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A. REPORTS BY THE GEOLOGICAL SURVEY

THE ENGINEERING GEOLOGY OF SWAKOPMUND

by

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ABSTRACT

An engineering geological survey of Swakopmund, one of South West Africa's major developing centres, has been undertaken in order to provide an information base for further expansion. The town is located on Cenozoic fluvio-marine and alluvial deposits that overlie Precambrian Damara Sequence rocks and Karoo age dolerites. The coastal environment is highly corrosive, due to abundant airborne salts, the frequent fogs and salty, moist soils. Protective anti-corrosion measures should therefore be provided and construction materials must be chosen with care. Although foundation conditions are generally good, differential settlement can occur on some of the unconsolidated superficial deposits. Construction materials, in the form of fine and coarse aggregate for concrete, are readily available in the area.

1. INTRODUCTION

Swakopmund was founded in 1892 to provide the German territory of South West Africa with an alternative port to the British-held harbour of Walvis Bay, 30 km to the south. Although the town no longer functions as a port it thrives as South West Africa/Namibia's major holiday resort and as the nearest town serving the massive Rössing Uranium Limited open-cast mine some 55 km to the east.

Swakopmund falls within the extreme arid sector of the Namib Desert, but it's coastal location ensures moderate to cool temperatures and a high frequency of fogs (95 - 215 days/yr) generated by the cold Atlantic Ocean (Met. Services, R.N. and S.A.A.F., 1943). Fog precipitation yields some 34mm/yr, whereas rainfall is erratic and averages 15mm/yr (*op. cit.*). The dominant wind directions are SW (summer) and NE (winter). The combination of high relative humidity and abundance of salts in the atmosphere and soil make the SW.A. coast one of the most highly corrosive environments in southern Africa (Callaghan, 1983).

The broad sandy bed of the ephemeral Swakop River, occurring along Swakopmund's southern municipal boundary (Fig. 1), forms a natural barrier between the coastal dunes of the Namib Sand Sea to the south and the sand and gravel plains to the north. The geomorphology of the area has been shaped largely by fluvial, marine and arid pedogenic processes. Old drainage lines of the Swakop River, up to 5 km north of it's present course, are indicated by alluvial terraces and silty deposits. The Swakop River floods through to the Atlantic Ocean during periods of heavy rainfall in the catchment. Severe floods occurred in 1931 and 1933, when the railway bridge, houses and gardens were washed away (Stengel, 1964). Northerly longshore drift has resulted in a marked degradation of Swakopmund's beaches and rockfill breakwaters have been constructed to prevent further erosion (Swart, 1982).

An engineering geological survey of Swakopmund was undertaken during May and June 1983, in order to provide an information base for future development. The investigation commenced with a literature study, followed by detailed aerial photographic interpretation and ground truth checking. Relevant literature includes, inter alia, Brandt (1981); Brink (1981); Logan (1960); Marker (1981); Martin (1963); Porada and Hill (1974); Rust (1980); Schulze-Hulbe (1979) and Smith (1965). The scope of the survey did not allow for detailed subsurface investigations, such as drilling or excavation of inspection pits. Existing development also imposed limitations on the investigation, in that the natural ground is largely obscured and access restricted.

This paper summarises salient features of the engineering geology of Swakopmund, additional details of which may be obtained from the investigation report (Bulley, 1983).

2. GEOLOGY

The Swakopmund area is underlain by rocks of the Damara Sequence, intruded by dolerite dykes of Karoo age. The complex stratigraphic relationships within the Damara Sequence have not as yet been clearly defined and formation names attributed to the different rock types must be regarded as provisional. Cenozoic superficial deposits, comprising thin colluvial soils, alluvium and fluvio-marine deposits overlie the bedrock to varying depths.

A summarised stratigraphic column for the area is given in Table 1 and a description of each unit, with an engineering assessment, is provided in the legend of the geological map (Fig. 1).

TABLE 1: Stratigraphic column for the Swakopmund area.

