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GEOTECHNICAL INVESTIGATIONS FOR THE GAUTRAIN MASS TRANSIT RAPID LINK OVER DOLOMITE BEDROCK IN THE CENTURION AREA

BY

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The author also wishes to advise that the views and opinions expressed in this dissertation are solely those of the author and not those of the Province or Bombela.

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ABSTRACT

The Gautrain Rapid Rail Link is a state-of-the-art rail route and one of the ten Spatial Development Initiatives planned in Gauteng Province, South Africa. The route comprises two links, namely a link between Tshwane (Pretoria) and Johannesburg and a link between OR Tambo International Airport and Sandton.

A total of 10 stations are linked by approximately 80 kilometres of rail along the proposed route. Between Johannesburg and Pretoria in the southern Tshwane region, the rail alignment is underlain by dolomite bedrock for approximately 15km in the vicinity of Centurion between Nelmapius Drive and The Fountains, including nearly 6km elevated on a viaduct.

The stability of the rapid rail link constructed over the dolomitic sections was considered a major project risk due to its proneness to sinkholes and subsidences along this route. Construction on heterogeneous soils, pinnacled bedrock and other geohazards posed major challenges to the construction team.

To facilitate detailed design and adapt proper foundation options for the viaducts founded over the dolomitic terrain, rigorous and comprehensive ground investigations were conducted by the Bombela Civils Joint Venture (BCJV).

This work presents the different ground investigation methods used and how the results have led to the adoption of five suitable foundation solutions namely: large diameter shafts to rock, piles to rock, floating foundations over grouted ground, spread footings on shallow bedrock and concrete U shaped structures.

GLOSSARY

The following is a list of defined terminologies that are frequently used in this thesis.

Blanketing material

- The material overlying receptacles

Blanketing residuum

- The remains of dolomite left behind after diagenesis. It consists of chert gravel, wad and small quantities of clay.

Cavity

- a void within the unconsolidated overburden caused by subsurface erosion of this material into underlying solution cavern

Chert

- A silica rich rock occurring as interstratified siliceous bands in the chert-rich dolomite rocks.

Compaction subsidence

- A closed depression, often basin-shaped or roughly conical, funnel-shaped depressions usually formed in the karst land surface of carbonate rock area, as a result of solution or collapse of underlying carbonate rock strata. Dolines have a simple but variable form, e.g. cylindrical, conical, bowl or dish-shaped and may vary in size dimensions from a few metres to many hundreds of metres wide. Dolines may occur as a network of adjoining collapse or sinkhole features in polygonal karst, separated by narrow ridges of limestone; where two or more dolines may coalesce, the larger feature is usually known as a uvala
- Sides may be gently sloping to vertical or overhanging. Size: a few metres to many hundreds of metres across
- A closed depression draining underground in karst, formed by solution and or collapse of underlying rock strata. Shape is variable, but often conical or bowl shaped.
- A depression of the ground surface which occurs slowly and not as steep-sided as a sinkhole, although the final depth may be the same as that of a sinkhole.

Dolomite

- a calcium and magnesium carbonate rock consisting predominantly of the mineral dolomite

Grouting

- Ground improvement method to fill the cavities in bedrock and soil by controlled injection of material usually in temporary fluid phase, thereby increasing the bearing capacity and reducing risk of possible sinkhole.

Karst

- A terrain with distinctive landforms and drainage (often underground), mainly originating from SOLUTIONAL EROSION and commonly developed on carbonate rocks or EVAPORITES

Overburden

- Any loose, unconsolidated soil material overlying solid rock.

Pier

- A civil structure which supports a precast viaduct segment.

Pinnacle

- subsurface, steep-sided tower of bedrock formed due to dissolution of material along intersecting joints in the original rock mass

Sinkhole

- A word of American origin used to describe sites of sinking water in a carbonate rock (karst) area; often formed in a doline. Sinkholes also include swallets, and like dolines, can be mantled in by subsequent glacial drift deposits. (In the UK and other parts of Europe, a sinkhole is often referred to as a “swallowhole”.)
- In Australia, used for sites of sinking water in a karst area. Sinkholes also include swallets. Note that in USA the term is, by long established usage, synonymous with the term DOLINE, in the broader sense.
- A steep-sided surface depression, which occurs suddenly due to collapse of surface material into a cavity.

Solution cavern

- Large void within the solid dolomite bedrock due to chemical decomposition of carbonates by weakly acidic ground water.

Wad

- A generic name for (often poorly crystalline) soft manganese oxides/hydroxides, often containing significant amounts of hydroxides/oxides of other metals and adsorbed metals (iron and other transition metals, alkali elements, etc.) Palache et al, 1944.
- As defined in southern Africa. It refers to a black residuum, comprising of manganese and iron oxides, with a low density and high void ratio. It is compressible, insoluble and highly erodible.

1 INTRODUCTION

1.1 BACKGROUND

The Gautrain Rapid Rail Link is a state-of-the-art rail route and one of the ten Spatial Development Initiatives planned in Gauteng. The main objective of this project is to develop the economy and ease traffic congestion. The construction of the Gautrain was entrusted to Bombela group as a concession agreement to design, build, operate and finally handover the system rail to the Gauteng Provincial Government after 15 years. The Bombela consortium comprises several companies:

- Bouygues Travaux Public (civils)-France
- Strategic Partners Group (civils)-South Africa
- Murray and Roberts (civils)-South Africa
- Bombardier (train equipment)-Canada
- RATP Development (train operation, development and maintenance)-France

The route comprises two links, namely a link between Tshwane (Pretoria) and Johannesburg and a link between OR Tambo International Airport and Sandton.

A total of 10 stations (Figure 1) are linked by approximately 80 kilometres of rail along the route with 15 km section of tunnel between Park Station and the Marlboro Station. The project consists of 15 Viaducts from the Airport to Tshwane, with the longest viaduct (3100 m, Viaduct 5) being constructed along the Centurion section (Appendix A).

The Pretoria-Johannesburg link starts at Park Station in central Johannesburg and proceeds north underground for 6 kilometres beneath the Parktown Rigde and Oxford Road to Rosebank Station. From there the line continues underground for a further 5 kilometres beneath Dunkeld, Hyde Park, Inanda Ext1 and Rivonia Road to a station within the Sandton business district. After Sandton Station, the route remains underground beneath Sandown, Strathavon, the M1 and Marlboro Drive before appearing onto the surface in Marlboro, approximately 4 kilometres from Sandton.

From Marlboro Station, the route proceeds north, towards the Midrand Station. After Midrand Station, the route largely tracks the Old Pretoria-Johannesburg Road and the N1 before it stops at the Centurion Station, just north of Centurion Lake. The route then runs to the west of the Ben Schoeman highway from the Jean Avenue interchange down Snake Valley and east of Salvokop into Pretoria.

Pretoria Station, 11 kilometres from Centurion is the next stop. It is situated adjacent to the existing Pretoria Station. The route then runs east for 6 km to Hatfield Station.

The OR Tambo International Airport and Sandton link starts from Sandton Station, via Marlboro, crossing the northern boundary of the Linbro Park landfill, passing the Linbro Park Agricultural Holdings and across the Modderfontein property before connecting to the existing rail corridor, serving the Kelvin Power Station and the Spartan/Isando industrial area into Rhodesfield Station in Kempton Park. From there it connects to a station built within the airport terminal complex at OR Tambo International Airport.

Between Johannesburg and Pretoria in the southern Tshwane region, the rail alignment is underlain by dolomite for approximately 15 km in the vicinity of Centurion between Nelmapius Road and The Fountains including nearly 6 km elevated on a viaduct as documented by Storry et al. (2009).

The possibility therefore exists that features associated with dolomitic instability could occur on and in the vicinity of the proposed route. Apart from stability problems, areas underlain by dolomite also differ from areas underlain by most other rock-types in the unpredictable nature of the dolomite residuum overlying the bedrock and the variable depth to bedrock (Venter and Lourens, 2002). The presence of cavities, large floaters of solid rocks and effects of wad material, also posed major challenges to the construction team along this route.

This research project focuses on the dolomitic karst terrain, crossed by the rail link. It considers the different geotechnical investigation methods used to arrive at suitable foundation options along the Gautrain route.

The dolomitic terrain is typical of karst areas where surface instability due to sudden collapse settlement in the form of sinkholes or slow surface movements due to compaction subsidence may occur.

Surface instability on South African karst areas may be caused by amongst other factors, concentrated infiltration of surface water/water leaks or human imposed loads and vibrations. The extent of these surface distortions is dependent on the properties of the subsurface dolomite bedrock and the blanketing material overlying the rock and is being assessed according to South African practice in terms of an approach developed by Buttrick et al. (2001), for the purpose of housing construction.

Ground investigations in the study area underlain by dolomite bedrock have previously been carried out by the Council for Geoscience (CGS) according to the South African Institute for Engineering and Environmental Geologists (SAIEG, 2003) guidelines to determine the risk of sinkhole and compaction subsidence formation. These suggested investigation methods are not suitable for the purpose of a mass transit railway across the focus area as these guidelines were developed for residential development on dolomite bedrock. There was no local geotechnical investigation procedure that could be adopted to provide the needed measurements to properly assess the terrain since similar developments on dolomite are limited.

More rigorous and advanced ground investigations were conducted along the rail route to determine the geotechnical properties and subsurface conditions of the rocks and weathered materials. The methods used to gather data on the relevant characteristics of the geological materials included trial hole investigations, rotary core drilling, both small and large diameter auger drilling, cone penetration testing, standard penetration testing, gravity survey, pressuremeter testing, borehole radar survey, continuous surface wave, dynamic probing and percussion drilling.

Based on the results obtained from these investigation methods, suitable foundation solutions were designed to overcome the challenges on the dolomites underlying the route and the surface stability was evaluated according to the scenario supposition approach proposed by Buttrick and Schalkwyk (1995). This method requires the evaluation of the site’s geological conditions, the quantification of risk and the management of the risk.

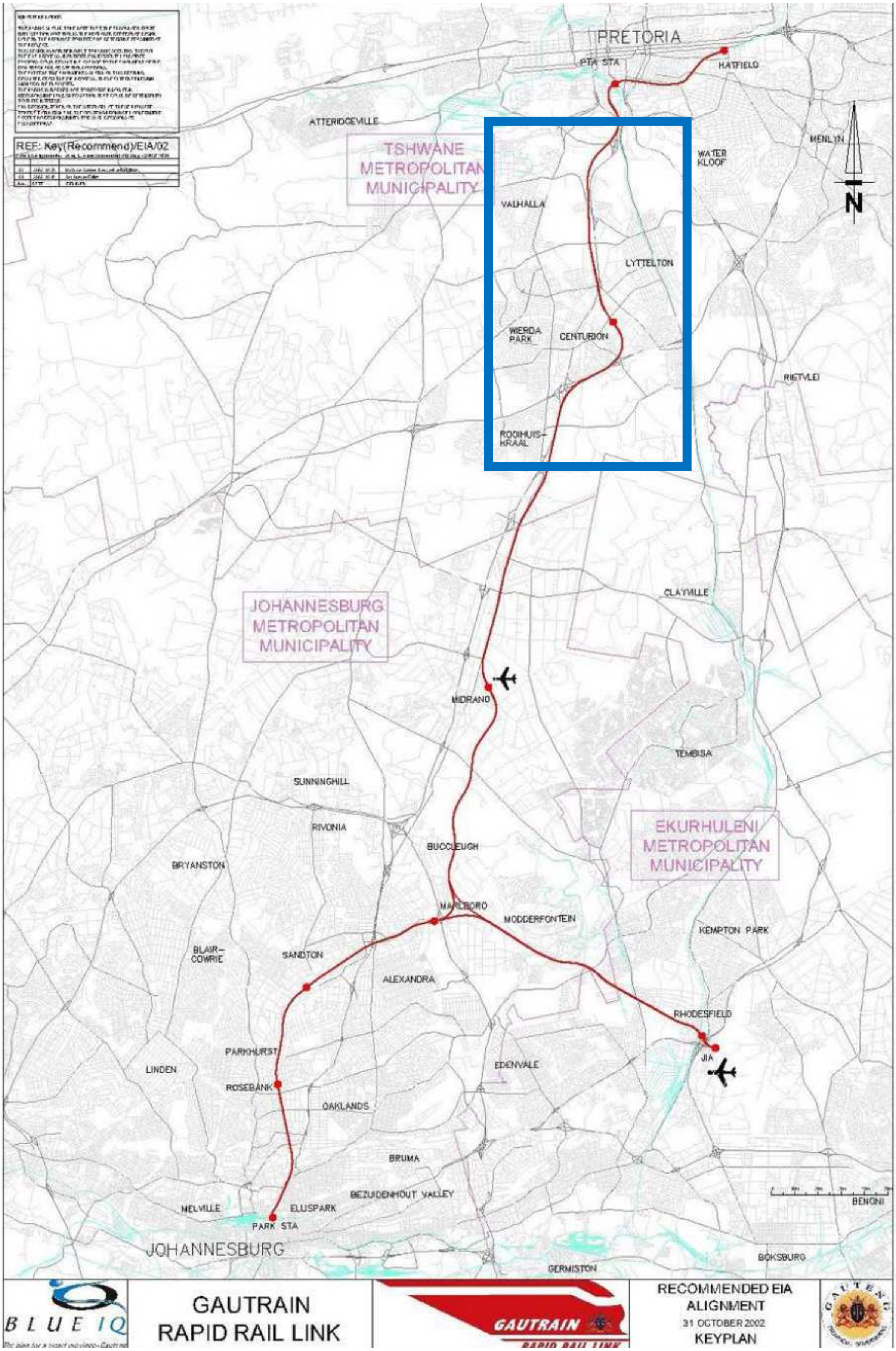


Figure 1: Map showing the Gautrain rapid rail link alignment with study area highlighted on blue. (Bombela CJV, 2006)

1.2 GEOLOGY OF THE STUDY AREA

The study area covers approximately 15 km of the northern section of the alignment and is underlain by the Malmani Subgroup, which belongs to the Chuniespoort Group, of the Transvaal Supergroup as shown in Figure 2. These dolomites, which are some 2200 million years old (Eriksson et al. 2006), extend through the longitudinal route of the Gautrain rapid rail link from the contact between the granite of the Johannesburg Granite Dome near the Techno Park (viaduct 5T) in the south, through John Vorster interchange (viaduct 5B), across Centurion Supersport Park along West Street (viaduct 5C) in Centurion down to Jean Avenue (viaduct 5D), and across the military area through Snake Valley to Eeufees Road (viaduct 6) in the north. The northern contact, dipping to the north, is between the dolomite bedrock and shale of the Pretoria Group.

