FACTUAL REPORT

GEOTECHNICAL INVESTIGATION

FOR

TENDER: NAMPORT 041/2010
TANKER BERTH AT SADC GATEWAY PORT

FOR

FAIRBROTHER GEOTECHNICAL ENGINEERING CC

Revision 2: 11 June 2014

CORE GEOTECHNICAL CONSULTANTS
Engineering Geology and Geohydrology

CONTACT DETAILS
Tel: +27 21 671 4274/80 **Fax:** +27 21 671 4277 **email:** admin@coregeotech.co.za
Postal address: Postnet Suite 177, Private Bag X3, Pumstead, 7801, Cape Town
Physical address: Unit b02, Clareview Business Park, 236 Imam Haron Road, Claremont, 7708, Cape Town, South Africa

FACTUAL REPORT
GEOTECHNICAL INVESTIGATION FOR
TENDER: NAMPORT 041/2010
TANKER BERTH AT SADC GATEWAY PORT

Date: May 2014 Project no: 164-13

Contents

CORE GEOTECHNICAL CONSULTANTS
Engineering Geology and Geohydrology

FACTUAL REPORT

GEOTECHNICAL INVESTIGATION FOR TENDER: NAMPORT 041/2010

TANKER BERTH AT SADC GATEWAY PORT

for

FAIRBROTHER GEOTECHNICAL ENGINEERING CC

Date: May 2014 Project no: 164-13

EXECUTIVE SUMMARY

The Namibian Ports Authority appointed Fairbrother Geotechical Engineering CC to carry out a rotary core drilling program with associated field and laboratory testing and to prepare a factual report as part of the geotechical investigation for the proposed new Tanker Berth at the SADC Gateway Port, in Walvis Bay, Namibia.

Fairbrother Geotechical Engineering CC, in turn, appointed Core Geotechncal Consultants to provide the engineering geological input required for core-logging and sample selection for laboratory testing purposes. In essence, therefore, this report is a factual report presenting the drilling, field and laboratory test data as gathered, with no interpretation offered, in accordance with the scope of work.

The larger site area consists of both an offshore and onshore component, covering an area totalling over 950 Ha. The offshore area is located within the greater Walvis Bay Port area, bounded to the west by the Walvis Peninsula and Pelican Point, and to the east by the Namibian mainland.The onshore area extends from the coastal beach, through the coastal dune area and further inland for approximately 2 km, into the desert dune belt. The topograhy of this area consists of mostly rolling desert and coastal sand dunes with interlying depressions

The investigation comprised the following:

- Thirty-three offshore and twenty-five onshore rotary cored boreholes with SPT testing .
- Fifteen vibrocores.
- Sampling and laboratory testing for geochemical and engineering purposes.

The general offshore profile consists of a diatomaceous clayey silt found at seabed level, with a variable sand fraction. These sediments are particularly well developed on the inner shelf of the continental margin in the Walvis Bay area. Sandy sediments directly underlie these silty soils. As one moves onshore however, transported sandy soils of variable thickness, sometimes alternating with thin slty sand horizons, occur at surface.

The transported soils are underlain by a sediment classified mostly as lithic arenite, consisting of fluvially transported lithic fragments of variable size that have been weakly to strongly cemented (mostly calcretized) in a matrix consisting of mostly fine to medium sand, but also containing a small silt and clay content.

This cemented sediment is underlain by intrusive plutonic rocks, consisting of granite, granodiorite or in some cases pegmatoidal rock, which forms the bedrock in the Walvis Bay area.

This report merely provides a brief summary of the scope of work of the project, as well as to present the necessary data, which can be found in the attached appendices.

1. Introduction and terms of reference

The Namibian Ports Authority appointed Fairbrother Geotechical Engineering CC to carry out a rotary core drilling program with associated field and labortaory testing and to prepare a factual report as part of the geotechical investigation for the proposed new Tanker Berth at the SADC Gateway Port, in Walvis Bay, Namibia.

Fairbrother Geotechical Engineering CC, in turn, appointed Core Geotechncal Consultants to provide the engineering geological input required for core-logging and sample selection for laboratory testing purposes.

The tanker berth will be a reinforced concrete dolphin-type structure and will most likely require deep piled foundations. It will be linked to the shore by an above water trestle. A new access channel from deeper waters, is also planned to be dredged.

The aim of the geotechnical investigation and this factual report is to provide the tenderers and selected contractors with the required, relevent factual geotechnical information gathered during the investigation, so as to design and construct the new tanker berth. Limited geological and geotechnical information is available for this area and this an extensive investigation was thus required.

