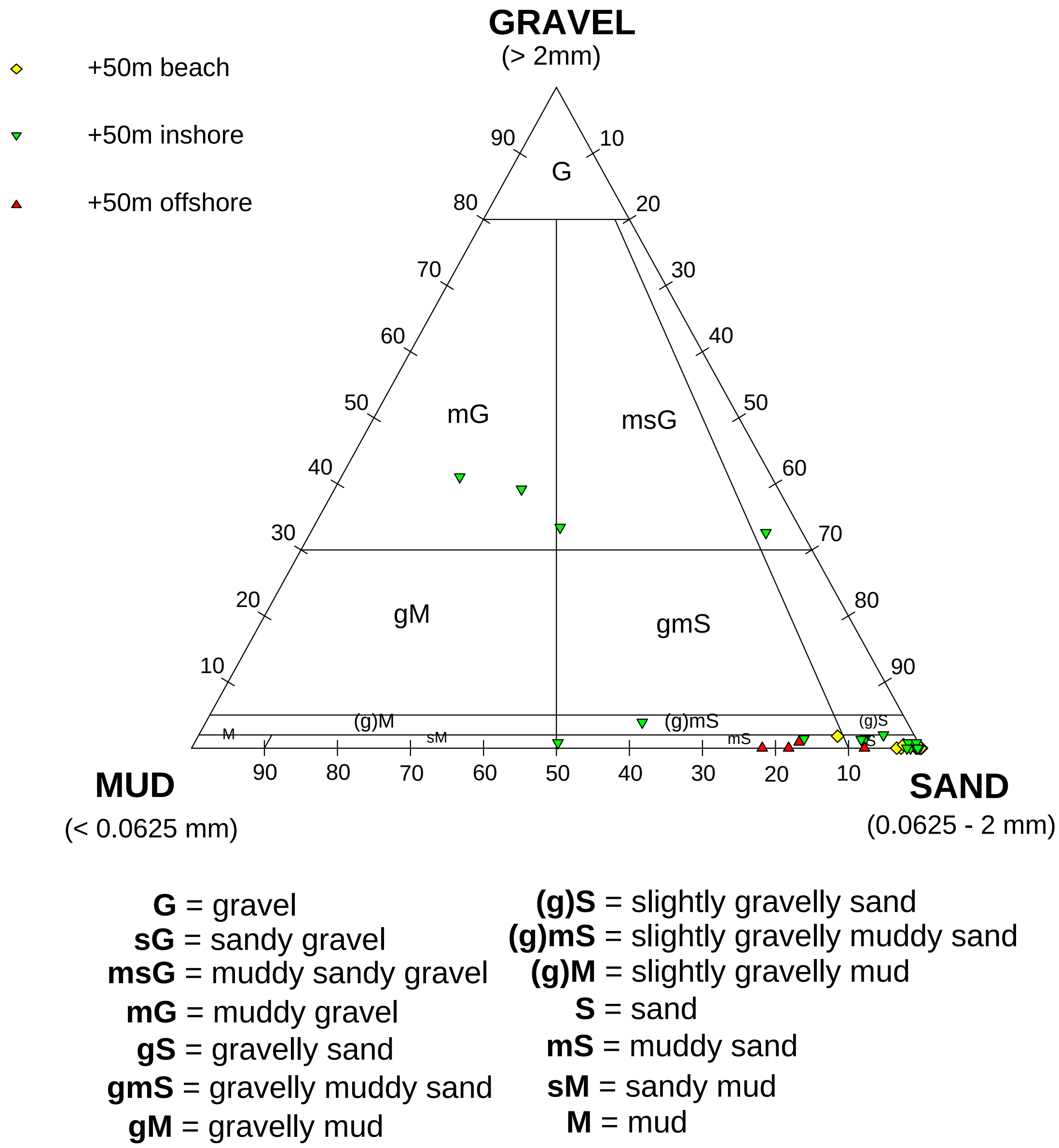


Figure 3.10: Textural classification of samples in the +50m package. Offshore n=4, inshore n=17, beachface n=9.

In the inshore environment of the +50m package a wide range of particle sizes are recorded, from fine sand to very small pebbles or granules (Figure 3.10). Initially, the breaking surf transports the coarser particles seawards from the beach into the surf zone and the break in the slope at the coarse end of a size-frequency diagram is termed the surf break (Schopf, 1980). Histograms of the Geelwal Karoo samples reveal graphs with both bi- and polymodal distributions (Appendix 2, Table 3). Furthermore, there appears to be an equal representation of positive and negatively skewed grain size populations. The greater the wave height, the greater the disturbance and in the wave zone sediments are generally negatively skewed (more coarse material) and very poorly sorted (Schopf, 1980).

The sorting improves further inshore and although the Geelwal Karoo samples show a general improvement in the sorting from very poor to moderately well sorted, it is difficult to relate this to a decrease in water depth along the beach profile.

A Visher diagram of a typical offshore (breaker zone) sample shows a saltation population with a slope of more than 65 degrees (Visher, 1969). The breaker zone is characterised by a large traction load and little suspension load is present. There are generally 3 populations in evidence, with the saltation load being well sorted and ranging between 2 and 3.3 phi. In the surf zone (inshore), the traction carpet becomes intermittent. Most of the inshore samples at Geelwal Karoo had little traction load and therefore represent the inshore rather than offshore facies.

A particle size analysis shows the beach zone to be more uniform and to consist mostly of sand with only minor amounts of gravel (Figure 3.10). The latter is mostly in the form of small pebbles and granules and these are often found associated with *Donax* shells. The histograms of this unit show a preference for unimodal, positively skewed grain size distributions. The samples in this environment tend to be moderately well sorted and typically there are no examples of poor sorting. The sand was classified as medium to fine-grained. Mud was found in some of the samples and because of its association with post-depositional weathering was excluded from the results. The calcrete cement had to be crushed to loosen the samples for particle size analysis and the mud fraction was highest in the samples where the cementation was most severe.

The horizontal parallel stratification formed by the alternating fine-grained heavy minerals laminae overlain by a coarser light mineral laminae, is indicative of a foreshore environment (Photograph 3.24: Reading, 1991). According to Reading (1991), all types of size frequency distributions can be expected in this environment, ranging from unimodal, well sorted to bimodal, poorly sorted populations. Mid-beachface sediments lack coarse material and are better sorted than the surf zone sediments. Due to the swash/backwash action on the shore, the frequency distribution of the foreshore environment, typically display two traction populations, (Schopf, 1980). Subtle truncation planes reflect brief periods of erosion and often divide laminae into discrete sets. These laminae are attributed to grain segregation under conditions of plane bed sediment transport during swash-backwash flow. Strong, fast-moving currents produce this type of cross-stratification. The landward, swash action of the waves, carries coarse material to the developing beachface, whereas the seaward, backwash phase has less energy, and plays a role in sorting the beach material and leaves only the coarsest material behind (Southard, 1999).

A typical Visher diagram of the beachface unit displays four populations and the truncation points may vary, and so too, the slope (sorting). More often than not there is a break at 2 phi between the two traction populations. In the samples at Geelwal Karoo, the majority display two populations and the break at 2 phi is not visible. The high concentration of heavy minerals in the beach of Geelwal Karoo makes it difficult to compare the size frequency distributions of these samples with the predominantly quartz-rich samples provided by Visher (1969).

The Friedman scatter plot seen in Figure 3.4 shows that most of the samples in the +50m package were the product of a bi-directional flow regime. This is best explained by the swash and backwash action on the beachface and the oscillatory effect of waves in the offshore environments.

3.3.3 Mineralogy

The mineral diversity was greatest in this unit and for this reason a study of the mineral abundance in “whole rock” samples was conducted. This study revealed that in most of the samples quartz dominates the mineral assemblage (Appendix 3, Table 1). Abundant concentrations of ore minerals, rock fragments or ferro-silicates were found in the samples in which quartz does not dominate the assemblage. A study of the heavy mineral assemblage of the +50m package sediments revealed that, together with the +30m package, there is double the concentration of opaque minerals than in either the fluvial or aeolian units (Table 3.1). The ZTR index of these sediments was one of the lowest (average of 5, Appendix 3, Table 2) suggesting a very mature mineral assemblage.

In the offshore of the +50m package the quartz grains are either clear or have an iron coating which gives them a yellow colour. Although some of the quartz grains are angular, most have a sub-angular, sub-rounded or rounded shape. The presence of kaolin in the mud fraction of the offshore sample indicates a degree of reworking of the channel clay unit (Figure 3.11). The overall THM concentration of the offshore is relatively low and averages 18%. The heavy mineral assemblage of this unit is characterised by higher concentrations of garnet, leucoxene and glauconite than the other +50m package units (Table 3.4).

Although the quartz grains in the inshore of the +50m package are either clear or milky in colour, some of the grains are covered by an iron coating and are thus yellow or red in colour. No angular quartz grains were in evidence, most of the grains being either sub-angular or sub-rounded. The heavy mineral assemblage of this unit can be distinguished by its higher concentrations of ilmenite (Photograph 3.27) and hydrated ilmenite, Table 3.4.

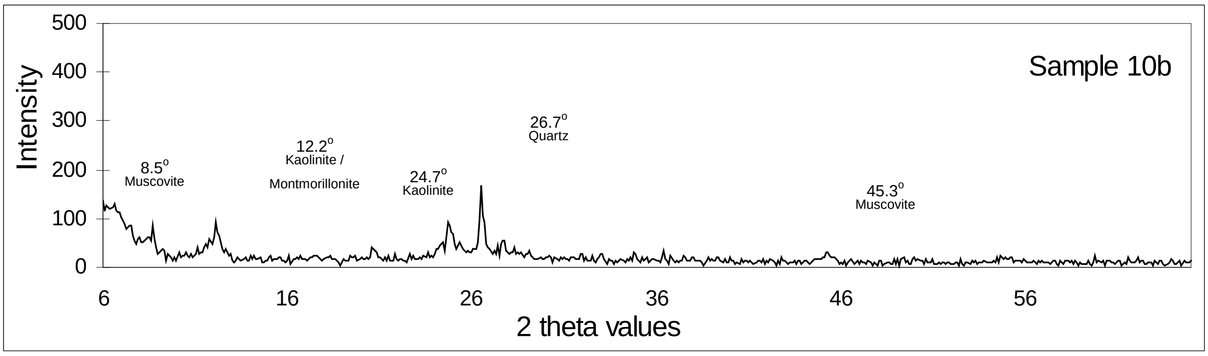
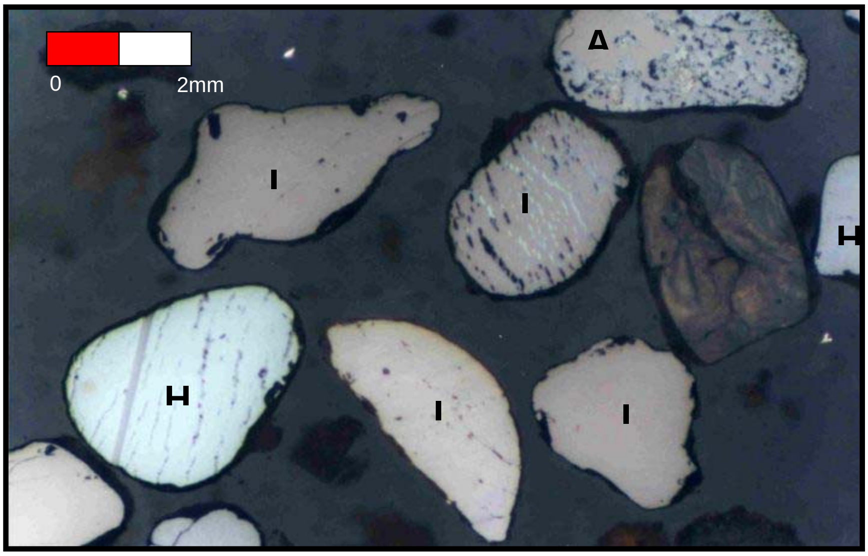


Figure 3.11: XRD diffractogram of sample 10b from the offshore of the +50m package.(XRD: Cu radiation, 40mA, 40 kV, window = 100, scan rate = 1 deg/min)

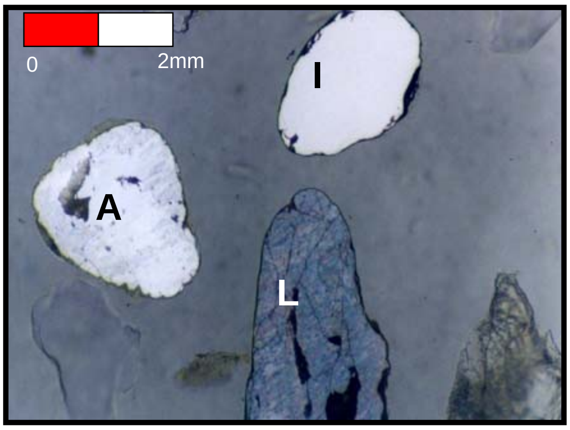
Both clear and milky (hydrothermal) quartz grains were recorded in the +50m beach, as well as grains with iron coatings (i.e. grains that are red and yellow). Almost 50% of the grains are sub-rounded to rounded and this suggests a mature assemblage that has been subjected to a great deal of reworking, which is confirmed by the low ZTR index. The %THM concentration of the +50m beach is high and averages 32.49%. Table 3.4 shows that the heavy mineral assemblage of this unit is distinguished by augite, weathered grains (Photograph 3.28) and iron-bearing rock fragments

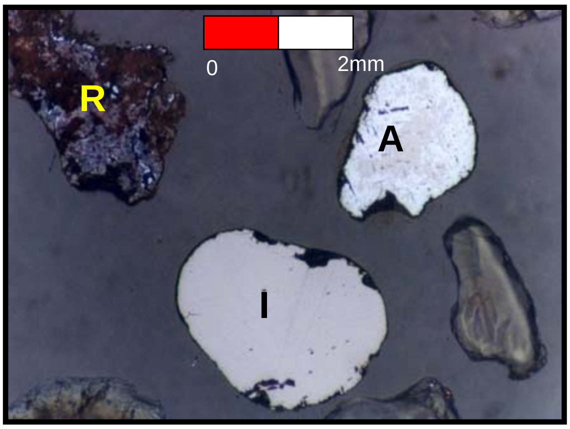


Photograph 3.27 Ilmenite (I), hematite (H) and altered ferro-silicate (A) grains from the inshore of the +50m package. Some of the hematite and ilmenite grains show exsolution lamellae of ilmenite and hematite, respectively. (Sample 7c; heavy fraction mount; 200x magnification; oil immersion; reflected light; crossed nichols)

Table 3.4: Point count data for the heavy mineral fraction of the +50m package. Data presented as a percentage of the total heavy fraction. Off = offshore and In = Inshore.

Sample number	**10**	**27**	**84**	**Average**	**90**	**7c**	**20**	**7a**	**85**	**6**	**Average**
Facies	Off	Off	Off		In	In	In	In	In	In	
Sampling elevation	19.02	25.44	31.27		32.10	33.70	35.02	35.73	37.65	39.50	
Distance from nouthern gate (km)	3.50	11.50	10.50		11.00	10.00	10.50	10.00	10.50	10.00	
Rutile	6	2	1	3	4	4	3	1	3	3	3
Zircon	1	1	0	1	3	4	1	0	1	3	2
Garnet	23	26	6	18	11	7	8	5	12	10	9
Augite	2	4	17	8	1	1	38	8	15	5	11
Hornblende	0	2	1	1	0	0	1	0	2	1	1
Weathered grains	3	2	25	10	0	1	6	2	25	24	10
Tourmaline	0	2	0	1	0	1	2	0	1	1	1
Kyanite	0	0	0	0	0	0	0	0	0	0	0
Monosite	0	0	0	0	0	0	0	0	0	0	0
Staurolite	0	0	0	0	0	0	1	0	0	0	0
Ilmenite	29	22	1	17	37	29	3	36	7	24	23
Hydrated ilmenite	20	17	1	13	30	44	2	35	4	18	22
Leucoxene	5	6	2	4	4	2	2	2	3	3	3
Other opaque minerals	2	4	0	2	5	4	1	5	3	4	4
Magnetite	0	2	0	1	0	0	0	0	1	2	1
Chromite	0	0	0	0	1	0	0	0	1	0	0
Pseudorutile	2	1	0	1	1	0	0	1	0	0	0
Glauconite	2	0	0	1	1	0	0	0	0	0	0
Rock fragments	2	2	6	3	0	0	8	0	10	1	3
Carbonates	0	0	3	1	0	0	4	0	2	0	1
Total heavy minerals	**98**	**93**	**63**	**85**	**99**	**98**	**80**	**96**	**89**	**98**	**93**
Feldspar	0	0	3	1	0	0	1	0	1	0	0
Quartz	2	7	33	14	1	2	19	4	11	2	6
Grand total all minerals	100	100	100	100	100	100	100	100	100	100	100
%THM of whole sample	1.18	4.38	48.91	18	13.62	56.69	40.53	17.51	67.82	30.61	38
% Ti-mineral only	63	52	7	41	77	81	13	79	19	49	53
%Ti-minerals of THM for whole sample	0.75	2.28	3.35	2.13	10.42	45.93	5.26	13.75	12.75	15.15	17.21





Photograph 3.28 A selection of ore minerals found in the beach zone of the +50m package. (I) Ilmenite (L) Leucoxene (R) Rutile (A) Altered ilmenite (hydrated ilmenite). (Sample 86; heavy fraction mount; 200x magnification; oil immersion; reflected light; crossed nichols)

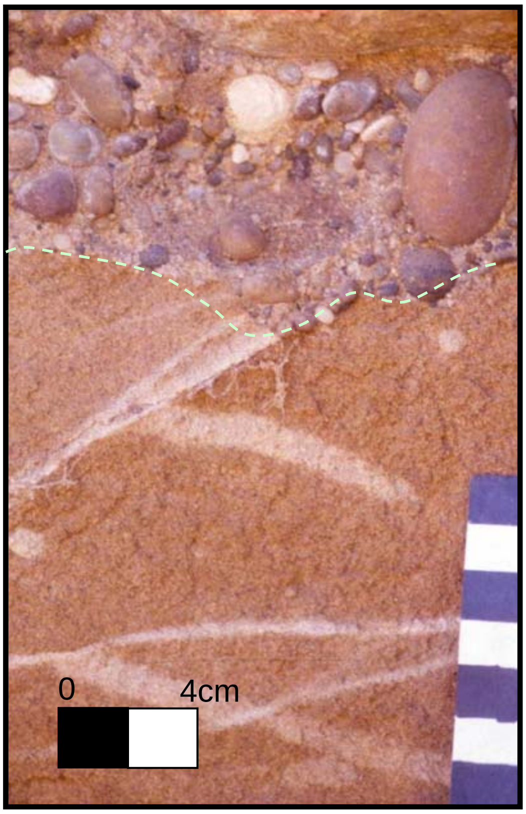
Table 3.4 (continued): Point count data for the heavy mineral fraction of the +50m package. Data presented as a percent of the total heavy fraction.

Sample number	**86**	**50**	**17e**	**17a**	**Average**
Facies	Beach	Beach	Beach	Beach	
Sampling elevation	41.82	42.72	48.10	50.11	
Distance from nouthern gate (km)	10.50	9.00	10.50	10.50	
Rutile	1	3	1	2	2
Zircon	3	2	1	1	2
Garnet	11	28	5	12	14
Augite	13	17	21	7	15
Hornblende	0	1	0	0	0
Weathered grains	29	12	21	15	19
Tourmaline	0	0	1	1	0
Kyanite	0	0	0	0	0
Monosite	0	0	0	0	0
Staurolite	0	0	0	0	0
Ilmenite	18	15	7	22	16
Hydrated ilmenite	13	10	3	17	11
Leucoxene	2	1	1	1	1
Other opaque minerals	3	3	2	7	4
Magnetite	0	1	0	0	0
Chromite	0	0	0	1	0
Pseudorutile	1	0	1	1	1
Glauconite	0	0	0	0	0
Rock fragments	1	1	18	2	6
Carbonates	0	2	0	0	1
Total heavy minerals	**94**	**96**	**83**	**89**	**90**
Feldspar	0	0	5	1	2
Quartz	6	4	12	10	8
Grand total all minerals	100	100	100	100	100
%THM of whole sample	35.89	85.85	25.66	52.51	50
% Ti-mineral only	36	30	17	49	33
%Ti-minerals of THM for whole sample	12.85	26.02	4.24	25.47	17.15

3.3.4 Alteration

In the +50m package, the effects of pedogenesis were observed all the units and this was in the form of calcrete lenses (Photograph 3.29) which formed upon sea level regression and subsequent subaerial exposure.

The diffractogram in Figure 3.11 is of mud samples taken from the offshore zone. The presence of kaolin, muscovite, quartz and dolomite is evident. The presence of kaolin and muscovite can be ascribed to the result of reworking of the channel clay unit and the basement phyllites. Dolomite can be expected in offshore and inshore samples (Berner, 1980).



Photograph 3.29 The contact (dashed green line) between the offshore unit (below) of the +50m package and the inshore of the +30m package showing the carbonate veins within the offshore unit. Photograph taken at profile 4b.

Calcrete formation in the +50m package followed a drop in the sea level. The marine sediments of the +50m package were left stranded on the shore and were consequently subjected to groundwater action. During groundwater action, carbonates were leached from the shell lags in the foreshore and then re-deposited as near-surface lenses and veins of low magnesium calcite (Berner, 1980). Under the binocular microscope these lenses reveal a loose arrangement of quartz grains cemented by a yellowish white core of calcareous material. In contrast to the calcareous layers found in the aeolianite, there is a violent reaction with dilute HCL and this is ascribed to a higher carbonate content of the cement.

In the offshore zone of the +50m package, very few quartz grains show iron oxide coatings, whereas in the beachface and inshore units, a number of quartz grains possess iron oxide coatings. The iron oxide coatings are also the result of groundwater action and the leaching and re-deposition of iron appears to have been restricted to the upper portion of the sedimentary succession at Geelwal Karoo.

The presence of minerals such as hydrated ilmenite, leucoxene and pseudorutile in the heavy mineral assemblage of the beachface environment of the +50m package suggests advanced weathering of the ore minerals. According to Force (1991), evidence for predepositional weathering can be found in one or more of the following forms. Weathered grains typically show a polish or are embedded in a calcareous cement; another indication of predepositional weathering is when the weathered grains are larger than an unaltered precursor currently in the heavy mineral assemblage. In the Geelwal Karoo samples, leucoxene was found throughout the beachface zone and these grains were either the same size or smaller than the surrounding ilmenites. The pseudorutile grains, however, were found to be much larger than the average rutile grain in the assemblage and this seems to indicate a degree of *in situ* weathering in the heavy mineral provenance area. Unfortunately, according to Pettijohn et al. (1973), minerals susceptible to both acidic and alkaline weathering will tend to display the same weathering structures for both types of geochemical environments and identifying the type of alteration seen in these grains will not help to point to a provenance.

The pyroxene grains in the heavy mineral assemblage of Geelwal Karoo do not show many signs of local weathering and the heavy mineral grains were preserved by calcareous cement relatively quickly after deposition. According to Mange and Maure (1991), pyroxene and hornblende grains are soluble in alkaline solutions. This dissolution is evident in “hacksaw” or cockscomb terminations on hornblende grains and in the Geelwal Karoo samples, most of these terminations have been rounded through erosion. Generally the alteration of detrital pyroxene grains starts on the exterior and gradually migrates inward. This is demarcated by colour changes, bleaching and finally either produces a single homogeneous mineral or irregularly extinguishing mineral aggregates with a low refraction index. In the +50m package samples the whole range between the intact unaltered pyroxene grains to the non-descript mass of weathered ferro-silicate was noted. On the whole however, the weathered grains dominate the heavy mineral assemblage in the beachface zone, making up to 9.62% of the total concentration. The buffering effect of the calcrete horizons must be excluded as an explanation as the beachface zone of the +50m packages is not only the most cemented horizon but also hosts the most altered ferro-silicates. It is believed that at the elevation of between 40 and 60m a.s.l., the beachface unit of the +50m package was subjected to the most leaching through groundwater.

3.4 The +30m package

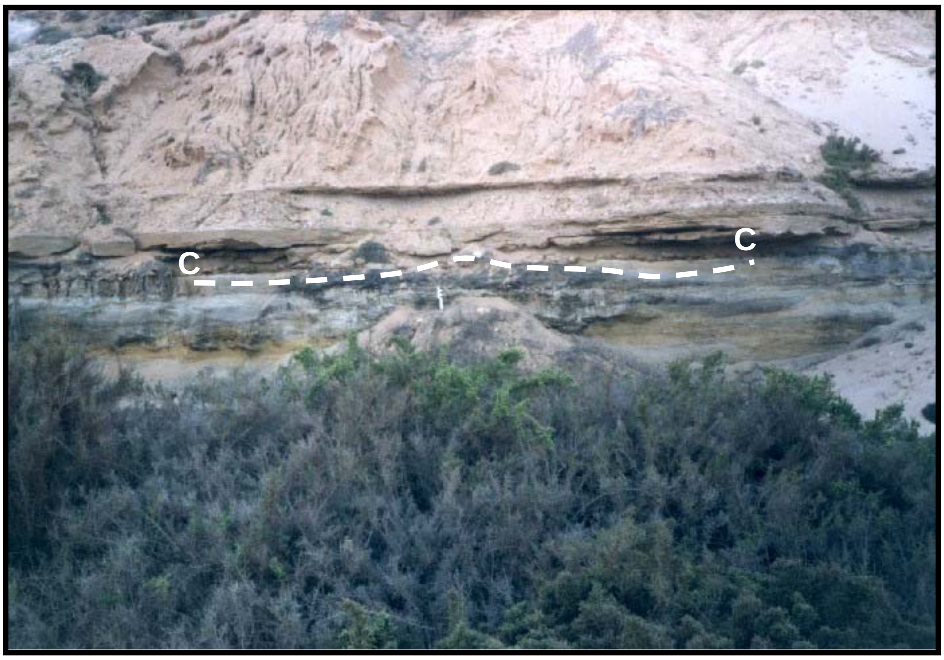
3.4.1 Occurrence, characteristics and stratigraphy

Although the +30m sediments overlap onto the +50m package the bulk of the +30m package was deposited below 30m a.s.l. Much of the 30m package sediments have been eroded during the present highstand and at Geelwal Karoo, exposures are limited to the areas where the bedrock elevation is lowest (Figure 3.1). *In situ* outcrops of the offshore and inshore environments were identified in profile 9 (Photograph 3.30) and in the extreme south of Geelwal Karoo (at profile 12) the inshore of the +30m package were initially identified by virtue of its elevation (lower than the adjacent +50m inshore) and then by differences in sedimentary characteristics.

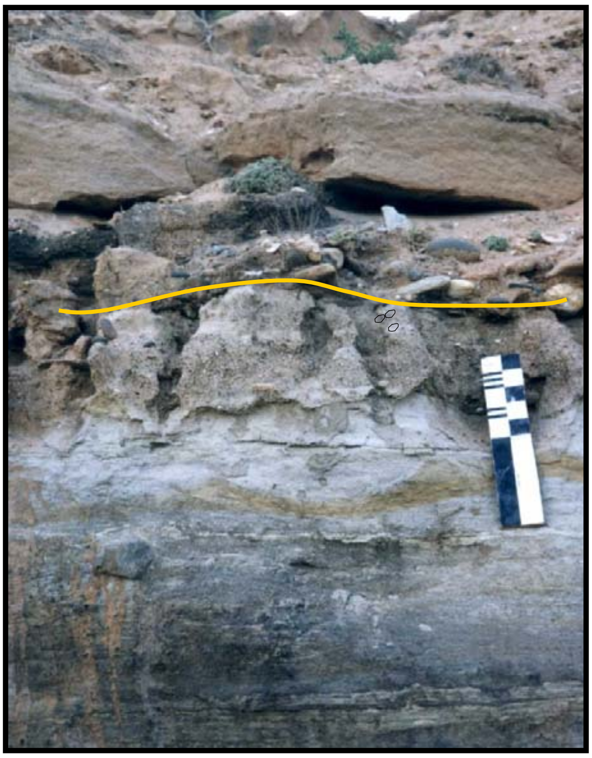
In the exposure at profile 9, there is no exposed basal contact with the basement rocks but the sharp contact with the inshore of the +30m package is clearly visible. The offshore sediments of the +30m package are found between 24 and 26m a.s.l. and they have a distinctive greenish black colour. They are well cemented by carbonate, which helped preserve laminations and cross-bedding (Photograph 3.31).

The inshore sediments of the +30m package lie directly on the basement gneiss in profile 10 and extends to the south, up to and including profile 3, a distance of approximately 5km (Figure 3.1). The inshore zone of the +30m package has a basal elevation of about 26m a.s.l., an average thickness of about 3m and the matrix has a gray-orange colour. Although generally there was a single gravel lag in the +30m gravel layer, in profile 4 several gravel lags were observed. The clasts in the +30m gravel lags are typically smaller (less cobble-sized clasts) than those encountered in the +50m.

Despite the larger clasts in the +50m package (all local material), the multiple gravel lags (of profile 4) and the coarser sand successions seem to indicate that the +30m package represents a more vigorous, higher energy wave regime.



Photograph 3.30 The offshore and inshore of the +30m package in profile 9. The sharp upper contact of the offshore with the inshore facies is indicated (c).



Photograph 3.31: A close-up view of the offshore and inshore of the +30m package at profile 9. A yellow line marks the contact between the two units.

The gravel lag of the +30m package contains fossil shell fragments rather than complete shells. A whale rib-bone was excavated from the gravel lag in profile 1 and this helped to confirm the marine nature of the unit. The +30m package's inshore in profile 4 (Photograph 3.32) is characterised by a succession of gravel lags which shows an overall upward fining in the clast size. The sorting within the gravel layers is generally poor and the gravel lags are intercalated with sand and silt.

A unique feature exists in profile 1 and 4 where +50m package offshore zone sediments are found preserved beneath the inshore zone of the +30m package (Figure 3.12). The contact is sharp and erosional and the +30m package appears to have been less erosive in this area and rather than reworking the older sediments it buried them beneath a thick succession of inshore sediments. Remnants of re-worked older strandlines are often found in the +30m inshore (Photograph 3.33). These remnants occur as slumped, well-cemented blocks of heavy mineral-enriched sediments, which are identified by steeply dipping bedding.

Photograph 3.32 The top contact between the offshore of the +50m package and the inshore of the +30m package at profile 4b. Geological hammer for scale.

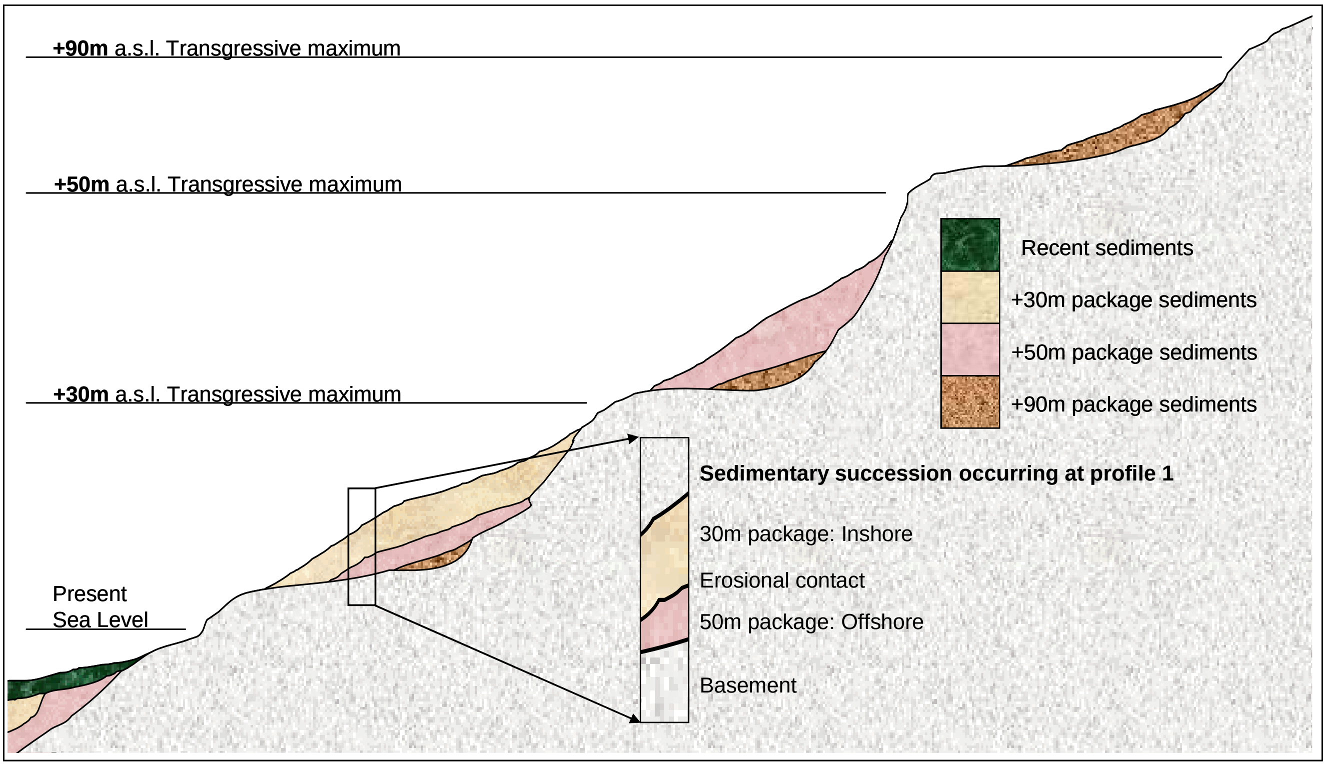
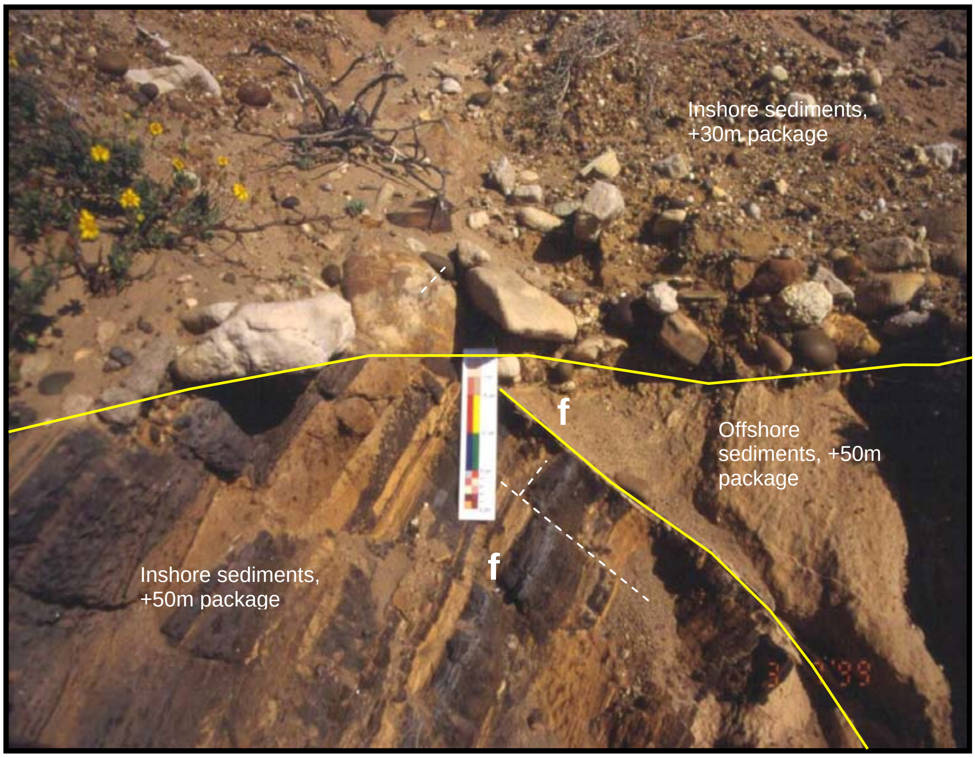


Figure 3.12 Schematic diagram illustrating the spatial relationship of the +90m, +50m, and +30m packages as they occur today along the West Coast.



Photograph 3.33 Well-cemented heavy mineral-enriched layers of +50m package succession capped by the basal gravel lag of the inshore of the +30m package. Micro faulting is evident and is the result of erosion and consequent reworking of the older succession (f).

Above the inshore of the +30m package in profile 9 and as loose blocks on the present beachface (Photograph 3.34), a sandy unit with a pale orange colour was discovered. In the embankment, this unit is entirely concealed by red aeolian sand and was subsequently identified as the *in situ* remains of the +30m package beachface.

Photograph 3.34 Cemented blocks of the inshore of the +30m package found on the present beachface. The geological hammer is placed amongst fossilized mussel shells.

Although laterally the +30m beachface appears to occur over a distance of approximately 5km, the vertical extent of the unit is unknown. This unit was not found in the prospecting trench dug behind profile 10 and therefore cannot extend more than 10m inland. No gravel lags, cementing or finer mud and silt fractions were in evidence in the *in situ* sediments, but in the eroded blocks found on the present beachface both appeared to be present (Photograph 3.34). These cemented blocks yielded fossilised mussel shells. *Donax rogersi* shells were however found exposed on the surface of the embankment about 200m south of profile 10.

3.4.2 Sedimentology

In the unprepared samples, mud dominates the samples of the +30m package (Figure 3.15) and in the washed samples, the grain size analysis of the offshore sediments revealed a range of fine, medium and coarse sand (Appendix 2, Table 4). In general, the histograms of these samples show a bimodal distribution with a negative skewness. The samples are moderately to well-sorted.

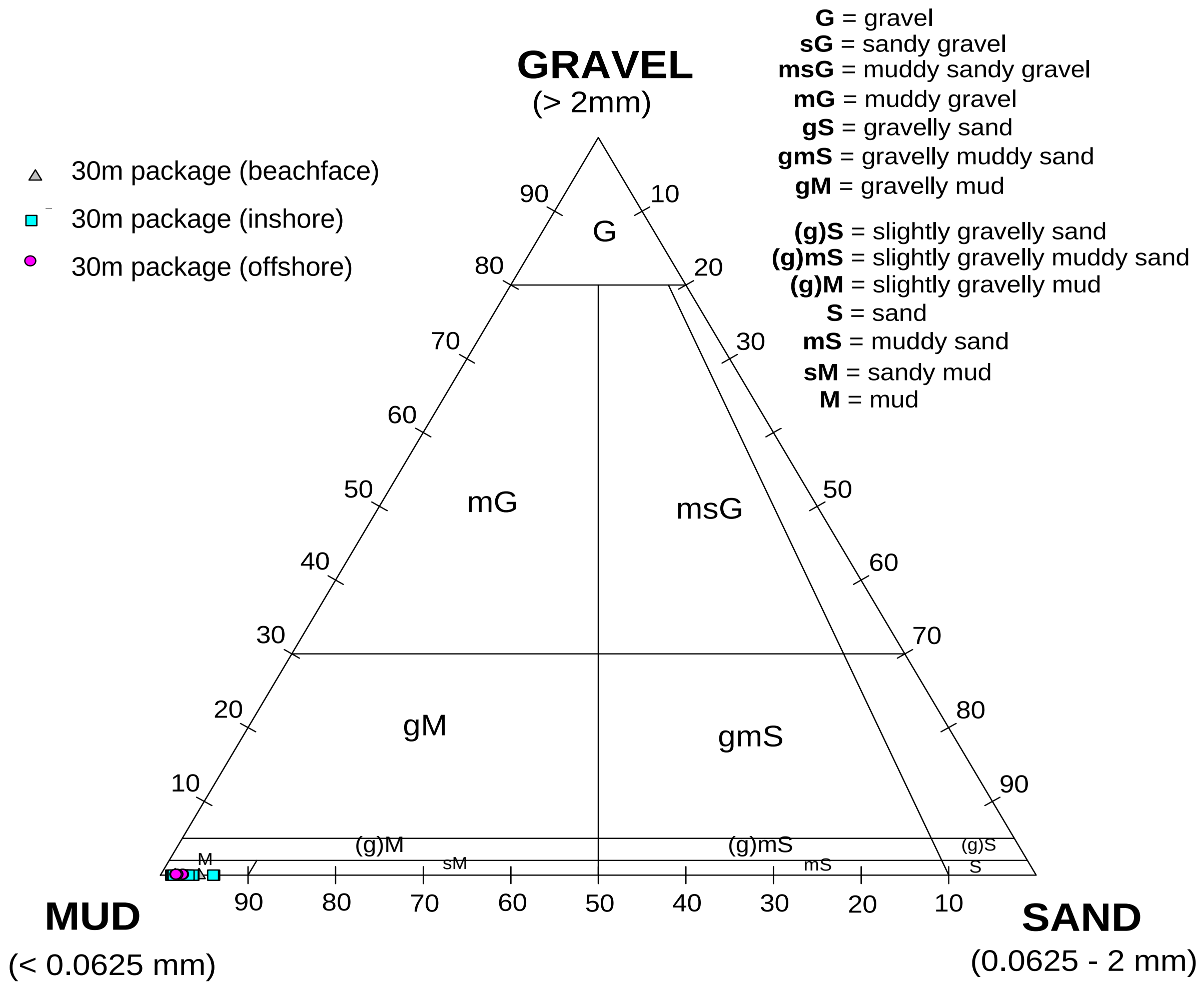
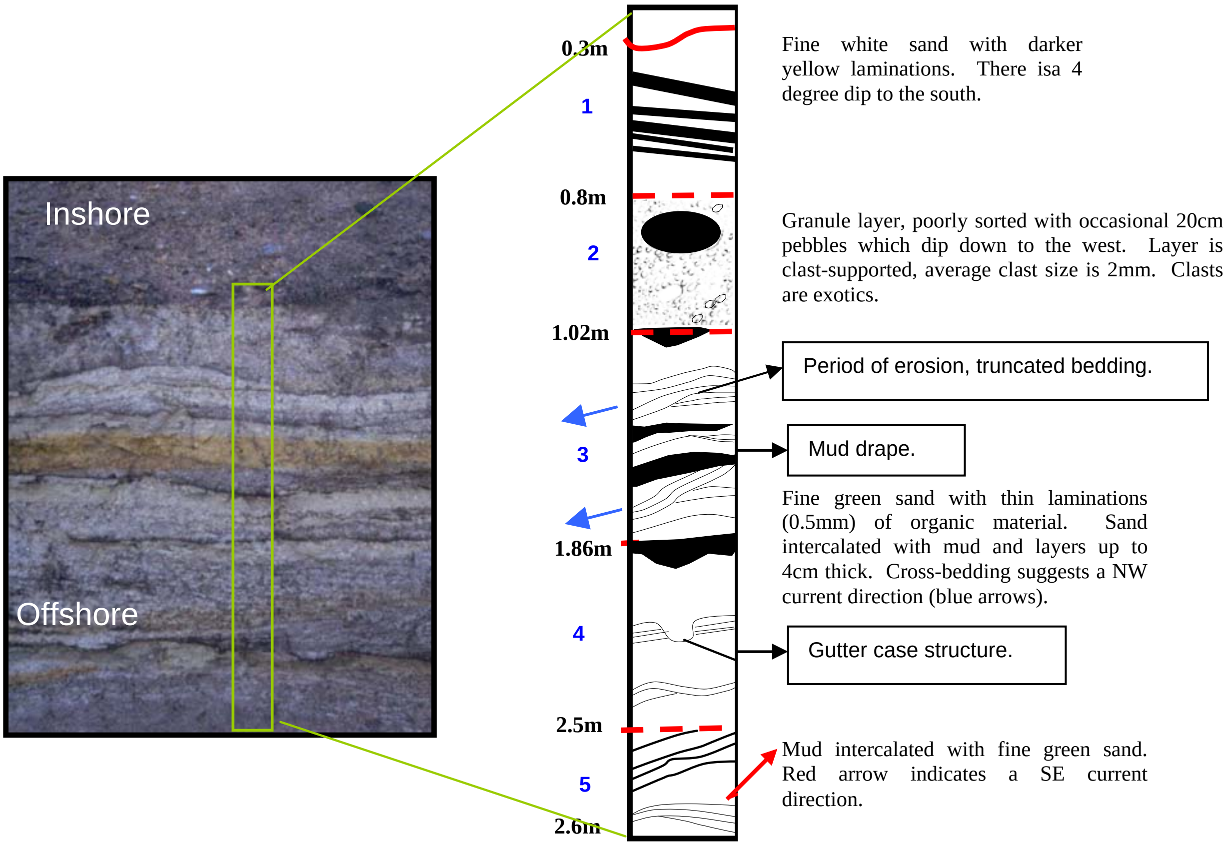


Figure 3.13: Textural classification of samples in the +30m package.

The bedding of the +30m offshore sediments is enhanced by the presence of darker organic material (Photograph 3.35). The stratification seen in the photograph (particularly in area 4 and 5) was identified as planar lamination and it is produced by the fallout of sediment onto a planar substrate without traction (Southard, 1999). It is typical of an environment where sediment supply is relatively high but where fluid movement is slow or non-existent. The abundant organic material seems to re-inforce the evidence for a low energy environment.

Towards the top of the photograph (area 3), changes in the flow regime are evident. The planar bedding is truncated by hollows, which are the result of periods of active erosion. Three such periods of erosion were identified in the sketch below after which the original flow regime appears to have been re-established. These periods of active sediment transport can be attributed to stormy conditions, the turbulence of which occasionally reaches the offshore zone (Southard, 1999).



Photograph 3.35 Detailed view of the offshore facies of the +30m package. The darker laminae are organic enriched layers, alternating with mud drapes (yellow) and silt laminae (white). The contact with the coarse grit inshore facies is indicated.

The grain size characteristics of the +30m inshore environment are similar to those of the +50m package. A wide range of particle sizes was recorded and the samples rang in size from fine sand to very fine pebbles or granules. Both bi- and polymodal distributions (Appendix 2, Table 4) are in evidence and there is an equal representation of positive and negatively skewed grain size populations.

The Visher diagram of the surf zone (inshore) shows a traction carpet that becomes intermittent. Most of the +30m inshore samples show little traction load and therefore represent the surf rather than the breaker zone (offshore). The exception was sample 36b and this sample was found in close association with the offshore sediments of the +50m package in profile 4b. It is possibly part of the breaker zone in the inshore unit (Figure 3.9).

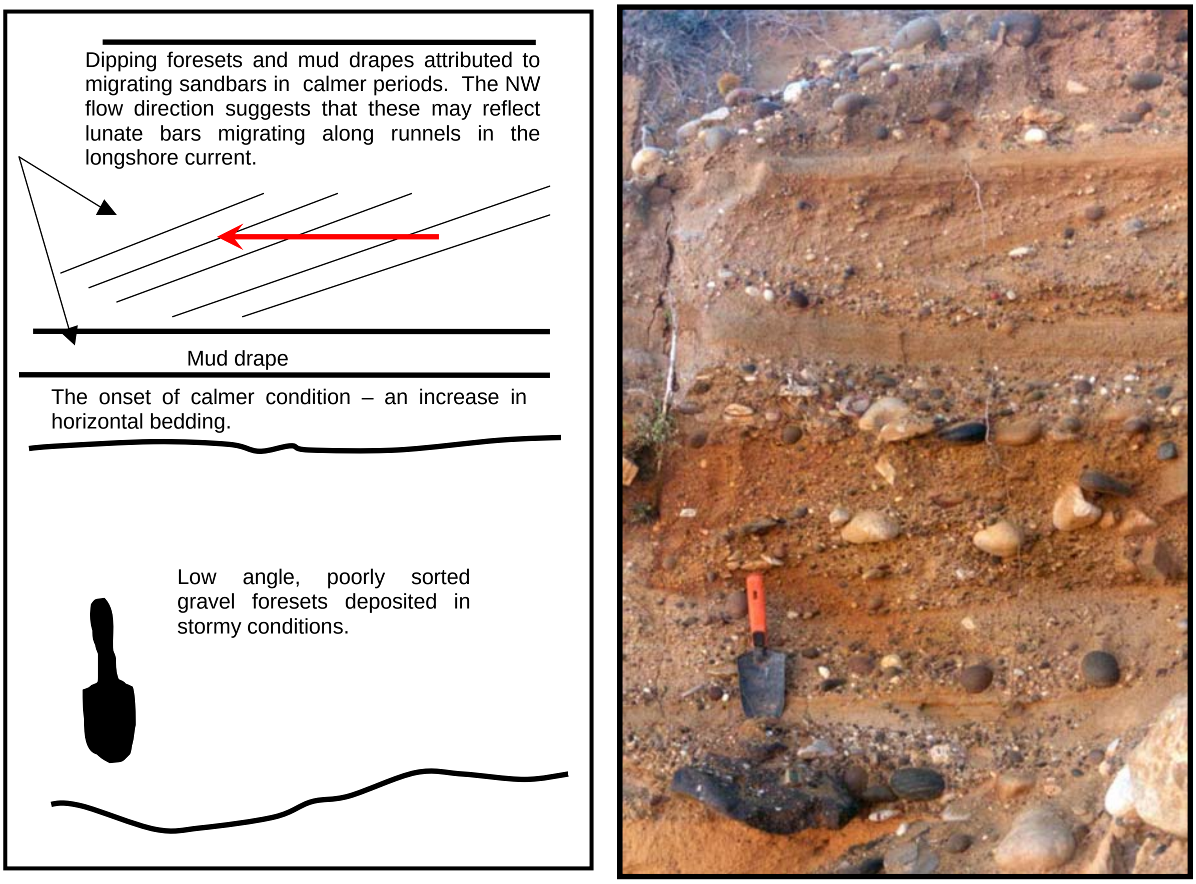
The stratification seen in Photograph 3.36 reveals the sedimentary history of the +30m inshore. The unit represents periods of fair weather and storm conditions; the former is represented by the dipping foresets of gradually prograding sandbars.

The angle of the foresets remains relatively constant and does not increase towards the top suggesting that the current was fairly strong and that the sediment supply did not fluctuate. The fair weather was truncated by stormy periods, in which relatively thick gravel and sand lags were deposited in quick succession by fast-moving currents. These storm lags are typically poorly sorted, show planar stratification and are characteristically aggradational. The latter is a function of the waning current strength towards the end of the storm. The storm gravel lags together with the overlying calmer weather sand and silt units is seen to represent a single erosional cycle, which in the Geelwal Karoo samples is no more than 1.5m thick.

In Photograph 3.37, evidence of cross-stratification within the +30m inshore is evident. Unfortunately, this cross-stratification is on one of the loose-cemented blocks and no deductions as to flow direction / sand bar migration could therefore be made.

The +30m beachface shows similar particle size distributions to that of the +50m package. The samples are predominantly sand (unlike the +50m package, very little gravel was recorded). The histograms show unimodal, positively skewed grain size distributions and the sands are moderately well sorted, classified as medium to fine-grained. In the Visher diagram of these samples the break at 2 phi between the two saltation populations is not always visible. No exposures of the +30m beachface were found (buried beneath aeolian sand) and therefore no bedding was seen.

The Friedman scatter plot (Figure 3.4) of the +30m package shows that most samples plot in the bi-directional flow regime and like the 50m package, this is best explained by the swash and backwash action on the beachface and the oscillatory effect of waves in the inshore environment. Two samples plot in the unidirectional flow regime and these might reveal the position of a rip or longshore current.



Photograph 3.36 A close-up of the inshore facies of the +30m package in profile 4b. The red arrow indicates a seaward (NW) flow direction.

Photograph 3.37 Cross stratification seen on a loose cemented block of the inshore facies of the +30m package.

3.4.3 Mineralogy

A study of the heavy mineral assemblage of the +30m package sediments revealed that together with the +50m package, there is double the concentration of opaque minerals than in either the fluvial or aeolian units (Table 3.1). The most distinguishing characteristic of the +30m package samples is the high feldspar content (Appendix 3, Table 2). Consequently, the ZTR index of these sediments is higher (average of 9, Appendix 3, Table 2) than both the Recent unit and +50m package, suggesting a less mature mineral assemblage. The +30m package can also be distinguished from the other marine and aeolian units by the presence of staurolite and from all the other sedimentary units by its high glauconite concentrations.

In the offshore of the +30m package, the quartz grains are either sub-rounded or rounded and dominate the mineral assemblage. The overall THM concentration of the offshore zone is very low and averages 0.5%. The high concentrations of pseudorutile in the heavy mineral assemblage (Table 3.5) can be ascribed to reworking of the fluvial unit.

All the glauconite in the +30m package is found in the +30m offshore and the unit gets its green colour from the presence of this mineral (glauconite up to 20% of the total sample weight). The yellowish-green colour, rounding, sub-prismoidal shape and hardness of less than 2, identify the glauconite grains in the Geelwal Karoo samples. Another distinguishing feature of glauconite is that, under crossed nichols, the glauconite grains are distinctly cryptocrystalline (Photograph 3.38). Glauconite can be used as an environmental indicator as it is generally formed in a marine environment and is confined to areas of low rates of deposition, (Berner, 1980). Furthermore, glauconite forms at the sediment-water interface, is associated with organic matter and is formed in an overall aerobic environment (Berner, *op. cit.).* The high concentration of organic matter in these samples supports the idea of a biological origin for the glauconite.

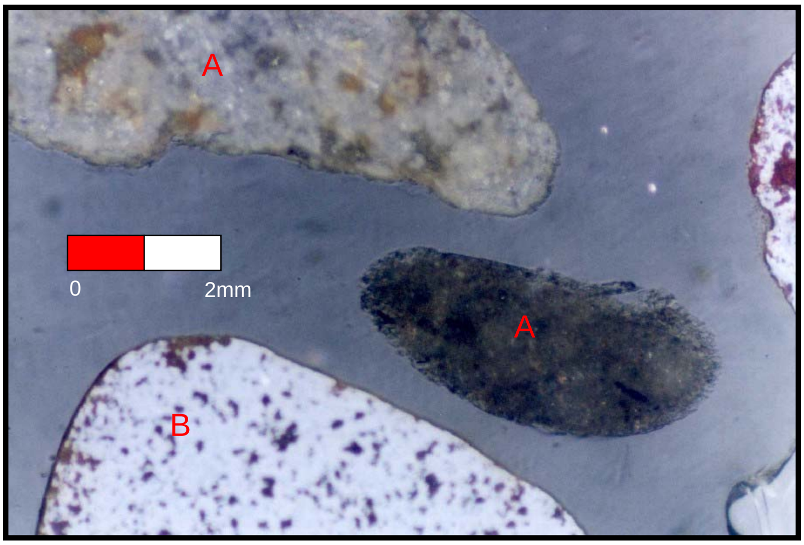
In the +30m inshore zone, a large proportion of the quartz grains were found to be sub-angular and rather than being interpreted as being a low energy environment can be related to the close proximity of an angular quartz source (i.e. the channel clay unit). There is also an higher average feldspar content in the +30m inshore sediments than those found in the +50m package. The THM concentration is highest for the +30m package in the inshore samples and reaches an average of 2.5%. Zircon, garnet and tourmaline dominate the heavy mineral assemblage of the +30m inshore (Table 3.5).

Table 3.5: Point count data for the heavy mineral fraction of the +30m package. Data presented as a percentage of the total heavy fraction. Off = offshore, In = inshore.

Sample number	**100**	**98**	**Average**	**36b**	**58**	**11b**	**11**	**11c**	**59**	**11d**	**14**	**Average**	**60**
Facies	Off	Off		In	In	In	In	In	In	In	In		Beach
Sampling elevation	23.57	25.22		25.56	25.95	25.97	26.09	26.28	26.61	27.19	28.09		37.43
Distance from nouthern gate (km)	1.00	1.00		11.50	1.00	3.50	3.50	3.50	1.00	3.50	3.50		1.00
Rutile	7	7	7	9	2	3	2	4	7	3	2	4	9
Zircon	0	0	0	0	2	2	19	0	3	2	6	4	1
Garnet	0	0	0	1	53	11	6	9	37	41	14	22	11
Augite	2	2	2	3	5	1	1	5	13	14	17	7	16
Hornblende	0	0	0	0	0	0	0	2	1	2	2	1	2
Weathered grains	1	1	1	0	9	2	0	4	0	0	18	4	27
Tourmaline	0	0	0	0	0	1	0	1	0	2	1	1	0
Kyanite	0	0	0	0	0	0	0	0	0	0	0	0	0
Monosite	0	0	0	0	0	0	0	0	1	0	0	0	0
Staurolite	1	1	1	0	0	3	0	0	0	0	0	0	1
Ilmenite	35	35	35	46	6	15	34	29	5	11	13	20	3
Hydrated ilmenite	21	21	21	33	3	22	34	17	5	6	8	16	0
Leucoxene	8	8	8	2	2	5	1	9	3	5	0	3	11
Other opaque minerals	5	5	5	1	3	5	1	3	3	2	4	3	2
Magnetite	0	0	0	0	0	0	0	1	0	0	0	0	0
Chromite	0	0	0	1	0	0	0	0	1	0	0	0	0
Pseudorutile	13	13	13	4	3	8	1	6	0	1	2	3	0
Glauconite	2	2	2	0	0	2	0	0	0	0	0	0	0
Rock fragments	2	2	2	0	5	19	1	5	7	7	2	6	14
Carbonates	0	0	0	0	0	0	0	0	1	0	3	1	0
Total heavy minerals	**97**	**97**	**97**	**99**	**94**	**98**	**99**	**96**	**86**	**96**	**91**	**95**	**96**
Feldspar	0	0	0	0	0	1	0	0	7	0	0	1	0
Quartz	3	3	3	1	6	2	1	4	7	4	9	4	4
Grand total all minerals	100	100	100	100	100	100	100	100	100	100	100	100	100
%THM of whole sample	0.42	0.52	0	95.29	0.84	0.60	4.27	0.48	0.47	2.31	8.34	14	0.21
% Ti-mineral only	82	86	84	95	72	54	17	68	27	27	23	48	24
%Ti-minerals of THM for whole sample	0.34	0.45	0.40	90.49	0.60	0.32	0.71	0.33	0.13	0.62	1.94	11.89	0.05

Photograph 3.38 Glauconite grain from the offshore unit of the +30m package. (Sample 90; heavy fraction mount; 200x magnification; oil immersion; transmitted light; uncrossed nichols)

Only one sample of the beachface zone of the +30m package was studied. Although the mineral assemblage is dominated by quartz, contamination with the more recent red aeolian unit is evident. Despite the fact that there is only one sample it is interesting to note that like the +50m beachface, the heavy mineral assemblage of the +30m beachface is also distinguished from the inshore and offshore by its relatively high concentrations of augite, weathered grains and rock fragments (Photograph 3.39).



Photograph 3.39 Two rock fragments (A) and a pseudorutile (B) grain from the inshore of the +30m package. (Sample 59; heavy fraction mount; 200x magnification; oil immersion; reflected light; uncrossed nichols)

3.4.4 Alteration

Evidence of groundwater action was found in the offshore, inshore and beachface units of the +30m package. It was seen in the form of calcrete layers, very similar to those found in the +50m package.

In the offshore facies of the +30m package, some of the quartz grains are coated with iron and are therefore yellow in colour. The iron coating is also a function of groundwater action, which predated the formation of the calcrete layers as the grains cemented in the calcrete layer also show iron coatings. The calcrete layers have therefore helped to preserve the detrital grains, particularly the feldspar, from subsequent weathering.

3.5 The Recent unit

3.5.1 Occurrence, characteristics and stratigraphy

This unit has been included in this study as a means of comparison with the older sedimentary units. By definition, it includes the thin veneer of aeolian sand found overlying all the sediments on the embankment and the intertidal sediments found on the present beachface. The recent aeolian sand is ubiquitous and the colour of this unit varies from light brown to dark yellowish orange. The occurrence of *Trigonephrus* shells and Late Stone Age middens (Photograph 3.40) are common within this unit.

The present beachface has been described in detail by Macdonald (1996) and is considered to be a good example of a modern-day heavy sand placer. It consists of a thick (in excess of 15m) succession of medium- to fine-grained intertidal sand. Mussel shell lags are common in the backshore zone.

Modern marine fauna, for example, Isopoda are plentiful and they are responsible for a great deal of bioturbation in the beachface unit of the Recent unit. Like the +30m and +50m packages, there is a basal gravel lag in the inshore environment (breaker zone) of the modern unit and this is currently being mined for diamonds.

No gravel lags were noted in any of the aeolian units, except in profile 1. In profile 1 a layer of pebbles were found cemented by a mixture of mud and gypsum and this was seen to indicate recent reworking of the marine terrace through debris-flow associated with flash floods.

3.5.2 Sedimentology

The samples of the Recent unit consist mostly of sand with only minor amounts of gravel (beachface) and mud (dune) (Figure 3.14). A grain size analysis of the Recent unit (both aeolian and marine) reveals an average particle size of medium to fine sand (Appendix 2, Table 5). The higher concentrations of fine sediment distinguish the aeolian from the marine samples and consequently the aeolian sample is poorly sorted (Appendix 2, Figure 9), whereas the marine histogram shows moderate to good sorting.

Photograph 3.40 The Recent aeolian unit on top of profile 12. Geological hammer for scale. The ripples, on the flanks of the dune, are accentuated by heavy mineral laminae. The wind direction is from left to right and the sand is migrating in a northeasterly direction. Calcrete debris, derived from the underlying aeolianite, is present in the foreground.

Photograph 3.41 The present beach component of the Recent unit. Photograph taken on top of profile 7. Garnet and ilmenite-enriched layers show up in stark contrast to the white quartz-rich parts of the beach.

Most of the Visher diagrams of the Recent aeolian sands are in keeping with Visher's templates. They display a single large (up to 90% of the graph) saltation population which has a slope of 50 degrees (well sorted) and ranges between 2 and 3 phi, (Appendix 2, Figure 9). The Visher diagrams of the Recent beachface (Appendix 2, Figure 10) only display one population and that differs from the four populations seen in Visher's original diagrams (Addendum 3, Figure 3.2). The difference can be explained in terms of the high concentration of heavy minerals in the beach zone of the Geelwal Karoo.

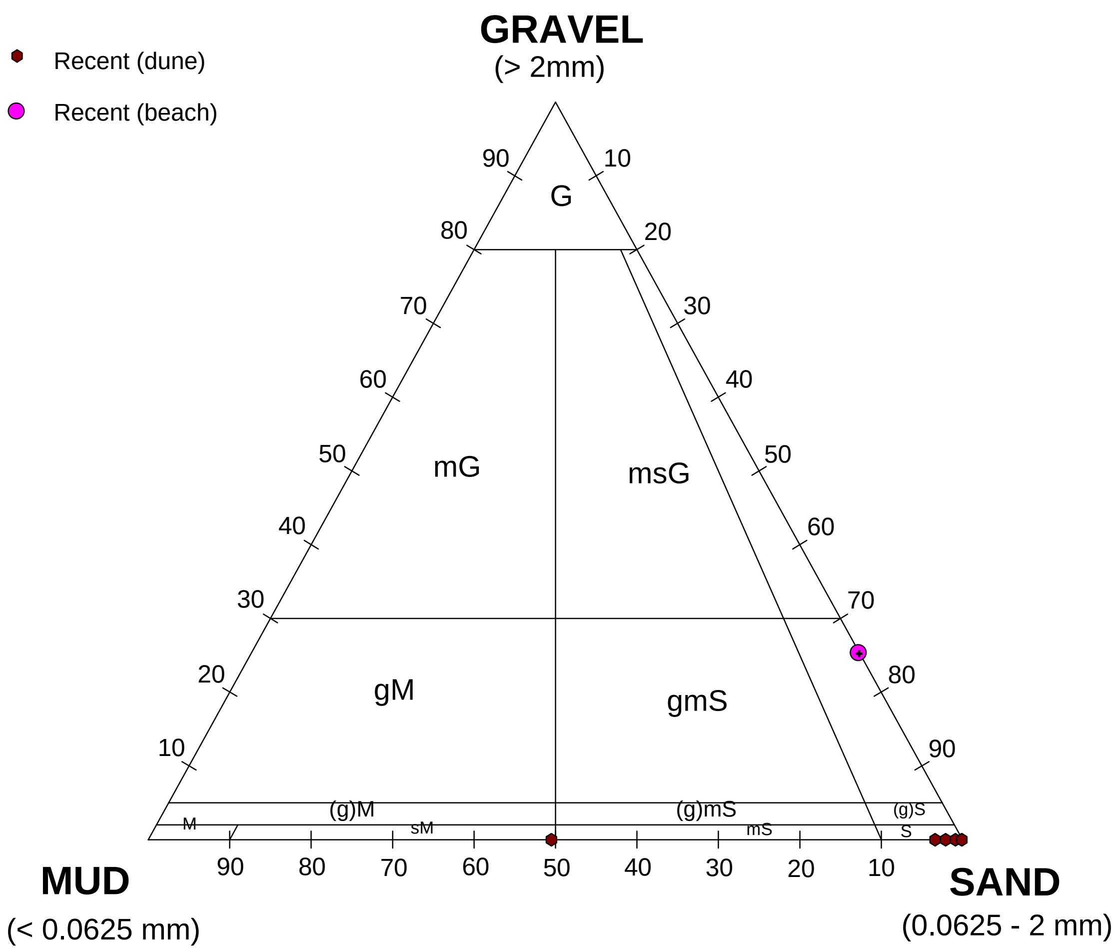
Most of the Recent aeolian samples show a coarse traction load, which according to Visher (1969) should be very small (less than 2%) or non-existent in dune sands. The presence of this coarser fraction can be attributed to high wind speeds and the close proximity of the marine environment.

In the Friedman scatter plot shown in Figure 3.4, the Recent marine sample plots in the bi-directional flow regime and like the other marine units, this is explained by the swash and backwash action on the beach. Most of the Recent aeolian samples also plots in the bi-directional field and this is an indication of changes in the dominant wind direction from southerly to easterly winds.

3.5.3 Mineralogy

Quartz dominates the mineral assemblage and in the present beach sample shows the best rounding (rounded to well rounded) of all the sedimentary units discussed so far in this study. A study of the heavy mineral assemblage showed the Recent unit to have the second highest concentration of non-opaque heavy minerals (Table 3.1). The average THM concentration for the Recent unit (marine and aeolian units) is 9% and this high value can be explained in terms of the close proximity of the +50m package to the heavy sand placer.

Dilution of the heavy minerals would come in the form of reworked dorbank sediments and from the current sediment load of the Olifants River. The average ZTR index (Appendix 3, Table 2) of these samples is 7%, indicating a mature mineral assemblage. This is to be expected given the fact that it is the product of many erosional cycles.



G = gravel
sG = sandy gravel
msG = muddy sandy gravel
mG = muddy gravel
gS = gravelly sand
gmS = gravelly muddy sand
gM = gravelly mud

(g)S = slightly gravelly sand
(g)mS = slightly gravelly muddy sand
(g)M = slightly gravelly mud
S = sand
mS = muddy sand
sM = sandy mud
M = mud

Figure 3.14: Textural classification of samples in the Recent unit.

The heavy mineral assemblage of the Recent beach sample can be distinguished from the Recent aeolian samples by the higher concentrations of garnet and weathered grains. In the four heavy mineral-enriched beachface samples studied by Macdonald (1996), great variation in the heavy mineral concentration was observed and a range of 60 to 90% THM was reported. Garnet (1.63%) and ilmenite (1.51%) dominated the heavy mineral assemblage of these samples.

Table 3.5 Point-count data for the heavy mineral fraction of the recent unit. Data presented as a percentage of the total heavy fraction.

Sample number	13	15	64	Average	gwp	55	Average
Facies	Dune	Dune	Dune		Beach	Beach	
Sampling elevation	28.81	29.10	65.43		5.00	18.67	
%THM of whole sample	6.68	12.39	13.34		78.00	8.17	
Distance from nouthern gate (km)	3.50	3.50	12.00		10.00	1.00	
Rutile	8	0	4	4	0	4	2
Zircon	6	0	3	3	0	5	3
Garnet	18	6	22	15	12	63	37
Augite	5	16	6	9	16	2	9
Hornblende	0	0	1	1	0	1	1
Weathered grains	1	13	2	5	31	3	17
Tourmaline	2	0	3	1	0	1	1
Kyanite	0	1	0	0	0	0	0
Monosite	1	0	0	0	0	0	0
Staurolite	0	0	0	0	0	0	0
Ilmenite	17	1	24	14	2	6	4
Hydrated ilmenite	5	0	15	7	1	3	2
Leucoxene	2	1	4	2	1	1	1
Other opaque minerals	9	0	8	6	2	2	2
Magnetite	0	0	1	0	0	0	0
Chromite	0	0	0	0	0	1	0
Pseudorutile	0	1	0	1	0	0	0
Glauconite	0	0	0	0	0	0	0
Rock fragments	11	16	1	9	4	5	4
Carbonates	7	5	0	4	0	0	0
Total heavy minerals	**93**	**60**	**95**	**83**	**70**	**97**	**83**
Feldspar	0	0	0	**0**	3	0	**2**
Quartz	7	40	5	**17**	27	3	**15**
Grand total all minerals	100	100	100	**100**	100	100	**100**
%THM of whole sample	6.68	12.39	13.34	10.8	not known	8.17	8.17
% Ti-mineral only	35	7	49	**30**	6	14	**10**
%Ti-minerals of THM for whole sample	2.36	0.83	6.58	**3.25**	4.85	1.18	**3.02**

3.5.4 Alteration

Very little evidence of groundwater action was found in the sediments of this unit and there is no evidence of calcretisation in either the marine or aeolian zones of the Recent unit.

Although some of the grains in the Recent aeolian unit have iron coatings, this is not due to red bed formation, but rather due to reworked older red bed material. The lack of calcrete cementation or red bed formation in the Recent unit can be ascribed to the fact that the grains are still mobile in the current erosional cycle.

4. REGIONAL CORRELATION OF GEELWAL KAROO

Based on his observations at Hondeklip Bay, Pether (1986) found evidence of terrestrial, marine and fluvial deposits in the Cenozoic successions of that area. In the marine deposits, a series of three “packages” were identified and described as seaward - thickening suites of shallow nearshore sediments. Each package was laid down during regression from three separate transgressive maxima; one at +90m, another at +50m and the last at +30m a.s.l. and hence the nomenclature of +90m, +50m and +30m packages (Figure 1.2). Pether (1994) explained the accumulation of marine sediments at any specific time along the western margin as being a function of variations in the rate of sea-level change, the bedrock topography and the sediment supply. The interaction of these factors with each other and the possibility of localized changes must be taken into account when making comparisons. Furthermore this study follows Pether (1986) by using depositional, rather than erosional records. The different statigraphic units have been described in terms of transgressive and regressive cycles rather than as a series of sedimentary events or sea level changes often recognized in geomorphological features such as terraces and platforms.

At Geelwal Karoo the terrestrial, marine and fluvial deposits have been classified as aeolianite (consisting of two dune series), a fluvial channel clay unit, the +50m and +30m marine packages (Table 2.1; Figure 4.1). A Recent unit was also described and this includes both marine and terrestrial Holocene sediments.

4.1 Channel clay unit

4.1.1 Stratigraphic Correlation

The predominantly quartz-rich clast assemblage, high concentration of kaolin and its position in relation to the other Cenozoic sediments at Geelwal Karoo, makes the channel clay unit similar to the “channel clay formation” found at Kleinzee (Pether, pers. comm.). At Hondeklip Bay, Pether (1994) describes the unit as being a fluvial arkosic infill (Figure 4.1), which has subsequently been kaolinised. It forms part of the Koingnaas Complex and is essentially a well developed dendritic fluvial system, which is overlain by the +30m package, +50m package and the more Recent marine terraces.

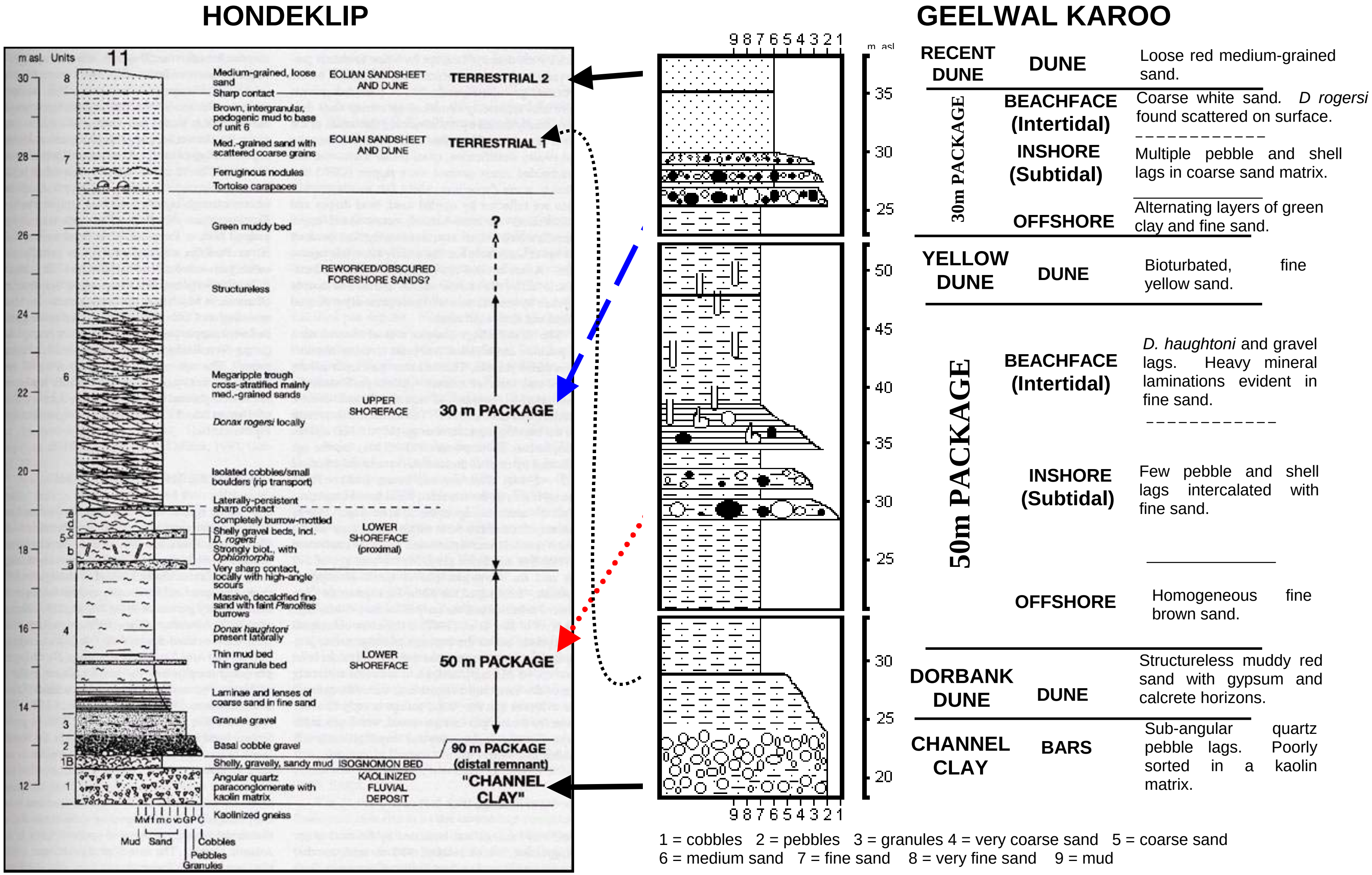


Figure 4.1 A comparison between the Cenozoic geology found at Hondeklip and at Geelwal Karoo

Cole and Roberts (1996) identify the same unit in samples drilled in the Schaapvlei, Karoovlei and Koekenaap areas (Figure 4.2). In the Schaapvlei area, the channel clay unit was described as having “coarse, angular fluvial sands, which possess well developed successions of interbedded and interdigitated clays, sandy clays, clayey sands, sands, gravel horizons and lignites”. The mud content of this unit was found to increase with depth and the sands were poorly to well sorted, with subangular to rounded grains. Green, yellow, grey and red hues were noted and the reddish colours were attributed to ferruginous nodules, present in the upper portions of the unit. Pure kaolinitic clays were found in the Koekenaap samples and these clay horizons reached a thickness of no more than 4m.

These clays contained much carbonaceous material, which was seen in numerous bands of sulphide-rich fusinite. Some of the clay samples at Geelwal Karoo contained trace amounts of carbonaceous matter but in general, it can be said that these samples were noticeably deficient in organic material of any sort. This difference should not, however, prevent correlation with the Schaapvlei sediments and should be explained in terms of changes in the vegetation related to the drainage pattern of the channel clay system. The criterion for equating this unit with the channel clay formation of the north rather than that of the Elandsfontyn Formation was the relatively low clay content (Figure 4.2).

At Graauwduinen, 40km north of the Olifants River Mouth, Cilliers (1995) identified a basal quartz arenite (BQA) unit overlying the bedrock. The unit is described as being a succession of unmineralised, yellow-white coloured sands that is medium-grained and contains rounded grains. The samples showed negative skewing, good sorting and a low percentage of mud (7.58%). Furthermore, the unit is characterised by a very low heavy mineral content of 0.87%, low feldspar content of 3.85% but with a high concentration of zircon.

The close proximity of Cole and Robert’s study area together with the fact that there is a low heavy mineral (but high zircon) concentration suggests that this unit can be equated with the channel clay unit. The good rounding and sorting, the lack of kaolin clay in this unit at Graauwduinen dispels a correlation but these differences could be explained in terms of reworked channel sediment deposited during a transgressive marine cycle.