GEOLOGICAL UNIT		THICKNESS
Colluvial soils		< O,5m
Swakop River alluvium		Generally < 10m, but up to 30m in deep channels
Fluvio-marine deposits		1 - 5m
		ROCK TYPE
Damara Sequence	Karibib Formation	Calc-silicate rock
	Karibib Formation	Marble
	Rössing Formation	Dolomitic marble
	-	Gneissic-granite

3. ENGINEERING GEOLOGICAL ASSESSMENT

3.1 Founding Conditions

3.1.1 Bedrock

Bedrock occurs on or near-surface in much of Swakopmund's eastern and central suburbs. The slightly to moderately weathered bedrock generally has a high bearing capacity and provides a good base for foundations. Problems are, however, encountered during excavations for foundation and services trenches, particularly in areas of prominent surface outcrop, where it is necessary to resort to the use of jack hammers and blasting. Low ridges of marble, up to several metres high, occur in parts of Industrial Extensions 5 and 10, near the railway line. Future development should preferably avoid these ridges, as site levelling and founding excavations would require blasting, thereby substantially increasing the cost of development. Localised dykes of dolerite (e.g., in Mondesa Ext. 2) will present similar problems.

Foundation excavations in rock should be checked, as a matter of routine, for isolated pockets or zones of deep weathering or fracturing. Such zones, which may occur adjacent to dolerite dykes, should be removed and excavations taken through the highly weathered material into competent rock. For larger developments, it may be necessary to key the foundations into bedrock, but for smaller structures with a low bearing pressure, it should be sufficient to cast the footings into the clean bedrock surface using shutters.

3.1.2 Superficial Deposits

Many buildings in Swakopmund are founded on the deep fluvio-marine deposits. These deposits consist largely of non-cohesive, granular, gravelly, medium-grained sands. The upper surface layer is generally loose, but the medium dense to dense sands at depths of about 0,5 m and greater have a sufficiently high bearing capacity to support most light structures.

Examination of soil profiles indicates that the sands generally have a low collapse potential, but the upper loose surface layers are compressible and subject to substantial settlement under load.

Structural cracking, mostly of a minor nature, has occurred in some dwellings in Mondesa and Tamariskia. This is attributed largely to founding at too shallow a depth on loose compressible sands with resultant differential settlement. In some instances the situation has been aggravated by wetting the subsoils, induced by broken water pipes and watering of gardens adjacent to the external walls.

Differential settlement may also be caused by variable founding conditions across a site, e.g. when a dwelling is founded partly on bedrock and partly on fill or loose colluvial sand. Settlement of foundations on medium dense to dense sands can be expected to be well within tolerable limits for most normal buildings with low to moderate bearing pressures. However, for larger buildings with a high bearing pressure or low settlement tolerance (e.g., water towers or buildings containing sensitive machinery or panel walls), it is recommended that laboratory and field testing be carried out to predict the likely settlement of footings on the sand. Precautionary measures, in the form of increasing the depth of founding onto denser sands or widening the footings, will generally prove to be sufficient. Prewetting and compaction of the sand at founding level may also be considered.

In the case of high end-bearing loads, like water towers, it will be necessary to key the foundations into the unweathered bedrock underlying the sands.

Extensions 8 and 9 of Vineta, zoned for future residential development, are located on the fluvio-marine deposits. The medium dense sands at a depth of about 0,5 m are expected to provide suitable founding conditions for most normal residential dwellings. Deeper founding levels or widened strip footings, as outlined above, should, however, be considered for shopping centres, schools and blocks of flats.

Adverse founding conditions on gypsiferous materials have been reported from various countries, particularly Turkey (Yuzer, 1982). Problems are related largely to removal of soluble gypsum by groundwater, with the resultant development of cavities or voids, decrease of shear strength or weakening of sands cemented by gypsum. Groundwater activity in Swakopmund is relatively restricted, therefore it is expected that dissolution of gypsum will be minimal and more likely to be caused artifically, e.g., associated with broken water pipes. In areas with a shallow water table, excavations should be checked carefully for the presence of solution cavities or a porous, honeycombed texture in the subsoils.

Swakopmund also has the advantage of a relatively deep and static water table and allowances do not normally have to be made for saturated soils at founding level. Rare zones of seepage or shallow water table do, however, occur, e.g., on Strand Street, and this should be taken into account prior to construction. Groundwater conditions are relatively stable due to the low rainfall and the detrimental effects due to periodic saturation and desiccation of soils are unlikely.

Zones of micaceous sandy silt have been identified, particularly in parts of Vineta and Tamariskia. The silts are cohesive but sometimes loose to very loose due to desiccation. Therefore, these silts are likely to be highly compressible, particularly when saturated, and are consequently not suitable for foundations. As the silt often forms layers and lenses, it will often be possible to increase the depth of founding into more dense sands, or to remove the silty material.

