REPORT TO
GCS (PTY) LTD ON A PRELIMINARY
GEOTECHNICAL ASSESSMENT OF
SEAFACING SLOPE AND CLIFF
FACE STABILITY DURING
BEACH MINING OPERATIONS,
TORMIN MINERAL SANDS PROJECT,
WEST COAST, RSA

Reference
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1. TERMS OF REFERENCE

In response to the Mining Right Application submitted by Mineral Sands Resources (Pty) Ltd (MSR), the Department of Minerals and Energy (DME) and Department of the Environmental Affairs and Tourism (DEAT) expressed concern regarding their requirement for continued stability of the sea-facing slopes and cliff faces during mining on the beach and subsequent sand tailings disposal and rehabilitation of the beach. GCS (Pty) Limited appointed Davies Lynn & Partners (Pty) Ltd (DLP) to undertake a preliminary geotechnical assessment of the stability of the sea-facing slopes and cliff faces in terms of the proposed beach mining operations, sand tailings disposal and rehabilitation of the beach.

2. INFORMATION SUPPLIED

2.1 A copy of a paper entitled *"The Geelwal Karoo heavy mineral deposit : a modern day beach placer"* by W.G. MacDonald & A. Rozendaal published in the Journal of African Earth Sciences Vol. 21, No. 1, pp 187 – 200 dated 1995.

2.2 Pending Application 5/2/2/812 : Tormin Mineral Sands Project Application for a Prospecting Permit for Heavy Minerals in the Sea Shore Area Adjoining Farm Geelwal Karoo 262 in the Vredendal Magisterial District.

2.3 MRC Executive Summary – Mineral Sands Projects June 2005.

2.4 Information installed on a DVD issued by GCS (Pty) Limited which included : orthophotographs of the area, plans, images, maps, a process flow diagram of beach mining operations and wet concentrator plant layout.

3. HISTORICAL BEACH MINING OPERATIONS

The Trans Hex Group has successfully mined through the beach deposits down to the basal diamondiferous pebble conglomerates and gravels on more than one occasion since 1983. This has involved the temporary removal by mechanical means of all the overlying sands that contain the heavy minerals.

The methodology adopted by the Trans Hex Group mining contractors has generally involved the construction of a 5 to 10m horizontal toe berm of approximately ≤2m height at the bases of the existing sea-facing slopes. *PLATE 1 (P98)* Furthermore, a temporary barrier comprising boulders or slabs of rock is sometimes placed in the near-shore surf zone to dissipate wave energy *PLATE 2 (P99)* or alternatively a sand berm constructed between the surf zone and the excavation. *PLATE 3 (P41) AND PLATE 4 (P42)*

The Trans Hex Group beach mining operations have thus been taking place for 23 years to depths substantially greater than the proposed heavy mineral mining and experience gained by the contractors in terms of prevailing sea conditions and the seasonal variations in beach profiles.

4. PROPOSED BEACH MINING METHODOLOGY FOR HEAVY MINERAL RECOVERY

It is proposed that two (2No.) different mining methodologies are used over different portions of the beach, these being :

- an Excavator equipped with a 450t/hr DOP pump (EDOP) to remove sands below water level between the shoreline and the mid (to upper) portion of the beach zone.

- a Front End Loader (FEL) to remove ore rich sands above the water table (sea level) in the upper beach zone only i.e. on the beach above the area of the Excavator and DOP pump (EDOP).

The sands containing the heavy minerals will feed from the DOP pump directly into a slurry bin. The sands excavated by the FEL within the upper beach zone will be deposited into the same slurry bin.

The slurried sand will then be pumped at a rate of approximately 375t/hr from the slurry bin via a pipeline up to the ROM Stockpile located at the Wet Concentrator Plant where the water will be removed by cycloning during deposition. A five (5No.) day ROM stockpile is envisaged to be built up with time to provide a retention capacity for the Wet Plant.