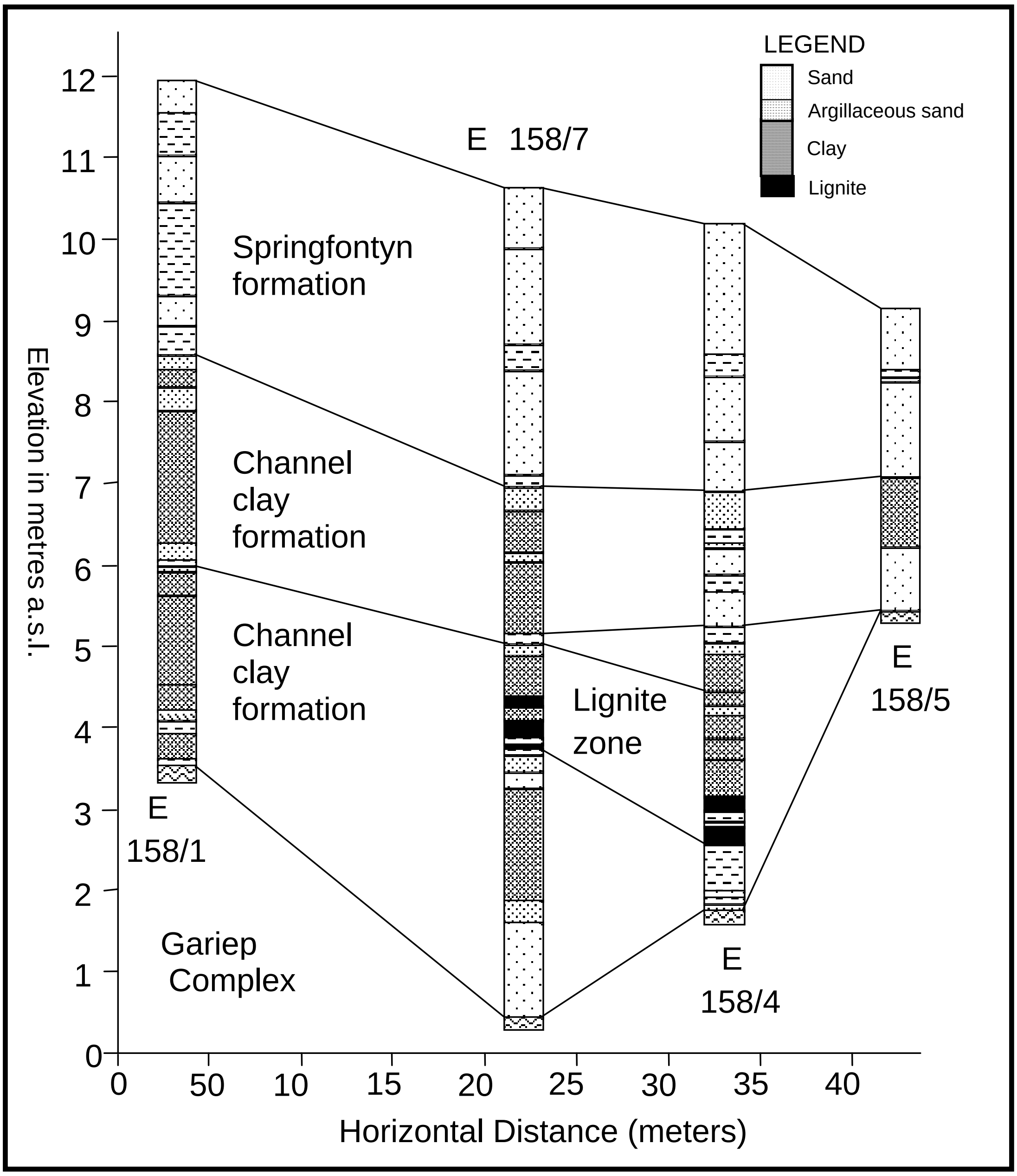


Figure 4.2: Data from the boreholes drilled north of the Schaapvlei homestead (Cole and Roberts, 1996).

4.1.2 Age determination

Pether (1994) described the channel clay formation as the oldest succession found at Hondeklip Bay (Figure 4.3) and goes on to say that the date of channel incision, established by Siesser and Dingle (1981) was during a major Oligocene regression. Pether has since revised his earlier views. Working with I.K. McMillian, Pether now agrees that the micropalaeontological evidence seems to point to a Mid-Cretaceous age for the deposition of the channel clay unit (Pether *pers. Comm., 1998*.). This fact is further corroborated by the Neocomian age that was determined for pollen grains found in the channel clay unit at

Kleinzee (Rogers *et al.,* 1990).

Initially, Cole and Roberts (1996) correlated the channel clay unit with the Elandsfontyn and Arries Drift Formation. The age of the Elandsfontyn Formation was determined with the help of pollen grains from a subtropical species of palm tree (*Asteraceae*), which confirms a Late Oligocene age (Dingle et al., 1983). Cole and Roberts (1996) state that lignite dating (also through palynology) of one of the boreholes at Schaapvlei, produced a Neogene age for the lignite beds in the channel clay unit of this area and therefore the correlation is possible but not conclusive. Roberts has subsequently revised his thinking and no longer attempts to correlate the channel clay and Elandsfontyn Formation (Pether *et. al*., 2000.). Although the Cretaceous age for channel incision is accepted, the Neogene age of these lignite beds is also taken into account. The younger age of the pollen grains is explained in terms of a complex sedimentary record with the channels being active over a considerable time span.

The presence of a deeply kaolinised weathering profile, which is capped by silcrete duricrusts, is indicative of increased desiccation associated with global cooling (Botha, 2000). Although wetter periods have been documented in the Neogene period none are as clearly associated with kaolinization and then subsequent silcrete formation as those fluvial systems operational at the end of the Cretaceous (Pether *et. al*., 2000). This study therefore accepts this view and proposes that the channel clay unit at Geelwal Karoo is Cretaceous in age.

4.1.3 Geological model

During the Cretaceous, the Great Escarpment was formed along the West Coast of Southern Africa. The latter encompasses a series of cliffs that resulted from the combination of down-thrusting, tensional tectonics (associated with the breaking up of the west of Gondwana) and the differential erosion of Table Mountain Sandstone, Gariep and Namaqualand Metamorphic Complex bedrock. The humid and tropical climate of this period meant that during floods these steep ravines (with gradients of between 20^o - 30^o) provided the perfect setting for the accumulation of fluvial and to a lesser extent mass flow deposits. Cole and Roberts (1996) describe the Koekenaap area as being part of a series of small, alluvial fans, which originated in highlands of moderate relief. Vigorous streams and avalanches carried high concentrations of bed-load material down towards the sea. During sea level regressions the offshore was exposed with the result that the coarse fractions being eroded by rivers during the Cretaceous were deposited in extensive alluvial fan deposits at the base of what today is seen as the inner offshore slope (De Decker and Woodborne, 1996; Figure 4.4). At Geelwal

Karoo one such fan-shaped wedge of sediment was developed at the base of the ravine found in the "Torings" area.

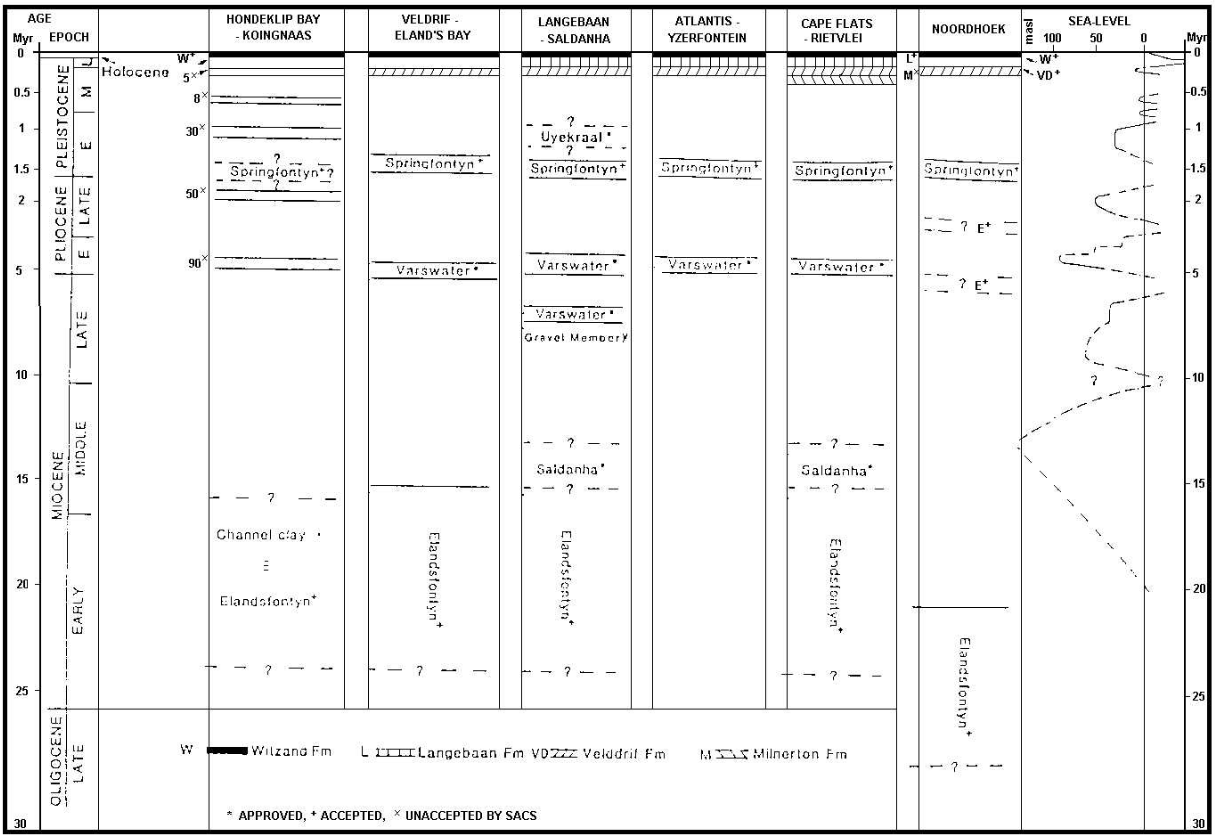


Figure 4.3: Stratigraphic correlation of the Cenozoic sediments of the West Coast (Cole and Roberts, 1996). 5, 8, 30, 50, 90 refer to marine packages found at these elevations. Hondeklip Bay - Koingnaas: after Dingle et al. (1983), Pether (1986) and Rogers et al. (1990). Velddrif - Eland's Bay: after Tankard (1976), Rogers (1980, 1983), Rogers et al. (1990) and Dingle et al. (1983). Langebaan - Saldanha: after Tankard (1975, 1976), Tankard and Rogers (1978), Dingle et al. (1979, 1983), Rogers (1980, 1983), Rogers et al. (1990), Hendey (1981), Siesser and Dingle (1981), Coetzee and Rogers (1982), Hendey and Dingle (1983) and Theron et al. (1992). Atlantis - Yzerfontein: after Rogers (1980, 1983), Rogers et al. (1990) and Theron et al. (1992). Cape Flats -Rietvlei: after Tankard (1975), Rogers et al. (1980, 1983), Rogers et al., (1990), Dingle et al. (1983) and Theron et al. (1992). Noordhoek: after Coetzee (1978), Dingle et al. (1983), Rogers (1983) and Harnady and Rogers (1990). Sea level movements: after Hendey (1981), Siesser and Dingle (1981), Pether (1986) and Haq et al. (1987).

At Geelwal Karoo no clear clast imbrication was visible in the outcrops of this unit. The close proximity of the present Olifants River however suggests a connection with this fluvial system and the flow direction is therefore assumed to be orientated perpendicular to the coast (Figure 4.5). The main channel or inner bank of the palaeo-river system was situated in the south at Geelwal Karoo where the sediments are thickest and these then taper to the north to where the outer bank is found in the region of profile 11, Figure 3.1. The angular nature of the quartz clasts coupled to the poor sorting suggests that the flow (at least in the initial stages) was ephemeral and that the quartz clasts appear to have been derived from a local source. The source is seen to be the base of the Peninsula Formation which, in the vicinity of Vanrhynsdorp, consists of a vein quartz pebble and cobble conglomerate less than 1m thick (De Beer et al., 2002).

Approximately three erosional cycles (Addendum 1, Table 1.4) were found preserved in the basal gravel lag. Each gravel lag shows a fining upward profile attributed to the waning fluvial energy towards the each of a flood cycle. The gravel lags become increasingly thinner and are more affected by marine reworking higher up in the succession. The latter can be seen in the fact that the clasts in these gravel lags are more rounded and there is little or no clay in evidence (better sorting). In profile 11, the gravel lags are entirely absent and all that remains is a very well sorted, quartz sandstone succession.

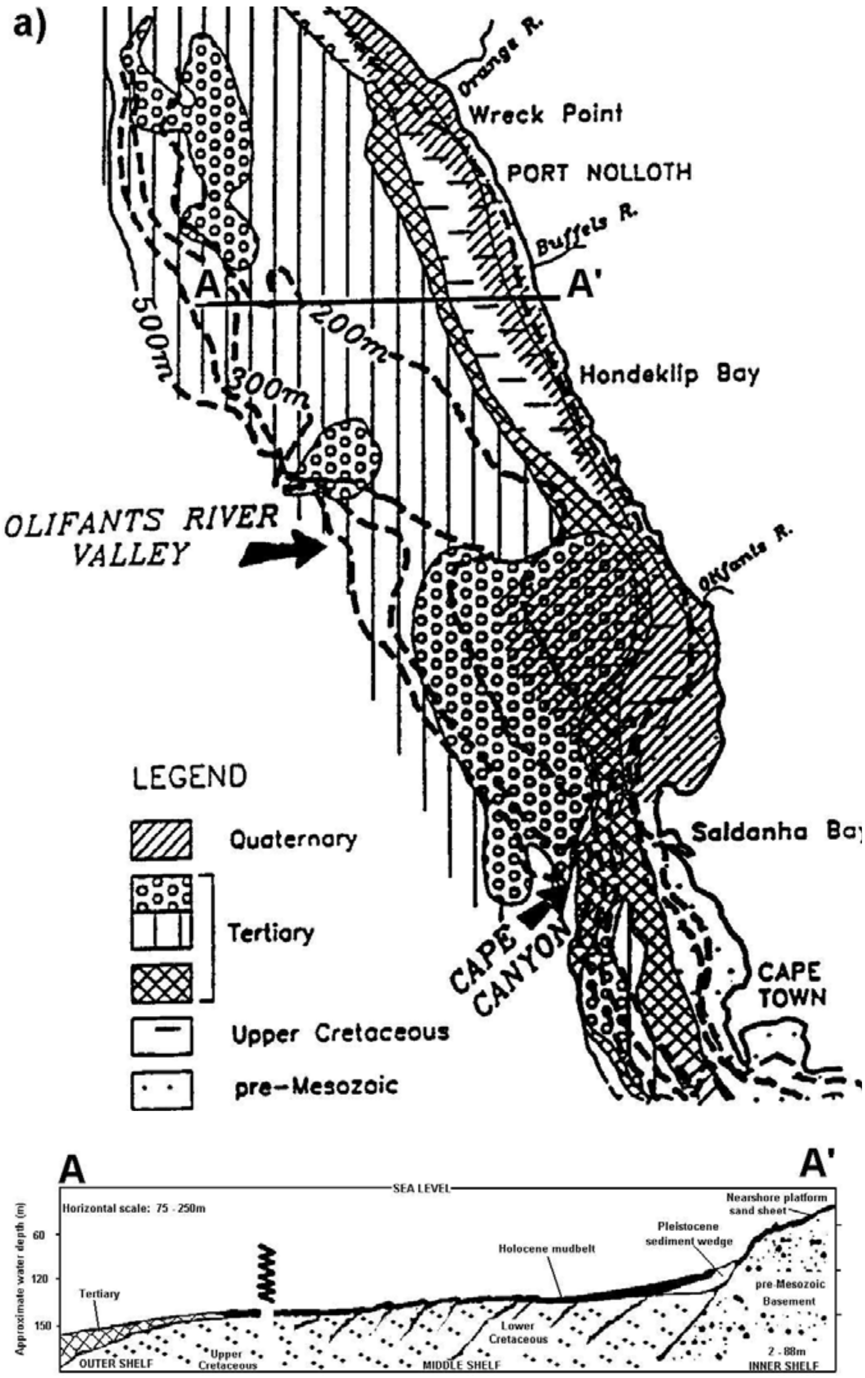


Figure 4.4 Position and extent of the Lower Cretaceous sediment belt off the West Coast. (Dingle et al., 1983; Rogers, 1977; and Birch, 1975). The geology of the continental margin off southern Africa. The position of the Cape Canyon and the Olifants River Valley are shown. (after: Dingle, 1973; Rogers, 1977; Birch, 1975; and De Decke and Woodborne, 1996). A schematic cross section through the offshore, showing the spatial relationship of the most important successions. (after Rogers, 1977; De Decker and Woodborne, 1996)

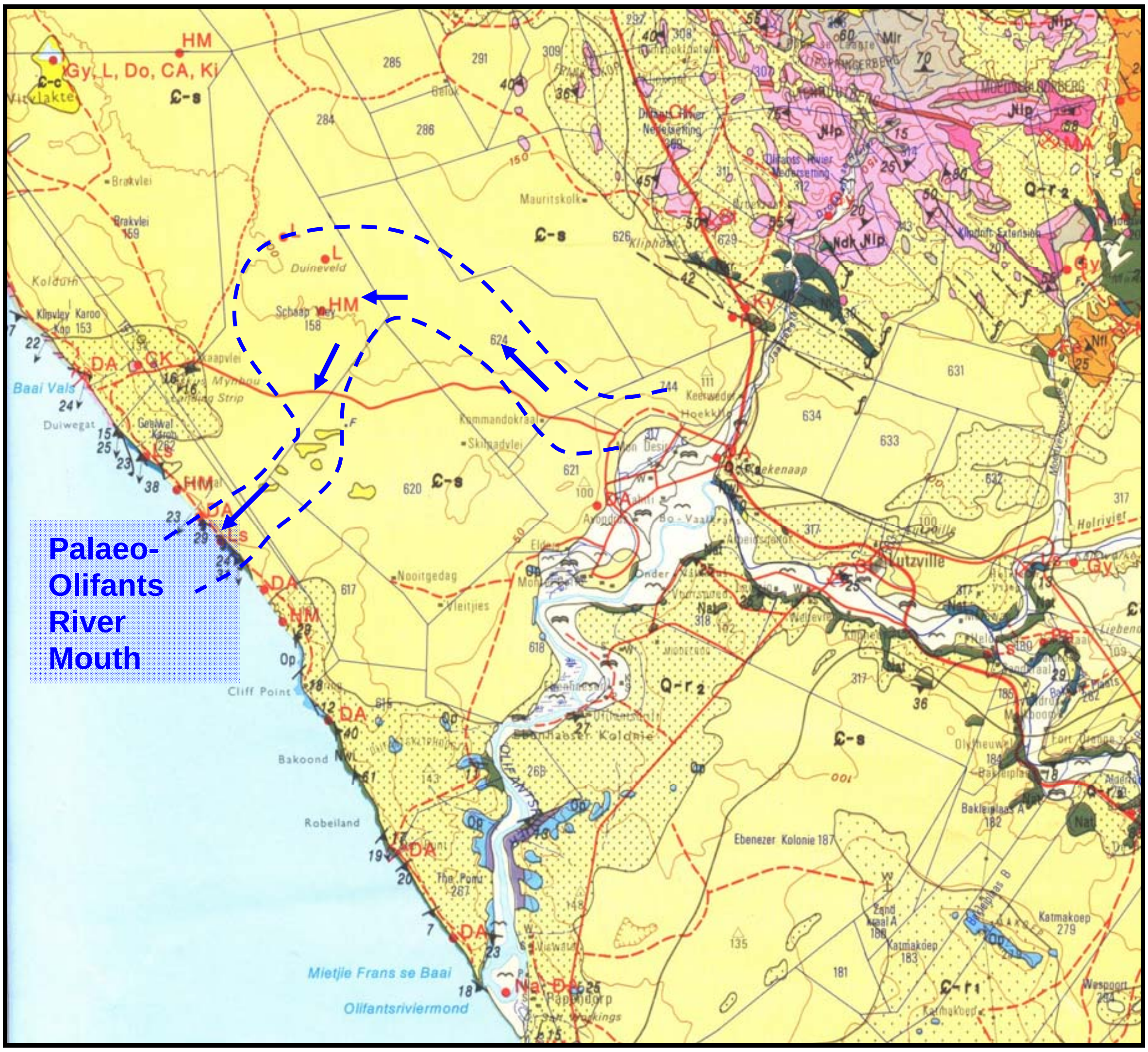
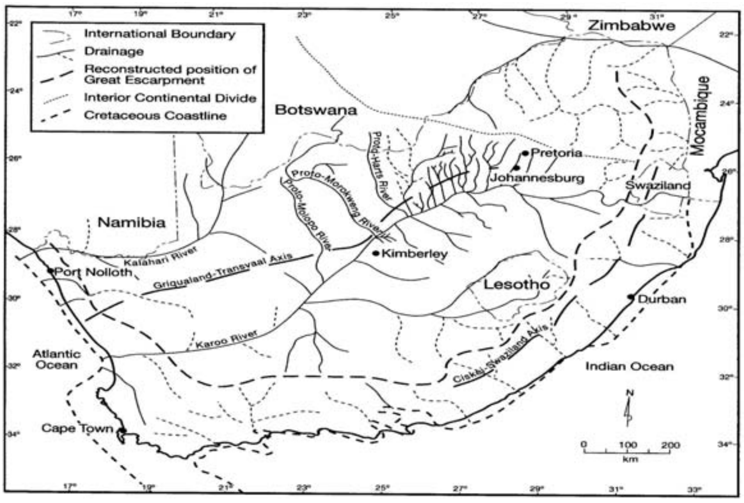
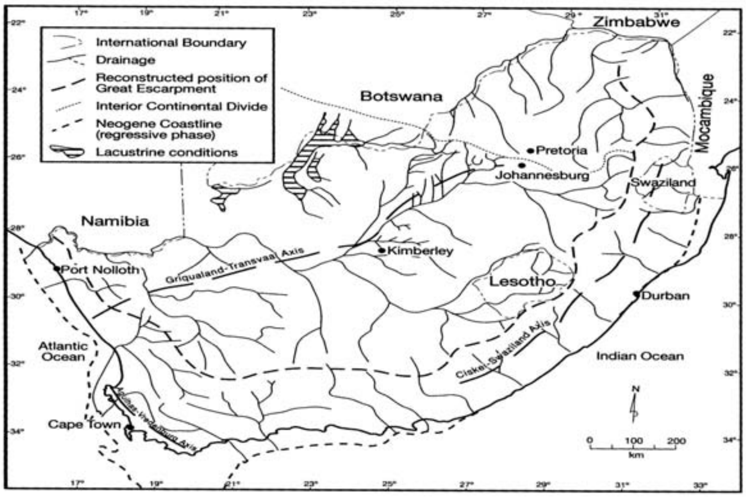


Figure 4.5 Inferred position of the palaeo-Olifants River Mouth in relation to the present Olifants River, modified after De Beer et al, 2002.

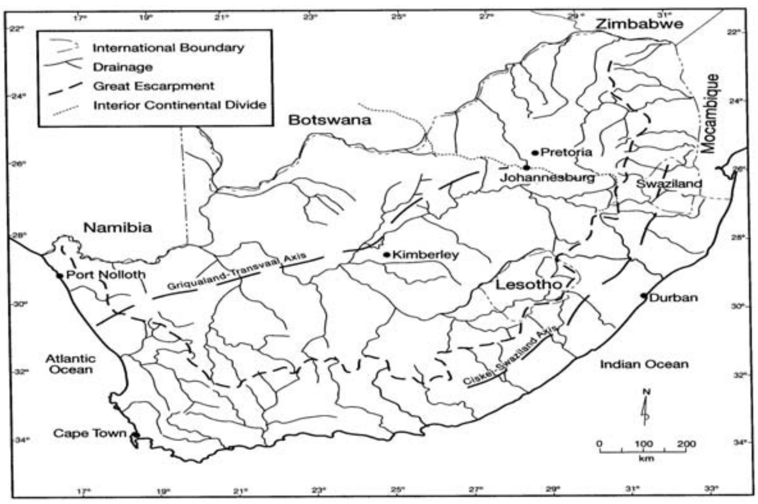
Rifting of West Gondwana during the Early Cretaceous also initiated two major river systems; the Karoo and the Kalahari Rivers (De Wit, 1993, Figure 4.6). The Karoo River entered the Atlantic Ocean via the present-day lower Olifants River and was responsible for draining most of the North-West Province, the Free State and Lesotho. Due to the narrowness and shallowness of the channel clay incision at Geelwal Karoo it seems unlikely that the latter unit was in anyway connected to the Karoo River system. It is the view held by this study that the channel clay unit predates the Karoo River although it could still have been coeval with the Cretaceous precursor to the Karoo River. It is still uncertain when the first of the siliclastic bed-load was introduced to the coast and this fact is intrinsic to the development of the Karoo/Olifants River system.



Mid-Cretaceous



Mid-Tertiary



Plio-Pleistocene

Figure 4.6: Reconstruction of the evolution of the drainage of southern Africa. (after Partridge, 1988; De Wit *et al*., 2000)

This is because the clast assemblage of the channel clay river was dominated by an angular quartzo-feldspathic bed-load, whereas the palaeoterraces of the Olifants River shows a bed-load composed of siliclastic clasts. The former seems to indicate a local provenance with minimal erosion, whereas in the latter the clasts are well rounded and deposited in clearly defined bar successions, thereby showing the characteristics of a well-established, mature fluvial system.

The humid and tropical climate of the Early Cretaceous persisted to into the Late Cretaceous and resulted in the extensive weathering and kaolinization of the channel clay unit. This pluvial period was replaced by a period of increased desiccation, decreased sediment supply and the formation of a thick silcrete layer across the African surface (De Wit *et. al*., 2000). Cole and Roberts (1996) find evidence of this period of aridity in the channel clay unit by describing the presence of lenses and nodules of anhydrite and gypsum underlying the lignites at Schaapvlei. Evidence of subsequent erosion can be found in the Middle Miocene, when the sea transgressed and eventually deposited the sediments of the +90m package. The accretion of these sediments was accompanied by localized subsidence within the channel clay unit. The subsidence together with the silicification helped preserve this unit in the present sedimentary record at Geelwal Karoo.

4.2 Aeolianite

4.2.1 Stratigraphic correlations

The first aeolian unit identified in the embankment at Geelwal is the “blood-red” or “dorbank” aeolian unit, situated at the extreme proximal (inland) end of the Cenozoic sediments. At Avontuur-A (Hondeklip Bay), Pether (1994) identifies a similar older terrestrial deposit as consisting of a massive, muddy, medium-grained sand facies. Cilliers (1995) also identifies the unit at Graauwduinen (Figure 4.7) and called it the quartzitic aeolian sand (QAS) unit. Although this unit is genetically related to the +20m strandline through its heavy mineral assemblage, the QAS unit is seen as being a separate sedimentary event. In both the +20m strandline and the QAS trace amounts of glauconite were found and the only difference in the mineralogy of the two is the fact that there were less pyroxene grains reported in the QAS unit.

The QAS unit is described as the most extensive at Graauwduinen, attaining a maximum thickness of 18.2m and is being overlain by the red aeolian sand (RAS) unit. There is extensive calcareous hard layer development at the top of this unit.

This cemented portion is referred to as the "dorbank" and attains a thickness of between 1 and 10m. Sand samples from the QAS unit were found to be fine- to medium-grained, moderately well sorted and rounded, with a high mud concentration of 11.29%. The feldspar content of the QAS is low (4.68%), classifying it as a quartz arenite.

Aeolian sands with a reddish colour were described by Cole and Roberts (1996) in the Schaapvlei area, as being fine-grained and consisting of rounded grains. These aeolian sands were found to overlie the channel clay unit and were tentatively equated with the Springfontyn Formation of the south (Figure 4.3). This unit was described at Strandfontein as having an upper series of up to six superimposed calcretised palaeosols reaching a total thickness of 41.4m. Initially, a correlation of the Springfontyn Formation with Geelwal Karoo's dorbank unit was proposed. This view has been revised when a description of the aeolianites of the Prospect Hill Formation was published by Pether *et al*. (2000). These findings and the position of the aeolianite in the West Coast stratigraphy are summarized in Figure 4.8.

The aeolianites of the Prospect Hill Formation reach an elevation of +120m a.s.l. and have a maximum thickness of about 70m (Pether *et al.,* 2000). These aeolianites are fine- to medium-grained and moderately well cemented by secondary carbonate (calcite) but with some highly indurated pedogenic calcretes. The aeolianites are rich in mollusc shells and the grains bear an iron staining which give it a characteristic reddish-orange colour. Root structures, including rhizotubules, rhizocretions and replacement features, are ubiquitous. The latter description is deemed more fitting for the dorbank unit at Geelwal Karoo and therefore this unit is now correlated with the Prospect Hill Formation rather than the Springfontyn Formation. De Beer et al. (2002) describe the "dorbank" as calcareous and gypsiferous soils in the vicinity of Vanrhynsdrop.

The second aeolian unit identified in the embankment at Geelwal appears to be closely associated with the backshore environment of the +50m package. It is much thinner than the "dorbank" and is a characteristic yellow colour. At Graauwduinen, Cilliers (1995) identifies a feldspathic aeolian sand (FAS) unit, describing it as being moderately well sorted, with medium sand. Visher diagrams indicate an aeolian environment.

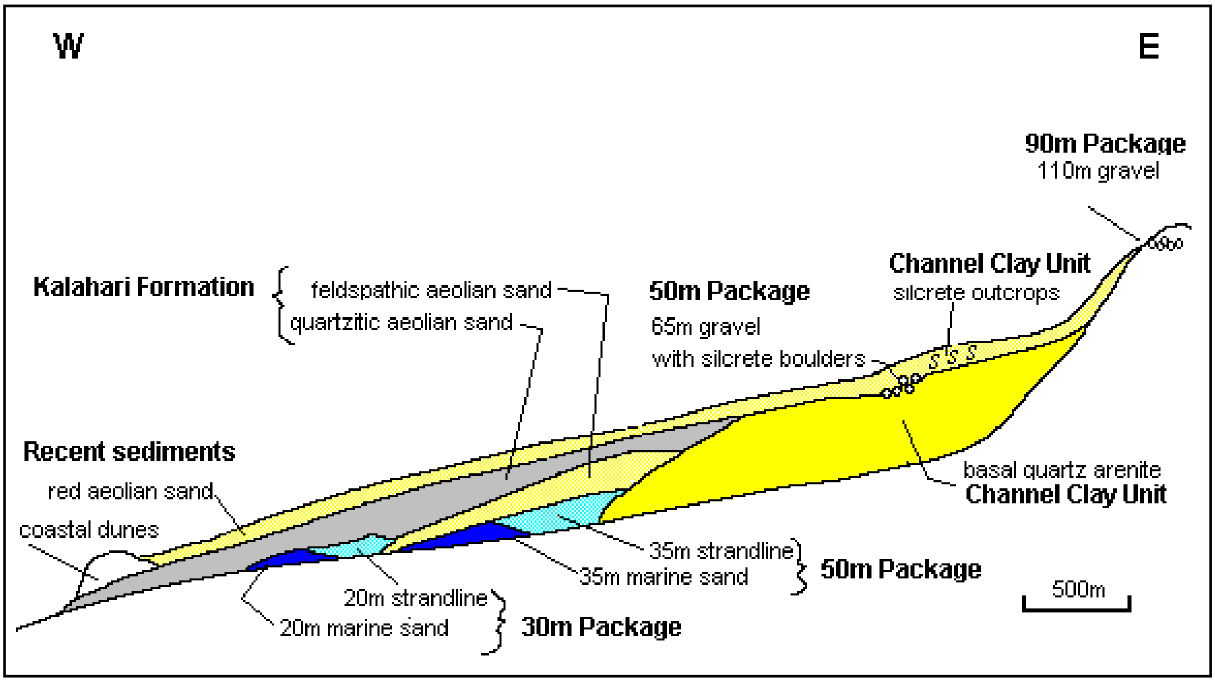


Figure 4.8 Schematic representation of the Graauwduinen ore body (Cilliers 1995, modified by Macdonald, 1996).

Mineralogically the FAS was found to be similar to the +35m strandline (Cilliers, op. cit.). Because the +35m strandline has already been equated with the +50m package found at Geelwal Karoo it makes sense to equate the FAS with the yellow aeolian dune unit found at Geelwal Karoo. The extent of the FAS unit was difficult to establish and save for differences in mineralogy (more feldspar and pyroxene in FAS) was very similar to the overlying quartzitic aeolian sand unit (QAS).

Originally identified by Cole and Roberts (1996) to be in evidence at Schaapvlei, the Springfontyn Formation has also subsequently been described by Pether et al. (2000). It is composed of unconsolidated, well-sorted quartzose, fine- to medium-grained sand, which is muddy and peaty in places. It reaches a maximum thickness of 67.4m (near Atlantis) and is distinguished by ancient termite mounds and a general scarcity in calcareous fossil material. In the Northern Cape, the sands of the Holocene Witzand Formation overlie it. In this study the yellow dune belt above the +50m package at Geelwal Karoo is seen to fit this description and therefore correlated with the Springfontyn Formation.

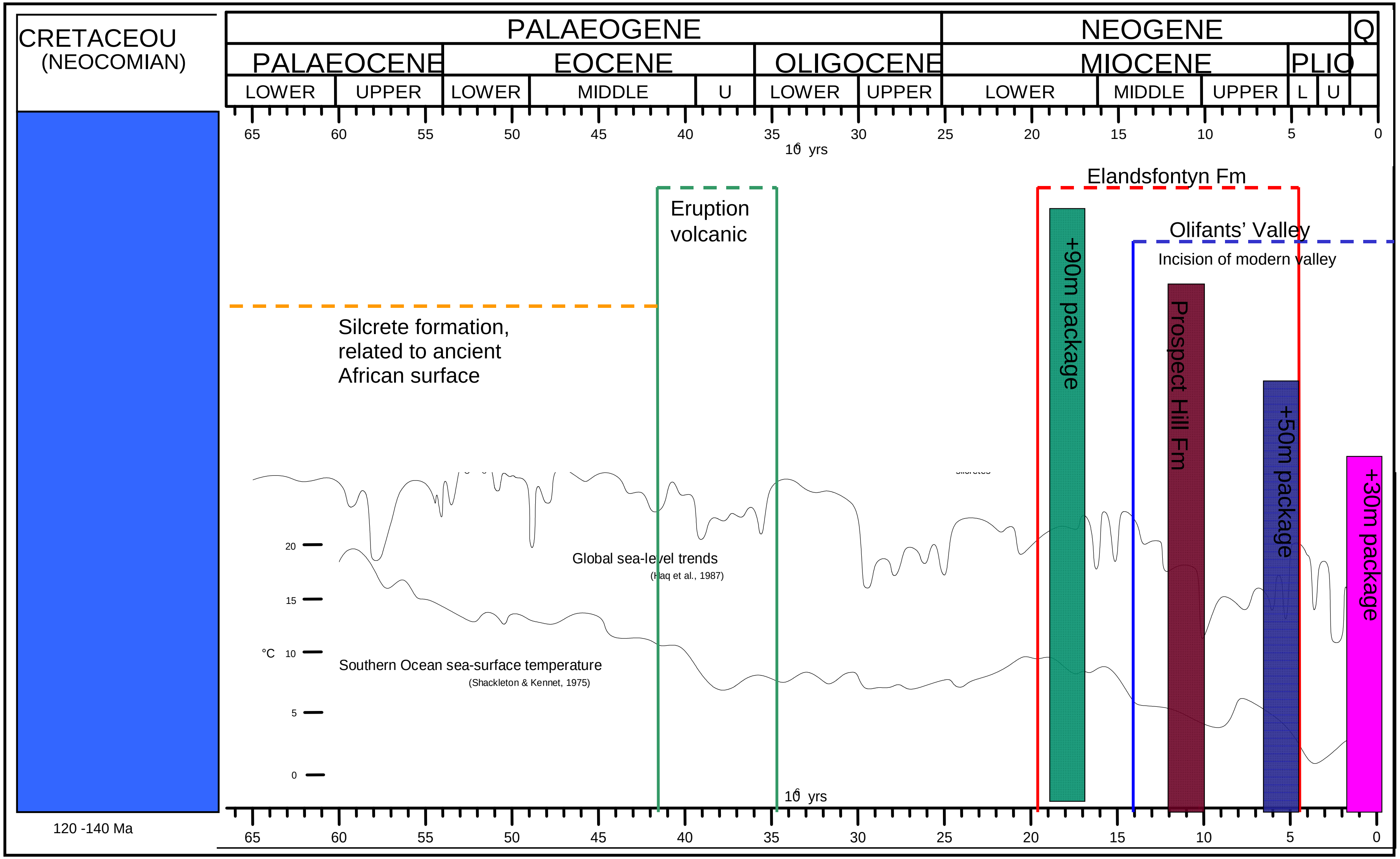


Figure 4.7 A summary of the Cenozoic geology of the West Coast (modified after Pether *et al*., 2000, Jacob, 2001).

4.2.2 Age determination

At Geelwal Karoo, the +50m package sediments appear to overlie the dorbank unit and therefore would appear to be the younger of the two units. The dorbank sands have been equated with the Prospect Hill Formation and the presence of the fossil eggshell of a giant struthious bird *Diamantornis wardi* in this formation gives it an age of approximately 12 – 10 Ma (Senut and Pickford, 1995). Furthermore De Beer et al. (2002) suggest that parts of the dorbank unit represent remnants of the Post-African I (Miocene) surface.

The second aeolian unit at Geelwal Karoo shows a gradational contact with the backshore sediments of the +50m package. It is therefore younger than the +50m package and the early Pleistocene age for the Springfontyn Formation (Cole and Roberts, 1996) is accepted although the age of this formation is still undetermined (Pether *et al.*, 2000).

4.2.3 Geological Model

The Prospect Hill Formation has steep foresets, which are unimodally inclined in a northerly direction, demonstrating a prevalent palaeo-wind direction similar to that of the present day south-southwest (Pether *et. al*. 2000). At Avontuur-A (Hondeklip Bay), Pether (1994) describes the older terrestrial deposits as an amalgamation of aeolian sand sheets and parabolic dunes. Although the unit is almost homogeneous, periods of small-scale fluvial deposition have resulted in the aeolian sand becoming cemented to form hard compacted surfaces. Although it should be considered a modern analogy, an example of one such period of fluvial erosion was identified in profile 1. This observation further strengthens the correlation between the terrestrial deposit of Hondeklip and the aeolianite found at Geelwal Karoo.

Along the coast at Geelwal Karoo, a terrestrial sand sheet developed in response to the overall marine regression in the Middle Miocene (Figure 4.7). These regressive dunes were fed by the abundant sand supply provided initially by the Olifants River and then later by the +90m package. These dunes formed in response to the predominant S to SW wind direction and can be associated with the heavy sand deposits, as the dunes become detached from beachface deposits and migrate inland (Force & Lynd, 1984). These aeolian successions often overlie lagoonal sediments and there are two types; longwall dunes, which remain parallel to the shore and migrate over low relief topography, and cliff-top dunes, characteristically parabolic and composed of sand transported up aeolian ramps on cliffed shorelines.

Both types of transgressive dune are seen to have formed at Geelwal Karoo and through time, these extensive dune sheets migrated inland to eventually provide the foundations of the Graauwduinen heavy sand deposit.

Although the accumulation of the yellow dune unit could well predate the deposition of the +50m package, all the field evidence seems to indicate that it was coeval with this marine package. Sediment accumulation would have therefore commenced from the time of the sea level regression at 5 Ma, which marked the last phase of the deposition of the +50m package. The yellow aeolianite is interpreted as a foredune, an aeolian dune ridge that formed immediately adjacent to the beachface deposits in the backshore environment. These dunes form the backbone of many barrier islands and ridges in accretion beachface-ridge complexes and may be interbedded with true beachface deposits in extreme high tides (Force & Lynd, 1984). At Geelwal Karoo, these dunes would have accompanied sea level regression from +50m a.s.l. (and later from +30m a.s.l.) and would also have formed in response to the predominant S to SW wind direction.

The extent and thickness of the entire aeolianite suggests that there has been an abundant sand supply (from a marine and/or fluvial environment) and that this supply was deflated by the dominant wind regime over time along the coast at Geelwal Karoo. Furthermore the evidence of Recent aeolian dunes superimposed on older Miocene dune belts suggests that the aeolian transport corridor, currently active at Geelwal Karoo, has been (and continues to be) active in this area over a considerable period of time.

4.3 The +50m package

4.3.1 Stratigraphic correlation

Visser and Toerien (1971) were the first to mention the presence of a heavy mineral bearing marine terrace situated at +27m in the embankment at Geelwal Karoo. These heavy mineral-bearing sediments were later found to contain shell lags of the zone fossil *Donax haughtoni* which confirmed the correlation with the +50m package of Hondeklip Bay (Figure 1.2).

At Hondeklip Bay, Pether *et al.* (2001) described a marine succession, which he terms the

+50m package and correlates with the Early Pliocene Varswater Formation of Langebaanweg.

He relates both the Varswater and the +50m package to the transgressive sea level period TP1 of Vail and Hardenbol (1979: Figure 1.2; Column 4) and adds that the vertebrate fossils found within the +50m package confirm the Mio-Pliocene age of the unit. Besides the phosphate-mineralized marine and terrestrial vertebrate fossils, fragmentary worm burrows occur within this unit. According to Kensley and Pether (1986), the fossil assemblage seems to indicate both beach and offshore sediments, which settled during a regression in an embayment setting. The entire sequence is seen as a offshore fossil lag, the result of more than one sea-level fluctuation. The +90m package is preserved as remnant deposits in bedrock depressions below the +50m package. These remnants consist of partly indurated, mouldic, coquina with authigenic phosphorite, the existence of which has been attributed to the influence of up-welling (Pether, 1986).

Pether (1986) described the +50m package as consisting of a lower shoreface, upper shoreface, foreshore and aeolian environment (Figure 4.9). The lower shoreface environment was identified as basal, quartzo-felspathic gravel layers that were deposited directly onto the bedrock. These gravel layers are 4m thick, overlain by horizontal low angle cross-stratification, laminated fine sand with wave ripples and muddy, bioturbated intervals. An overall upward increase in the degree of bioturbation from sporadic to strong was noted.

The gravel layers in this environment at Hondeklip (and at Geelwal Karoo) are generally fining upward and this Pether explains in terms of a transgressive veneer, which was reworked and redeposited during a marine regression. To substantiate this, he adds that the accumulations of transgressive gravels are usually scattered, thin, and often covered by nearshore shelf muddy sands. The upper shoreface of the +50m package at Hondeklip was found to be 3m thick (Pether, 1994). It was characterised by trough cross-stratified coarse sand with laminated fine sand showing sporadic bioturbation. At Geelwal Karoo, despite the gradational contact between the upper shoreface and intertidal facies, the thickness of the upper shoreface sediments were estimated to be about 4m (Addendum 1, Table1.2).

The foreshore facies of the +50m package was identified at Geelwal Karoo and Hondeklip Bay. At Geelwal Karoo, the gradational contact between foreshore and backshore zones did not allow for these two to be distinguished from one another. At Hondeklip, Pether

(1994) described the foreshore in detail and recorded a thickness of between 2 and 3m. At Hondeklip the foreshore was characterised by mottled fine to medium quartzose sand, which showed pedogenic alteration and had evidence of moderate to strong bioturbation. The foreshore sediments at Geelwal Karoo appeared to be more heavy-mineral enriched than those found at Hondeklip, which can be attributed to differences in provenance and coastal morphology.

The aeolian environment of the +50m package at Geelwal Karoo is found in the backshore and apart from the pronounced laminations in the foreshore zone, there appears to be little or no difference in the sediments between the two units. A tidal inlet and backbarrier deposit was identified in the +50m package at Hondeklip but these environments were not seen at Geelwal Karoo.

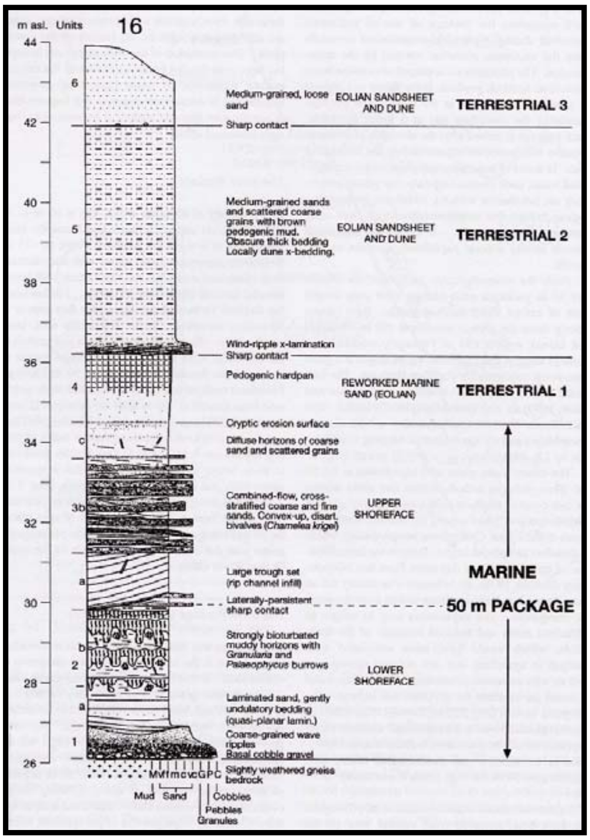


Figure 4.7: Section of the +50m package with preserved inshore facies (Pether *et. al*., 2000).

In their drilling programme in the Schaapvlei area, Cole and Roberts (1996) reported the presence of a super-mature, silicified beachface or aeolian succession. They not only equated this succession with the +50m package but also presented the most recent stratigraphic correlation for the Neogene and Quaternary successions along the West

Coast (Figure 4.4). Apparent in this figure is the fact that the outcrops of the +50m and +30m packages appear to be limited to the Hondeklip Bay area and that they are absent from the records at and south of Eland's Bay.

By presenting evidence for the +30m and +50m packages at Geelwal Karoo, this study has therefore updated this table and the Olifants River Mouth rather than Hondeklip Bay should be regarded as the southernmost outcrop of these packages. In the samples drilled at Schaapvlei, the +50m package attained a maximum thickness of 41.4m and was situated between elevations which ranged from +10 to +89 m above the present sea level. At elevations of approximately +20m a.s.l., lenticular shaped shell beds associated with the development of a back-barrier facies where intercepted. The sands in these beds are clean, fine-grained and well sorted. The relatively high concentrations of heavy sands reported in these sands suggest that the beds record a marine stillstand during the marine regression from +50m.

At Graauwduinen, Cilliers (1995) describes a heavy mineral enriched +35m strandline (Graauwduinen-East ore body) situated between +34.8 and +47m a.s.l. (Figure 4.9). The strandline is situated about 2 km inland of the coast and consists of two sediment bodies that lie buried beneath an aeolian dune field. Based on similarities seen in the heavy mineral assemblage and concentration, the +35m strandline is correlated with the +50m package. The +50m package at Graauwduinen is described by Cilliers (1995) as being an elongated body that extends parallel to the present coast with a gravel horizon, approximately 3m thick, at its base. The southern part of the ore body lies on bedrock, whereas the northern part unconformably overlies the basal quartz arenite (BQA) unit. The +50m package in this area contains fine- to medium-grained sand, which is moderately well sorted and has rounded grains. The Visher diagrams show most of the samples to be marine sand, although some were found to be typical of an aeolian depositional environment.

The clay and silt fraction of these samples is extremely high (16.55%), which is due to contamination during drilling. The mineralogy of the strandline shows a very high feldspar concentration (8.35%) and, consequently, the strandline was classified as a subarkose.

4.3.2 Age determination

A ^{87}Sr / ^{86}Sr isotope age was obtained for oyster shell fragments collected from the +35m strandline at Graauwduinen and this indicated an age of (5.4 Ma. ± 0.5 Ma.) (Cilliers, 1995).

Pether (1994) states that the +50m package of Hondeklip Bay could not be older than 2 Ma.
Based on the evidence presented by the remains of macrofossils (found in the basal gravel lags) and a seal in the Varswater Formation, he has revised his view and now agrees that an age of 5 Ma is more appropriate for this marine succession. Pether et al. (2000) accept the link between the +50m package and the Varswater Formation supported by the Early Pliocene high stand of Haq et al. (1987). Pether (1994) however explains that, because the +50m package is a regressive cycle, it is correlated with the fall in sea level from this highstand and therefore is coeval with only part of the Varswater Formation. This study therefore accepts the 5 Ma age suggested for the +50m package of Cilliers (*op.cit*.).

4.3.3 Geological model

The Late Cretaceous is regarded as a time of maximum sediment supply and within a relatively short period of time, large amounts of sediment were brought to and deposited along the West Coast (De Wit, 1993). The sediment introduced to the coast during the Cretaceous produced a pronounced wedge of sediment that extends through the Cape Canyon, (De Decker, 1996; Figure 4.4). According to De Wit (1993), the current drainage pathway for the Karoo-Olifants River was in more or less the same position by the Miocene.

The Olifants River drains an area composed almost entirely of quartzitic sandstone and quartzites of the Table Mountain Group of the Cape Supergroup. A tributary of the Olifants, the Doring River, drains the western and southern portions of the catchment area and erodes sandstones, quartzites deposits of the TMS group, shale deposits of the Bokkeveld Group and shales and quartzites deposits of the Witteberg Group. The streams and rivers in the eastern and northern part of the Olifants catchment area drain a provenance of Karoo Supergroup rocks, and would therefore be responsible for bringing clasts (particularly tillites) of the Dwyka Group and shales and sandstones of the Ecca Group to the coast. The northwestern part of the Olifants Rivers' drainage is situated on the schists, gneisses and migmatites of the Namaqua Province, whereas the central portion of the Olifants drainage is situated in the Gariep Supergroup shales, greywackes and limestones.

In the Early Miocene, the Karoo River still drained parts of the northern interior, with the result that jaspers, riebeckites and other banded ironstone clasts (derived from reworked Dwyka deposits) were introduced to the West Coast. The Dwyka glaciers originally eroded the banded ironstones from the Griqualand West Succession.

In the Middle Miocene, a wetter climate however enabled the lower Kalahari River to capture the middle Kalahari (De Wit *et al*., 2000) and this meant that the western reaches of the Karoo River became defunct (Figure 4.6). It is considered here that the provenance of the Karoo/Olifants was thereby altered and the sediment load which had up till now been dominated by cobbles and boulders became composed chiefly of sand. It therefore follows that the basal gravel lags seen in the +50m and +30m at Geelwal Karoo are the result of the reworking and redeposition of older marine terraces rather than being the result of a continuous coarse sediment contribution made by the Karoo River. Evidence for this can be found in the fact that *in situ* exposures along the West Coast of the +90m package are scarce and that most evidence of this marine package is found reworked into the +50m package. This phenomenon of reworking older marine terrace sediments appears to have been repeated in the +30m package, with the result that in the coarse gravel component of the terraces there does not appear to have been much change over time.

According to the classification proposed by Reading (1991), Geelwal Karoo today has a wave-dominated shoreline, characterised by a microtidal regime (there is a difference of <2m between high and low tides). Such a tidal regime is associated with beaches, extensive barrier islands and cheniers. The scenario was different in the Early Miocene, however, when the sea level reached a maximum of +90m a.s.l. and the offshore was much wider. During this time, the coastline would either have been classified as a mixed wave-tide influenced shoreline (characterised by mesotidal barrier islands, tidal inlets and ebb/flood-tidal deltas) or as a tide-dominated shoreline, which is marked by the development of extensive tidal flats and estuaries. When the sea level dropped in the Late Miocene, this would have lead to the inevitable narrowing of the offshore, and the currents of the Miocene coastline could be equated with the fast-flowing modern day Agulhas Current of the East Coast of Africa.

The eroded gravel lags originally introduced to the coast via the Karoo River Mouth would have been transported northwards by the longshore drift and eventually with the help of a wave-dominated coast, incorporated into a series of marine terraces. In the Late Pliocene, one such terrace would have been deposited as a transgressive cycle up to a maximum of +50m a.s.l. The wave-dominated coastline would have ensured that the sediments making up this new terrace were a combination of newer sandy sediment introduced by the Karoo River as well as the material (gravel-bearing) from older marine terraces. After reaching the highstand at about 5 Ma, the sea receded.

The result was that the sediments deposited as transgressive sedimentary units were preserved and today are known as the +50m package nearshore succession.

The vertical stratigraphic section of Geelwal Karoo in Figure 4.1 shows a transgressive succession and evidence for the prograded regressive nature of the sediments (Pether, 1986) as seen at Hondeklip Bay was either absent or obscured by erosion. Pether confirms the regressive nature of the sediments by stating that, at Hondeklip Bay, there is a decreasing elevation of the foreshore westwards, indicating a steadily falling sea level. He goes on to say that as the sea level regressed from +50m a.s.l., it was punctuated with minor episodes of marine stillstands. The sediments of the +50m package continued to prograde outward, changing from a high energy to a more sheltered environment. As a result, the +50m package is characterised by anomalously thick, heavy mineral-bearing, foreshore sediments and well developed barrier complexes. The heavy mineral placer at Geelwal Karoo and the back barrier sediments in the Schaapvlei in the Koekenaap area could just as easily have formed during marine transgression.

At Geelwal Karoo, it was the combination of a marine stillstand at +37m a.s.l. and the local bedrock morphology that produced the Geelwal Karoo heavy sand palaeoplacer deposit in the foreshore and backshore zones of the +50m package. The protruding limb of the erosion-resistant Table Mountain Group seen at Cliff Point, formed an ideal J-bay setting for the accumulation of this placer deposit. Waves were, and still are, refracted around this headland (Macdonald, 1996). They followed an oblique path towards the coast, with the result that excluding the +50m package, not one but at least two successions of superimposed heavy sand placer deposits have formed in this area (discussed further in the following section on the +30m package).

In response to an ice age between 4.7 and 4.3 Ma, the Miocene transgression was interrupted and the sea regressed (Siesser & Dingle, 1981; Hendey, 1981; Dingle *et al.*, 1983). This has been inferred from the widespread aeolian deposits onshore (in the southern Cape) and also from the destruction and reworking of phosphorite beds at Langebaanweg, which were reduced to gravel lags by wave action (Hendey, 1981). This meant that in the Early Pliocene, the accumulation of the +50m package sediments was truncated by a sea level regression reworking of the existing sediments was kept to a minimum (possibly due to regressive progradation). During sea level regression the +50m package were exposed to groundwater action. The latter not only led to extensive de-calcification of the foreshore facies but also played a role in the large-scale cementation seen in these sediments.

This cementation, the continued regression of the sea and the abundant supply of aeolian sand (linked to the continued aridification of the West Coast) helped to preserve the +50m package in the embankment at Geelwal Karoo.

4.4 +30m package

4.4.1 Stratigraphic correlations

Pether (1986) considers the +30m package to be a standard reference for Quaternary sea level changes around Southern Africa. The zone fossil, *Donax rogersi*, can recognised at various locations, over 1500 km of the southern and western coastline of Africa. Correlations cannot, however, be extended to the east coast and for this purpose *Donax serra* is used. In 1986, Pether mentioned the presence of *Donax rogersi* in the rubble of prospecting pits, just north of the Olifants River Mouth. Subsequent to this the presence of the offshore and inshore facies of the +30m package has been confirmed at Duiwegat.

Cole and Roberts (1996) described boreholes drilled in the Schaapvlei-Karoovlei area intersecting a succession of marine sands, occurring at an elevation of +20m above sea level. The sands contain shelly material, trace fossil burrows and heavy sands. These quartzose sands were described as being fine- to coarse-grained, sorted to well sorted with rounded to subrounded quartz grains. The sediments were interpreted to be the product of a super-mature, silicified foreshore environment and the presence of heavy sands was attributed to a marine stillstand during a regression. Overlying these marine sands was a succession of aeolian sands. Given the close proximity of Schaapvlei to Geelwal Karoo, it is possible that Cole and Roberts (*op.cit*.) refer to either the +30m or the +50m package, but the low elevation seems to suggest that it is the +30m package. At Geelwal Karoo, exposure of the +30m package is minimal and these are notably devoid of heavy minerals. Instead it is the foreshore of the +50m package that is heavy mineral enriched. If one looks at the present beachface at Geelwal Karoo however, it is also heavy mineral enriched in the Torings area but towards Duiwegat, it becomes a beachface composed almost entirely of quartz. This change in lithology can be explained in terms of a change in the hydrodynamic environment controlling placer development. At Cliff Point there is a clearly defined J-bay, whereas at Duiwegat, a linear beach is found. It is therefore possible to have both heavy mineral-enriched and heavy mineral-poor beaches in a single sedimentary unit and therefore the correlation with the +30m package by virtue of elevation with the foreshore sand of Cole and Roberts (*op.cit*.) is retained in this study.

Cilliers (1995) describes a second ore body (Graauwduinen-West) and calls it the +20m strandline. For the purposes of this study and based on the bedrock elevation recorded for this marine succession, the +20m strandline at Graauwduinen has been equated with the +30m package at Geelwal Karoo. Like the +35m strandline, it is overlain by an aeolian dune belt, is heavy mineral-enriched and forms an elongated body parallel to the present coast. It is roughly 2km in length and has an average thickness of 15m, thinning out northwards. In places, it covers the bedrock, reaching an average elevation of +23m above sea level.

The +20m strandline lies closer to the Atlantic Ocean and bears a greater heavy mineral concentration than the +35m strandline. Cilliers (1995) describes it as having a complex history with more than one heavy mineral layer interbedded with non-enriched layers over a vertical distance of 15m. The eastern edge of the strandline was exposed in a prospecting trench, Site A, and the base of the +20m strandline was found to consist of a layer of cemented pebbles and cobbles. The latter is equated with the inshore zone of the +30m package at Geelwal Karoo. At Site A, the gravel lag was overlain by a homogeneous, 5-6m thick layer of dark, yellow to light olive, poorly lithified sand with an extremely high heavy mineral content. Extensive bioturbation is evident and the sands in this unit are fine- to medium-grained, rounded and moderately well sorted.

The feldspar content averages 5.8% and low concentrations of mud were reported. The latter description appears to fit a beachface, and more specifically, a foreshore zone of the +30m package. Although the beach zone of the +30m package at Geelwal Karoo proved to be heavy mineral deficient, Cilliers (1995) mentions that just as was the case with the +35m strandline, a heavy mineral-poor unit is found seaward of the +20m strandline. The offshore facies of the +30m package is absent at Graauwduinen and this in keeping with the transgressive nature of the model (Graauwduinen too far inland).

The +30m package extends to near the present-day shoreline, where it is overlain by deposits relating to a ~+10m a.s.l. sea level transgression (Pether *et al.,* 2000). In contrast to the +50m package, the inshore facies of the +30m package is extensively preserved whereas the foreshore is often subjected to terrestrial reworking. The proximal part of the inshore of the +30m package is typically dominated by thick trough cross-laminated sets, whereas thin gravelly units represent the distal part of the inshore. These gravel units were entirely reworked after deposition.

4.4.2 Age determination

A ^{87}Sr / ^{86}Sr isotope age on a shell fragment from the +20m strandline at Graauwduinen yielded an age of 4.3 (± 0.5) Ma, exactly 1 million years younger than the +35m strandline (+50m package) (Cilliers, 1995). However, to date there are no reliable age constraints on the +30m package (Pether *et al.*, 2000). This succession has been related to either the transgression starting at 3.3Ma or the one at the Plio-Pleistocene border at 1.6 Ma (Pether, 1994; Pether *et al*., 2000). The fossils of the +30m marine package suggest an age of 3 Ma (Kensley & Pether, 1986) and therefore this study correlates the +30m package with the older transgression at 3.3 Ma.

4.4.3 Geological model

Regression in the Pliocene was terminated by another transgression which reached a maximum elevation of +30m a.s.l. During this transgression another prograded wedge of sediment built out seaward and these are today known as the +30m package. The bedding features observed in the +30m package seem to suggest that there was a greater sediment supply to the littoral zone during +30m package times relative to the +50m package (Pether *et al*., 2000). There was a marine stillstand at approximately 1.5 Ma and a heavy sand placer was formed at Graauwduinen, and would also have formed in the Cliff Point area at Geelwal Karoo (Cilliers, 1995).

Despite the intensification of upwelling along the coast from Late Miocene times, its influence was not as great as in the present interglacial period (Pether *et al*., 2000). The phenomenon of upwelling has been linked to the onset of aridity along the West Coast (Ward and Corbett, 1990). It was however, the onset of bipolar glaciation in the Pleistocene climatic mode that impacted locally and forced considerable extinction and speciation, particularly in shallow marine molluscan faunas (Pether *et al*., 2000). The result of several periods of glaciation was that the post-+30m package fauna are essentially modern with no evidence of warm water species. The +30m package can be construed as the transition period between the warmer water conditions in the Pliocene and the colder conditions in the Quaternary. The molluscan faunal contrast between the +50m and +30m packages is not confined to the *Donax* species, but is sufficiently distinct to exclude the possibility of a fauna change across a barrier. A sharp contact and an unconformable facies relationship separate the +50m and +30m packages. The deposition of both these packages took place during the early stages of recovery after deglaciation (Cole and Roberts, 1996). Pether (1986) suggests that the zone fossil of the +30m package, *Donax rogersi*, evolved from *Donax haughtoni*.

The +30m package unconformably onlaps onto the +50m package and like the +50m package, is described as a seaward-thickening suite of prograded nearshore sediments laid down during a regression from a transgression maximum of +30m a.s.l. (Pether, 1986). At Geelwal Karoo only evidence for the transgressive nature of the gravel lags was found and little was found for the regressive progradational nature of the package.

A study of the clast assemblages and mineralogy of the +50m and +30m marine packages reveals no significant changes in their provenance. This is seen to be due to the fact that they both represent reworked, older terraces and therefore have the same point source. Although the gravel lags in the +30m package appear to have a smaller clast size than the +50m package, the gravel layers are in some areas up to 5 layers thick. This fact together with the fact that the sand fraction is generally coarser than that of the +50m package suggest that during the +30m package the sediment load of the Olifants was becoming coarser-grained than it was during the deposition of the +50m package. The extensive aeolianite that bridges the time gap between the +30m and +50m packages is testimony to the increased aridity that was facing the West Coast at that time and the sheer volume of aeolian sand implies a period of abundant sand supply to the coast.

It is highly probable that a +30m package heavy sand placer was developed in the area adjacent “Torings” as there are placers found both in the +50m package and in the present beachface in this area. There is however nothing left of the +30m package placer at Geelwal Karoo as it has subsequently been eroded and reworked into the present beach. Furthermore, the +30m foreshore units, have been subjected to severe decalcification (Pether *et al*., 2000). This has not only denudated the beachface unit of marine fossils but also fed the ground water with the necessary carbonates to form numerous evaporitic (calcareous) layers as well as giving it the appearance of a terrestrial deposit. This is particularly true at Geelwal Karoo in the Duiwegat area, where the only indications of the presence of the +30m package foreshore were a few *Donax rogersi* shells lying on the surface.

4.5 Recent unit

4.5.1 Stratigraphic Correlations

In the Cenozoic record at Geelwal Karoo, the Recent unit is taken to include the present beach sediments and the thin veneer of red dune sand currently being deposited over the embankment sediments.

The contact between the Recent aeolian sand cover and the older aeolianite is not always clear and generally the younger dune unit, called “red aeolian sand”, occurs at the highest elevations at Geelwal Karoo. Cole and Roberts (1996) intersected this aeolian unit at Schaapvlei and classified it as the Witzand Formation. The latter is the uppermost unit of the Sandveld Group and is defined as being an unconsolidated, coastal sand dune unit found between Noordhoek in the Cape and Hondeklip Bay. At Geelwal Karoo it is characterized by minimal calcareous cementation and numerous *Trigonephrus* shells. The lithology of the group varies from fine- to medium-grained sand and the unit is well sorted with minimal mud. A more reddish colouration is associated with a lower carbonate (shell) content (Pether *et al*., 2000).

At Hondeklip Bay, a “recent aeolian sand” unit was identified by Pether (1994) and was described as being a pale orange-brown, clean, loose, medium-grained sandy succession with a grain-size distribution very similar to the underlying, older, terrestrial (dorbank) unit. Cilliers (1995) refers to the RAS or Red Aeolian Sand unit at Graauwduinen and describes it as being a dark, red heavy mineral-enriched aeolian sand, the colour of which is a function of the pedogenic process and which varies from yellow-orange to red. The sands of this unit were found to be fine-grained, well sorted and rounded. A grain size analysis and bioturbation confirmed the terrestrial depositional environment. Although generally considered to be homogeneous, patches of heavy mineral-rich lamina were noted. Also present within these sands and restricted to the lower portion of the unit, were the random occurrence of subrounded quartz grits, which were interpreted as deflation surfaces.

The Recent unit at Geelwal Karoo also includes the marine succession on the present beachface. The nearshore succession reaches a maximum thickness of 12m and is a lenticular, “shoe-string” body of sediment. Four distinct units where described, namely: 1) a basal pebble conglomerate that overlies the bedrock. This can be equated with the inshore zone; 2) a marine sand consisting of red to black (heavy mineral-rich) layers alternating with light coloured quartzose layers. These marine sands are well sorted and there is evidence of bioturbation. The sandy units are medium- to fine-grained with rounded to well-rounded quartz grains. This unit is equated with the foreshore/beachface zone. 3) At the back of the beachface is a poorly sorted, yellow mud and pebble wash. This unit is interpreted as a scree deposit that was washed down from the older marine sediments in the embankment. 4) a series of small dunes banked against the cliff. They are heavy mineral-bearing aeolian deposits and are associated with the backshore zone of the beachface environment.

Three quaternary marine units or RETs (Recent emergent terraces) have been described by Partridge *et al.* (2000) along the Namibian coast. These terraces are intermittently presented and are called the +8 to +12m, the +4 to +6m and +2 to +3m terraces. They range in age from middle Pleistocene for the +8 to+12m terrace to Holocene for the +2 to +3m terrace.

At Hondeklip Bay, the +2 - +3m package was identified (Pether, 1994), which is characterized by a basal conglomerate layer, covered by marine sands deposited during a middle Holocene sea level high. These sands, in turn, overlie a compacted aeolian sand unit. At Graauwduinen, Cilliers (1995) identifies all three terraces and describes them as being buried beneath aeolian sand. They were identified by their well rounded pebbles and cobbles of jasper and banded ironstone and, seen in profile, they displayed a multistage depositional succession with more than one gravel horizon. At Geelwal Karoo no RETs were identified.

4.5.2 Age determination

The age of the aeolian component of the Recent unit at Geelwal Karoo has not been conclusively determined, although the middens found on the surface (photograph 4.1) appear to be of the Late Stone Age (D. Noli; pers comm.) This would mean that a maximum age of about 5 000 years is feasible for the aeolian sand unit of the Recent unit.

Photograph 4.1 Late stone age midden found on the surface of the dorbank aeolianite. Geological hammer for scale.

For the marine component of the Recent unit at Geelwal Karoo, evidence presented by the CSIR (1984) suggests that the present beachface is the result of the last transgressive cycle, which started approximately 5000 years ago.

4.5.3 Geological Model

Based on the increased number of Cape fynbos flora, Pether *et al*., (2000) conclude that more arid Mediterranean weather patterns resembling present conditions evolved during the late Neogene and Quaternary. After the sea level retreat from the +30m package transgressive maximum, three more transgressions are recorded and these form part of the RETs. The latter all bear evidence of cold-water marine fauna similar to those found along the coast today (Pether *et al*., 2000.) These packages are related to a specific cycle of marine transgression and regression and each comprises a package of marine sediments deposited during regressive progradation seaward from the maximum elevation reached by the transgression. The packages are arranged *en echelon* down the coastal bedrock gradient, from oldest and highest to youngest and lowest, each package truncating the preceding one at a lower elevation. At Geelwal Karoo, the absence of RET terraces is due to the steep bedrock profile (particularly in the Cliff Point area), which does not allow for sediment accumulation and preservation.

Cole and Roberts (1996) state that the Witzand Formation is associated with sand deflation from the modern beachfaces and, in places, attains a thickness of 28 meters. This is in part true for the Recent aeolian cover found at Geelwal Karoo, where sand is swept off the present beachface by the predominantly SW winds and incorporated into the embankment succession. At Hondeklip Bay however, it has been proved that the bulk of the sediment making up the recent aeolian sand is derived from a fluvial source terrain, the Swartlintjies River (Pether, 1994). It is therefore not unreasonable to say that some of the aeolian cover at Geelwal Karoo is derived from the present banks of the Olifants River. At Hondeklip Bay, the recent aeolian cover is deposited in a series of Holocene barchanoid dunes. Because the grain-size of Recent and older “dorbank” units are so similar, Pether (1994) deduces that the two terrestrial units were and still are being deposited by similar processes. The Witzand Formation at Geelwal Karoo occurs as retentive dunes, which due to their vegetation are characterised by vertical accretion resulting in shoreline-parallel dune systems which show less inclination to migrate inland (Pether *et al*., 2000).

5. ECONOMIC POTENTIAL OF GEELWAL KAROO

The Neogene marine packages and the kaolinised fluvial palaeochannel of the West Coast are known to contain exploitable reserves of diamonds (Pether *et al.,* 2000; Figure 5.1). In this chapter the diamond and, in the case of the marine unit, the heavy sand potential of each of Geelwal Karoo's Cenozoic successions are discussed in more detail.

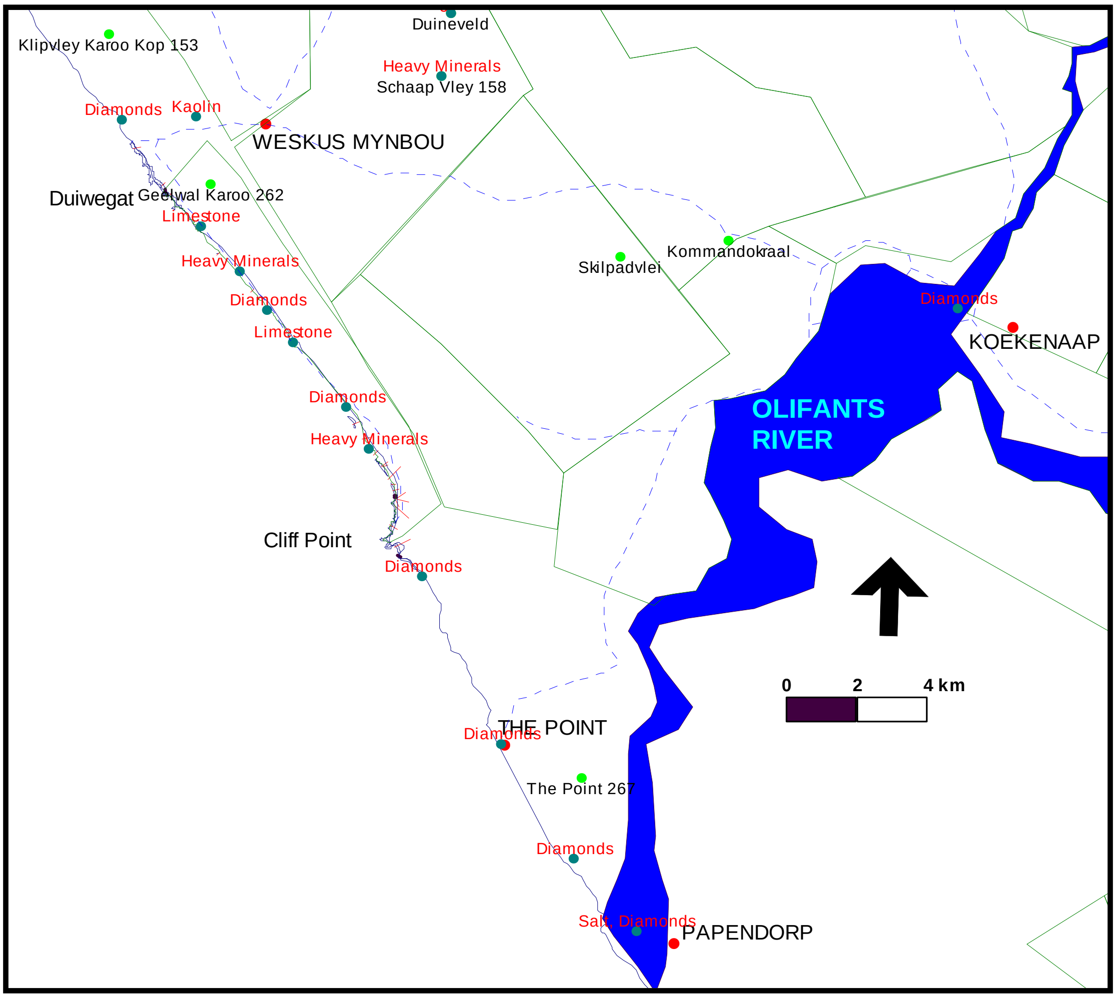


Figure 5.1: A summary of the known resources surrounding Geelwal Karoo.

5.1 Channel clay unit

The channel clay unit at Koingnaas has been mined for its diamonds since 1968. De Decker and Woodborne (1996) observed that the submarine Upper Cretaceous fan-delta sediments found on the middle offshore along the West Coast often contain diamonds with grades reaching between 0.01 and 0.05 cts/ton. The potential for finding diamonds in the Cretaceous fluvial environment is therefore comparatively high (Rogers *et al.* 1990).

De Decker and Woodborne (1996) maintain that the marine diamonds in the channel sediments found offshore originated from Cretaceous-aged kimberlites, which intruded into the heart if the African continent between 120 and 80 Ma ago. These diamonds were transported to the coast by the Karoo River that debouched onto the offshore via the Swartlintjies, Orange and Karoo /Olifants River. In this study, it is sugested that more than one generation of diamonds were introduced to the coast. The first set was before the Karoo/Olifants River was established and that the diamonds were transported to the coast in Cretaceous times by not one but a network of dendritic channels. At Geelwal Karoo, an example of one such channel is seen in the channel clay unit.

The very angular clasts and the lack of sorting suggest that the channel clay fluvial system had a very local provenance and travelled a short distance to the coast. This means that in the case of the channel clay unit there could possibly be a secondary rather than primary source for diamonds and that the diamond potential of the bedrock material is a matter that needs to be explored. At Geelwal Karoo, the distal portion of the channel clay unit is incised into Gariep bedrock, while proximally the bedrock is the Table Mountain Group (Cape Supergroup.

Given the similarities in specific density, heavy mineral concentrations can be used as an indication of the diamond potential. A study of the vertical and horizontal variations in the percentage of heavy minerals was done for Geelwal Karoo (Table 5.1).

Table 5.1 The variation seen in heavy mineral concentration with distance along the coast. Refer to Figure 3.1 for the exact positions of the profiles.

	+30m package	+50m package	Aeolianite	Channel clay	Recent	
AVERAGE	4.21	40.47	9.89	1.71	8.83	Vertical distance
AVERAGE	3.26	29.06	9.37	1.24	8.65	Horizonal distance

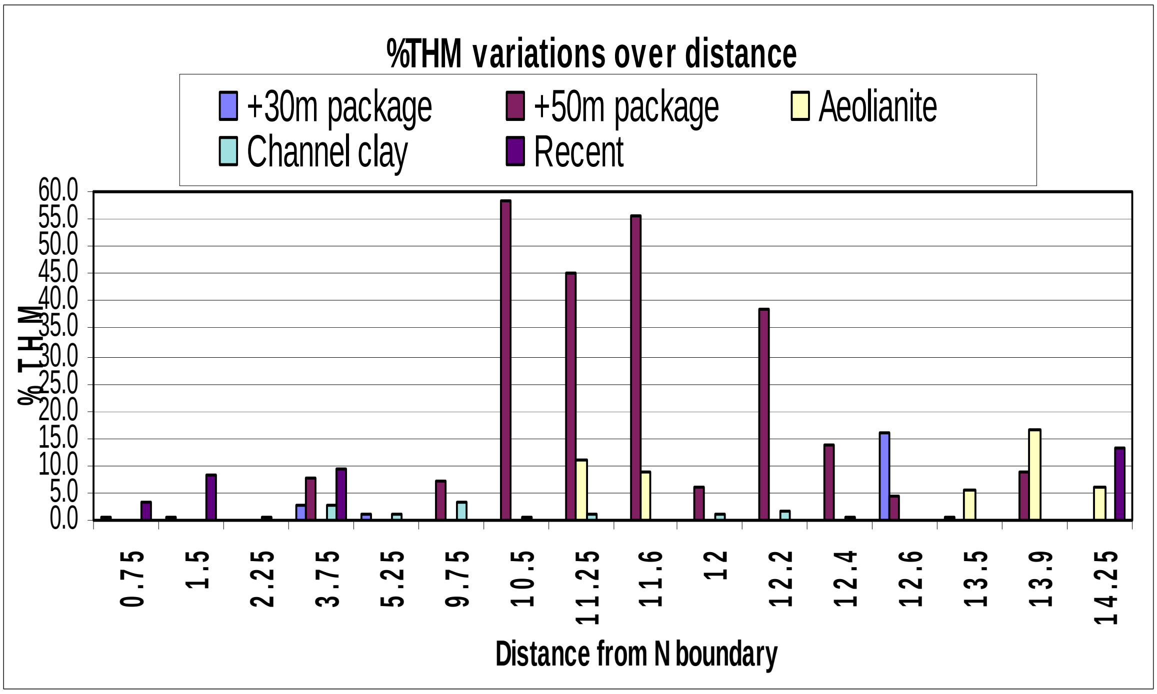


Figure 5.2: Weight% heavy mineral variations in along length of Geelwal Karoo. **0.75km** = Profile 10; **1.5km** = Profile 9; **2.25km** = Profile 11; **3.75km** = Profile 1; **5.25km** = Profiles 17,3; **9.75km** = Profile 7; **10.5km** = Profile 5; **11.3km** = Profile 13; **11.6km** = Profile 6; **12km** = Profile 14; **12.2km** = Profile 2; **12.4km** = Profile 15; **12.6km** = Profile 4; **13.5km** = Profile 8, **13.9km** = Profile 16; **14.3km** = Profile 12.

The few data available on the heavy mineral concentrations of the channel clay unit seem to indicate that along the coast, the area with the highest heavy mineral concentrations (and therefore greatest diamond potential) is found near Profile 1 and 7. The field observations at Profile 1 (Appendix 1) and Profile 7 suggest that the higher heavy mineral concentration appears to be related to the presence of gravel lags which show better sorting. In both profile sites the channel clay unit is relatively thin (less than 4m) and this would mean a higher energy flow regime and consequently better sorting. Profile 1 has evidence of coarse basal gravel while profile 7 forms part of the upper fine unit. The heavy mineral concentration appears to be equally distributed in the gravel lags of both the basal and upper units within the channel clay system.

It is quite possible that another Early Cretaceous channel existed where the present Olifants River’s mouth is today and that the remnants of this older fluvial system were eroded with the maturation of the ancient Karoo River drainage system. The latter fluvial system introduced a new population of diamonds to the coast, most of whereas were probably derived from a primary kimberlitic source and whereas were subsequently reworked into the basal gravel lags of the Neogene marine successions.

5.2 Aeolianite

Despite being described as two separate stratigraphic units, due to the low tonnage associated with the yellow dune unit, the economic potential of the two aeolian units at Geelwal Karoo will be discussed as one. Significant heavy sand aeolian placers are found in the USA, Australia and at Richards Bay in the RSA. Their great volume and homogeneity make them economically viable even at low grades (Force & Lynd, 1984). At Namakwa Sands (Graauwduinen), the aeolianite is currently being mined for its heavy minerals. The total heavy mineral concentration for the QAS unit is 8.73%, whereas the FAS has a THM of 6.59%. At Schaapvlei, the Springfontyn Fm was found to have a total heavy mineral concentration of less than 1%. The heavy mineral assemblage differs from Graauwduinen, in that they report high percentages of zircon (32%), rutile (22%) and ilmenite (46%), with some samples also containing dravite (40%), anatase (53%) and hematite (28%).

The resource calculations done for the aeolianite can be found in Tables 5.3 and 5.4. For the "dorbank" unit a THM of 9% was used and for the yellow dune belt, the THM was 10%. Corbett (1989) observed along the Sperrgebiet coast that marine beachface successions often acted as point sources for wind-aligned dune trains. This observation would best explain the high THM values of the yellow dunes at Geelwal Karoo (very close to the placer source in the +50m package) and the lower values seen in the FAS of the Graauwduinen resource (situated 30km inland of Geelwal Karoo).

Table 5.3 Resource parameters for the aeolianite.