These rocks have weathered extensively since deposition and have been subjected to severe tectonic events such as the Vredefort impact to the south and the intrusion of the Bushveld and Pilanesberg complexes and associated dykes and sills to the north and north west.

The structural pattern of the area is dominated by faults which are associated with syncline and anticline formation within the Johannesburg Granite Dome formed in the Pre-Transvaal times. These are faults, fractures and shear zones partly reactivated in Post-Transvaal times. Many of these faults also show strike-slip motion as documented by Eriksson et al. (2006).

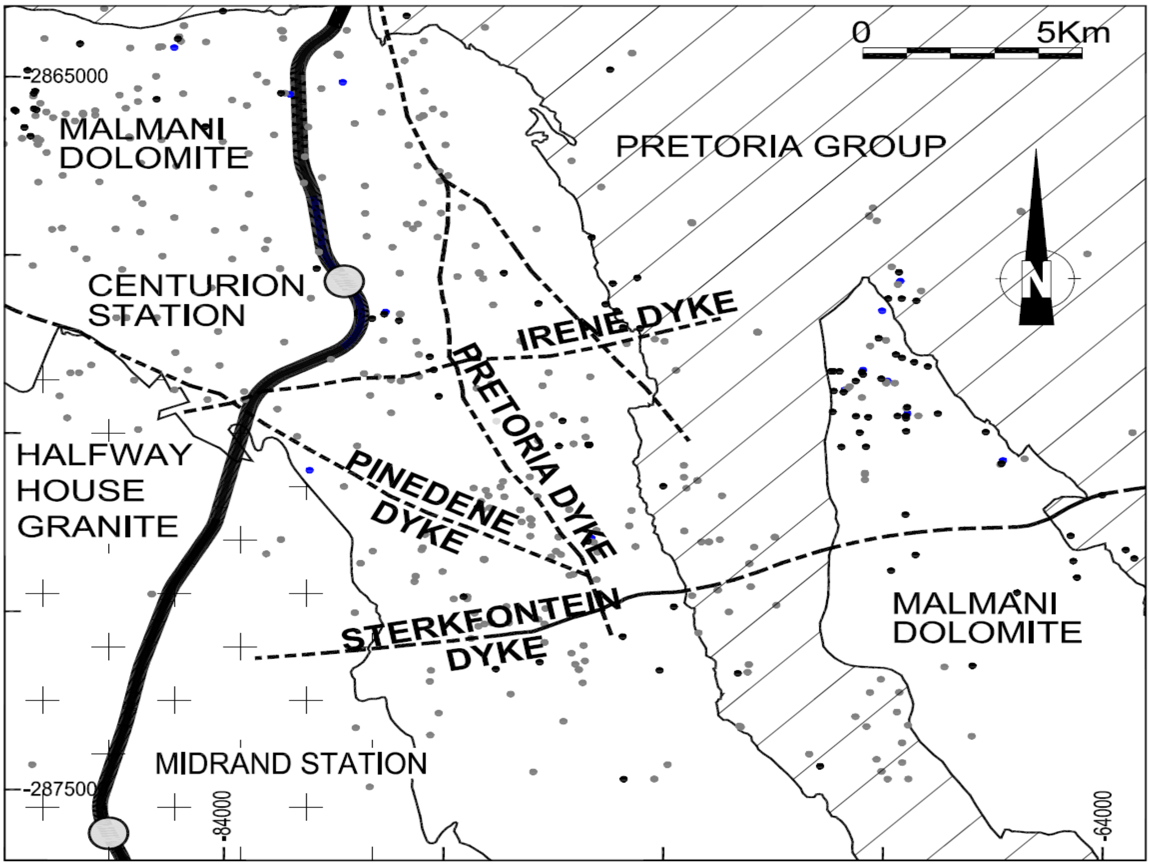


Figure 2: Geology of the study area (Bombela CJV, 2009)

1.3 TOPOGRAPHY

The groundwater level in dolomitic aquifers as documented by Barnard, (2000), does not necessarily follow the topography. More often than not, it occurs as a nearly horizontal surface indicative of a low hydraulic gradient and very permeable formation. This characteristic partly explains the occurrence of extremely deep groundwater rest levels in areas of raised topography (Barnard, 2000).

In instances where the direction of groundwater movement is towards the dolomite, the groundwater gradient is generally much steeper through the quartzitic rocks than in the dolomitic formations.

According to Barnard, (2000), this characteristic has been demonstrated in the area southwest of Pretoria, where the Black Reef Formation separates the Basement Complex granite of the

Johannesburg Granite dome from the dolomite of the Chuniespoort Group. The steeper gradient is attributed to the poorer transmissive properties of the quartzite compared with those of the dolomite. According to Kirsten, (2003), the study area which extends from south of Centurion to South of Pretoria forms part of the Kromdraai Land System, which is characterized by some steep hills with moderate relief.

The general topography of the area is gently undulating. The southern part has a topographic high, which lowers towards the Hennops River drainage basin and then increase towards the two west-east ridges in the north of the study area. These ridges form low hills with maximum elevation of 1 540 m above mean sea level and rise above a valley floor of approximately 1 400 m above mean sea level (AGES, 2006). The drainage around the study area with dolomite compartments is shown in Figure 3.

To the southeast of the suburb of Irene, the Hennops River has eroded a steep sided valley into the dolomite bedrock. The valleys are generally open with moderate slopes. The rare steep hillocks (Dumb Bell Hill, Swartkop, Bay Hill and others) are related to the erosion resistance of thick chert and chert breccia bands. The hill slopes are characteristically concave except for free faces and highly dissected pediments that are present to a very minor extent as documented by Kirsten, (2003).

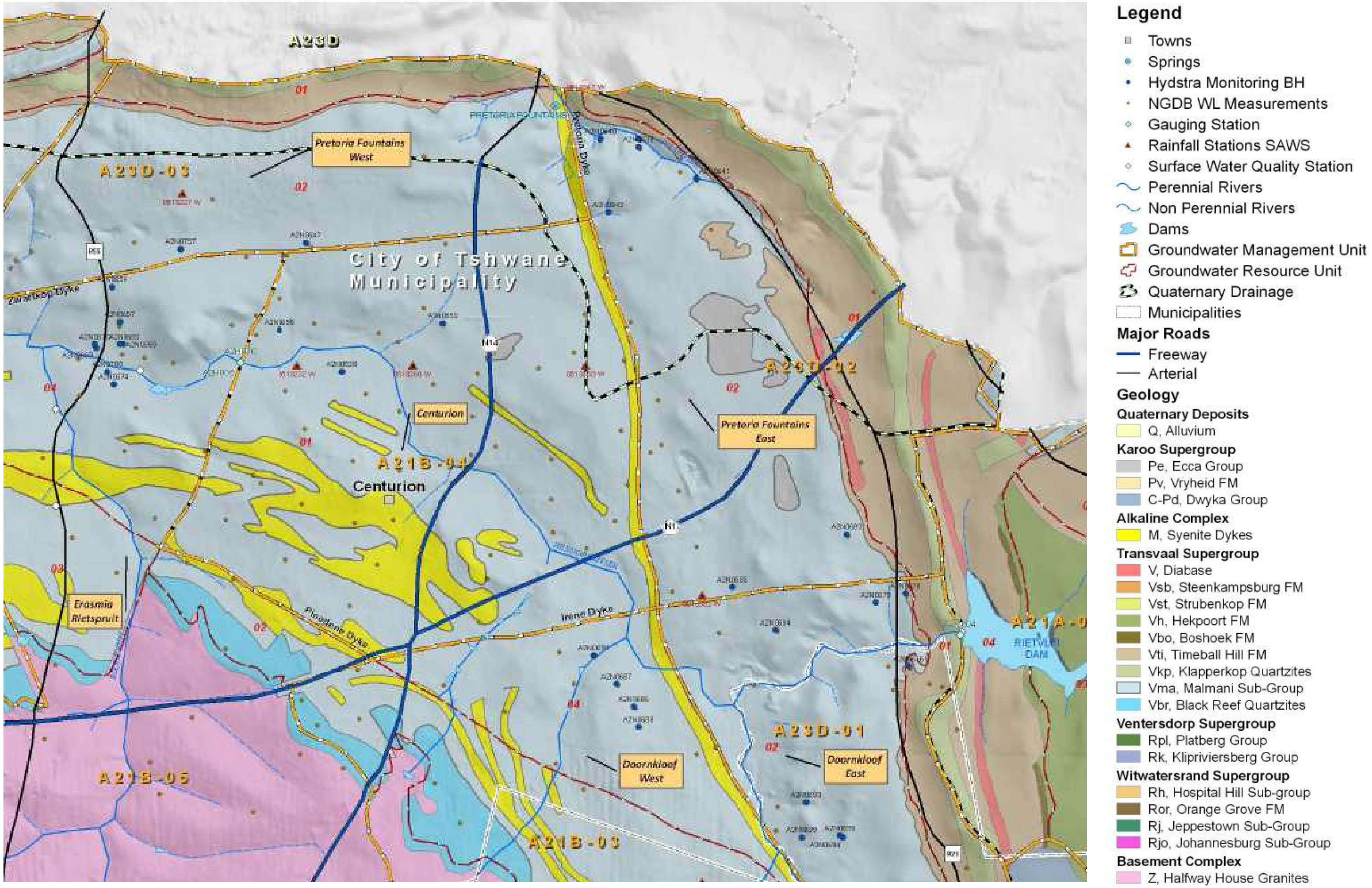


Figure 3: Drainage map showing dolomite compactments (after department of water affairs, 2009. 1:50000)

1.4 DRAINAGE

According to Barnard, (2000), three main drainage systems occur in the area (hydrogeological map 2526), bordering the Gautrain route alignment from Johannesburg to Pretoria. These are the Limpopo River system (Primary drainage Region A) which drains approximately 30% of the area, the Olifants River system (Primary Drainage Region B) draining 25% of the area and the Vaal River system (Primary Drainage Region C) draining the remaining 45% of the area. The tributaries that drain the headwaters of the Limpopo and Olifants Rivers flow mainly northwards. Those of the Vaal River system drain in a predominantly southerly to southwesterly direction as shown in Figure 4, while the major dams in the map area are shown in Table 1.

The alluvial sediments that adjoin the Crocodile River in the area downstream of the Roodekopjes and Vaalkop dams represent the only primary aquifer in the map area (Barnard, 2000) and its distinguishing feature is its hydraulic connection with the Crocodile River. The major drainage in the study section is formed by the Sesmyl Spruit. It enters the study area in the southeast, flowing west at 1 460 mamsl and cutting across the dolomite. It flows out of the study area on the west at 1 360 mamsl (Ages, 2006).

The groundwater drainage pattern in the area encompassing the Gautrain route alignment as documented by Barnard, (2000), generally mimics that of surface water which, in turn is determined by the topography. The groundwater divides therefore also commonly coincide with surface watersheds. Diffuse seepages typically occur along the base of valley slopes where the groundwater level intersects the land surface. The formation of sinkholes and compaction subsidence is mostly due to interference with surface drainage or ingress of water from storm water ponding or leaking services.