2. Information used in the study

The following information sources were used in the investigation: -

- Remote imagery (Google 2014)
- A layout plan of the proposed new tanker berth including the entrance channel, tanker berth basin, turning area, as well as the future channel and port basin. The site plan included proposed offshore, onshore and vibrocore positions and was provided by Namibian Ports Authority (Namport).
- Geotechnical Report on the Marine Geotechnical Investigation In The Port of Walvis Bay, prepared for Namport by 7 Sea Geosciences (Pty) Ltd.
- Geotechnical Investigation for Dredging The Port of Walvis Bay, Namibia, prepared for Namibian Ports Authority by M van Wieringen & Associates in December 1999.
- Geotechnical Report for the Expansion to Container Quay, Ship Repair Hub and Fishing Terminal prepared for Namibian Ports Authority by M van Wieringen & Associates in June 2008.
- A summary of various correlations between point load index and UCS values found in : *Correlation between Uniaxial Compressive Strength and Point Load Index for Salt-Range Rocks* by M. Akram and M.Z.A. Bakar, published in Pak. J. Engg. & Appl. Sci. Vol. 1, July 2007.

3. Site description

The larger site area consists of both an offshore and onshore component, covering an area totalling over 950 Ha.

The offshore area is located within the greater Walvis Bay Port area, bounded to the west by the Walvis Peninsula and Pelican Point, and to the east by the Namibian mainland. It extends from the beach and intertidal zones onto the continental shelf.

Seabed elevations for this area range from 1.6m above chart datum (CD), within the tidal zone, further seaward to -9.59m CD. This area includes the site for the new tanker berth and water trestle (located just north to north-east of the town of Walvis Bay at a distance of approximately 1.7km north-east of the town), as well as the area where additional boreholes were required for a potential additional berth, to be constructed at a later stage.

The onshore area extends from the coastal beach, through the coastal dune area and further inland for approximately 2km, into the desert dune belt. The topograhy of this area consists of elevated, rolling desert and coastal sand dunes with interlying depressions, with elevations varying from +0.8m CD to +41.6m CD. The general topography rises from the coast towards the high sand dunes located towards the north-east and east. The onshore area is for the most part, sandy and unvegetated.

Climatic conditions for Walvis Bay are generally cool to warm with a predominantly southwesterly wind and windspeeds of 10 – 15 knots, but seasonally increasing to as much as 25 knots. Fog is also common between the months of April to September.

Remote imagery showing the larger site area, including the onshore site topograpahy can be seen in Appendix F, Figure 1.

4. Nature of the investigation

The following investigation methods were required to assess the geotechnical nature of the underlying soils and rock, below surface and the seabed:-

4.1 Rotary cored boreholes, in-situ Standard Penetration Test (SPT) testing and vibrocoring

4.1.1 Offshore Drilling

Thirty three offshore, rotary cored boreholes were drilled on the site using NWD4-size core barrels and temporary casing, where required. The offshore boreholes were drilled from a self-elevating, floating platform which was pulled or maneuvered into position either by a tugboat or an onboard motor. Once in position, four legs were hydraulically lowered onto the seabed, lifting the platform until it was standing stable above the ocean, thus independent of tides and ocean conditions.

The boreholes were drilled to a depth of approximately 35m below the seabed. Some boreholes were drilled deeper or shorter depending on the strata encountered within the borehole and the clients specific requirements for that borehole. In-situ Standard Penetration Tests (SPT) were conducted, where possible at 1.0 m intervals up to a depth of 6m and then at 1.5m intervals after, until the SPT met refusal.

Recovered borehole core was logged relative to chart datum (CD), photographed and sampled for appropriate laboratory testing. Offshore borehole coordinates and coller elevations relative to CD are shown in Table 4.1. The positions are also shown on the attached site plans (see Appendix F, Figure 2). Borehole logs are included in Appendix A and the full laboratory test results are attached in Appendices C & D.

4.1.2 Onshore drilling

Similarly, onshore rotary cored boreholes were drilled as part of the investigation for the associated future channel and port basin structure.

The same drilling procedure regarding core size and SPT testing was conducted for the onshore drilling. These onshore holes were also drilled to a depth of 35m below ground level or until a suitable depth within the bedrock was reached to negate the possibility of a potential boulder or corestone.

Recovered borehole core was logged relative to surface and CD, photographed and sampled. Onshore borehole coordinates and coller elevations relative to CD are shown in Table 4.2 and the borehole positions are also shown on the site plan (see Appendix F, Figure 2) and the borehole logs are included Appendix A and the laboratory testing results in Appendices C & D.