Samp. no.	Profile	km from N boundary	%THM	AVERAGE
Ave 76,81,79,77,78	13	11.25	11.18	
4	6	11.60	8.56	
Ave 39,40	8	13.50	5.34	
Ave 93,94	16	13.90	16.69	
Ave 69,68	12	14.25	5.10	9.37

Table 5.4 Resource estimates for the aeolianite. (Ti-bearing minerals include ilmenite, rutile, psuedorutile, hydrated lmenite and leucoxene.)

	Yellow Dunes	Dorbank	Comments	TOTAL
Length of placer (metres):	4,500.00	4,500.00		
Average thickness of placer (metres):	7.6	16.3		
Total width or distance inland of placer body (in meters):	10	2000	Value is best estimate, maximum	
Volume of placer (m3):	171,000.00	73,350,000.00	Assumes placer has a wedge shape, therefore half the volume	73,521,000.0
Average % THM (grade)	11.3	7.7		9.5
Volume of THM (m3):	19,323.00	5,647,950.00		5,667,273.0
Average % Ti in THM *	**1.7**	**1.5**	titanium bearing minerals only	**1.6**
Volume of Ti-bearing material (m3)	328.49	84,719.25		85,047.7
Tons of Ti-bearing material in placer body	492.74	127,078.88	Assuming bulking factor of 1.5 for sand	127,571.6

The iron coatings on the grains in the heavy mineral assemblage made point counting difficult and, for the reserve calculation, it was decided to use a general value of 1.6% to represent the Ti-bearing component in the heavy mineral suite. From Table 5.4, it should be clear that most of the mineralization in the aeolianite is present in the dorbank unit.

The exact "width" of the aeolianites could not be determined and theoretical values of 10m and 2km were therefore used to calculate the width of the yellow dune and dorbank unit respectively. (It must be borne in mind that the dorbank may well extend further inland). It was calculated that the aeolianite of Geelwal Karoo comprises roughly 73 million m^3 of sediment (roughly 110M tons) at an average grade of approximately 9% THM. Only 1.6% of this volume comprises economically important minerals (titanium-bearing) and it can therefore be said that there are 127 000 tons of titanium-bearing minerals in the aeolianite at Geelwal Karoo. If mining the +50m package were to become an option, the added cost of mining through the calcrete horizons of the overlying dorbank unit should be considered.

5.3 +50m package

The presence of a heavy sand placer in the embankment (+50m package) was first noted by Visser and Toerien (1971) and then later confirmed by Macdonald (1996). The placer was described as being fine-grained with a total heavy mineral concentration varying between 60 and 90%. The highest total heavy mineral (THM) concentrations were recorded in the intertidal or beachface environment, but considering only the titanium bearing minerals, there are equal amounts of placer material situated in the inshore and beachface environments.
The backshore environment (seen in the higher elevations of the beachface facies in Table 5.2.) also reported reasonable concentrations of heavy minerals.

The offshore zone of the +50m package had relatively low heavy mineral concentrations but was included in the resource calculations. Along the coast, the highest heavy mineral concentrations were reported between 10.5 and 12.2km from the northern gate. This position corresponds to the linear beachface beyond the point of diffraction associated with the J-Bay behind the "Torings" headland, Macdonald (1996).

The resource estimate of the placer in the +50m package can be seen in Tables 5.5 and 5.6. It must however be borne in mind that the values for the "width" could not be measured (no drilling data) and that a width of 200m for the inshore and +50m for the beachface facies were assumed. These parametres were assumed after observing the scenario on the present beachface and consulting the dimensions presented by Pether (1994) for Hondeklip Bay. It was found that, although the inshore may be the thinner of the two zones, it generally extends over a larger surface area.

Calculations reveal that the placer deposit in the +50m package at Geelwal Karoo comprises a total of roughly 1.4 million m^3 of sediment (2.1M tons) at an average grade of approximately 44% THM. This equates to 608 000 m^3 of heavy minerals of whereas 17% are Ti-bearing minerals. It can therefore be said that there are 104 thousand tons of titanium-bearing minerals in the palaeoplacer at Geelwal Karoo.

Table 5.5 Resource parameters for the +50m package

Samp. no.	Profile	km from N boundary	%THM	AVERAGE
Ave 10, 10b	1	3.75	7.85	
112	7	9.75	7.39	
ave 48,49,50	5	10.50	58.59	
Ave 75,72,74	13	11.25	45.18	
Ave 7c,7a,6,7b,3c,3b,3a	6	11.60	55.48	
Ave 86,84,85	14	12.00	50.87	
Ave 17e,17a,17b,20,21a,17d	2	12.20	38.50	
90	15	12.40	13.62	
27	4	12.60	4.38	
92	16	14.25	8.72	29.06

Table 5.6 Resource estimates for the +50m package. (Ti-bearing minerals include ilmenite, rutile, psuedorutile, hydrated ilmenite and leucoxene.)

	Shelf	Shoreface	Beach	Comments	TOTAL
Length of placer (metres):	1,700.00	1,700.00	1,700.00		
Thickness of placer (metres):	5.8	6.5	9.0		
Total width or distance inland of placer body (in meters):	50	200	50	Value is best estimate, maximum	
Volume of placer (m3):	246,500.00	1,105,000.00	382,500.00	Assumes placer has a wedge shape, therefore half the volume	1,487,500.0
Average % THM (grade)	18.2	37.8	50.0		43.9
Volume of THM (m3):	44,863.00	417,690.00	191,250.00		608,940.0
Average % Ti in THM *	**2.1**	**17.2**	**17.1**	titanium bearing minerals only	**17.2**
Volume of Ti-bearing material (m3)	942.12	71,842.68	32,703.75		104,546.4
Tons of Ti-bearing material in placer body	1,413.18	107,764.02	49,055.63	Assuming bulking factor of 1.5 for sand	156,819.6

The reserve estimate for Namakwa Sands (Graauwduinen) was calculated to be 500Mt @ 8.9% THM (45 Mt heavy minerals; Palmer, 1994). Although the placer at Geelwal Karoo is much smaller, the grade is much higher. This can be explained by the fact that there is a large terrestrial component to the Namakwa Sands ore body and the resource estimated for Geelwal Karoo only considers marine sediments. Cilliers (1995) reported that the total heavy mineral concentration of the +50m package at Graauwduinen was 21.84%, with local concentrations of 67.4% and these values reflect the marine component (35m strandline) of the ore body. The figures associated with Graauwduinen' resource compare favourably with those calculated for Geelwal Karoo. Cilliers (1995) states that in the 35m strandline, pyroxene was found to make up 56% of the total heavy mineral assemblage (Table 5.7). At Geelwal Karoo, the total augite concentration (pyroxene) is 34% and if the weathered ferro-silicate minerals are also taken into account, the total concentration increases to 73%. The difference between the Graauwduinen and Geelwal Karoo placers can therefore be explained in terms of differences in groundwater action.

Table 5.7: A summary of the relative proportions of the heavy mineral assemblage in the Graauwduinen succession (after Cilliers, 1995).

Unit	RAS	avg QAS	avg +20m strl	avg FAS	35m strl	BQA
Pyroxene	12.19	28.73	53.11	55.30	56.00	23.73
Tourmaline	1.88	1.11	1.20	1.31	1.05	2.78
Garnet	15.21	18.61	16.93	18.34	17.89	22.75
Rutile	11.10	4.63	2.68	3.18	1.74	5.40
Zircon	16.00	11.84	5.30	5.04	2.97	9.98
Ilmenite	41.97	31.54	18.81	14.97	20.17	25.53
Leucoxene	1.59	3.57	1.99	1.67	0.18	9.98

At Schaapvlei the maximum total heavy mineral (THM) concentration of the +50m package averaged 2.78 % (Table 5.6). For marine sediments this concentration of heavy minerals may appear very low but in the context of a back-barrier setting, it would pass as reasonable.

The small volume of the +50m package's heavy sand placer does not appear to make this placer a feasible option at this stage. It is made that much more unattractive by the fact that a large percentage of the heavy mineral-bearing sands are cemented with calcrete. Although blasting does not appear to be necessary at the mine face, it would require a crushing facility at the treatment plant to process the mined material. Stripping is not necessary for this placer as the overlying yellow dune (aeolianite unit) is heavy mineral enriched and could be mined at the same time.

Table 5.7: A summary of the heavy mineral analyses done in the Schaapvlei area (Cole and Roberts, 1996).

Borehole	K11	K11	K11	K11	K11	S13	S13	S13	S13	S13	Ave
Depth	2.1	8.3	12.7	18	23.3	6.6	17.7	23	28.3	38.4	
Anatase	9.0	53.0	20.0	0.0	23.0	10.0	0.0	11.0	7.0	16.0	14.9
Rutile	14.0	9.0	11.0	22.0	0.0	19.0	22.0	14.0	21.0	16.0	14.8
Zircon	19.0	9.0	16.0	0.0	18.0	20.0	0.0	0.0	32.0	6.0	12.0
Ilmenite	18.0	9.0	0.0	0.0	0.0	40.0	5.0	39.0	39.0	46.0	19.6
Hematite	10.0	3.0	2.0	28.0	27.0	8.0	0.0	0.0	0.0	2.0	8.0
Goethite	0.0	7.0	3.0	0.0	0.0	0.0	34.0	0.0	0.0	0.0	4.4
Magnetite	0.0	6.0	0.0	0.0	0.0	0.0	0.0	21.0	0.0	0.0	2.7
Dravite	5.0	0.0	40.0	22.0	23.0	0.0	0.0	0.0	0.0	9.0	9.9
Pyrrhotite	19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
Cobaltite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	1.5
Quartz	6.0	4.0	8.0	28.0	9.0	3.0	39.0	0.0	1.0	5.0	10.3
Total %HM	2.32	2.23	2.31	2.10	2.79	3.71	3.19	3.29	2.89	2.95	2.78

Diamonds have been found in both alluvial and marine terraces, the most lucrative placers invariably being associated with a marine environment. The inter-dependence between marine and fluvial systems for placer formation cannot, however, be ignored and very often the largest concentrations of marine diamonds occur immediately north and south of diamondiferous river / palaeo-river mouths. Along the Namaqualand coast, several mines are in operation today that are associated with the Buffels, the Swartlintjies and the Olifants River Mouths.

The modern diamond reserves found offshore at Geelwal Karoo are derived from Cretaceous fluvial and deltaic gravels, which have been upgraded 4 to 20 times the value of the original grade by the addition of eroded, diamond-bearing ferricreted conglomerates (De Decker and Woodborne, 1996).

Knowledge of the diamond potential of the +50m package (on land) is limited to the fact that the odd diamond was found in the basal gravel lags. This is in keeping with the general thinking that diamonds are found close to bedrock, deposited in high energy environments and are often associated with the transportation of cobbles, boulders and pebbles (De Decker and Woodborne, 1996). In the marine environment and along the Namaqualand coast, most of the diamonds occur in the modern, inner offshore sediments, in basal gravel and shell lags whereas are seldom more than 5m thick. The inshore environment of the +50m package is therefore the target area for diamonds.

Micro-diamonds have been found in the foreshore environment of the +50m Package at Kleinzee. These diamond-bearing sediments are often storm-beachface deposits, whereas accumulate along the base of low cliffs that back wave-cut terraces. Large blocks of ferruginized conglomerates have been noted in the basal gravels of the +50m package at Geelwal Karoo and these are explained in terms of remnants of the +90m package. Reworking through erosion results in the occurrence of so called “jackpots” and these deposits are the result of polycyclic erosion processes, often being discontinuous and irregular in size and occurrence. The texture and composition of the diamondiferous deposits vary greatly but, in general, they consist of well rounded pebbles derived from a cratonic source region. Clasts include jasper, banded ironstone and agates, and the following minerals are considered to be indicators: garnets, ilmenite, zircon and rutile. According to Hallam (1964), along the West Coast heavy minerals are preferentially concentrated on the northern side of south-facing bays, on the south side of westerly projecting headlands and in north-facing log-spiral bays. At Geelwal Karoo, the Cliff Point area is an example of a north-facing, log-spiral bay and would therefore be a potential exploration site for diamonds. Within the Cliff Point Bay area, according to De Decker (1996), in the search for diamonds the best targets would lie at the seaward end of SSW trending gullies, potholes and bedrock depressions.

In conclusion, it must be said that although the heavy sand placer in the +50m package appears to be economically uninteresting, the prospect of finding diamonds beneath the heavy-mineral bearing sands should not be overlooked

5.4 +30m package

The +30m heavy sand placer is not preserved at Geelwal Karoo as this resource has been eroded and reworked into the present beachface. As an indication of the potential of the latter resource, it is interesting to note that the +20m strandline at Graauwduinen reported a heavy mineral concentration of 15.28% and that locally it was found to reach concentrations of 66.5%. The heavy mineral assemblage showed an even distribution between the stable (zircon, ilmenite, rutile) and unstable (pyroxene) minerals.

Historically, diamonds along the Namaqualand coast have been associated with the oyster line, and subsequently, this oyster line has been linked with outcrops of *Donax rogersi*. South of the Orange River, diamonds have been found in a series of well-defined marine terraces ranging in elevation from 90, 50, 30, 20, 9-0, -20, -30, -40, -60, -80 and –100m (Murray *et al*., 1970).

At Geelwal Karoo, because diamond and heavy sand placers are generically linked, very little potential is seen for finding diamonds in the outcrops of the +30m package sediments on land in the Duiwegat area.

5.5 Recent Unit

Macdonald (1996) discusses the modern day heavy sand placer and a resource of 10 Mt was calculated at 67% THM. A resource of approximately 7 million tons of ilmenite-bearing minerals was proposed for this modern day placer. It was concluded that the total resource for the Geelwal Karoo placers (both modern and fossil) is small when viewed on an international scale. Added to this was the fact that the titanium content of the ilmenite grains at Geelwal Karoo was not high enough to be of economic interest and the “by-product minerals” of rutile and zircons were not present in significant enough amounts to raise the placer’s potential.

Some economic potential was, however, seen in the fact that the modern day placer could be subjected to small-scale replenishment mining. A resource situated offshore and a point source of the +50m package palaeoplacer was proposed as a source for this modern day placer. The view held by this study, however, is that the latter point source plays less of a role in replenishing the modern placer than originally proposed.

The source of the modern beach-face placer is more likely the +30m package or even the older marine terraces found offshore. Most of the heavy mineral-bearing sands present in the +50m package at Geelwal Karoo have been, and still are being, transported inland by the predominantly SW winds.

The RAS unit has a heavy mineral concentration of 10.83% and is currently being mined at Graauwduinen for its heavy minerals. The THM of the red aeolian sand at Geelwal Karoo is in the order of 8.99%. Given the poor economic potential of the placer in the +50m package at Geelwal Karoo, however, it seems unlikely that the red aeolian unit will ever be mined for its heavy minerals.

Trans Hex sampled the heavy sands on the present beachface and the results showed little hope of turning these sediments into a resource in the near future (Macdonald, 1996).

6. Summary and conclusions

Fluvial, marine and terrestrial sedimentary environments are identified in the post-Gondwana exposures in the embankment at Geelwal Karoo. The fluvial unit is deposited in bedrock-incised channels and has a distinct white colour. It is characterized by an aggradational succession of poorly sorted angular gravel lags, which prograde upwards into a thick bank of white sand and clay. Quartz dominates the mineral assemblage and a maximum of 1% THM was recorded. Pedogenesis is most advanced in this unit, with extensive kaolinization and the formation of a silcrete capping. The unit is correlated with the channel clay formation at Kleinzee and incision occurred during the Cretaceous when numerous alluvial fan-type channels formed in response to a wet, humid climate. These channels drained the newly formed coastline following on the separation of Africa and South America and dates on the lignite suggest that they were active until the Neogene. Heavy minerals are found in the gravel lags of the channel clay unit and the highest concentrations (less then 2% THM) are associated with improved sorting. The diamond-bearing potential of the channel clay unit is linked to the basement rocks of the area as the nature of the channel clay sediment suggests a local provenance for this sedimentary environment.

Aside from the current dune system, two additional terrestrial or aeolian units were recognized at Geelwal Karoo. The oldest of these is referred to as the dorbank dune sands. This unit has a distinctive dark red colour and like the other aeolian units is composed of fine- to medium-grained sand. It is the thickest aeolian unit and is distinguished by numerous calcrete and red bed horizons. The dorbank unit has an average THM concentration of 8%. It has been equated with the Prospect Hill Formation and the age of the latter is estimated to be Middle Miocene (Pether, *et al.,* 2000). The second aeolian unit at Geelwal Karoo has a yellow colour and is found in direct contact with the backshore zone of the +50m package. Exposure of this unit is limited to the south and the contact with the dorbank is gradational. In the yellow dune belt, a tortoise fossil shell and fossilized burrows and roots were found. The yellow dune unit averaged a THM concentration of 11% and the diversity in the heavy mineral assemblage was very similar to the intertidal zone of the +50m marine package. This unit has been correlated with the early Pleistocene to modern Springfontyn Formation (Pether *et al.,* 2000).

Both terrestrial units comprise fine- to medium-grained sand that is well sorted with a single large saltation population (Visher, 1969). This study accepts the view that the wind direction along the West coast has not changed much from the Miocene to the present and the geological model for the units within the aeolianite is therefore the same. The dominant wind direction was SW with an occasional change to E in the winter months. The aeolian dunes developed as a series of transgressive dunes and their development was contemporaneous with the deposition of the marine packages. The heavy mineral resource of the aeolianite unit would add 127 000 tons of ilmenite-bearing minerals to the heavy mineral resource if the mining of the marine portion of the +50m package is considered to be a feasible option.

Aside from the current marine system, two other marine successions were found onshore at Geelwal Karoo and these have been correlated with the Late Miocene, early Pleistocene, +50m and +30m packages of Hondeklip Bay respectively (Pether, 1994). In both packages, three environments are preserved; an offshore, an inshore and a beachface environment. The +50m offshore at Geelwal Karoo is limited to the Torings area and unlike Hondeklip it consists of fine silty sand, which shows moderate sorting and lacks bedding. The mineral assemblage is dominated by quartz and the overall THM concentration averages 18%. The inshore environment is distinguished by gravel lags, which are intercalated with layers of fine sand. There is an overall fining upward trend in the clast size. The gravel lags can be classified as cobble/pebble lags and sorting is poor. The THM concentration averages 38% and this unit has the highest concentration of Ti-bearing minerals. The beachface environment is well represented and occurs over a distance of approximately 1.7 km. It is composed of medium- to fine-grained sand and is characterised by sporadic lags of the zone fossil, *Donax haughtoni*. The sand in the beachface environment is moderately to well sorted and although it is predominantly quartz-rich, in the Torings area there are high concentrations of heavy minerals (more than 15%) and averaging a THM concentration of 50%. The +35m strandline at Graauwduinen is equated with the +50m package and therefore given an age of 5.4 Ma. A resource of 156 thousand tons of ilmenite-bearing minerals was calculated for the intertidal zone of the +50m package at an overall grade of 44%THM.

The gravel layers in the inshore sediments of the +30m and +50m packages were originally introduced to the coast via the ancient Karoo River in the Late Cretaceous.

At the same time the latter fluvial system introduced a new population of diamonds to the coast, most of which were probably derived from primary kimberlitic sources which were subsequently reworked into the basal gravel lags of the Neogene +50m and +30m marine successions. In the middle Miocene the drainage pattern of the Karoo/Olifants was altered and the sediment load became composed chiefly of sand. It therefore follows that the basal gravel lags in the +50m and +30m at Geelwal Karoo are the product of reworked older marine terraces that became progressively diluted through time with sand.

The marine sediments of the +50m and +30m packages are the product of transgressive shorelines. Each package downlaps along the coastal bedrock gradient and although there is little evidence for it on land, there were two regressive cycles (with little erosion) one after the +50m transgression (Early Pliocene) and another after the +30m transgression (Late Pliocene). At Geelwal Karoo, it was the combination of a marine stillstand at about +30m a.s.l. and the J-Bay formed from the Table Mountain Group at Cliff Point that produced the +50m heavy sand palaeoplacer. The J-Bay continued having an effect on the marine sediments in the area that resulted in at least two superimposed heavy sand placer deposits. During the sea level regressions the +50m and +30m packages were exposed to groundwater action. The latter not only led to extensive decalcification of the foreshore succession but also played a role in the large-scale cementation of these sediments. This cementation, the continued regression of the sea and the abundant supply of aeolian sand (linked to the continued aridification of the West Coast) helped to preserve the +50m package in the embankment at Geelwal Karoo.

The +30m package at Geelwal Karoo has been subjected to extensive erosion, particularly in the area north of “Torings” (basement high). The offshore environment is recognised by a distinctive greenish-black colour and consists of layers of fine, clayey or silty sand with occasional grit lenses. The sediments are well cemented with calcrete and the laminations are the result of darker organic horizons intercalated with layers of fine sand. This unit can be distinguished by its high concentrations of glauconite. The overall THM concentration of the offshore zone is very low and averages 0.5%. The inshore environment consists of numerous pebble-sized lags and remnants of re-worked older strandlines are common. These remnants can be identified by their steeply dipping bedding or by the fact that they are cemented with phosphorite or ferricrete. The THM concentration of the +30m inshore averages 2.5%. Most of the +30m beachface environment is buried beneath the Recent dune cover and therefore could not be studied in any detail.

The Recent unit comprises the sand of the present beachface and the current dune system. They form the third marine and aeolian units found at Geelwal Karoo. The Recent aeolian sand is ubiquitous, whereas the Recent marine unit is limited to the current beachface. Relatively high concentrations of mud, *Trigonephris* shells, Late Stone Age middens and the lack of any calcrete or red bed horizons are characteristic, which distinguish it from the Recent aeolian unit. The average THM concentration of the recent aeolian sand is 10%, while Macdonald (1996) determined the average THM of the Recent beachface to be 67%. The Recent aeolian unit is correlated with the Recent Witzand Formation.

Even though the economic future of the Cenozoic sediments at Geelwal Karoo appears to hold no promise for either heavy sand or diamond placers, it must be borne in mind that there are few data available on the buried parts of this resource. Much can be said for embarking on a drilling, or even a sampling programme, particularly in the Cliff Point area of Geelwal Karoo. For the time being, however, Geelwal Karoo will continue to provide all those involved in West Coast sedimentology with an ideal onshore reference point to study the changes in the depositional history of the West Coast over the last 65 Ma.

THIS STUDY	1. GRAAUDUINEN	2. SCHAAPVLEI	3. HONDEKLIP	4. GEELWAL KAROO	5. WEST COAST	6. VANRHYNSDORP AREA
Channel clay unit	Basal quartz arenite (BQA)	Channel clay	Channel clay formation		Fluvial palaeochannels	Fluvial terraces
Dorbank unit	Quartsitic aeolian sand (QAS)	Springbokfontyn Formation	Terrestrial 1		Prospect Hill Formation	Calcareous and gypsiferous soils
+50m package unit	35m strandline	+50m package	50m package	35m palaeostrandline	50m package	27m marine terrace
Yellow dune unit	Feldspathic aeolian sand (FAS)	Springbokfontyn Formation	Terrestrial 2		Springbokfontyn Formation	White to pale-red sandy soils
+30m package unit	20m strandline		30m package		30m package	18m marine terrace
Recent marine unit	Recent emergence terraces (RET)		2-3m package	Geelwal Karoo heavy mineral placer		
Recent aeolian unit	Red aeolian sand (RAS)	Witzand formation	Recent aeolian sand		Witzand formation	Red aeolian sand

Table 6.1 A summary of the various stratigraphic correlations of the Cenozoic geology in the vicinity of Geelwal Karoo.

1. Cilliers (1996), 2.Cole & Roberts (1996), 3. Pether (1996), 4. Macdonald *et al.* (1997) 5. Partridge & Maud, (2000),
6. De Beer *et al.* (2002).

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ADDENDUM 1: FIELD WORK

Mapping method

Mapping was done with the aid of a measuring tape and spirit level. Breaks in the mapping of a profile were registered either at erosional or lithological contacts or at about 15m (the maximum extent of the measuring tape). At each mapping break, the dip of the sedimentary succession was measured with a spirit level and recorded for later use in the calculation of the vertical thickness of the succession.

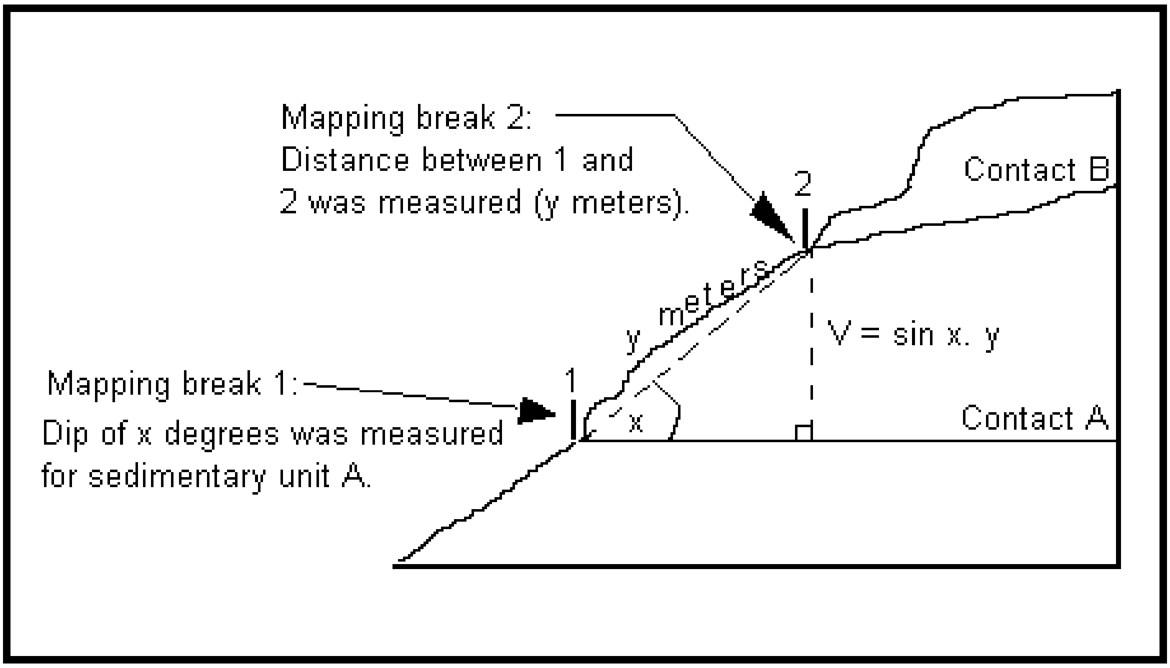


Figure 1.1: The mapping method and calculation of "V" the vertical thickness. The **vertical thickness (V) = sin S. W,** where S is the slope angle of the unit and W is the slope distance measured with the tape measure. If more than one slope was measured for one sedimentary unit, then an average reading was determined.

The theoretical maximum and minimum elevations for each profile site was determined from an orthophotograph of the area. The erosional bottom contact of the basal marine gravel (BMG) occurs throughout the study area and it was decided to use the elevation of this contact as a standard reference point for all the profiles. After plotting the maximum and minimum elevations as well as the elevation of the base of the BMG unit for each profile a trend was seen. The BMG unit or upper shoreface facies of the +30m and +50m packages could be distinguished. Some of the profiles, showed deviation from the overall trend in the elevation and for this reason, corrections were made to their initial elevations. A summary of these calculations can be found in Tables 1.1 and 1.2.

Table 1.1. Basal marine gravel (BMG) unit elevations for the +30m package.

Profile no	10	9	11	1	17	3	4A	4B	4C	8	12			
Profile Max	30	40	20	30	30	30	60	80	50	75	65			
Profile Min	5	5	10	7	6	10	8	8	8	8	5	**Ave**	(+)5m	(-)5m
Bottom BMG	17.49	20.84	16.1	26.25	19.25	25.41	25.72	26.6	26.28	28.01	27.77	**23.611**	28.611	18.611
Top BMG	19.18	21.2	16.15	29.4	20.55	26.71	31.11	28.07	30.8	30.31	27.81	**25.572**	30.572	20.572
Thick BMG	1.69	0.36	0.05	3.15	1.3	1.3	5.39	1.47	4.52	2.3	0.04	**1.9609**		
correct on bmg elev	0	0	0	(-)0.59	0	(-)0.7	(-)3.1	0	(-)2.1	0	(+)1.62			

Table 1.2. Basal marine gravel (BMG) unit elevations for the +50m package.

Profile no	7	5	13	6B	6	14	2	15	16			
Profile Max	60	60	80	73.72	70	75	75	55	70			
Profile Min	10	6	5	2	10	10	7	10	5	**Ave**	(+)5m	(-)5m
Bottom BMG	34.45	31.63	31.25	31.55	31.13	31.52	31.21	31.78	37.7	**32.469**	37.469	27.469
Top BMG	35.6	34.32	38.99	38.05	36.81	36.64	36.11	33.17	37.8	**36.388**	41.388	31.388
Thick BMG	1.15	2.69	7.74	6.5	5.68	5.12	4.9	1.39	0.1	**3.9189**		
correct on bmg elev	0	0	0	0	(+)3.44	0	(-)9.92	(-)1.7	(-)1.03			

Once corrected and calibrated, a summary of the all the mapping data of Geelwal Karoo could be made and the results are presented in Table 1.3. The following codes were used in the table, Th = thickness, RB = Recent marine, B = basement, CC = channel clay, 30m = +30m package, 50m = +50m package, AY = yellow aeolian, AD = dorbank aeolian and AR = Recent aeolian. The shoreface environment includes both the wave and surf zones and likewise the beach environment includes both the foreshore and backshore zones.

In order to substantiate the field observations, a detailed table was made of the channel clay mapping data.

Table 1.3. A summary of all the stratigraphic units and their elevations in metres a.s.l.

Facies	Unit	Bot elev	Top elev	Th (ave)
Beach	RB	0.0	11.3	10.1
Basement	B	9.1	20.9	11.8
Fluvial	CC	17.2	27.7	10.5
Shelf	30m	23.6	25.8	2.3
Shelf	50m	21.8	27.6	5.8
Subtidal	30m	25.6	28.2	2.6
Subtidal	50m	31.4	38.0	6.5
Beach	30m	29.3	35.8	6.5
Beach	50m	38.4	47.4	9.0
Dune	AY	45.8	53.4	7.6
Dune	AD	43.1	59.4	16.3
Dune	AR	50.3	54.6	4.3
		AVERAGE		

Table 1.4. A summary of the mapping data of the channel clay unit to show the distinction of the two subunits.

Description	Comments	Thick	Elev	Profile	Class
Quartz Pebble 1	Granule layers, matrix supported. Larger pebbles, top with yellow "rust".	0.36	9.18	13	BASAL COARSE SUBUNIT
Quartz pebble 1	Pebble lenses in coarse sand.	3.18	11.18	2	
White clay	Fine white sand with yellow, horizontal X-lamenations.	0.21	15.06	1	
Debris	Pebbles and clay, accumulate particularly in erosion channels.	1.60	16.22	4b	
Quartz Pebble Layers	Angular quartz pebbles. Dip 5 (down to south).	6.50	16.23	14	
Quartz pebble 1	Poorly sorted, sub-angular, matrix supported.	0.27	16.52	17	
Sand unit 1	Scattered pebbles and granules.	0.24	16.76	17	
Clay unit 1	Patches of clay blocks, more obvious towards top.	7.65	16.83	13	
Quartz pebble 2		0.26	17.02	17	
Quartz pebble 1	Well sorted, matrix-supported, pebbles and granules.	5.87	17.06	2	
Sand unit 2	Scattered pebbles and granules.	0.35	17.37	17	
Clay lense 1		0.09	17.46	17	
Quartz pebble		2.51	17.57	1	
Debris		1.41	17.63	4b	
Quartz pebble 3		0.36	17.82	17	
Clay		4.24	18.88	4a	
Quartz Pebble Layers		2.86	19.09	14	
Quartz Pebble Layer	Larger, angular quartz pebbles.	2.67	19.51	15	
Clay		0.86	19.73	4a	UPPER FINE SUBUNIT
Sand unit 3		2.08	19.90	17	
Debris		2.56	20.19	4b	
Clay	Photo taken of distinct blocks.	0.63	20.36	4a	
Clay lense 2		0.79	20.69	17	
Sand unit 1		3.68	20.74	2	
Sand unit 4	With granule lenses.	0.69	21.38	17	
Clay	Portion of dipping, pay-dirt layer was found ontop of clay outcrop.	1.41	21.60	4b	
Clay lense 3	Silicification increases towards the top.	0.59	21.97	17	
Quartz Pebble Layer	Finer, angular quartz pebbles.	2.67	22.18	15	
White clay	Quartz layer dips 20 (down to north - probably due to slumping.)	1.82	22.78	3	
Clay	Clay is white with gravel lenses.	6.96	23.02	6	
Debris		1.62	23.22	4b	
Debris	White sand and pebbles.	0.54	23.55	6	
Clay	Clay is white with gravel lenses.	5.76	23.74	6b	
Fine sand	Quartz pebble layers stop. Fine sand and clay blocks, silcrete layers.	4.73	23.82	14	
Debris	First pebble layer at 3.40	3.53	23.90	4a	
Debris		0.81	24.03	4b	
Debris	Clay, sand and pebbles.	0.74	24.29	6	
Quartz pebble 2	Granule lenses. Well sorted. Yellow laminations.	4.09	24.83	2	
Sand unit 5	2 Pebble lenses, silicified. X-bedding shows N flowing stream.	3.15	25.13	17	
White clay		2.64	25.41	3	
White sand	More fine,white sand than clay, becomes very steep in the last 0.5m.	3.46	25.53	11	
Debris	Oysters more abundant at top	1.83	25.72	4a	
Debris	White sand and pebbles.	2.67	26.41	6b	
Fine sand	Clay blocks lying in a layer.	4.24	26.41	15	
Sand unit 1	Coarse sand with few granule lenses. Dips 23 (down to north).	10.61	27.44	13	
Debris	Clay, sand and pebbles.	2.68	29.09	6b	
Fine sand and clay	Fine sand is silcretised.	3.32	29.74	15	
Quartz Pebble 1	Clast supported, poorly sorted. Biggest clasts here. Clay lenses, folded.	2.00	30.01	7	
Sand unit 1	Coarse gray sand with granule lenses.Yellow, horizontal cross-laminations.	0.45	30.46	7	
Clay	Clay becomes stained red and is covered by large silcreet blocks.	6.84	31.13	6	
Clay unit 1		6.38	31.21	2	
Clay unit 2	Clay in blocks.	3.82	31.25	13	
Quartz Pebble 2	Clast supported, also with yellow laminae.	0.80	31.26	7	
Clay	Clay becomes stained red and is covered by large silcreet blocks.	2.46	31.55	6b	
Sand unit 2	Very fine white sand with (mm) horizontal cross-laminations.Not silicified.	0.30	31.56	7	
Clay	White clay, appears to be cemented in places.	0.15	31.63	5	
Fine sand and clay	Silcretised sand, forms outcrop for top 2m.	2.04	31.78	15	

ADDENDUM 2: SAMPLING AND SAMPLE DESCRIPTIONS

The following figure represents an ideal mapping situation and sometimes the sampling was hampered by calcrete and silcrete cementation.

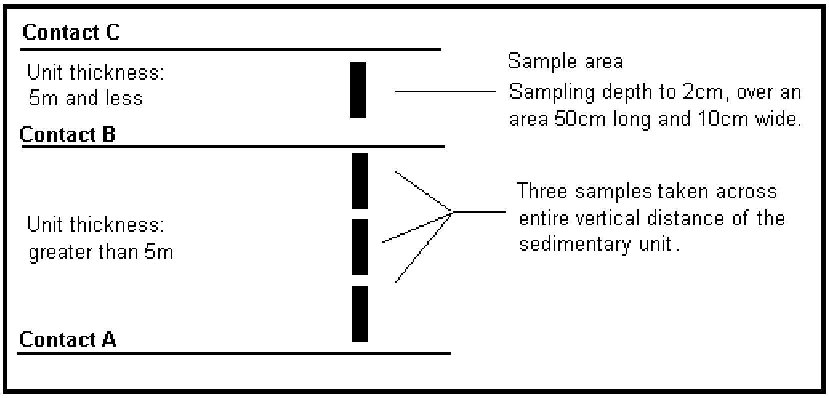


Figure 2.1: The sampling technique applied in this study.

Samples were colour coded in the field by comparison with the Munsell rock colour chart.

Table 2.1: The colour codes for the samples at Geelwal Karoo

CODE	COLOUR
(N9)	White
(5 Y 5/6)	Light olive brown
(5 Y 5/2)	Light olive gray
(5 Y 6/4)	Pale olive
(5 Y 7/2)	Yellowish gray
(10 Y 6/2)	Pale yellow
(5 YR 8/1)	Pinkish gray
(5 YR 5/6)	Light brown
(10 YR 8/2)	Very pale orange
(10 YR 8/6)	Pale yellowish orange
(10 YR 7/4)	Grayish orange
(10 YR 6/2)	Pale yellowish brown
(10 YR 6/6)	Dark yellowish orange
(10 YR 6/4)	Light yellowish brown
(10 YR 5/4)	Moderate yellowish brown
(10 YR 4/2)	Dark yellowish brown
(10 YR 2/2)	Dusky yellowish brown
(10 R 4/6)	Moderate reddish brown

The sieving data helped to classify the samples according to the average grain diameter and this was done with the help of the following table.

Table 2.2: Classifying sediments according to particle size. Attached is the Udden - Wentworth grain size scale.

Udden-Wentworth (1922)		phi	mm	Friedman & Sanders (1978)	
				V. large	Boulder
		-11	2048	Large	
Cobbles		-10	1024	Medium	
		-9	512	Small	
		-8	256	Large	Cobbles
		-7	128	Small	
		-6	64	V. coarse	Pebbles
Pebbles		-5	32	Coarse	
		-4	16	Medium	
		-3	8	Fine	
		-2	4	V.fine	
	Granules	-1	2	V.coarse	Sand
Sand	V.coarse	0	1	Coarse	
	Coarse	1	microns 500	Medium	
	Medium	2	250	Fine	
	Fine	3	125	V.fine	
	V.fine	4	62	V.coarse	Silt
		5	31	Coarse	
		6	16	Medium	
		7	8	Fine	
		8	4	V.fine	
Clay		9	2	Clay	

Samples were classified in terms of silt and clay contents and the following ternary diagram was used to do this.

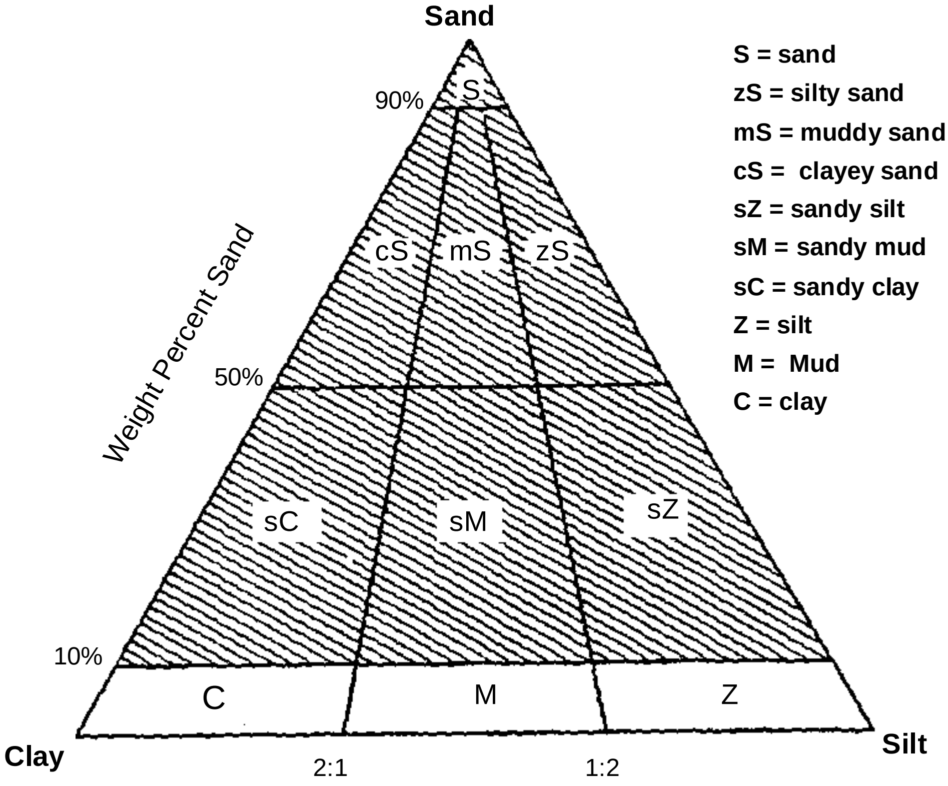


Figure 2.2: A ternary diagram, depicting a classification scheme for mud-bearing sediments. (Lewis, 1984)

Quartz was used to determine the degree of rounding and the sphericity within the sample. This was done by comparison with the following figure.

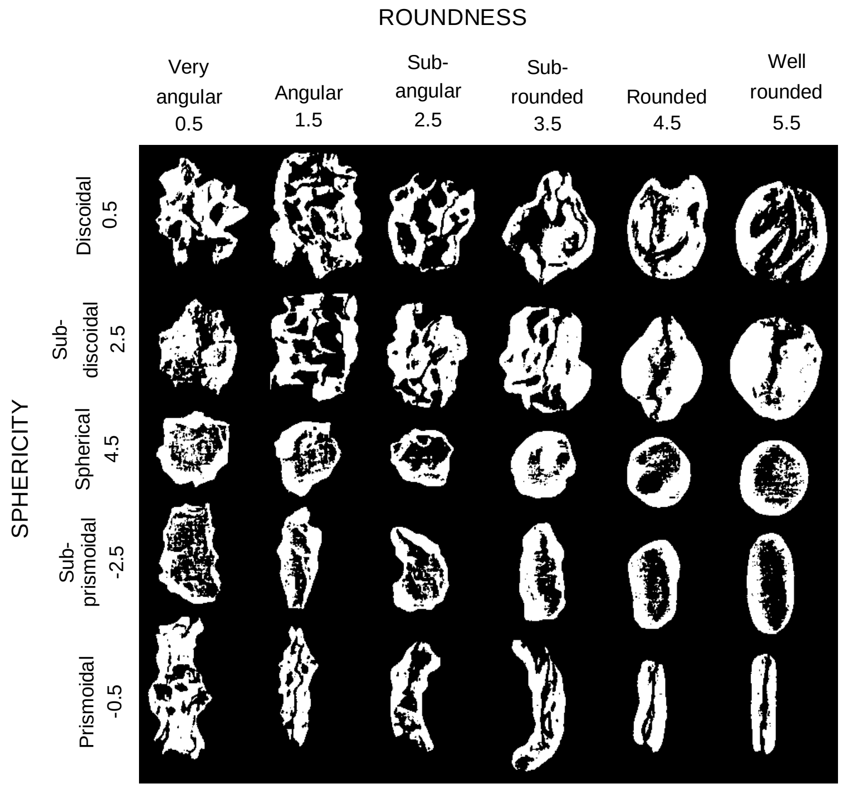


Figure 2.3: A chart for estimating the degree of rounding and sphericity. (Tucker, 1988)

In the binocular microscope study of the samples, the mineral's shape was found, particularly in the more erosion resistant varieties, to be a very good way of identifying it. For this reason, the following figures were compiled to aid in mineral identification.

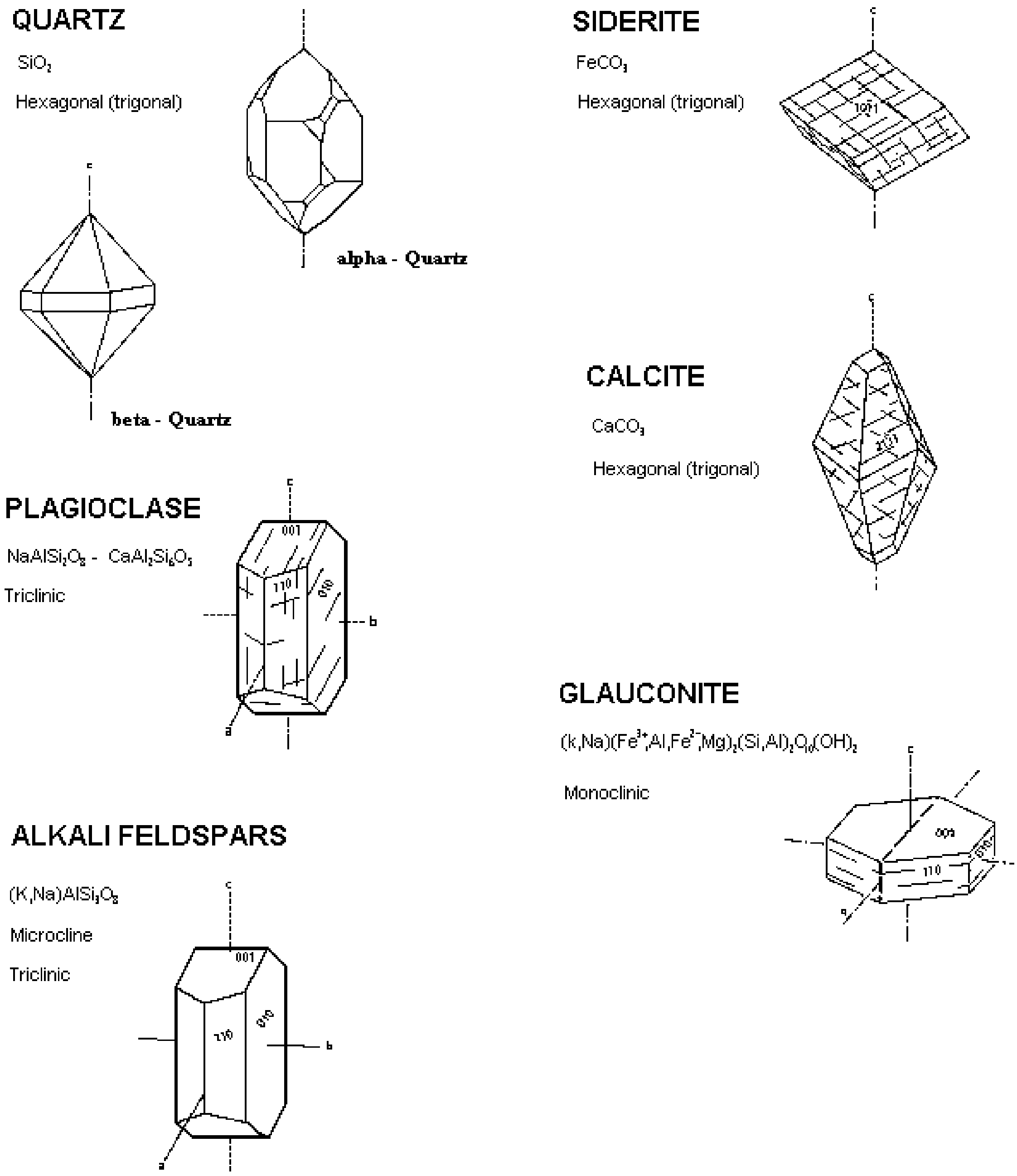


Figure 2.4: Selected minerals with specific density less than 2.8
(SG Bromoform = 2.8) (Nesse, 1986)

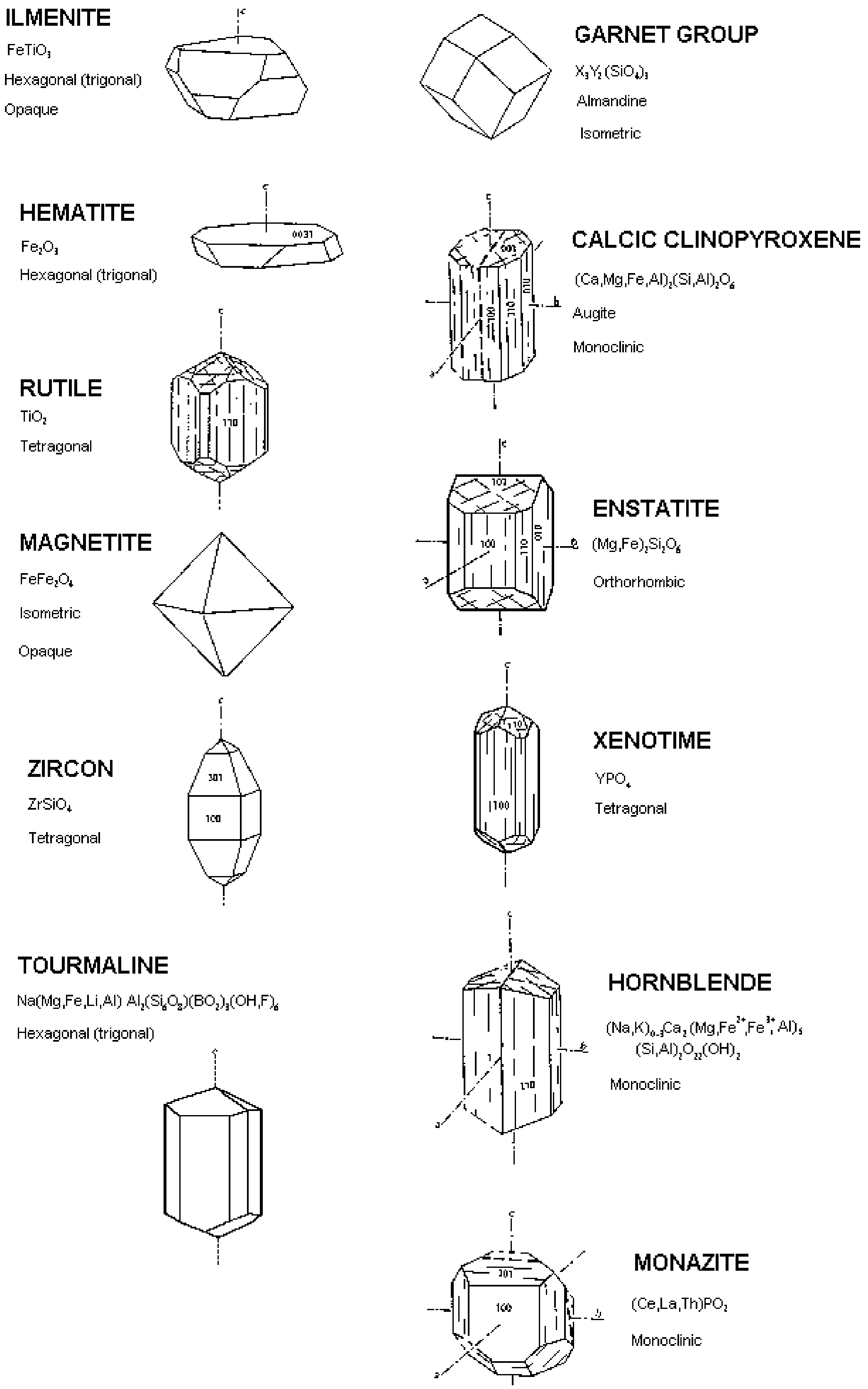


Figure 2.5: Selected minerals with specific density greater than 2.8.
(SG Bromoform = 2.8) (Nesse, 1986)

The following minerals and mineral groups were identified with binocular microscope in the Geelwal Karoo samples and coded as follows: quartz (qz), rock fragments (rock), feldspars (felds), halite(ha), carbonate-bearing minerals (carb), iron and titanium oxides(ore), pyroxenes and amphiboles (pyx), garnets (ga), zircons (zr), muscovite, kyanite (ky) and non-descript weathered grains (alt) and glauconite (glau). The relative abundance of each mineral group was then estimated by comparison with the following figure.

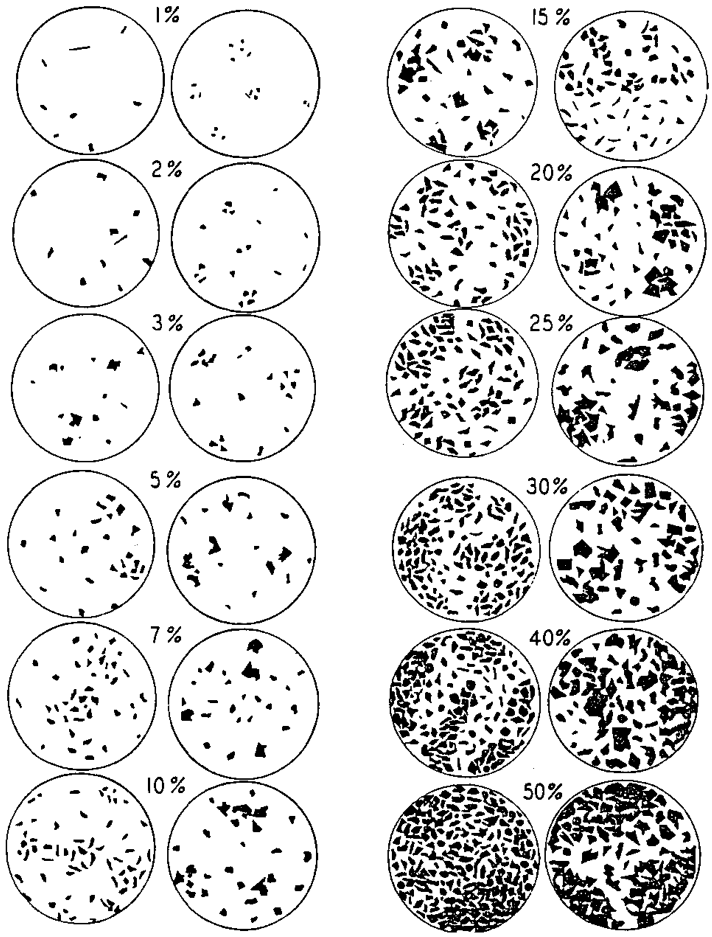


Figure 2.6. A method for determining the relative percentage concentration of mineral species or group of minerals.
(Tucker, 1988)

Using these data, the samples were then further classified according to the following scheme:

>90% quartz	(qz,qz,qz)
65 - 89% quartz	(qz,qz, *)
50 - 64% quartz	(qz,*,*)
<49% quartz	(*,*,*)

The * indicates that the position of the next most abundant mineral or mineral group.

ADDENDUM 3: GRAIN SIZE ANALYSIS

3.1. Sample preparation

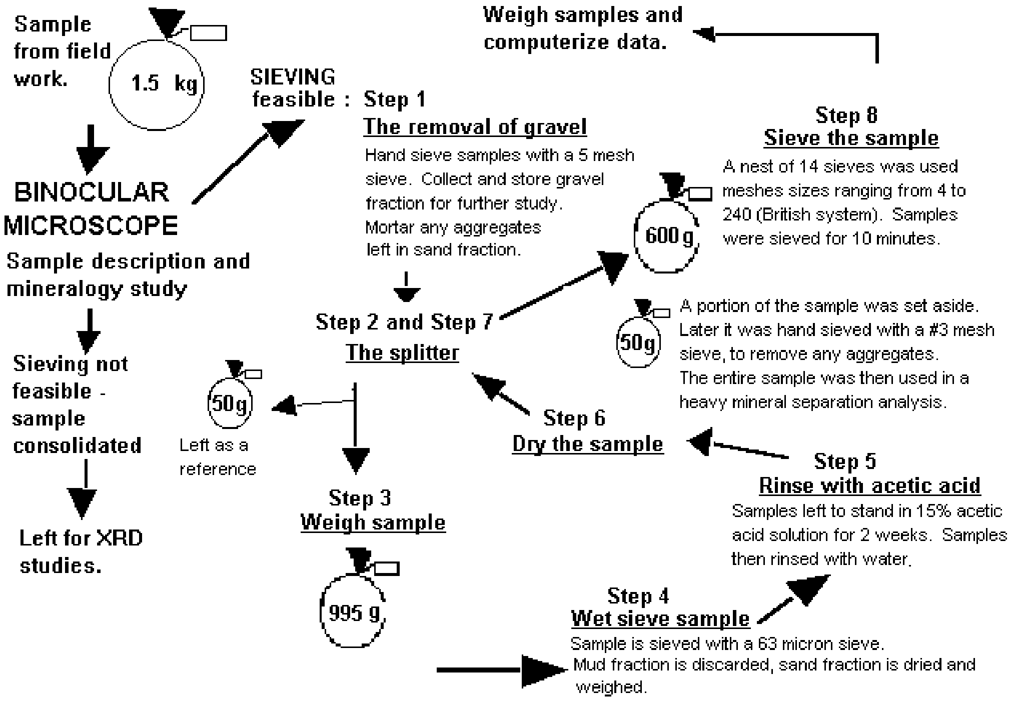


Figure 3.1: A summary of the sample preparation.

3.2. Sieving

A total of 13 sieves was used (2 nests) and, including the pan residue at the base of the last nest, produced 14 sieve fractions of a half phi interval each. The sieve nests were placed on a mechanical shaker, which took 15 minutes to sieve each nest. The following conversions were necessary.

Mesh number to micrometers

Those sieves that represented the most comprehensive range and could be fitted into one another were made in either South Africa (Protea test sieves) or in England for a South African Company; Taeuber & Corssen (Pty.) Ltd. The latter was made to the specifications of Endecotts (Test sieves) Limited, and these are in accordance with a U.S. standard sieve series. It was thus decided to use the U.S.A. (ASTM) specification E-11-70, as a reference for correlating the mesh number given on the sieve with the grain diameter in mm.

Micrometers to millimeters

63 micrometers is equivalent to 0.063 mm, i.e. 0.000063 micrometers = 0.063 mm.

Millimeters to phi units

The Udden and Wentworth scale for sediment classification by particle size requires the use of a geometric scale in phi units (Addendum 2). This scale is widely used and for the purposes of comparison, was used in this study.

Statistically, the scale was designed to ensure that the same amount of emphasis is placed on small variations within the fine fraction as there is on the larger differences in the coarser particles. The value of **phi (ø)** is calculated by $\mathbf{\log_2 d / d_0}$, where d_0 is the diameter of a 1 mm grain.

Because counting individual grains is impractical, various statistical formulas are used in sedimentology to describe the distribution (frequency) of grain sizes within a sample, Tucker (1988). These formulas have been modified from those used in conventional statistics, and deal with weight percentages rather than percentages, Tucker (1988). The statistical formulae are, however, based on the assumption that there is no significant difference in grain densities within the samples, and consequently, comparison between quartz-, heavy mineral-, glauconite- or shell/rock fragments - rich sands should be avoided.

In the tables of grain size analysis data in the Appendix 2 there is a row headed with the title of "%?wt". The values given in this row represent the difference between the initial weight of the sample and the total weight of the sample calculated after a grain size analysis. The high mud concentrations of the samples is largely responsible for this portion of so-called “missing” weight and is seldom less than 5%. For this reason the graphical method, as described by Tucker (1988), was preferred over the moment method for calculating the statistical values such as the mean, sorting, skewness and kurtosis, as it is designed for open ended grain size distributions. For the actual statistical calculations, the percentage of mud was ignored (seen as a post-depositional feature) and, only the weight of each sieve fraction was typed into the computer.

The Graphical Method

In graphical statistics, the values for the established formulae are derived directly from plotted cumulative curves (Tucker, 1988). This method has the advantage of illustrating the sample's characteristics in the form of histograms and curves, and thereby, making comparisons easier.

The simplest method to present grain size data graphically is by means of a frequency histogram where grain size, in phi units ranging from the coarsest (far left) to the finest, is given on the x axis, Tucker (1988). The y axis represents the weight percentage of each sieve fraction and the frequency histograms of the Geelwal Karoo samples are illustrated in the appendix, section I2.

Histograms or bar graphs are converted into frequency curves by joining the midpoint of each grain size column and, so doing, forming a line graph, Tucker (1988). The following statistical terms can be calculated from these graphs and their definitions are quoted from Tucker (1988);

1) The highest point on the frequency curve provides the **modal value** of the sample. 2) The **modal size** of a sample is the commonest grain size in a distribution. 3) The **median** (Md) is half way between the furthermost extent of the coarse fraction and the furthermost extent of the finer grains. Represented graphically by the phi value at 50 % weight percentage. 4) The **mean** (M) of a sample is the average grain size. The mean can also be calculated from a cumulative frequency curve by using the following formula:

$$M = (ø_{16} + ø_{50} + ø_{84})/3$$

The graphs of most use, statistically, are the cumulative frequency curves (Tucker, 1988). The x axis remains a representation of grain size in phi units while the y axis shows the cumulative frequency by weight of the sample and should reach a maximum of 100. Cumulative frequency curves form the basis for Visher diagrams which will be discussed later in this section.

By describing the spread of grains sizes about the average, the degree of sorting within the sample can be determined (Tucker, 1988). **Sorting** is calculated by the following formula:

$$ó = 1/2\ [(ø_{84} - ø_{16})/2 + (ø_{95} - ø_{5})/3.3]$$

and where the various ø values are calculated from the cumulative frequency curve plotted for a particular sample. For example $ø_{84}$, is the phi value at a weight percent of 84 on the cumulative frequency curve.

In a normal bell-shaped frequency curve, the median and mean values coincide, Tucker (1988). Should the curve deviate from a normal distribution the mean and median values differ. The differences in these values are used to calculate the **skewness** of a sample with the following equation:

$$S_K = [(ø_{16} + ø_{84} - 2\ ø_{50})/2(ø_{84} - ø_{16})] + [(ø_{5} + ø_{95} - 2\ ø_{50})/2(ø_{95} - ø_{5})]$$

The value of skewness can be both positive and negative and lies between -1 and 1.

The **kurtosis** of a sample is related both to the dispersion and the normality of a distribution, Tucker (1988). It is calculated in the following manner:

$$K_G = (ø_{95} - ø_{5})/2.44\ (ø_{75} - ø_{25})$$

To save time, the phi values for each weight percentages given in these formulae was calculated using a computer program. The program was written in q-basic by Carlo Philander and is based on the work done by Friedman and Sanders (1978).

3.3. Visher Diagrams

Based on the observation that a change in the mechanism of sediment transport affects the sorting of a sediment, Visher (1969) devised a mathematical means of determining the origin of sediments.

A)

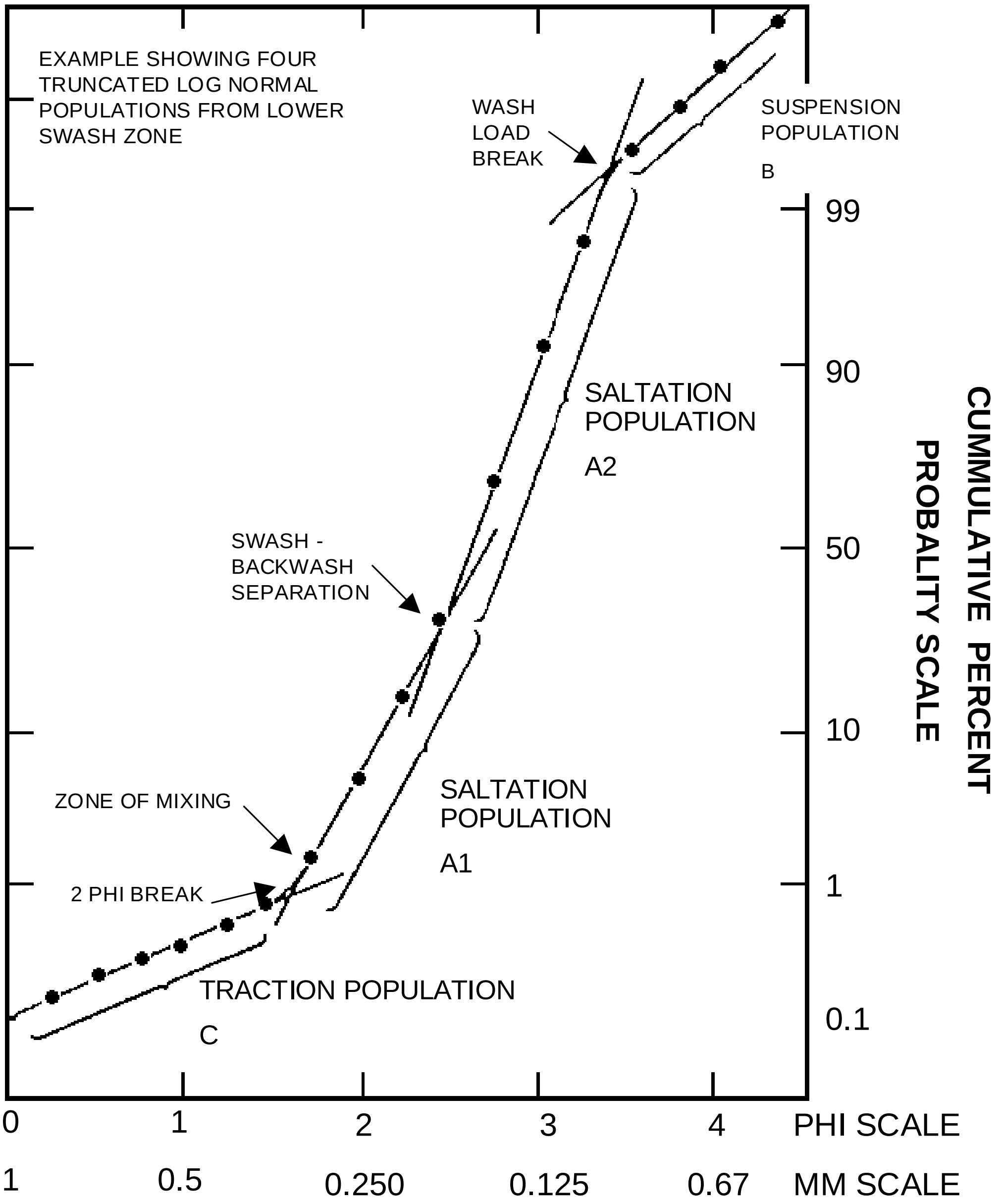


Figure 3.2: Examples of Visher diagrams. (**A**) A Visher diagram of a sieved, foreshore sample.

B)

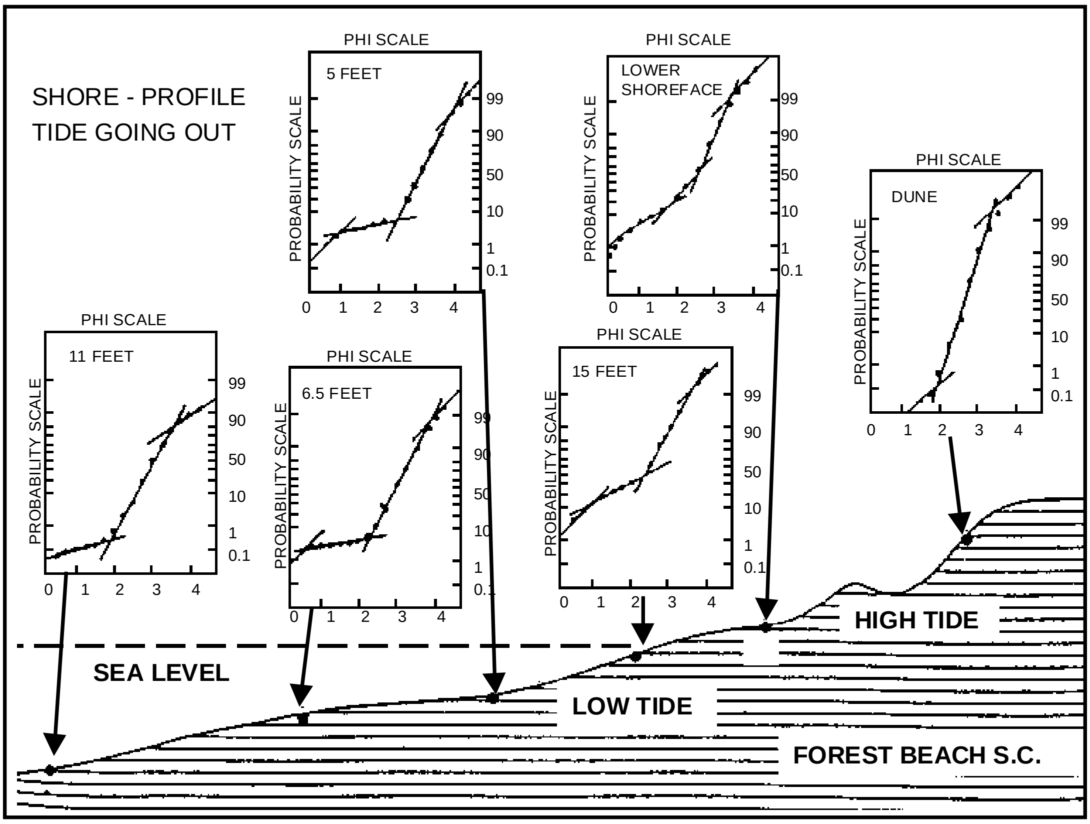


Figure 3.2: Examples of Visher diagrams. (**B**) A number of Visher diagrams showing the variations in grain size distributions along a beach profile.

A Visher diagram is produced by changing the scale of the y-axis of a cumulative frequency curve, to that of a probability scale and then joining the points on the graph with regression lines. A size-frequency distribution of nearly all sediments is a mixture of 3 textures; 1) gravel which, typically, has a median of -3.5 to -2 phi units, 2) sand, characterized by a median of between 1.5 and 4 phi units and, 3) clay, which is composed of the particles finer than 4 phi units, (Schopf, 1980). Further, it must be said that, sediment moved by sliding or rolling is termed the “traction load” and, is generally, applicable to particles of between 0 and 2 phi units. Material which is intermittently suspended is termed the saltation load and includes the particles between 2 and 3.5 phi units, while the continuos suspension load is present in particles finer than 3.5 phi.

Additional to this, it must be said, that the agents of sediment transportation chiefly alter the size-frequency distribution of sediments in the finer or coarser ends and, thus, affect the nature of the “tails” of a distribution. Because of the fact that ancient sediments, in general, possess more finer material than modern sediments (this is due to diagenesis) more emphasis should be placed on the effects of the coarser end of the distribution than the fines when comparing Visher diagrams of different samples (Schopf, 1980).

The number of populations, the slope of the regression lines and the position of the graph in relation to the y-axis of the Visher diagrams can help make deductions regarding the sorting of the sample, the mode of particle transportation, and the sedimentary environment in which the sample was deposited, Visher (1969). Visher diagrams were made of the Geelwal Karoo sand samples (Appendix 2) and these were then compared with the following references.

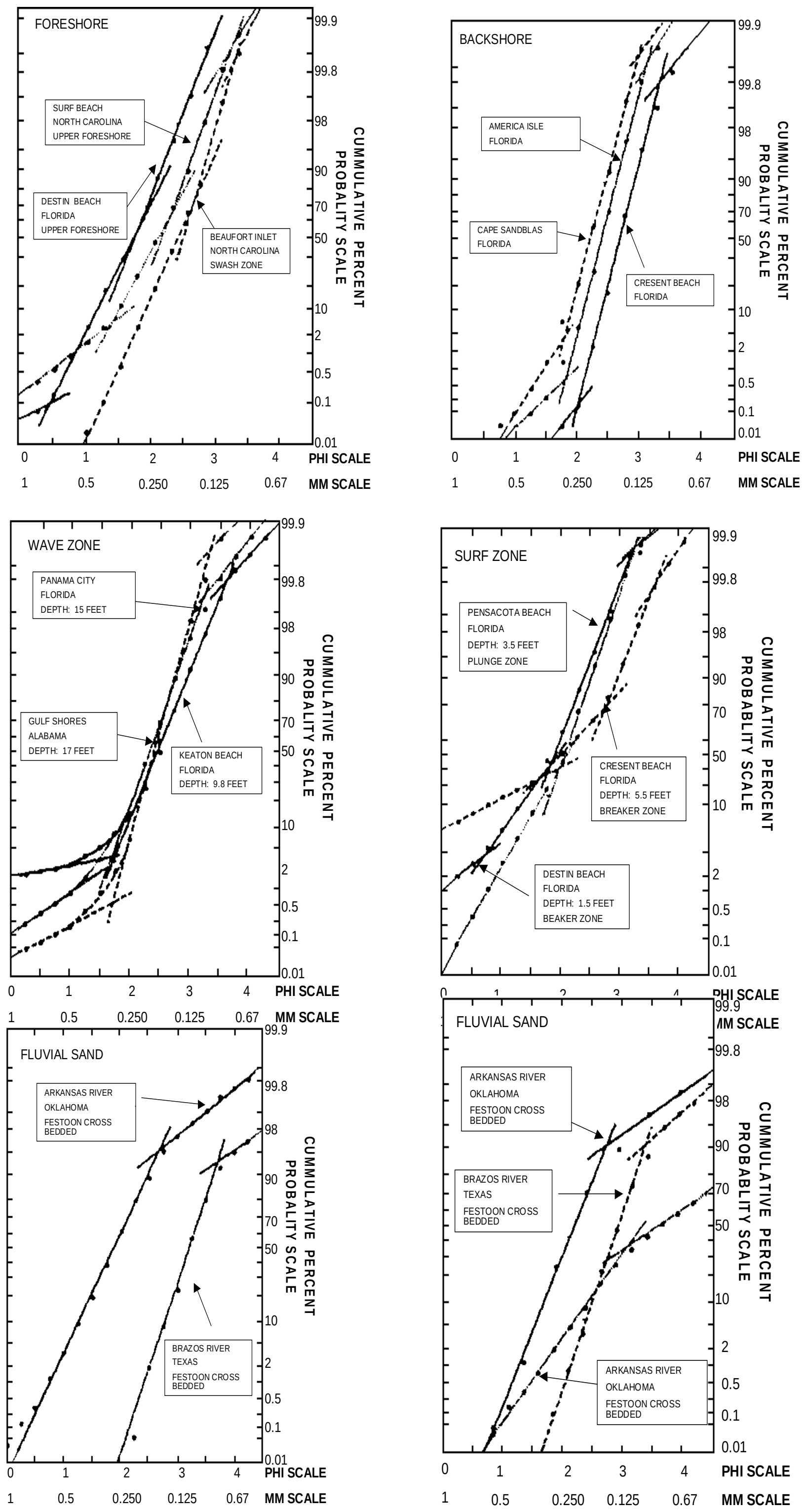


Figure 3.3: Reference diagrams for interpretation of Visher diagrams. (Visher, 1969)

The following points were borne in mind when interpreting the Visher diagrams of Geelwal:

- Observation made in the field regarding the depositional environment were kept close at hand and consulted before the evidence provided by a Visher diagram could be validated.
- Although plots of up to -5.5 phi could have been made, only the portion of the graph between 0 and 4.5 phi could be used for comparisons.
- When making comparisons, particular attention was given to the following:
    - the position of both the coarse and fine truncation points, did the regression lines cross above or below line.
    - the regression line's intersection with the y-axis was noted.
    - the number and slope of the various populations were noted and compared.

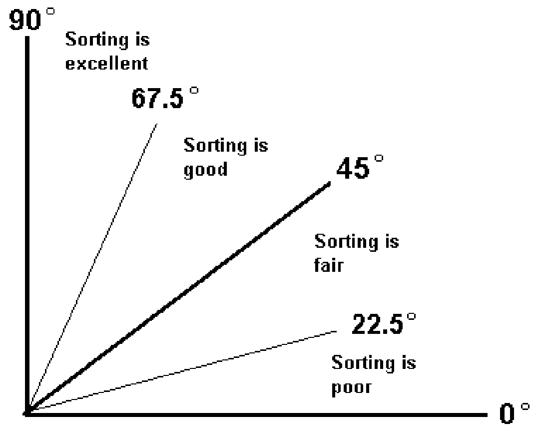


Figure 3.4: The sorting determined by the slope in Visher diagrams

- The concentrations of mud and gravel fractions measured during sieving (see Tmud and Tpeb, in Appendix, Section I2) were consulted when studying their effects on the truncation points of the Visher diagrams.
- The y-axis co-ordinates of the coarse truncation (C.T.) and the fine truncation (F.T.) were also noted.

In conclusion, the Geelwal Visher plots never matched the reference Visher diagrams, and, more often than not, the Visher diagrams were incomplete or proved inconclusive plots. The results of these comparisons can be found in the tables in the Appendix 2 under the heading of "**VishC**". "R" stands for river sample, "l" for lagoon and "c.s." for continental shelf. These comparisons did not work well for samples with abnormally high heavy mineral concentrations and the most convincing results were obtained on the fluvial samples of Geelwal which average a THM of 1 %. Arranging samples in increasing elevation, in most cases, helped to isolate trends in sedimentary facies and also made identifying unknown samples easier as these could always be related to the known samples on either side.

ADDENDUM 4: HEAVY MINERAL SEPARATION

The principle of heavy mineral separation is that when sediment is immersed in (tribromomethane) bromoform, certain minerals will sink while others will tend to float on the surface depending on whether or not their densities are above or below 2.8 (density of bromoform).

Table 4.1 Specific density of selected minerals.

Mineral	Density
Glauconite	2.3
Microcline	2.54-2.57
Orthoclase	2.57
Anorthoclase	2.58-2.68
Albite	2.62
Plagioclase	2.62-2.76
Quartz, Chert, Oligoclase	2.65
Andesine	2.69
Labradorite	2.71
Calcite	2.72
Bytownite	2.74
Anorthite	2.76
BROMOFORM	**2.8**
Muscovite	2.76-3.1
Biotite	2.8-3.2
Anthophyllite	2.85-3.2
Amphibole	2.85-3.45
Aragonite	2.95
Tourmaline	3.0-3.25
Cummingtonite	3.1-3.6
Andalusite	3.16-3.20
Hornblende, Forsterite	3.2
Diopside	3.2-3.3
Augite, Pigeonite	3.2-3.4
Enstatite	3.2-3.5
Olivine	3.27-4.37
Epidote	3.35-3.45
Aegerine	3.40-3.55
Diamond	3.5
Pyrope	3.51
Garnet	3.5-4.3
Kyanite	3.56-3.66
Staurolite	3.65-3.75
Pyroxene	3.7
Fayalite	4.14
Rutile	4.18-4.25
Chromite	4.3-4.6
Xenotime	4.4-5.1
Zircon	4.68
Ilmenite	4.7
Monazite	5.0-5.3
Magnetite	5.18
Hematite	5.26

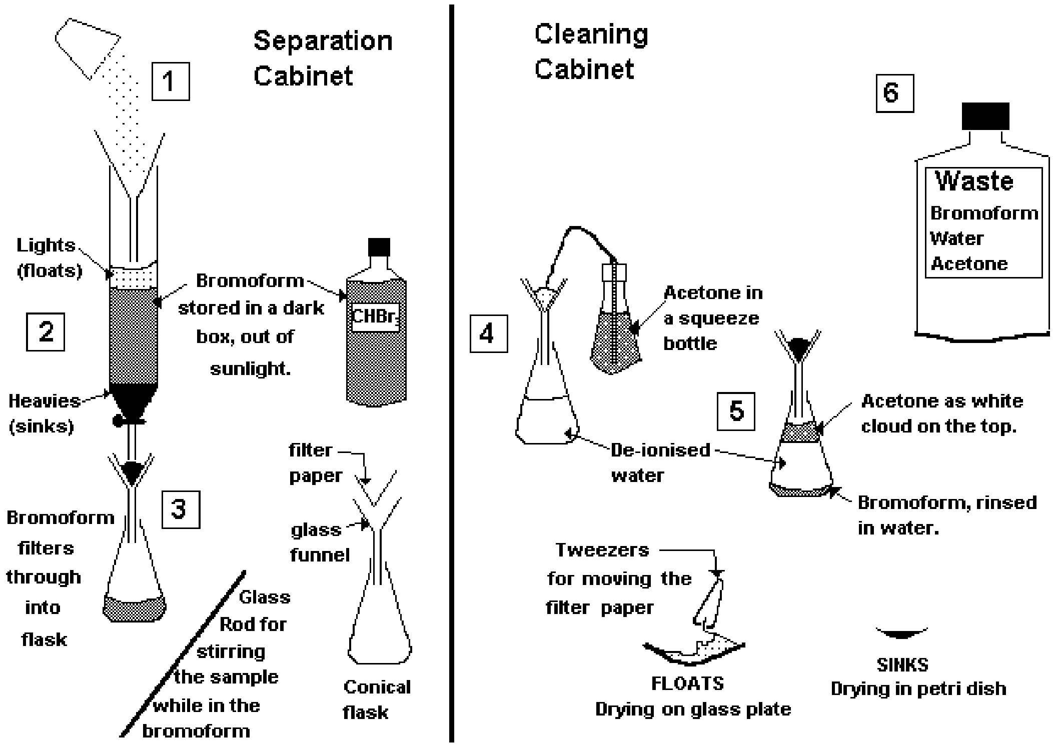


Figure 4.1: The procedures followed for heavy mineral separation

Step 1

After approximately 100ml of bromoform has been added to the separating flask, the dry sample is added via a glass funnel. This is to ensure that the sand grains of the sample have an even distribution within the bromoform and to avoid having the sample stick to the wet sides of the flask. Should the latter happen, the grains are washed down by adding more bromoform.