In areas of the Basement Complex rocks as interpreted by Barnard, (2000), the low surface relief and the porous nature of the weathered granite gives rise to groundwater seeps or seepages rather than to well-defined springs.

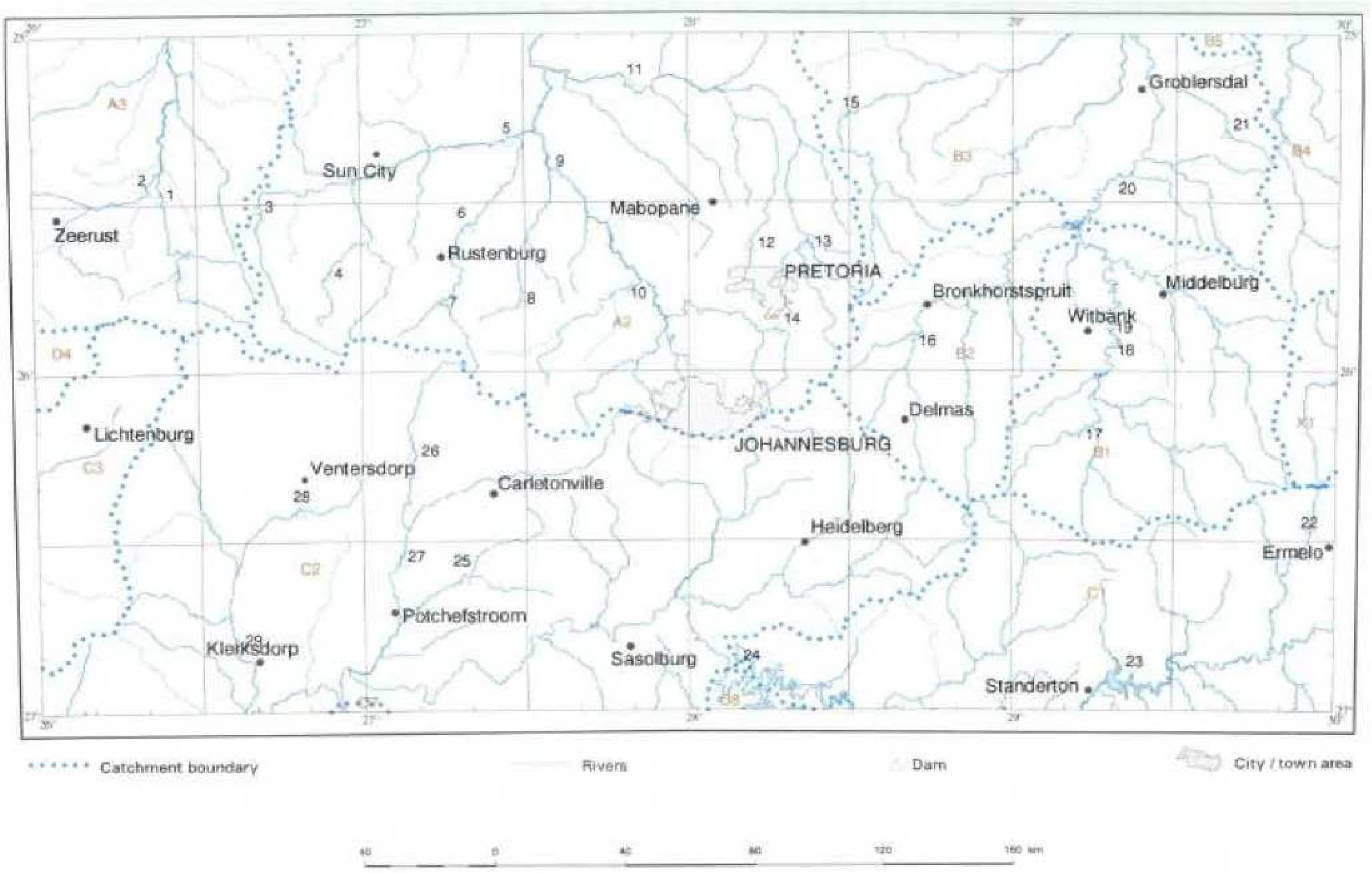


Figure 4: Drainage regions, majors dams and rivers (after Barnard, 2000)

Table1: Major dams in map area (after Barnard, 2000)

NAME OF DAM	NUMBER IN FIGURE 3	DRAINAGE BASIN	RIVER	STORAGE CAPACITY $(\times 10^6\ m^3)$
Marico-Bosveld	1	A3	Groot Marico	27.0
Kromellenboog	2	A3	Groot Marico	9.3
Lindley's Poort	3	A2	Elands	14.3
Koster	4	A2	Elands	12.8
Vaalkop	5	A2	Elands	56.0
Bospoort	6	A2	Hex	18.2
Olifantsnek	7	A2	Hex	13.6
Buffelspoort	8	A2	Crocodile	10.3
Roodekopjes	9	A2	Crocodile	103.0
Hartbeespoort	10	A2	Crocodile	186.0
Klipvoor	11	A2	Moretele	42.1
Bon Accord	12	A2	Apies	4.4
Roodeplaat	13	A2	Pienaars	41.2
Rietvlei	14	A2	Kafferspruit	12.3
Rust de Winter	15	B3	Elands	26.9
Bronkhorstspruit	16	B2	Bronkhorstspruit	58.0
Trichardtsfontein	17	B1	Rietspruit	15.3
Witbank	18	B1	Olifants	104.0
Doringpoort	19	B1	Olifants	9.2
Loskop	20	B3	Olifants	362.0
Rooikraal	21	B3	Bloed	2.1
Willem Brummer	22	C1	Klein-Kafferspruit	1.2
Grootdraai	23	C1	Vaal	356.0
Vaal	24	C1	Vaal	2 603.0
Klipdrift	25	C2	Loopspruit	13.6
Klerkskraal	26	C2	Mooirivier	8.3
Boskop	27	C2	Mooirivier	20.6
Rietspruit	28	C2	Rietspruit	7.2
Klerksdorp	29	C2	Skoonspruit	5.6

1.5 PROBLEM STATEMENT

Urban and related infrastructure development on karst areas are influenced by historic and ongoing karst processes including the epikarst materials and hydrological changes that may result in surface movements.

Surface movements, manifesting as sudden collapse settlements (sinkhole) and slow compaction settlements (subsidence), are usually a response of the existing epikarst conditions to changes due to local surface water ingress or regional and local groundwater fluctuations.

Typical effects of surface instability are damage to or complete loss of surface and sub-surface structures and services, injury or loss of life and groundwater vulnerability to pollutants.

The possible risk to lives and damage to property as a result of land subsidence caused by karst processes should be prevented or minimized.

1.6 OBJECTIVES

This dissertation aims to address the following aspects:

- Describe the general geological conditions specifically related to the karst area along the Gautrain rapid rail link centreline.
- Describe the factors impacting on the Gautrain rail link where it crosses the dolomite bedrock area between Midrand and Pretoria
- Give a comprehensive description of the investigation methods used and the results obtained during the site investigations on the dolomite bedrock area.
- Highlight the design requirements and geotechnical data used in the design process.
- Discuss the appropriate foundation and precautionary measures implemented in different karst conditions along the rail route.

2 GEOLOGY

2.1 REGIONAL GEOLOGY

The route along the centreline of the Gautrain rail link from the south station at the present Park Station in central Johannesburg to the northern station in Hatfield, Pretoria, is underlain by rocks of the Randian and Vaalian Erathems as shown in Figure 5. The south section of the route comprise the Halfway House Granite and Witwatersrand quartzite/shale formations as documented by Tosen et al. (2009), while towards the north, the granite and greenstone forms the basement onto which the younger sediments and volcanic rocks of the Witwatersrand, Ventersdorp and Transvaal Supergroups were intruded (Eriksson et al, 2006).

The Pre-Cambrian Witwatersrand Supergroup is the oldest sedimentary sequence along the route with its lower base overlying the rocks of the Dominion Group (Eriksson et al, 2006). This Supergroup is an oval-shaped basin with its axes about 400km long in an NE-SW direction and 200km wide in the NW-SE axis with the Vredefort dome situated in the centre (Brink, 1979). The age of this supergroup is placed between 2 714 Ma and 2 914 Ma as documented by Eriksson et al. (2006).

Lying on top the Witwatersrand Supergroup is the Ventersdorp Supergroup which consists of volcanics, amygdaloidal and porphyritic lavas, pyroclastics and sedimentary rocks. The Supergroup is composed predominantly of a massive accumulation of andesitic and basaltic lavas with related pyroclastic agglomerates and tuffs.

The Transvaal Supergroup is presented in the area by the dolomites and chert (chemical sedimentary rocks) of the Malmani Subgroup, Chuniespoort Group and clastic sedimentary rocks of the Pretoria Group. This Supergroup as shown in Table 2 overlies the Archaean basement, Witwatersrand and Ventersdorp Supergroup and forms the floor of the Bushveld Igneous Complex. The strata dip towards the centrally located Bushveld lithologies and encompass one of the world’s earliest carbonate platform successions with well preserved and extensive stromatolites and an excellent record of cyanobacterial and bacterial evolution, recording the early history of life on earth as documented by Eriksson et al. (2006).

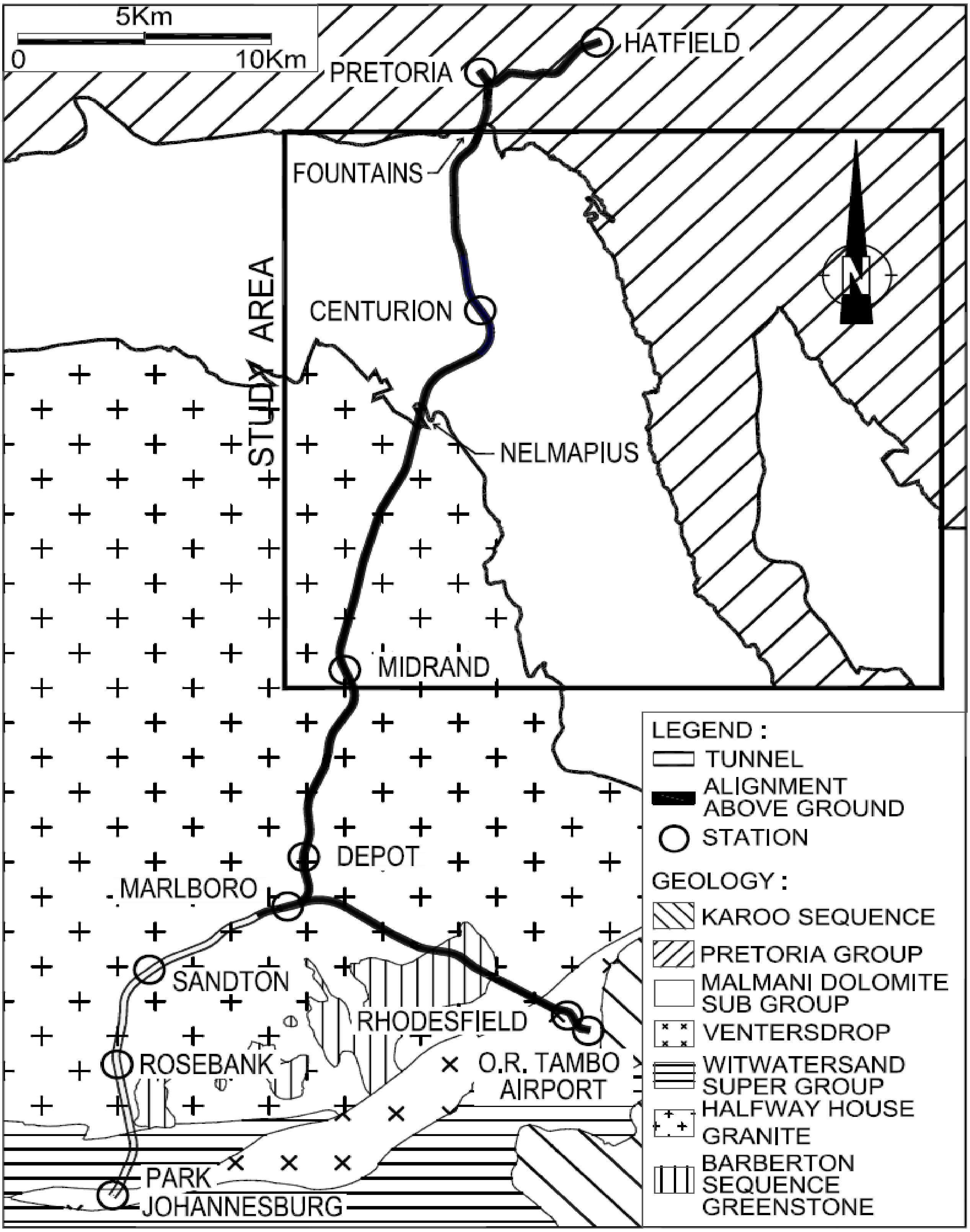


Figure 5: Geology along the Gautrain Rapid Rail Link (Bombela CJV, 2009)

The Chuniespoort Group of the Transvaal Supergroup forms two broad arcs of chemical sediments encircling the younger clastic strata of the Pretoria Group. It occupies an area of approximately 15 500 km^2 in Gauteng (Buttrick, 1986) and comprises the Malmani Subgroup, followed by the Penge Formation, which is in turn, unconformably overlain by the Duitschland Formation.