The sand tailings remaining after removal of the economic heavy mineral concentrate (say 7 per cent) would immediately be slurried and pumped back via a pipeline to the beach, where it is proposed to discharge the sand slurry directly on to the mined beach without dewatering. The pumping of the ROM sands up to the Plant and the return of the sand tailings to the beach would therefore be a continuous process and result in rapid reinstatement of excavations made to remove the mineralized sands on the beach.

5. FACTORS INFLUENCING THE STABILITY OF THE EXISTING SEA-FACING SLOPES AND CLIFF FACES

The existing sea-facing slopes and cliff faces are largely a product of :

- geology
- surface erosion by wind and runoff water
- climatic conditions

- vegetation
- basal marine erosion
- geotechnical shear strength parameters

5.1 General Geology

The geology revealed on the sea-facing slopes comprises predominantly loose reddish orange medium grained sands and medium dense to dense cemented reddish orange moderately clayey sands to sandy clays in the Geelwal North mining area (P3 to P55) together with a subordinate central section of cemented light grey sands, grits and conglomerates containing a clay matrix, and weathered rocks of the Gariep Formation (P24 to P43).

The geology of the slopes and cliffs in the Geelwal South mining area (incorporating the Steenvas section) i.e. P55 to P101, indicate approximately equal lengths of coastline comprising cemented reddish orange sands to the south and cemented light grey sands, grits and conglomerates containing a clay matrix to the north (including two minor outcrops of weathered rocks of the Gariep Formation).

The geology of the sea-facing slopes and cliff faces exposed over the southern section of this coastline including Inaccessible Bay, Chip Bay and Scratch Patch reveal largely cemented light grey sands, grits and conglomerates, containing a clay matrix together with loose sands, silcrete slabs and boulders and two minor exposures of weathered Gariep Formation rocks.

5.2 Surface Erosion by Wind and Stormwater

Notwithstanding the very low total annual precipitation it appears from the exposed water eroded slopes, particularly within the cemented light grey sands, grits and conglomerates containing a clay matrix which are located in the southern section, that the impermeable nature of these sediments results in a high and concentrated stormwater runoff. This leads to preferential surface drainage courses and surface weathering. *PLATE 5 (P13), PLATE 6 (P79), PLATE 7 (P141) AND PLATE 8 (P142) refer.*

Wind generally appears to affect only the slopes comprising reddish orange sands where they are sparsely vegetated. Otherwise wind transports dry sands largely within the upper beach zone in the vicinity of the bases of the slopes.

5.3 Climatic Conditions

The low rainfall and dry climate result in the soils possessing a low natural moisture content typically ranging between 6 and 10 per cent. This results in any soils possessing a significant clay content of approximately 20 per cent or greater becoming highly dessicated and stiff to hard in consistency. *PLATE 9 (P22) refers.*

5.4 Vegetation

The well vegetated slopes are less susceptible to wind and water erosion and often correlate with stable slopes in a particular geological setting as would be anticipated. *PLATE 10 (P4) refers*

5.4 Basal Marine Erosion

On the basis of a number of relict arcuate slope failures visible in the sea-facing slopes *PLATE 11 (P10), PLATE 12 (P15) AND PLATE 13 (P114)* and widespread evidence of undercutting of the upper portion of the beach profile and the bases of the sea-facing slopes, it is evident that marine erosion is the factor primarily responsible for destabilizing sea-facing slopes and cliff faces. *PLATE 14 (P11), PLATE 15 (P12), PLATE 16 (P14), PLATE 17 (P20), PLATE 18 (P90), PLATE 19 (P113), PLATE 20 (P125) PLATE 21 (P128)* It is to be anticipated that substantial sediment movement will take place during extreme storm events, with partial or complete removal of the beach sediments in order to dissipate the particular wave energy involved and then the subsequent reinstatement of the sediments as the energy dissipation requirements reduce. Where the sand forming the normal beach profile is largely removed during extreme storm events, the sea will dissipate the wave energy against the toe of the sea-facing slope or cliff face. Where well cemented or cohesive materials or weathered rocks comprise the toe of the slope or cliff face the landward erosion will be very gradual and virtually undetectably after a single storm event. However, where the toes of the slopes comprise cohesionless sands, the landward erosion will normally be rapid and highly visible after a single event.