Step 2

Separation between heavy and light minerals should be immediately apparent and the sample is then left for a few minutes until the heavy and light fractions are clearly separated by a yellow layer of bromoform. The tap of the separation flask is then opened and the all heavy minerals are carefully poured onto the filter paper below. The sample is then stirred and again left for a few minutes. This procedure is repeated until the heavy minerals cease to collect at the bottom of the flask. The conical flask containing the heavy minerals is then removed and gently knocked to ensure that all the residue bromoform is collected in the flask below. A new flask with a clean filter paper is used to collect the light minerals once the tap of the separation flask is opened.

Step 3

Once all the bromoform has been collected in the conical flask, the remaining sample in the separating flask is gently prodded through the neck of the flask with a glass rod. The flask is then removed and replaced with another conical flask, containing water and bearing a filter paper in a plastic funnel. A squeeze bottle filled with acetone is used to remove the light minerals from the separation flask.

Step 4

The filter papers bearing the light and heavy mineral fractions respectively are each carefully removed from the funnels with the help of a plastic tweezers and placed in two conical flasks filled with water and bearing plastic funnels. The sand in the two filter papers is carefully rinsed with acetone, until no more bromoform is seen to collect at the bottom of the flask.

Step 5

When the sand is free of bromoform, the filter paper is gently lifted and the heavy mineral fraction is placed on a petri dish to dry, while the larger light mineral fraction, is placed on a glass plate. The flasks bearing the diluted bromoform are subjected to two more rinses with de-ionised water. Each time, the water should carefully be poured off, and the bromoform is finally poured into the waste bottle.

Step 6

When mineral separation is at an end, the bromoform in the waste bottle is poured into the empty, separation flask. A used bromoform bottle is placed below the tap together with a glass funnel bearing two filter papers. When the tap is opened, the bromoform is carefully collected in the bottle and together with the unused bromoform bottles stored in a dark place, out of sunlight.

ADDENDUM 5: MICROSCOPY

A rotary splitter was used to reduce the sample to aproximately 1g and this representative sample was then split further by cone and quartering with the aid of a plastic funnel and razor blade until only a teaspoon full remained. This small fraction of the sample was used to make a “whole rock” thin section, in which the sand is poured onto a glass slide and mixed with a paste consisting of araldite and hardener. The slide is then baked in an oven at 120oC and the result is a durable and permanent epoxy resin grain mount.

With the aid of plane polarized light, a study of the non-opaque minerals was carried out using a Leitz, Laborlux, 12 POLS petrographic microscope with the following 4 objective lenses: 5x, 10x, 20x and 50x and these were mounted on a rotating nosepiece. A blue filter was placed above the light source to ensure that there was polychromatic illumination. The 10x objective lens was used to calibrate the ocular micrometer scale. With the aid of a mm scale viewed through the lens, it was calculated that 47micrometers = 1mm and the size of individual grains could therefore be determined.

Studying detrital mineral grains in thin section becomes more challenging as mineral paragenesis, cleavage, form and optic figures are either poorly preserved, not visible or non-existant (Mange and Maure, 1991). Much emphasis is therefore placed on mineral characteristics such as: colouration and pleochroism; relief, size and roundness; birefringence and extinction angles. The technique used in slide preparation is not ideal. The sand is mixed into the araldite glue on top of the slide prior to baking, with the result that the mounted mineral grains are embedded at various levels within the araldite. Anomalous high interference colours for a thick, quartz grain must sometimes be accepted in order to study a thinner, feldspar grain closer to the polishing surface.

Point counting was done on the thin sections to determine the relative concentrations of each of the minerals. This was done using the ribbon counting method in which, with the help of a mechanical stage, the slide is manaeuvered along randomly selected ribbons or bands within the slide (Mange and Maure, 1991). The width of the ribbons remains constant and the results are independent of grain size. The results of this method are not considered reliable until at least 500 grains have been counted. The computer program could only handle 10 variables at a time and this meant that for each slide, first the non-opaques and then the opaques were counted.

ADDENDUM 6: CLAY SAMPLES

- **Sample preparation**

The slow precipitation rates of clay particles make washing and general sample preparation a lengthly and time-consuming business. It was therefore decided to try and do both grain size determinations and XRD work on the same samples. 8 clay samples were selected. These samples were selected because they represented the major clay-containing units at Geelwal Karoo and they were present in sufficient quantities to enable grain size determinations.

The following seven steps were followed in preparing the clay samples for XRD analysis and then grain size determination with SediGraph.

Step 1: The drying of samples

The clay samples were first dried in an oven at 40^{o}C for 6 hours.

Step 2: The weighing and crushing of the samples

The dried samples were weighed and then, using a mortar and pestle, the aggregates were crushed. The clay powder was then dry sieved with a 4 phi sieve, and the % mud (finer than 4 phi) of the sample was determined.

Step 3: The removal of organic matter from the samples

1. The sample was submerged in distilled water.
2. A 30% H_2O_2 solution was added to the wet sample in small amounts.
3. To make the reaction more effective, a few drops of 1M HCL were added.
4. The sample solution was then stirred, until effervescence ceased. (The samples were covered with a watch glass if frothing became too much.)
5. The supply of hydrogen peroxide was replenished, until there was no more effervescence.
6. The samples was then heated slowly to 60-70^{o}C (H_2O_2 decomposes above 70^{o}C.)
7. More H_2O_2 was added, until there was no further reaction.

Bubbling vigorously and bubbling over, was seen to be the result of a sample which had much organic material. Bubbling was seen to indicate the presence of a moderate amount of organic matter, while no reaction indicated very little or no organic material.

Step 4: The removal of iron oxides from the samples

After all the organic material had been removed, the iron oxides were removed from the wet samples.

1. It is necessary to ensure that for every 100g of sample, 300ml of distilled water is present, (i.e. add more if necessary).
2. Add 24g solid sodium citrate and 2.8g solid sodium bicarbonate.
3. In a water bath, heat the samples to 75 - 80^{o}C, while stirring continuously.
4. At the correct temperature, add 7g solid sodium hyposulfite (sodium dithionite = $Na_2S_2O_4$ + H_2O.)
5. Stir the samples constantly for a further 5 minutes and then intermittently for 10 minutes.
6. Remove sample from water bath and allow to cool. If all the iron oxides have been removed, the sample should turn gray. If the sample is not gray or white, repeat step 4.

If the sample stayed the same colour, it was seen to contain very little iron. Samples that frothed with addition of Na-diothionite, were seen to contain a little iron. Samples that changed colour to black and green, were said to contain a moderate amount of iron and the samples that went completely white, contained much iron.

Step 5: Rinsing the samples

The treated samples contain many free ions and these need to be removed, before further XRD or SediGraph analyses can be done. To do this, some authors suggest a rinse with a weak solution of HCL, while others seem to prefer a rinse with a 1% neutralising NaCl solution. Because of the close proximity of the sea, I avoided the NaCl solution and opted for a final rinse with a 0.5M solution of HCL. The latter could, at the same time, leach away any carbonate material in the samples.

The samples were then treated with 10ml of acetone to encourage flocculation and then washed twice. Allowance was made for a period of sedimentation and decantation. This means that the samples were rinsed with distilled water and then left to stand for a minimum of two days, before the clear surface layer was decanted and discarded.

Certain of the samples still showed a black and yellow liquid above the silt and clay after the second rinse and it was obvious that further rinsing would be required. For this purpose, a large centrifuge was used to speed up the sedimentation process. Each sample was split into 5, 100ml bottles (about 5cm in diameter), carefully weighed and the difference in weight between the bottles was balanced by the addition of distilled water. The bottles were then placed in the centrifuge and spun at a rate of 4000rpm, for 10 minutes. The supernatant liquid at the top of each bottle was drained off and discarded. The remaining sample in the bottle was removed from the bottle with the aid of as little water as possible. After the second centrifuging, all the samples reported clear supernatant.

Step 6: Drying of the samples (See step 1).

Table 6.1: The results obtained after the preparation of the clay samples.

Sample no:	**61**	**30**	**118**	**28**	**114**	**10B**	**56**	**12**
Prof.	**11**	**4A**	**2**	**4B**	**13**	**1**	**9**	**1**
Unit:	Bedrock	Bedrock	Channel clay	Channel clay	Channel clay	50m package	30m package	30m package
Weight:	8.8	8.71	8.72	8.94	8.93			
Colour:	White	White-green	White	Red	White	Yellow-green	Black-grey	Yellow-green
% silt:	73.98	61.61	46.66	43.17	55.91	36.35	26.16	33.54
% organic:	much	very little	moderate	moderate	much	much	much	much
% Fe:	very little	little	very little	much	very little	moderate	moderate	moderate
% heavy minerals	much	none	little	little	none	none	none	little

- **Particle size analysis on the clay samples**

The high concentrations of material finer than 4 phi, in certain of the fluvial and marine samples, resulted in an uneven distribution in the grain size histograms of these samples. In order to reduce the amount of uncertainty presented by these large amounts of fine material, and also, hopefully, to shed more light on the origin (detrital or authigenic) of the clay within the sediments, a particle size analysis on the clay was considered.

Stokes Law states that particles of different sizes, settle from suspension at predictable rates and this is the principle behind a particle size analysis on clays. A particle size analysis was done by means of a SediGraph and essentially is a measure of the density variations of the sediment-water suspension within a given time, as the particles start settling from the solution. A SediGraph makes use of a collimated X-ray beam which is programmed to move up and down the entire length of a cell containing the sample suspension.

At fixed time intervals, the density of the liquid medium at that particular depth is measured and the particle size, is then calculated.

The SediGraph was preferred over the hydrometer as a method of grain size analysis, for a number of reasons. The SediGraph has the advantage of reducing the amount of time and labour required for each sample analysis, it is also not affected by factors such as temperature fluctuations or sample disturbances during the analysis. The SediGraph is, however, susceptible to concentration differences, especially high concentrations of heavy minerals and Fe-ions which both have to be removed before an analysis can be made. SediGraphs are also affected by diffusion and particles less than 1 micron are considered too small for the SediGraph as they are susceptible to Brownian movement. Factors such as the container wall and sample X-ray absorption properties will also affect the results of a SediGraph particle size analysis.

Before a particle size analysis with a SediGraph, all the free Fe ions must be removed from the sample (might mean rinsing and centrifuging sample a few times). The sample must then be dried an carefully sieved so that only the material finer than 4 phi is present. A minimum of 8g is required for a particle size analysis and, for this reason, only 6 Geelwal clay samples, of the original 8 samples could be used. The exact weight of the dry sample must be known before it is treated with the dispersant (1.5% sodium hexametaphosphate solution). The optimum density of the sample and dispersant mixture for a SediGraph analysis is between 1 - 2%. When is it is thoroughly mixed and all the heavy minerals have been removed (magnetic stirrer), the entire sample is then poured into the SediGraph cylinder with the help of a large funnel. The temperature of the cylinder is then noted and the SediGraph is then turned on. If the results of various samples are to be compared with one another, it is important to ensure that the conditions of the analysis remain constant (i.e. try and do all the samples on one day.)

- **XRD and the identification of clays**

After the sample was prepared (see first paragraphs) the supernatant liquid of the washed sample was carefully removed. The extracted liquid is then re-suspended and poured into a beaker, containing a clear, glass slide. The sample is left undisturbed until completely dried (may use infrared lamp to speed up the process). During sedimentation, the plate-like clay particles are stacked one on top of each other to produce an orientated thin section.

Bragg's Law states that the crystalline lattice spacings of a mineral can be determined by the following equation: $2d \sin \theta = n\lambda$, where n is an integer, λ is the wavelength of the X-ray , d is the lattice spacings in angströms and θ is the angle of diffraction. "Each clay mineral group is therefore characterised by a particular type of layer structure and interlayer material" (Tucker, 1988).

The method used in this study was "qualitative analysis" (Tucker, 1988) and minerals were identified by comparing their X-ray scans with standard patterns available from sources such as the Joint Committee on Powder Diffraction Standards (JCPDS) index. Correlations between diffractograms of the sample and references usually involve a search for the minerals that are best able to explain the strongest peak or peaks, and then the choice is confirmed by finding similiar correlations for the positions of the weaker peaks. This procedure is repeated until all the peaks of the sample diffractogram can be explained. Numerical correlations are also made when the measured 2θ values of the peak in the sample scan are converted to lattice (d spacing). A minimum of 3 peaks or d-values is required for a positive identification.

When identifying clays, however, the following must be borne in mind. The JCPDS card index is based on a study of unorientated powder mounts and the strongest hkl peaks are listed, (Tucker, 1988). Clays are commonly studied as orientated powder mounts and the strongest reflections are not always visible. Only a cursory qualitative analysis was done on the clay samples in this study and no use of solvents such as ethylene glycol and heating were made to enhance the results.

The intensity (peak height or area) of the diffraction pattern of the mineral is proportional to its concentration. There is always a danger of some clays e.g. kaolin, responding stronger than smectites such as chlorite and most quantitave analysis involve calibration of curves with minerals of known quantities (Tucker, 1988).

The dominant clay mineral in the Geelwal samples proved to be kaolinite. In kaolinite the octahedral layer is filled with aluminium, OH- and O- ions, while the tetrahedral layer is made-up of silica (Tucker, 1988). Substitution is kept to a mininum and the charge balance is nil. Kaolinite, $Al_2(Si_2O_5)(OH)_4$, is composed of one sheet silica and another of gibbsite.

A single crystal may be composed of many of these layers. Ball clay is a fine-grained sediment composed almost entirely of kaolinite and has therefore been equated with those clays found in the channel clay formation. Trace amounts of rutile, anatase, montmorillonite and carbonaceous matter may be present in ball clays and they are generally highly plastic and exhibit great drying shrinkage. Deposits are lenticular in shape and lacustrine in origin although some are fluvial. These clays become lean or silty clay when silt is present.

APPENDIX I: FIELD DATA

Summary data for each profile mapped.

APPENDIX II: LABORARTORY DATA

Summary data for laboratory work completed.

APPENDIX III: MINERALOGICAL DATA

Summary data for mineralogical analysis completed

1.1 Profile 10

Profile 10 is situated at the northernmost boundary of Geelwal Karoo study area. *Donax rogersi* shells were identified as being bigger, more symmetrical and better preserved than the *Donax haughtoni* specimens found in heavy sand layers at “Torings”. The +30m package is either almost completely covered by red aeolian sands or occurs as loose cemented conglomerates lying on the present beach. Mussel, oyster and fragmented *Donax* shells are present in these conglomerates. The pebbles in the cemented basal marine gravel unit, are gray, black, red and brown shales and they have an average diameter of 3cm.

The sand of the +30m package is well sorted, with sub- to well-rounded grains and is lighter in colour than the red aeolian sand. Approximately 2cm of red aeolian sand had to first be cleared away to reveal the sand of the +30m package below.

A prospecting pit was found further south and 0.5km inland of the coast. No clear evidence of marine sedimentation was found and at its maximum, the exposure was about 20m thick and consisted of a homogeneous-looking succession of aeolian sand. Numerous calcareous root horizons was present and, as a whole, the trench is very similar to that found at Site A, Graauwduinen.

Table 1: Summary of units mapped in profile 10.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete column.		12.00	12	12.00	Beach	RB
2a	Gneiss	4.70	10	Isolated chunk protruding on present beach.	52	0.82	12.82		Basement	B
2b	Gneiss	7.34	14			1.78	14.59			
2c	Present beach	15.37	8	Sand rich with garnets and heavy minerals.	53	2.14	16.73			
2d	Present beach	15.37	12	Scattered, angular pieces of NMC.		3.20	19.93			
2e	Debris	12.07	20			4.13	24.05			
2f	Gneiss	2.00	46			1.44	25.49	13.49		
3a	Gravel layer	3.00	34	Gravels are cemented to contact with basement.	54	1.68	27.17	1.68	Subtidal	30m
4a	Red aeolian	12.37	10	D. rogersi discovered in white sand, covered by red sand (lasts for 2m).		2.15	29.32	2.15	Beach	30m
4b	Red aeolian	15.37	8	Red sand.		2.14	31.46		Dune	AR
4c	Red aeolian	15.37	12	Red sand.		3.20	34.65	5.33		
5	Red aeolian	16.89	15	Red sand covered with plant growth.	96	4.37	39.03	4.37		
					TOTAL:	**39.03**				

LEGEND for table: W= Width measured in the field, S= slope in field of sedimentary unit, V= vertical thickness of sedimentary unit, Elev= Elevation of unit, Th= thickness of unit, B=Basement, CC= Channel clay, AD= Dorbank aeolianite, AY Yellow aeolianite, +50m= +50m package, +30m= +30m package, AR= Recent aeolianite, RB= Recent beach.

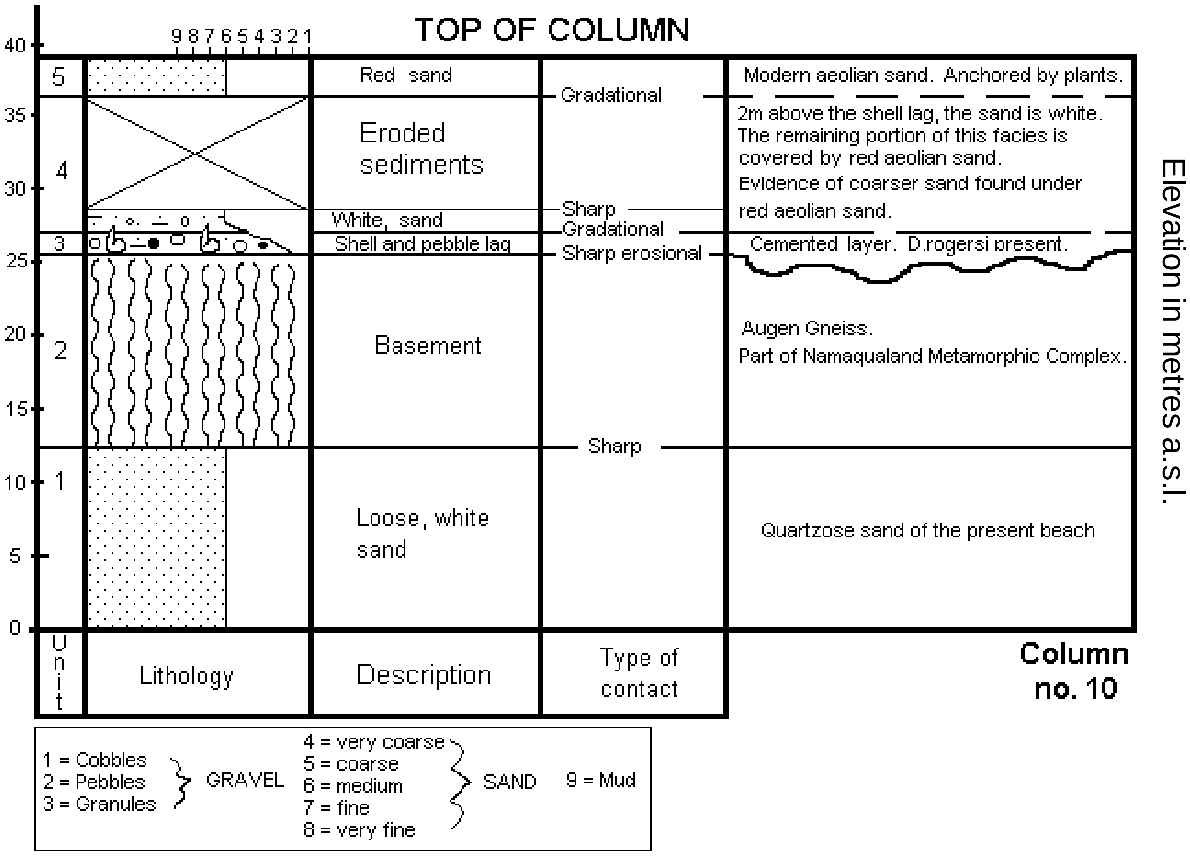


Figure 1: Lithological section of profile 10.

1.2 Profile 9

The shelf facies of the +30m package (green clay unit) appeared to be a mixture of fine sand and clay and, on closer inspection, consisted of more sand than clay. Noticeable black layers were seen to be interbedded with white sand. At first, these layers were thought to be heavy mineral laminae but when treated with hydrogen peroxide, the black aggregates bubbled furiously and were therefore identified as being organic material. This unit could further be divided into a yellow sand section at the bottom and a top portion of green sand and clay. The former consisted of fine granule lenses.

The extent of the coarser light coloured intertidal facies of the +30m package could not be determined due to the extensive covering of red aeolian sand.

Table 2: Summary of units mapped in profile 9.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present Beach			Added to complete stratigraphic column.		10.00	10	10.00	Beach	RB
1b	Present Beach	15.37	8	White sand with scattered mussel shell fragments and pebbles.		2.14	12.14			
1c	Present Beach	15.37	4			1.07	13.21			
1d	Present Beach	15.37	2			0.54	13.75			
1e	Present Beach	15.37	3			0.80	14.55	14.55		
2a	20m Terrace	16.37	8			2.28	16.83			
2b	20m Terrace	15.37	10	Yellow sand layered with calc chunks and pebbles. Becomes steeper.	55	2.67	19.50			
2c	Debris	8.51	3	Associated with road.		0.45	19.94			
3a	Debris	8.58	0	A hollow of white sand found beyond road.		0.00	19.94			
3b	Debris	16.10	13			3.62	23.57	9.01		
3c	Yellow clay unit	0.10	82	Higher clay content than any of other units - Sandy Clay unit.	57 100	0.10	23.67		Shelf	30m
3d	Green sand unit	1.48	82	Fine sand, cross-bedding (hummocky).Mud lenses (flaser bedding), max 4cm.	56	1.47	25.13			
3e	Granule layer	0.22	82	Some cobbles (bearing 225 and dip down to west). Unit clast supported.	98	0.22	25.35			
3f	White sand unit	0.50	82	Fine white sand with yellow, horizontal cross-lamenations. Dips 4 (down to S).	99	0.50	25.84	2.28		
4a	Basal Pebble Layer	0.10	80	Sorting is very poor, larger rocks at top. NMC rocks not very rounded.		0.10	25.94		Subtidal	30m
4b	Sand Unit	0.10	35	White sand with darker yellow laminae.	58	0.06	26.00			
4c	Calcreet Conglomerate	0.30	35	Pebbles are well-rounded, small (less 2cm) and sorting is moderate.		0.17	26.17			
5a	Shell Layers	0.80	35	Shells exclusively of oysters with few pebbles here and there.	59	0.46	26.63			
5b	Calcreet shells layer	0.05	30	Oysters embedded in calcreet cement.		0.03	26.66	0.81		
5c	White sand	15.37	34			8.59	35.25		Beach	30m
5d	White sand / red sand	15.87	11	Covered by red aeolian sand with calc chunks. Contacts not easily seen	60	3.03	38.28	11.62		
6a	Red aeolian	15.37	18			4.75	43.03	4.75	Dune	AR
7	Red aeolian	14.75	10			2.56	45.59	2.56		
					Total:	**45.59**				

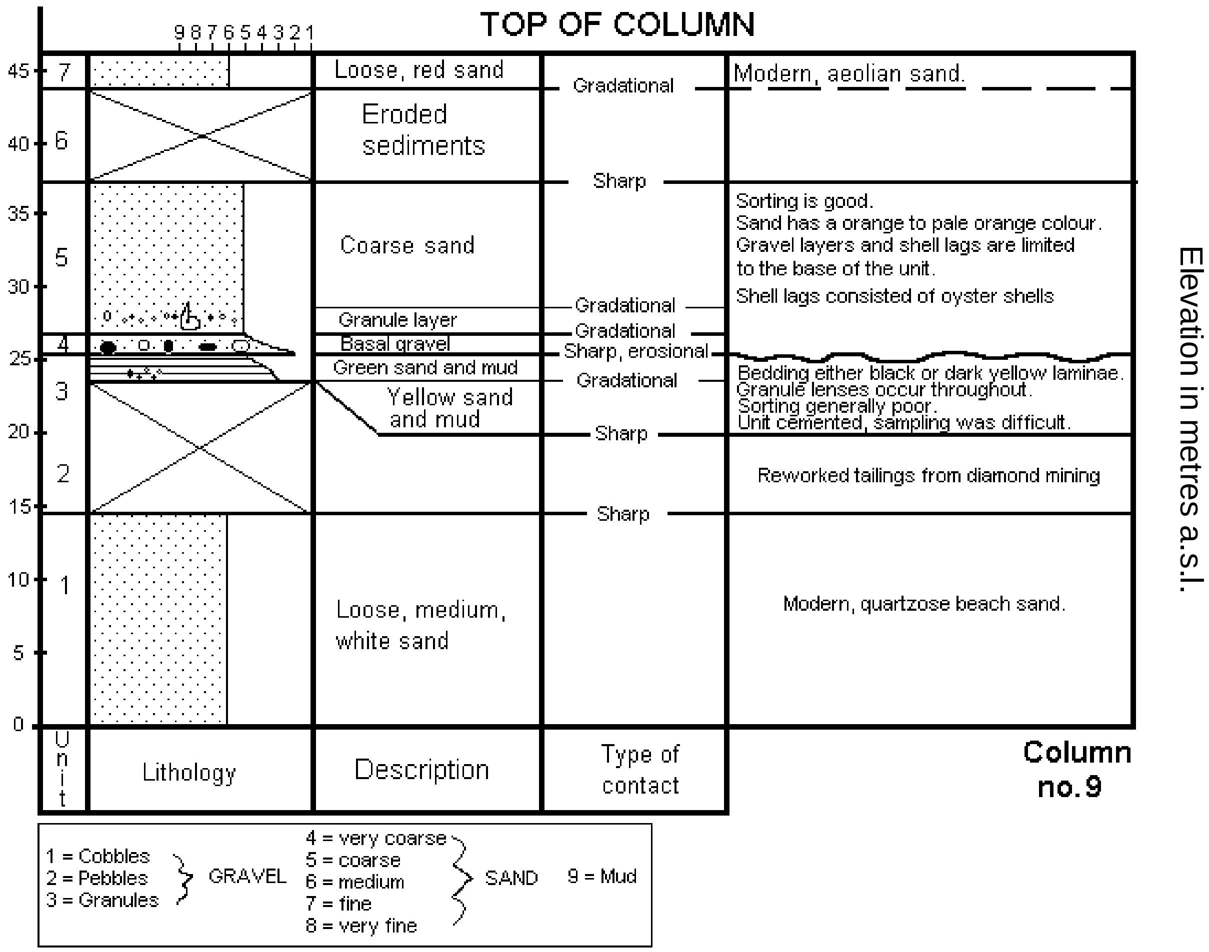


Figure 2: Lithological section of profile 9.

1.3 Profile 11

The white sand at the base of the profile is a distinctive and was eventually classified as a fluvial unit, similar to that found in the “Torings” area. Profile 11 thus has the northernmost outcrop of the fluvial unit and in this area it is cemented with silica. The basal marine gravel unit is also cemented (bubbles furiously with acid). The basal marine gravel layers have oysters which are very similiar to those found in Profile 9 and were therefore classified as the subtidal facies of the +30m package. This profile was very accessible, but also had much debris associated with road building.

Table 3: Summary of units mapped in profile 11.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column		15.00	15	15.00	Beach	RB
2a	Debris	2.80	14	Mainly white sand of palaeo-strandline.		0.68	15.68			
2b	Brown Dolomite	1.30	65	Crumbling yellowish brown rocks.	61	1.18	16.86	1.18		B
3a	Debris	7.38	45	A mixture of white and red sand, large pebbles and larger phosphorite chunks.		5.22	22.07			
3b	White sand	3.68	70	More fine,white sand than clay, becomes very steep in the last 0.5m.	101	3.46	25.53	3.46	Fluvial	CC
4	Basal pebble layer	0.05	85	Pebbles in white sand, covered in places by red aeolian.	97	0.05	25.58		Subtidal	30m
5	Sand + shell layer	0.12	34	Sand is light-coloured and shells are exclusively oysters.		0.07	25.65	0.12		
6	Red aeolian	6.80	33	Covered by plants.		3.70	29.35	3.70	Dune	AR
					TOTAL:	29.35				

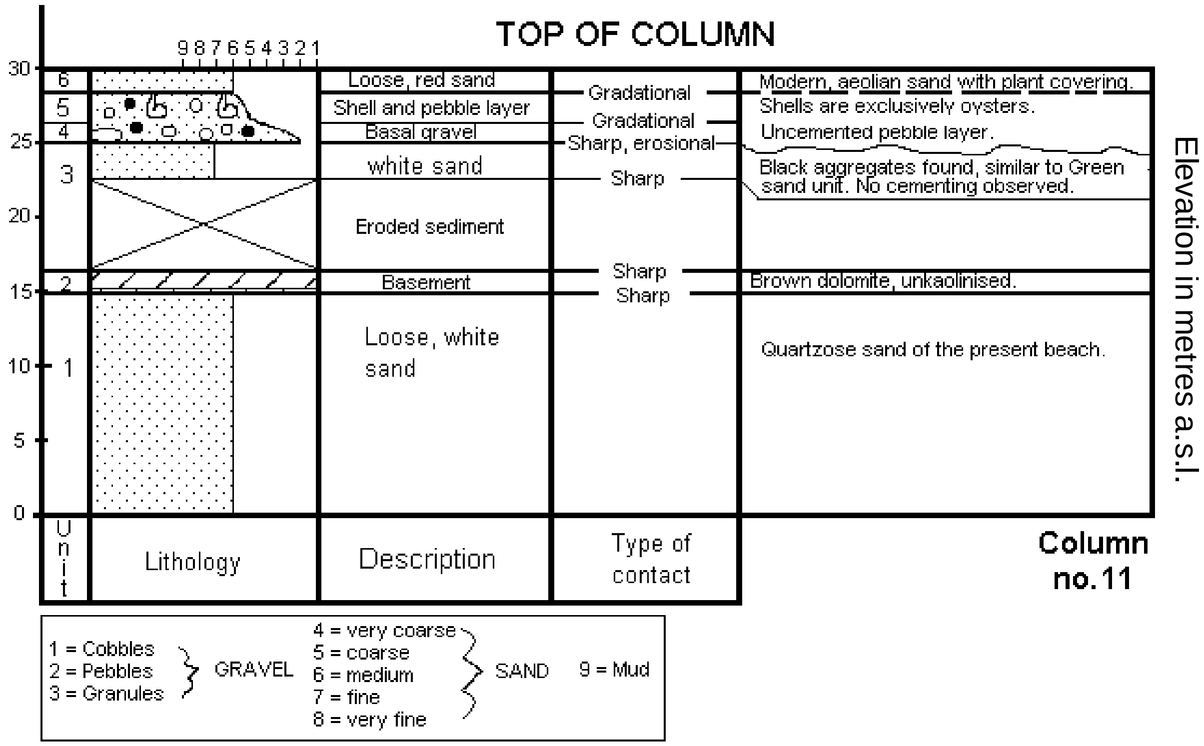


Figure 3: Lithological section of profile 11.

1.4 Profile 1

The fluvial, quartz pebble layer at the base of this profile, is horizontal and the matrix between the pebbles is pure clay. The pebble layer consists almost entirely of quartz grains that are generally well rounded but poorly sorted. No exotic pebbles are found in this layer. The profiles further south, however, show the same, bottom fluvial, quartz pebble layer in direct contact with basement clay. Above the quartz pebble layer is the shelf facies of the +50m package. It consists of dark and lighter laminae of sand, with sparse accumulations of very small, well-rounded pebbles. These sediments have been tentatively equated with the continental shelf deposits of the +50m package.

The contact between the subtidal facies of the +30m package and the shelf sediments of the +50m package is distinctly erosive and a clear "channel-like layer" contact was noted. The lower pebble layer of the +30m package is coarser and the larger pebbles accumulate at the base of these micro-gully features. This pebble layer is prograding with an fining upward succession clearly visible. The discovery of a whale rib bone at the base of one of the eroded channels, confirmed the presence of a marine environment.

The profile is capped by red aeolian sand, which covers a gravel layer. The uppermost gravel layer is cemented by a mixture of mud and calcrete and seemed to suggest more recent fluvial erosion and reworking.

Table 4: Summary of units mapped in profile 1.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		6.41	6.41	6.41	Beach	RB
1b	Debris	27.3	18	Very steep profile, more exposure but also more debris.		8.44	14.85	8.43		
2a	White clay	0.3	45	Fine white sand with yellow, horizontal X-lamenations.	8 8b	0.21	15.06		Fluvial	CC
2b	Quartz pebble	2.9	60		9 9b	2.51	17.57	2.72		
3a	? Sand	7.8	50	Very fine yellow sand. Granules scattered throughout.	10	5.98	23.54		Shelf	50m
3b	? Sand	2.64	53	Granules are exotics (not just quartz) - no fixed layers.	10b	2.11	25.65	8.08		
4a	Channel infill	1.5	20	Pebbles concentrated at base of channels, get less dense at top.	12,11,11b	0.51	26.17		Subtidal	30m
4b	Channel infill	2.1	35	Pebble layers alternate with yellow sand	11c 11d	1.20	27.37			
4c	Calc Layer	0.7	85	Penetrates yellow sand layer. Has appearance of mud hard pan.	14 15	0.70	28.07			
4d	Gravel layer	1.4	32	Muddy nature indicates that deposit might recently have been reworked.	16	0.74	28.81	3.16		
5	Red Aeolian	1.6	11	Aeolian sand covered by plants	13	0.31	29.12	0.31	Dune	AR
					Total:	**29.12**				

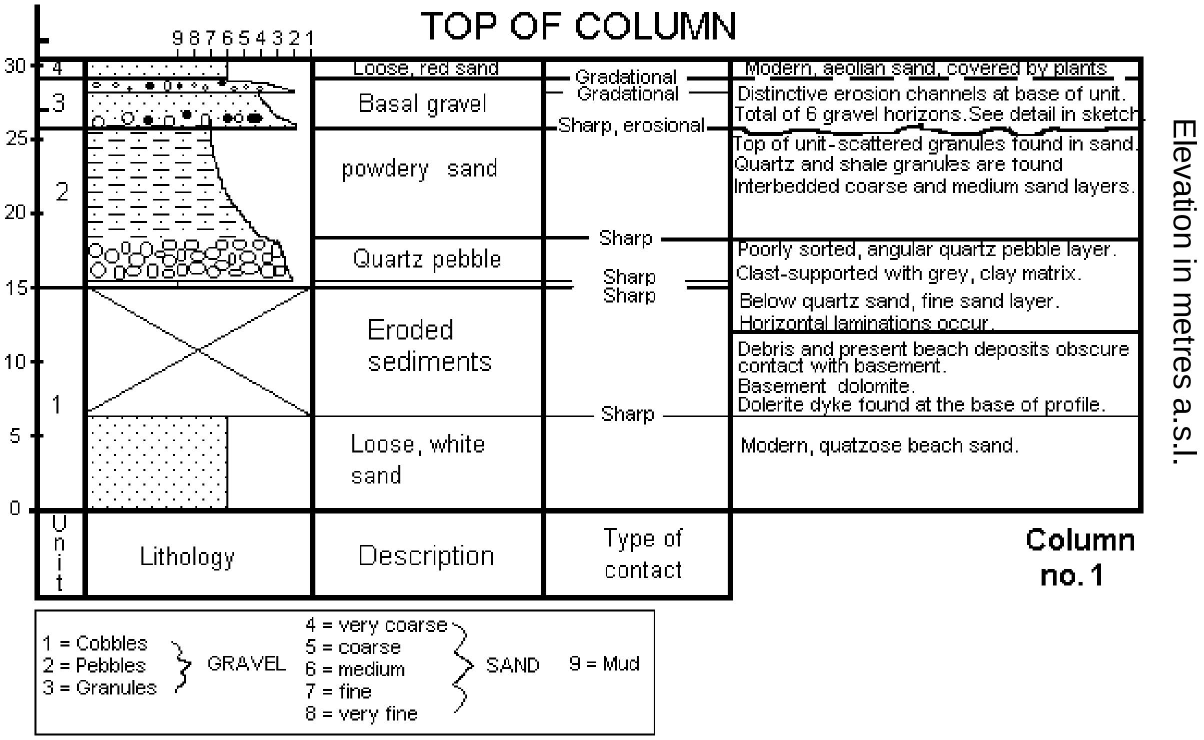


Figure 4: Lithological section of profile 1.

1.5 Profile 17

The cementing at the top impeded the sampling of the white fluvial unit in this profile. The silcrete blocks found at the base of this profile are associated with the cementation. Within the silicified sand unit at the top, a low angle cross-bedding (dip of 18 degrees) was visible and it indicated a northward flowing stream direction. An occasional granule lense was noted in this silicified sand unit.

A yellow-orange sand unit, very similar to that found in Profile 1, was visible above the white clays. This unit was classified as being part of the basal marine gravels. Gravel of various sizes (granules to pebbles) are found scattered in this unit and are found in association with very large ferricreted, conglomerate blocks. (Light microscope study revealed the cement to be hematite and not phosphorite as originally thought.)

The ferricrete blocks are chocolate brown and form a continuous layer, visible as protrusions through a covering of red aeolian sand. The ferricrete blocks are very irregular in shape with only slightly rounded edges. It was concluded that the ferricrete blocks were subjected to little erosion and might well have being part of an older marine unit situated at this elevation.

The dorbank unit found above the ferricrete layer, has a very distinctive weathering pattern. It has very steep faces, with no plant cover. Characteristic, eroded trenches were noted.

Table 5: Summary of units mapped in profile 17.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column		10.00	10		Beach	RB
1b	Present beach	15.37	18	Garnets and heavies.		4.75	14.75			
1c	Present beach	7.20	12	Debris of present beach and yellow sand.		1.50	16.25	16.25		
2a	Quartz pebble 1	0.32	59	Poorly sorted, sub-angular, matrix supported.	102	0.27	16.52		Fluvial	CC
2b	Sand unit 1	0.28	60	Scattered pebbles and granules.		0.24	16.76			
2c	Quartz pebble 2	0.30	59			0.26	17.02			
2d	Sand unit 2	0.40	60	Scattered pebbles and granules.	103	0.35	17.37			
2e	Clay lense 1	0.10	62			0.09	17.46			
2f	Quartz pebble 3	0.44	55		104	0.36	17.82			
2g	Sand unit 3	2.36	62		105	2.08	19.90			
2h	Clay lense 2	1.10	46		106	0.79	20.69			
2i	Sand unit 4	0.90	50	With granule lenses.		0.69	21.38			
2j	Clay lense 3	0.80	48	Silicification increases towards the top.		0.59	21.97			
2k	Sand unit 5	4.54	44	2 Pebble lenses, silicified. X-bedding shows N flowing stream.		3.15	25.13	8.88		
3	Ferricreet layer	1.50	60	Seen as being basal marine gravel unit, covered by red sand.	107	1.30	26.43	1.30	Subtidal	30m
4	Orange sand	5.90	60	Loose pebbles and granules, covered by red sand.		5.11	31.54	5.11	Beach	30m
5	Red sand	6.30	45	Covered by plants.		4.45	35.99	4.45	Dune	AR
					TOTAL:	35.99				

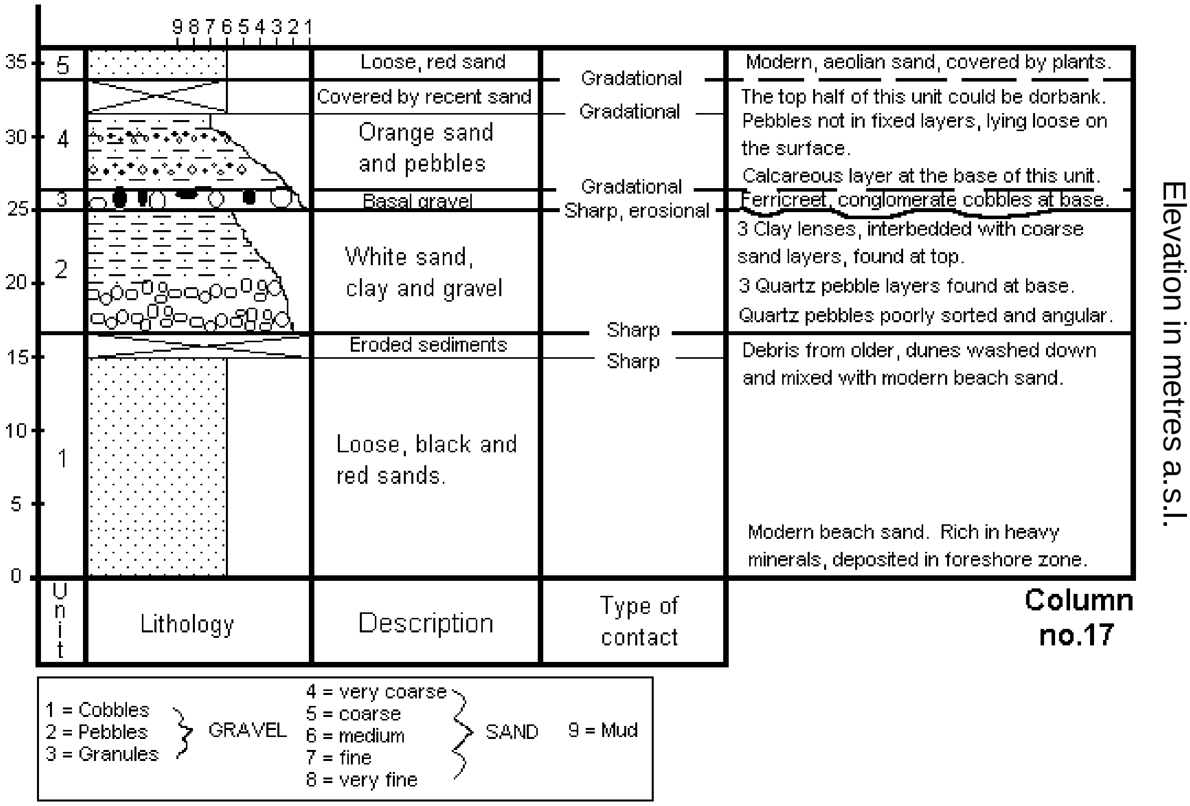


Figure 5: Lithological section of profile 17.

1.6 Profile 3

The sand of the present beach is garnet-rich (pink) and forms a dune in the backshore that extends from the base at sea level up to an elevation of 22m (this is way above the high and storm water marks).

The Gariep Supergroup is represented in this mapping site as a bluish-grey schist and a black (possibly carbon-rich) schist. The latter occurs around the corner from the profile, as an isolated island in the middle of the beach.

The fluvial white clay is partially covered by the aeolian sand of the present beach and contains distinctive quartz pebble layers. The pebble layer in this profile has a dip of 16 degrees, down to the west, and becomes pure clay towards the top.

The layer of ferricreted, conglomerate blocks found above the white clay, is embedded in a layer of red aeolian sand. They can be used as a stratigraphic marker and, although present as loose blocks, are still found lying roughly in a continuous layer. The blood red aeolian sand can be distinguished from the red aeolian sand found above by its deeper red colour and distinctive erosional features seen on the surface. The red sand found below the ferricrete layer is not quite blood red and appears to be similar to the sand found at the top of the profile.

Table 6: Summary of units mapped in profile 3.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		9.30	9.3		Beach	RB
1b	Present aeolian dune	6.22	23	Marine component (storm deposit) probably overlain by aeolian sand.		2.43	11.73		Backshore	
1c	Present aeolian dune	4.39	26	Ripples orientated almost perpendicular to beach suggest aeolian nature.		1.92	13.65			
1d	Present aeolian dune	4.24	31	Sand rich in heavies.		2.18	15.84			
1e	Present aeolian dune	3.4	33	Pink, garnet-rich sand, with separation into black, pink and white bands .		1.85	17.69			
1f	Present aeolian dune	2.94	18			0.91	18.60	18.60		
2a	Debris	7.62	18			2.35	20.95			
2b	White clay	3.18	35	Quartz layer dips 20 (down to north - probably due to slumping.)		1.82	22.78		Fluvial	CC
2c	White clay	4.1	40			2.64	25.41	4.46		
3	Ferricreet layer	1.5	60	Ferricreet chunks do not appear to be continuous.		1.30	26.71	1.30	Subtidal	30m
4	Blood red aeolian	4.21	50	Distinctive weathering, grooves chisseled into cliff face.		3.23	29.94	3.23	Dune	AD
5	Red aeolian	3.59	18	Covered by vegetation at the top, not as red as previous unit.		1.11	31.05	1.11	Dune	AR
					TOTAL:	**31.05**				

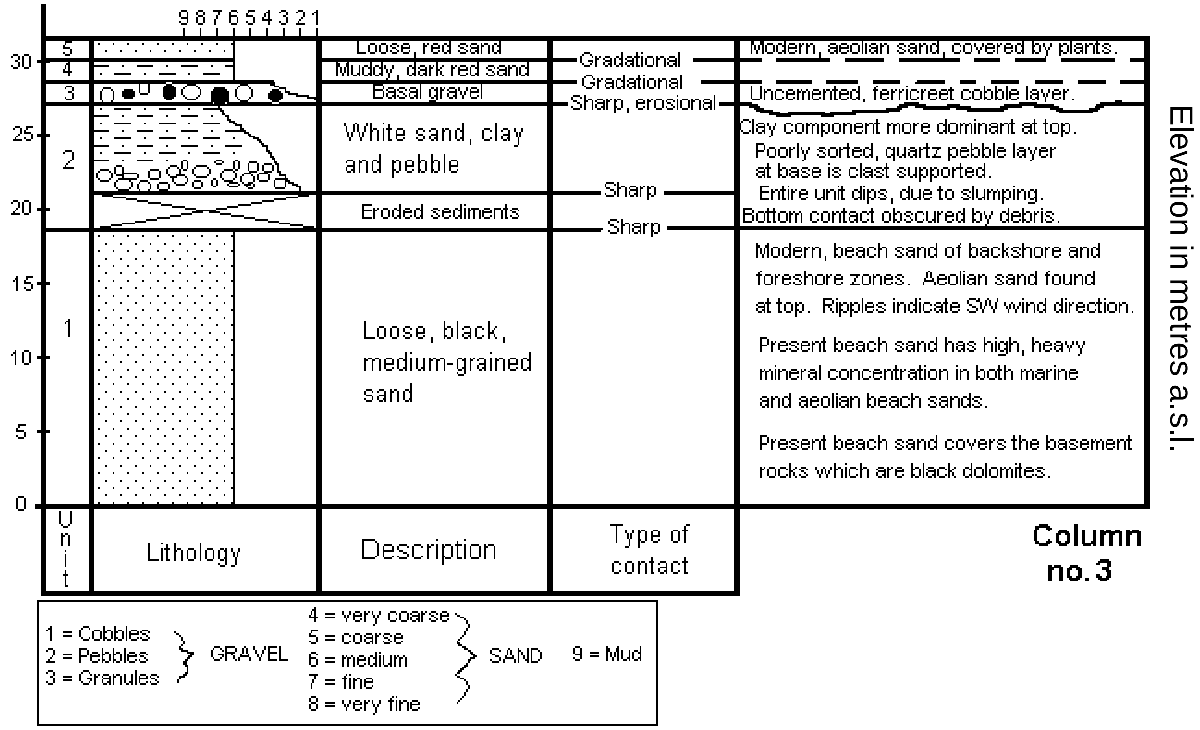


Figure 6: Lithological section of profile 3.

1.7 Profile 7

Exposure is very limited in this profile. The backshore sediments of the present beach are well represented and composed of heavy mineral layers interlayed with red aeolian sand.

Three types of clay were reported in this profile. The brown and blue-grey clays at the base were associated with the basement dolomite and schists. The blue clay reacted more vigorously with cold HCL and the contact between the blue and brown clays was very sharp. The blue clay showed outcrops of quartz veins in places and these were not strata-bound.

The third type of clay was white and associated with the fluvial unit of this profile. Quartz pebbles were present in the unit and these occurred in clearly defined layers or lenses and, in places, with a dip. The latter dip in the quartz pebble layers was attributed to slumping. The pebble layers are not horizontally continuous and consists exclusively of quartz pebbles. These gravel horizons are more commonly interbedded with coarse, quartzose sand but the odd clay lense was also noted.

Above the fluvial unit is the basal marine gravel unit which, in this profile is part of the subtidal facies of the +50m package. Gravel unit is poorly represented and often buried beneath red aeolian sand. The lowest pebble layer had the largest clasts which were large silcrete cobbles.

Table 7: Summary of units mapped in profile 7.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		10.00	10	10.00	Backshore	RB
2a	Brown Dolomite	0.40	44	Dolomites are very weathered with angular quartz fragments. Reacts HCL.		0.28	10.28		Basement	B
2b	Blue Dolomite	2.80	44		51	1.95	12.22			
2c	Debris	15.37	20	Classified as red aeolian with plants and calc chunks.	62	5.26	17.48			
2d	Debris	20.50	30	Consists mostly of red aeolian sand with plants and clay chunks.		10.25	27.73			
2e	White phyllite	0.50	34	Unit appears to be dipping North.		0.28	28.01	18.01		
3a	Quartz Pebble 1	4.00	30	Clast supported, poorly sorted. Biggest clasts here. Clay lenses, folded.	108	2.00	30.01		Fluvial	CC
3b	Sand unit 1	0.90	30	Coarse gray sand with granule lenses. Yellow, horizontal cross-laminations.	109	0.45	30.46			
3c	Quartz Pebble 2	1.60	30	Clast supported, also with yellow laminae.	110	0.80	31.26			
3d	Sand unit 2	0.60	30	Very fine white sand with (mm) horizontal cross-laminations. Not silicified.	111	0.30	31.56	3.55		
4a	Basal Pebble	0.30	35	Exotic pebbles and cobbles, well rounded, matrix-supported at top.		0.17	31.73		Subtidal	50m
4b	Sand unit 1	1.20	35	Yellow sand with horizontal, black cross-laminations (<mm).	112	0.69	32.42			
4c	Granule layer 2	0.20	35	Clast supported, not very well exposed.		0.11	32.53			
4d	Sand unit 2	0.20	35	Yellow sand with horizontal, black cross-laminations (<mm).		0.11	32.65			
4e	Pebble layer 3	0.10	35	Matrix supported, pebbles smaller than basal pebble layer.		0.06	32.71	1.15		
5a	Red Aeolian	15.37	20	Red aeolian sand with scattered calc occurrences.		5.26	37.96		Beach	50m
5b	Red Aeolian	15.37	12	Loose pebbles and oyster shells visible.		3.20	41.16			
5c	Red Aeolian	15.37	12			3.20	44.35	11.65		
5d	Red Aeolian	15.37	12			3.20	47.55		Dune	AD
5e	Red Aeolian	15.37	8			2.14	49.69			
5f	Red Aeolian	15.88	8			2.21	51.90			
5g	Calc Outcrop	0.20	5			0.02	51.92			
5h	Calc Outcrop	30.00	8			4.18	56.09	11.74		
					TOTAL:	**56.09**				

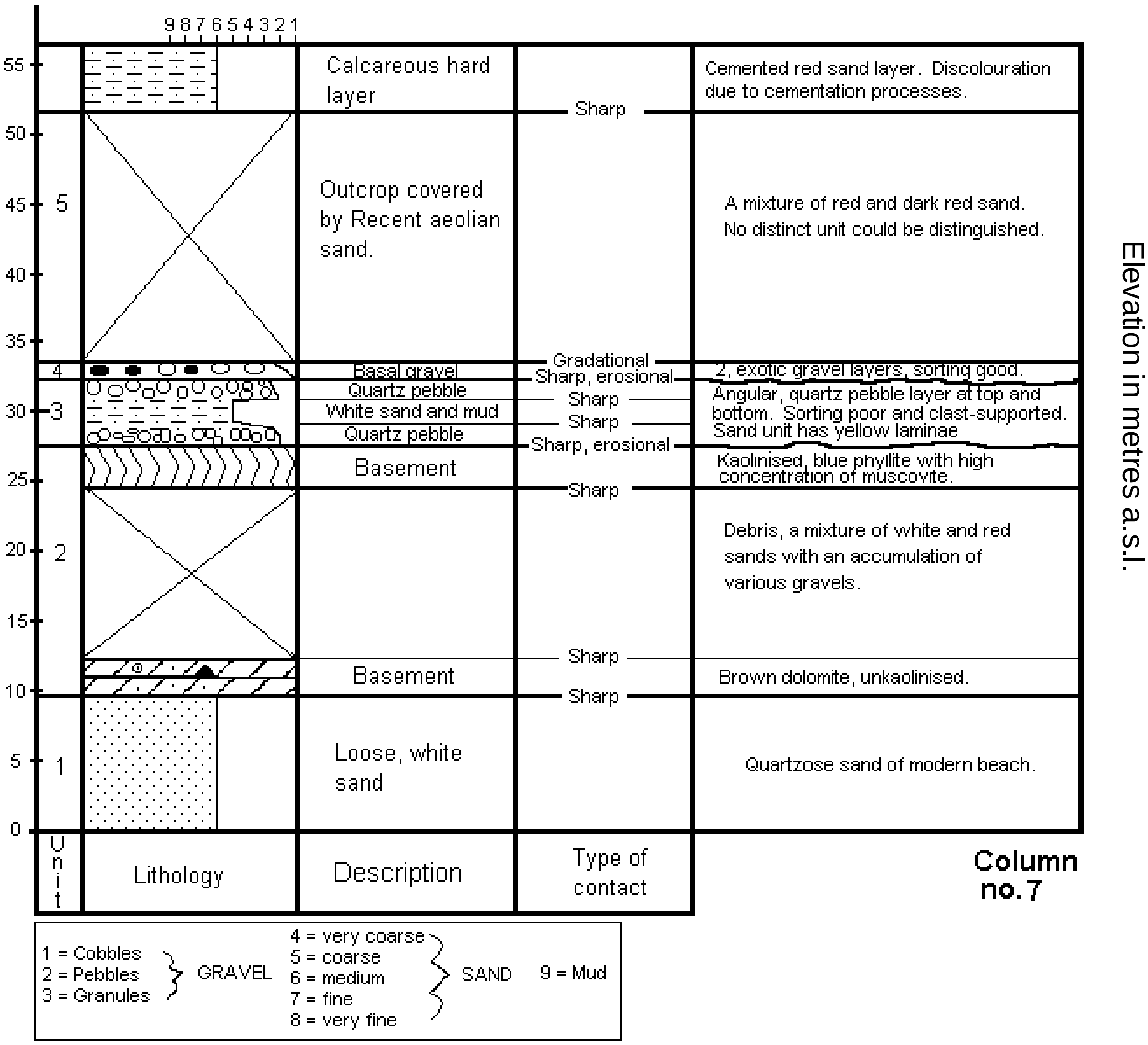


Figure 7: Lithological section of profile 7.

1.8 Profile 5

The base of the profile is at the high water mark of the present beach and has an accumulation of large silcrete blocks.

The basal marine gravels (subtidal facies) of the +50m package are not more than 0.5m thick and vary from having one to three separated pebble layers interspersed with a yellow sand unit. The sorting is very poor and the sand unit shows clear bedding. The pebble layers are cemented with calcrete. The calcrete is not pure calcium carbonate, as it does not react with cold HCL.

The intertidal facies of the +50m package was identified by its laminations of heavy minerals. There are also shell lags of *D. haughtoni* in this unit. The heavy mineral laminae are cemented and extend horizontally for no more than 2m in this profile. The shell lags are found above the heavy mineral layers and are up to 1m thick. The shell lags consist of a mixture of shell fragments and small pebbles, held together by a matrix of heavy mineral-rich sands. Above the shell lags, the heavy sands continue but are less concentrated. This placer sand in this profile differs from that found in Profile 6 in that it is more brownish-red, although the unit still has the prominent “forest” of calcified roots and trace fossils jutting up from the surface.

The dune sand at the top of this profile, remains a mystery, as it is not like the dorbank or recent aeolian sand units of the other profiles.

Table 8: Summary of units mapped in profile 5.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		6.00	6	6.00	Beach	RB
1b	Debris	14.70	23	Pebbles, cobbles and (5m+) silcreet boulders lying ontop of present beach sand.		5.74	11.74			
1c	2m Terrace	2.40	23	Horizontal bedding of alternating pebble and sand (white,red and yellow) layers.		0.94	12.68			
2a	Debris	15.37	23	Predominantly sand, less structured than previous unit.		6.01	18.69			
2b	Debris	16.37	23	Pebbles smaller, sand changes from yellow to white. Shells found towards top.	45	6.40	25.08			
2c	Debris	12.80	30	No silcreet boulders. Debris:sand, pebbles,shells,calc and phosphorite.	46	6.40	31.48	25.48		
2d	Clay	0.30	30	White clay, appears to be cemented in places.	47	0.15	31.63	0.15	Fluvial	CC
3a	Basal Pebble Layer	0.20	25	Sorting is poor and overall trend could not be seen.		0.08	31.72		Subtidal	50m
3b	Sand unit 1	1.20	25	Sand with cross-bedding.		0.51	32.22			
3c	Pebble Layer 2	0.15	25	Moderately sorted, prograding: larger pebbles at top of layer.		0.06	32.29			
3d	Sand unit 2	0.80	25	Sand with cross-bedding.		0.34	32.63			
3e	Pebble Layer 3	0.25	25	Moderately sorted, prograding: larger pebbles at top of layer.		0.11	32.73			
3f	Sand Unit 3	3.75	25	Sand with horizontal laminae, could also be start of palaeo-placer unit.	48	1.58	34.32			
4a	Cemented sand unit 4	0.50	29	? start of paleo-placer due to cementing and heavy mineral laminae.		0.24	34.56			
4b	Shell Layer no 1	0.20	29	Contact of unit not easily seen due to cementing.	49	0.10	34.66			
4c	Sand unit 5	0.60	29	Sand unit is structureless and colour is more grey-white than sand below.		0.29	34.95			
4d	Shell Layer no 2	0.20	29	Donax and oysters shells. Large pebbles (+12cm) at top. Little sand.		0.10	35.04			
4e	Sand unit 6	0.40	29	Whitish-grey sand unit that is structureless.		0.19	35.24			
4f	Shell Layer no 3	0.20	29	Two thin shell layers (oysters, Donax fragments). More sand.		0.10	35.34			
4g	Sand unit 7	0.80	29	Sand is structureless.		0.39	35.72			
4h	Shell Layer no 4	0.30	29	Donax, oyster shell pieces, pebbles and fine calcareous tubes (bioturbation).		0.15	35.87	4.24		
4i	Sand unit 8	18.30	29	Structureless black sand with numerous protruding calc tubes.	50	8.87	44.74	8.87	Beach	50m
6a	Brown/red sand	15.70	21	Weathering: distinctive channels. Colour brownish red. No bioturbation.		5.63	50.37		Dune	AD
6b	Brown/red sand	13.50	21			4.84	55.20	10.46		
7	Red aeolian	12.40	21	Covered with plants.		4.44	59.65	4.44	Dune	AR
					TOTAL:	59.65				

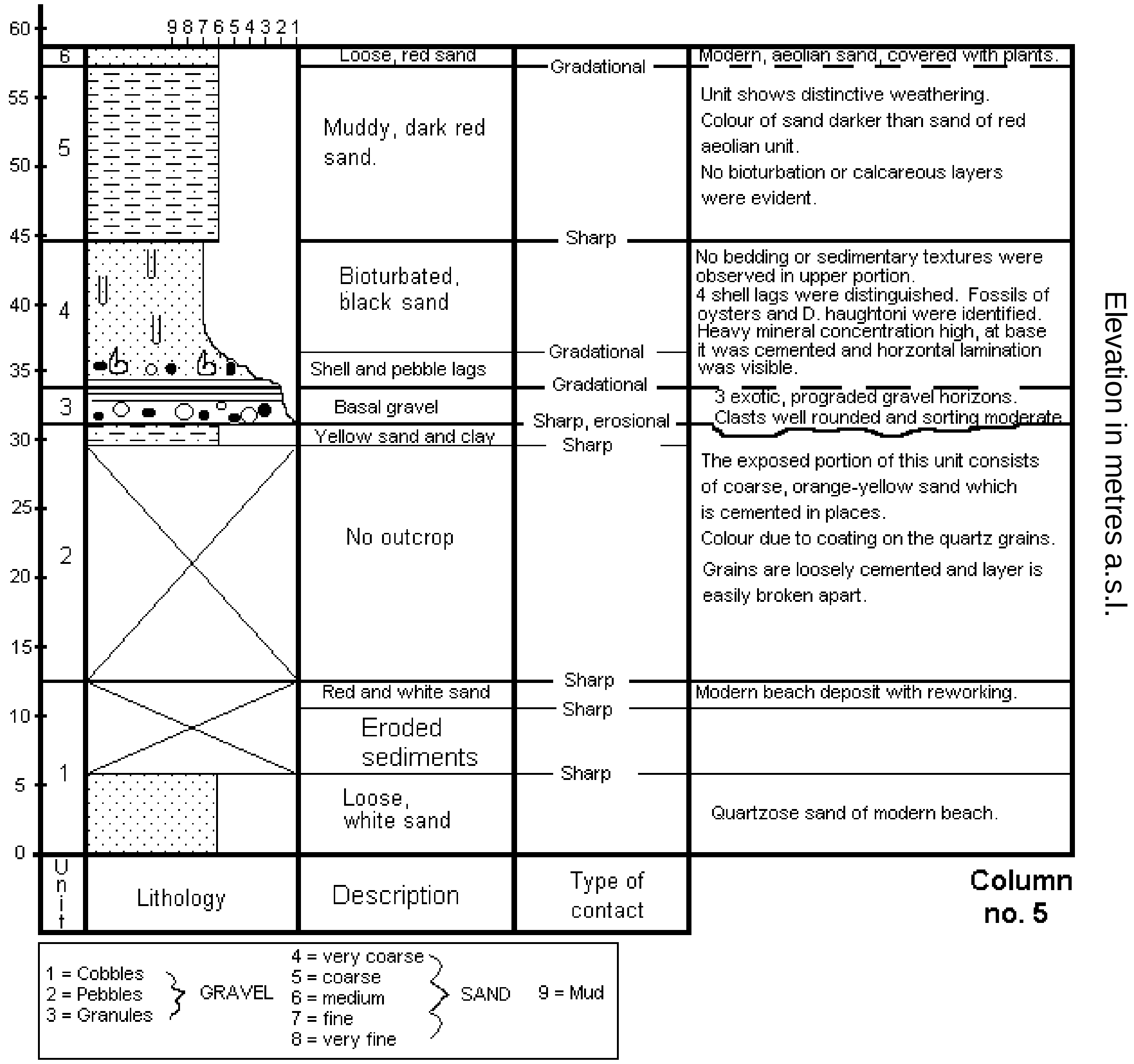


Figure 8: Lithological section of profile 5.

1.9 Profile 13

There were no quartz pebble layers in the fluvial sediments of this profile. The fluvial unit was composed of coarse sand, which was interbedded with a layers of eroded clay blocks. The thickness of the clay layers varied from 0.5m to 2m at the top of the unit. The fluvial unit was characterised by a dip of 30°, down to the north. Slumping might be a feasible explanation for this dip as there are no gravel horizons to anchor the sediments. The top portion is silicified and silcrete blocks collect in the gullies eroded into this unit. At the base of the profile, a cemented block of coarse sand showed clear cross-bedding and was studied in detail. Again a northward to northwesterly flowing stream direction was indicated.

The basal marine gravel (subtidal facies) appeared to be continuous with the placer sand (intertidal) unit and both units form part of the +50m package. The placer sand unit was thinner than that found in Profile 6, while the dune units appeared thicker and made up for the difference in volume between the two profiles. The placer and dune units were affected by calcareous layers and, in places, resulted in local colour changes within the units.

Table 9: Summary of units mapped in profile 13.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		5.00	5		Backshore	RB
1b	Present beach	15.37	3	Predominantly garnet-rich sand.		0.80	5.80			
1c	Present beach	11.91	7	High concentration of heavy minerals.		1.45	7.26	7.26		
1d	2 m Terrace	2.00	38	Yellow and present beach sand interbedded.		1.23	8.49			
1e	Debris	9.71	2	Road and associated debris.		0.34	8.83	1.57		
2a	Quartz Pebble 1	0.41	60	Granule layers, matrix supported. Larger pebbles, top with yellow "rust".	113	0.36	9.18		Fluvial	CC
2b	Clay unit 1	11.90	40	Patches of clay blocks, more obvious towards top.	114	7.65	16.83			
2c	Sand unit 1	16.50	40	Coarse sand with few granule lenses. Dips 23 (down to north).	115	10.61	27.44			
2d	Clay unit 2	5.40	45	Clay in blocks.	116	3.82	31.25	22.43		
3a	Debris	2.20	18	No basal pebble layer apparent but large silcreet cobbles are present.		0.68	31.93		Subtidal	50m
3b	Sand unit 1	0.30	75	Low angle X-bedding, dark brown. Current flowing N.		0.29	32.22			
3c	Pebble layer 2	0.10	75	Pebbles and cobbles, matrix-supported, poorly sorted.	71	0.10	32.32			
3d	Sand unit 2	0.10	75	Scattered with pebbles and cobbles.		0.10	32.42			
3e	Pebble layer 3	0.20	75	Poorly sorted, pebbles and cobbles. No fixed bearing, dipping down to N or S.		0.19	32.61			
3f	Sand unit 3	0.40	75	Scattered pebbles and cobbles.		0.39	33.00			
3g	Calc Layer B	0.20	75			0.19	33.19			
3h	Sand Unit 2	0.20	75	Loose rubble.	72	0.19	33.38			
3i	Calc Layer C	0.10	75			0.10	33.48			
3j	Sand Unit 3	0.20	75	Loose rubble.		0.19	33.67			
3k	Calc Layer D	0.20	75			0.19	33.87			
3l	Sand Unit 4	0.10	75	Loose rubble.		0.10	33.96			
3m	Calc Layer E	0.50	75	Cemented conglomerate layer (0.5m), poorly sorted pebbles.		0.48	34.45			
3n	Sand and pebble 1	0.80	75	Yellow /brown sand laminae, also thin pebble layers. Cross bedding.	73	0.77	35.22			
3o	Calc Layer F	0.80	75			0.77	35.99			
3p	Sand and pebble 2	1.40	85			1.39	37.39			
3q	Calc Layer G	0.20	90			0.20	37.59			
3r	Sand and pebble 3	1.40	90			1.40	38.99			
3s	Calc Layer H	0.80	90			0.80	39.79			
4a	Sand and shell 1	0.50	24	Donax fragments and oysters. Pebbles present and sand is white.		0.20	39.99			
4b	Calc Layer I	0.20	24			0.08	40.07			
4c	Sand and shell 2	5.23	16	Donax fragments and oysters. Pebbles present and sand is white.	74	1.44	41.51	10.26		
4d	Calc Layer J	0.80	24			0.33	41.84		Beach	50m
4e	Black sand	15.37	32	With calc tubes.	75	8.14	49.98			
4f	Debris	2.00	26	Blood red sand		0.88	50.86	10.79		
5a	Yellow sand	13.37	26		77	5.86	56.72		Dune	AY
5b	Yellow sand	5.00	24		78	2.03	58.75	7.89		
6a	Blood red sand	10.57	25		76 79	4.47	63.22		Dune	AD
6b	Calc Layer	9.50	60		80	8.23	71.45			
6c	Blood Red Sand	5.20	32	Penetrated by calc veins.	81	2.76	74.20	15.45		
7	Red Aeolian	15.37	5	Covered by plants.		1.34	75.54	1.34	Dune	AR
					TOTAL:	**75.54**				

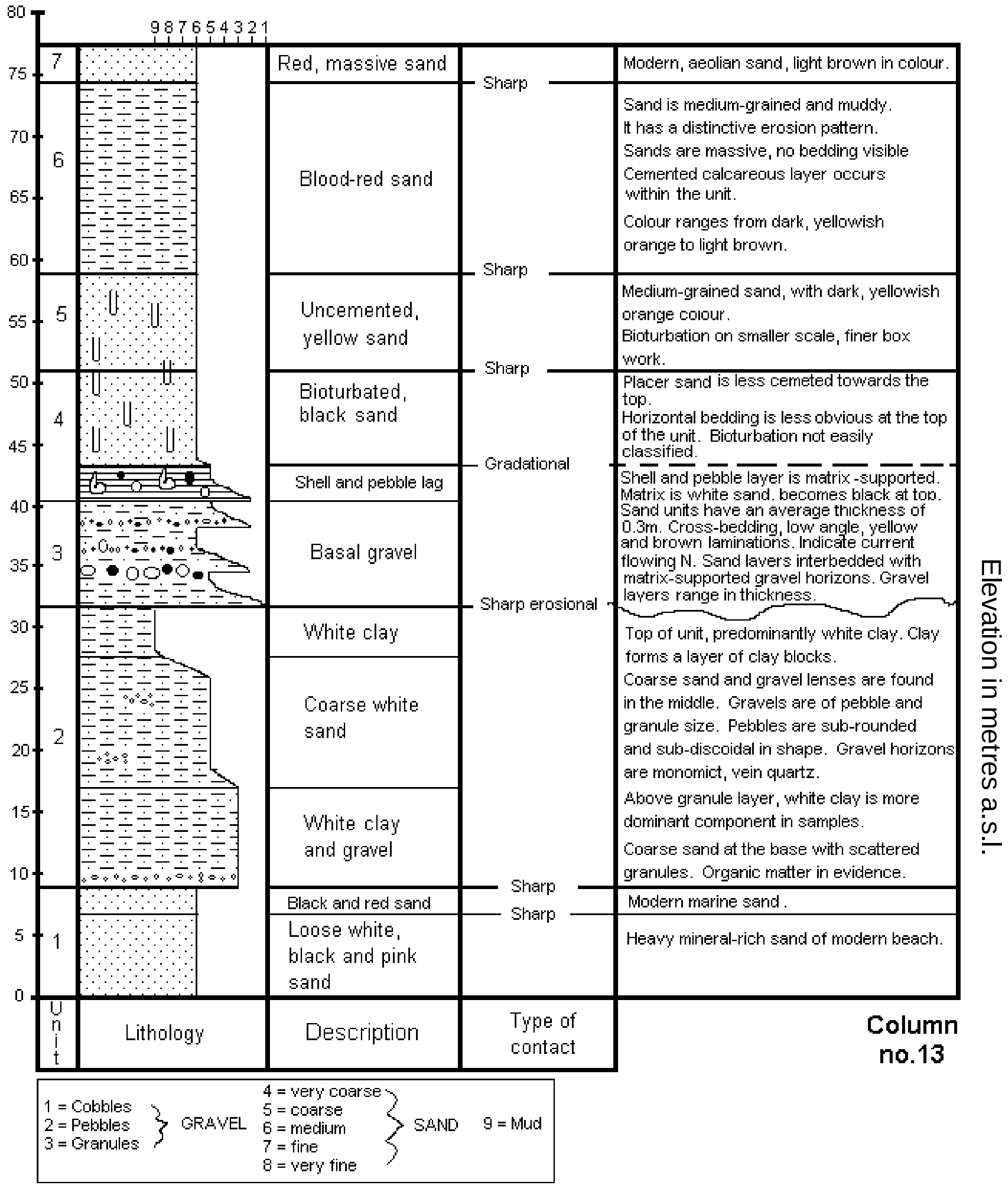


Figure 9: Lithological section of profile 13.

1.10 Profile 6b

The contact between basal marine gravel unit (subtidal facies) and the intertidal (placer sand) unit in the +50m package appeared to be gradational. There were no reworked dipping cemented blocks or gneiss clasts found in the subtidal facies of this profile.

The origin and age of the yellow dune sand unit found above the placer sands is still unclear. The bioturbation in the dune sand (calcified tubes) is on a much smaller scale than that found in the placer unit. (The tube diameters are smaller and boxwork is more intricate.)

Table 10: Summary of units mapped in profile 6b.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present Beach			Added to complete stratigraphic column.		2.00	2		Backshore	RB
1b	Present Beach	15.37	5	Garnets, heavies and quartz.		1.34	3.34			
1c	Present Beach	15.37	4	Just quartz.		1.07	4.41			
1d	Present Beach	15.37	4	Very rich in heavy minerals.		1.07	5.48	5.48		
1e	2m Terrace	3.33	25	Alternating red and black sand with gravel layers.		1.41	6.89	1.41		
2	Brown Dolomite	12.14	66			11.09	17.98	11.09		B
3a	Clay	15.37	22	Clay is white with gravel lenses.		5.76	23.74		Fluvial	CC
3b	Debris	15.37	10	White sand and pebbles.		2.67	26.41			
3c	Debris	14.06	11	Clay, sand and pebbles.		2.68	29.09			
3d	Clay	11.85	12	Clay becomes stained red and is covered by large silcreet blocks.		2.46	31.55	13.57		
4a	Basal Pebble Layer	0.70	42	Very poor sorting, possibly prograding.		0.47	32.02		Subtidal	50m
4b	Debris	7.03	42	White sand with pebbles scattered here and there.		4.70	36.73			
4c	Calc Layer A	0.02	42			0.01	36.74			
4d	Sand + Pebble	1.01	42	Yellow sand with pebbles that are coated with a white substance.		0.68	37.42			
4e	Calc Layer B	0.25	42			0.17	37.58			
4f	Sand Unit	0.32	42	Yellow sand with darker bands of heavy minerals.		0.21	37.80			
4g	Calc Layer C	0.35	42			0.23	38.03			
4h	Sand Unit	3.57	42	Yellow sand with alternating light and darker bands. The sand is very fine.		2.39	40.42			
5a	Shell Layer no 1	0.70	24	Mostly shell pieces: Donax, oysters and few Patellas. Cobbles present.		0.28	40.71			
5b	Sand Unit	0.58	24	Alternating grey and black laminae. Black layers rich in heavy minerals.		0.24	40.94			
5c	Shell Layer no 2	2.57	24	Shells of pedominantly Donax fragments are concentrated towards the top.		1.05	41.99	10.43		
5d	Sand Unit	3.72	22	Heavy mineral laminae found either scattered or in one thick band.		1.39	43.38		Beach	50m
5e	Calc Layer D	0.70	22			0.26	43.64			
5f	Sand Unit	1.31	22	Alternating grey and black laminae. Black layers rich in heavy minerals.		0.49	44.13			
5g	Calc Layer E	0.70	22			0.26	44.40			
5h	Sand + Calc layer	3.78	22	The calc layer is covered by sand which also has dark and light laminae.		1.42	45.81			
5i	Sand Unit	15.87	12	No bedding in middle: loose, homogenous black sand with calc tubes.		3.30	49.11	7.12		
6a	Yellow sand	3.63	34	Yellow sand: alternating white/yellow laminae. Fine tubes found here.		2.03	51.14		Dune	AY
6b	Yellow sand	4.10	17			1.20	52.34	3.23		
7a	Red Aeolian	6.35	12	No plants and distinctive erosion channels.		1.32	53.66		Dune	AR
7b	Red Aeolian	15.37	12	Covered by plants.		3.20	56.86			
7c	Red Aeolian	15.37	8	Covered by plants.		2.14	58.99			
7d	Red Aeolian	15.37	11	Covered by plants.		2.93	61.93			
7e	Red Aeolian	15.37	14	Covered by plants.		3.72	65.65			
7f	Red Aeolian	15.37	5	Covered by plants.		1.34	66.99			
7g	Calc layer	15.37	26	Big gravel pits dug into the gravel at the top of this profile.		6.74	73.72	21.38		
					TOTAL:	**73.72**				

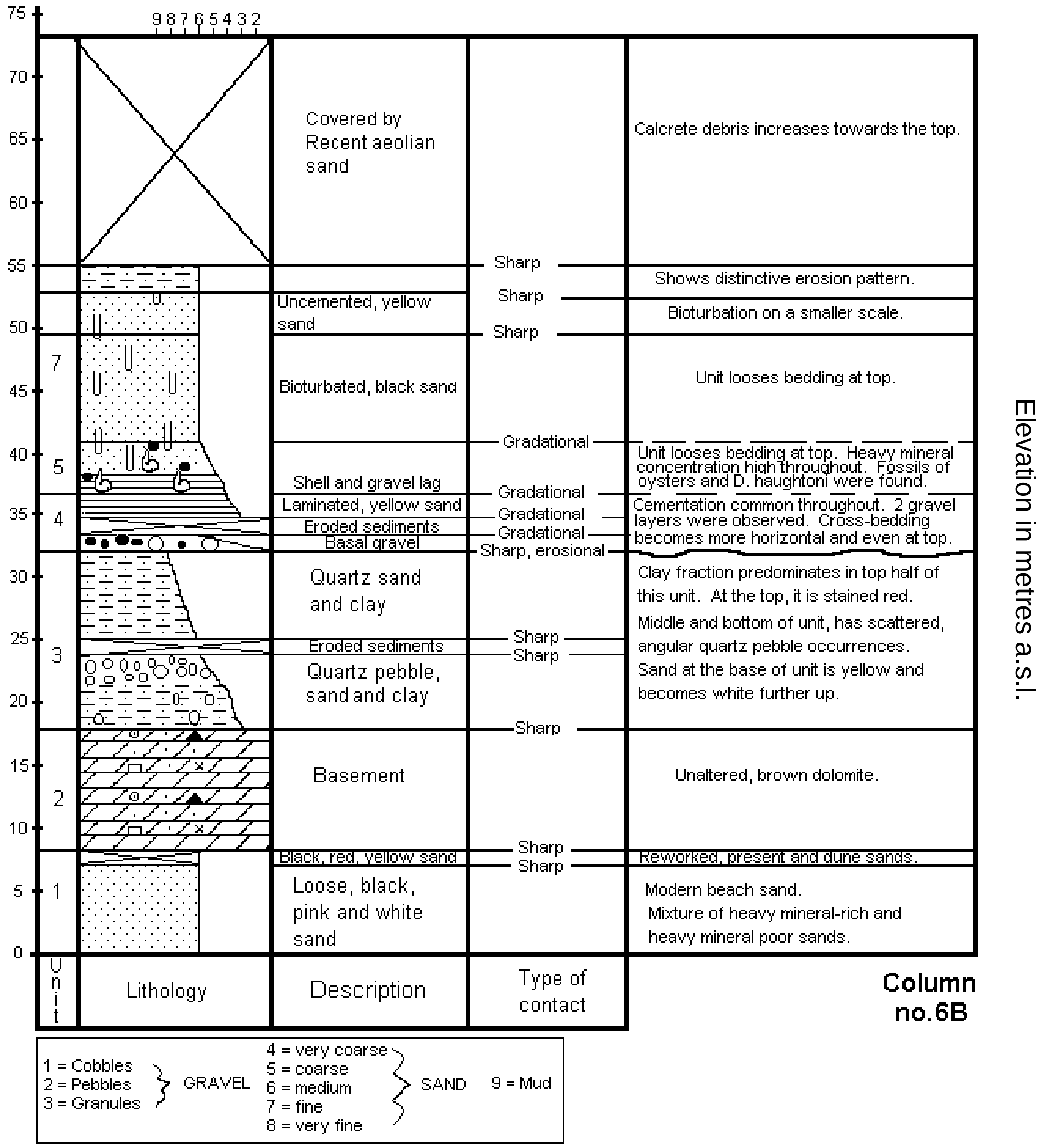


Figure 10: Lithological section of profile 6b.