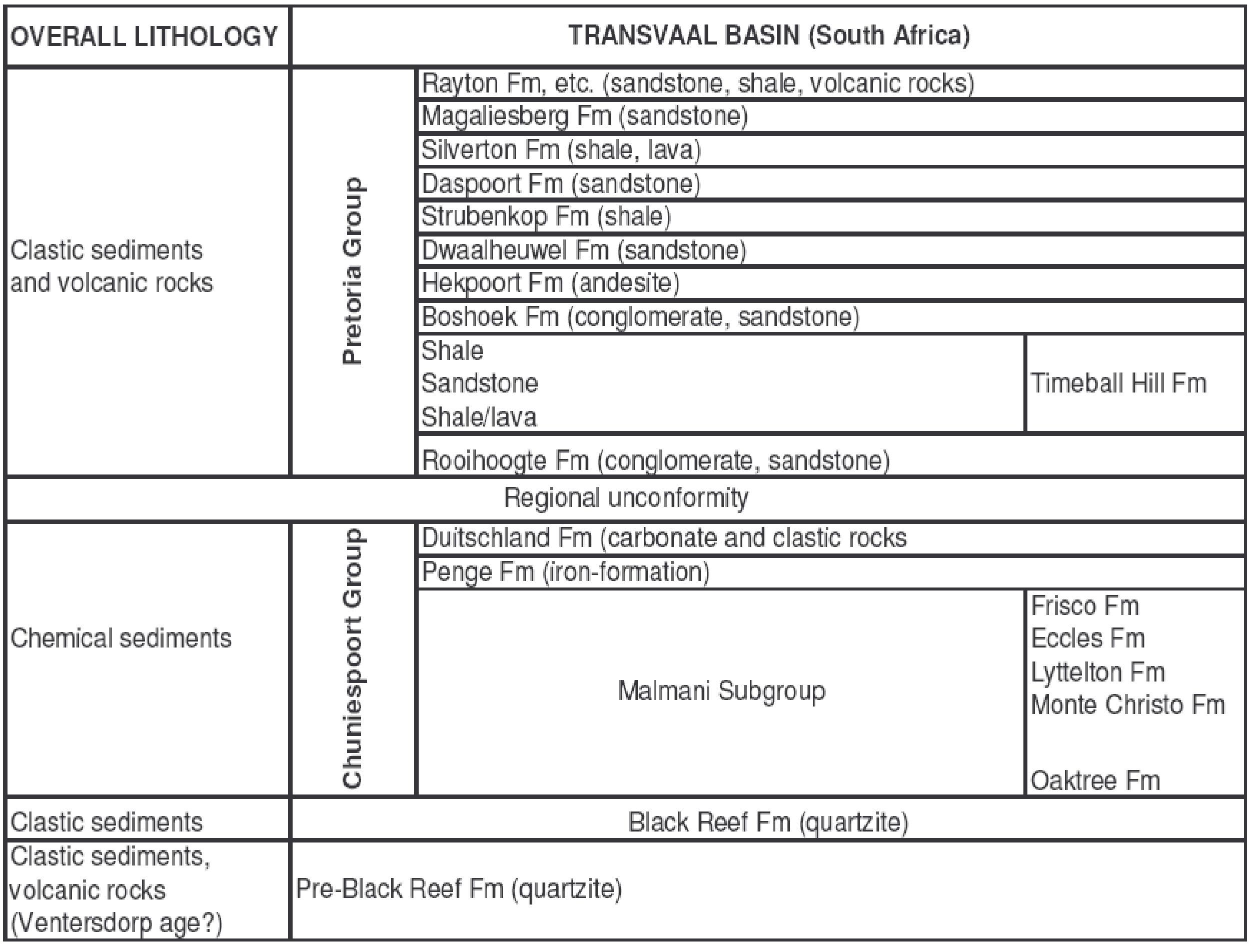
In the central area, which covers the study area under consideration, the Chuniespoort Group is marked by only the four lowermost formations of the Malmani Subgroup as documented by Wagener, (1982).

The Pretoria Group as shown in Figure 6 is approximately 6 to 7 km thick and overlies the Chuniespoort Group, forming the uppermost group of the Transvaal Supergroup. It occupies a continuous strip about 80 km wide around the oval-shaped basin of the Bushveld Complex and comprises predominantly mudrocks alternating with quartzitic sandstones, significantly interbedded basaltic-andesitic lavas, and subordinate conglomerates, diamictites and carbonate rocks all of which have been subjected to low-grade metamorphism (Eriksson et al. 2006). A general sheet-like geometry is evident for most of the nine lower formations, with certain sandstone and lava units exhibiting more wedge-like three dimensional forms. Only one radiometric age is available for the Pretoria Group, with lavas of the Hekpoort Formation being dated at 2 224 +_21 Ma (Eriksson et al. 2006).

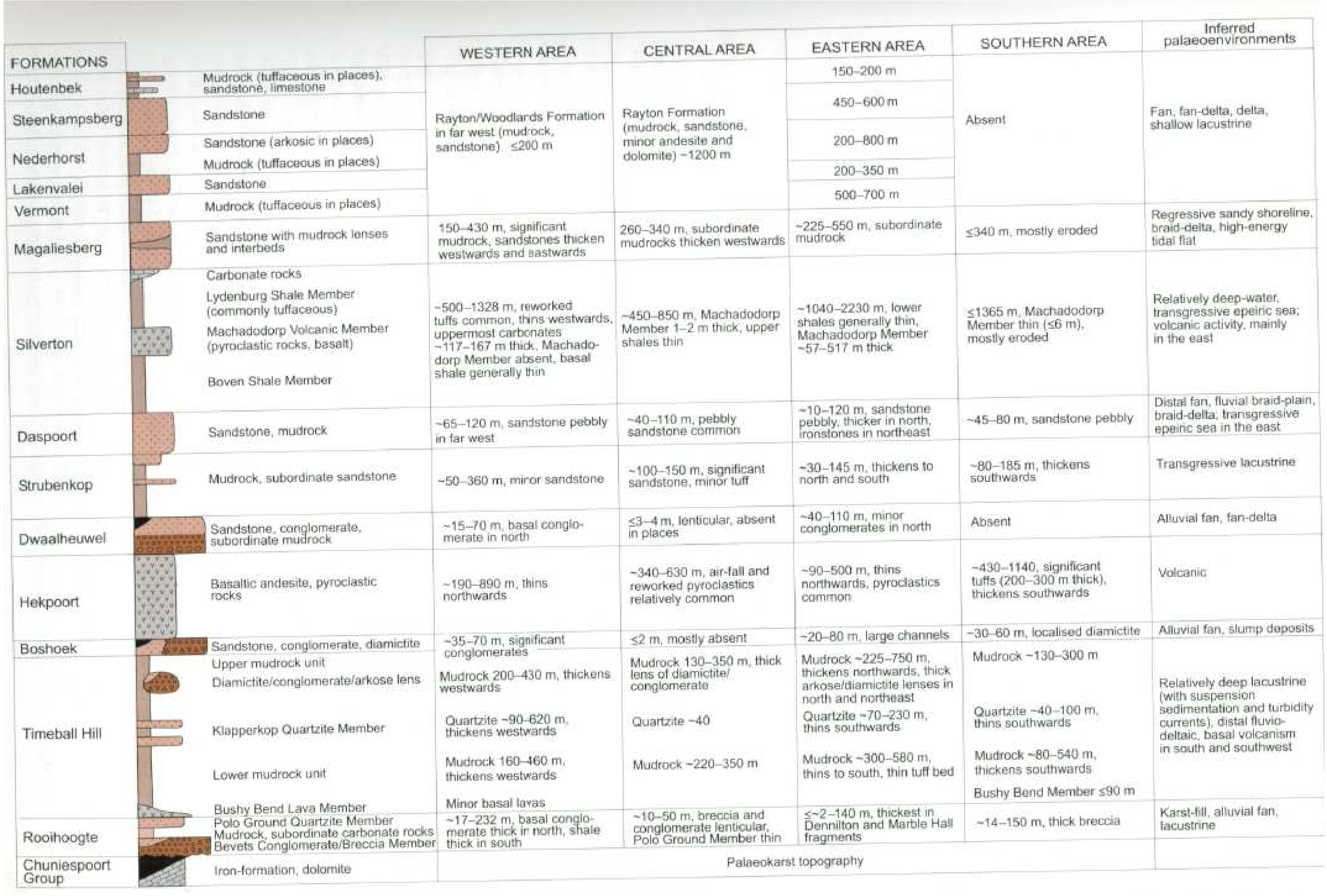
The basal Rooihoogte Formation of the Pretoria Group overlies a deeply weathered karstic palaeotopography developed on the Chuniespoort Group carbonates and wad fills palaeosinkholes in many areas (Eriksson et al. 2006).

There has been a lively debate over the years regarding the depositional basin of the Pretoria Group, but qualified use of boron contents indicates the distinct possibility that the Rooihoogte to Strubenkop Formations were laid down in a closed basin, succeeded by transgressive/regressive marine sediments of the Daspoort, Silverton and Magaliesberg Formations. The general tectonic setting of the Pretoria Group basin is inferred to lie in the rift-to-intracratonic-sag-type continuum according to Jonhson et al. (2006).

Table 2: Stratigraphic subdivision of the Transvaal Supergroup (after Eriksson et al. 2006)



OVERALL LITHOLOGY	**TRANSVAAL BASIN (South Africa)**		
Clastic sediments and volcanic rocks	Pretoria Group	Rayton Fm, etc. (sandstone, shale, volcanic rocks)	
		Magaliesberg Fm (sandstone)	
		Silverton Fm (shale, lava)	
		Daspoort Fm (sandstone)	
		Strubenkop Fm (shale)	
		Dwaalheuwel Fm (sandstone)	
		Hekpoort Fm (andesite)	
		Boshoek Fm (conglomerate, sandstone)	
		Shale Sandstone Shale/lava	Timeball Hill Fm
		Rooihoogte Fm (conglomerate, sandstone)	
Regional unconformity			
Chemical sediments	Chuniespoort Group	Duitschland Fm (carbonate and clastic rocks	
		Penge Fm (iron-formation)	
		Malmani Subgroup	Frisco Fm Eccles Fm Lyttelton Fm Monte Christo Fm Oaktree Fm
Clastic sediments	Black Reef Fm (quartzite)		
Clastic sediments, volcanic rocks (Ventersdorp age?)	Pre-Black Reef Fm (quartzite)		