5.6 Relevant Geotechnical Parameters

The geotechnical parameters that control the behaviour of the sea-facing slopes and cliff faces largely include the following :

- the classification of the soils or materials with the use of sieve, hydrometer analyses and Atterberg Limits
- permeability which is closely related to the classification
- the unconfined shear strength in the dry cemented upper portion of the slope
- the drained shear strength parameters for the relatively dry cohesionless soils on the slopes
- the undrained shear strength parameters for saturated cohesive materials at or below sea-level
- the drained shear strength parameters for the saturated cohesionless sands at or below sea-level.

- the orientations of the major joint sets and bedding planes in weathered rock.

6. LABORATORY TESTING

6.1 Loose to Medium Dense Reddish Orange Medium Grained Sands

These sands are largely exposed in the sea-facing slopes of the northern section of Geelwal North. The grading and hydrometer analyses are tabulated in Table 6.1 below.

Table 6.1.1
Classification of Soils

Sample No.	Gravel %	Sand %	Silt %	Clay %	Grading Modulus	Unified Classification	Uniformity Co-efficient
A	0	94	1	5	1.0574	SP – SM	2.74
B	1	92	1	6	1.0071	SP - SM	3.01

The reddish orange medium grained sands were recompacted to a dry density of 1750 kg/m^3 and tested at natural moisture content in a shearbox to simulate conditions in the existing slopes above sea level. The results are tabulated in Table 6.1.2 below.

Table 6.1.2
Results of Shearbox Tests

Normal Stress kN/m^2	Dry Density kg/m^3	Moisture Content %	Shear Strain %	Shear Stress kN/m^2	c kN/m^2	Ø degrees
50	1750	10.0	2.5	46.1		
150	1750	10.0	5.0	124.1	8	37
300	1750	10.0	5.8	237.0		

While the shear strength parameter c = 8kN/m^2 and Ø = 37 degrees will be a function of the dry density and degree of saturation, the results correlate closely with the steeper slopes in the reddish orange sands as measured in the field. It would be anticipated that a reduction in insitu density will result in a decrease in Ø to approximately 30 degrees in a loose state.

6.2 Cemented Reddish Orange Moderately Clayey Sands and Sandy Clays

These cemented reddish orange clayey sands and sandy clays frequently form prominent steep scarps towards the crests of the sea-facing slopes and may extend down to beach level in places.

The grading and hydrometer analyses are given in Table 6.2.1 below.

Table 6.2.1

Classification of Soils

Sample No.	Gravel %	Sand %			Silt %	Clay %	PI	Grading Modulus	Unified Classification	Uniformity Co-efficient
		c	m	f						
BLOCK 1	0	6	48	18	1	27	6	0.7842	SMd	>99
BLOCK 2	0	6	49	19	2	24	5	0.8012	SMd	>99
BLOCK 3	0	6	52	20	10	12	4	0.8329	SMd	>99

It is apparent that the clay content varies significantly in the cemented sands, while the sand fractions remain remarkably consistent.

Undisturbed samples of the cemented reddish orange clayey sands and sandy clays were tested under saturated and undrained conditions to determine the shear strength parameters typically anticipated below sea-level on removal of supporting material. The results are given in Table 6.2.2 below.

Table 6.2.2

Results of Saturated Undrained Shear Strength Tests on Block 3

Normal Stress kN/m^2	Dry Density kg/m^3	Moisture Content %	Shear Strain %	Shear Stress kN/m^2	c_u kN/m^2	$Ø_u$ degrees
50	1762	9.0	4.2	28.9		
150	1782	7.3	5.8	88.0	0	30
300	1775	7.0	11.7	175.2		

It is evident that the relatively lower clay content of the Block 3 sample tested resulted in the sample being sufficiently permeable to drain during rapid shearing. For relatively less permeable samples i.e. higher clay content, a cohesion intercept would be anticipated, which would result in a cut face standing temporarily at a steeper angle than the purely frictional material of $Ø_u$ = 30 degrees as analysed above.