Table 4.1. Offshore borehole coordinates and collar elevations (WGS84 UTM33)

Borehole ID	X	Y	Collar depth(m) below CD
SPTW1	451773.741	7466323.958	4.900
SPTW2	451464.002	7466321.537	5.540
SPTW3	451256.574	7466317.000	5.100
SPTW4	451205.773	7466412.124	6.190
SPTW5	451156.109	7466497.335	5.800
SPTW6	451113.481	7466589.332	6.250
SPTW7	451059.703	7466671.129	6.860
SPTW8	451013.566	7466757.076	7.020
SPTW9	450969.217	7466852.119	7.330
SPTW10	450913.399	7466931.987	7.790
SPTW11	450864.040	7467021.234	8.220
SPTW12	450815.827	7467112.751	8.490
SPTW13	450772.343	7467198.990	8.620
SPTW14	450723.474	7467287.115	8.490
SPTW15	452352.577	7467298.297	5.430
SPTW16	451259.889	7467254.798	8.120
SPTW17	450594.479	7466882.032	8.330
SPTW18	451255.695	7467000.693	6.970
SPTW19	451740.200	7467279.263	7.250
SPTW20	451457.840	7467495.735	7.840
SPTW21	451885.226	7467500.207	7.480
SPTW22	451356.397	7467924.007	8.630
SPTW23	451311.315	7466760.315	6.750
SPTW24	451604.392	7466683.167	6.070
SPTW25	451362.328	7467329.406	8.010
SPTW26	451228.627	7467568.079	7.660
SPTW27	451109.459	7467810.219	8.170
SPTW28	450977.778	7468042.304	8.750
SPTW29	450839.768	7468289.622	9.200
SPTW30	450688.450	7468544.414	9.590
SPTW31	451488.860	7468203.874	7.600
SPTW32	452389.928	7468204.841	5.600
JM5	451237.252	7466354.649	4.480

Table 4.2. Onshore borehole coordinates and collar elevations (WGS84 UTM33)

Borehole ID	X	Y	Collar depth(m) above CD
SPT1	452393.282	7465755.185	2.06
SPT2	453000.271	7466000.209	2.08
SPT3	454020.461	7465942.000	2.64
SPT4	452579.580	7466454.580	2.11
SPT5	453420.712	7466403.746	2.48
SPT6	454624.347	7466428.741	7.79
SPT7	453004.237	7466944.926	1.47
SPT8	454012.387	7466961.554	4.12
SPT9	454836.013	7466962.804	10.40
SPT10	452936.836	7467590.148	1.96
SPT11	454007.725	7467973.702	7.15
SPT12	453176.382	7468349.915	1.72
SPT13	454850.693	7468485.932	41.37
SPT14	452707.912	7466800.105	2.30
SPT15	453067.492	7466562.211	1.85
SPT16	453600.888	7466803.311	0.80
SPT18	454383.553	7466710.073	6.38
JM1 (SPT17)	452468.595	7466704.493	1.76
JM2	453033.812	7466226.203	2.01
JM3	452367.907	7466143.180	2.26
JM4	452253.857	7466306.330	1.63
SPT21	455385.056	7463715.082	9.48
SPT22	456151.409	7461387.294	7.50
SPT23	456315.886	7459308.994	10.48
SPT24	457292.993	7458749.911	17.93

4.1.3 Vibrocoring

The entrance channel to the tanker berth is to be dredged to a depth of -16m CD. To optimize the dredging, fifteen vibrocores were taken from seabed at selected locations.The aim of the vibrocoring was to characterize the soil so as to determine the dredger type, risks of pollution and investigate the potential reduction of the required dredged material to be disposed of.

The vibrocores were taken to a maximum depth of 6m. During the vibrocoring process, the core tube with a core catcher was first lowered and settled onto the seabed and then checked and align for stability, before coring would commence. It was found that within the bay area, a suspended silt horizon occurs at seabed and this progressively deepens with distance from the shore and with increasing water depth. The specific gravity (SG) of this material was however similar to that of the seawater which entered vibrocore tube during the lowering and positioning process. This resulted in the suspended silt material to be displaced as the tube penetrated this horizon, making it difficult to capture this material within the vibrocore tube. This continued until these soils were less suspended and of a consistency that it could enter the tube thus esxpelling the seawater within.

The material captured from the vibrocores was logged relative to CD, photographed and sampled for laboratory testing.

Vibrocore coordinates and coller elevations relative to CD are shown in Table 4.2, and positions are shown on the attached site plan (see Appendix F, Figure 3). The soil profiles from the vibrocores are included in Appendix B and the Laboratory test results are attached in Appendices C & E.