FORMATIONS		WESTERN AREA	CENTRAL AREA	EASTERN AREA	SOUTHERN AREA	Inferred palaeoenvironments
Houtenbek	Mudrock (tuffaceous in places), sandstone, limestone	Rayton/Woodlards Formation in far west (mudrock, sandstone) ≤200 m	Rayton Formation (mudrock, sandstone, minor andesite and dolomite) ~1200 m	150–200 m	Absent	Fan, fan-delta, delta, shallow lacustrine
Steenkampsberg	Sandstone			450–600 m		
Nederhorst	Sandstone (arkosic in places) Mudrock (tuffaceous in places)			200–800 m		
Lakenvalei	Sandstone			200–350 m		
Vermont	Mudrock (tuffaceous in places)			500–700 m		
Magaliesberg	Sandstone with mudrock lenses and interbeds	150–430 m, significant mudrock, sandstones thicken westwards and eastwards	260–340 m, subordinate mudrocks thicken westwards	~225–550 m, subordinate mudrock	≤340 m, mostly eroded	Regressive sandy shoreline, braid-delta, high-energy tidal flat
Silverton	Carbonate rocks Lydenburg Shale Member (commonly tuffaceous) Machadodorp Volcanic Member (pyroclastic rocks, basalt) Boven Shale Member	~500–1328 m, reworked tuffs common, thins westwards, uppermost carbonates ~117–167 m thick, Machadodorp Member absent, basal shale generally thin	~450–850 m, Machadodorp Member 1–2 m thick, upper shales thin	~1040–2230 m, lower shales generally thin, Machadodorp Member ~57–517 m thick	≤1365 m, Machadodorp Member thin (≤6 m), mostly eroded	Relatively deep-water, transgressive epeiric sea; volcanic activity, mainly in the east
Daspoort	Sandstone, mudrock	~65–120 m, sandstone pebbly in far west	~40–110 m, pebbly sandstone common	~10–120 m, sandstone pebbly, thicker in north, ironstones in northeast	~45–80 m, sandstone pebbly	Distal fan, fluvial braid-plain, braid-delta; transgressive epeiric sea in the east
Strubenkop	Mudrock, subordinate sandstone	~50–360 m, miror sandstone	~100–150 m, significant sandstone, minor tuff	~30–145 m, thickens to north and south	~80–185 m, thickens southwards	Transgressive lacustrine
Dwaalheuwel	Sandstone, conglomerate, subordinate mudrock	~15–70 m, basal conglomerate in north	≤3–4 m, lenticular, absent in places	~40–110 m, minor conglomerates in north	Absent	Alluvial fan, fan-delta
Hekpoort	Basaltic andesite, pyroclastic rocks	~190–890 m, thins northwards	~340–630 m, air-fall and reworked pyroclastics relatively common	~90–500 m, thins northwards, pyroclastics common	~430–1140, significant tuffs (200–300 m thick), thickens southwards	Volcanic
Boshoek	Sandstone, conglomerate, diamictite	~35–70 m, significant conglomerates	≤2 m, mostly absent	~20–80 m, large channels	~30–60 m, localised diamictite	Alluvial fan, slump deposits
Timeball Hill	Upper mudrock unit Diamictite/conglomerate/arkose lens Klapperkop Quartzite Member Lower mudrock unit Bushy Bend Lava Member	Mudrock 200–430 m, thickens westwards Quartzite ~90-620 m, thickens westwards Mudrock 160–460 m, thickens westwards Minor basal lavas	Mudrock 130–350 m, thick lens of diamictite/ conglomerate Quartzite ~40 Mudrock ~220–350 m	Mudrock ~225–750 m, thickens northwards, thick arkose/diamictite lenses in north and northeast Quartzite ~70–230 m, thins southwards Mudrock ~300–580 m, thins to south, thin tuff bed	Mudrock ~130–300 m Quartzite ~40–100 m, thins southwards Mudrock ~80–540 m, thickens southwards Bushy Bend Member ≤90 m	Relatively deep lacustrine (with suspension sedimentation and turbidity currents), distal fluvio-deltaic, basal volcanism in south and southwest
Rooihoogte	Polo Ground Quartzite Member Mudrock, subordinate carbonate rocks Bevets Conglomerate/Breccia Member	~17–232 m, basal conglomerate thick in north, shale thick in south	~10–50 m, breccia and conglomerate lenticular, Polo Ground Member thin	≤~2–140 m, thickest in Dennilton and Marble Hall fragments	~14–150 m, thick breccia	Karst-fill, alluvial fan, lacustrine
Chuniespoort Group	Iron-formation, dolomite	Palaeokarst topography				

Figure 6: Summary profile for the Pretoria Group (after Eriksson et al. 2006).

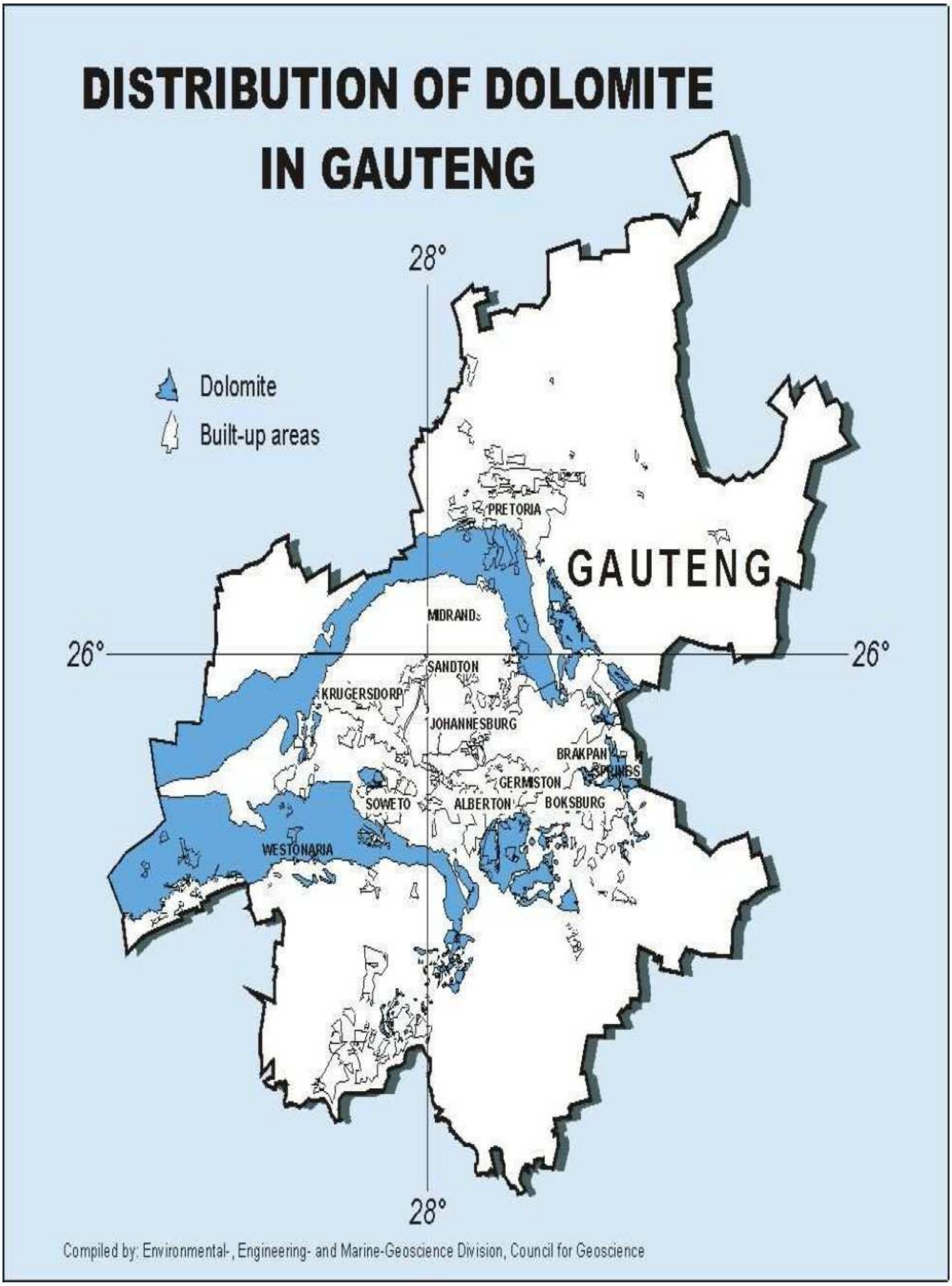
2.2 DOLOMITE

About 20%, or approximately 15 500 km^2 of the densely populated region embracing Gauteng Province, the central northern part of South Africa is underlain by dolomitic rocks (Figure 7), as are most of the gold mining regions of the Far West Rand (Van Schalkwyk, 1998).

The term dolomitic land is used in South Africa for areas underlain directly or at shallow depth (less than 100 m) by dolomite bedrock of the Chuniespoort or Ghaap Groups of the Transvaal Supergroup (Proterozoic age). It therefore includes areas where dolomite is covered by younger deposits (Pretoria Group) of the Transvaal Supergroup, the Karoo Supergroup (Palaeozoic age) or unconsolidated deposits of Cenozoic age according to Buttrick et al. (1995).

According to Moore (1984), ground surface instability may occur naturally in such areas when there is fluctuation in the level of the ground water table and subsurface mobilization of residuum, leading to the occurrence of subsidence, new collapse features and flooding, but is accelerated many orders of magnitude by human activities. The primary triggering mechanisms in such instances include the ingress of water from leaking water-bearing services, poorly managed surface water drainage and indiscriminate groundwater level drawdown. Instability usually occurs in the form of sinkholes and compaction subsidence.

Sinkholes result from various mechanisms (Sowers, 1976). This includes consolidation from loading and dewatering, hydraulic compaction, settling as materials are removed by groundwater flow, stoping or ravelling of materials into a void, and instantaneous collapse into a void. Sinkhole formation can also occur above solution enlarged fractures, which have formed caves or mudseams. Water-table drawdown can cause soil voids to migrate along solution features eventually leading to sinkhole at a distance from the well.



DISTRIBUTION OF DOLOMITE IN GAUTENG

Compiled by: Environmental-, Engineering- and Marine-Geoscience Division, Council for Geoscience

Figure 7: Distribution of dolomite in Gauteng. (after Council for Geoscience, 2004)

The mechanism of sinkhole and subsidence formations are shown and illustrated in Figures 8 and 9, according to Brink, (1979).

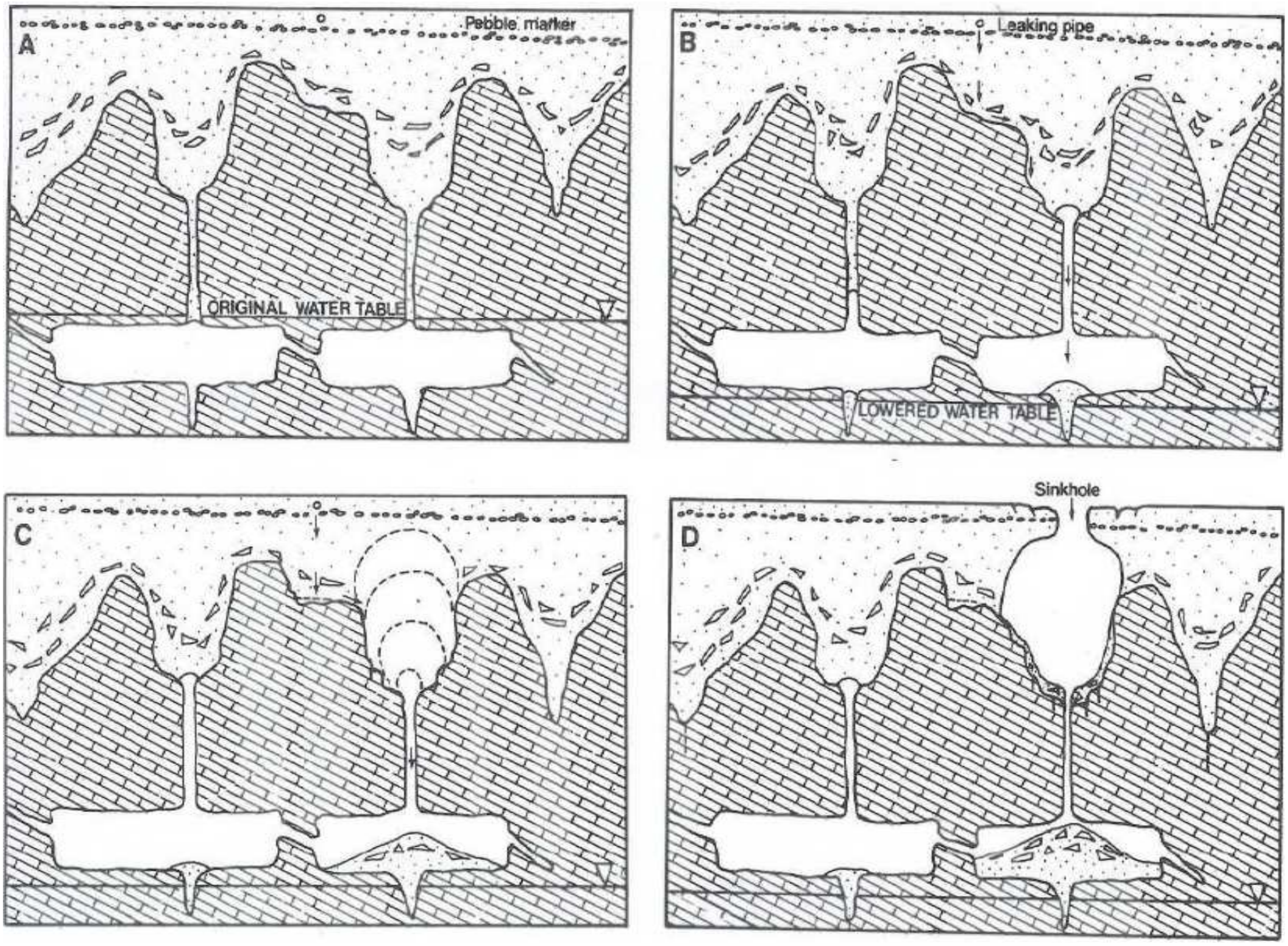


Figure 8: Mechanism of the development of a sinkhole (After Brink, 1979).

Diagram A shows the equilibrium situation before the lowering of the water table. B is the position after the lowering of the water table. There is active subsurface erosion. The slot is flushed out by a process of headward erosion. C shows the progressive collapse of the roof of the vault, possibly temporarily arrested by the ferruginised pebble marker. D shows the collapse of the last arch to produce a sinkhole surrounded by concentric tension cracks.