Unconsolidated undrained Triaxial compression tests were carried out on undisturbed Block 1 samples at natural moisture content. The results of these tests are given in Table 6.2.3 overleaf.

Table 6.2.3

Results of Unconsolidated Undrained Triaxial Compression Tests

Sample No.	Nat. Dry Density kg/m^3	Nat. Moisture Content %	Cell Pressure kN/m^2	Axial Strain %	Deviator Stress kN/m^2	Shear Stress kN/m^2	Angle of Shear Plane degrees
BLOCK 1	1779	8.2	25	2.46	493	246	60
	1794	6.7	50	1.83	880	440	63
	1759	6.6	150	3.05	1176	588	61
	1770	6.4	300	6.14	1682	841	59

These sandy clays exhibit very high undrained shear strengths which arise largely as a result of desiccation in an arid environment. The materials thus exhibit significant negative porewater pressures particularly at ground surface.

6.3 Cemented Light Grey Sands and Gravels Containing a Clay Matrix

These light grey to white cemented alluvial sands and gravels vary substantially in composition along the coastline, but are invariably medium dense to dense or stiff in consistency where the clay content is significant and contain Interlayered horizons of rounded pebbles. The grading and hydrometer results are given in Table 6.3 below.

Table 6.3

Classification of Soils

Sample No.	Gravel %	Sand %			Silt %	Clay %	Grading Modulus	Unified Classification	Uniformity Co-efficient
		c	m	f					
C	14	24	37	16	2	7	1.4559	SP – SM	5.73
D	11	37	23	11	10	8	1.4526	SMd	>99

7. OFFSET PARAMETERS PROPOSED TO MAINTAIN OR ENSURE SEA-FACING SLOPE STABILITY DURING BEACH MINING OPERATIONS

It is evident from the various sea-facing slope failures observed along the coastline that the destabilizing force is in all cases undercutting of the bases of the sea-facing slopes by storm surf. Furthermore, it is clear that where the bases of sea-facing slopes comprise reddish orange sands the effects of undercutting is almost immediate and highly visible. These slopes fail as a series of shallow, progressive failures that migrate up the slope from the base. This type of failure is termed a "slab slide" as the common failure surface is non-circular and invariably shallower but almost parallel to the existing ground surface. The slab slides within the reddish orange sands appear to fail along failure surfaces inclined between a lower bound of 30 degrees and 37 degrees or more, depending on the clay content of the sands and vegetal cover.

Where the bases of the slopes comprise cemented light grey or white sands and gravels or dark brown and grey or dusky brown highly weathered rocks of the Gariep Formation, the erosion of these cohesive materials by storm surf is muted and undercutting at the base proceeds very gradually. Consequently, the slopes in these latter materials generally exhibit slopes varying between 45 degrees and subvertical. *PLATE 22 (P61)*

Accordingly, if the beach mining operations in the vicinity of the bases of the slopes in the reddish orange sands is undertaken outside or seaward of an imaginary line projected from the bases of the slopes at a lower bound angle of 30 degrees to the horizontal, the slope above will remain stable. This translates to an offset distance from the toe of the slope of 1,75 times the depth to which it is proposed to remove beach sand at a particular location by Front End Loader above the water / sea-level. For example, if the mineralized sands occur to a depth of 3m, an offset distance of 3*1.75 = 5.25m is required at 3m depth, for a 5m depth an offset distance of 8.75m is required at 5m depth as set out in Table 7.1 overleaf.

Table 7.1

Offset Distances and Depths of Beach Mining Adjacent to Slopes Comprising Reddish Orange Sands (Calculated at 1 vertical to 1.75 horizontal)

Depth of Beach Mining metres	Horizontal Offset Distance from Toe / Base of Slope at Applicable Depth of Mining metres
1	1.75
2	3.50
3	5.25
4	7.00
5	8.75

Similarly, beach mining operations in the vicinity of slopes comprising the cohesive well cemented light grey sands and gravels and the weathered rocks of the Gariep Formation should be undertaken outside / seaward of an imaginary line projected at a lower bound of 45 degrees from the bases of these slopes as set out in Table 7.2 overleaf.