1.11 Profile 6

This profile is the most complete and accessible of all the profiles. The base of the profile is made up of dolomite and fluvial white clay. The latter bears a reddish stain towards the top, which might be as a result of the leaching of the overlying iron-rich clasts.

In contact with the fluvial unit is the prograding, basal pebble layer of the basal marine gravel unit (subtidal of +50m package). Within this unit are strongly dipping pebble and sand layers. The sand is yellow in colour and has very high heavy mineralsconcentrations ("pay-dirt" layers). Overlying the dipping layers, with a sharp contact is the horizontal, yellow sand and pebble layers of the basal marine gravel unit.

The basal marine gravels are overlain by a white sand layer which is seen being the lower portion of the heavy sand placer unit (intertidal facies) of the +50m package. The white sand is situated directly below the hard calcretised fossil shell lags, which are visible from the beach. Also found in this white sand is layer of loose phosphorite chunks and scattered fragments of the ferricreted conglomerate material.

The upper portion of the placer units differs from the lower half, in that it exhibits no bedding and is a homogeneous, heavy mineral bearing layer. The scattered remains of a tortoise shell were found in the latter unit, which strongly suggests an aeolian component to the placer unit. The bioturbation, seen in the form of these calcified tubes, appears to become larger and less concentrated higher up on the profile and is eventually absent on the uppermost (black-green coloured sand) aeolian component of the placer sand.

Above the placer sands is found a unit of fine, yellow dune sand. A calcareous layer marks the top contact of this unit with the higher dorbank dune sands.

Table 11: Summary of units mapped in profile 6.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		10.00	10	10.00	Backshore	RB
2	Brown Dolomite	11.12	33			6.06	16.06	6.06		B
3a	Clay	10.02	44	Clay is white with gravel lenses.		6.96	23.02		Fluvial	CC
3b	Debris	15.37	2	White sand and pebbles.		0.54	23.55			
3c	Debris	14.06	3	Clay, sand and pebbles.		0.74	24.29			
3d	Clay	10.22	42	Clay becomes stained red and is covered by large silcreet blocks.		6.84	31.13	15.07		
4a	Yellow pebble layer	3.21	47		7b	2.35	33.48		Subtidal	50m
4b	Yellow pebble layer	2.45	32	Calc layer end of dipping layers.	7c 35	1.30	34.77			
4c	Yellow pebble layer	5.94	20	Dip now horizontal.	7a, 7d	2.03	36.81			
5a	White sand	5.73	20	Whiter sand, appears to be aeolian	37	1.96	38.76			
5b	Shell layer 1 and 2	8.96	20	Fossils fragments of Donax with pebbles	6, 3d	3.06	41.83	10.70		
5c	Black sand	12.3	15	Fossilized roots become longer	3c	3.18	45.01		Beach	50m
5d	Black sand	12.1	18		3b	3.74	48.75			
5e	Black sand	13.21	12	Appears to form layers near top.	3a	2.75	51.50			
5f	Black sand	17.5	12	Becomes darker green/brown at top.		3.64	55.14	13.31		
6a	Yellow calc layer	10.72	19	Calc layer has specks, still aeolian placer	4	3.49	58.63		Dune	AY
6b	Yellow calc layer	13.29	10			2.31	60.93	5.80		
7a	Blood red aeolian sand	7.12	22	Still has calc chunks		2.67	63.60		Dune	AD
7b	Blood red sand	9	21			3.23	66.83	5.89		
8	Aeolian/top	11	21	Top (lighter yellow sand) has been graded	5	3.94	70.77	3.94	Dune	AR
					TOTAL:	**70.77**				

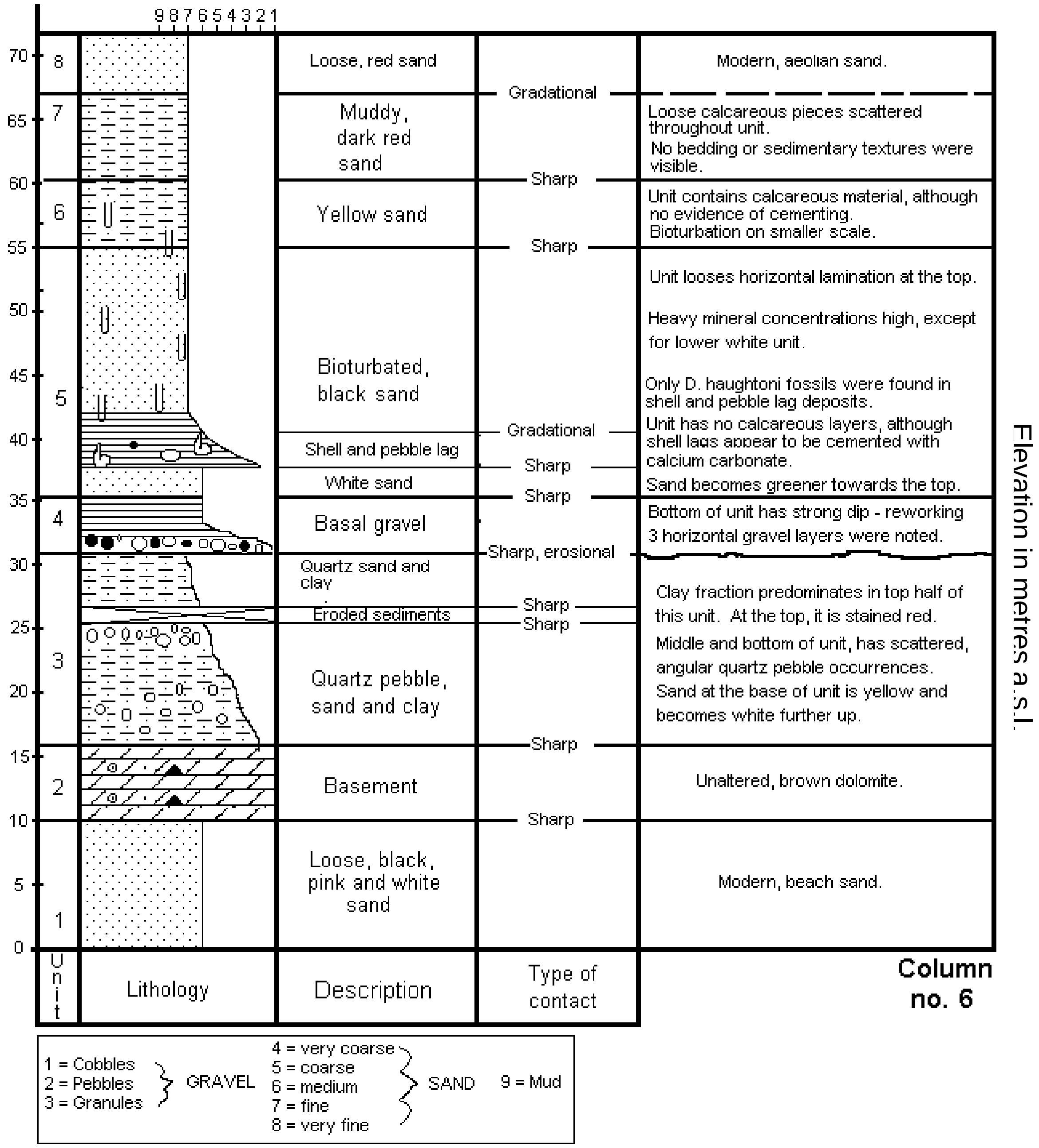


Figure 11: Lithological section of profile 6.

1.12 Profile 14

No basement is found in this profile site, even on the contact with the present beach and it was therefore assumed that the fluvial sediments are at their thickest in this profile (maximum depth of fluvial channel). An outcrop of green phyllite limits the horizontal extent of the channel, 200m to the south and of white phyllite, 150m to the north of this profile. The base of the white fluvial unit in this profile consists of numerous quartz pebble layers, which are embedded in a matrix of coarse, pale orange sand. Sporadic brown/orange “rust” patches are found throughout this unit and these were later identified as patches of organic material. Although the angular, quartz pebbles predominate in the gravel horizons, the occasionally occurrence of grey or brown clay cavaties was noted. The latter was presumed to be the relicts of shale/silt pebble clasts, which have subsequently been weathered away. The fluvial unit, seen as a whole, is fining upward with a layer of pure white clay being present at the top. Within the clay unit is found a layer of clay blocks, which may reach a maximum diameter of 7cm in length.

The subtidal (basal marine gravel layer) of the +50m package marks the start of the marine sediments and, in this profile, it is very thin. The entire basal marine gravel unit was poorly exposed in this profile and mapping data on this unit was obtained from an eroded trench 6m north of this profile site. The intertidal placer unit and the associated shell lags were free of calcareous material and, consequently, bedding features. In general, this unit was badly preserved. Shells were present in three layers and were mainly composed of *Donax haughtoni*. A single *Patella* shell was noted. A few small pebbles were found between the shells in the shell lags. No outcrop of the yellow dune sand unit was found above the placer unit.

At the top of this profile is found the blood red sand of the dorbank unit. There is a single calcareous layer within this unit.

Table 12: Summary of units mapped in profile 14.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		6.00	6		Backshore	RB
1b	Present beach	15.37	11	Garnet and heavy minerals present. Forms a berm in top meter.		2.93	8.93			
1c	Present Beach	11.50	4	Clay lies over top.		0.80	9.73	9.73		
2a	Quartz Pebble Layers	15.37	25	Angular quartz pebbles. Dip 5 (down to south).	82	6.50	16.23		Fluvial	CC
2b	Quartz Pebble Layers	5.90	29		83	2.86	19.09			
2c	Fine sand	5.00	71	Quartz pebble layers stop. Fine sand and clay blocks, silcrete layers.		4.73	23.82	14.08		
3a	Brown sand	13.10	36	Structureless.	84	7.70	31.52	7.70	Shelf	50m
3b	Brown/yellow sand	7.80	41	Shows horizontal layering in patches.		5.12	36.64		Subtidal	50m
4a	Shell Layer 1	1.70	23			0.66	37.30			
4b	Sand unit	1.90	23		85	0.74	38.04			
4c	Shell Layer 2	0.80	23	D. haughtoni, Patella, oysters and pebble lags.		0.31	38.36			
4d	Sand unit	3.70	23			1.45	39.80			
4e	Shell Layer 3	0.90	26			0.39	40.20	8.68		
4f	Sand unit	11.87	32		86	6.29	46.49	6.29	Beach	50m
5a	Calc Layer	1.30	65			1.18	47.66		Dune	AD
5b	Blood red sand	14.30	40			9.19	56.86			
5c	Debris	6.40	28			3.00	59.86	13.37		
6	Red aeolian	8.70	28	Covered by plants.		4.08	63.94	4.08	Dune	AR
					TOTAL:	**63.94**				

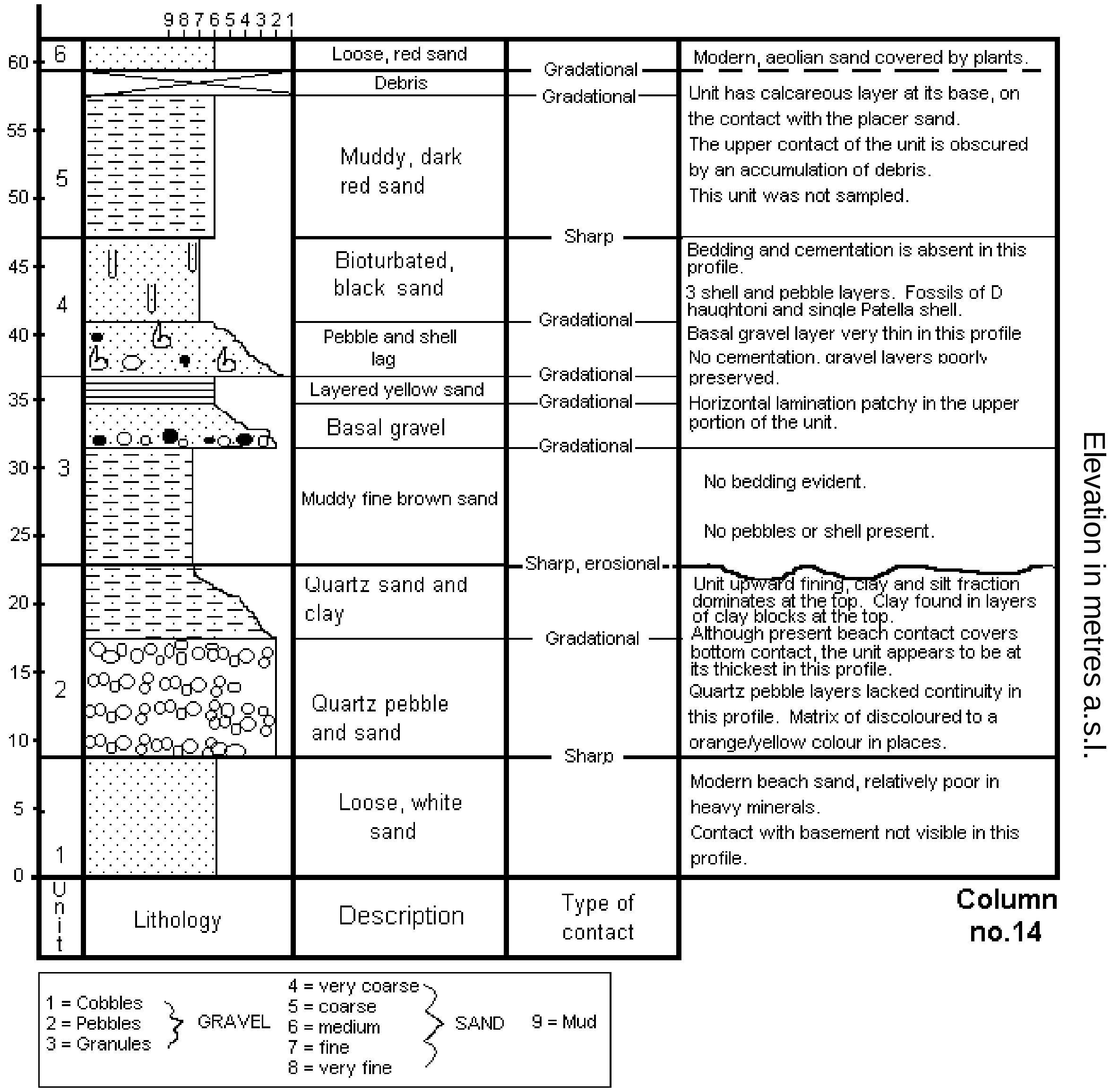


Figure 12: Lithological section of profile 14.

1.13 Profile 2

The white fluvial unit is overlain by the prograding, pebble layer of the basal marine gravel unit (subtidal facies) of the +50m package. The basal pebble layer contains clasts consisting of ferricreted conglomerate. The pebbles within these ferricrete blocks are well rounded. The sand above and below the pebble layer is yellow, fine grained, and often shows cross-bedding and laminations. The bedding of these layers are all horizontal, and no other evidence of reworked (strongly dipping pebble layers) older marine terraces were found. The base of the intertidal unit of the +50m package is characterised by dark heavy mineral-bearing sand and the quartz-rich sand is entirely absent. Horizontal bedding in the form of alternating dark and light heavy mineral laminations is clearly visible. The bedding disappears towards the top of the profile and this has been attributed to a combination of increased bioturbation and also a shift from a marine to aeolian environment. A single fossil shell lag of *Donax haughtoni*, is present and has an intricate network of calcified tubes. The shells of this layer are well preserved and tend to be large and limited to specimens of *Donax*. It has been suggested that the shells are juvenile *D. rogersi.* In the light of the positive identification made by Pether of the shells found in profile 6, they *are D. haughtoni* implying that these sediments are of the +50m package. Identification of the bioturbation was not possible as no distinguishing characteristic could be observed. The top can be described as homogeneous black sand, which upon closer inspection contains aggregations of darker black minerals.

A calcrete overhang was found directly above the placer sands. The stalactites, seen on the exposed underside of the layer is evidence enough for the active ground water action in the area. The material from the calcareous layer is more wind resistant and, consequently, pieces of calcrete are found lying exposed in the sand above and below the solidified calcrete layer.

A yellow, calcareous dune belt unit is found at the top of the profile. The contact with the red aeolian and dorbank sand units is not clear.

Table 13: Summary of units mapped in profile 2.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		5.00	5	5.00	Backshore	RB
2	White phyllite	17.3	10	Readings deceptive as in erosional channel.		3.00	8.00	3.00		B
3a	Quartz pebble 1	9.3	20	Pebble lenses in coarse sand.	117a	3.18	11.18		Fluvial	CC
3b	Quartz pebble 1	13.9	25	Well sorted, matrix-supported, pebbles and granules.	117b117c	5.87	17.06			
3c	Sand unit 1	8.4	26		118	3.68	20.74			
3d	Quartz pebble 2	9	27	Granule lenses. Well sorted. Yellow laminations.		4.09	24.83			
3e	Clay unit 1	13.6	28		19 119	6.38	31.21	23.21		
4a	Basal pebble layer	2	16	Cobbles and boulders. Poorly sorted, matrix-supported. Dip to W,N and E.	21b	0.55	31.76		Subtidal	50m
4b	Sand and pebble	2.1	16	6, granule layers: matrix-supported, dip down W, S. Sand yellower at top.	21a	0.58	32.34			
4c	Sand unit	1.5	16	Horizontal X-bedding of heavy mineral bands.		0.41	32.76			
4d	Debris	7.3	6		18	0.76	33.52			
4e	Calc Layer A	2.6	85		20	2.59	36.11			
5a	Black sand	1	10	Showing clear horizontal bands of heavy mineral layers.		0.17	36.28			
5b	Calc layer	2.6	28			1.22	37.50			
5c	Shell and sand 1	6.1	13	Embedded in calcreet, has pebbles.		1.37	38.88			
5d	Black sand	0.5	14	Showing clear horizontal bands of heavy mineral layers.	17d	0.12	39.00			
5e	Shell and sand 2	4.5	15	Embedded in calcreet, has pebbles.	22	1.16	40.16	8.95		
5f	Black sand	31.8	17	Calcified tubes more intircate and dense at bottom.	17e 17c	9.03	49.19		Beach	50m
5g	Black sand	21.35	11	No calcified tubes found, sand is structureless and green colour at top.	17a 17b	4.07	53.27	13.11		
6a	Calcareous layer	5.2	11	Has black specks, perhaps manganese.		0.99	54.26		Dune	AY
6b	Yellow calc layer	25	11	No dark red sand was noted in this profile.		4.77	59.03	5.76		
7	Red aeolian sand	15.37	5			1.34	60.37	1.34	Dune	AR
					TOTAL:	**60.37**				

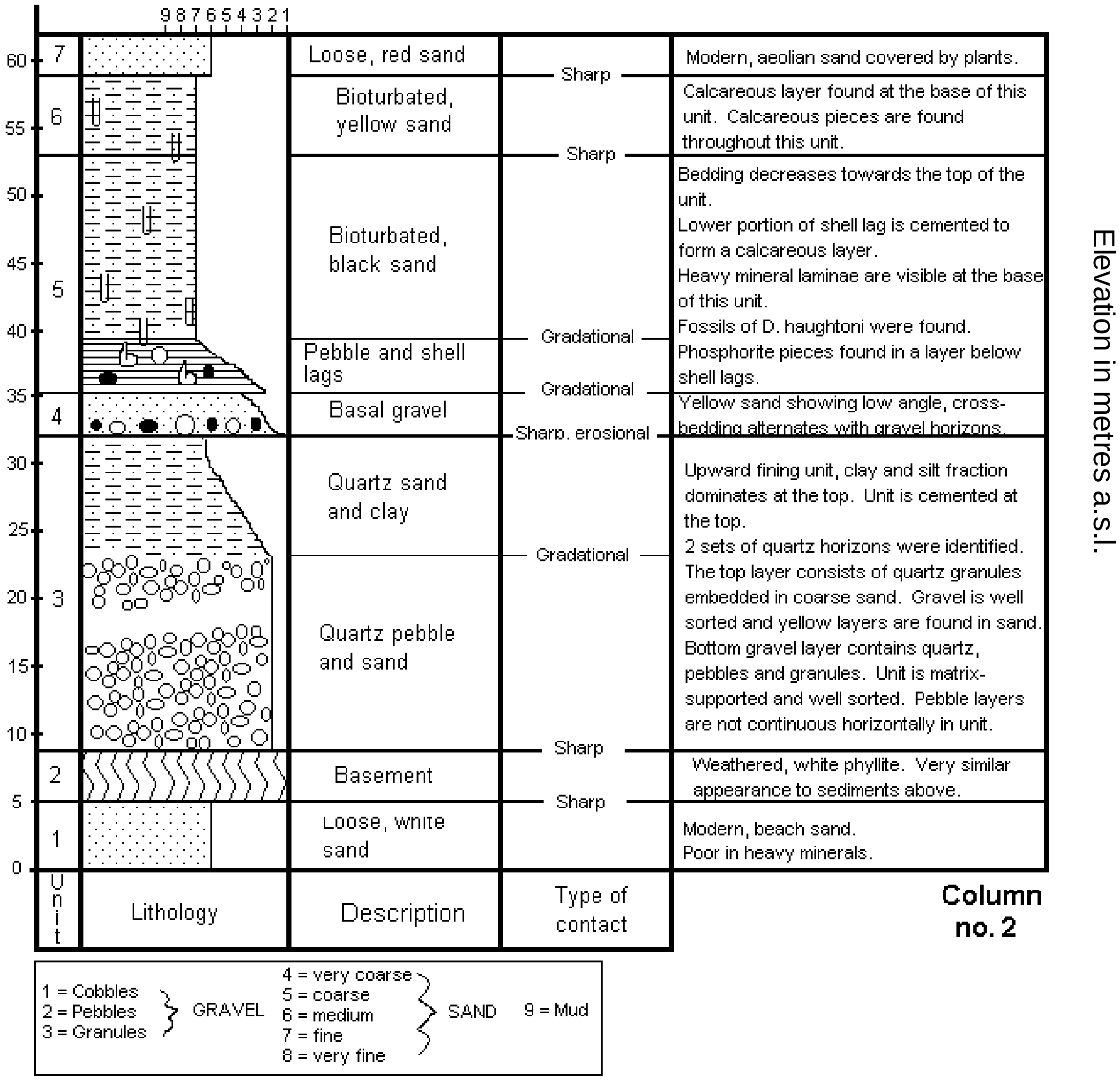


Figure 13: Lithological section of profile 2.

1.14 Profile 15

The bedrock in this profile is green phyllite and the mapping path followed a narrow erosion channel between green and white phyllites.

The basal contact of the fluvial quartz pebble layers with the bedrock is clearly visible in this profile. The pebble layers in the south was steeply dipping and this was the result of slumping. Pebble layers are interbedded with white sand was streaked with yellow organic matter in places. The pebbles in the fluvial unit of this profile are exclusively quartz and appear to become smaller towards the top and are completely absent in the top 10m of the fluvial unit. The top portion of the fluvial unit consists of white clay, which is silcified in the upper reaches. Under the sillicified portion is a layer of clay blocks.

The basal marine gravels or subtidal facies of the +50m package form a sharp contact with the silicified fluvial unit. The basal pebble layer is thick and contains large cobbles of ferruginized conglomerate. There are only three pebble layers in this profile.

Table 14: Summary of units mapped in profile 15.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		8.30	8.3		Backshore	RB
1b	Present beach	15.37	3	Rich in heavy minerals.		0.80	9.10			
1c	Present beach	15.37	3	Mixture of present beach and debris of dune sand.		0.80	9.91	9.91		
2a	Brown Dolomite	15.37	3	Erosion channel 5m wide, walls of green phyllite with S of 58.		0.80	10.71			B
2b	Green Phyllite	15.37	4	Base of channel, covered by debris.		1.07	11.79			
2c	Green Phyllite	15.37	14			3.72	15.50			
2d	Green Phyllite	9.60	8			1.34	16.84	6.93		
3a	Quartz Pebble Layer	15.37	10	Larger, angular quartz pebbles.	87	2.67	19.51		Fluvial	CC
3b	Quartz Pebble Layer	15.37	10	Finer, angular quartz pebbles.		2.67	22.18			
3c	Fine sand	15.37	16	Clay blocks lying in a layer.	88	4.24	26.41			
3d	Fine sand and clay	8.50	23	Fine sand is silcretised.	89	3.32	29.74			
3e	Fine sand and clay	8.44	14	Silcretised sand, forms outcrop for top 2m.		2.04	31.78	14.94		
4a	Basal marine pebble	0.50	17			0.15	31.92		Subtidal	50m
4b	Sand unit 1	0.60	16			0.17	32.09			
4c	Pebble layer 2	0.10	15		90	0.03	32.11			
4d	Sand unit 2	0.20	14			0.05	32.16			
4e	Pebble layer 3	0.10	19			0.03	32.20			
4f	Debris	1.70	35			0.98	33.17	1.39		
5	Red sand	9.60	45	Calcified tubes found on surface.		6.79	39.96		Dune	AR
6	Red sand	5.70	45			4.03	43.99	10.82		
					TOTAL:	**43.99**				

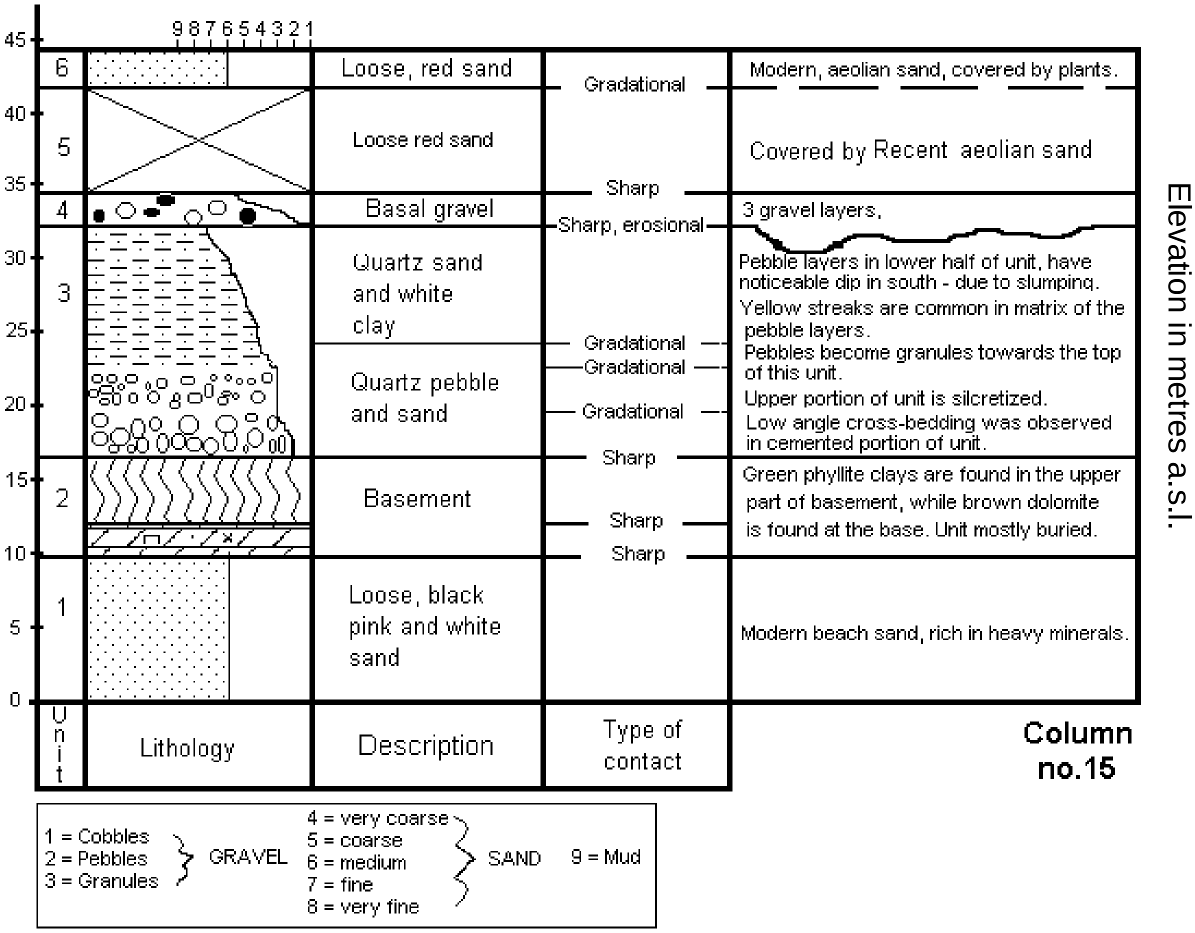


Figure 14: Lithological section of profile 15.

1.15 Profile 4a

Much of the stratigraphy of this profile is covered by eroded material and although the different layers could be distinguished their relation to one another remains unclear. The basement of Table Mountain Sandstone consists exclusively of consolidated, white sand and, given the amount of faults present in this area, could almost be described as a quartzite rather than sandstone. The contact between the white Table Mountain Sandstone and white clay of the fluvial unit is not easily seen and the latter appears to pinch out against the former.

The first pebble layer of the basal marine gravels, is deposited directly onto the basement of Table Mountain Sandstone in this profile. It is a prograding pebble layer and was seen to overlie a succession of strongly dipping yellow sand and pebble layers. The latter is cemented in places to form chunks of solid ilmenite. Within the pebble units, ferruginized conglomerate blocks were present.

This profile is marked by a high oyster concentration, instead of *Donax* shells in the fossil layers found above the basal marine gravel unit. The concentration of oyster shells, appears to hint at palaeo-estuarine environment present in this profile, as opposed to the shoreface facies characterized by *Donax* shells. No placer sand unit is present and instead, there is a succession of yellow sand layers bearing the same calcified tubes and even calcified termite mounds. The calcareous material becomes more concentrated towards the top where it forms a solid calcareous layer. The calcareous layer is speckled with small grains of black minerals which suggests that the sand might well have been placer sand (aeolian) before it was later calcified.

Above the calcareous layer the sand becomes redder and gradually becomes dorbank sand. The dorbank also contains calcareous material and appears to be composed of a series of red and yellow sand layers. Discoloration of sand appears to be associated with the calcareous layers.

Table 15: Summary of units mapped in profile 4a.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		5.00	5	5.00	Backshore	RB
2a	T.M. Sandstone	12.49	7	See sketch of basement rocks.	30	1.52	6.52			B
2b	T.M. Sandstone	16.2	14	Covered by clay and pebble debris		3.92	10.44			
2c	T.M. Sandstone	7.91	32	Clay covering thickens towards top		4.19	14.63	9.63		
3a	Clay	10.86	23			4.24	18.88		Fluvial	CC
3b	Clay	8.21	6			0.86	19.73			
3c	Clay	9.02	4	Photo taken of distinct blocks.		0.63	20.36			
3d	Debris	8.06	26	First pebble layer at 3.40		3.53	23.90			
3e	Debris	8.12	13	Oysters more abundant at top		1.83	25.72	11.09		
4a	Yellow sand	4.42	25	Very fine with horizontal layering	36a	1.87	27.59		Subtidal	30m
4b	Yellow sand	6.29	34	Dip is 02 NW.		3.52	31.11			
5a	Oyster layer	12.83	6			1.34	32.45	6.73		
5b	Debris	12.11	20	Calc becomes concentrated at top		4.14	36.59		Beach	30m
5c	Debris	8.13	26	To base of calc layer.	34	3.56	40.16	7.71		
6a	Calc layer	1.1	57	Possibly calcified red aeolian layer		0.92	41.08		Dune	AD
6b	Debris	8.72	13			1.96	43.04			
6c	Blood red aeolian	15.3	13			3.44	46.48			
6d	Blood red aeolian	15.3	2		32	0.53	47.02			
6e	Red aeolian	26.5	12			5.51	52.53	12.37		
7	Red aeolian	14.5	12			3.01	55.54	3.01	Dune	AR
					TOTAL:	55.54				

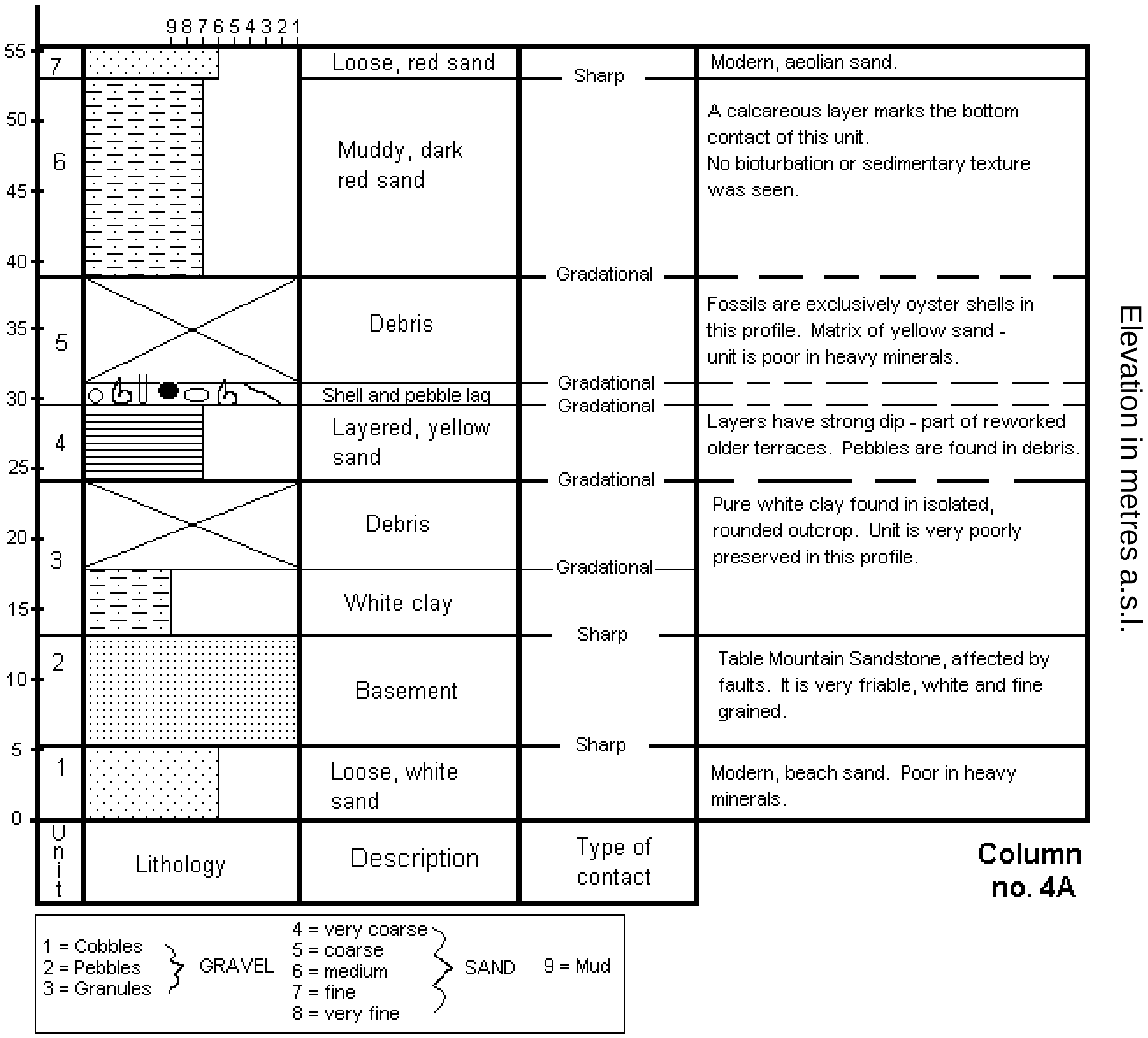


Figure 15: Lithological section of profile 4a.

1.16 Profile 4b

This profile is situated in an eroded valley and the top half of the profile is covered by eroded material. The shelf sediments of the +50m package are represented in this profile. The basal marine gravel layers (subtidal facies) of the +50m package in this profile contains shell fragments and are cemented in places.

Table 16: Summary of units mapped in profile 4b.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		5.00	5	5.00	Backshore	RB
2a	T.M. Sandstone	12.49	7	White, crumbling sandstone with dip EW of 18 away from sea.		1.52	6.52			B
2b	T.M. Sandstone	16.2	12	Black tips to eroded outcrops are clearly visible.		3.37	9.89			
2c	T.M. Sandstone	15.3	18	A large normal fault as well as minor faults were in evidence.		4.73	14.62	9.62		
3a	Debris	15.32	6	Pebbles and clay, accumulate particularly in erosion channels.		1.60	16.22		Fluvial	CC
3b	Debris	26.91	3			1.41	17.63			
3c	Debris	48.93	3			2.56	20.19			
3d	Clay	20.23	4	Portion of dipping, pay-dirt layer was found ontop of clay outcrop.		1.41	21.60			
3e	Debris	18.61	5			1.62	23.22			
3f	Debris	7.72	6		28	0.81	24.03	9.41		
4	? Sand	4.44	20	Structureless yellow sand with calc veins.	27	1.52	25.55	1.52	Shelf	50m
5a	Sand and pebble 1	0.26	20	Sand with darker yellow bands in isolated pockets.	26,36b	0.09	25.64		Subtidal	30m
5b	Pebble layer 1	0.34	20	Pebbles of 5cm and greater. Poorly sorted.		0.12	25.75			
5c	Sand and pebble 2	0.44	20	Thick sandy wedge with table cross bedding and pebble lenses.		0.15	25.90			
5d	Pebble layer 2	0.08	20	Well sorted, fine pebble layer.	25	0.03	25.93			
5e	Sand unit 1	0.1	20	Yellow sand.		0.03	25.96			
5f	Pebble layer 3	0.04	20	Well sorted pebble layer, small pebbles only.		0.01	25.98			
5g	Sand unit 2	0.08	20	Horizontal bedding clearly visible.		0.03	26.01			
5h	Pebble layer 4	0.32	20	Pebbles vary in size but not as large as layer below.	24b	0.11	26.12			
5i	Sand unit 3	0.06	20	Horizontal bedding structures.		0.02	26.14			
5j	Pebble and shell 1	0.28	20	Poorly sorted, pebble sizes vary greatly.	24a	0.10	26.23			
5k	Calc layer	2.54	18	Very thin layer, appears to be unrelated to the topmost calc layer.	23	0.78	27.02	1.47		
6a	Debris	15.39	9	No bedding structures, non-descript sand temporarly classified as debris.		2.41	29.42		Dune	AY
6b	Debris	8.6	10	Still the debris package, no definite colour to the sand.	33	1.49	30.92			
6c	Debris	2.5	11	Loose pebbles and shell fragments.		0.48	31.39	4.38		
6d	Debris	162	13	Brown sand with scattered calc chunks.		36.44	67.84	36.44	Dune	AD
7	Red aeolian sand	18	13	Red aeolian extends to the top of the hill.		4.05	71.89	4.05	Dune	AR
					TOTAL:	**71.89**				

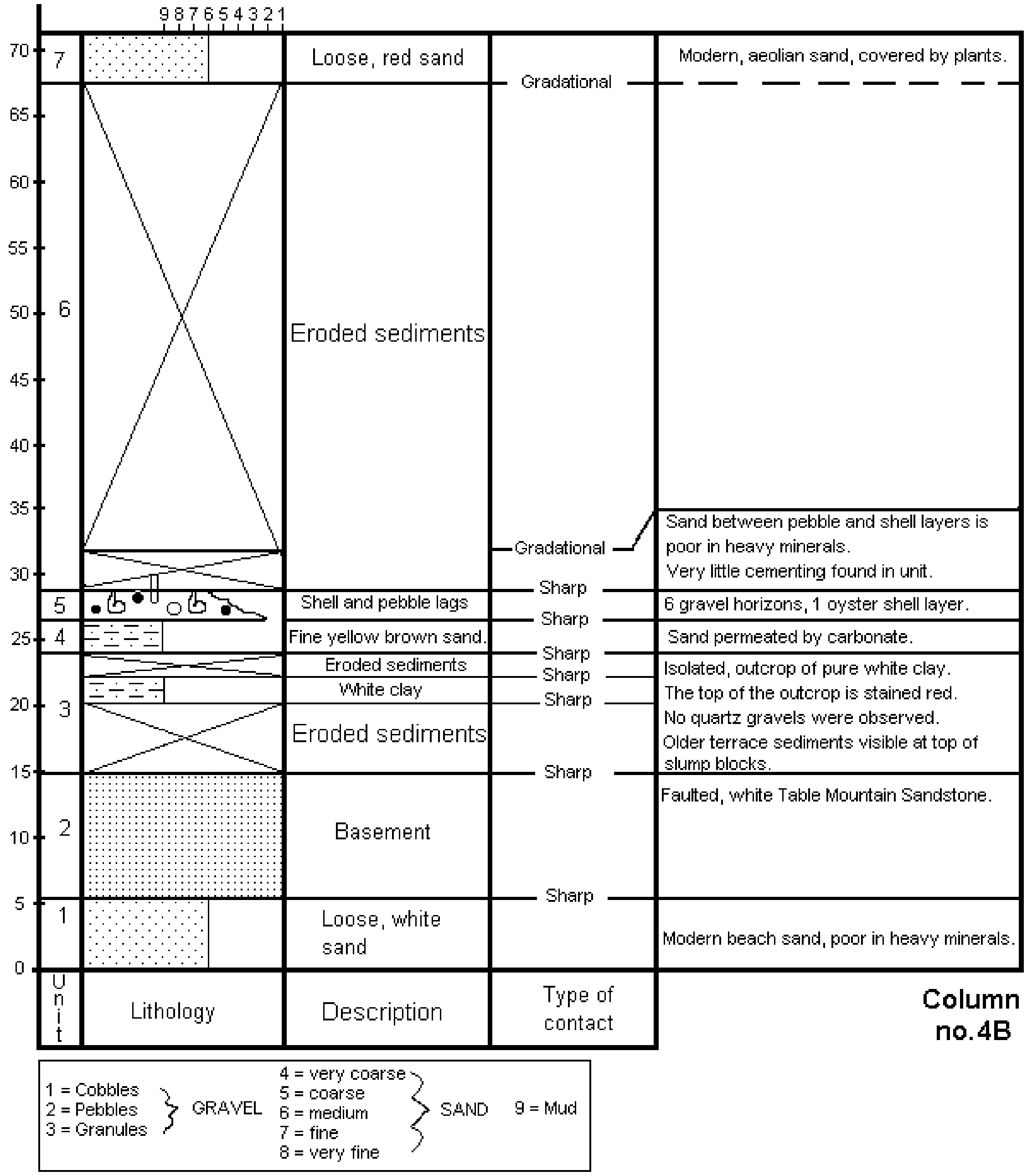


Figure 16: Lithological section of profile 4b.

1.17 Profile 4c

The bedrock of white Table Mountain sandstone has a distinct dip to the east, of 16 degrees and has a bearing of 321 degrees.

The white fluvial unit is noticeably absent in this profile.

The prograding, basal pebble layer of the basal marine gravel units of the +50m package is present in this profile and lies directly in contact with the basement.

Fossil shells are scarce in this profile and limited to a few oyster shells and *Patella's*, found higher up, and embedded in the sand of the yellow calcareous sand unit. The *Patella* shells are part of a midden found at the top of the profile. The black placer sand continues to be absent and the yellow calcareous sand unit is the heavy mineral-deficient equivalent of this unit.

A thin dorbank layer is found at the top of this profile and it lies directly above a calcareous layer.

Table 17: Summary of units mapped in profile 4c.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column		6.00	6	6.00	Backshore	RB
2a	T.M. Sandstone	15.63	32	Dip of 16 and bearing of 321.	31	8.28	14.283			B
2b	T.M. Sandstone	15.32	19			4.99	19.27			
2c	T.M. Sandstone	15.42	24	Pebbles more concentrated at top.	29	6.27	25.54	19.54		
3a	Debris	15.44	17	Pebbles and oysters.		4.51	30.06	4.51	Subtidal	30m
4a	Debris	45.88	6	Patella shells possibly midden. Yellow sand with calc. Loose gravel.		4.80	34.85			
4b	Debris	45.6	8	Sand colour change very subtle. Yellow sand with calc.		6.35	41.20			
4c	Debris	15.28	10	Red sand with calc. Loose gravel present.		2.65	43.85			
4d	Calc layer	3.45	11			0.66	44.51	14.45		
5	Blood red aeolian	5.56	37	Heavy sand specks present.		3.35	47.86	3.35	Dune	AD
					TOTAL:	**47.86**				

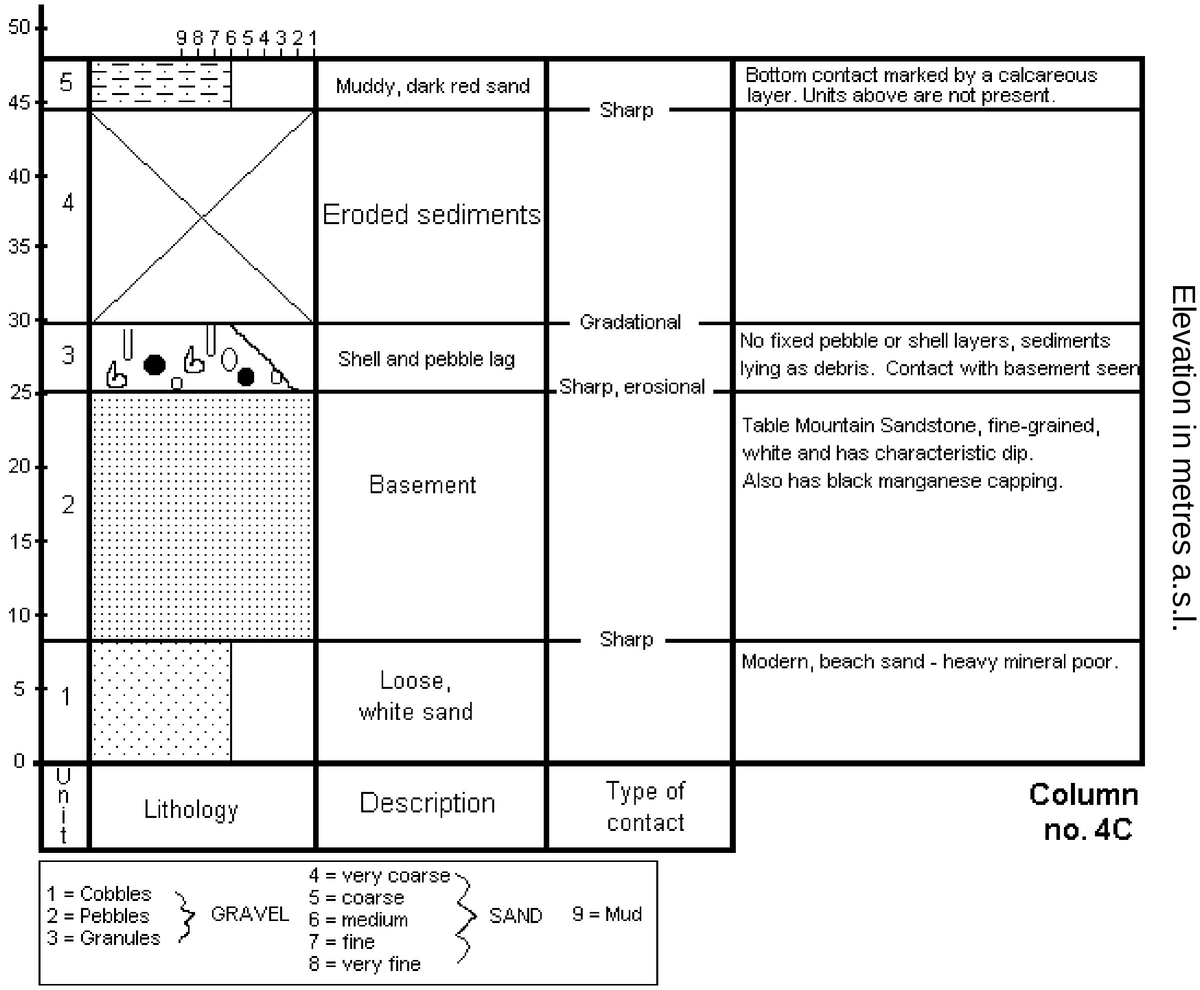


Figure 17: Lithological section of profile 4c.

1.18 Profile 8

Three roads bisect this profile and consequently, a large amount of debris is present at the top. In contact with the basement are the gravels of the basal marine gravel unit (subtidal facies) of the +50m package. In this profile, these gravels contain pieces of shell and amongst the pieces were those of gastropods, oysters and *Patellas*. Loose pieces of phosphorite are also present in the gravels, but no ferruginzed conglomerate blocks were observed.

The yellow sand of the basal marine gravels appears to continue up into the next succession of yellow calcareous sand, which is the heavy mineral deficient equivalent of the placer sands of the +50m package. This unit bears many calcified burrows or tubes and 5m above the contact with the basal marine gravels, in the walls of a road cutting, a more or less continuous layer of tortoise shells was found. The latter marks a shift from a marine to a terrestrial sedimentary environment. The trace fossils in this sand are extensive and in the form of intricate systems of calcified tubes, which start off with relatively small diameter tubes and gradually increases in size towards the top of the sedimentary succession. The calcified trace fossils, continue into the dorbank unit found above the yellow calcrete layer. They become most concentrated in the lower dorbank layer, which is separated from the layers by a calcrete horizon. The dorbank shows discolouration and this is seen to be a a response to ground water action. Within the upper dorbank layer, there is no calcareous material. It is however capped by a calcarete layer and the entire dorbank unit appears to have a high accumulation of heavy minerals, particularly above the second calcareous layer where there is the faint remains of a succession of darker green/black sand. The upper calcareous outcrop has a different texture and colouration to those found below and this is attributed to the fact that it was precipitated on the surface and subjected to subaerial conditions.

Table 18: Summary of units mapped in profile 8.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1	Present beach			Added to complete stratigraphic column.		8.00	8	8.00	Backshore	RB
2a	Debris	25	18	Construction of road added to debris		7.73	15.725			B
2b	T.M. Sandstone	13	50	Dip 28, down SW		9.96	25.68	17.68		
3	Yellow pebble layer	7.43	18	Shell fragments and gravels.	43	2.30	27.98		Subtidal	30m
4a	Yellow calc layer	15.3	22	Has shell layers and worms	44	5.73	33.71	8.03		
4b	Yellow calc layer	16.13	21	Makes hump on profile		5.78	39.49	5.78	Beach	30m
4c	Two roads	16.3	8	Second road higher elevation		2.27	41.76		Dune	AY
4d	Debris	15.3	26	See sketch of road cutting for detail.	2	6.71	48.47			
4e	Debris/Yellow sand	15.3	8	Start of a palaeo river bed. Tortoise shells found here.		2.13	50.60			
4f	Yellow calc layer	15.3	30		41	7.65	58.25	18.75		
5a	Blood red aeolian	15.3	18	Second calc layer starts at 10.60, ends 11.40	42	4.73	62.97		Dune	AD
5b	Blood red aeolian	15.3	23	Worm burrows become more intricate	40	5.98	68.95			
5c	Brown/green sand	9.9	28		39	4.65	73.60			
5d	Calc outcrop	1.1	86		38	1.10	74.70	16.45		
6	Red aeolian	11	2	First 5m still with loose calc chunks	1	0.38	75.08	0.38	Dune	AR
					TOTAL:	**75.08**				

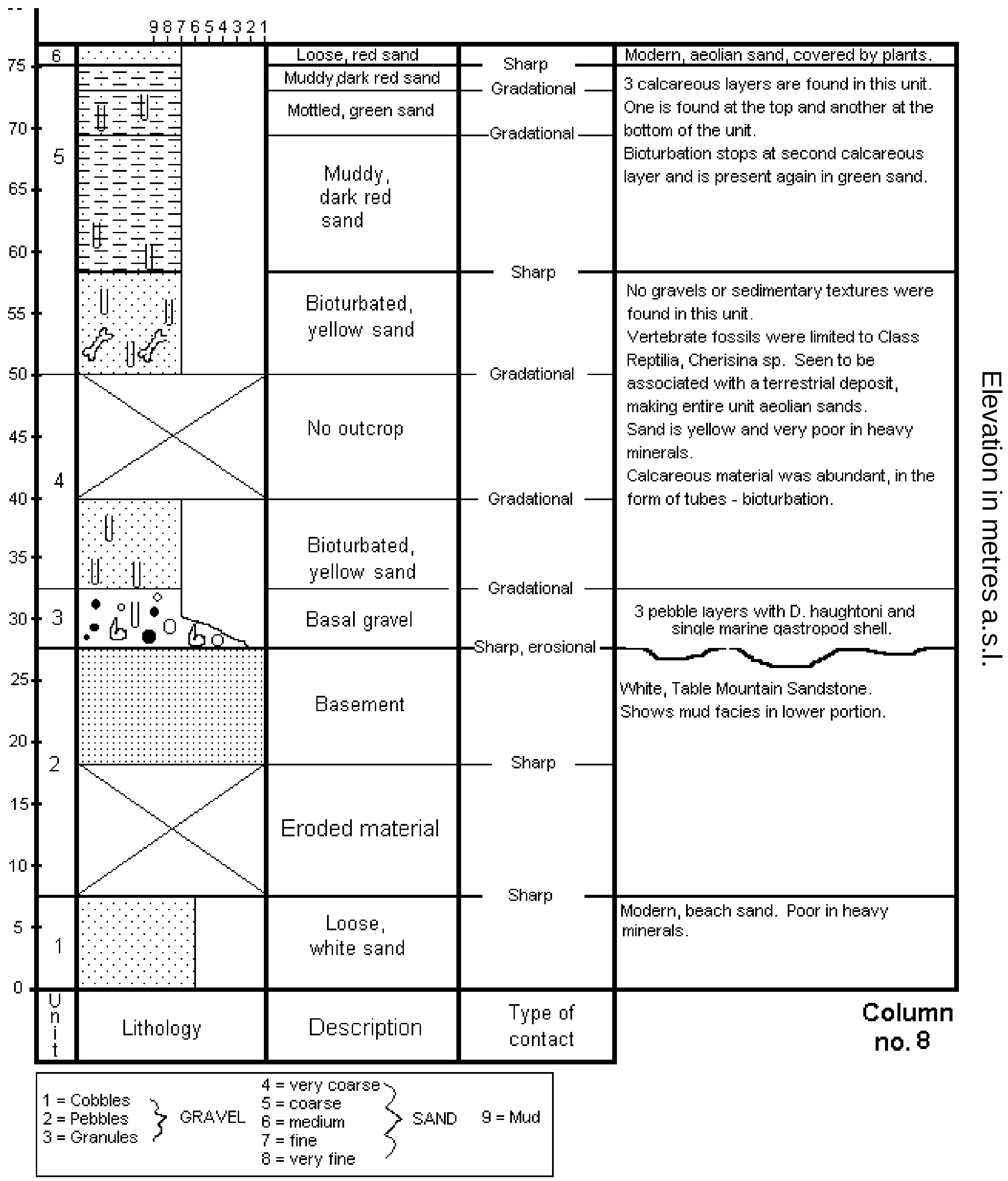


Figure 18: Lithological section of profile 8.

1.19 Profile 16

The basement of Table Mountain Sandstone differs from that found at Cliff Point in that it is more brittle. At the base of the profile there are loose blocks of highly foliated basement layers which could represent the Gariep Supergroup. The basement just below the basal marine gravels has the remnants of a conglomerate layer associated with the Table Mountain Sandstone Group. The presence of two mud layers was noted in the Table Mountain Sandstones and these are a purpelish red colour.

The basal marine gravel unit of the +50m package in this profile lies directly above the basement rocks and is cemented with calcrete (does not react to HCL). Within the gravels of the first pebble layer, a piece of quartz pebble conglomerate was found which was seen to be the result of erosion of the Table Mountain Sandstone.

Above the basal marine gravel unit, and buried beneath a thin layer of red aeolian sand, was found a succession of white, marine sand. The latter was found to possess predominantly *Patella* shells, although oysters and a few *Donax haughtoni* fragments were also observed.

The dorbank unit lies over the white marine sand and consists of a “blood red” layers as well as a green sand unit toward the top. The dorbank unit had evidence of much sheetwash flows and this can be attributed to post-depositional erosion by flash flood events. The mottled green zone at the top of the dorbank might indicate a marine input. There is a calcrete horizon at the top of the profile.

Table 19: Summary of units mapped in profile 16

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		2.00	2		Backshore	RB
1b	Present beach	30.00	10	Mussel shell lags.		5.21	7.21	7.21		
2a	Debris	19.00	14	Associated with road.		4.60	11.81			B
2b	TMS	48.00	24	Covered by debris of shells. Near top, cemented quartz conglomerate.		19.52	31.33	24.12		
3	Basal Pebble layer	0.30	15	Cemented by calc material.	91	0.08	31.41		Subtidal	50m
4a	Shell layer	8.60	20	White sand between oyster, patella and Donax haughtoni shells.	92	2.94	34.35	3.02		
4b	Calc Layer	0.70	65			0.63	34.98	0.63	Beach	50m
5a	Blood red sand	9.30	22	Probably debris covering placer sand. Has calc tubes.	93	3.48	38.47		Dune	AD
5b	Greenish brown sand	2.40	35		94	1.38	39.84			
5c	Debris	10.40	8	A mixture of red and green sand.		1.45	41.29			
5d	Blood red sand	23.40	10			4.06	45.35			
5e	Debris	30.00	8	Could be position of surface limestone outcrop.		4.18	49.53			
5f	Red sand	30.00	9	Aeolian sand rich in heavy minerals.	95	4.69	54.22			
5g	Debris	40.00	11	Debris associated with limestone mining and road building.		7.63	61.85	26.87		
					TOTAL:	61.85				

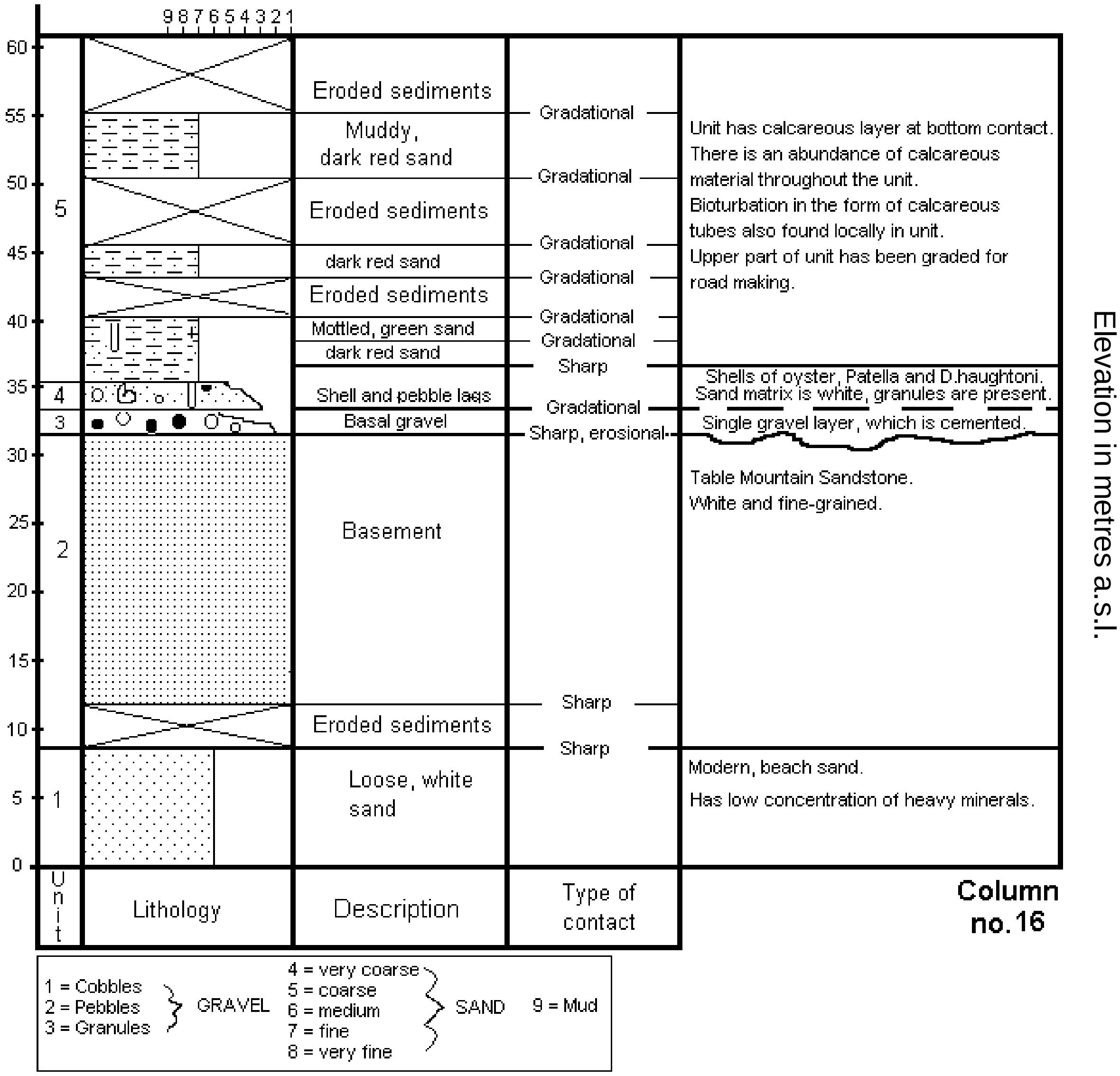


Figure 19: Lithological section of profile 16.

1.20 Profile 12

This profile marks the southernmost limit of the study area. The basement of Table Mountain Sandstone was seen to have a dip of 18 degrees to the NW. South of this profile site, the relief is considerably less and this is the result of the differential erosion of the more resistant Table Mountain Group as opposed to the Gariep Supergroup to the north and south of the Cliff Point area.

A thin layer of subtidal, basal marine gravel of the +50m package is present and it is cemented with calcrete.

Three major calcrete layers were identified in the dorbank unit. The top two layers were very similar in texture and appearance and the sand unit between them is impregnated with calicified tubes (trace fossils). The latter become smaller and more intricate towards the bottom of the profile. The lowest calcrete layer forms the contact between the dorbank and basal marine gravel unit. The heavy mineral concentration increases towards the top of the dorbank unit and there is a suggestion of an ancient placer deposit, lying beneath the red aeolian sand. A midden with chiselled stones and *Patella* shells was found at the top of this profile. Of particular interest is the modern mussel shells in this midden site. Ancient, calcified, termite mounds were also found lying exposed at the top of this profile.

Table 20: Summary of units mapped in profile 12.

No.	Description	W	S	Comments	Samples	V	Elev	Th	Facies	Unit
1a	Present beach			Added to complete stratigraphic column.		6.62	6.62		Backshore	RB
1b	Present beach	5.00	3			0.26	6.88			
1c	Debris	15.37	6			1.61	8.49			
1d	Debris	15.37	9			2.40	10.89			
1e	? 20m Terrace	15.37	8	Very similiar to unit described below, could also be debris.		2.14	13.03	13.03		
2a	Debris	15.37	8	Red aeolian sand with scattered pebbles and calc chunks.		2.14	15.17			B
2b	Sandstone	16.32	40	Very slight dip NW of 18 degrees.		10.49	25.66	12.63		
3	Basal pebble layer	0.05	45		71	0.04	25.70	0.04	Subtidal	30m
4a	Blood red sand	3.70	35	No pebbles or shells present.	70	2.12	27.82		Dune	AD
4b	Calc Layer	7.30	35	Calcified tubes are present.		4.19	32.01			
4c	Dull red sand	6.35	80	Seems to be another calc layer.		6.25	38.26			
4d	Blood red sand	9.85	33		69	5.36	43.62			
4e	Green sand	5.82	12	Starts as blood red becomes red-green and ends as blood red sand.	68	1.21	44.83			
4f	Blood red sand	15.37	80	Not so penetrated by calc.	67	15.14	59.97			
4g	Calc Layer	1.36	85	Appears to divide the blood red sand unit.	66	1.35	61.33			
4h	Blood red sand	10.75	26	Penetrated with network of calc veins. Red aeolian lies ontop.	65	4.71	66.04	40.34		
5	Red aeolian sand	4.00	26	Covered by plants.	64	1.75	67.79	1.75	Dune	AR
					TOTAL:	**67.79**				

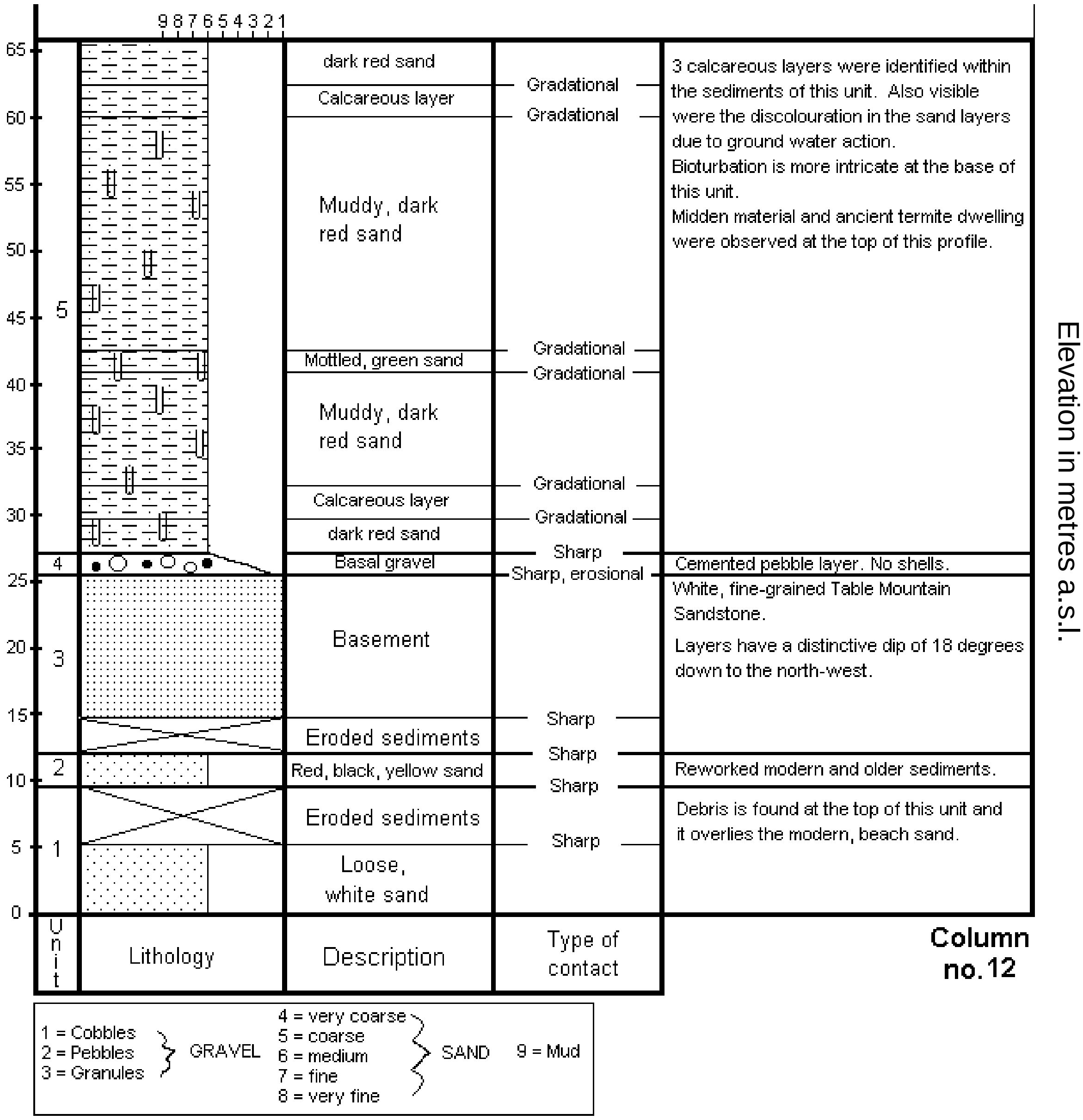


Figure 20: Lithological section of profile 12.

Table 1: Laboratory data for the channel clay unit.

Sample:	117a	113	117b	117c	8	8b
Unit:	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm
Profile:	2	13	2	2	1	1
Type:	Pebble	Pebble	Pebble	Pebble	Sand	Sand
S elev:	8.1	9.1	13.39	14.51	14.9	15.01
Colour:	10 YR 7/4	N9	10 YR 8/2	N9	10 YR 8/2	10 YR 8/2
Group:	sC	sC	cS	zS	cS	sC
Col Qz:	w, y	cl, y	w, cl, y	cl	w, cl, y	w, y
Roun Qz:	10	7	7	3	11	10
Minerals:	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz
Mud	1.49	211.15	122.15	65.15	127.15	357.15
>(-)5	0.00	0.00	94.57	71.35	0.00	0.00
-5	0.00	0.00	119.12	40.71	0.00	0.00
-4.5	56.22	0.00	123.27	60.38	0.00	0.00
-4	101.02	7.03	283.54	189.68	0.00	0.00
-3.5	31.48	25.13	97.91	91.00	3.54	0.00
-3	199.86	185.17	152.58	267.79	0.86	0.00
-2.5	22.39	28.04	22.18	26.89	0.00	0.00
-2	41.12	18.50	38.95	29.25	0.00	1.02
-1.5	56.57	57.82	51.05	50.38	0.63	0.46
-1	41.89	61.87	39.39	34.26	0.65	0.64
-0.5	32.28	87.78	36.54	26.47	0.72	0.69
0	26.45	130.87	40.02	21.77	0.75	0.78
0.5	24.28	173.72	45.64	21.09	1.18	1.12
1	29.71	219.27	50.82	24.71	2.48	2.65
1.5	36.08	156.46	55.18	31.57	26.83	18.15
2	52.45	107.59	64.46	41.86	155.12	182.22
2.5	61.48	59.55	36.89	35.39	260.65	399.80
3	78.41	35.90	23.74	24.03	210.80	298.48
3.5	64.84	15.67	13.91	9.81	73.07	68.71
4	43.21	4.63	7.02	3.18	19.22	20.02
<4	11.53	1.78	1.74	1.20	1.98	2.24
Tsieve	1011.27	1376.78	1398.52	1102.77	758.48	996.98
%?wt	0.15	13.30	14.25	11.69	14.36	26.37
mode	many	two	many	many	two	two
median	-1.527	0.248	-3.598	-3.317	2.358	2.364
mean	-0.908	-0.392	-2.587	-2.472	2.354	2.372
class	**V.coarse S**	**V.coarse S**	**fine P**	**fine P**	**fine S**	**fine S**
kurtosis	0.617	0.977	0.215	0.303	0.985	1.04
skewness	0.267	-0.343	2.628	2.528	0.041	0.053
sorting	2.896	1.998	1.744	1.525	0.577	0.517
sortC	**V. poor**	**poor**	**poor**	**poor**	**mod. well**	**mod. well**
VishC	beach	not clear	not clear	not clear	R, b or c.s.	R, b or c.s.
TOTAL	1012.76	1587.93	1520.67	1167.92	885.63	1354.13
Tgravel	57.63	34.23	68.97	74.07	0.84	0.28
Tsand	42.37	65.77	24.27	19.46	99.16	99.72
Tmud	0.00	0.00	6.76	6.47	0.00	0.00
Heavy	0.46	1.19	0.77	2.91	0.06	0.06

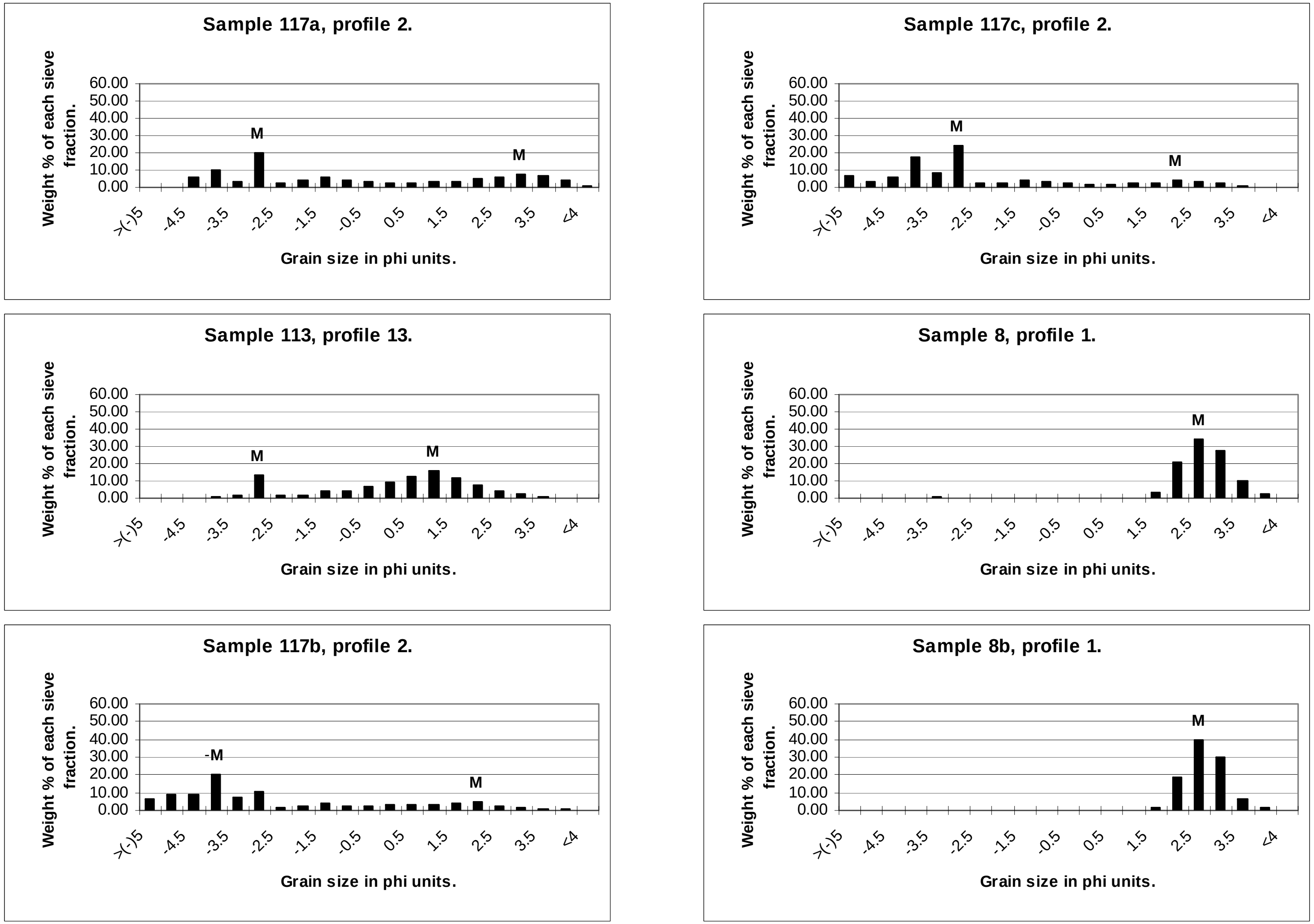


Figure 1: Grain size analysis histograms for the channel clay unit.

Figure 2: Visher diagrams of the channel clay unit.

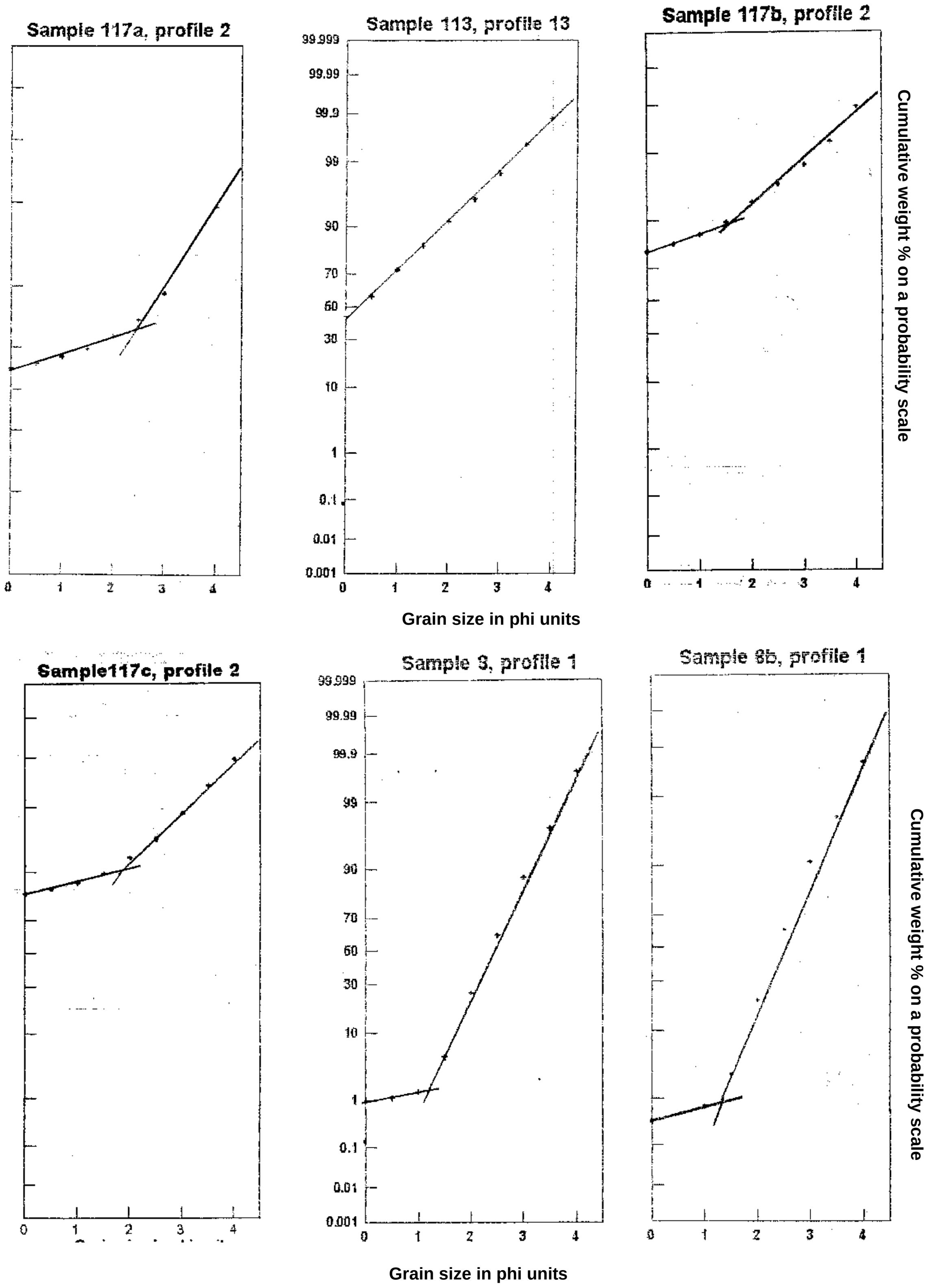


Table 1(Cont.): Laboratory data for the channel clay unit.