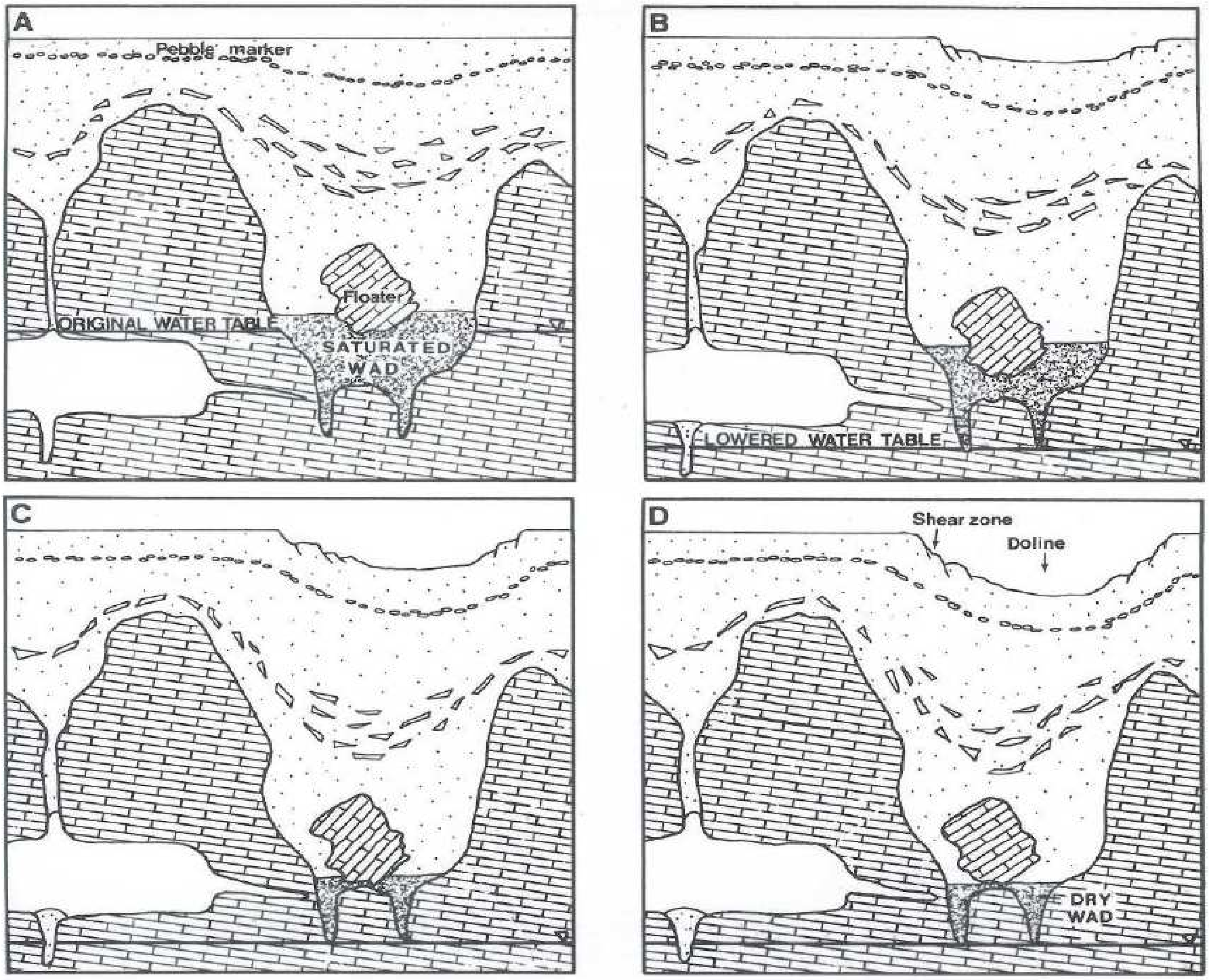


Figure 9: Mechanism of the development of a subsidence (After Brink, 1979).

Diagram A shows the equilibrium situation before the lowering of the water table. The paleo-subsidence is not apparent at the surface but is indicated by sagging chert rubble and the pebble marker. B is the position after the lowering of the water table. Reactivated subsidence development becomes apparent as a surface subsidence is caused by consolidation of wad. The periphery of the subsidence is characterised by a shear zone and tension cracks. C indicates the progressive consolidation of the wad, which causes progressive subsidence on the surface. D is the final equilibrium situation, where the wad is completely consolidated and the subsidence development is complete.

The following conditions are necessary for the formation of sinkholes (Wagener, 1982):

- The presence of cavities close to the surface into which the loose material can slump
- The water table must be deep as the rate of movement of percolating water above the water table is higher than below. In addition, the moisture content, and hence strength, of the material can fluctuate above the water table.
- Near-vertical pillars or walls of dolomite near the surface are required for the sudden slumping of loose material into solution cavities. Where 15 m or more of chert rubble or soil occurs over a fairly large area, slumping of the material into deeper cavities can at most cause slow settling of the surface.

A different hypothesis was presented as illustrated by Wagener (1982), listing the following conditions below for the formation of sinkholes:

- There must be voids to receive the eroded material
- There must be a permeable soil cover and sufficient seepage water
- The soil must be erodable
- The soil must have enough inherent strength to arch over an eroded area forming a roof.

Where soils are too weak to form an arch, subsidence will occur instead of sinkhole formation as documented by Wagener (1982).

Damage to structures and loss of life has been more severe on dolomite land than any other geological formation in southern Africa. Construction problems have been encountered on dolomite since the arrival of industrial development in this country (Wagener, 1982).

The dolomite areas traversed by the Gautrain are characterized by sub-surface bedrock pinnacles, the presence of highly compressible wad material as well as hard rock floaters and extremely strong chert layers.

The Snake Valley area which lies within the alignment of the Gautrain Rapid Rail Link in the study area has never been developed as a residential township due in part to the underlying dolomitic substrate present. A number of sinkholes have occurred in this vicinity and in 2006 a sinkhole event led to the temporary closure and realignment of the N14 national highway which runs through the area (Gigsa, 2009).

According to Buttrick et al. (1993), records from Lyttleton and Valhalla over a 12 year period shows that 63 sinkholes developed in areas of high-density housing where infrastructure is not well maintained while only 5 sinkholes developed in areas of well-maintained low-density housing.

On the 18th June, 1982 a small sinkhole opened up where the Pretoria/Germiston railway line passes under the Pretoria eastern bypass (Wagener, 1982).

During January 1978, flooding caused by heavy rains triggered the occurrence of sinkholes and subsidences on a large number of properties in the residential township of Valhalla, south-west of Pretoria as documented by Brink, (1979).

There were occurrences of sinkholes and compaction subsidences between 2007 and 2009 in and around the study area (Figure 10), during ground investigation and construction phase of the Gautrain Rapid Rail Link, which are documented in the Gautrain sinkhole data base.

Similar problems were also being experienced on dolomite in other parts of the then Transvaal Province. It was found that soon after development started in an area, subsidence in the form of sinkholes and compaction subsidence took place. It was realized that these subsidences were triggered by water ingress and that they occurred in areas where certain conditions existed in the overburden and in the underlying dolomite as documented by Wagener, (1982).

Figure 10a: Sinkhole in Laudium corner 7th Avenue and Pendant street measuring 20 m x 10 m in dimension (July, 2007.)

Figure 10b: Sinkhole in Valhalla, west of old Johannesburg road. (December 2006)

Figure 10c: Sinkhole in Centurion, corner Gerhard Street and West Avenue. (October 2007)

2.2.1 DEPOSITIONAL ENVIRONMENT

As proposed by Wagener (1982), the environment of deposition in any sequence of dolomite, determines to a large extent the engineering characteristics of the residuum.

The Transvaal basin developed as a result of a major period of erosion in post-Ventersdorp times. This basin was occupied by water rich in bicarbonates and silica, leached from decomposed rocks of the Basement Complex and Ventersdorp Supergroup lavas. Carbonates were deposited from the water by both chemical and organic precipitation (Brink, 1979).

$Ca(HCO_3)_2$ dissociates to form insoluble $CaCO_3$, which accumulated over geologic time, forming thick sequences of $CaCO_3$ (Limestone) which is the original precipitate. Magnesium^{-}, Iron^{-} and Manganese rich seawater seeped through this precipitate altering the minerals to form dolomite.

2.2.2 STRATIGRAPHY OF THE DOLOMITE

The Malmani Subgroup is dated between 2 600 Ma and 2 500 Ma but the age of its base remains uncertain. This subgroup in the Transvaal Basin is up to 2 000 m thick and is subdivided into five formations based on the chert content, stromatolite morphology, intercalated shales and erosion surfaces (Eriksson et al. 2006).

The Malmani Subgroup is divided into four Formations in the dolomite section along the Gautrain Rail Link (Kirsten and Venter, 2003; Eriksson et al. 2006), with a total thickness of 1 400 m in the central area (Brink, 1979). It generally dips at an angle of 10° to 20° to the east, with the dip direction bending to the north as the strike bends from N-S to E-W around the Johannesburg Granite Dome. Appendix B shows the different formations along the study route from Jean Avenue Pier 81 across the military area, through Snake Valley down to Eeufees Road in the north.

A description of the four Formations from oldest at the base to the youngest follows:

Oaktree Formation: This Formation is dolomite–rich and chert poor. It is characterized by shallow bedrock and constitutes the base of the Chuniespoort Group with a total thickness of 380m in the central area.

The Oaktree Formation is transitional from siliciclastic sedimentation to platform carbonates and consists of 10-200 m of carbonaceous shales, stromatolitic dolomites and locally developed quartzites (Eriksson et al. 2006).

Monte Christo Formation: This horizon overlies the Oaktree Formation. It is 300 m – 500 m thick and begins with an erosive breccia and continues with stromatolitic and oolitic platformal dolomites (Eriksson et al. 2006).

Dolomite is interbedded with chert in this Formation. The depositional environment was a high-energy intertidal zone and the sediments are biogenic (Wagener, 1982). The depth to bedrock varies from shallow outcrops to areas where the depth is generally greater than 30 m (Buttrick, 1986).

Lyttelton Formation: This follows the Monte Christo Formation with 100-200 m of shales, quartzites and stromatolitic dolomites with little or no chert and high percentage of Iron and Manganese (Eriksson et al. 2006). The strata are from low-energy sub-tidal depositional environment with a thickness of 150 m. Dolomite pinnacles are found at various depths with wad between the pinnacles in several stages of consolidation.

Eccles Formation: Overlying the Lyttelton Formation is the Eccles Formation. This Formation is up to 600 m thick and includes a series of erosion breccias. These breccias within the Eccles Formation are locally auriferous, mineralisation being attributed to the hydrothermal remobilisation of fluids by the Bushveld Complex (Eriksson et al. 2006). This formation consists of dolomite interbedded with massive chert layers. The chert-rich dolomite comprises stromatolitic and oolitic bands. The overburden of dolomite and chert residuum varies in thickness and composition. The environment of deposition was a low-energy supratidal zone and sediments are basically chemical. Dolomite from the Lyttelton Formation with high manganese content is expected to contain substantial amounts of dolomitic residuum (wad) while on the other hand residuum from the Eccles Formation will contain abundant chert.

2.2.3 WEATHERING PROCESS

Dolomitic limestone consists largely of calcium and magnesium carbonate which dissolves in weak acidic water formed by the reaction between carbon dioxide and ground water and leads to the formation of solution cavities.

Rain water contains small amounts of carbon dioxide in solution. As this water reaches the soil surface and percolates through the dolomite profile, there is enrichment of carbon dioxide. The concentration of this gas may be 90 times more in the air in the soil voids than in the atmosphere, (Buttrick, 1986). The water and the carbon dioxide combine to form a weak carbonic acid

$$H_2O + CO_2 \longrightarrow H_2CO_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Dolomite bedrock material is impervious with a porosity of less than 0.3% while the highly fractured, jointed and faulted dolomite rock mass permits access and ingress of water along the discontinuities.

Solution of the bedrock along the joints results in the widening of joints and fractures above the water table. Dolomite, calcite and magnesite dissolve in the weakly acidic groundwater to form bicarbonates. The solution of dolomite by weakly acidic water may be represented as

$$CaMg(CO_3) + 2H_2CO_3 \longrightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2 \ldots\ldots\ldots\ldots \qquad 2$$

As the process of dissolution progresses in the weakly acidic groundwater, joints and fractures gradually open. Pinnacles develop as remnant pillars of rock and are sub-rounded by solution from surface. Due to the insoluble nature of the chert present in chert-dolomite, it remains intact in the residuum between the pinnacles and may weather to a friable white grit due to prolonged exposure.

Below the water table, the water is more acidic with increased rates of mobilization resulting in the slow development of caverns. Due to the highly soluble nature of the magnesite, it is dissolved from the rock, while iron and manganese are in turn oxidized to Fe^{3+} and Mn^{4+} during the weathering process. The solubility of the iron and manganese decrease under intense oxidation such that the hydrates of iron and manganese oxide are deposited with the soluble constituents of the dolomite to form dolomite residuum or also called wad.