The shallow colluvium overlying the bedrock in some parts is usually loose to very loose. It is preferable to found through the colluvium onto the underlying bedrock surface. Precautions should be taken to ensure that founding conditions are consistent throughout the development and that any pockets of colluvium or weak material are removed.

3.2 Corrosion

The highly corrosive environment can be attributed to a combination of fog moisture, high relative humidity and an abundance of airborne salts, notably chlorides and sulphates. In addition, there is an abundance of corrosive salts in the soils, the surface layers of which are frequently wet due to fog moisture condensation. Therefore, construction materials have to be chosen with care, particularly as regards steel work.

Long-term investigations on atmospheric corrosion carried out by the Council for Scientific and Industrial Research (CSIR) indicate that the Walvis Bay environment is particularly corrosive as regards zinc and zinc coatings, and recommends against their use in this area (Callaghan, 1983). Similar conditions may be assumed to apply in Swakopmund. Aluminium and stainless steel alloys generally proved to have relatively low corrosion rates (Callaghan, 1983, p. 28-29).

Sand-cement bricks, commonly used in construction, are prone to attack by salts. The corrosive solutions containing most significantly, sulphate (SO_4), are drawn into the absorbent brick by capillary action and concentration of salts occurs by evaporation. Chemical reaction with the cement and subsequent crystallisation of the products in pores induces expansive forces which result in cracking and disintegration of the brick. The normal procedure to prevent this process is to use bricks with a very low absorption below the damp proof course, or for one course below ground surface and three courses above. Naturally occurring rock material, such as marble, dolomite or even the red gneissic-granite is suitable for this purpose. Certain types of dense face-brick are sometimes used, and surface-coatings can also provide an alternative. Concrete work is also subject to attack, both atmospherically and by sulphate salts in the soil and groundwater. Spalling, pitting and general deterioration of the concrete can result, thereby considerably reducing it's durability and life-span. Equally important is the disintegration of reinforcing steel within the concrete, a process which is accelerated by the presence of chlorides.

A dense concrete of low permeability will be considerably more resistant to deterioration than a porous or low quality concrete. A well proportioned mix, with a low water-cement ratio, is essential and attention should be paid to thoroughly vibrating the mix and correct curing. Care should be taken to clean steel reinforcing before use, particularly if it has been stockpiled in Swakopmund's corrosive climate. Good cover should always be provided for steel reinforcement. A good example of the effects of corrosion is provided by the water pipeline to Rössing, portions of which disintegrated within two years after installation. The subsurface pipes, consisting of concrete-coated steel casings reinforced with prestressed wire, were subjected to penetration by salty moisture from the surrounding soil. Rapid corrosion and failure of the reinforcing wires took place, followed by disintegration of the pipe itself. These subsurface pipes have since been replaced by coated steel pipes on surface.

3.3 Excavations

Excavations for services, pipelines and foundations frequently require blasting in areas of shallow bedrock. The variable, heterogeneous nature of the red gneissic-granite presents difficulties in obtaining a smooth, even profile during blasting. This was exemplified during blasting for the secondary settlement tank at the sewerage works, where the brittle pegmatite veins tended to shatter whereas the xenoliths proved to be relatively resistant. This resulted in an uneven excavation profile, with large areas of overbreak in the pegmatite veins. Consequently, portions of the excavation had to be backfilled with a weak concrete.

Layers of gypsum or gypsum-cemented sands and gravels frequently have to be blasted during the course of excavations for sewerage and water pipelines. The relatively hard, dense layers tend to absorb the impact of the blast without fragmenting into blocks of workable size.

3.4 Further Investigations

It is recommended that further site-specific investigations should be carried out for any proposed major developments in the area. The scope, nature and intensity of the investigations should be geared to suit the individual requirements of the proposed development. The main objective of most investigations will be to provide geotechnical information on the superficial deposits and the underlying bedrock. The depth to competent bedrock will be a primary consideration in determining founding levels. In the event of relatively deep deposits overlying bedrock, it will be necessary to establish strength and settlement characteristics of the surficial materials, with identification of possible low strength, compressible silt layers. Investigations for most structures can, however, be limited to the superficial deposits and the upper bedrock surface except for larger underground works such as shafts and tunnels. For most developments in areas of shallow soils, judiciously spaced inspection pits will probably be sufficient. The pits will allow a detailed examination of soil profiles, an assessment of their engineering properties and provide an indication of depth to and nature of the bedrock. Sampling for laboratory testing can also be carried out in the inspection pits.