Table 4.3. Vibrocore coordinates and collar elevations (WGS84 UTM33)

Vibrocore ID	X	Y	Collar depth(m) below CD
VB001	451800.22	7466579.92	3.69
VB002	451824.36	7466947.16	6.2
VB003	450964.45	7466403.57	5.38
VB004	451373.02	7467017.15	5.65
VB005	451218.99	7467293.53	6.62
VB006	451089.43	7467526.01	7.3
VB007	450913.27	7467842.12	7.62
VB008	450719.32	7468190.14	8.3
VB009	450317.33	7468500.62	8.8
VB010	450295.9	7468949.92	9.4
VB011	450109.42	7469284.53	10.05
VB012	449735.42	7469544.79	10.96
VB013	449724.01	7469976.11	11.53
VB014	449503.41	7470371.95	12.39
VB015	4491125.35	7470639.5	12.9

4.2 Field and laboratory testing

4.2.1 Standard specifications used

The following standard specifications were applicable for this contract:

- Standard Penetration Test (SPT) was carried out in accordance with ASTM D 1586-99:99
- Point load testing was carried out according to the ISRM : Suggested Method for Determining Point Load Strength.

Laboratory testing was carried out to the following standard specifications where applicable:

- Sieve Analysis 0.075mm (Mass Grading) : TMH1 A1
- Atterberg Limits <0.425mm : TMH1 A2, A3, A4
- Hydrometer Analysis : ASTM D422
- Bulk,Dry Density : AASHTO 233
- Unconfined Compressive Strength (UCS) : According to ISRM Specifications
- Chemical Analysis : Element analyisis : W044-28-O
- Mineral Oil fraction : E042-12-W Based on E.P.A. 8015 B
- Volatile organic compunds : Based on EPA 8260B & EPA 5035
- Organic content : BS 1377-1: 1990

4.2.2 Point Load Testing (PLT) and Unconfined Compressive Strength (UCS) testing

Due to the presence of rock, both of a sedimentary and plutonic origin occurring within the profile, SPT penetration was limited to the softer near surface layers. It was therefore necessary to conduct Unconfined or Uniaxial Compressive Strength (UCS) testing to determine rock strength, which tends to vary throughout the profile. This method for testing rock strength has been well standardized. It is however time consuming and indirect methods such as obtaining the Point Load Index ($I_s(50)$: corrected to 50 mm diameter core) from Point Load Testing (PLT) can be used to predict an equivalent UCS value.

The point load test requires little sample preparation and the test can be done in the field as part of formal core logging. Where possible, samples for point load testing were taken at depths and within the same rock material to correspond with the samples taken for UCS testing. Point load testing was conducted both perpendicular and parallel to the core axis, where possible.

Point load index to UCS conversion factors are very much rock dependent and numerous correlation exist in the literature. To determine a more site specific correlation, the point load index values (Is(50)) from the point load testing results were plotted against the corresponding UCS values obtained from the laboratory testing. Only the diametral (core positioned horizontal or perpendicular to core axis) tests were used in this regard as they were considered the most accurate. This was because most of the axial tests resulted in the fracture surface of the specimen passing through only one of the loading points, which is considered an invalid axial test according to the ISRM: *Suggested Methods for Determining Point Load Strength*. This plot (Figure 4.1) yielded the following correlation:

- $UCS = 30.954(I_s(50) + 15.664$

Where:-

- Is(50) =Point Load Index for 50mm diameter core obtained using a size correction factor
- UCS = Unconfined Compressive Strength in Mpa

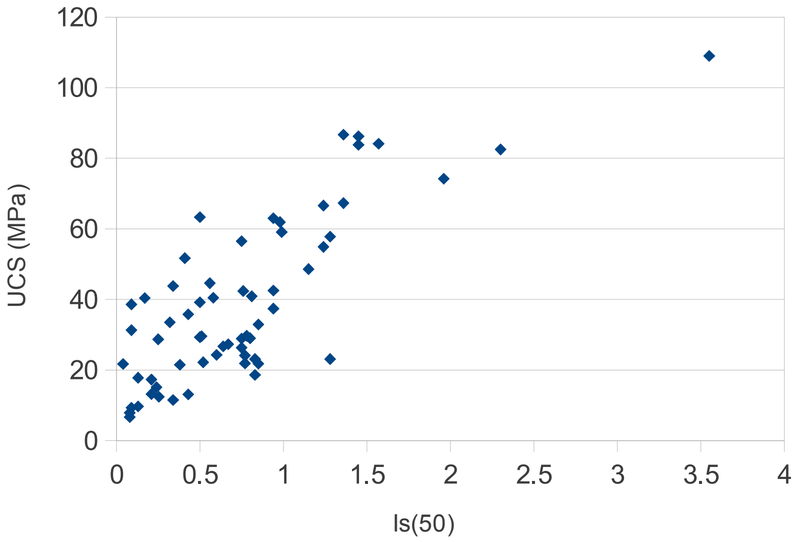

Figure 4.1 Plot of Point load index ($I_s(50)$) against actual laboratory determined UCS values, showing correlation trendline with formula.