3 METHOD OF INVESTIGATION

The main purpose of this chapter is to give a brief definition and detailed description of the different geotechnical investigation methods adopted during the site investigations for the Gautrain Rapid Rail Link in the study area.

Both qualitative and quantitative methods were employed for the gathering, processing and analysing of field data.

3.1 Available information

A detailed literature survey was conducted to gather the published literature on the dolomites of the Malmani Subgroup which underlie the study area.

Prior to the commencement of this investigation, a desktop study was undertaken to determine the geology along the proposed rail link route in the study area. This entailed evaluation of data from previous works carried out in the area and included the following sources:

- BKS (Pty) Ltd 2002. Gauteng SDI Rail Link (Gautrain). Report on the dolomitic stability and geotechnical investigations for route selection purposes, southern Tshwane.
- CGS (2007) Approach to sites on dolomite land
- AGES (2006) Baseline Geohydrological Investigation. A technical report conducted by Africa Geo-Environmental Services on behalf of Bombela Civils Joint Venture for the baseline geohydrological investigation.

3.2 Geotechnical Investigation

Ground investigations conducted at the feasibility and preliminary design stages of the project utilised a combination of gravimetric surveys and boreholes drilled using conventional percussive methods, together with remote techniques including airborne geophysical techniques (EM & Magnetic), localised refraction and electrical surveys. A total of 127 boreholes were drilled along the alignment in the dolomitic area, but the actual depth to rock and the nature of the overburden was not established over significant lengths of the route (Storry et al. 2009).

The detailed geotechnical investigation for the Gautrain Rapid Rail Link started in 2006. The process at every pier position included:

a)

- Typical percussion drilling using a combination of symmetrix and reverse circulation to provide support to the borehole by introducing temporary casing as the borehole advances.
- Each pier comprising (4 to 6) 165 mm diameter rotary percussion boreholes spaced 5 to 9 m apart were drilled 15 m into solid rock in order to fully understand the variation of the rock profile.
- Percussion drilling rigs were fitted with Jean-Lutz parameter recording which enabled relative assessment of the consistency of superficial deposits and hardness of the rock to be evaluated, with stiff drill stem to maintain verticality measurement on steep pinnacle bedrock.
- Borehole radar to establish voidedness, occurrence of floaters (boulders) between bedrock and steeply dipping rock heads
- Test pitting using a specially procured 50 ton excavator.

b) Specialised investigations comprised Cone Penetration Testing, Continuous Surface Wave testing and Pressuremeter testing.

Each of the methods used for gathering and analysing of data is described below.

3.2.1 Drilling

Both down the hole (DTH) percussion drilling and rotary core drilling were used during ground investigation along the route alignment.

3.2.1.1 Percussion Borehole

Percussion boreholes were drilled to determine the nature of the subsurface materials and to ascertain the depth to the groundwater table.

Percussion boreholes are done using percussion hammer which is driven by air and which imparts a rapid series of impacts to the drill bit which is part of the hammer. The rotation drive to the drill stem is provided by a top drive head. The down-the-hole hammer is favoured for geotechnical investigation purposes because of greater versatility and sensitivity particularly when recording penetration times as illustrated by Byrne et al. (1995).

A total of 384 percussion boreholes from 96 piers were investigated along the route alignment from Viaduct 5B (John Vorster interchange) to Viaduct 6 (Eeufees Road), with another 28 percussion boreholes drilled at Centurion Station.

At each pier position between 3 and 5 boreholes were drilled depending on the geotechnical requirement. Pier platforms positions were located at distances of 45 m away from the preceding pier in the study section.

Each borehole commenced by pre-digging to 1.5 m using both hand augers and backhoes, and installing a 1.2 m long 250 mm diameter casing in the inspection pit. This was done to check for any utility prior to commencement of drilling.

Drilling commenced by using the Symmetrix method (168.3 mm diameter), with a Symmetrix casing and heat treated rope threads from the surface down through the 1.2 m steel casing. The boreholes were advanced by this method beyond any soft ground, floaters and cavities until casing extended 6 m into the bedrock.

This method was used to stabilise the ground and prevent the sidewalls from collapsing and was followed by reverse circulation (121 mm diameter) to the end of hole in order to increase drilling efficiency. The termination criterion for each borehole was the intersection of 15 m of continuous solid rock or at a maximum depth of 80 m depending on the subsurface geology.

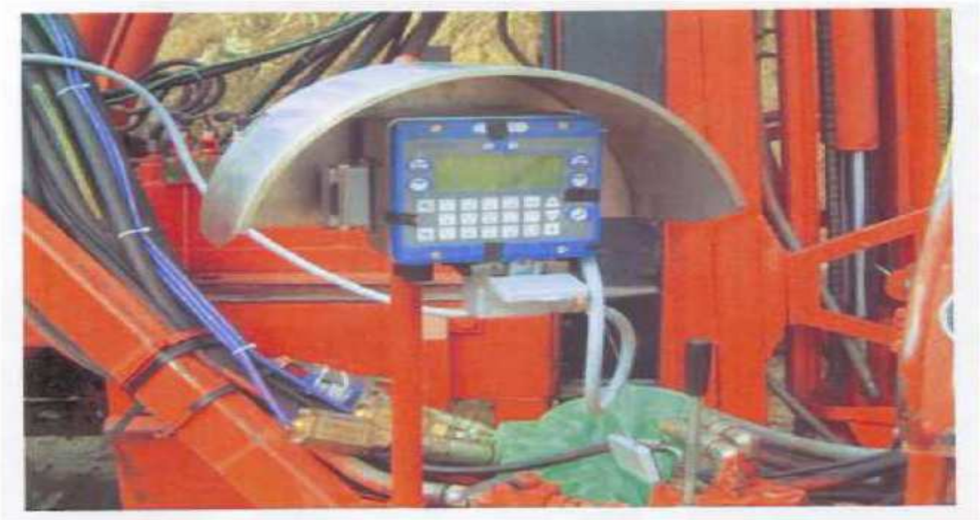
Sampling was carried out for every one metre interval by recording the penetration time in accordance with the percussion record sheet as per BCJV, (2006) and recovering the chippings on to a plastic sheet and then placed on a sample tray, while during the reverse circulation stage samples were taken at 1 m intervals through a cyclone. During drilling operations, records such as the penetration time per metre, air loss, levels of water strikes and intersection of cavities were noted by the operator on a drilling sheet.

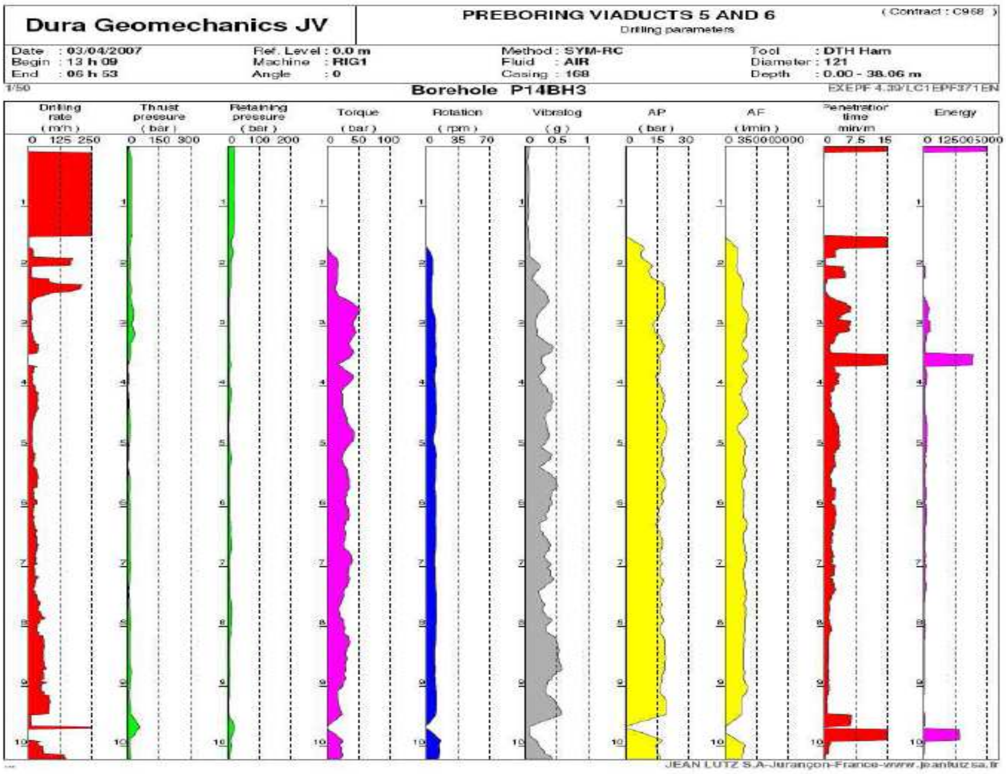
Drilling parameters for each hole were recorded according to the Jean Lutz system for both reverse circulation and symmetrix drilling (DGJV, 2006). The Jean Lutz System is a computerized drilling parameter recording system which monitors a series of sensors installed on standard drilling equipment. These sensors continuously and automatically collect data on all aspects of drilling, in real time, without interfering with the drilling progress. It uses a memobloc which is a credit card type memory card to record all drilling parameters such as the drilling rate, thrust pressure, retaining pressure, torque, rotation, vibralog, air pressure, air fluid, penetration time and energy. The Memobloc was placed in a LT3 computerized system on the drilling rig prior to commencement of drilling as shown in Figure 11 and all parameters recorded. This information was in turn transferred to a computer (EXCEL and PDF files).

Using individual drilling parameter recording measurements, variations in the drilling parameters are interpreted to indicate the presence of fractures, changes in lithology, and competency of the bedrock. For example, under constant thrust and rotation rate, a variation in advance rate would suggest either a change in stratigraphy or the presence of an anomaly such as a cavity or a fracture (Benoit et al. 2002). Appendix C shows the Jean Lutz data, while Appendix D shows the borehole logs for each of the boreholes drilled along the alignment in the study area.

The Jean Lutz data sheet was used in conjunction with the driller’s log during logging to provide additional information such as:

- The drilling parameters recorded by the Jean Lutz during drilling provide a clearer and more accurate explanation of the material in the borehole.
- Additional parameters in the Jean Lutz that are not in driller’s log, e.g. Vibrolog gives more information in terms of hardness i.e. less vibration is recorded if material is soft and more vibration if material is hard.
- Jean lutz data is very useful when there is a poor sample recovery or no sample recovery from a borehole because recorded parameters such as Thrust Pressure, Retaining Pressure, Torque and vibrolog explain the material type in terms of weathering.





Dura Geomechanics JV

PREBORING VIADUCTS 5 AND 6
Drilling parameters
(Contract : C968)