Standard Penetration Tests (SPT) and Dutch Probe soundings can provide valuable information on subsoil strength, bearing characteristics and expected settlements, particularly in areas of deep superficial deposits. The effectiveness of these methods in the Swakopmund area, may however, be limited in places by the presence of gravel, boulders and gypsum-cemented layers. Auger drilling will be likewise affected. Plate loading tests provide an alternative method for determining settlement and allowable bearing pressures of the unconsolidated sediments.

Depending on the nature of the development, consideration may also be given to rotary core drilling or percussion drilling. These methods are, however, relatively expensive and are normally only required for major engineering works.

3.5 Seismicity

Data on seismic events in S.W.A. are sparse and determination of earthquake hazard is therefore based on relatively little information. From available records, however, the coastal regions of S.W.A. have a low seismic risk (Korn and Martin, 1952; Fernandez and Guzman, 1979).

3.6 General

The first rail-bridge crossing the Swakop River on the main Walvis Bay line collapsed during a flood in January 1931 (Stengel, 1964). Remnants of the piers are still visible near the river mouth. The piers, supported on large concrete pads founded at depths of up to 5,5 m below river bed level, failed after extensive scouring of the subsoils below founding level. Some piers disappeared completely.

Seismic survey and drilling results obtained during preliminary investigations for the existing road bridge over the Swakop River (Ninham Shand and Partners, 1965), indicate average depths of between 3 and 9 m and rarely up to 30 m, of alluvial deposits overlying the bedrock. The report strongly recommended that all piers for the bridge should be founded on bedrock, using either large cylindrical caissons or large diameter bored piles.

4. CONSTRUCTION MATERIALS

4.1 Sand

Abundant, good quality sand for construction is available in the Swakop River bed. A large borrow pit area is currently being worked immediately to the south of Swakopmund which provides all of the town’s sand requirements. The sand is used in concrete and also for the manufacture of sand-cement bricks. It is recommended, however, that before use in high grade concrete, the mica and sulphate content of the sand should be checked.

Expansion of the borrow pit area is largely in a westerly direction, and depth of excavation is between 2 and 3 m below surface, to the water table. Expansion in a southerly direction is inadvisable due to the presence of yellowish brown, micaceous clayey silt layers up to about 1 m thick. Good quality, clean sands occur along the northern margin, but expansion in this direction is limited by the presence of a large marble ridge. In general, the deposits in the central portion of the river bed tend to contain a number of clayey silt and gravel layers, whilst the sands along the margins are relatively clean.

4.2 Rock Aggregate

Good quality rock aggregate for concrete is obtained from the Rössing Stone Crushers (Limited) quarry at Rössing Mountain, some 40 km to the east. The rock, which is also used for railroad ballast and road construction, consists of massive feldspar-pyroxene-hornblende quartzite of the Khan Formation, Damara Sequence. The physical properties of this material (data supplied by SA Transport Services) are provided below:-

Relative density	2,71
Aggregate crushing value %	21-23
Flakiness % on 19mm sieve	±20
L.A. abrasion value %	26,2
Weathering %	3,10
Shrinkage %	107,01
Absorption %	0,75

A disused open-pit quarry occurs 6,5 km to the south of Swakopmund near the Walvis Bay road. The quarry, some 200 m from the sea, consists of a massive greenish-grey meta-quartzite containing occasional large pegmatite veins. This rock type, also belonging to the Khan Formation, is suitable for use as concrete aggregate.

4.3 Road Building Materials

Apart from the major tarred roads and streets, most roads in Swakopmund are constructed by compacting layers of gypsiferous sand which have been prewetted with a concentrated brine solution obtained from the salt works. This method of construction, ideally suited to the coastal climate, provides a relatively cheap and satisfactory road surface.

Gypsiferous sands are ubiquitous in the area and the road construction materials are obtained from a number of shallow borrow areas to the north of Swakopmund, adjacent to the Henties Bay road. Sands containing a fine gypcrete gravel or powder are the most suitable.

4.4 General

Sand-cement bricks are the most important source of building bricks in Swakopmund. Clay or face bricks have to be imported from South Africa and are consequently far more expensive.

Local stone, generally marble, is also used, particularly in the plinth brickwork of many houses. The red gneissic-granite has also been used in the past and was obtained during the German colonial period from a quarry (since infilled) near Strand and Dolphin Streets. This material was also used in the construction of the yacht mole. Large blocks of red gneissic-granite, obtained from excavations for trenches and pits in the area, have been used to construct the breakwaters at Vineta.