Sample:	**9**	**9b**	**102**	**82**	**103**	**104**
Unit:	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm
Profile:	1	1	17	14	17	17
Type:	Pebble	Pebble	Pebble	Pebble	Pebble	Pebble
S elev:	15.42	16.44	16.5	16.11	17.3	17.6
Colour:	10 YR 8/2	10 YR 7/4	10 YR 8/2	10 YR 8/6	N9	10 YR 8/2
Group:	cS	cS	zS	cS	cS	zS
Col Qz:	cl, y	w, y	w, cl	w, cl	w, cl	w, cl
Roun Qz:	3	11	11	10	10	7
Minerals:	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz
Mud	721.70	71.15	2.15	111.15	225.15	9.15
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	78.28	0.00	0.00	0.00
-4.5	0.00	0.00	62.51	0.00	0.00	0.00
-4	182.97	148.62	313.74	127.83	0.00	134.14
-3.5	94.63	98.28	114.66	103.99	0.00	122.65
-3	179.38	347.01	284.70	426.99	6.68	413.19
-2.5	3.12	44.09	53.36	59.82	5.01	47.09
-2	0.39	56.86	21.50	38.16	9.11	36.37
-1.5	8.19	99.63	42.27	79.01	14.94	51.39
-1	26.35	71.69	32.37	59.61	24.03	32.06
-0.5	10.13	62.29	27.49	59.97	51.31	23.96
0	25.44	67.01	28.64	56.72	129.58	21.20
0.5	21.77	74.77	31.52	42.42	213.71	24.43
1	5.90	64.87	34.57	34.05	235.84	37.34
1.5	12.16	43.89	35.95	31.59	125.45	51.49
2	10.25	44.28	33.93	35.46	55.04	57.98
2.5	15.68	48.10	31.00	45.46	41.55	37.63
3	12.93	44.13	25.98	42.60	35.36	24.11
3.5	8.04	21.85	13.21	21.62	18.15	10.15
4	3.79	8.46	7.04	8.53	9.13	3.46
<4	3.70	3.30	5.74	3.03	7.09	2.28
Tsieve	624.83	1349.13	1278.46	1276.86	981.98	1130.92
%?wt	53.60	5.01	0.17	8.01	18.65	0.80
mode	many	many	many	many	two	many
median	-3.403	-2.175	-3.377	-3.024	0.578	-3.127
mean	-2.581	-1.617	-2.516	-1.964	0.613	-1.959
class	**fine P**	**fine P**	**fine P**	**V.fine P**	**coarse S**	**V. fine P**
kurtosis	1.089	0.812	0.303	0.968	1.402	0.996
skewness	0.652	0.377	2.773	0.684	0.079	0.683
sorting	2.063	2.205	1.444	2.143	1.085	2.212
sortC	**V. poor**	**V. poor**	**poor**	**V. poor**	**poor**	**V. poor**
VishC	beach	beach	not clear	not clear	not clear	not clear
TOTAL	1346.53	1420.28	1280.61	1388.01	1207.13	1140.07
Tgravel	80.85	68.82	80.63	74.82	11.31	76.12
Tsand	19.15	31.18	19.37	25.18	88.69	23.88
Tmud	0.00	0.00	0.00	0.00	0.00	0.00
Heavy	-	8	0.89	0.65	0.34	1.94

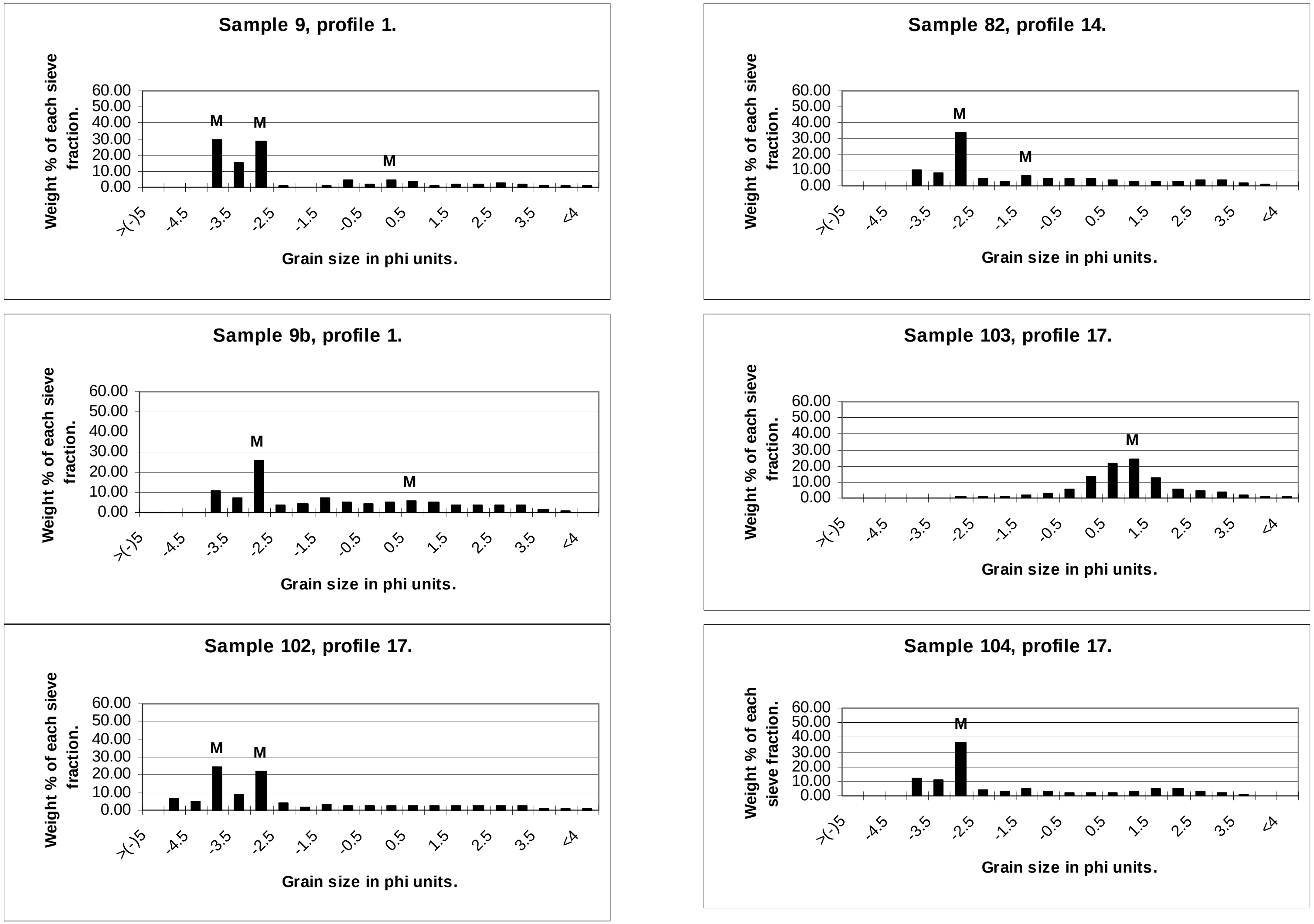


Figure 1 (Cont.): Grain size analysis for the channel clay unit.

Figure 2 (Cont.): Visher diagrams for the channel clay unit.

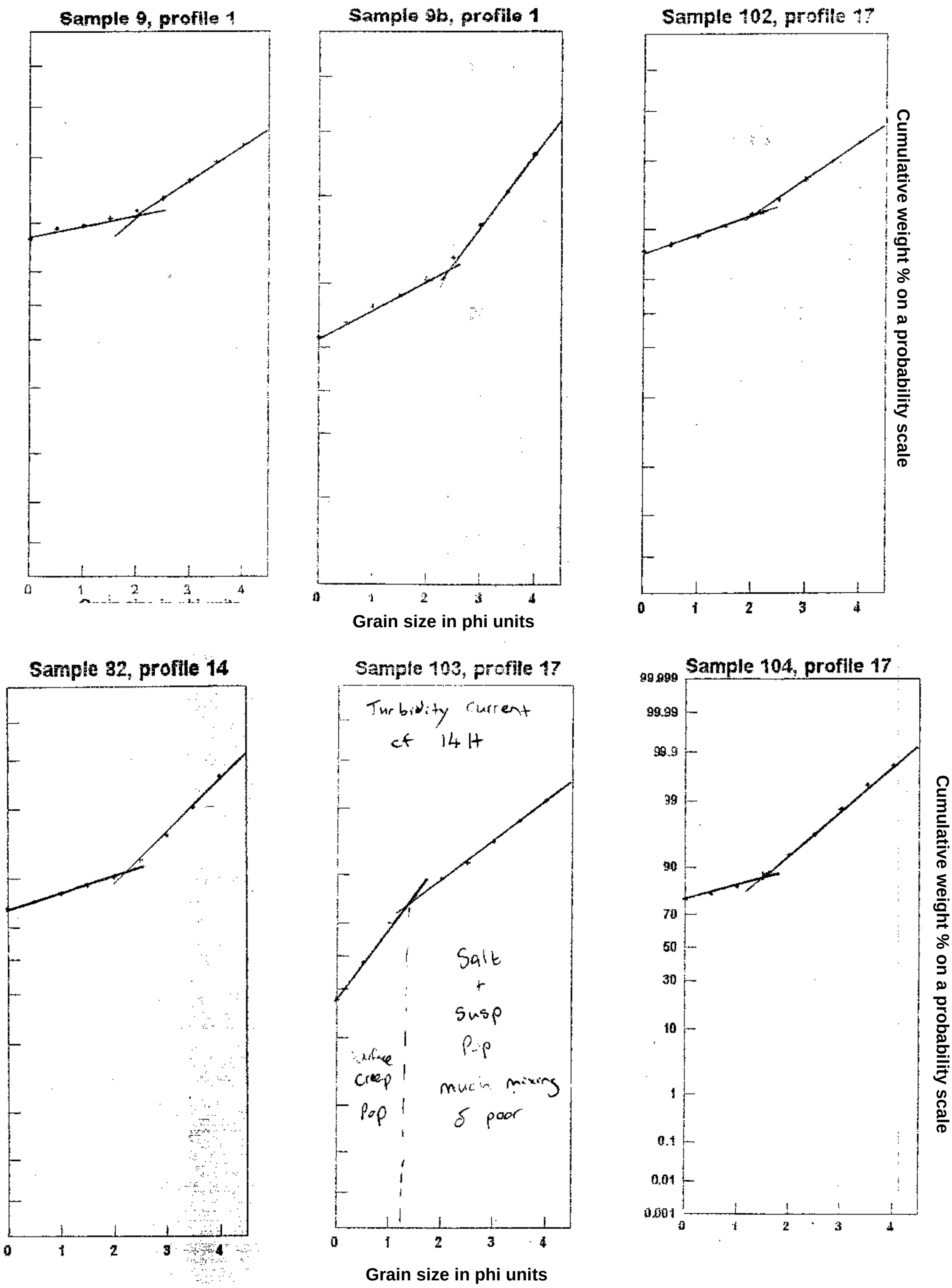


Table 1(Cont.): Laboratory data for the channel clay unit.

Sample:	87	118	83	105	115	106
Unit:	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm
Profile:	15	2	14	17	13	17
Type:	Pebble	Pebble	Pebble	Pebble	Clay	Clay
S elev:	17.84	18	19	19.38	20.45	20.59
Colour:	10 YR 8/2	5 Y 8/1	10 YR 8/2	10 YR 8/2	10 YR 8/2	5 B 9/1
Group:	cS	cS	cS	cS	cS	C
Col Qz:	w, cl, y	cl, y	w, cl	w, cl	cl, y	w, cl
Roun Qz:	10	7	10	10	7	10
Minerals:	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz
Mud	68.15	432.15	9.15	181.15	371.15	171.15
>(-)5	94.76	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	63.53	12.04	86.46	0.00	0.00	0.00
-3.5	16.95	2.73	29.03	0.00	0.00	4.98
-3	124.60	0.50	190.06	4.00	42.57	4.85
-2.5	37.32	0.00	28.54	1.43	20.10	1.43
-2	22.76	0.91	40.06	1.54	19.04	5.85
-1.5	53.40	0.67	61.91	4.32	38.63	13.92
-1	46.49	1.28	45.89	9.71	40.81	16.76
-0.5	47.01	1.62	35.25	18.41	51.14	14.66
0	61.68	3.08	32.97	57.79	73.69	15.76
0.5	100.90	7.33	39.93	176.15	109.64	44.78
1	186.56	20.19	68.42	356.82	191.77	97.31
1.5	168.87	57.31	106.28	201.14	212.38	40.43
2	57.70	118.27	88.28	73.12	181.33	34.15
2.5	12.20	101.00	38.37	51.61	98.09	145.97
3	7.85	108.17	29.75	47.16	58.34	418.59
3.5	6.69	75.85	25.58	23.23	22.98	30.65
4	5.05	34.89	20.86	10.77	6.50	5.79
<4	3.80	7.20	12.74	7.52	1.55	1.05
Tsieve	1118.12	553.04	980.38	1044.72	1168.56	896.93
%?wt	13.73	43.86	0.92	14.78	24.11	16.02
mode	many	two	many	two	two	many
median	-0.077	2.25	-0.883	0.849	0.992	2.509
mean	-0.772	2.259	-0.814	0.955	0.749	1.996
class	**V.coarse S**	**fine S**	**V.coarse S**	**coarse S**	**coarse S**	**medium S**
kurtosis	0.155	1.128	0.672	1.466	1.308	0.967
skewness	0.523	-0.04	0.07	0.22	-0.302	-0.721
sorting	1.415	0.998	2.429	0.901	1.501	1.185
sortC	**poor**	**moderate**	**V. poor**	**moderate**	**poor**	**poor**
VishC	not clear	all pos.	not clear	not clear	not clear	not clear
TOTAL	1186.27	985.19	989.53	1225.87	1539.71	1068.08
Tgravel	36.85	3.57	52.76	3.77	18.17	6.96
Tsand	54.67	96.43	47.24	96.23	81.83	93.04
Tmud	8.47	0.00	0.00	0.00	0.00	0.00
Heavy	0.01	0.1	1.05	0.13	0.92	1.18

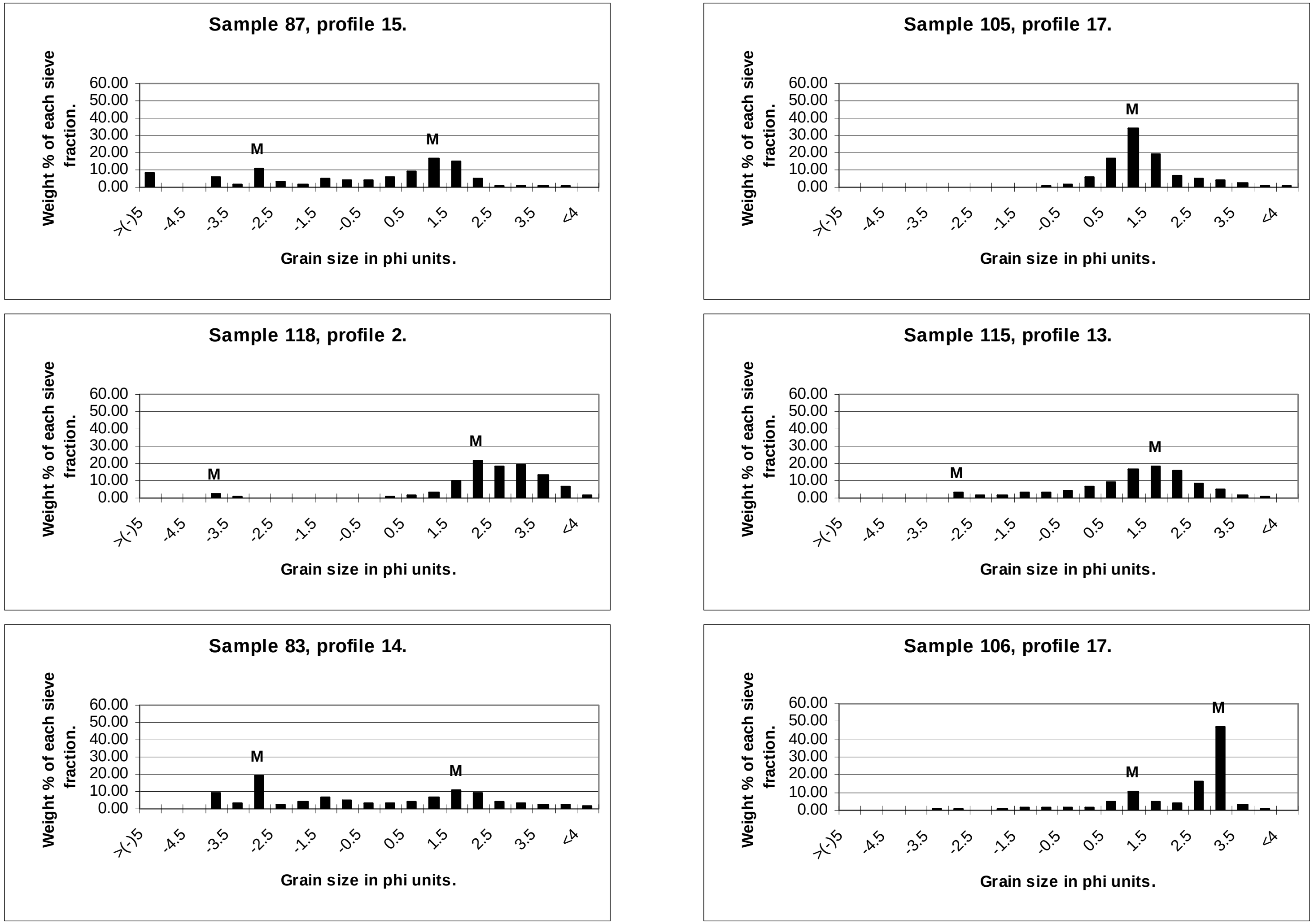


Figure 1 (Cont.): Grain size analysis for the channel clay unit.

Figure 2 (Cont.): Visher diagrams for the channel clay unit.

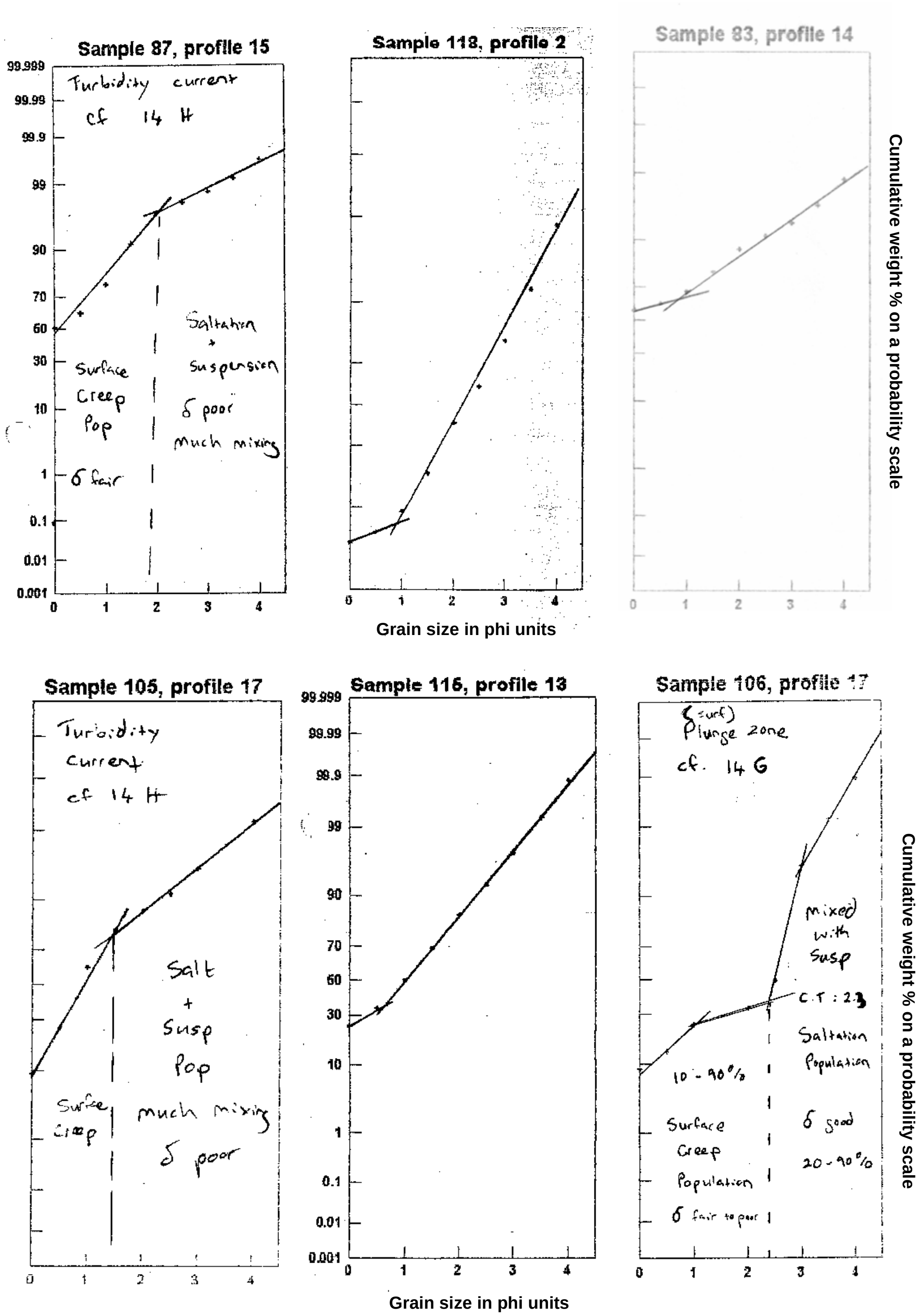


Table 1(Cont.): Laboratory data for the channel clay unit.

Sample:	101	88	108	109	111	47
Unit:	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm	Channel clay fm
Profile:	11	15	7	7	7	5
Type:	Sand	Sand	Pebble	Sand	Sand	Clay
S elev:	24.53	24.89	28.31	30.09	31.52	31.53
Colour:	5 Y 8/1	N9	10 YR 8/2	10 YR 8/2	10 YR 7/4	10 YR 8/6
Group:	S	sC	cS	sC	zS	cS
Col Qz:	w, y, r	w, cl	w, cl	w, cl	w, cl, y	y
Roun Qz:	13	2	7	7	7	10
Minerals:	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,qz	qz,qz,ore	qz,qz,qz
Mud	105.15	559.15	85.15	447.15	107.15	41.15
>(-)5	0.00	0.00	451.24	0.00	0.00	0.00
-5	0.00	0.00	79.82	0.00	0.00	0.00
-4.5	0.00	0.00	70.62	0.00	0.00	0.00
-4	0.00	0.00	131.18	5.58	0.00	0.00
-3.5	0.00	55.25	54.36	17.81	0.00	0.00
-3	0.00	202.76	211.37	109.80	0.00	0.00
-2.5	0.00	84.99	31.20	16.16	0.00	0.00
-2	0.00	56.92	27.57	21.07	0.76	0.00
-1.5	0.00	74.30	47.08	43.18	14.81	0.00
-1	0.98	48.38	36.34	37.15	80.38	0.00
-0.5	1.07	53.16	35.21	35.89	74.08	0.00
0	2.24	66.97	40.05	38.78	33.10	0.00
0.5	9.65	71.84	47.87	47.70	13.06	0.00
1	32.34	69.80	55.99	56.11	14.38	9.83
1.5	117.80	66.68	56.60	66.71	249.66	834.95
2	245.97	68.15	56.25	88.38	758.94	722.89
2.5	347.66	56.67	40.16	86.38	417.34	73.84
3	179.16	57.31	30.94	67.44	142.15	2.71
3.5	14.61	31.08	17.87	28.16	66.08	1.47
4	1.93	8.37	7.86	8.74	26.20	0.75
<4	1.31	1.30	4.82	5.06	1.64	0.45
Tsieve	954.72	1073.93	1534.40	780.10	1892.58	1646.89
%?wt	9.92	34.24	33.12	36.44	5.36	2.44
mode	two	many	many	many	many	one
median	2.097	-0.865	-3.684	0.324	1.807	1.487
mean	2.057	-0.734	-0.91	-0.227	1.791	1.504
class	**fine S**	**V.coarse S**	**V.coarse S**	**V.coarse S**	**medium S**	**medium S**
kurtosis	0.993	0.64	-0.753	0.741	2.248	0.739
skewness	-0.121	0.125	10.637	-0.235	-0.222	0.07
sorting	0.582	2.242	0.462	2.286	0.926	0.325
sortC	**mod. well**	**V. poor**	**well**	**V. poor**	**moderate**	**well**
VishC	beach	not clear	R, b or c.s.	all pos.	all pos.	beach
TOTAL	1059.87	1633.08	1619.55	1227.25	1999.73	1688.04
Tgravel	0.21	53.61	47.23	36.74	8.98	0.00
Tsand	99.79	46.39	23.36	63.26	91.02	100.00
Tmud	0.00	0.00	29.41	0.00	0.00	0.00
Heavy	0.47	1.28	0.58	0.72	8.59	0.04

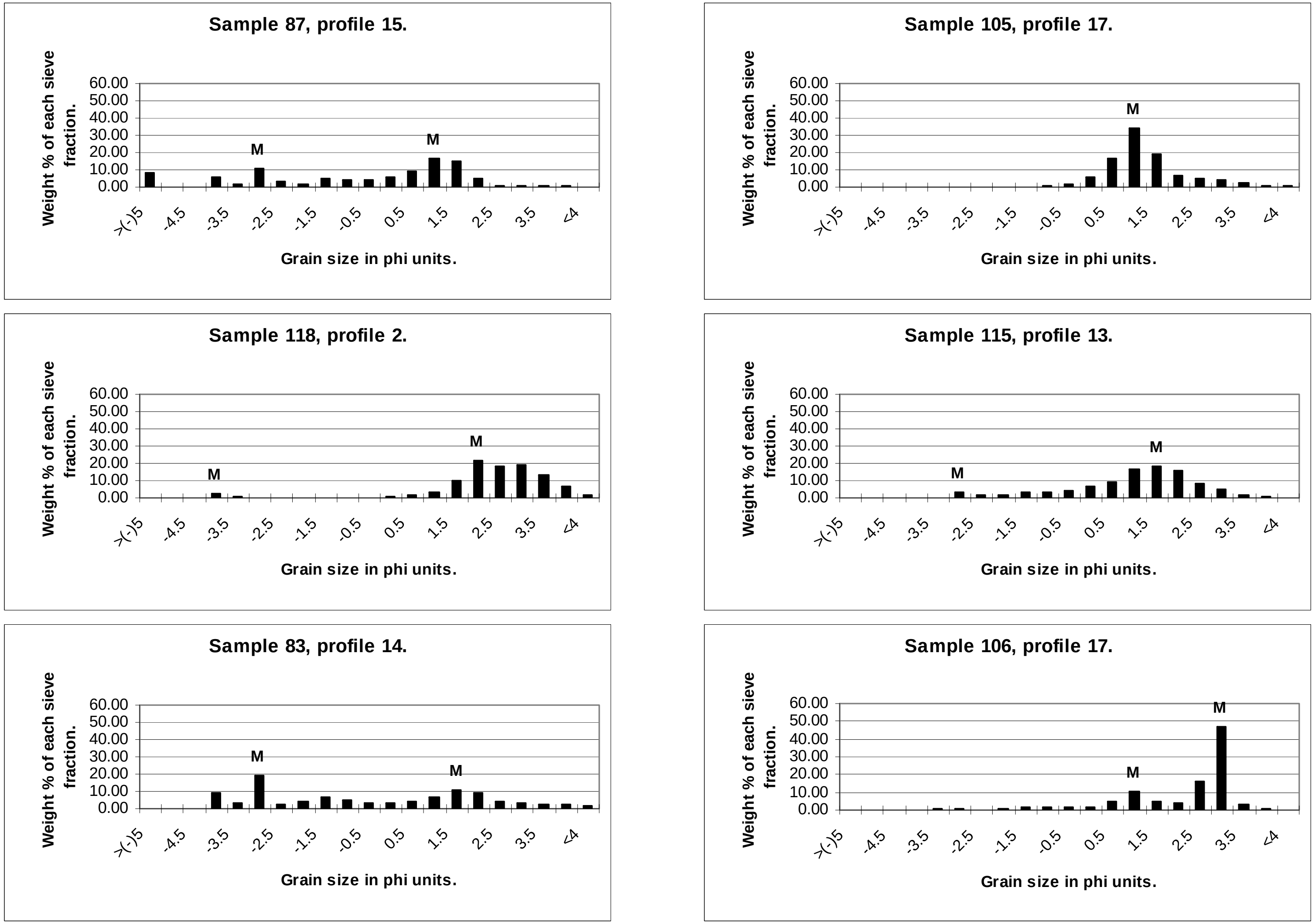


Figure 1 (Cont.): Grain size analysis for the channel clay unit.

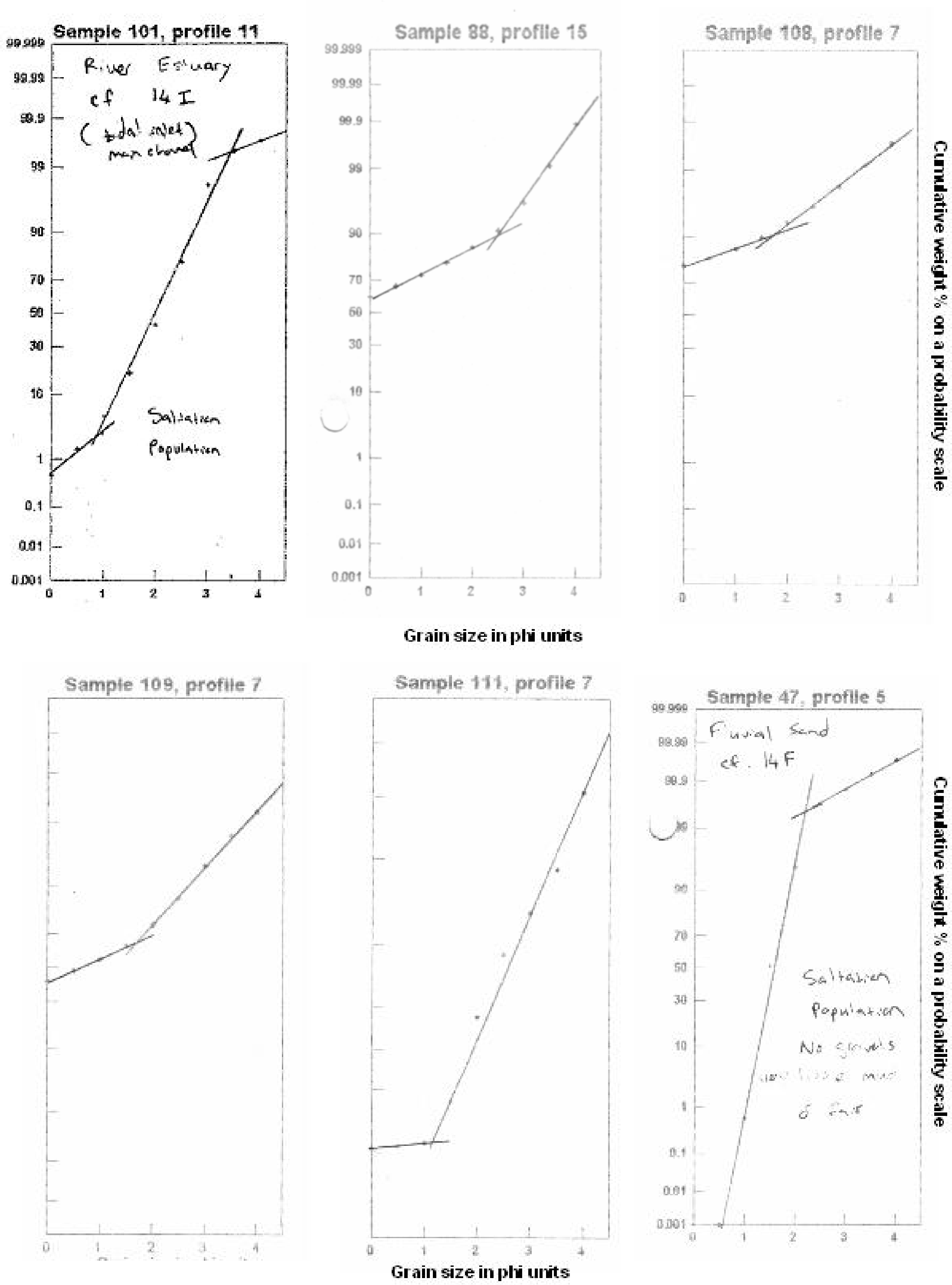


Figure 2 (Cont.): Visher diagrams for the channel clay unit.

Table 2: Laboratory data for the aeolianite.

Sample:	93	94	69	68	32	95
Unit:	Dorbank	Dorbank(Pp)	Dorbank	Dorbank(Pp)	Dorbank	Dorbank
Profile:	16	16	12	12	4A	16
Type:	Sand	Sand	Sand	Sand	Sand	Sand
S elev:	38.27	38.49	40.87	44.67	46.77	51.79
Colour:	5 YR 5/6	10 YR 7/4	10 YR 7/4	10 YR 7/4	10 YR 5/4	10 YR 5/4
Group:	zS	cS	zS	cS	cS	zS
Col Qz:	cl, y, r	w, cl, y, r	cl, y, r	cl, y, r	w, cl, y, r	cl, y, r
Roun Qz:	13.00	10.00	11.00	12.00	11.00	13.00
Minerals:	qz,qz,qz	qz,qz,pyx	qz,qz,qz	qz,qz,rock	qz,qz,calc	qz,qz,qz
Mud	204.15	78.15	44.15	85.15	198.42	185.15
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00	0.00	0.00
-3	0.00	0.00	0.00	0.00	0.00	0.00
-2.5	0.00	0.00	0.00	0.00	0.00	0.00
-2	0.00	0.00	0.00	0.00	0.00	0.00
-1.5	0.00	0.00	0.00	0.00	0.00	0.00
-1	1.18	0.00	0.00	0.00	0.00	0.00
-0.5	1.70	0.00	0.00	0.00	0.00	0.00
0	3.72	0.00	1.05	0.00	0.00	0.00
0.5	9.95	4.55	1.54	1.63	15.54	1.54
1	25.90	7.18	3.62	2.32	10.16	2.28
1.5	134.14	22.87	222.60	113.91	78.76	51.57
2	540.82	501.20	599.76	423.16	289.47	266.54
2.5	258.14	224.77	238.91	133.65	157.50	206.98
3	141.03	116.89	61.53	38.88	55.44	119.65
3.5	62.18	30.24	27.29	12.08	43.48	35.97
4	21.78	9.25	18.58	3.77	2.01	13.08
<4	4.57	1.09	6.16	1.02	21.27	1.42
Tsieve	1205.11	918.04	1181.04	730.42	673.62	699.03
%?wt	14.49	7.84	3.60	10.44	22.75	20.94
mode	two	two	one	two	two	two
median	1.894	1.923	1.802	1.792	1.901	2.067
mean	2.013	2.027	1.851	1.853	2.012	2.139
class	**fine S**	**fine S**	**medium S**	**medium S**	**fine S**	**fine S**
kurtosis	1.188	0.931	1.325	1.465	1.285	1.025
skewness	0.277	0.385	0.206	0.213	0.283	0.195
sorting	0.606	0.455	0.509	0.437	0.634	0.574
sortC	**mod. well**	**well**	**mod. well**	**well**	**mod. well**	**mod. well**
VishC	R, b. or c.s.	beach	beach	beach	all pos.	R, b. or c.s.
TOTAL	**1409.26**	**996.19**	**1225.19**	**815.57**	**872.04**	**884.18**
Tgravel	0.10	0.00	0.00	0.00	0.00	0.00
Tsand	99.52	99.88	99.48	99.86	96.84	99.80
Tmud	0.38	0.12	0.52	0.14	3.16	0.20
Heavy	4.77	28.61	4.29	5.90	left out	3.48

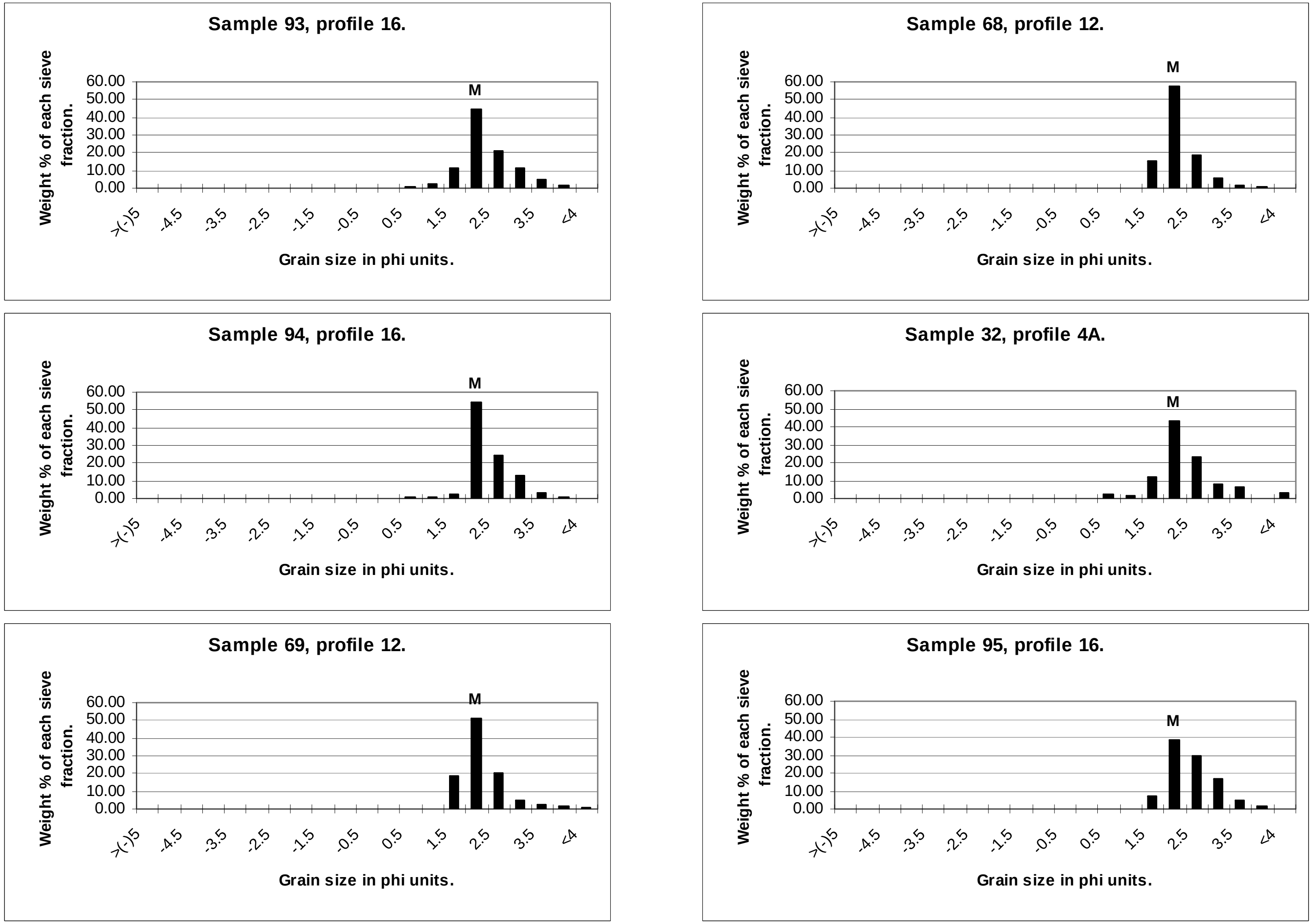


Figure 3: Grain size analysis histograms for the aeolianite.

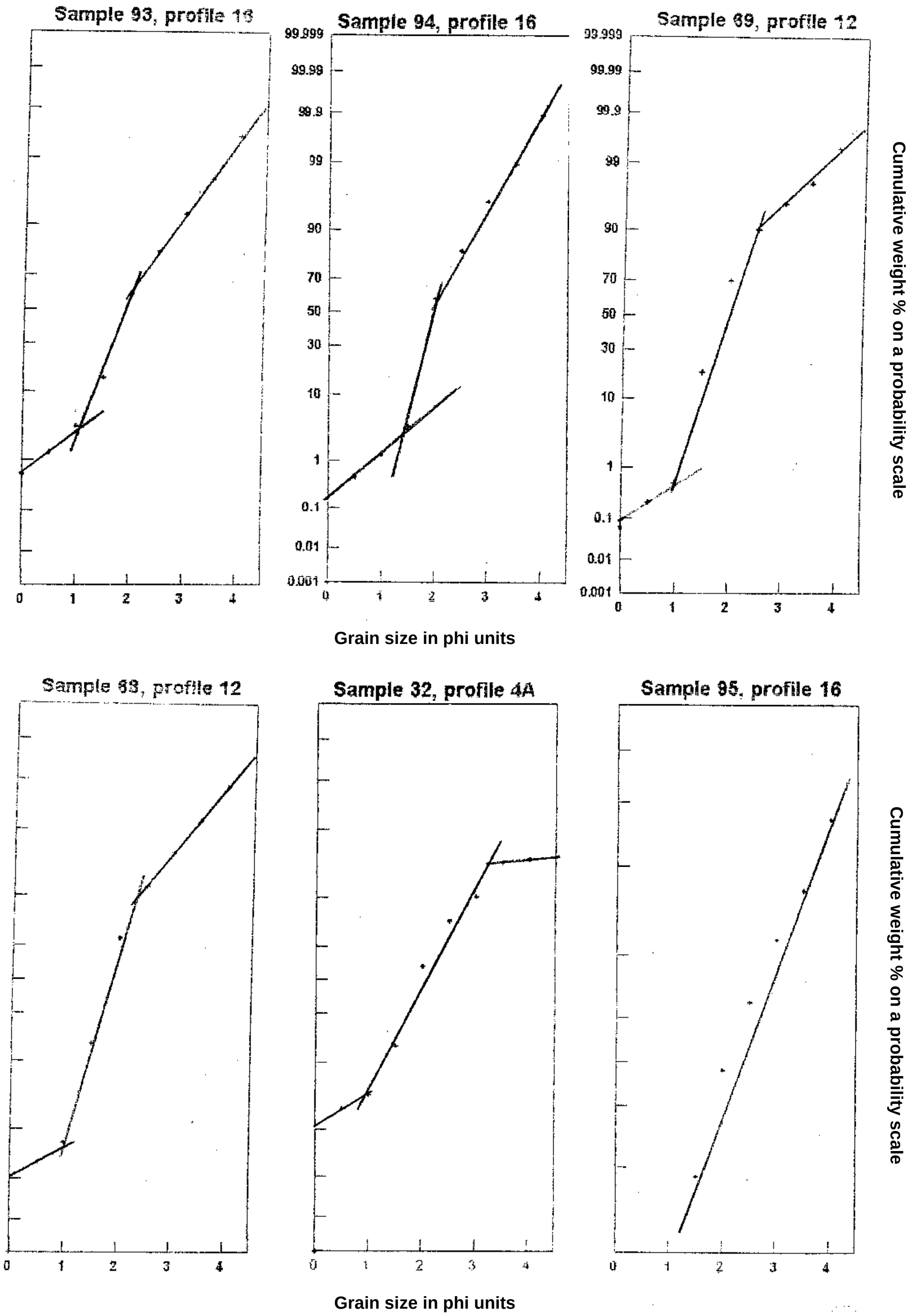


Figure 4: Visher diagrams for the aeolianite.

Table 2 (Cont.): Laboratory data for the aeolianite.

Sample:	**76**	**42**	**79**	**40**	**39**	**81**
Unit:	Dorbank	Dorbank	Dorbank	Dorbank	Dorbank(Pp)	Dorbank
Profile:	13	8	13	8	8	13
Type:	Sand	Sand	Sand	Sand	Sand	Sand
S elev:	60.32	61.65	62.54	66.57	70.88	73.08
Colour:	10 YR 6/6	5 YR 5/6	10 YR 6/6	5 YR 5/6	10 YR 6/6	5 YR 5/6
Group:	zS	zS	zS	zS	zS	zS
Col Qz:	y, r	cl, y, r	cl, y, r	cl, y, r	cl, y	cl, r
Roun Qz:	13.00	14.00	11.00	11.00	11.00	13.00
Minerals:	qz,qz,alt	qz,qz,ore	qz,qz,alt	qz,qz,qz	alt,rock,feld	qz,qz,qz
Mud	39.15	74.16	113.15	207.30	0.00	87.15
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00	0.00	0.00
-3	0.00	0.00	0.00	0.00	0.00	0.00
-2.5	0.00	0.00	0.00	0.00	0.00	0.00
-2	0.00	0.00	0.00	0.00	0.00	0.00
-1.5	0.00	0.00	0.00	0.00	0.00	0.00
-1	0.00	0.00	0.00	0.00	0.00	0.00
-0.5	0.00	0.00	0.00	0.00	0.00	0.00
0	4.51	0.00	4.66	0.00	0.00	0.00
0.5	34.57	3.86	9.53	3.90	0.88	3.38
1	155.23	0.00	15.83	1.10	0.81	8.24
1.5	685.39	51.22	80.39	12.37	45.50	75.46
2	524.00	418.76	361.66	161.40	278.67	270.67
2.5	318.25	203.56	307.52	190.32	121.31	122.62
3	124.25	68.61	97.66	27.77	47.83	36.79
3.5	25.93	49.69	29.91	11.79	8.89	13.62
4	12.47	29.66	5.54	2.83	1.06	3.12
<4	4.70	26.60	1.13	18.25	7.00	0.16
Tsieve	1889.30	851.97	913.83	429.74	511.96	534.06
%?wt	2.03	8.01	11.02	32.54	0.00	14.03
mode	one	two	two	two	one	two
median	1.562	1.943	1.979	2.095	1.875	1.832
mean	1.643	2.106	2.003	2.078	1.955	1.897
class	**medium S**	**fine S**	**fine S**	**fine S**	**medium S**	**medium S**
kurtosis	1.06	1.352	1.113	1.35	1.135	1.23
skewness	0.064	0.469	0.183	0.173	0.268	0.076
sorting	0.623	0.654	0.514	0.503	0.466	0.488
sortC	**mod. well**	**mod. well**	**mod. well**	**mod. well**	**well**	**well**
VishC	beach	R, b. or c.s.	beach	R, b. or c.s.	R, b. or c.s.	R, b or c.s.
TOTAL	**1928.45**	**926.13**	**1026.98**	**637.04**	**506.52**	**621.21**
Tgravel	0.00	0.00	0.00	0.00	0.00	0.00
Tsand	99.75	96.88	99.88	95.75	98.63	99.97
Tmud	0.25	3.12	0.12	4.25	1.37	0.03
Heavy	16.26	left out	10.28	2.45	8.22	3.89

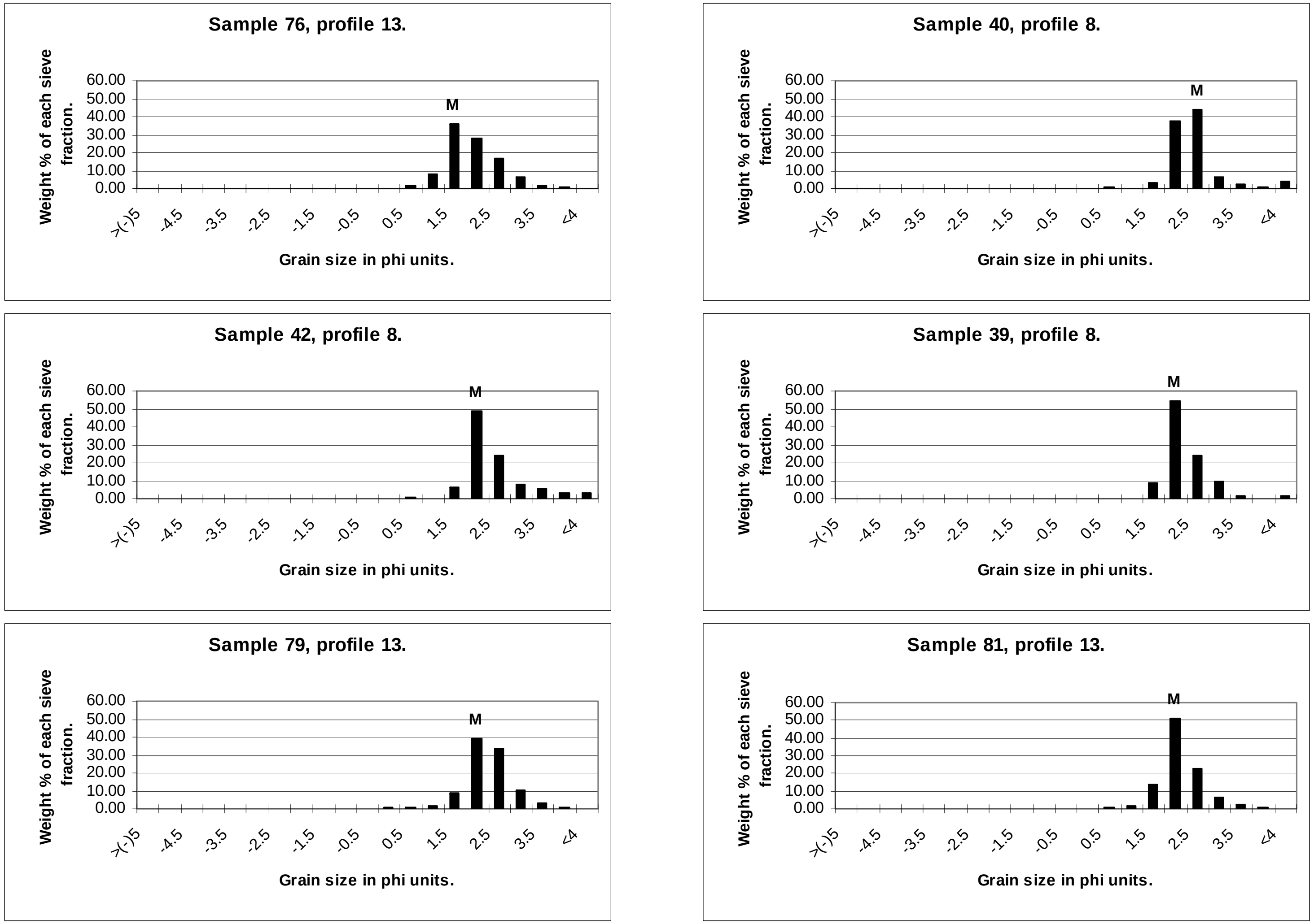


Figure 3 (Cont.): Grain size analysis histograms for the aeolianite.

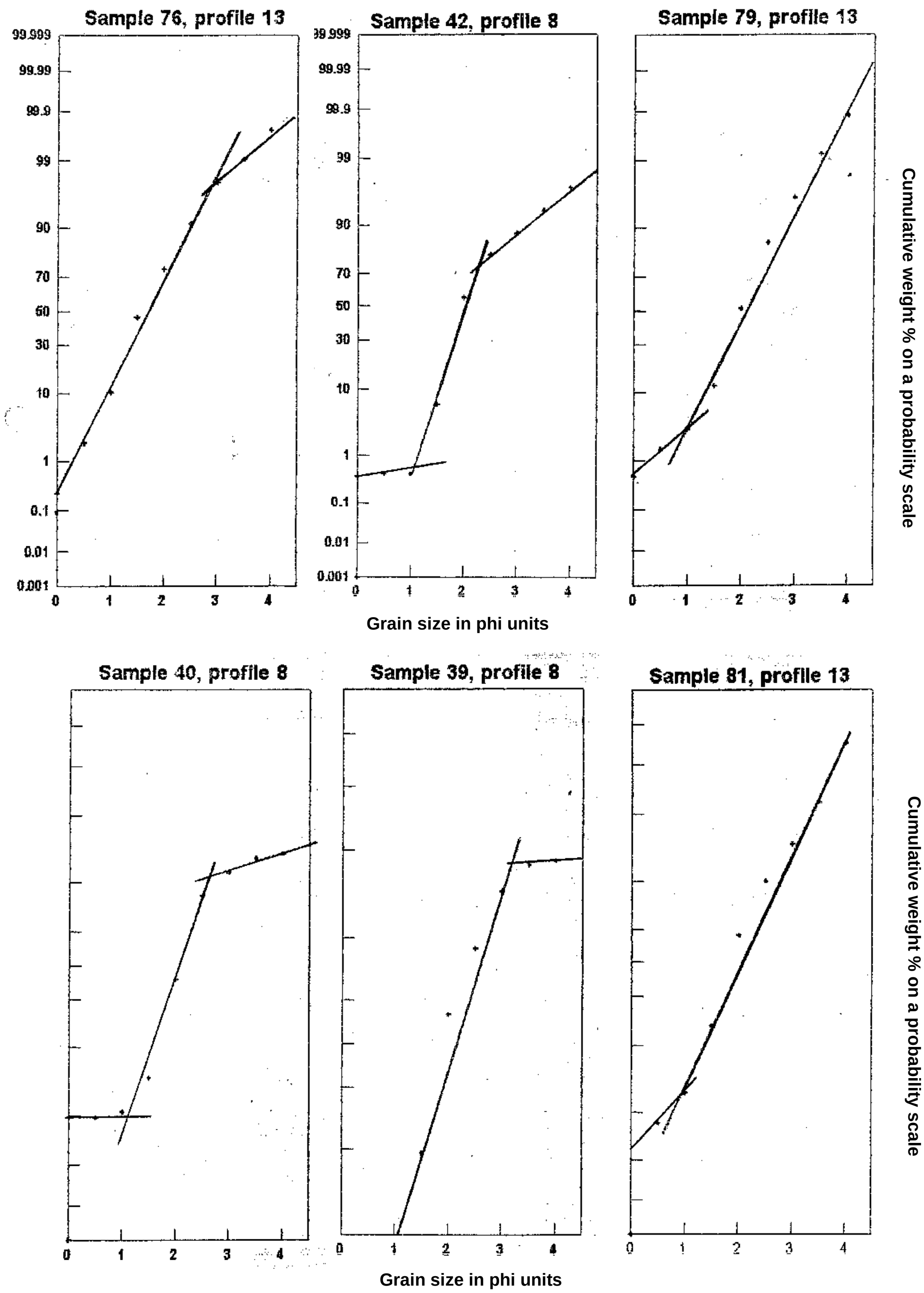


Figure 4 (Cont.): Visher diagrams for the aeolianite.

Table 2 (Cont.): Laboratory data for the aeolianite.

Sample:	**33**	**2**	**77**	**4**	**78**
Unit:	Yellow dune	Yellow dune	Yellow dune	Yellow dune	Yellow dune
Profile:	4B	8	13	6	13
Type:	Sand	Sand	Sand	Sand	Sand
S elev:	30.64	45.65	54.22	57.16	58.55
Colour:	5 YR 5/6	5 YR 5/6	10 YR 6/6	10 YR 7/4	10 YR 6/6
Group:	zS	zS	S	cS	S
Col Qz:	r	r	cl, y, r	w, cl, r	cl, y
Roun Qz:	8	11	10	11	7
Minerals:	qz,qz,qz	qz,qz,qz	qz,qz,rock	qz,qz,ore	pyx,rock,ore
Mud	0.00	0.00	18.15	34.07	23.15
>(-)5	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00	0.00
-3	0.00	0.00	0.00	0.00	0.00
-2.5	0.00	0.00	0.00	0.00	0.00
-2	0.00	0.00	0.00	0.00	0.00
-1.5	0.00	0.00	0.00	0.00	0.00
-1	0.00	0.00	0.00	0.00	0.00
-0.5	0.00	0.00	0.58	0.00	0.00
0	0.00	0.00	1.16	0.00	0.82
0.5	3.07	3.58	4.24	2.32	1.92
1	9.18	0.00	21.71	1.56	4.04
1.5	32.05	19.29	825.63	80.35	662.51
2	147.82	205.38	550.20	209.59	1153.68
2.5	148.96	226.27	303.44	247.50	326.19
3	65.28	36.28	97.94	171.39	102.34
3.5	32.70	35.73	24.16	26.23	18.51
4	17.54	7.12	4.92	7.85	3.24
<4	7.24	32.64	0.80	8.35	0.60
Tsieve	463.84	566.30	1834.78	755.14	2273.85
%?wt	0.00	0.00	0.98	4.32	1.01
mode	one	two	one	one	one
median	2.134	2.121	1.558	2.169	1.703
mean	2.202	2.193	1.649	2.176	1.702
class	**fine S**	**fine S**	**medium S**	**fine S**	**medium S**
kurtosis	1.211	1.445	0.944	0.935	1.15
skewness	0.179	0.328	-0.002	0.312	0.196
sorting	0.68	0.626	0.516	0.581	0.439
sortC	**mod. well**	**mod. well**	**mod. well**	**mod. well**	**well**
VishC	beach	beach	beach	beach	R, b or c.s.
TOTAL	**463.84**	**566.30**	**1852.93**	**789.21**	**2297.00**
Tgravel	0.00	0.00	0.00	0.00	0.00
Tsand	98.44	94.24	99.96	98.89	99.97
Tmud	1.56	5.76	0.04	1.11	0.03
Heavy	left out	left out	12.04	8.56	13.43

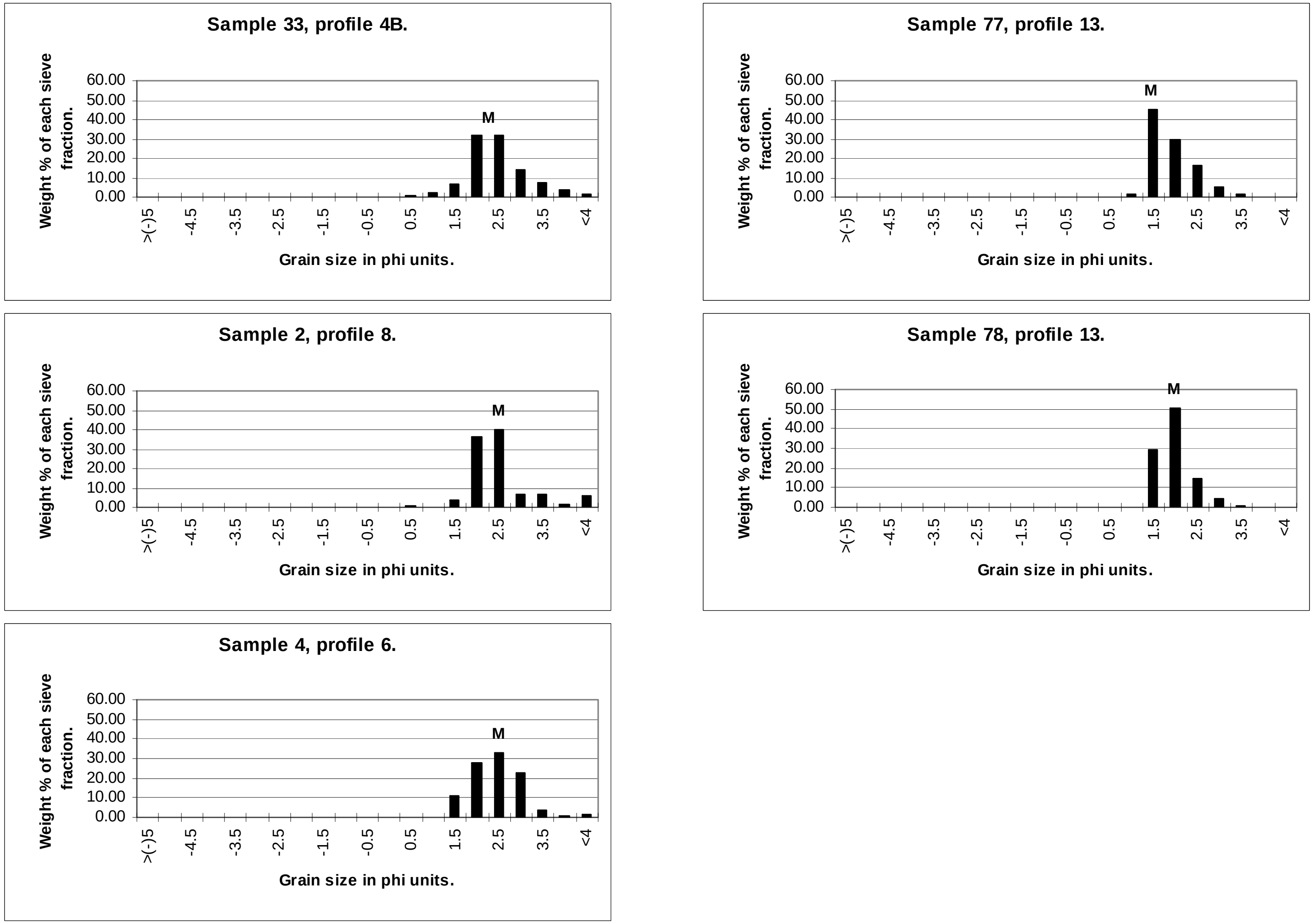


Figure 3 (Cont.): Grain size analysis histograms for the aeolianite.

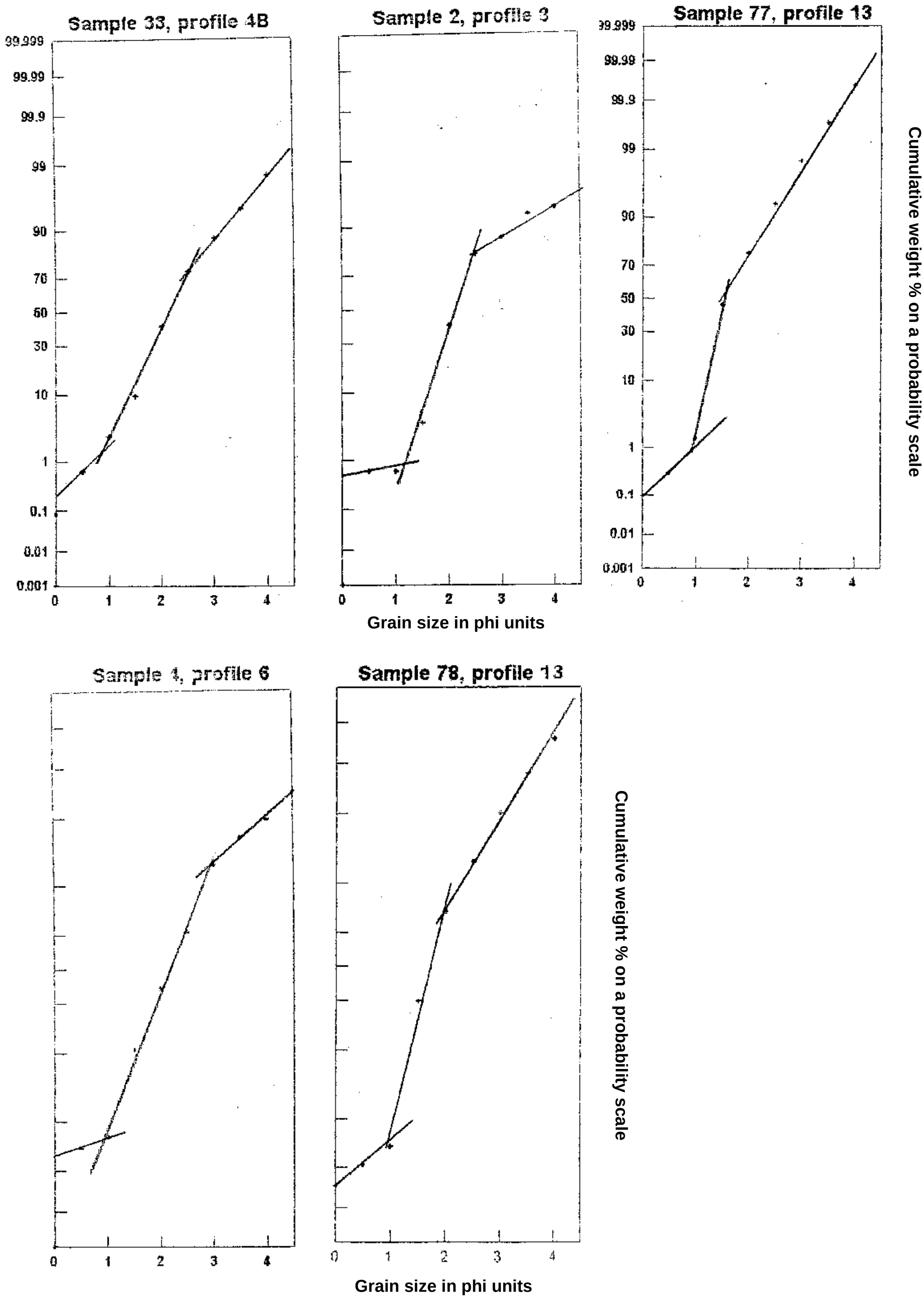


Figure 4 (Cont.): Visher diagrams for the aeolianite.

Table 3: Laboratory data for the +50m package.

Sample:	**10**	**10b**	**27**	**84**
Unit:	Shelf	Shelf	Shelf	Shelf
Profile:	1	1	4B	14
Type:	Clay	Sand	Sand	50 m
S elev:	19.02	23.66	25.44	31.27
Colour:	5 Y 6/4	5 Y 6/4	10 YR 6/6	10 YR 4/2
Group:	zS	cS	cS	S
Col Qz:	cl, y	y	y	w, cl, y, r
Roun Qz:	4	11	11	8
Minerals:	qz,rock,rut	qz,qz,rock	qz,alt,rock	qz,pyx,alt
Mud	96.01	160.15	95.80	52.15
>(-)5	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00
-3	0.00	0.00	0.00	0.00
-2.5	0.00	0.69	0.00	0.00
-2	0.00	2.52	0.00	0.00
-1.5	0.00	3.16	0.00	0.00
-1	0.00	2.86	0.00	0.00
-0.5	0.00	2.26	0.00	0.00
0	0.00	2.86	0.00	0.00
0.5	12.73	9.27	2.70	1.92
1	6.25	31.14	2.42	5.45
1.5	15.45	15.29	17.58	38.16
2	13.14	18.01	145.33	221.74
2.5	68.86	185.46	198.18	273.05
3	194.05	514.07	63.60	73.41
3.5	42.20	35.51	18.82	9.00
4	4.85	8.94	3.52	1.78
<4	3.47	1.72	5.08	0.91
Tsieve	361.01	833.76	457.22	625.42
%?wt	21.01	16.11	17.32	7.70
mode	two	two	two	two
median	2.665	2.639	2.15	2.08
mean	2.573	2.559	2.16	2.06
class	**fine S**	**fine S**	**fine S**	**fine S**
kurtosis	1.715	1.8	1.06	1.028
skewness	-0.359	-0.466	0.102	-0.037
sorting	0.599	0.543	0.487	0.448
sortC	**mod. well**	**mod.well**	**well**	**well**
VishC	R, b or c.s.	R, b or c.s.	R, l or c.s.	beach
TOTAL	**457.02**	**993.91**	**553.02**	**677.57**
%Tgravel	0.00	0.93	0.00	0.00
%Tsand	78.23	82.79	81.76	92.17
%Tmud	21.77	16.29	18.24	7.83
Heavy	1.18	14.51	4.38	48.91

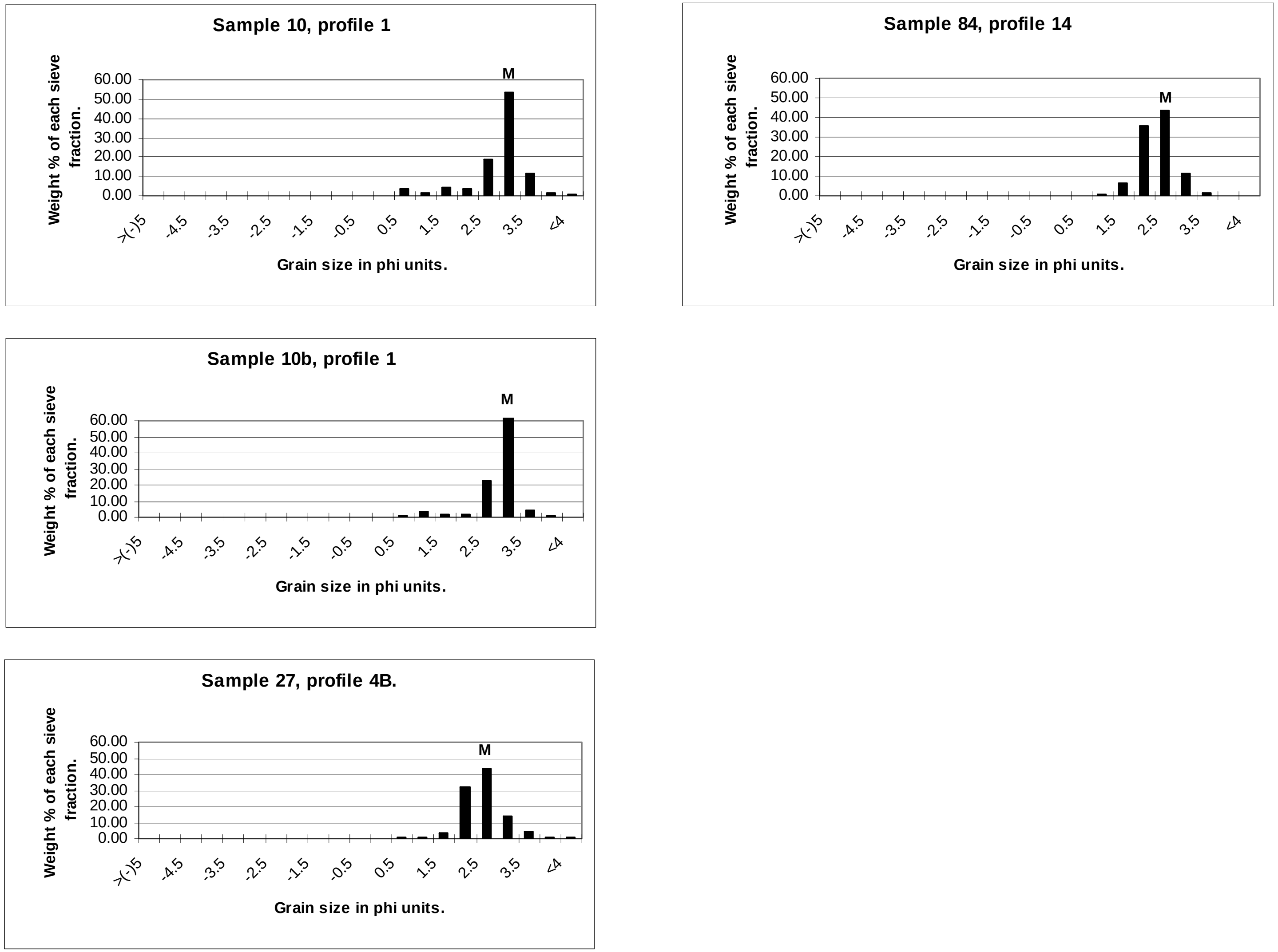


Figure 5: Grain size analysis histograms for the +50m package.

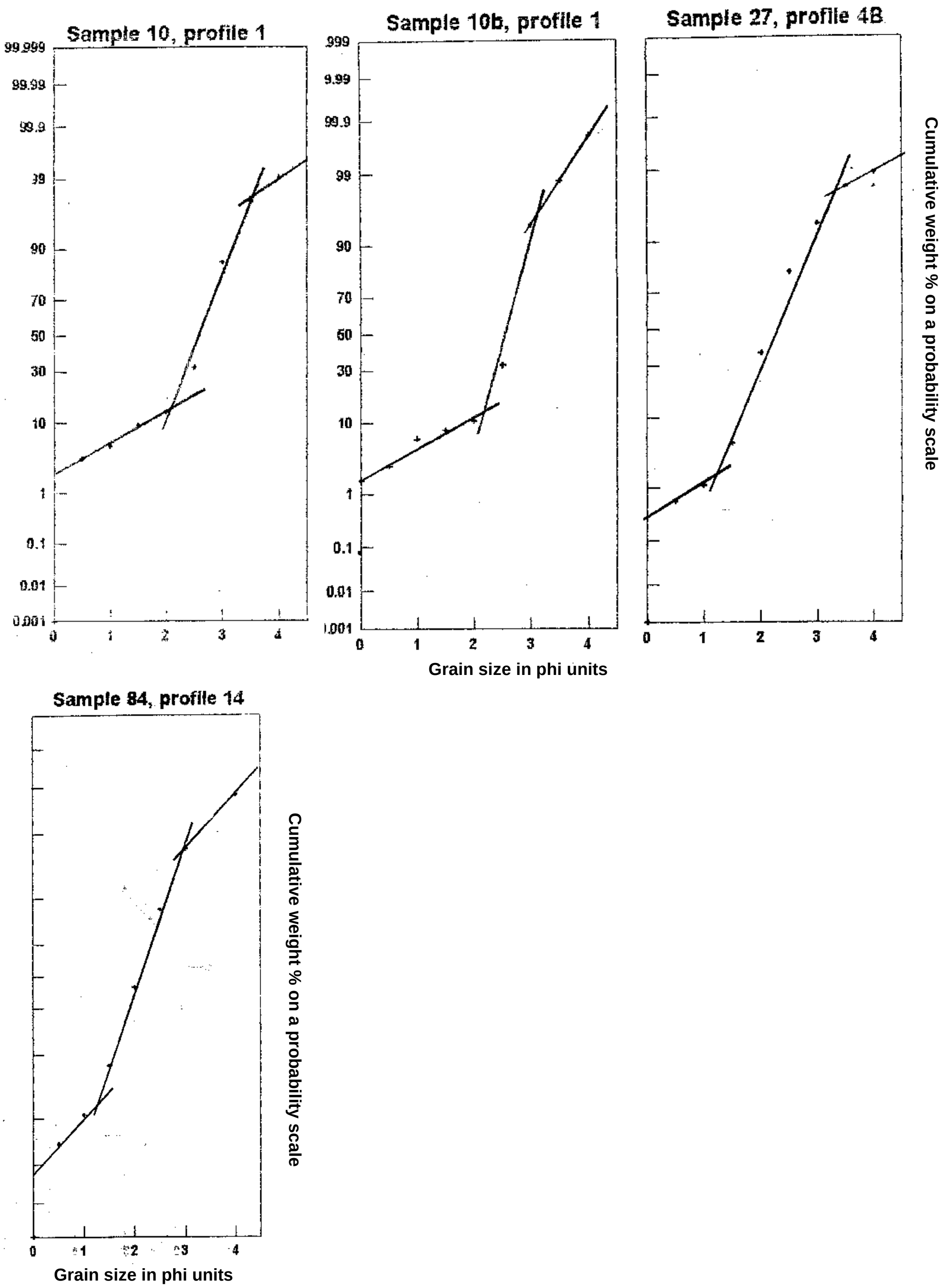


Figure 6: Visher diagrams for the +50m package.

Table 3 (Cont.): Laboratory data for the +50m package.