The UCS results from the laboratory testing, for both offshore and onshore boreholes, were plotted corresponding to the depth of the samples, in Figure 4.2. This plot shows a wide scatter of rock hardness with depth, from soft rock to very hard rock. It is also important to note that large zones of very soft rock do occur within the profile, but this material is generally too soft to sample and sampling for UCS testing could only be conducted on harder core specimens.

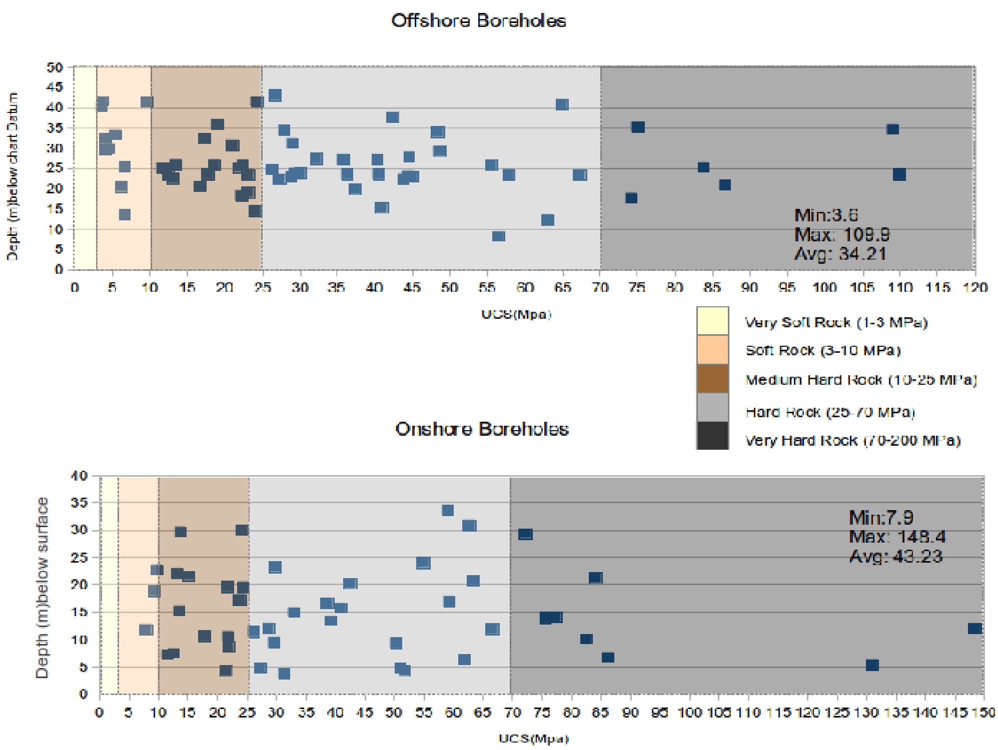

Figure 4.2 Plot of the laboratory tested UCS results with depth for offshore and onshore boreholes. Corresponding values of rock hardness are indicated by the shading shown in the key.

The final equivalent UCS values from the point load testing, as well as the actual UCS values, corresponding to the particular rock type and depth are also shown in the borehole logs in Appendix A. The point load testing results, a summary of the UCS testing, as well as the detailed laboratory UCS testing data sheets can be found in Appendix D.

4.2.3 Soil Property and Foundation Indicator tests (grading and Atterberg Limits analyses)

a) Offshore and Onshore boreholes

Indicator testing, namely particle size distribution and Atterberg limits were conducted on selected SPT samples to assess basic soils engineering properties. Depth of samples can be seen on the borehole logs in Appendix A. A summary of the indicator testing, as well as the detailed results can be seen in Appendix C. Table 4.4 shows the range of values from the indicator testing for the various soil types encountered both within the onshore and offshore boreholes, as well as typical engineering properties based on these results.

Table 4.4 Typical indicator results and soil engineering properties for soils encountered within the boreholes.