An exception occurs in the Chip Bay area between P113 and P116 as indicated in Dwg. 3102/01 where a 30° offset is applied over a short section rather than the 45 degree offset, considered the lower bound and appropriate for the well cemented light grey sands and gravels. The reason is that within this portion of the Chip Bay area there exists a limited section where the lower slopes are comprised of only slightly cohesive to cohesionless materials containing silcrete blocks.

Table 7.2
Offset Distances and Depths of Beach Mining Adjacent to Slopes Comprising Cemented Light Grey Sands & Gravels and Weathered Gariep Fm rocks (Calculated at 1 vertical to 1 horizontal)

Depth of Beach Mining metres	Horizontal Offset Distance from Toe / Base of Slope at Applicable Depth of Mining metres
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0

The recommendations made above have been plotted on to a drawing, Dwg. No. 3102/01, on which is indicated the areas in which either the 30 degrees (1 in 1.75 slope) or 45 degrees (1 in 1 slope) applies. The geological conditions have been colour coded and proposed mining areas named and indicated on the drawing.

8. COMMENTS ON PROPOSED BEACH MINING METHODOLGIES

A basic assumption made in the mining methodologies proposed by MRC is that the sea will be prevented from extending up to the bases of the sea-facing slopes. Since the Front End Loader (FEL) only will be removing mineralized sands above the water / sea-level in the upper beach area it would obviously not be advantageous for the beach mining operations if the sea were to gain access to the upper portion of the beach profile. Accordingly, it will be necessary to provide a protective sand berm between the sea and the upper beach mining operations using the FEL mining methodology.

Since the lower and mid portions of the beach profile are being mined using the Excavator and DOP pump (EDOP) methodology, it would appear reasonable for beach mining to proceed with the EDOP operation displaced ahead of the FEL operation. This would ensure that the EDOP operation did not provide an avenue / low area through which the sea could gain access to either the protective berm or the FEL excavations.

The return of the slurried sand tailings via pipeline from the Wet Concentrator Plant and the discharge of this sand on the beach may need to be used off the protective berm to the FEL operation in the direction of the sea to reinstate the EDOP areas as well eastwards into the FEL areas. A sand tailings pipeline located along the FEL protective berm parallel to the shoreline with discharge points to <u>either side of the protective berm</u> may be advantageous in providing flexibility in reinstating the mined out areas. The tidal action of the sea will also rapidly normalize the beach profile in terms of the sea-beach sediment dynamics.

9. COMMENTS ON PROPOSED ROAD AND PIPELINE ACCESS TO THE BEACH

It is apparent that road access to the beach along the proposed mining area is well catered for owing to the previous and current Trans Hex beach mining operations.

Disused roads down to the beach often show severe erosion by stormwater. *PLATE 23 (P84) AND PLATE 24 (P124)* This often appears to arise as a result of increasing the stormwater runoff by hardening of the road surfaces using partly cohesive materials and the use of steep road gradients. Since the annual rainfall is very low it would probably be more cost-effective to undertake regular maintenance of these roads than attempt to design and construct stormwater catchpits, pipelines and spreaders for possibly severe but only occasional events. *PLATE 25 (P47) AND PLATE 26 (P92)* show well maintained current beach access roads. The closure and rehabilitation of these roads once mining is completed would require longterm measures to be implemented to reduce concentrated runoff from the roadways by reshaping etc., reducing surface wind erosion and undertaking revegetation programmes.

The construction of pipelines between the beach and the Wet Concentrator Plant will require that the pipes be placed within a basal or semi-circular, impermeable sleeve in places so that any leakage that may arise from flanges etc. does not cause erosion on steep slopes in particular.