A number of disused, open-pit quarries occur in white Karibib Formation marbles about 3 km east of the Swakopmund salt works. The stone was used in the past for ornamental gravel on driveways and gardens in Swakopmund. The material may also be suitable for use as concrete aggregate. It is also worth mentioning here that many of the occurrences of Karibib Formation marble in the area consist of relatively pure calcitic marble (> 95% $CaCo_3$) which is suitable for the manufacture of cement. As South West Africa's cement requirements are currently imported from South Africa, it is possible that the Swakopmund area, among others, may be considered as a site for a cement factory.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Engineering geological conditions in Swakopmund are generally favourable for development. Precautions do, however, have to be taken to prevent deterioration of construction materials in the highly corrosive environment.

5.2 Areas underlain at shallow depth by bedrock provide good founding conditions although difficulties may be experienced with excavations in rock for services or site levelling.

5.3 The medium dense to dense gravelly sands of the fluvio-marine deposits provide adequate founding conditions for most types of structure. However, foundation excavations should be inspected for the presence of lower strength layers of silt, which have a reduced bearing capacity. If necessary, steps should be taken to found through such layers into underlying denser sands at greater depth. Excavations for services are generally simple, but blasting may be required in zones of gypsum-cemented sand or gypcrete. Detailed site investigations should be undertaken for major developments located on the fluvio-marine deposits.

5.4 Coarse and fine aggregate for concrete is readily available in the area.

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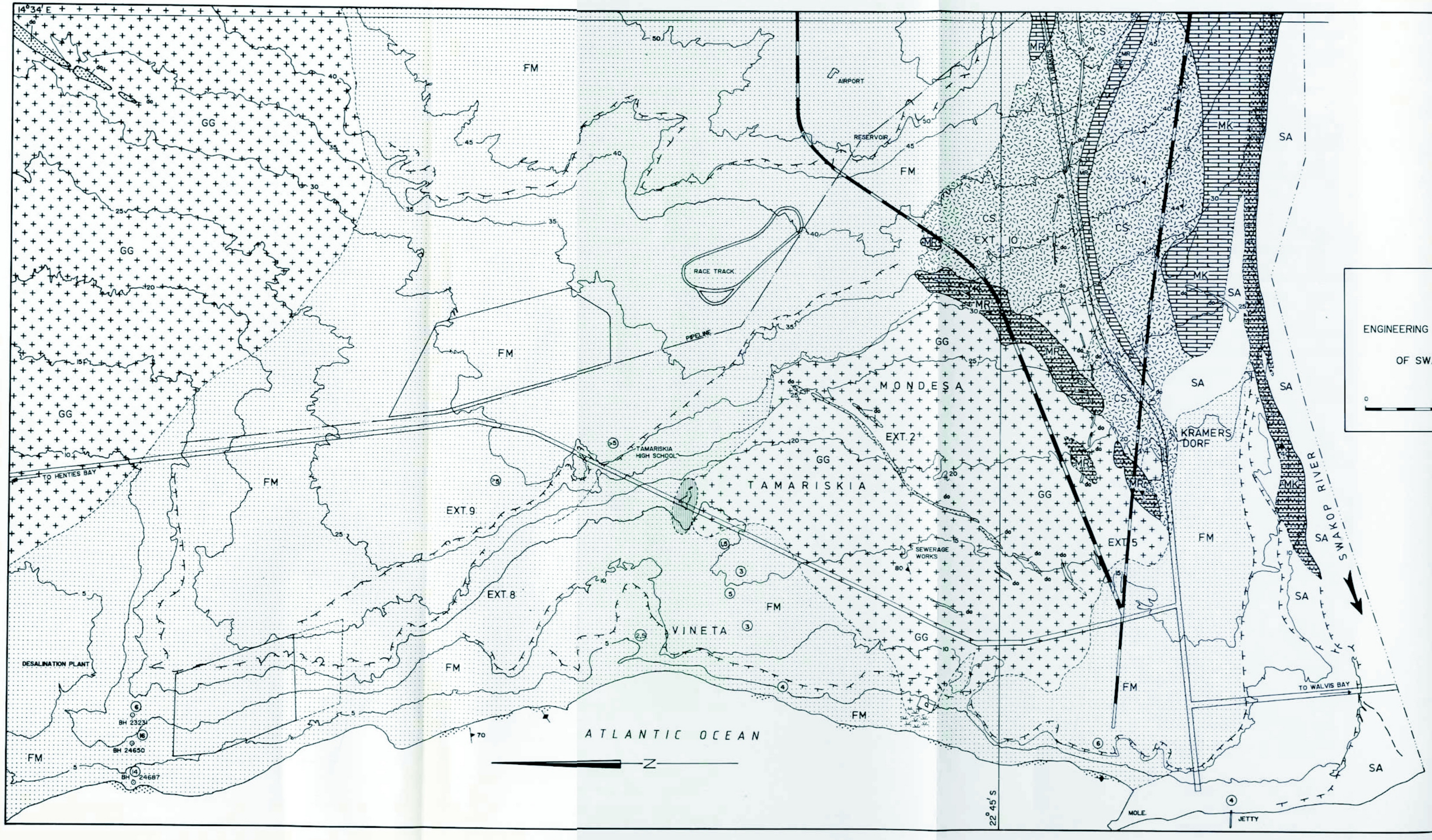