Soil Description	INDICATOR TESTING RESULTS					Typical Effective Friction angle	Typical Effective Cohesion	Typical Dry unit weight (kN/m3)
	LL	PI	LS	GM	Unified Classification			
OFFSHORE BOREHOLES								
Fine to medium sands/ Slightly silty sands	-	np	-	0.95-1.41	SP/SM	32-38	-	17-21
Sandy Silts to Silty sands	-	Np to sp	0-1.5	0.52-0.92	SM	29-33		18-21
Gravelly clayey sands	0-38	0-17	0-5.5	1.65-2.05	SW-SC/SP-SM/SP-SM	30-39	0-10	17-22
ONSHORE BOREHOLES								
Fine to coarse sands	-	np	-	0.98-1.62	SP/SW	32-38	-	17-21
Silty and clayey sands	0-41	0-5	0-2.5	0.75-1.1	SP/SM	29-36	0-5	17-21
Gravelly sands and Gravelly silty sands	-	-	-	1.42-1.8	SP/SM	32-39	-	17-21

Key: LL – liquid limit. PI – plasticity index: np – Non-plastic. sp – slightly plastic. LS - linear shrinkage. GM – grading modulus.

b) Vibrocores

To asses the basic engineering characteristics of the soil, so as to optimize dredging, indicator testing, namely particle size distribution and Atterberg limits was also conducted on vibrocore soil samples. Bulk Density testing was also conducted where possible. This was however very limited as once the vibrocores were opened, grooves and small cavities within the core samples indicated that there was some slippage and thus disturbance of the material within the vibrocore barrel. Testing on this disturbed material would produce inaccurate and variable results. Table 4.5 shows the range of values from the indicator testing for the various soil types encountered within the vibrocores as well as typical values for the engineering properties of these soils.

Table 4.5 Typical indicator results and soil engineering properties for soils encountered within the vibrocores.

Soil Description	INDICATOR TESTING RESULTS						Typical Soil Engineering Properties					
	LL	PI	LS	GM	Unified Classification	HRB Classification	Typical Bulk Density (kg/m3)	S.G.	Void ratio (e)	Typical Effective Friction angle	Typical Effective Cohesion	Typical Dry unit weight (kN/m3)
Clayey silt	119-147	13-21	6-6.5	0.14-0.22	N/A	A-7-5(20)	1100-1500	2.1-2.5	4-9	25-30	5-10	14-17
Silts	116-131	5-8	2.5-4.5	0.13-0.2	N/A	A-5(12)	1000-1400	2.2-2.6	3-8	25-30	2-8	14.5-18
Slightly clayey silts	25	9	4	0.03	CL	A-4(7)	1000-1400	2.2-2.5	0.5-2	25-32	2-10	14-20
clayey sandy silts	21-30	4-5	2.5	0.5-0.75	ML/SC-SM	A-4(0)	1200-1500	2.2-2.5	1-3	30-32	2-5	15-19
Sandy Silts	-	NP to SP	0-1.5	0.14-0.47	ML	-	1300-1600	2.5-2.65	0.5-3	29-33	0	17-21
Silty Sands	-	NP to SP	0-1.5	0.5-0.85	SM	A-2-4(0)	1400-1900	2.5-2.65	0.6-2	30-35	0	17-21
Fine to medium Sand	-	NP	-	0.9-1.5	SP	A-3(0)	1800-2100	2.6-2.7	0.5-0.8	32-38	0	18-21

Key: LL – liquid limit. PI – plasticity index: np – Non-plastic. sp – slightly plastic. LS - linear shrinkage. GM – grading modulus.

4.2.4 Geochemical testing

To asses the characteristics of the soil and presence of any possible pollutants that would affect the dredging operations, certain chemical testing was required on the vibrocore samples. To prevent any possible contaminants from outside sources, samples were taken from the cut open vibrocore samples using surgical gloves and a hand trowel, which was washed after each sample was taken. Samples were places in air tight glass jars, according to specifications by the independent laboratories contracted to conduct the testing. The following chemical testing was required:-

- Soil organic content
- Metals: Arsenic, cadmium, chromium, copper, mercury, lead, nickel,zinc.
- Volatile Aromatics: benzene, toluene, ethylbenzene, xylenes, total BETX, naphthalene.
- Halogenated Hydrocarbons: 1,2-dichloroethane,1,2-dichloroethylene, tetrachloromethane,1,1,1-trichloroethane,1,1,2trichloroethane, trichloroethylene, chloroform.
- Chlorobenzenes: Monochlorobenzene, dichlorobenzenes
- Mineral oil Fraction; Fraction C10-C12, Fraction C12-C22, Fraction C22- C30,Fraction C30-C40, Fraction C10-C40.

A statistical summary of the chemical results with increasing depth below the upper suspended silt horizon (which could be sampled during the vibrocoring process), can be seen in Table 4.6. This Table only highlights the organic content, metals and mineral oil fraction. The other volatile compounds tested were below detection limits ($<5\mu g/kg$) for the testing process used and thus not included in this summary. A more detailed summary of the results showing each sample tested, as well as the full detailed laboratory testing sheets can be found in Appendix E.