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PLATE 26 – P92 **Well maintained beach access road**

PLATE 25 – P47 **Well maintained beach access road**

PLATE 24 – P124 **Severe erosion of former access road by stormwater runoff**

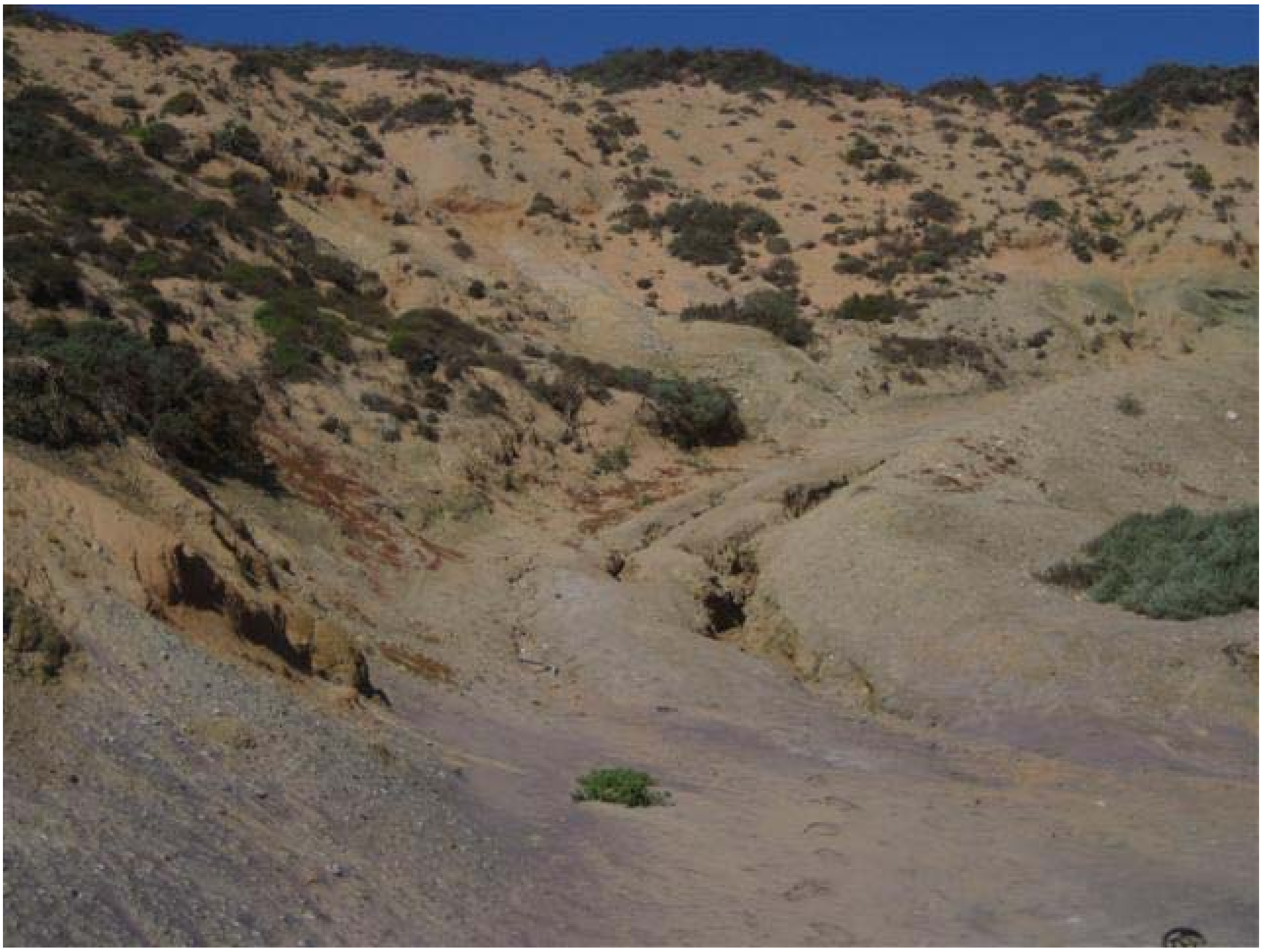


PLATE 23 – P84 **Erosion of disused road access by stormwater runoff**

PLATE 22 – P61 **Steep slopes evident down to the upper beach zone in both cemented light grey sands and gravels and weathered Gariep Fm. rocks. (LUTZ BAY)**