FIG. I

ENGINEERING GEOLOGICAL MAP OF SWAKOPMUND

GEOLOGICAL LEGEND

SA	Light grey , loose to medium dense , gravelly , fine to medium SAND containing lenses of yellowish brown , firm , finely laminated consolidated , micaceous , fine sandy SILT and occasional layers of coarse sandy rounded GRAVEL. Localised development of gypcrete.	SWAKOP RIVER ALLUVIUM
FM	Light grey to brown , loose to medium dense but locally strongly cemented by gypsum , gravelly fine to medium SAND with the localised development of moderately hard GYPCRETE layers. Zones of brown , firm , micaceous , fine sandy SILT occur in some parts of Vineta (indicated on map by lines) Thickness as indicated on map , generally >lm	FLUVIO-MARINE DEPOSITS
do	Dark grey , slightly to moderately weathered , fine-grained , high strength rock , DOLERITE with closely spaced , red stained , sub-vertical joints. Generally forms prominent rock outcrops or ridges	POST-KAROO INTRUSION
CS	Grey , slightly weathered , medium-grained , high strength CALC-SILICATE ROCK with close to medium spaced , calcite stained joints Contains occasional mica-rich layers. Generally intermittent surface outcrop with a sparse cover of greyish brown , loose subangular gravelly SAND - colluvium.	KARIBIB FORMATION (DAMARA SEQUENCE)
MK	Light grey to white , slightly weathered , coarse-grained , medium strength rock-MARBLE with medium to widely spaced , tight orange stained joints. Generally forms prominent outcrops with a thin cover of loose , sandy GRAVEL-colluvium.	KARIBIB FORMATION (DAMARA SEQUENCE)
MR	MARBLE , as for Karibib Formation marble above , but generally a light grey to greenish colour and containing the minerals **serpentine** and diopside	RÖSSING FORMATION (DAMARA SEQUENCE)
GG	Highly variable , light grey to red , moderately weathered , coarse grained , medium strength rock-RED GNEISSIC GRANITE with closely spaced , tight , red-stained joints contains large veins of pink PEGMATITE and layers of grey , medium grained MICA SCHIST. Outcrops as flat rock pavements or with a thin cover of reddish-brown loose , gravelly SAND-colluvium containing angular fragments of gneissic **granite and quartz**	(DAMARA SEQUENCE)

Prominent surface outcrop of rock or outcrop of rock on beach

Area of shallow water table or surface seepage

Terraces of fluvial and marine origin

Observed geological contact

Approximate geological contact

40 Dip and strike of foliation/bedding

2 Approximate depth (m) of superficial deposits overlying bedrock

BH 2356 Location of borehole (at desalination plant , Mile 4)

Q Approximate location of infilled quarry

ENGINEERING ASSESSMENT

SA	Well - drained areas of granular soils conditions generally favourable for foundation constructions , but settlement can occur on loose sand or silty material. Gypcrete layers or boulders may hinder excavation in parts..
FM	As above
do	Prominent dolerite outcrops present excavation and site-levelling difficulties. Zones of deep weathering may occur along the contact with country rock
CS	Bedrock generally occurs at shallow depths and founding conditions are good. Difficulties can be experienced with excavations for trenches
MK, MR	Areas of prominent outcrop presents difficulties with excavations and site levelling. Founding conditions are generally good
GG	Founding conditions are generally good , but highly variable nature of the rock results in zones of deeply weathered materials. Care should be taken to remove such zones (normally schists) during excavation for foundations. Blasting normally required for excavation of services trenches