Table 4.6 Summary of the main chemical results with depth below the upper suspended silt horizons from the vibrocore sampling.

Depth zone(m) below upper suspended silt		Carbon Content (%)		Metals (mg/Kg)								Mineral Oil fraction (mg/kg)
		Total Carbon as TOC	Carbonate, CO3	Arsenic	Cadmium	Chromium	Copper	Mercury	Lead	Nickel	Zinc	C10-C40
0-0.5	Max	2.70	13.40	59.00	16.60	8185.00	136.00	<0.1	24.00	3030.00	61.00	17.00
	Min	0.04	0.60	8.20	1.60	70.00	10.50	<0.1	3.00	16.40	5.40	0.70
	Avg	1.36	5.52	33.03	8.59	2242.73	50.05	<0.1	8.76	792.56	29.75	3.86
0.5-1.0	Max	2.40	7.10	39.00	21.00	5666.00	109.00	<0.1	6.90	2074.00	47.00	5.20
	Min	0.17	1.60	11.50	1.70	58.00	11.00	<0.1	1.60	12.00	12.10	1.40
	Avg	1.15	4.08	22.40	8.50	1318.00	35.90	<0.1	3.82	480.00	23.66	3.16
1.0-2.0	Max	2.60	9.20	52.00	22.00	757.00	185.00	<0.1	68.00	284.00	44.00	4.50
	Min	0.15	1.80	9.50	1.80	102.00	16.50	<0.1	2.30	31.00	15.40	1.60
	Avg	0.78	3.72	28.28	6.31	410.00	44.15	<0.1	11.80	155.20	30.64	2.58
2.0-3.0	Max	1.65	5.20	49.00	14.00	692.00	37.00	<0.1	43.00	267.00	68.00	7.50
	Min	0.05	0.83	16.40	1.60	49.00	10.90	<0.1	3.00	16.00	8.20	0.00
	Avg	0.68	2.80	34.22	4.95	292.36	22.32	<0.1	8.45	109.36	30.17	2.89
3.0-4.5	Max	0.35	4.80	67.00	3.30	260.00	22.00	<0.1	4.70	95.00	16.70	6.40
	Min	0.07	0.29	25.00	1.80	39.00	7.80	<0.1	3.40	16.10	7.60	2.70
	Avg	0.19	1.48	46.67	2.43	139.00	13.90	<0.1	4.38	46.12	12.07	4.78
4.5-6.0	Max	0.33	1.50	77.00	2.70	133.00	17.80	<0.1	5.00	43.00	9.00	5.10
	Min	0.08	0.70	39.00	1.50	50.00	7.00	<0.1	4.40	18.20	8.70	2.90
	Avg	0.17	1.13	52.33	2.10	100.67	13.40	<0.1	4.73	32.40	8.87	3.63

5. Site geology and geohydrology

5.1 General

The Walvis Bay area is underlain by Holocene to Late Quaternary sediments, a product of the modern Benguela Ecosystem and its interaction with the adjacent hinterland.

Offshore, the upper sediments comprise diatomaceous ooze, consisiting of diatoms formed from biogenic silica, together with a high organic content. This ooze is broadly described as a clayey silt with a variable sand fraction. These sediments are particularly well developed on the inner shelf of the continental margin in the Walvis Bay area. Sandy sediments directly underlie these silty soils.

The thickness of the diatamaceous ooze tends to decrease landwards and onshore, transported sandy soils alternating with thin silty sand horizons occur near surface. The upper sandy horizon has a variable thickness due to the presence of wind blown aeolean sand dunes of variable height, with interlying low areas and deprressions, as one moves further inland.

The transported soils are underlain by a cemented (calcified) rock of variable hardness. This rock consists of originally fluvially transported lithic fragments, varying in size from small boulder, to coarse sand sized, angular to subrounded fragments. These coarser grains and fragments have been moderately to strongly cemented (mostly calcretized) in a matrix consisting of mostly fine to medium sand (consisting of mostly lithic fragments and quartz grains) , but also containing a small silt and clay content (<5%). The degree of cementation, sorting and size of the coarser fraction varies throughout the profile. This horizon is also not continuous and in some areas alternates with poorly or un- cemented gravelly and sandy horizons. This most likely reflects the meandering and unstable nature of the fluvial environment along which this material was most likely, originally transported and deposited. This rock has been classified as a lithic arenite, but could also classifiy as a rudite or even a conglemeritic sandstone in certain circumstances, due to an abundance of coarser, small boulder to coarse gravel size lithic fragments. In some cases where only isolated larger clasts are present and a sand-sized lithic and quartz fraction dominates the composition, a classification of sublith-arenite was assigned. To more accurately classify this material, additional study and thin section would be required, but this was not required for an investigation of this nature.