PLATE 21 – P128 **A point on the coastline comprising cemented light grey sands and gravels that has been saturated and eroded by sea action to cause failure of the slope**

PLATE 20 – P125 **Interlayered silcretes, cemented light grey sands and gravels showing undercutting by the action of the sea with subsequent slope failure**

PLATE 19 – P113 **Undercutting at base of cemented light grey sands and gravels with Interlayered silcretes. Since these cemented materials form a point on the coastline they have obviously been subject to considerable battering by the sea resulting in undercutting and subsequent failure of the overlying materials**

PLATE 18 – P90

Base of slope in cemented reddish orange clayey sands and sandy clays showing evidence of undercutting and probable reduction in negative porewater pressures strength with saturation

PLATE 17 – P20 **Sparsely vegetated and relatively steeper lower slope revealing prior undercutting of the base of the slope**

PLATE 16 – P14 **Localized slope failure initiated by earlier undercutting of the base of the slope**

PLATE 15 – P12 **Slope failure across lower portion of slope initiated by undercutting of the base of the slope**

PLATE 14 – P11 **Relatively steeper lower slope indicates undercutting by stormsurf**

PLATE 13 – P114 **Arcuate scarp visible on the mid-slope as a result of undercutting at the base of the slope**

PLATE 12 – P15 **Two phases of slope failure visible at this location in reddish orange sands. The backscarp of the earlier failure occurs mid-way up the slope while the more recent failure is evident at the base of the slope**

PLATE 11 – P10 **Slope failure precipitated by undermining of the base of the slope by the sea in reddish orange sands**

PLATE 10 – P4 **Reddish soil slope with base well defined by intersection of revegetated raised beach deposit at base**

PLATE 9 – P22 **Dessication of clayey sands and sandy clays forming steep slopes – cemented reddish orange materials**

PLATE 8 – P142 **Stormwater runoff erosion of weathered Gariep Formation overlain by cemented light grey sands and gravels**

PLATE 7 – P141 **Stormwater runoff erosion of cemented light grey sands and gravels**

PLATE 6 – P79 **Stormwater runoff erosion of cemented light grey sands and gravels containing a clay matrix overlain by cemented reddish orange clayey sands and sandy clays**