Sample:	21b	90	21a	7b	112	48
Unit:	BMG	BMG	BMG	BMG	BMG	BMG
Profile:	2	15	2	6	7	5
Type:	Pebble	Pebble	Pebble	Sand	Pebble	Pebble
S elev:	31.68	32.1	32.26	32.4	32.22	33.23
Colour:	10 YR 7/4	10 YR 7/4	10 YR 7/4	10 YR 6/6	10 YR 7/4	10 YR 6/6
Group:	cS	zS	cS	cS	S	S
Col Qz:	w, cl, y, r	cl, y, r	w, cl, y, r	y	cl, y	w, y
Roun Qz:	8	11	11	13	8	8
Minerals:	qz,alt,rock	qz,ore,alt	qz,alt,rock	ore,alt,rock	qz,qz,rock	qz,pyx,alt
Mud	485.48	65.15	525.53	0.00	22.15	182.15
>(-)5	0.00	252.86	0.00	0.00	0.00	0.00
-5	0.00	53.38	0.00	0.00	0.00	0.00
-4.5	0.00	6.32	0.00	0.00	0.00	0.00
-4	55.79	26.51	103.97	0.00	0.00	0.00
-3.5	64.98	19.36	72.42	0.00	0.00	27.56
-3	76.55	25.21	214.11	0.00	1.57	6.97
-2.5	201.27	1.01	83.74	0.00	0.60	0.86
-2	0.99	17.53	0.68	0.00	2.16	0.00
-1.5	44.74	15.97	12.91	0.00	3.52	1.65
-1	95.84	12.66	18.08	0.00	5.39	0.88
-0.5	35.86	13.54	4.98	0.00	8.77	1.29
0	82.90	11.92	15.13	0.00	16.65	4.32
0.5	52.66	14.76	17.40	2.34	25.14	6.56
1	0.00	32.47	0.00	0.00	56.35	45.25
1.5	102.45	89.87	57.76	10.64	241.67	155.36
2	38.72	218.97	41.71	31.96	660.73	443.56
2.5	29.07	266.30	45.74	86.84	476.15	726.47
3	7.98	116.02	12.49	45.15	121.68	659.59
3.5	2.20	37.09	3.19	55.07	22.28	306.84
4	1.42	22.58	1.77	15.77	8.00	58.07
<4	0.00	1.22	1.14	3.90	1.00	1.87
Tsieve	893.41	1255.55	707.21	251.67	1651.66	2447.10
%?wt	35.21	24.08	42.63	0.00	1.32	6.93
mode	many	many	many	two	one	two
median	-1.49	1.58	-3.09	2.47	1.85	2.36
mean	-1.22	1.45	-1.86	2.57	1.84	2.34
class	**V. fine P**	**medium S**	**V. fine P**	**fine S**	**medium S**	**fine S**
kurtosis	0.815	0.176	0.751	0.97	1.26	1.04
skewness	0.157	-0.099	0.655	0.197	-0.068	-0.086
sorting	2.053	0.97	2.351	0.707	0.593	0.681
sortC	**V. poor**	**moderate**	**V. poor**	**moderate**	**mod. well**	**mod. well**
VishC	beach	R, l or c.s.	beach	beach	beach	R,b or c.s.
TOTAL	**1378.89**	**1320.70**	**1232.74**	**251.67**	**1673.81**	**2629.25**
%Tgravel	39.17	32.62	41.04	0.00	0.79	1.44
%Tsand	25.62	62.35	16.24	98.45	97.83	91.56
%Tmud	35.21	5.03	42.72	1.55	1.38	7.00
Heavy	left out	13.62	2.63	63.11	7.39	79

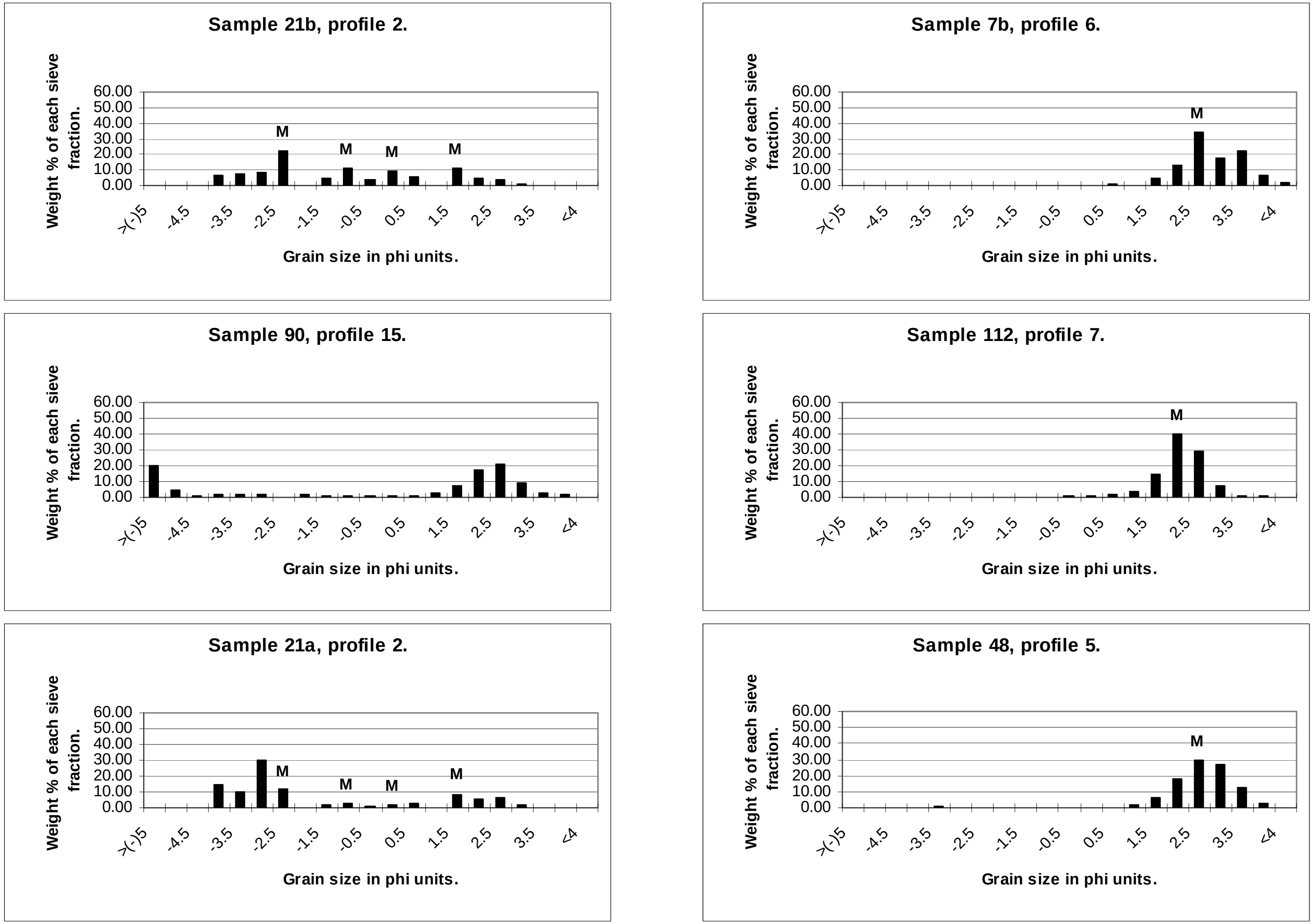


Figure 5 (Cont.): Grain size analysis histograms for the +50m package.

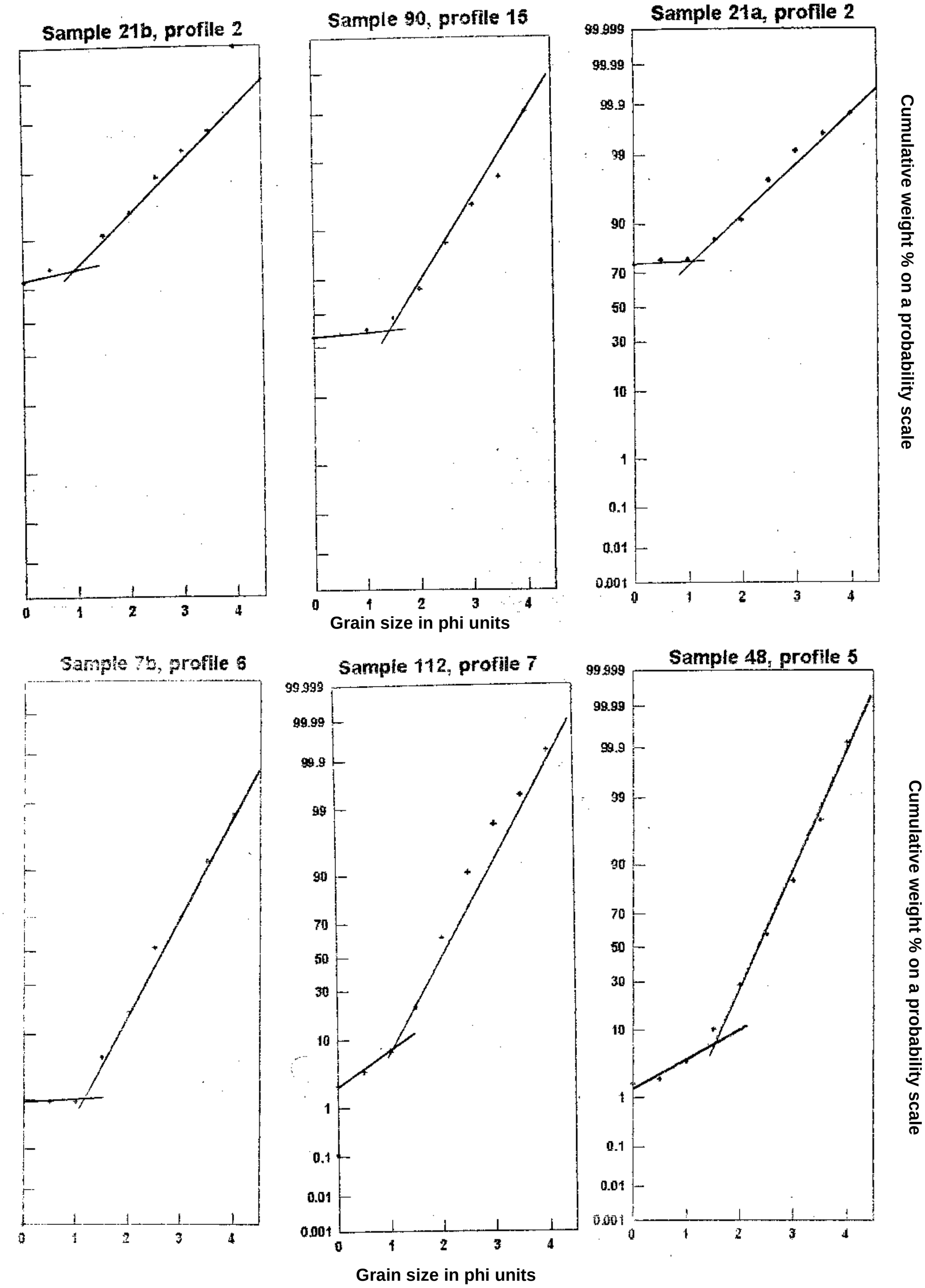


Figure 6 (Cont.): Visher diagrams for the +50m package.

Table 3 (Cont.): Laboratory data for the +50m package.

Sample:	72	18	7c	92	49	20
Unit:	BMG	BMG	BMG	BMG	BMG	BMG
Profile:	13	2	6	16	5	2
Type:	Pebble	Sand	Sand	Sand	Pebble	Sand
S elev:	33.27	33.43	33.7	34.33	34.56	35.02
Colour:	10 YR 6/6	10 YR 7/4	10 YR 6/6	5 YR 7/2	10 YR 7/4	10 YR 6/6
Group:	zS	cS	zS	S	S	S
Col Qz:	cl, y	w, cl, y, r	w, cl, y	w, y,r	w, cl, y	w, cl, y
Roun Qz:	11	10	11	11	11	11
Minerals:	ore,alt,rock	ore,alt,glauc	qz,alt,ore	qz,qz,glauc	qz,qz,rock	qz,alt,rock
Mud	285.15	0.00	0.00	70.15	32.15	0.00
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	12.78	0.00	0.00	0.00	0.00	0.00
-3.5	5.94	0.00	0.00	0.00	1.84	0.00
-3	9.78	0.00	0.00	0.00	6.33	0.00
-2.5	0.00	0.00	0.00	0.50	0.23	0.00
-2	1.01	2.47	0.00	1.97	2.27	0.00
-1.5	0.51	1.62	0.00	3.64	2.62	0.00
-1	0.99	1.61	0.00	5.77	2.57	0.00
-0.5	1.59	1.35	0.00	9.62	3.86	0.00
0	10.48	3.32	0.00	15.35	7.75	0.00
0.5	14.79	5.82	2.17	31.39	20.07	2.51
1	15.02	0.00	0.00	44.06	64.36	0.00
1.5	33.34	197.43	79.66	35.67	151.64	85.54
2	113.04	218.70	135.44	90.07	274.01	215.01
2.5	135.56	187.90	116.36	425.96	187.83	185.58
3	51.60	43.41	55.89	182.09	31.50	58.24
3.5	77.01	12.74	153.77	16.20	3.68	27.17
4	17.42	10.15	14.59	3.39	1.27	15.05
<4	0.08	1.80	3.98	0.93	0.93	1.50
Tsieve	500.94	688.32	561.86	866.61	762.76	590.60
%?wt	36.27	0.00	0.00	7.49	4.04	0.00
mode	many	one	many	two	one	one
median	2.12	1.80	2.27	2.23	1.72	1.98
mean	2.11	1.81	2.36	2.09	1.67	2.02
class	**fine S**	**medium S**	**fine S**	**fine S**	**medium S**	**fine S**
kurtosis	2.429	0.911	0.68	1.929	1.099	1.167
skewness	-0.305	0.104	0.09	-0.408	-0.198	0.163
sorting	1.5	0.567	0.784	0.756	0.649	0.581
sortC	**poor**	**mod. well**	**moderate**	**moderate**	**mod. well**	**mod. well**
VishC	R,b or c.s.	beach	beach	R, b. or c.s.	beach	beach
TOTAL	**786.09**	**688.32**	**561.86**	**936.76**	**794.91**	**590.6**
%Tgravel	3.94	0.83	0.00	1.27	2.00	0.00
%Tsand	59.77	98.91	99.29	91.14	93.84	99.75
%Tmud	36.28	0.26	0.71	7.59	4.16	0.25
Heavy	31.48	left out	56.69	8.72	10.93	40.53

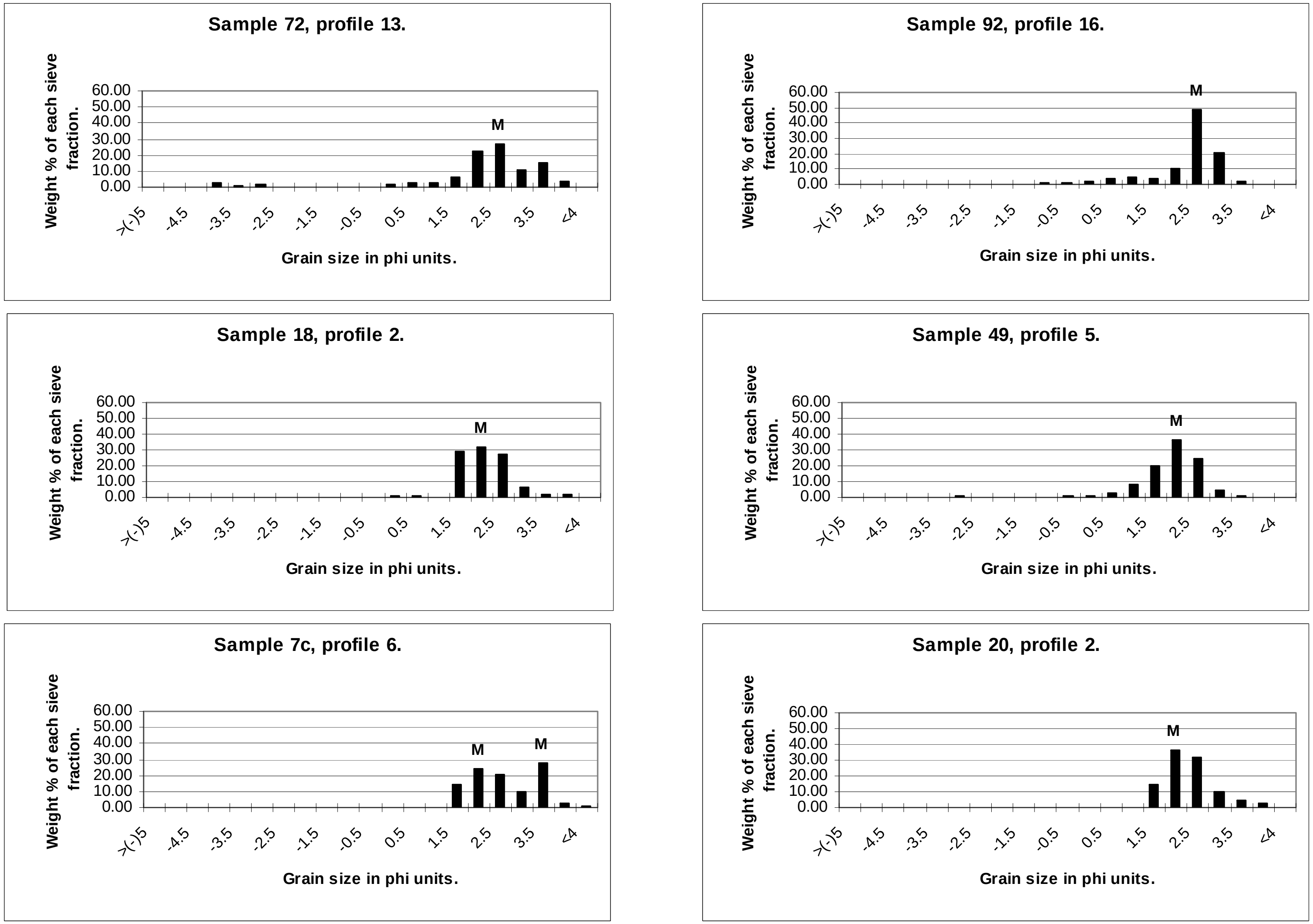


Figure 5 (Cont.): Grain size analysis histograms for the +50m package.

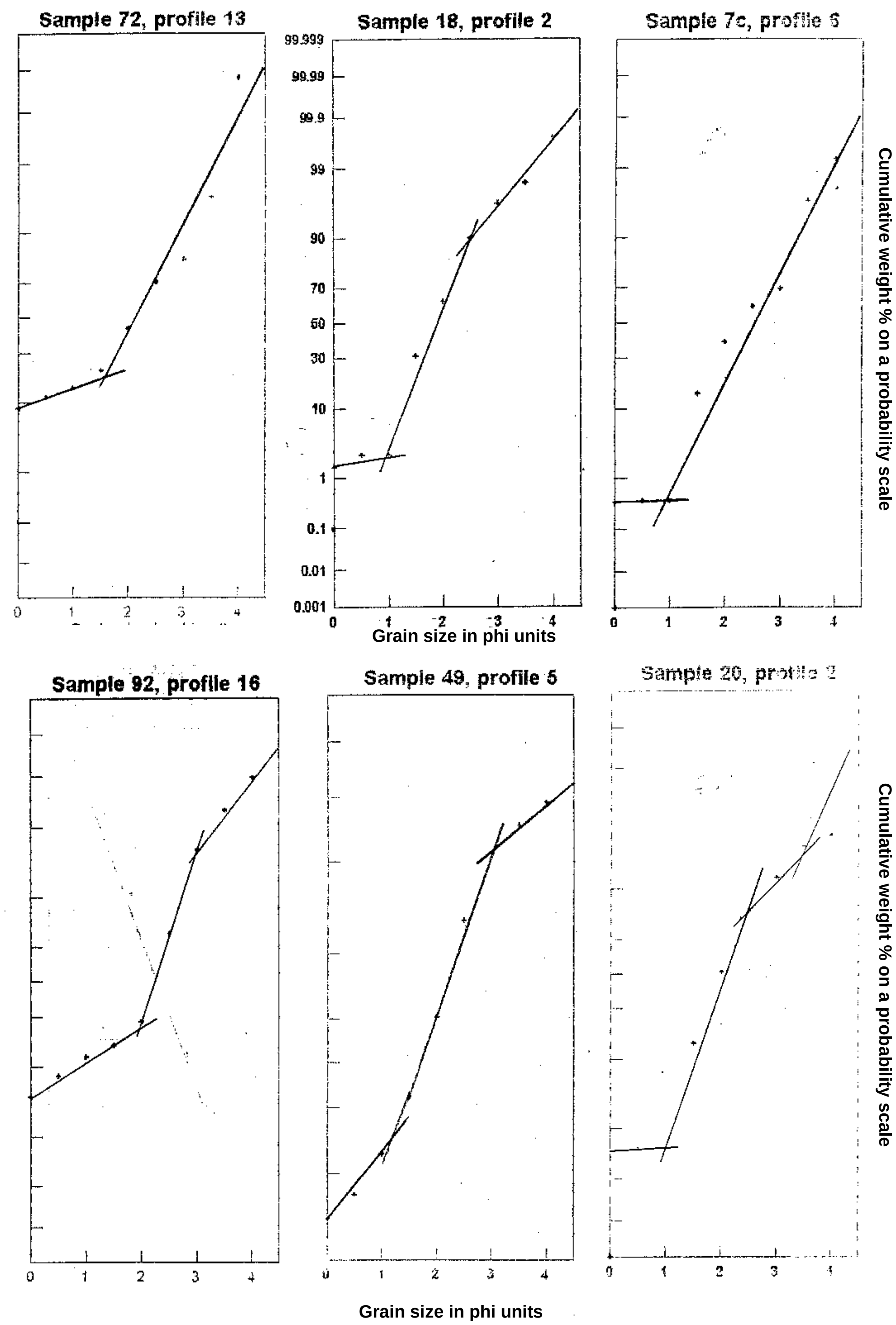


Figure 6 (Cont.): Visher diagrams for the +50m package.

Table 3 (Cont.): Laboratory data for the +50m package.

Sample:	85	7a	17d	6	74
Unit:	BMG	BMG	BMG	BMG	BMG
Profile:	14	6	2	6	13
Type:	Sand	Pebble	Sand	Sand	Pebble
S elev:	37.65	35.73	38.91	39.45	40.18
Colour:	10 YR 4/2	10 YR 6/6	5 Y 6/4	10 YR 4/2	10 YR 6/2
Group:	S	S	cS	S	S
Col Qz:	w, cl, y	cl, y, r	cl, y, r	cl, y	cl, y, r
Roun Qz:	10	12	11	10	11
Minerals:	ore,pyx,alt	qz,qz,alt	qz,pyx,ore	qz,ore,rock	qz,qz,rock
Mud	35.15	323.58	0.00	78.21	1021.42
>(-)5	0.00	0.00	0.00	0.00	2.57
-5	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00
-4	0.00	37.03	0.00	0.00	0.00
-3.5	0.00	36.31	0.00	0.00	2.57
-3	0.00	211.93	0.00	0.00	5.83
-2.5	0.00	11.85	0.00	0.00	3.18
-2	0.00	0.42	0.00	0.00	0.00
-1.5	0.00	13.45	0.00	2.78	1.44
-1	0.00	21.20	0.00	4.54	1.27
-0.5	0.00	7.09	0.00	2.44	1.89
0	0.47	20.22	0.00	5.96	3.10
0.5	2.75	38.22	0.00	9.36	9.13
1	18.60	0.98	0.00	0.00	40.24
1.5	369.28	121.53	0.00	120.15	238.60
2	626.33	52.29	111.80	136.83	424.81
2.5	477.34	44.85	149.73	98.08	212.69
3	214.79	21.27	104.41	32.14	80.84
3.5	35.14	21.65	43.81	18.14	18.02
4	5.10	7.79	4.25	9.53	1.71
<4	0.45	1.96	2.28	1.86	0.90
Tsieve	1750.25	670.04	416.28	441.82	1048.79
%?wt	1.97	32.57	0.00	15.04	49.46
mode	one	many	one	two	two
median	1.89	-0.80	2.32	1.78	1.75
mean	1.90	-0.77	2.35	1.81	1.77
class	**medium S**	**V.coarse S**	**fine S**	**medium S**	**medium S**
kurtosis	0.96	0.61	0.92	1.31	1.143
skewness	0.08	0.044	0.116	0.035	0.042
sorting	0.554	2.392	0.545	0.75	0.589
sortC	**mod. well**	**V. poor**	**mod. well**	**moderate**	**mod. well**
VishC	beach	R,l or c.s.	beach	R,l or c.s.	R,b or c.s.
TOTAL	**1785.40**	**993.62**	**416.28**	**520.03**	**2070.21**
%Tgravel	0.00	33.43	0.00	1.41	0.81
%Tsand	98.01	33.80	99.45	83.20	49.80
%Tmud	1.99	32.76	0.55	15.40	49.38
Heavy	67.82	17.51	43.1	30.61	27.12

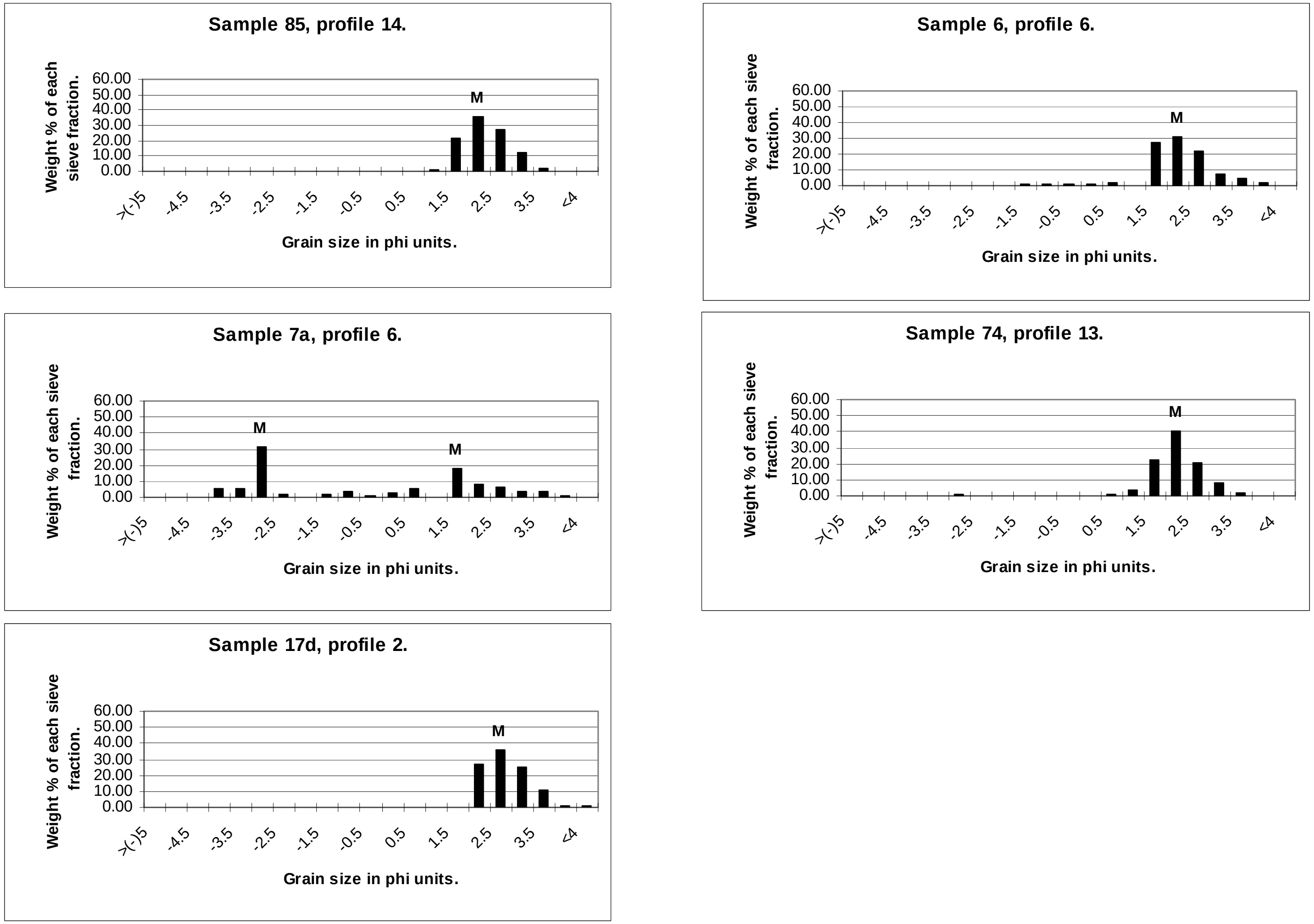


Figure 5 (Cont.): Grain size analysis histograms for the +50m package.

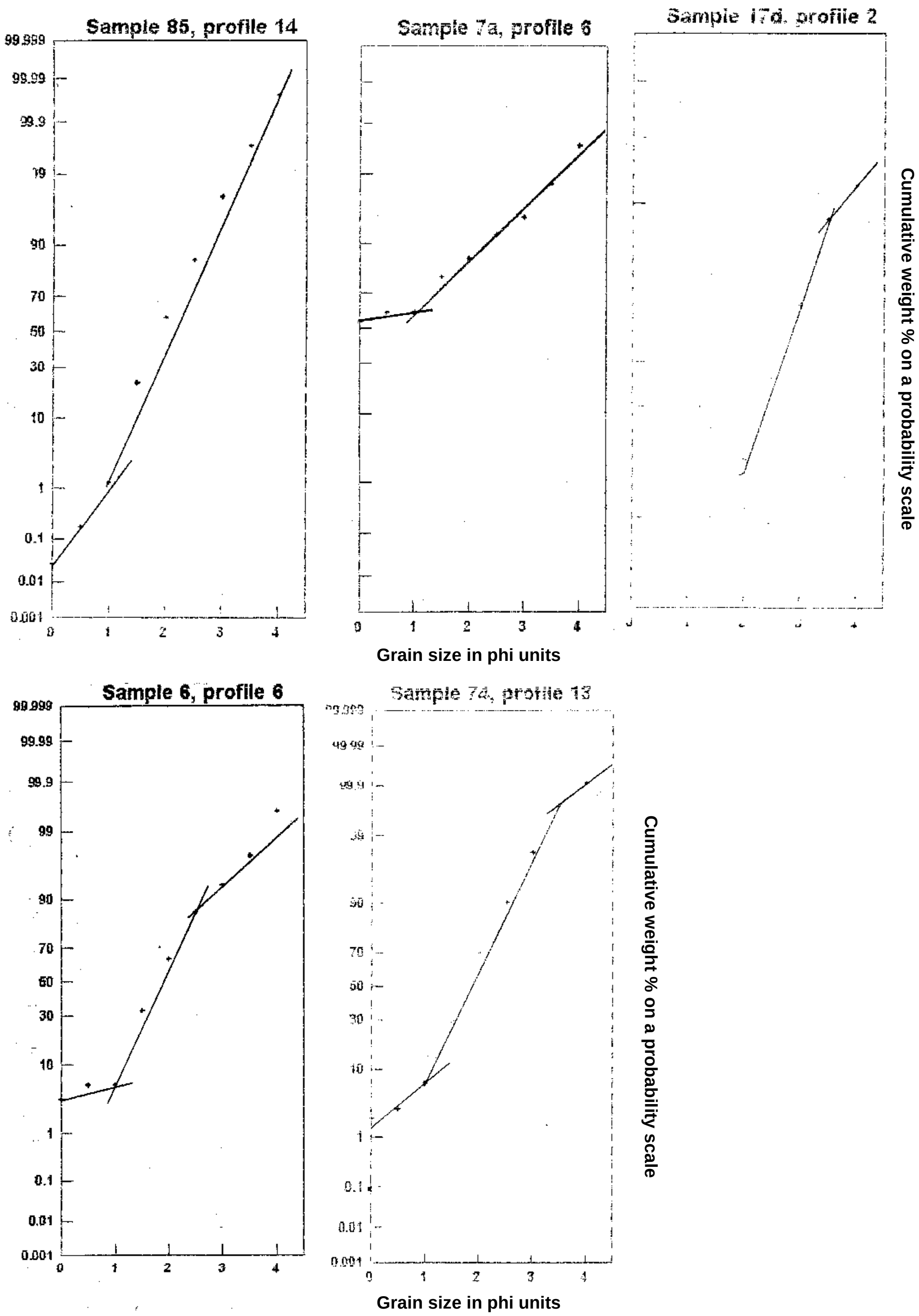


Figure 6 (Cont.): Visher diagrams for the +50m package.

Table 3 (Cont.): Laboratory data for the +50m package.

Sample:	**17c**	**86**	**50**	**3c**	**3b**	**75**
Unit:	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal
Profile:	2	14	5	6	6	13
Type:	Sand	Sand	Sand	Sand	Sand	Sand
S elev:	40.22	41.82	42.72	44.36	46.05	47.65
Colour:	10 YR 6/6	10 YR 4/2	5 Y 5/2	5 Y 5/2	10 YR 4/2	10 YR 4/2
Group:	cS	cS	S	S	S	S
Col Qz:	w, cl, y	w, cl, y, r	w, y	w, cl, r	cl, y, r	cl, y
Roun Qz:	10	7	7	10	11	11
Minerals:	alt,pyx,ore	pyx,rock,ore	ore,gar, pyx	pyx,ore,gar	pyx,ore,gar	pyx,alt,ore
Mud	0.00	140.15	61.15	0.00	0.00	30.15
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	6.29	0.00	0.00	0.00	0.00
-3	0.00	6.37	0.00	0.00	0.00	0.00
-2.5	0.00	2.18	0.00	0.00	0.00	0.00
-2	0.00	1.99	0.00	0.00	0.00	0.00
-1.5	0.00	3.29	0.00	0.00	0.00	0.00
-1	0.00	3.56	0.00	0.00	0.00	0.00
-0.5	0.00	3.46	0.00	0.00	0.00	0.00
0	0.00	4.23	2.31	0.00	0.00	0.00
0.5	0.00	8.25	8.20	0.00	0.00	6.88
1	0.00	29.53	13.23	0.00	0.00	12.96
1.5	0.00	104.54	33.57	0.00	0.00	49.70
2	199.74	364.77	257.50	113.95	57.86	411.20
2.5	154.23	424.82	899.64	298.88	286.12	263.67
3	73.78	186.24	770.89	207.10	226.07	95.27
3.5	28.12	42.64	175.46	153.02	100.44	12.51
4	1.44	14.55	10.96	6.80	8.72	1.68
<4	3.00	2.67	0.81	0.35	1.23	0.00
Tsieve	460.31	1209.38	2172.57	780.10	680.44	853.87
%?wt	0.00	10.39	2.74	0.00	0.00	3.41
mode	one	two	one	one	one	one
median	2.10	2.08	2.43	2.46	2.49	1.94
mean	2.17	2.08	2.45	2.53	2.53	1.99
class	**fine S**	**fine S**	**fine S**	**fine S**	**fine S**	**medium S**
kurtosis	0.97	1.16	1.04	0.91	0.97	1.058
skewness	0.265	-0.065	0.022	0.137	0.119	0.158
sorting	0.504	0.604	0.466	0.536	0.47	0.462
sortC	**mod. well**	**mod. well**	**well**	**mod. well**	**well**	**well**
VishC	beach	R,l or c.s.	beach	beach	beach	R,b or c.s.
TOTAL	**460.31**	**1349.53**	**2233.72**	**780.10**	**680.44**	**884.02**
%Tgravel	0.00	1.75	0.00	0.00	0.00	0.00
%Tsand	99.35	87.66	97.23	99.96	99.82	96.59
%Tmud	0.65	10.58	2.77	0.04	0.18	3.41
Heavy	45.19	35.89	85.85	79.1	79.1	76.95

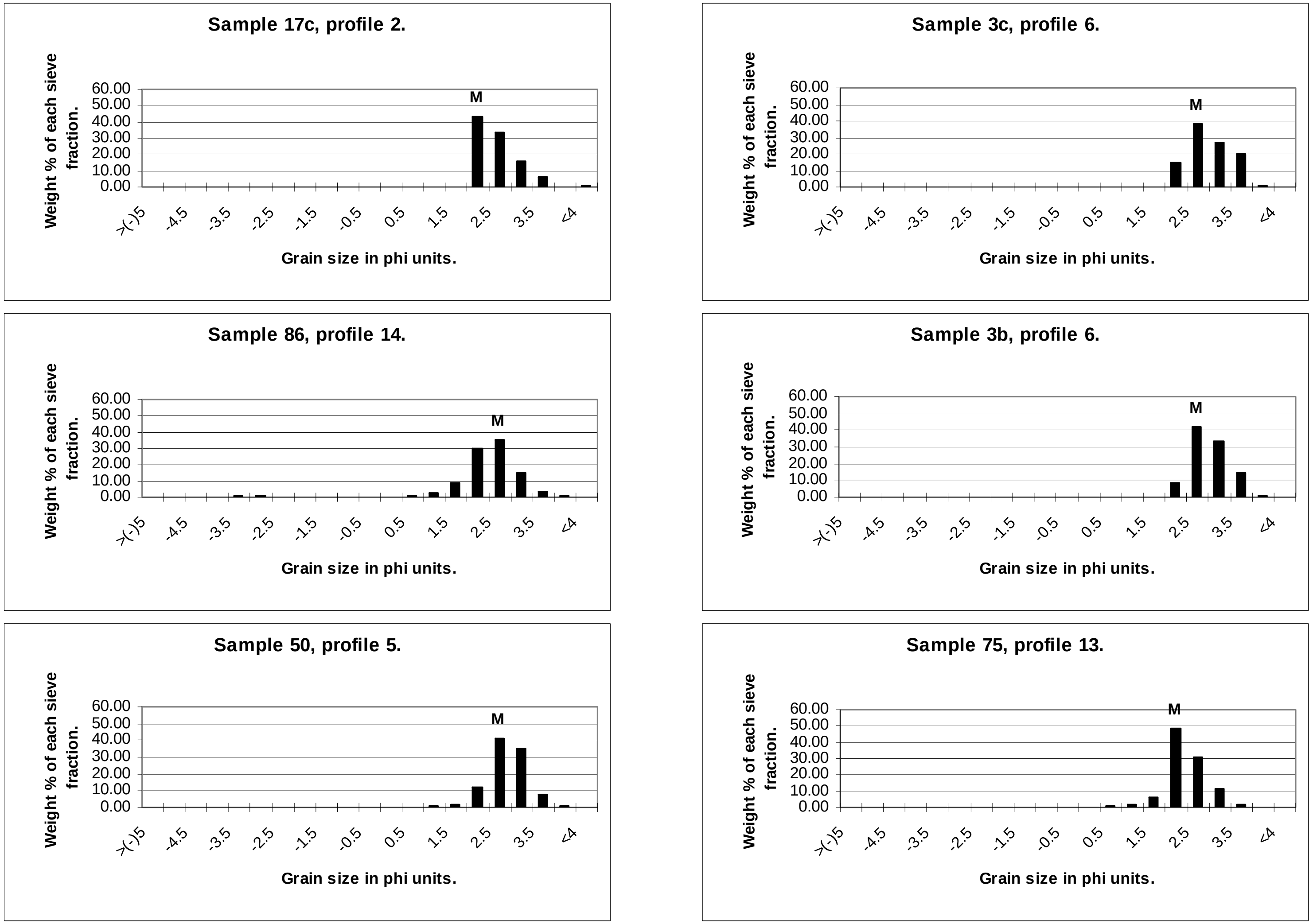


Figure 5 (Cont.): Grain size analysis histograms for the +50m package.

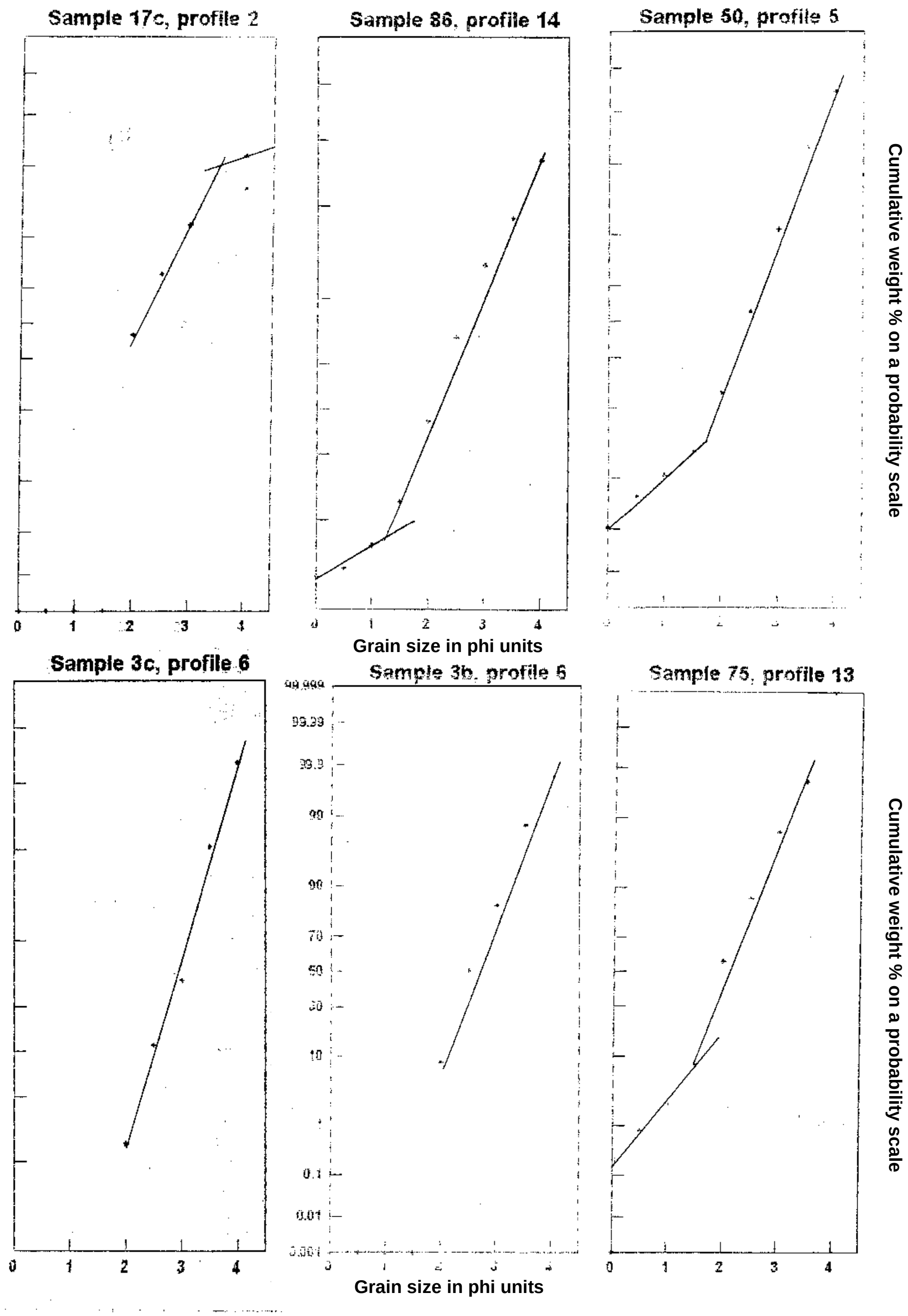
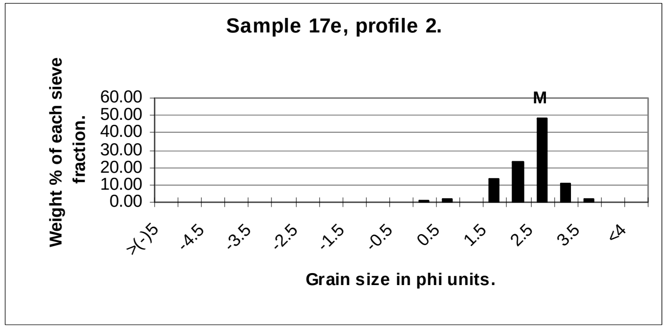
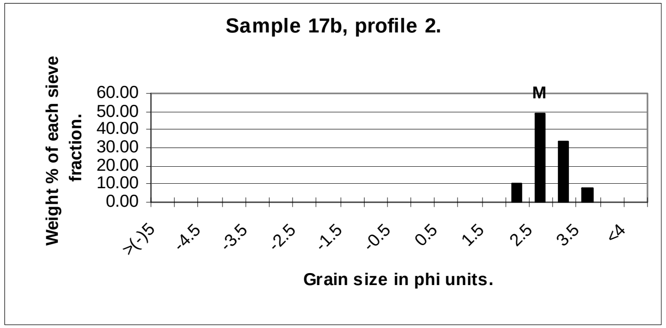


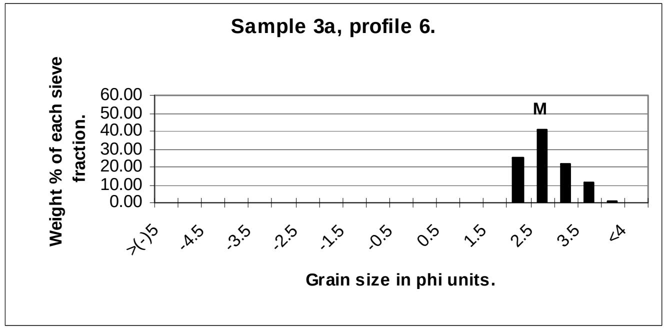
Figure 6 (Cont.): Visher diagrams for the +50m package.

Table 3 (Cont.): Laboratory data for the +50m package.

17e	3a	17a	17b
Intertidal	Intertidal	Intertidal	Intertidal
2	6	2	2
Pebble	Sand	Sand	Sand
48.1	49.16	50.11	52.89
5 Y 7/2	5 Y 5/2	10 YR 6/6	5 Y 5/2
S	S	S	cS
w, cl, y	w, cl, r	w, cl, y, r	w, cl, y, r
7	7	11	11
qz,pyx,rock	pyx,alt,rock	pyx,alt,ore	pyx,ore,rock
21.40	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00
3.61	0.00	0.00	0.00
0.00	0.00	0.00	0.00
1.94	0.00	0.00	0.00
1.74	0.00	0.00	0.00
5.03	0.00	1.02	0.00
15.26	0.00	6.48	0.00
0.00	0.00	0.00	0.00
138.05	0.00	81.30	0.00
231.99	148.43	109.13	50.28
485.67	241.62	163.61	246.39
107.33	129.66	180.05	169.23
15.94	64.62	53.81	37.37
1.49	4.52	7.07	1.73
1.61	0.00	4.01	0.41
1009.64	588.85	606.48	505.41
2.08	0.00	0.00	0.00
one	one	one	one
2.11	2.30	2.32	2.41
2.02	2.34	2.26	2.45
fine S	**fine S**	**fine S**	**fine S**
1.062	1.00	0.92	1.00
-0.219	0.142	-0.113	0.114
0.513	0.53	0.674	0.422
mod. well	**mod. well**	**mod. well**	**well**
beach	beach	beach	beach
1031.039	**588.85**	**606.479**	**505.41**
0.54	0.00	0.00	0.00
97.23	100.00	99.34	99.92
2.23	0.00	0.66	0.08
25.66	62.21	52.51	66.59







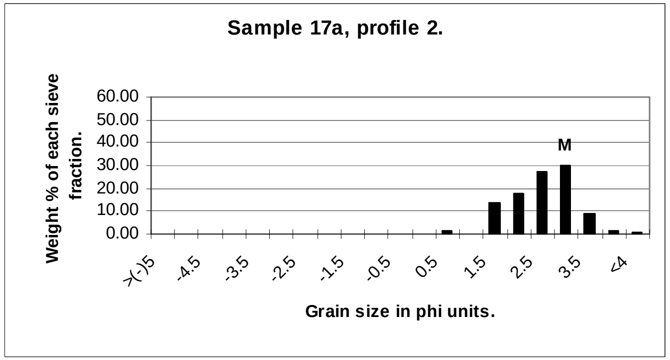


Figure 5 (Cont.): Grain size analysis histograms for the +50m package.

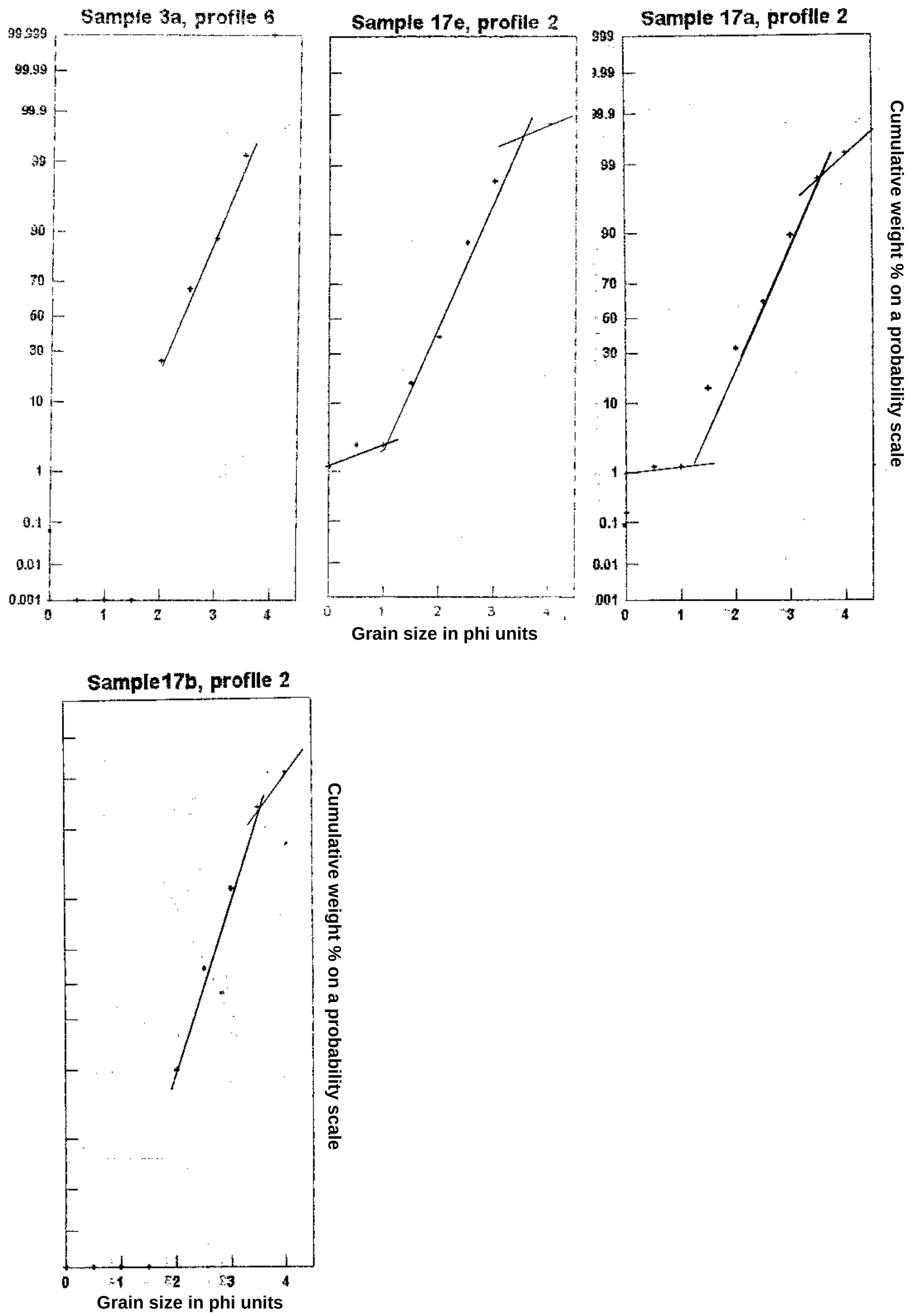


Figure 6 (Cont.): Visher diagrams for the +50m package.

Table 4: Laboratory data for the +30m package.

Sample:	100	57	56	98	99
Unit:	Shelf (green)	Shelf (green)	Shelf (green)	Shelf (green)	Shelf (green)
Profile:	9	9	9	9	9
Type:	Sand	Pebble	Pebble	Pebble	Sand
S elev:	23.57	23.61	24.23	25.22	25.36
Colour:	5 Y 5/6	5 Y 6/4	10 Y 6/2	10 YR 4/2	5 Y 7/2
Group:	cS	S	zS	S	zS
Col Qz:	cl, y	cl, y	cl	cl, y	cl
Roun Qz:	9	5	9	14	12
Minerals:	qz,qz,glauc	qz,qz,rock	alt,rock,rock	qz,qz,rock	qz,qz,glauc
Mud	486.15	370.15	370.15	47.15	152.15
>(-)5	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	8.02	0.00
-3	0.00	0.00	0.00	10.36	0.00
-2.5	0.00	0.00	0.00	3.34	0.00
-2	0.00	0.00	0.88	11.52	0.00
-1.5	0.00	1.63	0.00	32.75	0.00
-1	0.00	1.18	0.00	45.72	0.00
-0.5	1.62	2.24	1.75	113.19	1.65
0	4.38	8.48	5.65	313.39	5.53
0.5	8.46	17.78	8.25	453.24	19.90
1	7.60	22.08	22.11	62.97	17.84
1.5	4.83	9.37	22.04	12.82	18.05
2	8.47	22.43	52.09	24.80	50.85
2.5	40.45	189.51	206.97	115.38	752.58
3	215.69	334.46	434.46	146.27	316.65
3.5	85.11	26.06	55.55	8.36	13.86
4	13.60	3.48	8.43	1.08	3.75
<4	3.00	1.13	1.79	0.49	1.52
Tsieve	393.21	639.83	819.97	1363.70	1202.18
%?wt	55.28	31.10	31.10	3.34	11.23
mode	two	two	two	many	two
median	2.78	2.57	2.60	0.16	2.32
mean	2.78	2.50	2.52	0.62	2.37
class	**fine S**	**fine S**	**fine S**	**coarse S**	**fine S**
kurtosis	2.31	1.669	1.441	1.65	1.44
skewness	-0.229	-0.443	-0.35	0.369	0.001
sorting	0.622	0.588	0.549	1.338	0.398
sortC	**mod. well**	**mod. well**	**mod. well**	**poor**	**well**
VishC	beach	R,b or c.s.	R,b or c.s.	all pos.	beach
TOTAL	**879.36**	**910.98**	**1190.12**	**1410.85**	**1354.33**
%Tgravel	0.00	0.31	0.07	7.92	0.00
%Tsand	44.37	69.80	68.67	88.71	88.65
%Tmud	55.63	29.89	31.25	3.38	11.35
Heavy	0.42	0.09	0.16	0.52	0.07

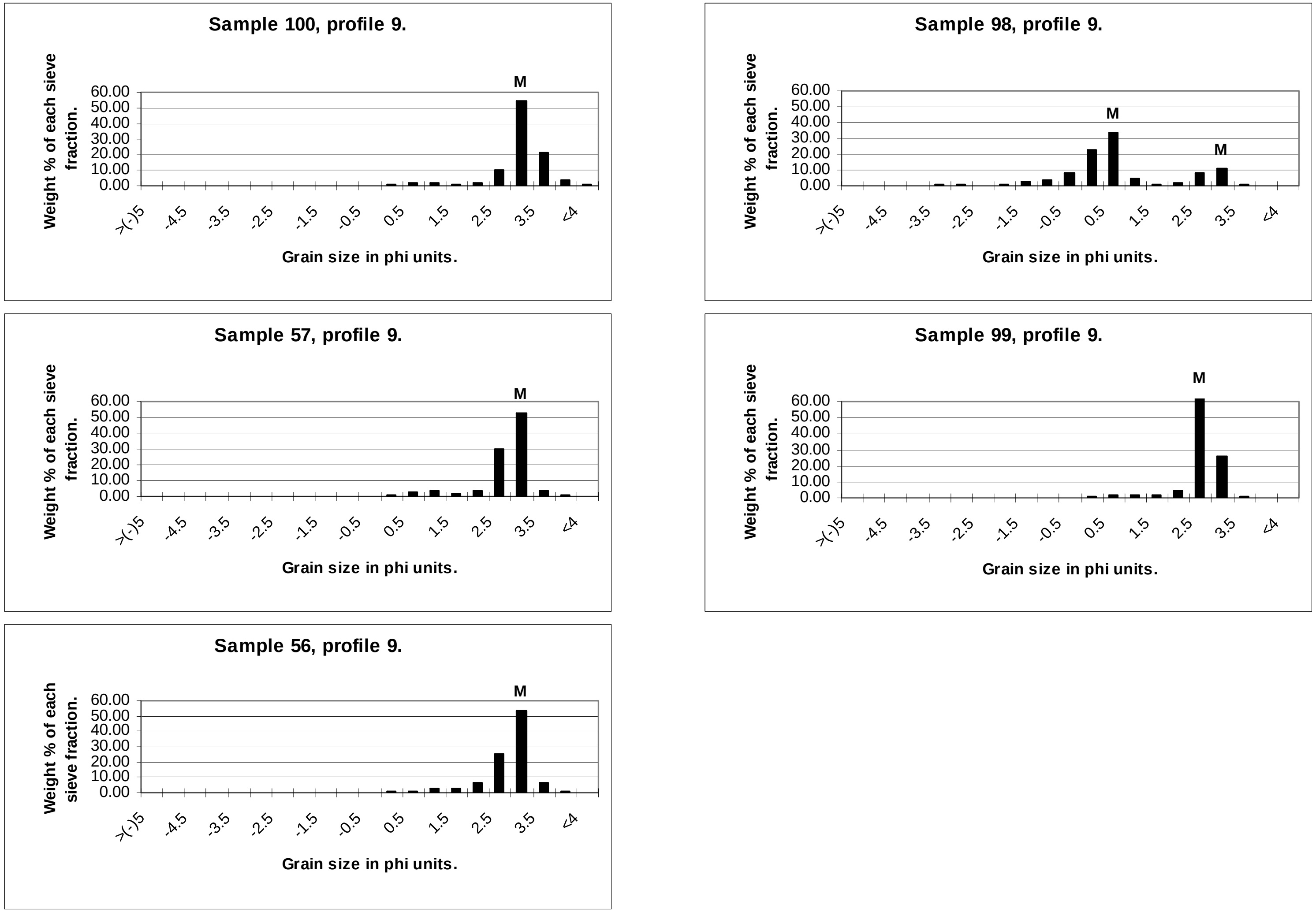


Figure 7: Grain size analysis histograms for the +30m package.

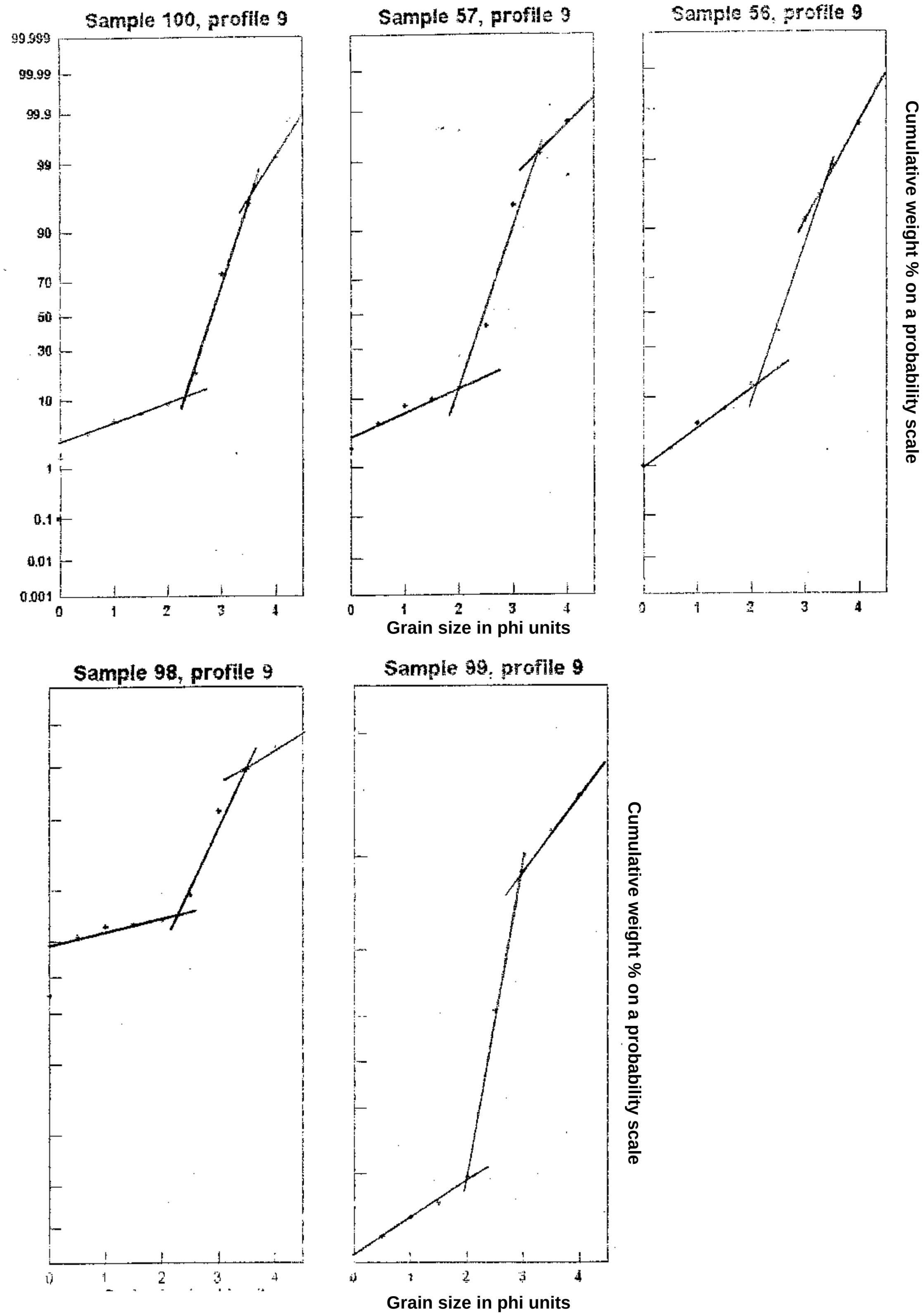


Figure 8: Visher diagrams for the +30m package.

Table 4 (Cont.): Laboratory data for the +30m package.

Sample:	**36b**	**26**	**107**	**25**	**58**	**11b**
Unit:	BMG	BMG	BMG	BMG	BMG	BMG
Profile:	4B	4B	17	4B	9	1
Type:	Sand	Sand	Sand	Pebble	Basal	Sand
S elev:	25.56	25.64	25.86	25.93	25.95	25.97
Colour:	10 YR 2/2	10 YR 7/4	10 YR 6/6	10 YR 7/4	10 YR 7/4	10 YR 7/4
Group:	zS	zS	zS	zS	S	zS
Col Qz:	y	w, cl, y	y, r	cl, y	cl, y, r	w, cl, y
Roun Qz:	11	7	11	8	12	7
Minerals:	ore,alt,zir	qz,alt,rock	qz,qz,qz	qz,alt,rock	qz,qz,rock	qz,qz,rock
Mud	410.18	283.60	554.15	606.72	24.15	20.15
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	114.54	0.00	0.00
-3.5	0.00	0.00	0.00	45.94	0.00	0.00
-3	0.00	0.00	0.00	131.27	0.00	2.03
-2.5	0.00	0.00	0.00	40.17	0.00	1.05
-2	0.00	0.00	0.00	0.70	8.75	4.46
-1.5	0.00	0.00	0.68	14.69	11.61	5.67
-1	0.00	0.00	0.43	45.76	8.36	7.69
-0.5	0.00	0.00	0.51	15.34	9.30	8.42
0	0.00	0.00	0.70	36.36	16.49	8.27
0.5	29.45	14.86	1.56	20.55	104.20	10.98
1	28.39	8.43	11.99	5.90	1210.98	30.02
1.5	59.12	142.23	83.83	26.42	557.34	89.02
2	37.93	290.51	189.00	41.46	152.57	219.06
2.5	85.40	337.46	122.82	78.66	25.36	217.33
3	244.95	72.53	37.28	27.31	11.91	230.12
3.5	599.87	12.44	21.11	3.27	3.01	38.58
4	36.34	1.95	15.17	1.67	1.62	2.47
<4	8.45	6.04	7.48	2.22	1.04	1.27
Tsieve	**1129.90**	**886.46**	**492.56**	**652.24**	**2122.54**	**876.44**
%?wt	26.63	24.24	52.94	48.19		2.25
mode	two	two	two	many	one	two
median	3.07	1.978	1.888	-2.572	0.873	2.119
mean	2.87	1.941	1.931	-1.52	0.939	2.084
class	**fine S**	**medium S**	**medium S**	**V. fine P**	**coarse S**	**fine S**
kurtosis	1.44	1.013	1.284	0.585	1.16	1.114
skewness	-0.572	-0.068	0.208	0.5	0.221	-0.212
sorting	0.69	0.52	0.652	2.569	0.433	0.771
sortC	**mod. well**	**mod. well**	**mod. well**	**V. poor**	**well**	**moderate**
VishC	R, l or c.s.	R, l or c.s.	all pos.	R, l or c.s.	beach	beach
TOTAL	**1540.08**	**1170.06**	**1046.71**	**1258.96**	**2146.69**	**896.59**
%Tgravel	0.00	0.00	0.11	31.22	1.34	2.33
%Tsand	72.82	75.25	46.24	20.41	97.49	95.28
%Tmud	27.18	24.75	53.66	48.37	1.17	2.39
Heavy	0.07	0.07	0.09	0.07	0.16	0.07

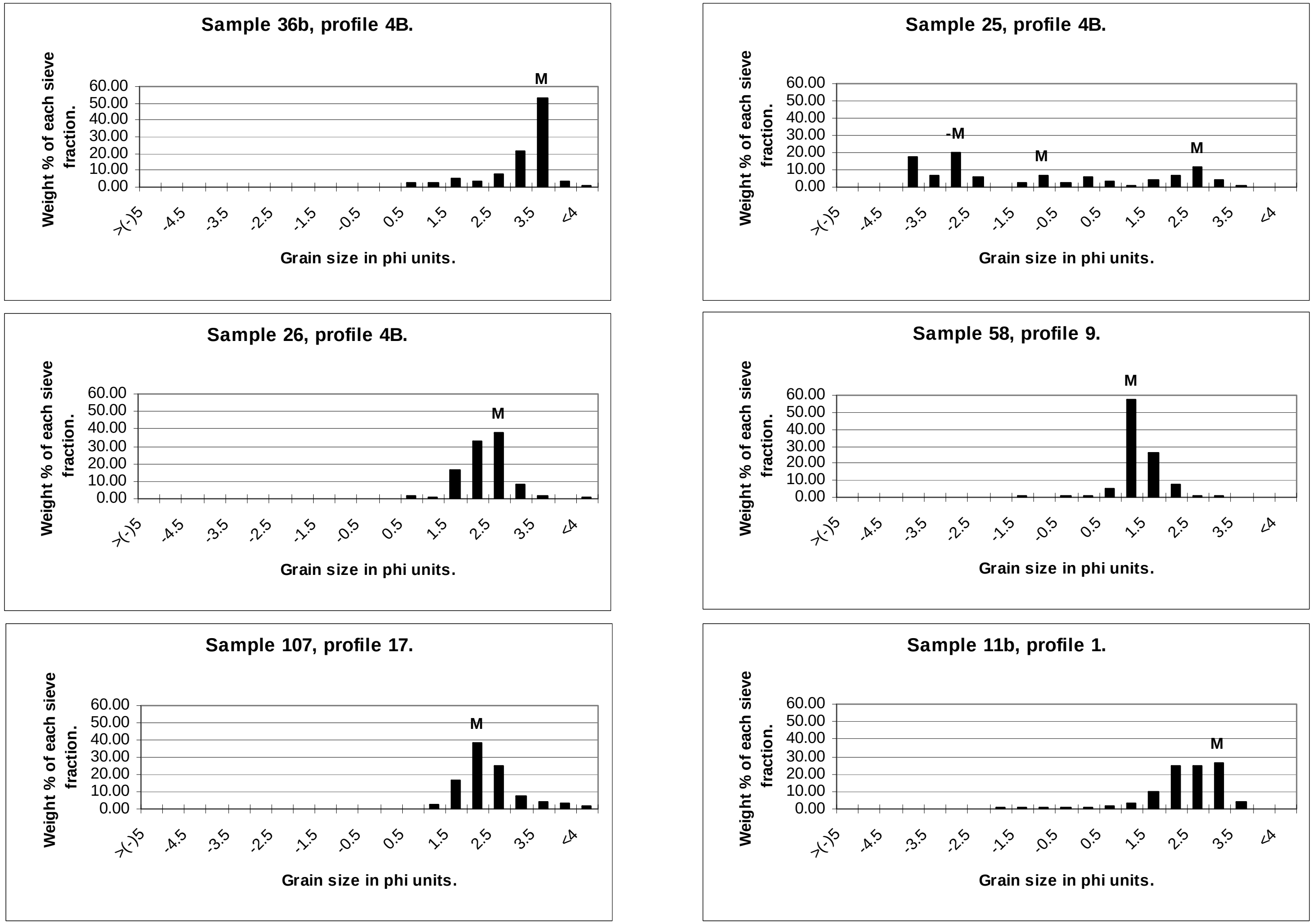


Figure 7 (Cont.): Grain size analysis histograms for the +30m package.

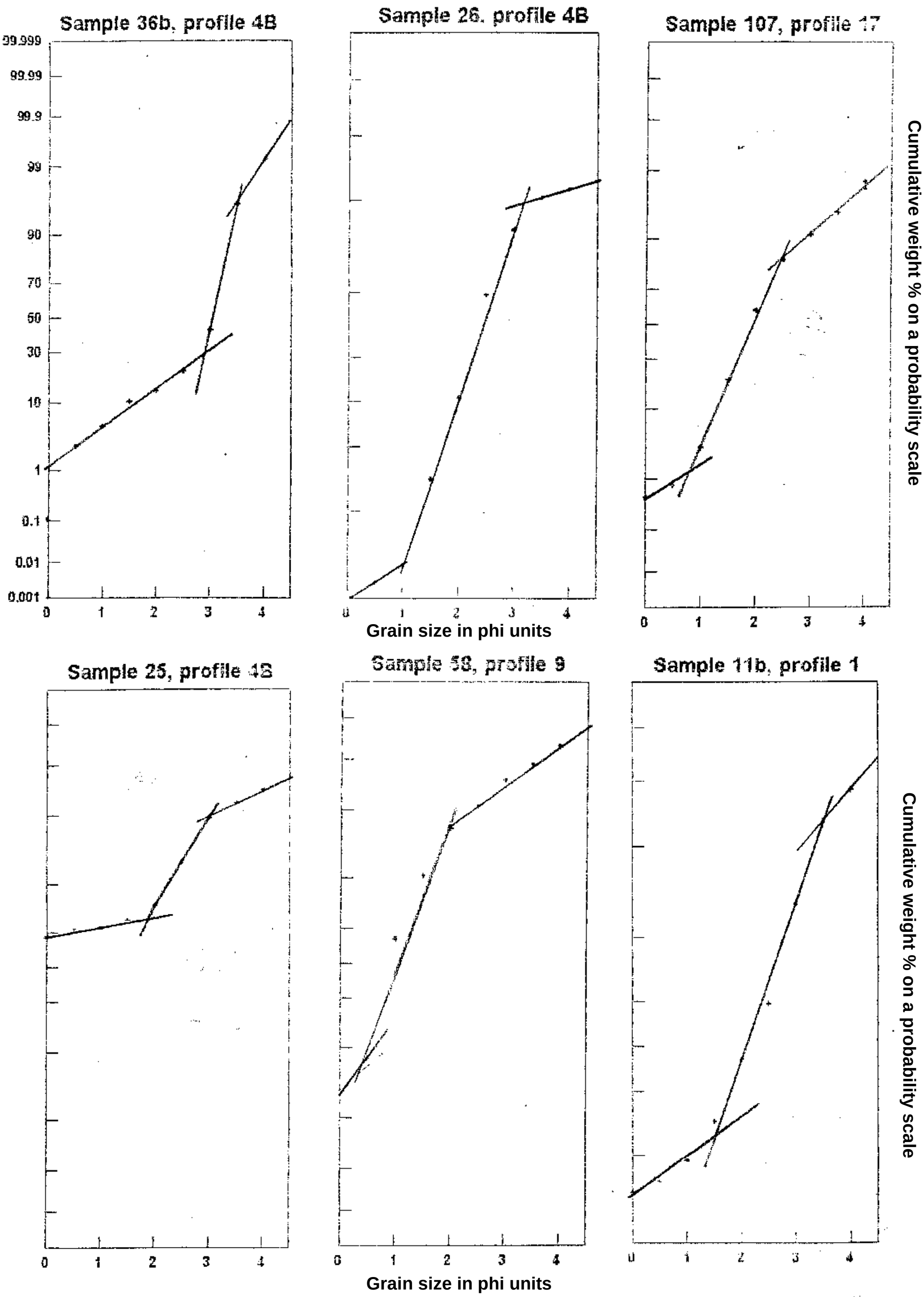


Figure 8 (Cont.): Visher diagrams for the +30m package.

Table 4 (Cont.): Laboratory data for the +30m package.

Sample:	12	11	54	24a	11c	36a
Unit:	BMG	BMG	BMG	BMG	BMG	BMG
Profile:	1	1	10	4B	1	4A
Type:	Sand	Pebbles	Sand	Pebble	Sand	Sand
S elev:	26.03	26.09	26.14	26.27	26.28	26.57
Colour:	10 YR 7/4	5 Y 7/2	10 YR 8/2	10 YR 8/2	5 Y 6/4	10 YR 2/2
Group:	zS	zS	zS	cS	cS	zS
Col Qz:	w, y	w, cl, y	cl, y, r	cl, y, r	w	y
Roun Qz:	7	7	14	8	7	10
Minerals:	qz,rock,alt	qz,rock,ore	qz,qz,rock	qz,qz,rock	qz,feld,rock	ore,alt,gar
Mud	210.75	54.15	86.15	88.24	84.66	210.87
>(-)5	0.00	0.00	0.00	399.80	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	45.67	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00	0.00	0.00
-3	0.00	9.04	0.00	0.00	0.00	0.00
-2.5	0.00	1.64	0.00	31.38	0.00	0.00
-2	0.00	4.65	0.00	0.15	0.00	0.00
-1.5	0.00	3.19	1.90	10.22	0.00	0.00
-1	0.00	2.90	2.30	60.19	0.00	0.00
-0.5	0.00	2.43	4.79	40.90	0.00	0.00
0	0.00	3.88	8.47	132.82	0.00	0.00
0.5	57.32	8.73	11.25	85.98	11.00	11.30
1	3.18	23.86	38.38	14.05	4.01	13.09
1.5	17.62	60.60	192.05	36.23	27.64	27.64
2	67.79	166.23	269.39	47.25	63.12	16.27
2.5	292.56	254.81	63.39	33.46	87.47	35.76
3	170.34	367.91	15.75	12.06	99.19	121.06
3.5	19.87	30.40	2.58	7.07	36.58	250.16
4	1.52	2.63	0.36	1.10	13.12	21.59
<4	1.09	0.68	0.01	1.11	2.20	16.31
Tsieve	**631.29**	**943.58**	**610.62**	**959.41**	**344.34**	**513.17**
%?wt	25.03	5.43	12.36	46.58	19.73	29.12
mode	many	two	two	many	one	two
median	2.29	2.362	1.586	-1.867	2.38	3.06
mean	2.243	2.264	1.545	-0.394	2.321	2.89
class	**fine S**	**fine S**	**medium S**	**V. coarse S**	**fine S**	**fine S**
kurtosis	1.899	1.052	1.194	-2.737	1.014	1.60
skewness	-0.311	-0.343	-0.132	8.78	-0.114	-0.442
sorting	0.684	0.655	0.508	0.385	0.715	0.729
sortC	**mod. well**	**mod. well**	**mod. well**	**well**	**moderate**	**moderate**
VishC	all pos.	all pos.	R, b or c.s.	R, b. or c.s.	R, b or c.s.	R, l or c.s.
TOTAL	**842.04**	**997.73**	**696.77**	**1047.65**	**429.00**	**724.04**
%Tgravel	0.00	2.15	0.60	52.25	0.00	0.00
%Tsand	74.84	92.36	87.03	39.22	79.75	68.62
%Tmud	25.16	5.50	12.37	8.53	20.25	31.38
Heavy	0.07	0.07	0.42	0.07	0.07	0.07

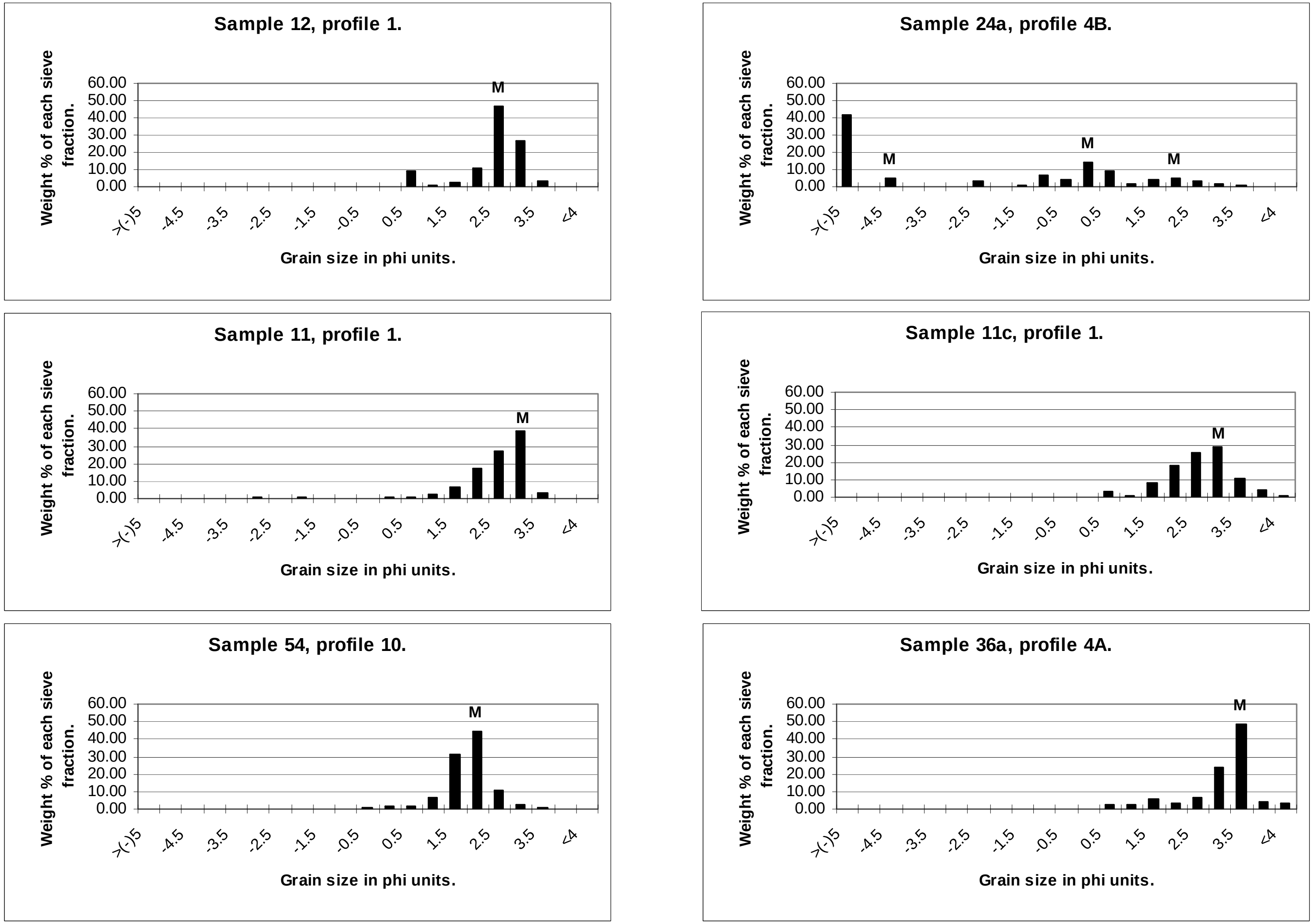


Figure 7 (Cont.): Grain size analysis histograms for the +30m package.