The predominantly lithic arenite is underlain by intrusive plutonic rocks, consisting of granite, granodiorite or in some cases pegmatoidal rock, which forms the bedrock in the Walvis Bay area. Regionally the bedrock consists of highly metamorphosed and deformed sediments that are heavily intruded by granites to diorites of various age during different stages of orogeny.

5.2 Soil profile – onshore and off shore

a) Vibrocores

Closer to the coast (VB1 to VB6) the general soil profile consists of a sludge-like clayey silt at seabed level, that contains shell fragments and is rich in plate-like mica minerals, which gives it a soapy texture. This sludge-like layer is underlain be alternating layers of sandy silt and silty sand with a gradual transition into a fine to medium grained sand and slightly silty sand. This sandy horizon is generally encountered within 2.0m of the seabed.

As one moves further out into the bay however, an upper suspended silt horizon is encountered at seabed level, that deepens with distance from the shore (thickness from approximately 1.5m in VB7 to greater than 4.5m in VB15). The suspended silt is underlain by the sludge-like clayey silt and deeper silty sandy material, as seen closer to the coast.

b) Offshore boreholes

As seen in the vibrocoring, a sludge-like clayey-silt to silty material occurs at the seabed. Thickness of this horizon varies through the bay from approximately 1.0m to 4.0 m thick. This upper sludge-like layer is underlain by alternating silty sand and sandy silt horizons, before grading into a fine to medium sand that extends to a depth of between -9.7m to -29.8m CD.

The underlying lithic arenite, for the most part, occurs in discontinuous lenses varying in thickness from 1.0m to 17.0 m. Interlayered zones consisting of slightly cemented gravelly clayey sand (possibly residual lithic arenite) and uncemented sandy soils occur in isolated or alternating horizons. There are however also areas where a continuous unbroken lithic arenite horizon of up to 29m thick occurs.

The underlying granitic bedrock was mostly encountered in the northern parts of the site. There are localized areas such as in SPTW8 and SPTW1, where these rock are encountered within the boreholes in the southern parts. SPTW8 is however a 45m borehole compared to the surrounding 35m boreholes and SPTW1 is situated close to the shore.

As one moves further seaward in a north-westerly direction, the lithic arenite horizon becomes thin and poorly developed. In SPTW27,28,20 & 30, no lithic arenite was encountered and the transported sandy soils directly overly the intrusive rocks, which are encountered within -17m to -26m CD, in this area.

c) Onshore boreholes

The onshore profile consists of transported silty sands and sandy soils at surface. This transported horizon has a thickness of between 0.6m (SPT18) to 32m (SPT13). The transported1.98cm sands are underlain by the same lithic arenite horizon seen in the offshore boreholes. The lithic arenite is also poorly sorted and variable in its composition and hardness, varying from very soft, to hard rock, with alternating zones of variable hardness throughout the profile. It also varies in thickness from 11m(SPT10) to greater than 32m (SPT11).

Similarly to the offshore boreholes, this cemented strata is underlain by the bedrock consisting of granite, granodiorite, or even pegmatoid (contining large crystals of quartz, garnet, hornblend and feldspar), which most likely forms part of the same intrusive body. The depth of this bedrock, where encountered, is very variable, and varies from -9.2m CD to greater than -32m CD. This is exected due to the variable weathering profile and the inconsistent nature of such intrusive bodies. The granite and granodiorite is generally jointed, completely weathered and is generally classified as very soft to hard rock, in terms of hardness, depending on the degree of weathering.

5.3 Water table

A perched water table is expected to develop at or close to the contact between the free draining sandy soils at surface, and the underlying cemented and very low permeable lithic arenite rock. Groundwater will tend to drain towards the west, towards the ocean.

Water tables were measured in the completed onshore boreholes, which indicated that the water table generally varies from +0.1677m CD to -1.957m CD, with an average elevation of +0.574m CD, which is slighlty below the mean sea level of 0.95m CD.

Water tables in boreholes close to the beach (JM3, JM4) are expected to fluctuate due to changing tidal levels.

6. Conclusions

The objectives of this report were to provide a brief summary of the scope of work of the project, as well as to present the necessary drilling, field and laboratory testing results in a factual format, with no interpretation offered. The factual data, summarized and referenced, is attached in full in the Appendices listed in the Table of Contents.

JOHN YATES

EUGENE LAUBSCHER