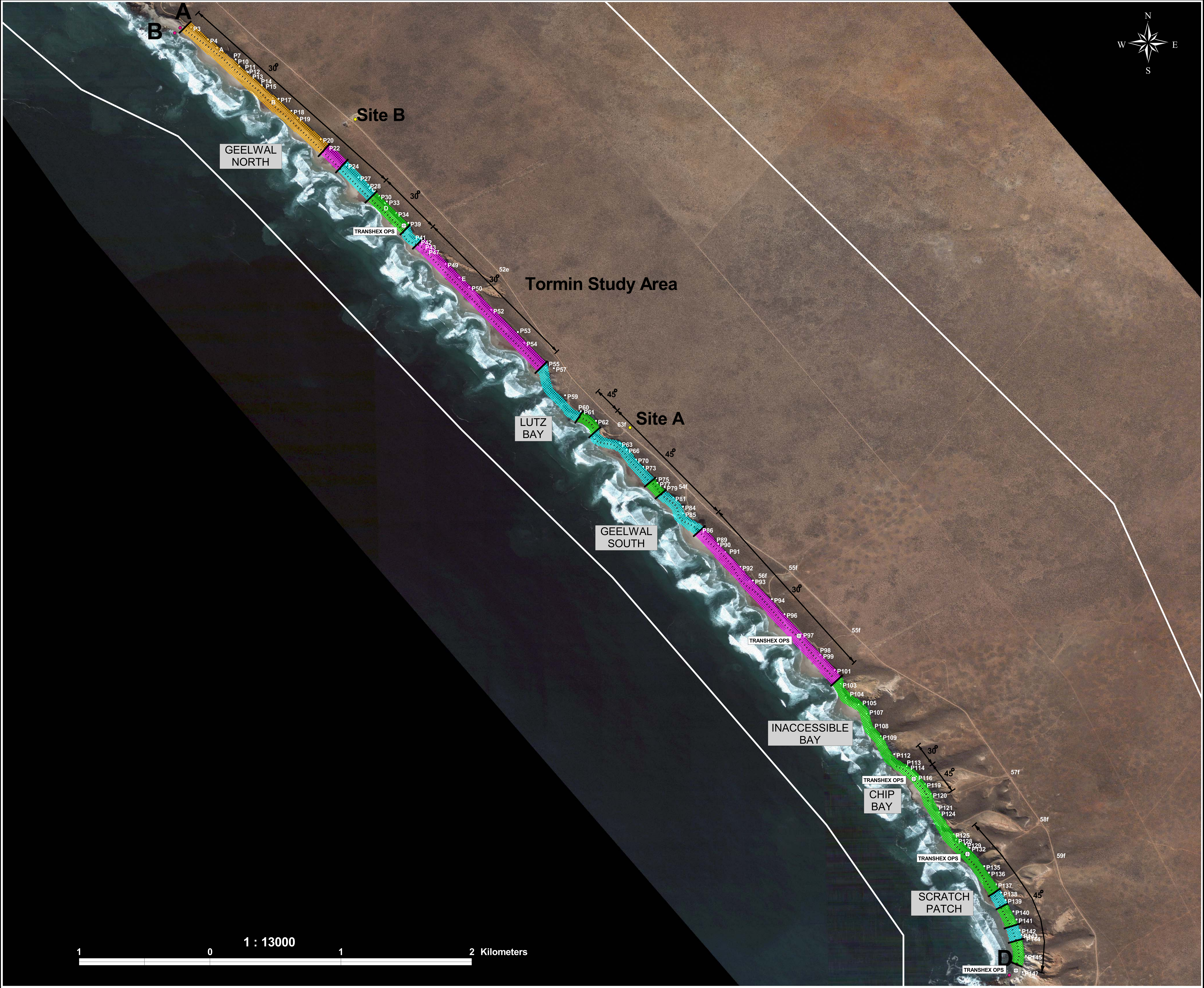
PLATE 5 – P13 **View northwards showing sparsely vegetated reddish orange sand slopes and deposit at toe of eroded and wind blown material**

PLATE 4 – P42 **Trans Hex Group diamond mining operations**
View northwards showing both slope toe protection berm and berm between surf-zone and excavation

PLATE 3 – P41 **Trans Hex Group diamond mining operations**
View seawards showing a sand berm constructed between the surf-zone and the excavation

PLATE 2 – P99 **Trans Hex Group diamond mining operations**
View seawards showing a temporary barrier of boulders or slabs of rock placed in the near-shore surf zone to dissapate wave energy. Stockpile of rocks in the foreground

PLATE 1 – P98 **Trans Hex Group diamond mining operations**
View northwards showing the berm constructed on the upper beach to protect the sea-facing reddish orange sand slopes



KEY:

- Loose reddish orange sands
- Cemented reddish orange sands
- Gariep fm suite of rocks / weathered in many places
- Cemented light grey conglomerates, grits, silcretes, coarse sands containing a clay matrix
- Areas defined for heavy mineral mining
- 30° Lateral extent of mining area to be mined at a maximum slope from the toe of the slope of 30° to the horizontal
- P37 Location of Photograph 37

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CLIENT

GCS (PTY) LIMITED

PROJECT

TORMIN MINERAL SANDS PROJECT VREDENDAL MAGISTERIAL DISTRICT R.S.A.

TITLE

SITE PLAN SHOWING LOCATIONS OF PHOTOGRAPHS, GENERAL GEOLOGY AND RECOMMENDED DESIGN SLOPES AT BASES OF SLOPES OR CLIFF FACES

SCALE	DWG NO.	REV
1 : 13000	3102/01	1