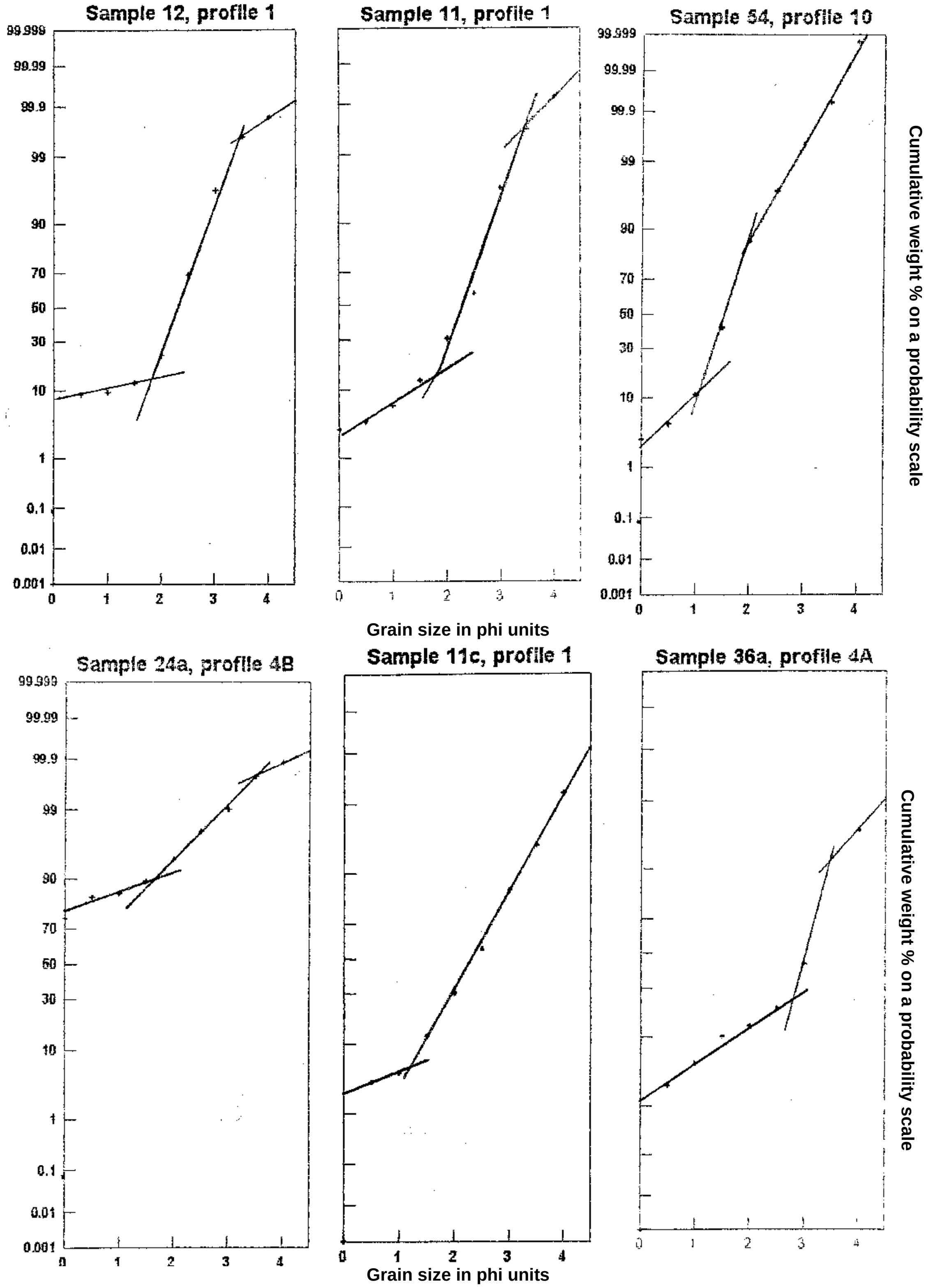


Figure 8 (Cont.): Visher diagrams for the +30m package.

Table 4 (Cont.): Laboratory data for the +30m package.

Sample:	**59**	**43**	**11d**	**14**	**44**
Unit:	BMG	BMG	BMG	BMG	BMG
Profile:	9	8	1	1	8
Type:	Pebbles	Sand	Pebbles	Sand	Sand
S elev:	26.61	26.97	27.19	28.09	33.08
Colour:	10 YR 7/4	10 YR 6/6	10 YR 7/4	10 YR 7/4	10 YR 6/6
Group:	S	S	cS	cS	zS
Col Qz:	cl, y	y, r	w	y	cl, y, r
Roun Qz:	14	11	11	8	11
Minerals:	cl, y	qz,qz,alt	qz,ore,glauc	qz,qz,rock	qz,qz,ore
Mud	49.15	42.15	78.15	211.37	98.15
>(-)5	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00
-4	11.17	0.00	0.00	0.00	0.00
-3.5	7.49	0.00	0.00	0.00	0.00
-3	34.26	0.00	11.18	0.00	0.00
-2.5	5.39	0.00	23.46	0.00	0.00
-2	23.51	0.00	37.33	0.00	0.00
-1.5	27.21	0.00	129.54	0.00	0.97
-1	19.52	0.00	216.04	0.00	1.48
-0.5	16.31	0.00	272.52	0.00	1.79
0	25.64	14.02	206.02	0.00	2.88
0.5	133.88	33.14	64.56	3.83	9.46
1	1050.77	39.43	35.42	4.93	29.14
1.5	481.01	161.55	48.70	193.25	77.69
2	72.91	391.70	106.58	298.75	161.26
2.5	26.87	191.93	340.29	130.31	83.67
3	10.57	114.62	229.94	23.45	42.55
3.5	5.12	60.98	18.16	6.37	32.95
4	2.88	25.11	2.41	4.25	7.96
<4	0.77	8.23	0.59	1.54	1.51
Tsieve	**1955.28**	**1040.71**	**1742.74**	**666.67**	**453.31**
%?wt	2.45	3.89	4.29	24.07	17.80
mode	one	one	many	two	two
median	0.82	1.847	-0.06	1.72	1.82
mean	0.874	1.927	0.359	1.733	1.88
class	**coarse S**	**medium S**	**coarse S**	**medium S**	**medium S**
kurtosis	2.603	1.341	0.615	1.031	1.234
skewness	-0.152	0.121	0.274	0.079	0.11
sorting	0.707	0.781	1.672	0.469	0.777
sortC	**moderate**	**moderate**	**poor**	**well**	**moderate**
VishC	beach	R, b. or c.s.	not clear	all pos.	R, l. or c.s.
TOTAL	**2004.43**	**1082.86**	**1820.89**	**878.04**	**551.46**
%Tgravel	6.41	0.00	22.93	0.00	0.44
%Tsand	91.10	95.35	72.74	75.75	81.48
%Tmud	2.49	4.65	4.32	24.25	18.07
Heavy	0.52	0.07	0.07	0.07	0.07

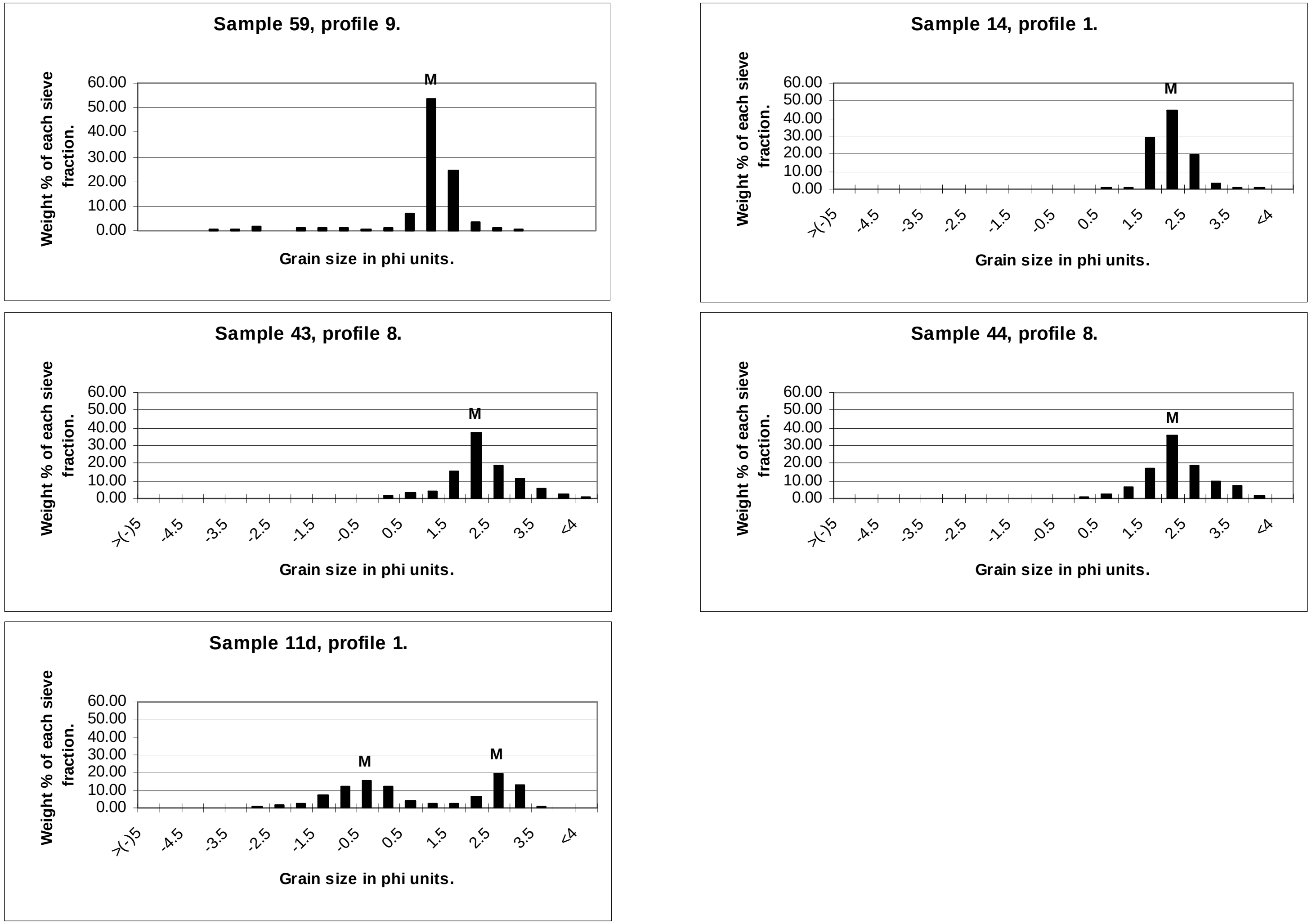


Figure 7 (Cont.): Grain size analysis histograms for the +30m package.

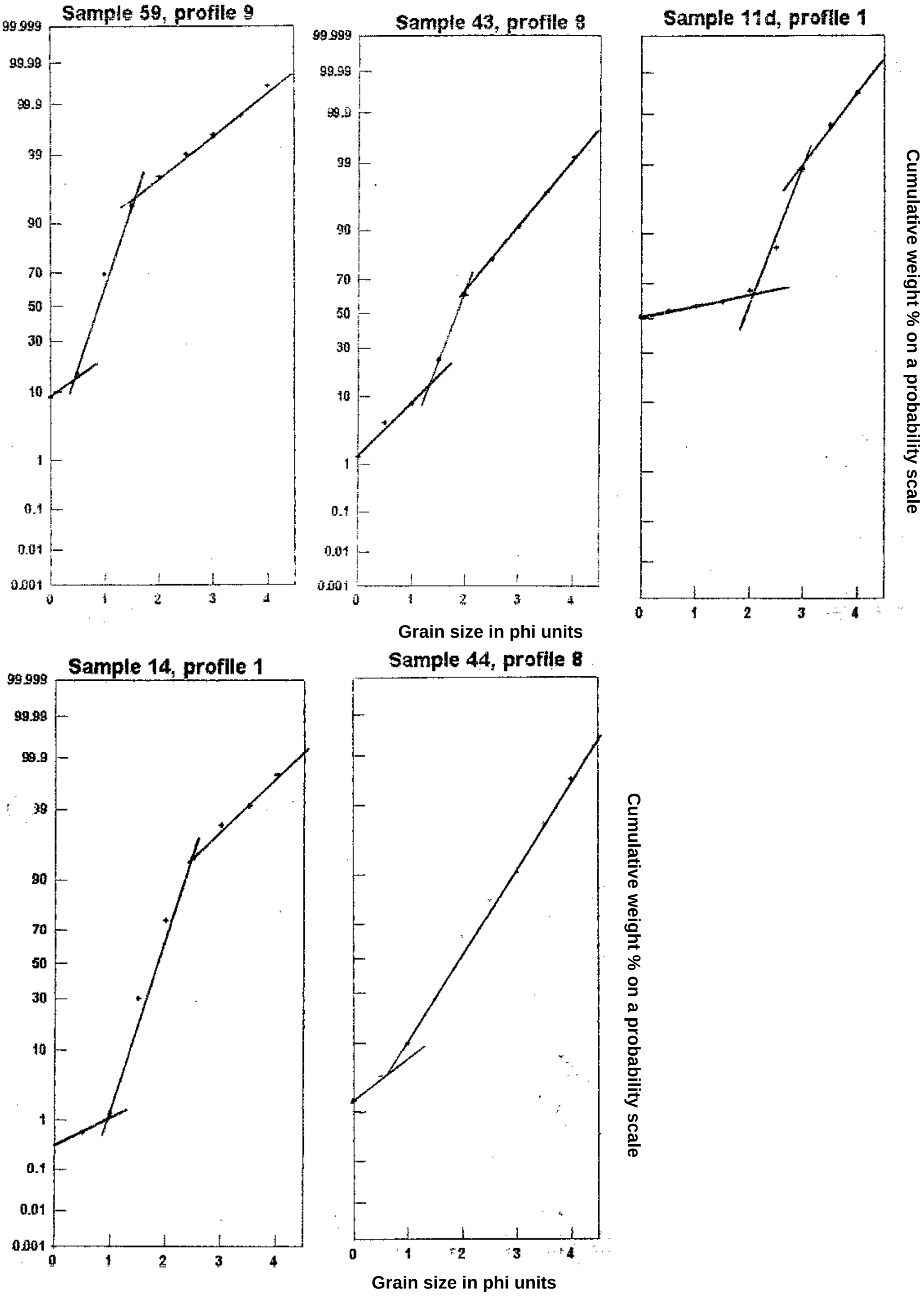
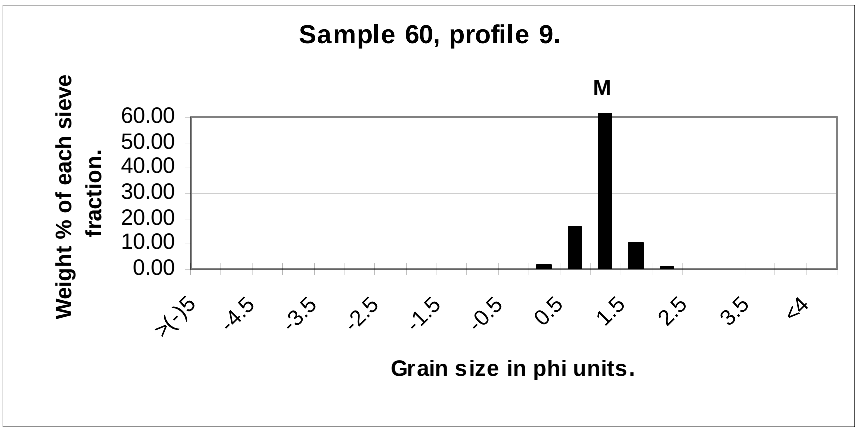


Figure 8 (Cont.): Visher diagrams for the +30m package.

Table 4 (Cont.): Laboratory data for the +30m package.

Sample:	**60**	**34**
Unit:	Intertidal	Intertidal
Profile:	9	4A
Type:	Sand	Sand
S elev:	37.43	39.24
Colour:	10 YR 8/2	10 YR 6/6
Group:	S	S
Col Qz:	cl, y	w, cl, y
Roun Qz:	12	8
Minerals:	qz,qz,rock	alt,ore,rock
Mud	18.15	207.73
>(-)5	0.00	0.00
-5	0.00	0.00
-4.5	0.00	0.00
-4	0.00	0.00
-3.5	0.00	0.00
-3	0.00	0.00
-2.5	0.00	0.00
-2	0.00	0.00
-1.5	1.04	0.00
-1	1.05	0.00
-0.5	2.49	0.00
0	29.20	0.00
0.5	362.38	0.00
1	1565.62	1.71
1.5	218.99	51.17
2	16.93	187.75
2.5	1.36	224.01
3	1.12	144.12
3.5	0.66	65.51
4	0.61	6.18
<4	0.54	6.34
Tsieve	**2201.99**	**686.79**
%?wt	0.82	23.22
mode	one	two
median	0.725	2.229
mean	0.71	2.257
class	**coarse S**	**fine S**
kurtosis	1.389	0.962
skewness	-0.064	0.081
sorting	0.312	0.615
sortC	**well**	**mod. well**
VishC	all pos.	R, b. or c.s.
TOTAL	**2220.14**	**894.52**
%Tgravel	0.09	0.00
%Tsand	99.06	76.07
%Tmud	0.84	23.93
Heavy	0.07	0.07



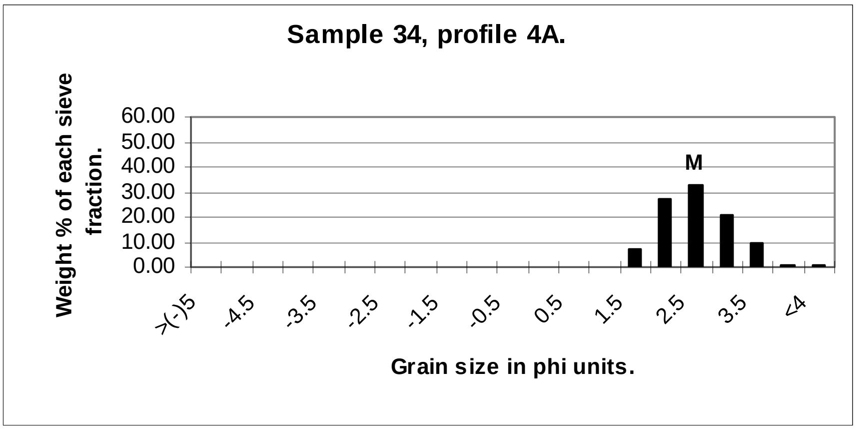


Figure 7 (Cont.): Grain size analysis histograms for the +30m package.

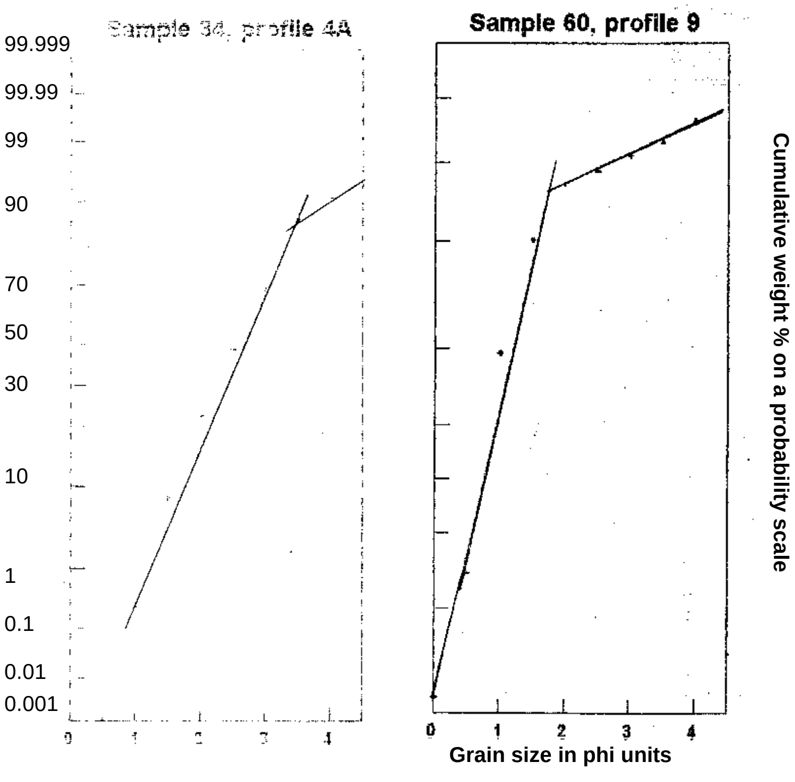


Figure 8 (Cont.): Visher diagrams for the +30m package.

Table 5: Laboratory data for the Recent unit.

Sample:	13	15	96	1	64	5
Unit:	Dune (RA)	Dune (RA)	Dune (RA)	Dune (RA)	Dune (RA)	Dune (RA)
Profile:	1	1	10	8	12	6
Type:	Sand	Sand	Sand	Sand	Sand	Sand
S elev:	28.81	29.1	38.28	74.9	65.43	70.72
Colour:	10 YR 6/6	10 YR 6/6	10 YR 6/6	10 YR 6/6	10 YR 6/6	5 YR 5/6
Group:	cS	zS	zS	zS	zS	cS
Col Qz:	y	y	y, r	cl, y	w, cl, y, r	y, r
Roun Qz:	11	10	11	11	11	11
Minerals:	qz,qz,qz	qz,qz,alt	qz,qz,qz	qz,qz,ore	qz,qz,ore	qz,qz,qz
Mud	201.69	206.80	326.15	15.82	7.15	0.27
>(-)5	0.00	0.00	0.00	0.00	0.00	0.00
-5	0.00	0.00	0.00	0.00	0.00	0.00
-4.5	0.00	0.00	0.00	0.00	0.00	0.00
-4	0.00	0.00	0.00	0.00	0.00	0.00
-3.5	0.00	0.00	0.00	0.00	0.00	0.00
-3	0.00	0.00	0.00	0.00	0.00	0.00
-2.5	0.00	0.00	0.00	0.00	0.00	0.00
-2	0.00	0.00	0.00	0.00	0.00	0.00
-1.5	0.00	0.00	0.00	0.00	0.00	0.00
-1	0.00	0.00	0.00	0.00	0.00	0.00
-0.5	0.00	0.00	2.84	0.00	0.00	0.00
0	0.00	0.00	4.20	0.00	0.00	0.00
0.5	5.33	5.19	7.11	2.91	0.00	2.89
1	5.78	6.46	74.06	0.00	0.42	0.00
1.5	126.84	238.73	287.96	8.25	1.41	42.24
2	166.40	255.96	531.95	58.08	254.38	135.13
2.5	104.14	112.19	322.72	212.79	750.35	151.59
3	48.51	36.19	81.20	118.34	247.88	44.05
3.5	24.32	10.84	27.36	79.16	43.38	21.00
4	11.34	2.52	8.94	10.47	14.34	17.05
<4	10.69	2.17	1.56	4.42	0.97	14.49
Tsieve	503.35	670.24	1349.90	494.42	1313.13	428.44
%?wt	28.61	23.58	19.46	3.10	0.54	0.06
mode	two	two	two	one	one	one
median	1.842	1.666	1.781	2.418	2.267	2.112
mean	1.921	1.706	1.784	2.512	2.29	2.172
class	**medium S**	**medium S**	**medium S**	**fine S**	**fine S**	**fine S**
kurtosis	1.085	1.046	1.101	0.99	1.274	1.449
skewness	0.256	0.194	0.034	0.191	0.073	0.23
sorting	0.704	0.522	0.578	0.544	0.402	0.702
sortC	**moderate**	**mod. well**	**mod. well**	**mod. well**	**well**	**moderate**
VishC	all pos.	all pos.	all pos.	beach	R, b. or c.s.	beach
TOTAL	**705.04**	**877.04**	**1676.05**	**510.24**	**1320.28**	**428.71**
Tgravel	0.00	0.00	0.00	0.00	0.00	0.00
Tsand	97.88	49.49	99.88	99.11	99.93	96.62
Tmud	2.12	50.51	0.12	0.89	0.07	3.38
Heavy	6.68	12.39	3.56	left out	13.34	left out

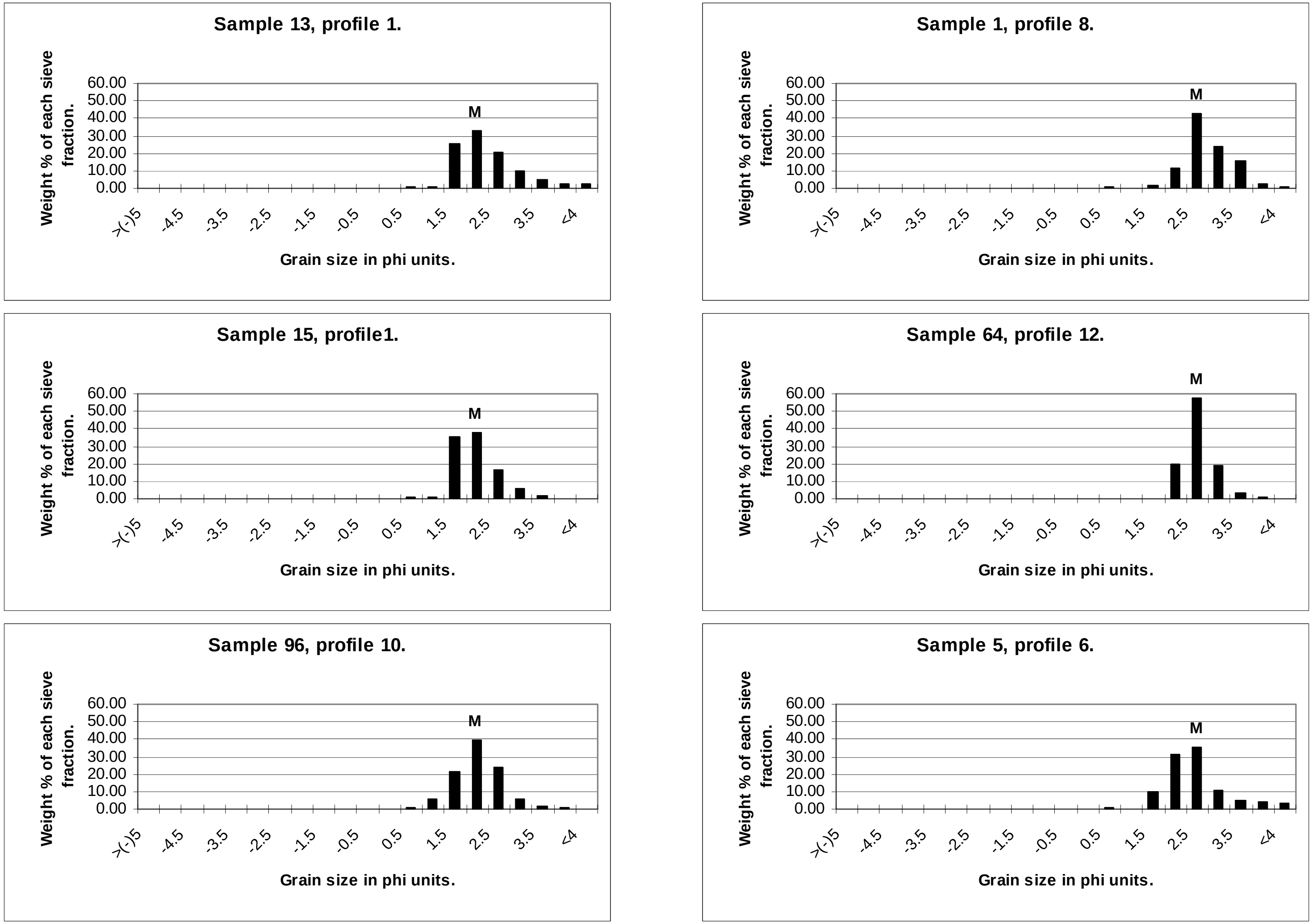


Figure 9: Grain size analysis histograms for the Recent unit.

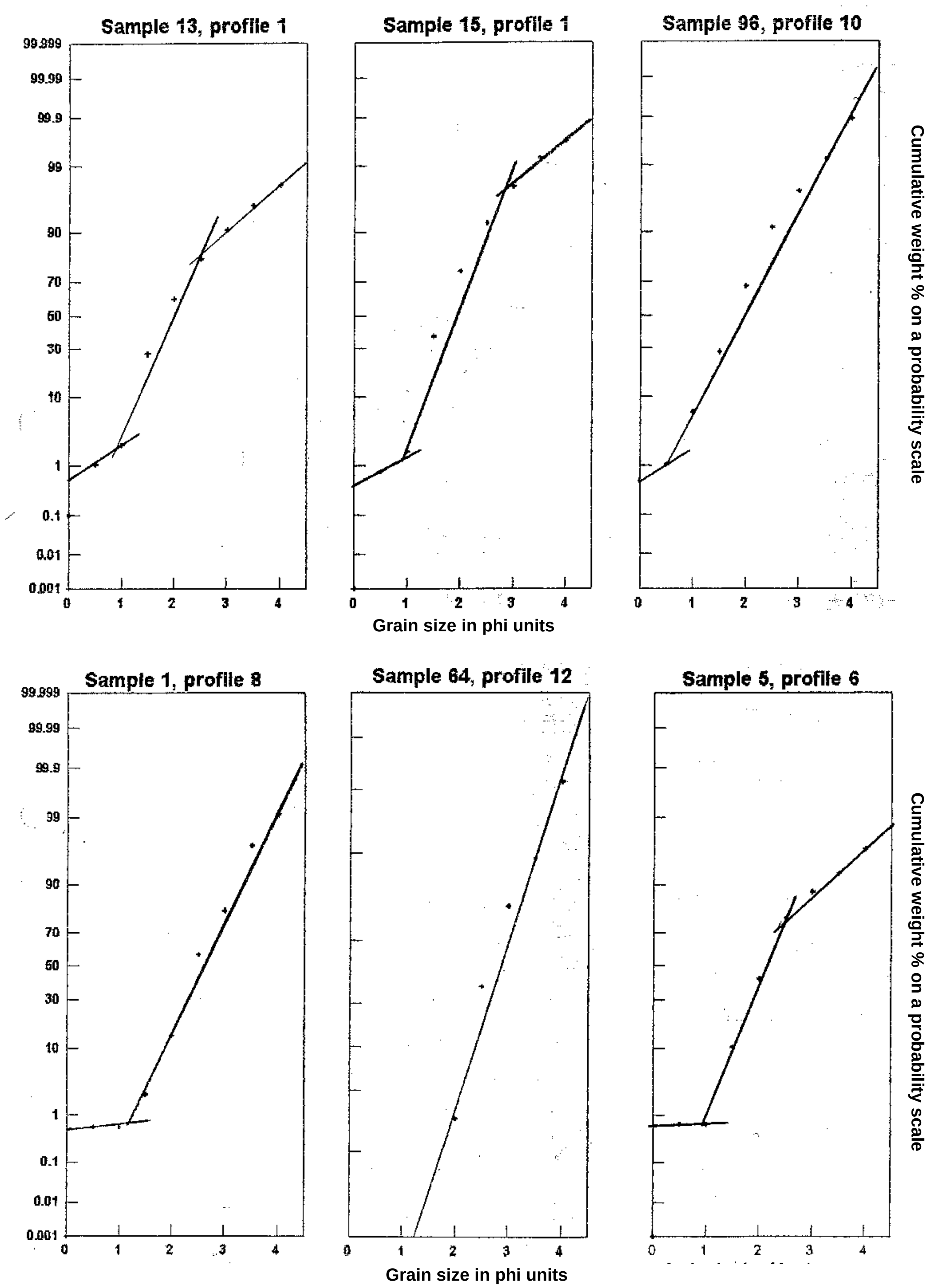


Figure 10: Visher diagrams for the Recent unit.

Table 5 (Cont.): Laboratory data for the Recent unit.

Sample:	55
Unit:	Intertidal
Profile:	9
Type:	20m
S elev:	18.67
Colour:	10 YR 7/4
Group:	zS
Col Qz:	cl, y
Roun Qz:	14
Minerals:	qz,qz,calc
Mud	59.15
>(-)5	0
-5	0
-4.5	9.29
-4	9.94
-3.5	28.62
-3	62.99
-2.5	20.88
-2	51.79
-1.5	91.76
-1	76.92
-0.5	76.86
0	94.57
0.5	148.72
1	256.36
1.5	204.71
2	145.05
2.5	80.17
3	24.59
3.5	8.99
4	3.27
<4	0.93
Tsieve	1396.41
%?wt	4.06
mode	many
median	0.55
mean	0.135
class	**coarse S**
kurtosis	0.998
skewness	-0.371
sorting	1.71
sortC	**poor**
VishC	not clear
TOTAL	**1455.56**
Tgravel	25.22
Tgravel	74.71
Tmud	0.07
Heavy	8.17

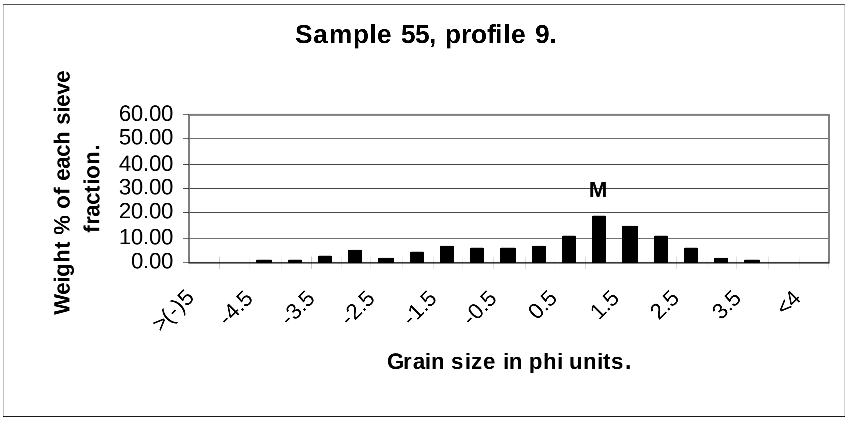


Figure 9 (Cont.): Grain size analysis histograms for the Recent unit.

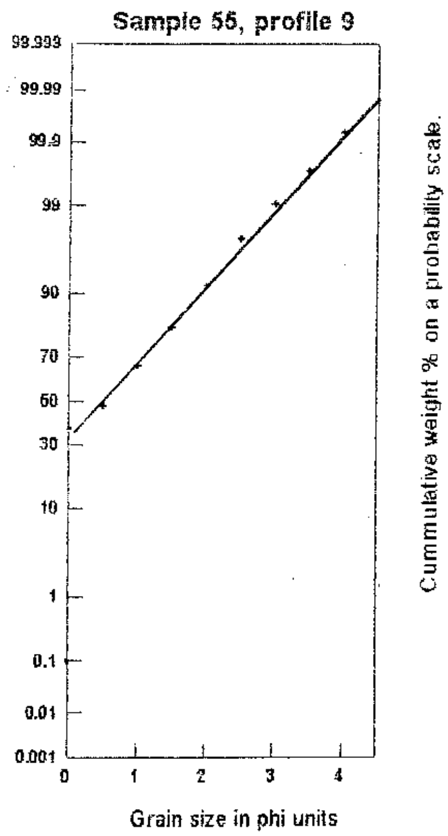


Figure 10 (Cont.): Visher diagrams for the Recent unit.

APPENDIX 3: Mineralogical data

Table 1: The point count data on the "whole rock" samples from the 50m package at Geelwal Karoo

Sample no.	Unit	Rutile	Zircon	Garnet	Ferro-silicates	Weathered grains	Tourmaline	Kyanite	Ilmenite	Hydrated ilmenite	Leucoxene	Hematite	Ore minerals	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Other minerals	Total
7b	50m_shoreface	29	18	55	4	0	0	0	0	0	0	0	225	0	10	1	7	146	5	500
7c	50m_shoreface	27	19	58	18	0	3	0	117	91	16	20	0	0	14	0	4	107	6	500
7a	50m_shoreface	5	7	25	79	0	1	0	44	7	9	9	0	0	61	6	18	226	3	500
21a	50m_shoreface	2	1	4	10	0	0	0	0	0	2	0	0	5	117	1	25	333	0	500
21b	50m_shoreface	1	0	11	4	0	0	0	0	0	0	0	9	16	84	0	18	357	0	500
18	50m_shoreface	2	1	13	13	0	0	0	0	0	0	0	18	39	58	0	52	301	3	500
6	50m_shoreface	9	20	37	23	0	0	0	0	0	0	0	145	11	25	8	14	207	1	500
20	50m_shoreface	3	9	27	30	0	0	0	0	0	0	0	78	24	25	29	8	266	1	500
GDE	50m_shoreface	4	3	10	7	49	1	0	8	1	8	1	0	0	50	0	5	353	0	500
3b	50m_beach	44	5	46	31	0	2	0	0	0	0	0	122	3	35	24	10	178	0	500
17c	50m_beach	6	1	24	147	0	0	0	7	3	1	2	0	0	43	3	27	236	0	500
17e	50m_beach	3	2	14	77	0	3	0	13	0	3	7	0	0	88	5	3	276	6	500
17a	50m_beach	8	7	41	88	0	3	0	48	18	4	7	0	0	23	6	8	236	3	500
17b	50m_beach	1	1	20	25	0	0	1	0	0	0	0	24	11	40	32	6	338	1	500
gwa	Recent_beach	5	3	57	29	16	1	1	47	18	3	8	0	11	24	4	6	267	0	500
GDD	Aeolianite_dorbank	4	22	35	7	5	0	0	28	24	4	15	0	1	8	0	3	339	5	500
GDW	30m_shoreface	1	2	25	6	33	0	0	1	0	2	1	0	6	16	0	12	394	1	500
7b	50m_shoreface	6	4	11	1	0	0	0	0	0	0	0	45	0	2	0	1	29	1	100
7c	50m_shoreface	5	4	12	4	0	1	0	23	18	3	4	0	0	3	0	1	21	1	100
7a	50m_shoreface	1	1	5	16	0	0	0	9	1	2	2	0	0	12	1	4	45	1	100
21a	50m_shoreface	0	0	1	2	0	0	0	0	0	0	0	0	1	23	0	5	67	0	100
21b	50m_shoreface	0	0	2	1	0	0	0	0	0	0	0	2	3	17	0	4	71	0	100
18	50m_shoreface	0	0	3	3	0	0	0	0	0	0	0	4	8	12	0	10	60	1	100
6	50m_shoreface	2	4	7	5	0	0	0	0	0	0	0	29	2	5	2	3	41	0	100
20	50m_shoreface	1	2	5	6	0	0	0	0	0	0	0	16	5	5	6	2	53	0	100
GDE	50m_shoreface	1	1	2	1	10	0	0	2	0	2	0	0	0	10	0	1	71	0	100
3b	50m_beach	9	1	9	6	0	0	0	0	0	0	0	24	1	7	5	2	36	0	100
17c	50m_beach	1	0	5	29	0	0	0	1	1	0	0	0	0	9	1	5	47	0	100
17e	50m_beach	1	0	3	15	0	1	0	3	0	1	1	0	0	18	1	1	55	1	100
17a	50m_beach	2	1	8	18	0	1	0	10	4	1	1	0	0	5	1	2	47	1	100
17b	50m_beach	0	0	4	5	0	0	0	0	0	0	0	5	2	8	6	1	68	0	100
gwa	Rec_beach	1	1	11	6	3	0	0	9	4	1	2	0	2	5	1	1	53	0	100
GDD	Aeo_dorbank	1	4	7	1	1	0	0	6	5	1	3	0	0	2	0	1	68	1	100
GDW	30m_shoreface	0	0	5	1	7	0	0	0	0	0	0	0	1	3	0	2	79	0	100
	50m_shoreface	2	2	5	4	1	0	0	4	2	1	1	11	2	10	1	3	51	0	AVE
	50m_beach	2	1	6	15	0	0	0	3	1	0	1	6	1	9	3	2	51	0	AVE

Table 2: The point count data on the heavy mineral fraction of the samples from Geelwal Karoo

Samp. no.	Unit	Profile	Samp. Elev.	km from N gate	Fraction	%THM	Rutile	Zircon	Garnet	Augite	Hornblende	Weathered grains	Tourmaline	Kyanite	Monosite	Staurolite	Ilmenite	Hydrated ilmenite	Leucoxene	Other opaques	Magnetite	Chromite	Psuedorutile	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Total	ZTR index
gwp	RB		5.00	10.00	f	-	1	1	35	49	1	93	0	0	0	0	6	3	2	6	0	0	1	0	11	0	10	81	300	1
55	RB	9	18.67	1.00	c	8.17	11	15	189	5	3	9	3	0	1	0	18	9	4	7	0	2	0	0	14	0	0	10	300	10
13	RA	1	28.81	3.50	m	6.68	25	19	53	16	1	3	5	0	2	1	52	16	5	26	1	1	1	0	32	21	0	20	300	16
15	RA	1	29.1	3.50	m	12.39	1	0	19	47	1	38	0	2	0	0	4	0	3	0	0	0	4	0	47	14	0	120	300	0
64	RA	12	65.43	12.00	f	13.34	12	10	66	19	3	6	8	0	0	0	72	45	11	24	3	0	0	0	4	1	0	16	300	10

Samp. no.	Unit	Profile	Samp. Elev.	km from N gate	Fraction	%THM	Rutile	Zircon	Garnet	Augite	Hornblende	Weathered grains	Tourmaline	Kyanite	Monosite	Staurolite	Ilmenite	Hydrated ilmenite	Leucoxene	Other opaques	Magnetite	Chromite	Psuedorutile	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Total	ZTR index
100	30m_shelf	9	23.57	1.00	f	0.42	42	6	13	5	0	5	0	0	0	0	139	40	18	9	1	0	0	10	4	0	0	8	300	16
98	30m_shelf	9	25.22	1.00	c	0.52	22	0	0	5	1	2	0	0	0	4	105	63	23	16	0	0	38	6	6	0	0	9	300	7
36b	30m_us	4b	25.56	11.50	f	95.29	27	0	2	8	0	0	0	0	0	0	139	100	5	3	0	2	12	0	0	0	0	2	300	9
58	30m_us	9	25.95	1.00	c	0.84	5	7	158	15	1	26	1	0	0	1	17	9	7	9	0	0	9	0	15	1	0	19	300	4
11b	30m_us	1	25.97	3.50	f	0.60	8	5	33	4	1	5	2	0	0	8	46	66	14	16	0	0	23	5	57	0	2	5	300	5
11	30m_us	1	26.09	3.50	f	4.27	5	56	19	4	1	0	0	0	0	0	102	101	2	2	0	0	3	0	2	0	0	3	300	20
11c	30m_us	1	26.28	3.50	f	0.48	12	1	28	15	7	12	2	0	0	0	87	52	26	9	2	0	19	0	16	0	0	12	300	5
59	30m_us	9	26.61	1.00	c	0.47	20	8	110	40	2	0	1	1	2	0	16	15	8	8	0	2	1	0	21	3	22	20	300	10
11d	30m_us	1	27.19	3.50	c	2.31	9	6	124	42	7	0	6	0	0	0	34	17	14	5	0	0	3	0	20	0	0	13	300	7
14	30m_us	1	28.09	3.50	m	8.34	6	17	42	51	6	54	2	0	0	0	38	23	1	12	0	0	5	0	7	10	0	26	300	8
60	30m_beach	9	37.43	1.00	c	0.21	27	3	32	49	5	80	1	0	0	2	10	0	32	5	0	0	0	0	41	0	0	13	300	10

Table 2 (continued): The point count data on the heavy mineral fraction of the samples from Geelwal Karoo

Samp. no.	Unit	Profile	Samp. Elev.	km from N gate	Fraction	%THM	Rutile	Zircon	Garnet	Augite	Hornblende	Weathered grains	Tourmaline	Kyanite	Monosite	Staurolite	Ilmenite	Hydrated ilmenite	Leucoxene	Other opaques	Magnetite	Chromite	Psuedorutile	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Total	ZTR index
10	50m_shelf	1	19.02	3.50	f	1.18	18	3	68	7	0	10	0	0	0	0	87	61	15	7	0	0	5	7	6	0	0	6	300	7
27	50m_shelf	4b	25.44	11.50	f	4.38	6	3	79	11	5	7	5	0	0	0	66	51	19	11	5	1	3	0	6	0	1	21	300	5
84	50m_shelf	14	31.27	10.50	f	48.91	2	0	19	52	3	74	1	0	0	0	2	2	6	1	0	0	1	0	18	9	10	100	300	1
90	50m_us	15	32.1	11.00	m	13.62	11	9	34	4	0	0	1	0	0	0	111	90	13	15	1	3	3	2	1	0	0	2	300	7
7c	50m_us	6	33.7	10.00	f	56.69	13	12	21	3	0	2	2	0	0	0	87	132	6	13	1	1	1	0	1	0	0	5	300	9
20	50m_us	2	35.02	10.50	f	40.53	10	3	23	113	4	17	5	0	0	2	10	5	6	3	1	0	0	1	25	11	3	58	300	6
7a	50m_us	6	35.73	10.00	c	17.51	4	1	15	25	0	6	0	0	0	0	108	106	6	14	1	0	3	0	0	0	0	11	300	2
85	50m_us	14	37.65	10.50	m	67.82	8	4	36	45	5	74	2	0	0	0	20	13	9	10	2	2	0	1	30	5	2	32	300	5
6	50m_us	6	39.5	10.00	m	30.61	10	8	29	16	2	73	2	0	0	0	72	54	9	11	5	0	0	0	2	0	0	7	300	7
86	50m_beach	14	41.82	10.50	f	35.89	3	8	34	38	0	88	0	0	0	0	53	38	5	10	0	0	2	1	2	0	0	18	300	4
50	50m_beach	5	42.72	9.00	f	85.85	9	5	83	52	2	36	1	0	0	0	45	30	3	9	2	0	0	0	3	7	0	13	300	5
17e	50m_beach	2	48.1	10.50	f	25.66	2	3	16	64	0	62	2	0	0	0	21	10	4	5	1	0	4	0	54	0	16	36	300	2
17a	50m_beach	2	50.11	10.50	f	52.51	6	4	35	22	1	44	2	0	0	0	67	51	3	20	1	2	3	0	7	0	2	30	300	4

LEGEND

RA = Recent dune, RB = Recent beach, 30m_shelf = 30m package shelf facies, 30m_beach = 30m package beach facies, 30m_us = 30m package upper shoreface, 50m_shelf = 50m package shelf facies, 50m_beach = 50m package beach facies, 50m_us = 50m package upper shoreface, AD = dorbank aeoliante, AY = yellow aeolianite, CC_upp = channel clay upper fine subunit, CC_bas = channel clay basal coarse subunit. Samp. = sample, elev. = elevation. F = fine, c = coarse, m = medium.

ZTR (the zircon, tourmaline, rutile) index is the sum of the normalized percentages of the given minerals

Table 2 (continued): The point count data on the heavy mineral fraction of the samples from Geelwal Karoo

Samp. no.	Unit	Profile	Samp. Elev.	km from N gate	Fraction	%THM	Rutile	Zircon	Garnet	Augite	Hornblende	Weathered grains	Tourmaline	Kyanite	Monosite	Staurolite	Ilmenite	Hydrated ilmenite	Leucoxene	Other opaques	Magnetite	Chromite	Psuedorutile	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Total	ZTR index
69	AD	12	40.87	12.00	m	4.29	3	9	111	37	1	28	8	0	0	2	17	24	9	5	0	0	1	1	22	2	0	20	300	7
68	AD	12	44.67	12.00	m	5.90	2	5	70	82	7	55	4	0	0	0	11	2	7	2	0	0	0	0	24	1	0	28	300	4
4	AY	6	53.78	10.00	f	8.56	1	3	36	29	3	63	0	0	0	0	40	14	6	5	4	0	5	0	23	0	2	66	300	1
77	AY	13	54.22	9.50	m	12.04	1	0	22	73	4	4	4	0	0	4	12	6	6	0	0	0	0	0	76	0	0	88	300	2
78	AY	13	58.55	9.50	m	13.43	0	0	32	78	2	55	2	0	0	0	15	5	3	1	0	0	0	0	31	0	10	66	300	1
76	AD	13	60.32	9.50	m	16.26	1	2	50	13	5	72	4	0	0	0	17	19	5	8	0	0	7	0	34	0	2	61	300	2
39	AD	8	70.88	11.50	m	8.22	1	2	24	28	3	102	3	0	0	0	9	7	9	2	0	0	5	0	26	0	5	74	300	2
81	AD	13	73.08	9.50	m	3.89	23	17	71	24	2	2	8	0	0	0	55	27	14	19	0	0	0	1	6	1	0	30	300	16

Samp. no.	Unit	Profile	Samp. Elev.	km from N gate	Fraction	%THM	Rutile	Zircon	Garnet	Augite	Hornblende	Weathered grains	Tourmaline	Kyanite	Monosite	Staurolite	Ilmenite	Hydrated ilmenite	Leucoxene	Other opaques	Magnetite	Chromite	Psuedorutile	Glauconite	Rock fragments	Carbonates	Feldspar	Quartz	Total	ZTR index
117a	CC_bas	2	8.10	10.50	c	0.46	16	27	25	7	0	30	3	3	1	0	48	9	35	7	0	0	22	0	2	1	0	64	300	15
113	CC_bas	13	9.10	9.50	c	1.19	22	26	32	9	2	73	8	13	2	0	24	25	5	8	0	1	0	0	22	0	0	28	300	19
117b	CC_bas	2	13.40	10.50	c	0.77	19	37	25	21	2	34	5	2	0	4	32	27	20	13	2	0	24	0	4	8	0	21	300	20
117c	CC_bas	2	14.50	10.50	c	2.91	8	21	28	25	3	5	6	4	0	2	32	34	28	13	1	0	41	2	2	4	0	41	300	12
8b	CC_bas	1	15.00	3.50	f	0.06	29	34	5	13	6	40	6	0	1	0	13	1	43	1	1	0	73	2	7	0	0	25	300	23
82	CC_bas	14	16.10	10.50	c	0.65	49	32	25	29	1	3	3	0	1	1	73	28	22	6	0	0	0	1	1	3	0	22	300	28
9b	CC_bas	1	16.40	3.50	c	8.00	16	8	2	5	0	36	0	137	0	8	5	1	14	2	0	0	29	5	7	0	0	25	300	8
118	CC_bas	2	18.00	10.50	f	0.10	6	30	11	35	0	6	4	0	0	1	7	15	54	3	1	0	61	1	6	4	0	55	300	13
83	CC_bas	14	19.00	10.50	c	1.05	12	10	27	52	3	48	5	1	0	0	29	27	35	9	0	0	22	0	4	0	0	16	300	9
115	CC_upp	13	20.50	9.50	c	-	27	64	30	45	1	5	4	2	0	0	24	23	13	4	0	1	13	1	10	5	0	28	300	32
47	CC_upp	5	31.53	9.00	m	0.04	10	18	42	32	0	40	7	7	0	1	38	18	8	7	3	6	6	2	5	0	0	50	300	12

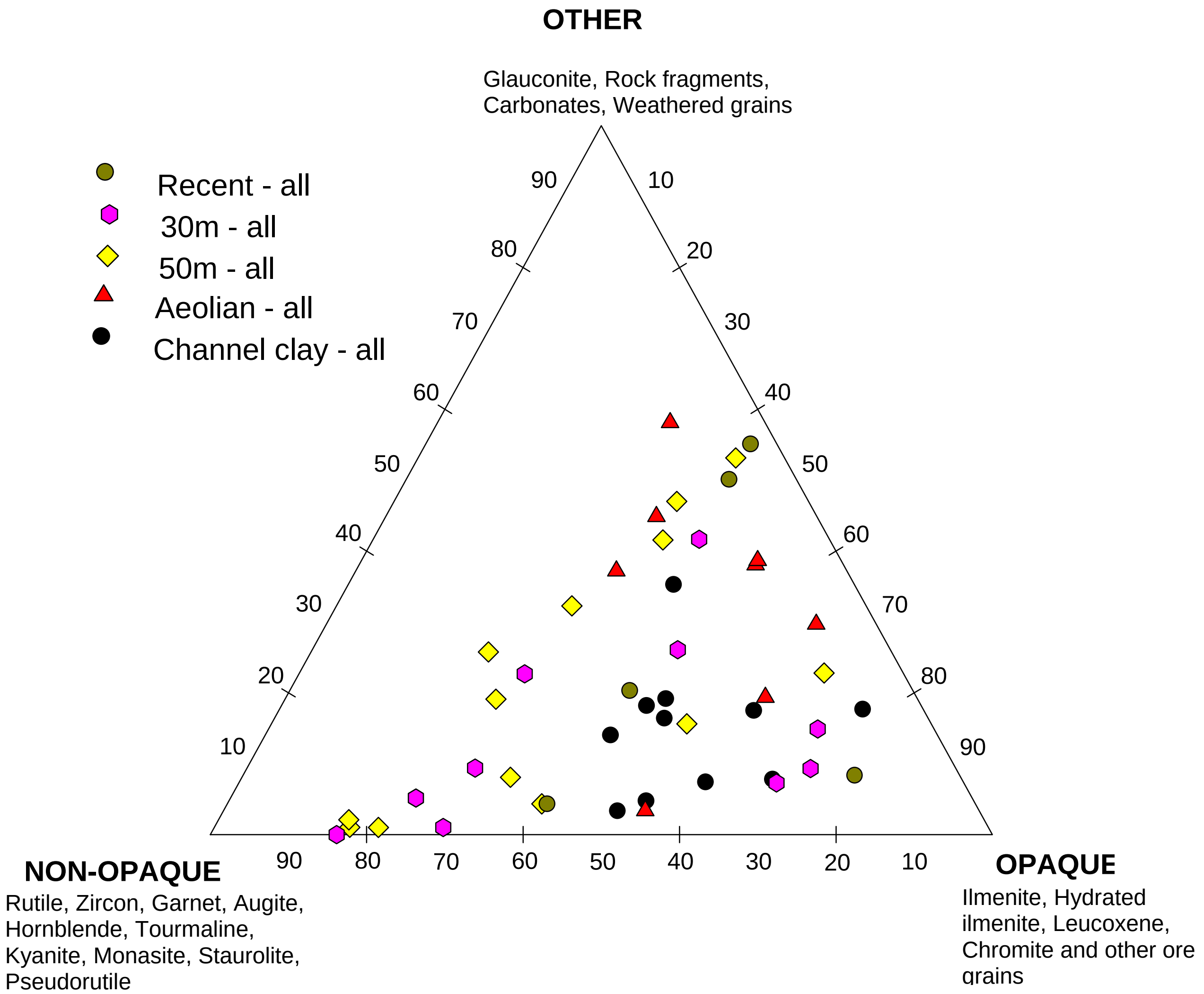


Figure 1: Ternary diagram to show the variations in the heavy mineral assemblage of the various stratigraphic units.

Table 3: A summary of the differences seen in the heavy mineral assemblage of the various stratigraphic units. Please refer to Figure 1 for a breakdown of the mineral categories.

	Channel clay	**Aeolianite**	**50m package**	**30m package**	**Recent**
Channel clay		More other	More other, More non-opaque	More non-opaques	No obvious difference
Aeolianite	Less other, more opaque		More non-opaques, less other	More non-opaquesr, less other	No obvious difference
50m package	Less non-opaques, Less other	Less non-opaque, more other		No obvious difference	Some more opaque
30m package	Less non-opqaues	More other, less non-opaques	No obvious difference		More non-opqaues, less other
Recent	No obvious difference	No obvious difference	Some more non opaques	Some more other	

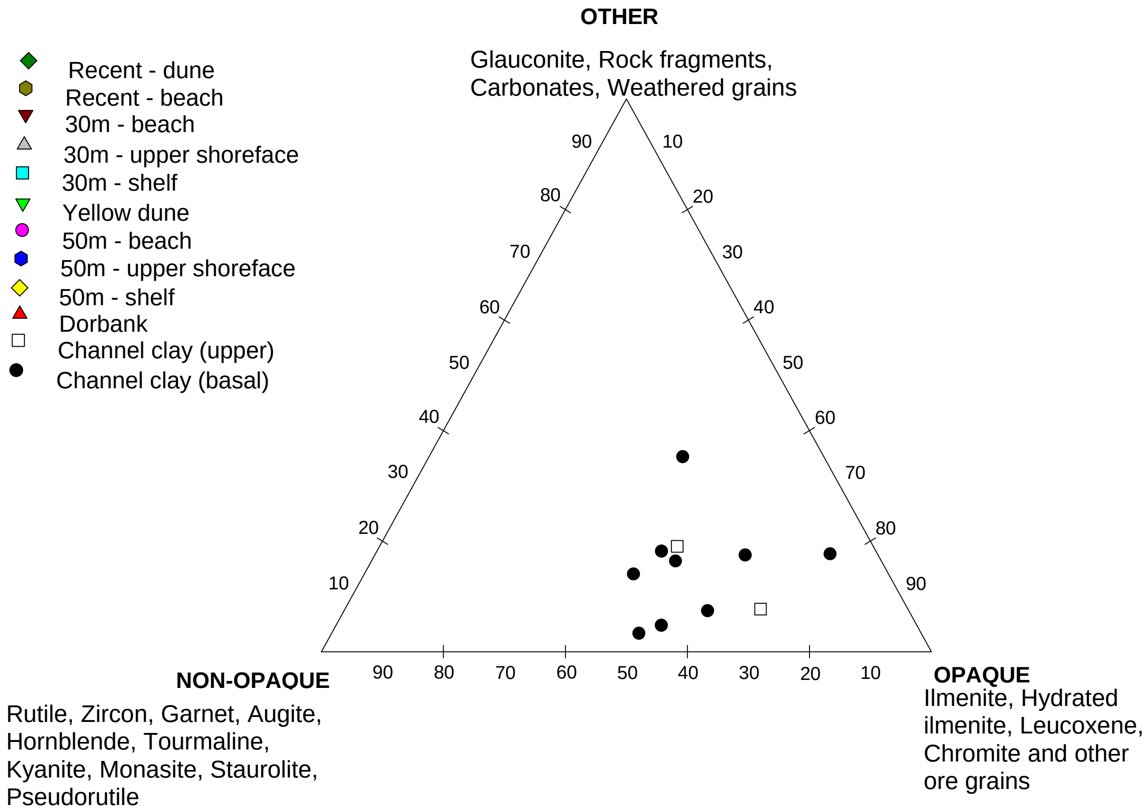


Figure 2a: Ternary diagram to show the variations in the heavy mineral assemblage of the channel clay unit.

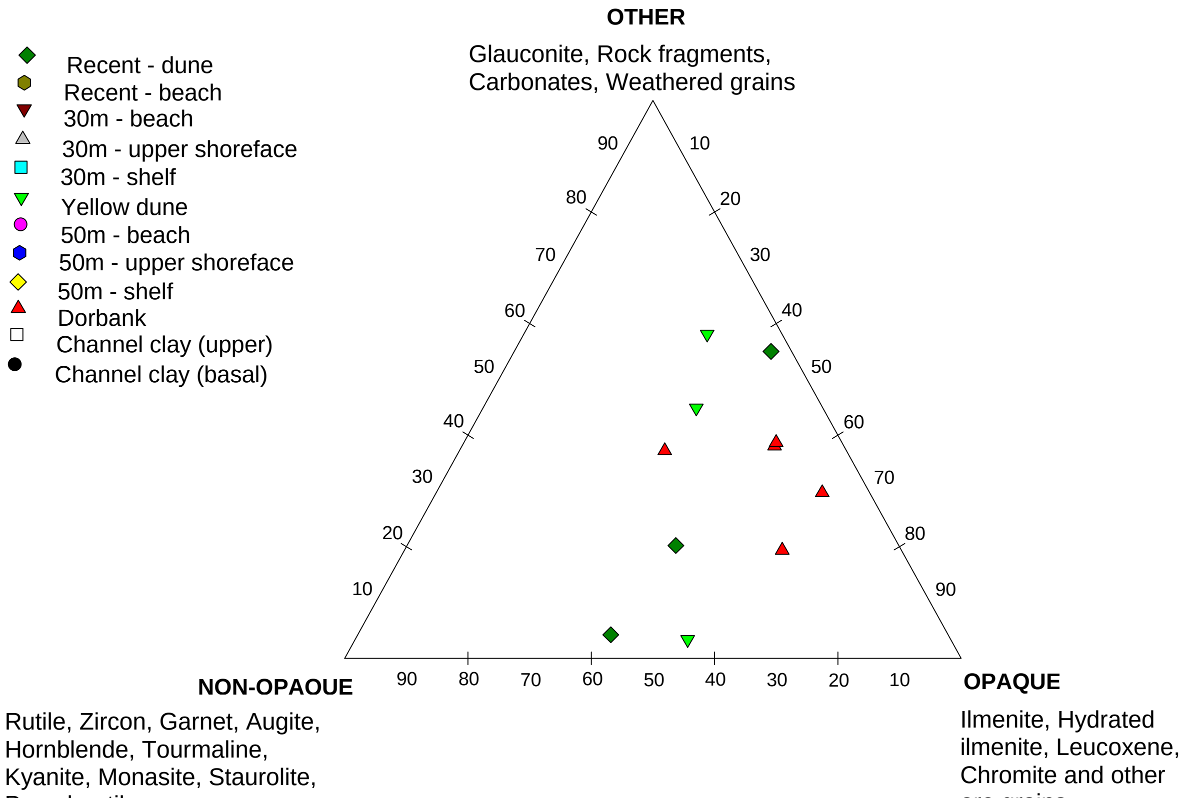


Figure 2b: Ternary diagram to show the variations in the heavy mineral assemblage of the aeolianite.

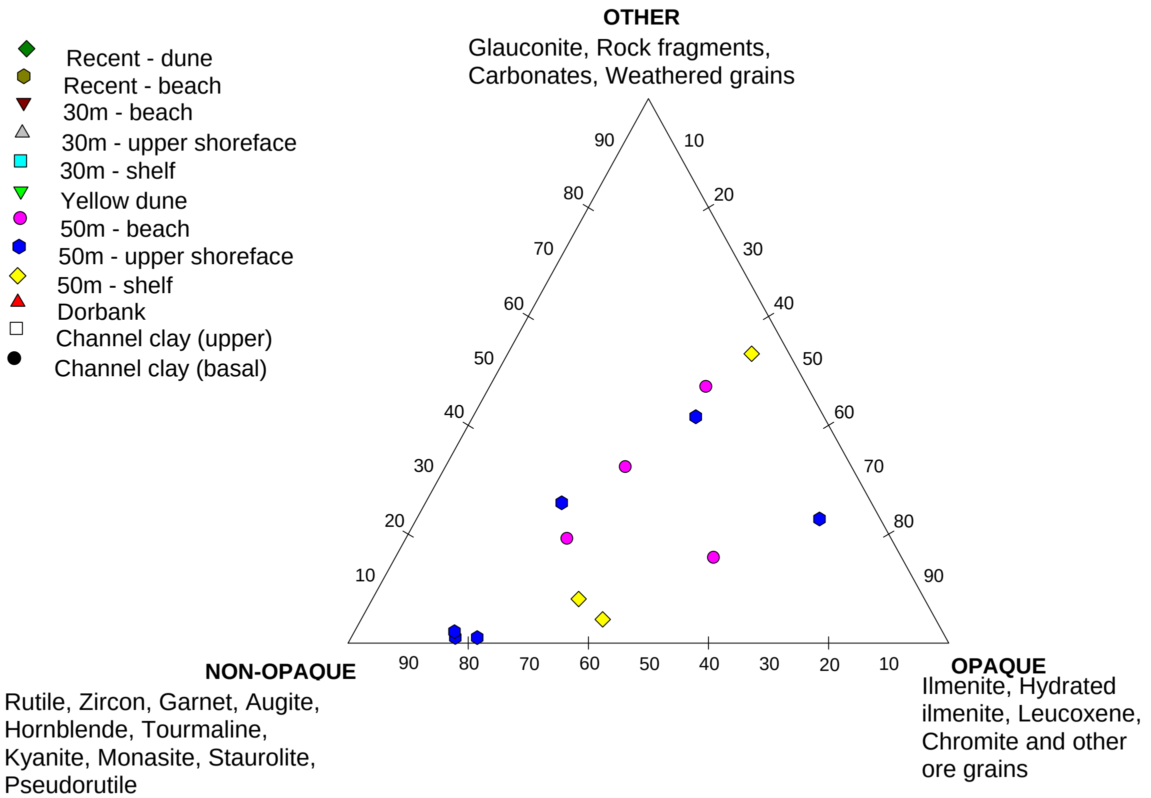


Figure 2c: Ternary diagram to show the variations in the heavy mineral assemblage of the 50m package.

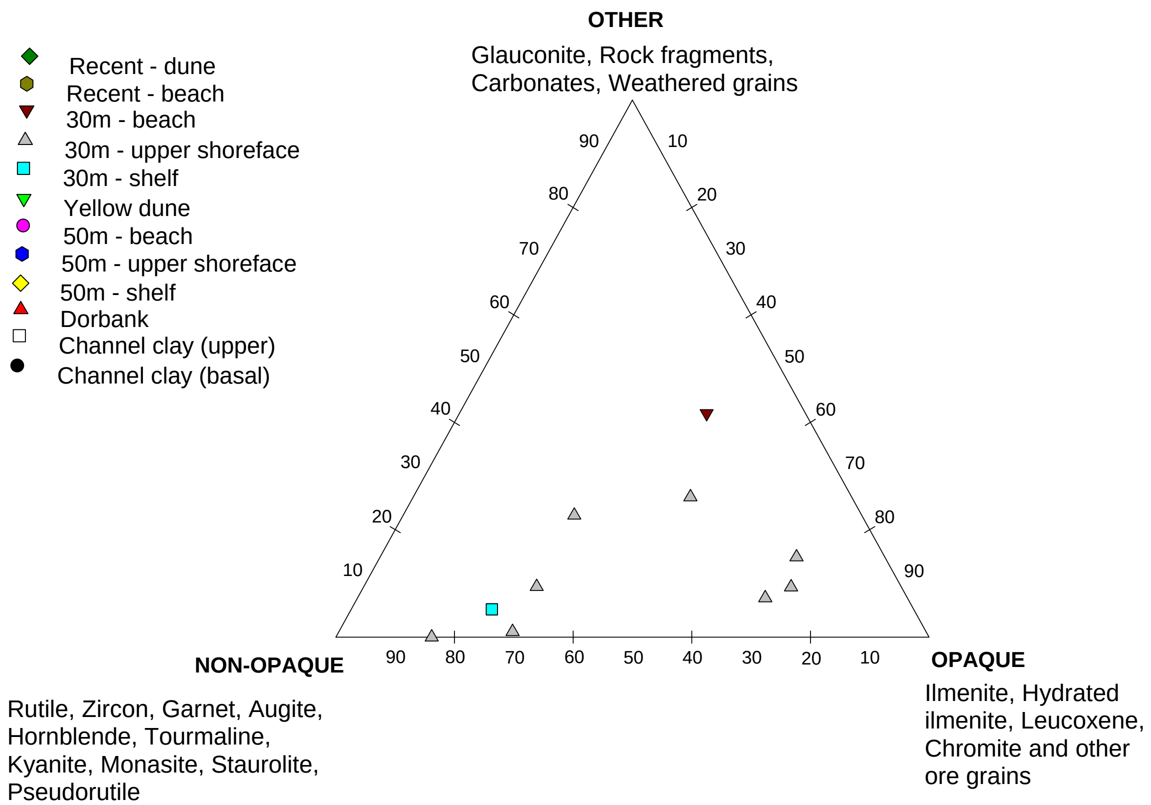


Figure 2d: Ternary diagram to show the variations in the heavy mineral assemblage of the 30m package.

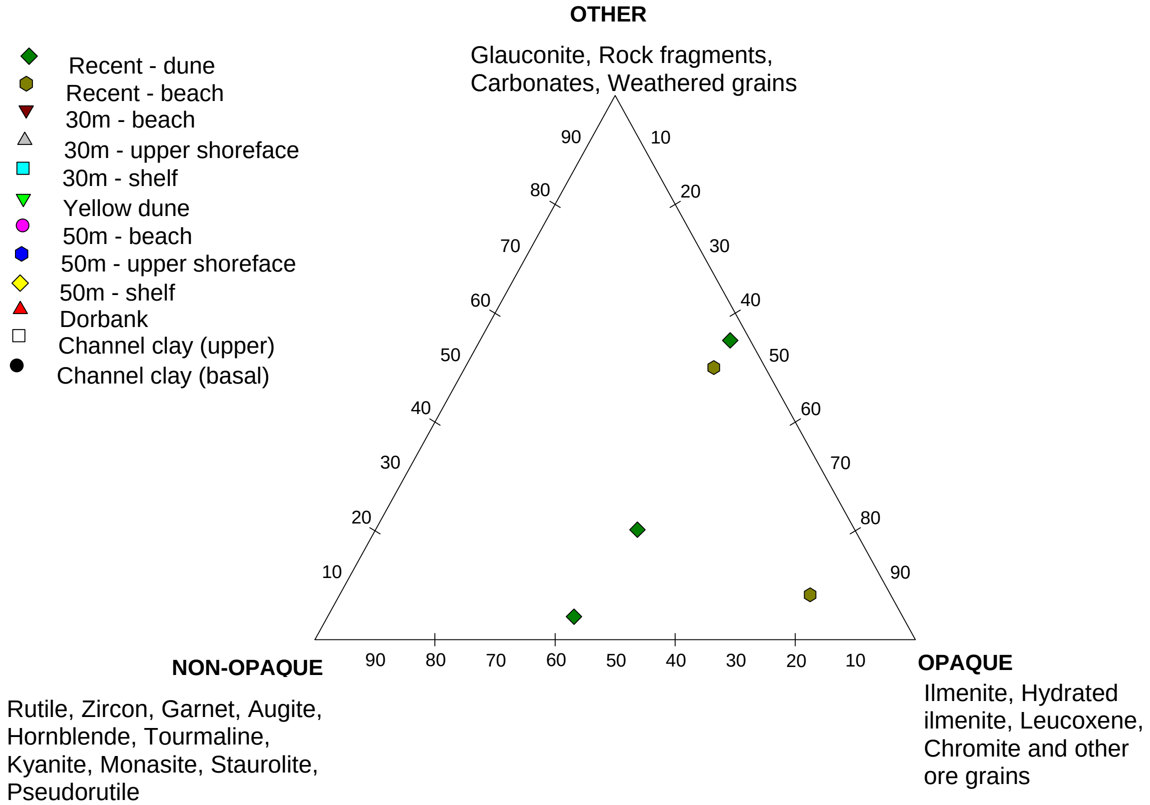


Figure 2e: Ternary diagram to show the variations in the heavy mineral assemblage of the Recent unit.

Table 4: Data collected while preparing the clay samples of Geelwal Karoo

Sample no:	Unit:	Colour:	% silt:	% organic:	% Fe	% heavy minerals
61	Bedrock	White	73.98	much	very little	much
30	Bedrock	White-green	61.61	very little	little	none
118	Channel clay	White	46.66	moderate	very little	little
28	Channel clay	Red	43.17	moderate	much	little
114	Channel clay	White	55.91	much	very little	none
10B	50m package	Yellow-green	36.35	much	moderate	none
56	30m package	Black-grey	26.16	much	moderate	none
12	30m package	Yellow-green	33.54	much	moderate	little

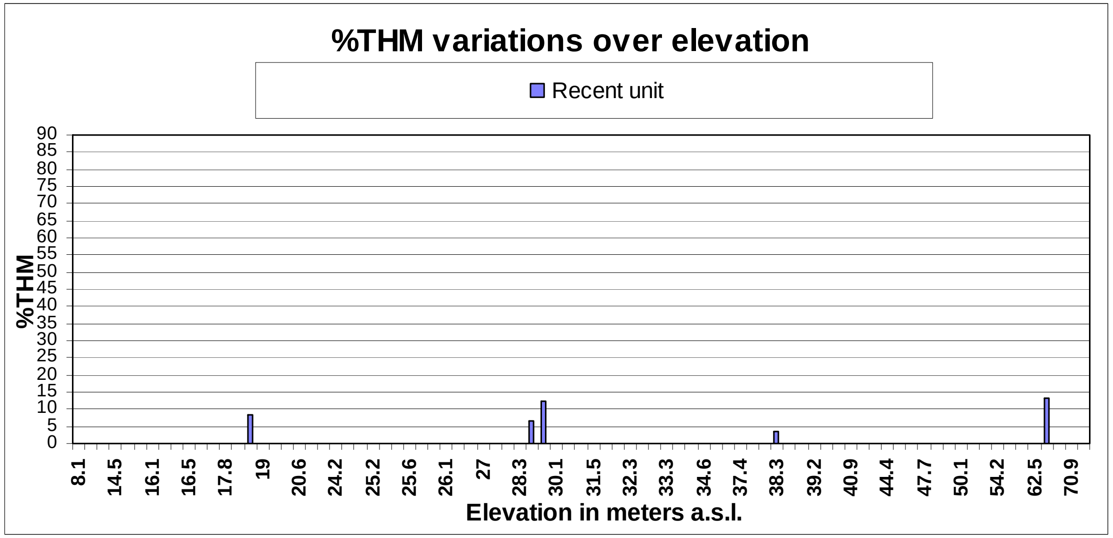


Figure 4a: Wt% heavy mineral variations in the Recent unit along length of Geelwal Karoo.

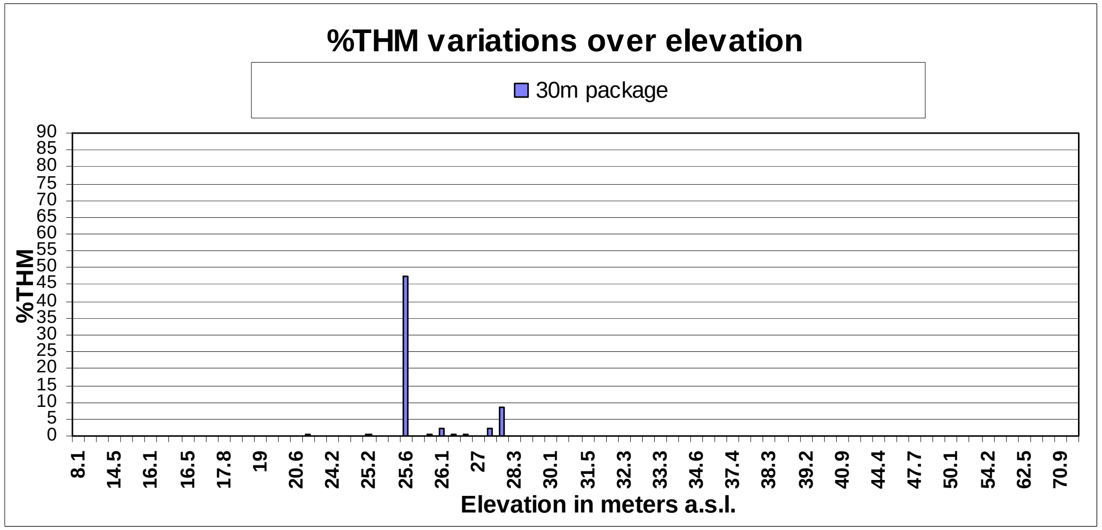


Figure 4b: Wt% heavy mineral variations in the 30m package unit along length of Geelwal Karoo.

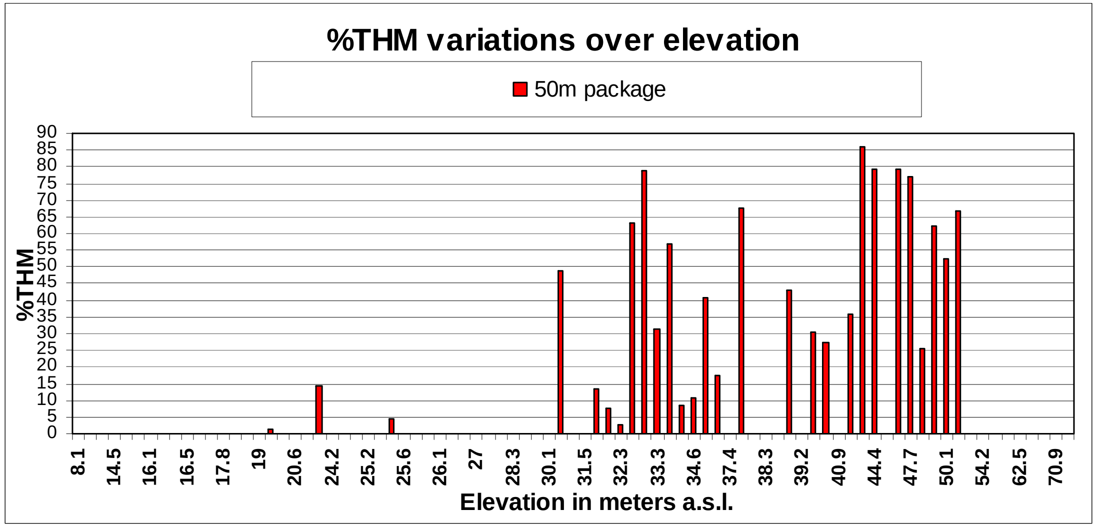


Figure 4c: Wt% heavy mineral variations in the 50m package along length of Geelwal Karoo.

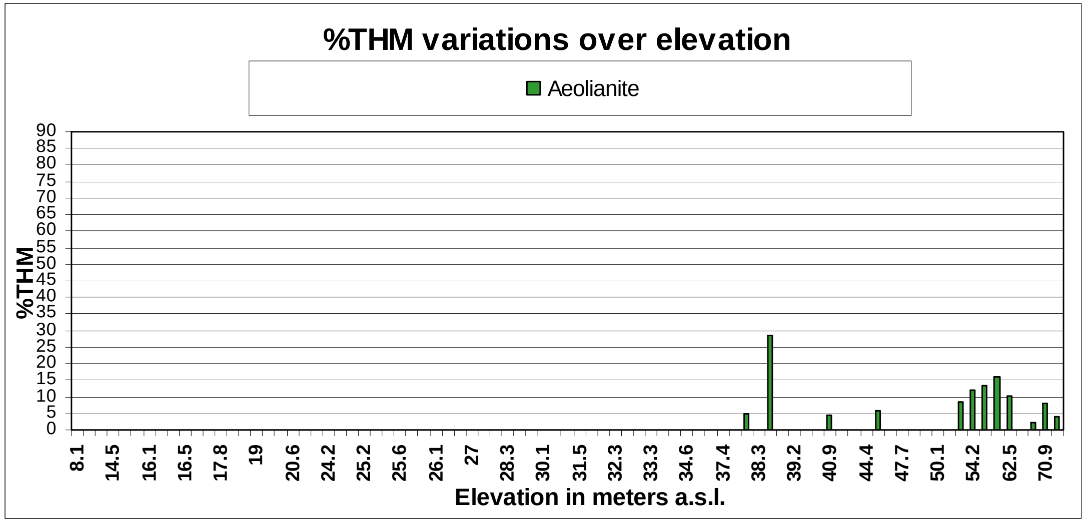


Figure 4d: Wt% heavy mineral variations in the aeolianite along length of Geelwal Karoo.

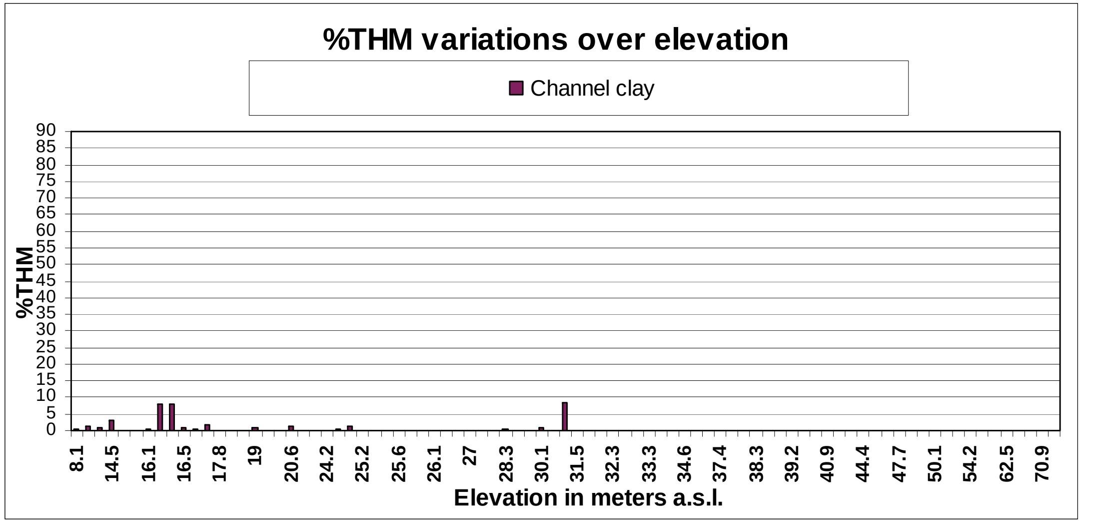


Figure 4e: Wt% heavy mineral variations in the channel clay unit length of Geelwal Karoo.