Date : 03/04/2007
Begin : 13 h 09
End : 06 h 53

Ref. Level : 0.0 m
Machine : RIG1
Angle : 0

Method : SYM-RC
Fluid : AIR
Casing : 168

Tool : DTH Ham
Diameter : 121
Depth : 0.00 - 38.06 m

1/50

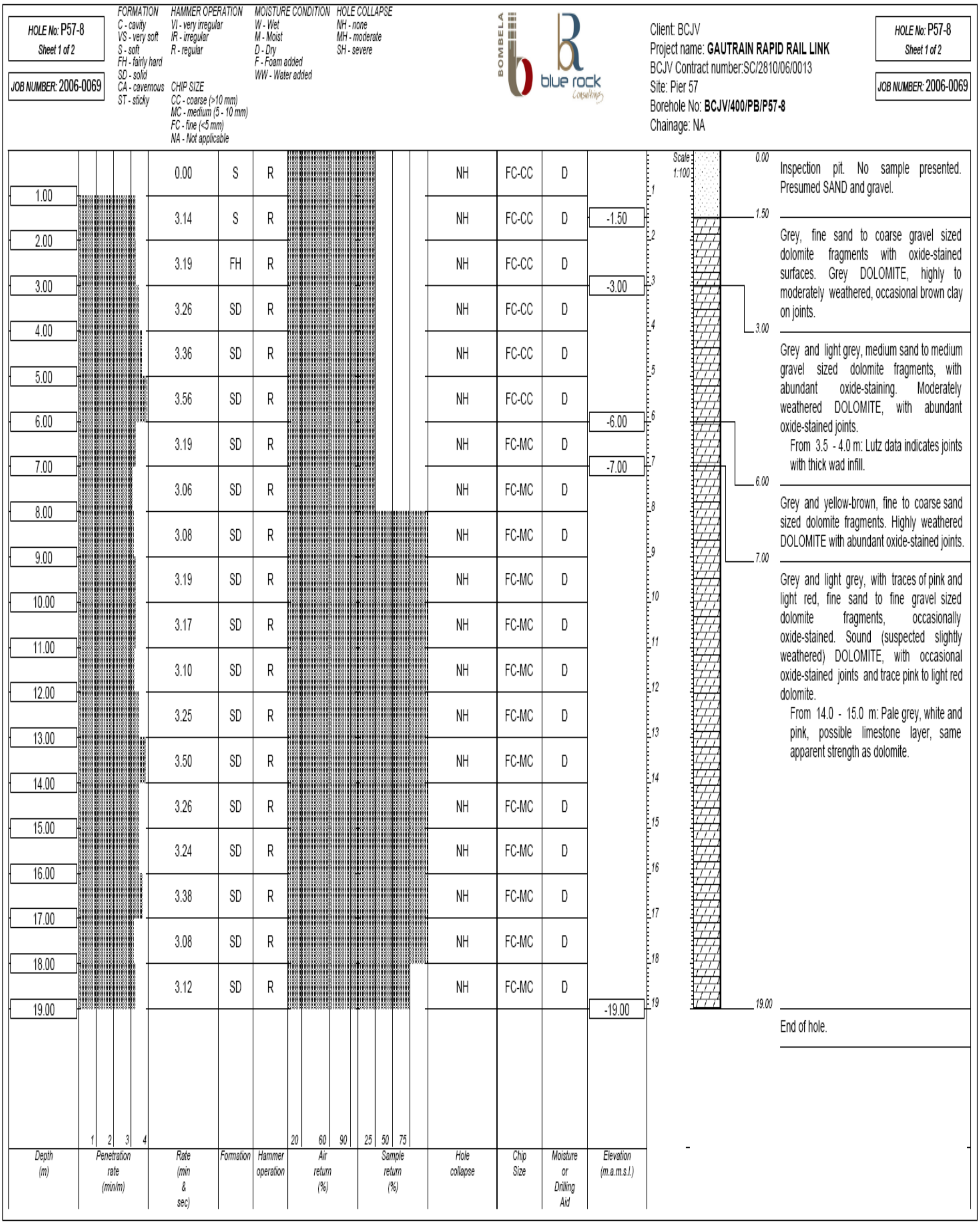
Borehole P14BH3

EXEPF 4.39/LC1EPF371EN

JEAN LUTZ S.A-Jurançon-France-www.jeanlutzsa.fr

Figure 11: LT3 computerized system and the parameters recorded during drilling

The disturbed samples were examined by an engineering geologist who drew up a borehole log as shown in Figure 12 for each borehole completed. Details about penetration time for each metre drilled, chip size, remarks from the driller’s log and description of the material are



HOLE No: P57-8
Sheet 1 of 2

JOB NUMBER: 2006-0069

FORMATION
C - cavity
VS - very soft
S - soft
FH - fairly hard
SD - solid
CA - cavernous
ST - sticky

HAMMER OPERATION
VI - very irregular
IR - irregular
R - regular

CHIP SIZE
CC - coarse (>10 mm)
MC - medium (5 - 10 mm)
FC - fine (<5 mm)
NA - Not applicable

MOISTURE CONDITION
W - Wet
M - Moist
D - Dry
F - Foam added
WW - Water added

HOLE COLLAPSE
NH - none
MH - moderate
SH - severe

Client: BCJV
Project name: **GAUTRAIN RAPID RAIL LINK**
BCJV Contract number:SC/2810/06/0013
Site: Pier 57
Borehole No: **BCJV/400/PB/P57-8**
Chainage: NA

HOLE No: P57-8
Sheet 1 of 2

JOB NUMBER: 2006-0069

Depth (m)	Rate (min & sec)	Formation	Hammer operation	Hole collapse	Chip Size	Moisture or Drilling Aid	Elevation (m.a.m.s.l.)
1.00	0.00	S	R	NH	FC-CC	D	
2.00	3.14	S	R	NH	FC-CC	D	-1.50
3.00	3.19	FH	R	NH	FC-CC	D	-3.00
4.00	3.26	SD	R	NH	FC-CC	D	
5.00	3.36	SD	R	NH	FC-CC	D	
6.00	3.56	SD	R	NH	FC-CC	D	-6.00
7.00	3.19	SD	R	NH	FC-MC	D	-7.00
8.00	3.06	SD	R	NH	FC-MC	D	
9.00	3.08	SD	R	NH	FC-MC	D	
10.00	3.19	SD	R	NH	FC-MC	D	
11.00	3.17	SD	R	NH	FC-MC	D	
12.00	3.10	SD	R	NH	FC-MC	D	
13.00	3.25	SD	R	NH	FC-MC	D	
14.00	3.50	SD	R	NH	FC-MC	D	
15.00	3.26	SD	R	NH	FC-MC	D	
16.00	3.24	SD	R	NH	FC-MC	D	
17.00	3.38	SD	R	NH	FC-MC	D	
18.00	3.08	SD	R	NH	FC-MC	D	
19.00	3.12	SD	R	NH	FC-MC	D	-19.00

Depth	Description
0.00	Inspection pit. No sample presented. Presumed SAND and gravel.
1.50	Grey, fine sand to coarse gravel sized dolomite fragments with oxide-stained surfaces. Grey DOLOMITE, highly to moderately weathered, occasional brown clay on joints.
3.00	Grey and light grey, medium sand to medium gravel sized dolomite fragments, with abundant oxide-staining. Moderately weathered DOLOMITE, with abundant oxide-stained joints. From 3.5 - 4.0 m: Lutz data indicates joints with thick wad infill.
6.00	Grey and yellow-brown, fine to coarse sand sized dolomite fragments. Highly weathered DOLOMITE with abundant oxide-stained joints.
7.00	Grey and light grey, with traces of pink and light red, fine sand to fine gravel sized dolomite fragments, occasionally oxide-stained. Sound (suspected slightly weathered) DOLOMITE, with occasional oxide-stained joints and trace pink to light red dolomite. From 14.0 - 15.0 m: Pale grey, white and pink, possible limestone layer, same apparent strength as dolomite.
19.00	End of hole.

Figure 12: Typical Borehole log with symmetrix and reverse circulation drilling.

contained in the borehole log. The borehole logs, Jean Lutz penetration data and the Borehole Radar data obtained from all boreholes on each pier were incorporated together to bring out a more detailed and comprehensive Geological Stem Plot for each pier as shown in Appendix E. This was then interpreted for every pier to get a more detailed understanding of the ground condition and hence proper design option for each pier.

Upon completion of each percussion hole, PVC casing (minimum internal diameter of 75 mm) was installed to the full depth of the hole and the symmetrix casing removed with the drilling rig's hydraulics from the surface.

The boreholes were then plugged and backfilled with concrete and an engraved plate showing clearly the hole number, depth and contractor's name attached to the concrete block.

3.2.1.2 Rotary Core Drilling

The rotary core drilling technique as shown in Figure 13 is used to drill a borehole which is normally cased through the upper soil profile using a casing fitted with a diamond/tungsten tipped casing shoe. A drilling fluid is used to remove the cuttings and flush them to the surface where they can be sampled. This technique for advancing the borehole is called wash boring and the samples are known as wash samples (Byrne et al. 1995). The borehole is advanced in stages with samples taken at the various depths required.

When materials of rock consistency are encountered and wash boring is no longer effective, rotary core drilling is used to advance the borehole and recover core samples. The cores are drilled using a core barrel which is fitted with a diamond tipped or impregnated drill crown. The core barrel with drill crown is rotated by the drilling rig which also has the means to hydraulically crowd the drill stem (Byrne et al. 1995). A drilling fluid is pumped through the core barrel to cool the drill bit and flush the cuttings to the surface.

Once the core barrel is full, the drill stem with core barrel is withdrawn from the hole and the core sample is recovered and stored in a core box. Core boxes are marked with the depths drilled so that a visual inspection of the core box shows what percentage of core was recovered relative to the depth drilled.

Figure 13: General view of a Rotary Core drilling rig

A total of 41 rotary core boreholes were drilled along the route alignment in the study area from John Vorster interchange to Eeufees Road, with profiles and photographs of these cores enclosed in Appendix F.

As with the percussion drilling, an inspection pit was excavated to a maximum depth of 1.5 m below existing ground level at each position to confirm the presence or absence of any subsurface services

The diameter of the rotary core boreholes was N-size (54 mm) and the drilling fluid consisted of water mixed with Eezymix.

Casing was used to maintain the stability of the drill hole in soft/collapsible formations. Soft formation core samples were obtained by means of NWD4 double (split inner tube) tube core barrels and rock core samples were obtained by TNW core barrels with a 1.5 m core barrel length.

A piezometer/standpipe was installed in each rotary hole or in places where standpipes were not required; the holes were backfilled or sealed off as instructed by the Design Engineer.

3.2.2 GEOPHYSICAL TECHNIQUES

Geophysical exploration is a form of field investigation in which a set of physical measurements relating to the underlying soil or rock strata is made at ground surface or in boreholes (Byrne et al. 1995). The measurements indicate variations in space or time of certain physical properties of the soil/rock materials. The properties of soils/rock which are of significance in geophysical exploration are density, magnetic susceptibility, electrical conductivity, elasticity modulus and thermal conductivity. Since these physical properties vary widely in soils/rock at least one of these properties usually shows marked changes from place to place which can be measured by sufficiently sensitive instrumentation (Byrne et al. 1995). The main application of geophysics in geotechnical investigations is the insertion of subsurface geological strata between carefully controlled drilling positions.

Geophysical methods started playing a role on the dolomites of this country in the late forties when problems associated with sinkholes and subsidences were being encountered in the military areas outside Pretoria (Wagener, 1982).

The techniques described below were used during the site investigations for the Gautrain rapid rail route over the dolomite area.

3.2.2.1 Gravity Survey

Gravity surveys involve the measurement of the earth's gravitational field using a gravimeter and the differences between the theoretical gravity and observed values are related to mass excesses in the earth's subsurface (Wagener, 1982). The unit of measurement is the gal (1 gal =1 cm/sec^2) with gravity contours being plotted in milligal (1 mgal = 10^{-3} gal). Gravity decreases by about 0.2 mgal per metre increase in elevation (Wagener, 1982).

During gravity survey every station should be visited at least twice, with a separate reading loop each time, as a check on repeatability which should be to an accuracy of + 0.025 mgal (Wagener, 1982).

Field observations are corrected for the effects of latitude, elevation, topography and earth-tides and the resultant anomalies are then contoured to produce a Bouguer gravity anomaly map. Mass excesses are represented as ‘gravity highs’ and mass deficiencies as gravity lows on the map (Wagener, 1982).

Gravity surveys are successful on dolomite sites because the bedrock usually has a subsurface relief (buried karst topography) and this is covered by material of a lower density than the solid rock. According to Wagener, (1982), it is estimated that the density of the materials on a dolomite site varies as follows:

Fresh dolomite	2850 kg/m^3
Partially leached dolomite	2600 kg/m^3
Completely leached dolomite and Cemented chert	2600 kg/m^3
Wad	100 – 1200 kg/m^3
Quaternary surface deposits	1600 kg/m^3
Karoo rocks	2000 – 2400 kg/m^3
Average for overburden	2100 kg/m^3

Gravity measurements can be vague due to material of variable density overlying the karst subsurface. A small dense body produces the same anomaly as a larger less dense body. For this reason, a number of boreholes always have to be drilled together with a gravity survey for calibration purposes (Wagener, 1982).

A gravity survey was conducted along part of the Gautrain route as it forms a vital part of the site investigation methods used in assessing dolomite stability.

Apart from existing data covering both the northern and central parts of the study area, infill data were also gathered over all sections of the rail route alignment in the study area.

The survey consisted of both single to three parallel lines, with station spacing varying from 10 m to 45 m in different sections along the route.

In the Centurion Station area, the survey required the merging of both pre-existing data (318 stations) with newly-collected data (126 stations) with varying station spacing from 10 m to 30 m.

3.2.2.2 Borehole Radar

The dolomites pose complicated ground conditions for foundation design due to the different soils overlying the bedrock and the karst formation in the dolomite bedrock which has resulted in an irregular bedrock profile and voids within the bedrock.

The karst rock weathering boundary is steep in the dolomites, and this sudden change from unweathered rock to weathered residuum (soils) meant that voids, soft zones and steeply dipping rockhead in very close distance to the boreholes would very likely go undetected by drilling alone. According to Tosen et al. (2009), the presence of these features was required to be known for foundation options in addition to defining the extent of ground improvement (void filling).

In order to more fully understand the ground conditions along the route and more specifically at each pier position, Bombela Civils Joint Venture undertook a rigorous approach to the ground investigations utilizing several techniques which could be used to cross check the data obtained. In addition to the gravity and drilling, it was decided to include a borehole radar survey. The quantitative results would provide a detailed evaluation of the dolomite bedrock topography, its integrity, and facilitate detail design. Borehole radar could detect features at a high resolution with good rock penetration in a short time.

The borehole Ground Penetration Radar (GPR) is the only geophysical technique capable of imaging individual small voids and fractures that do not intersect a borehole (Bergstrom, 2000).

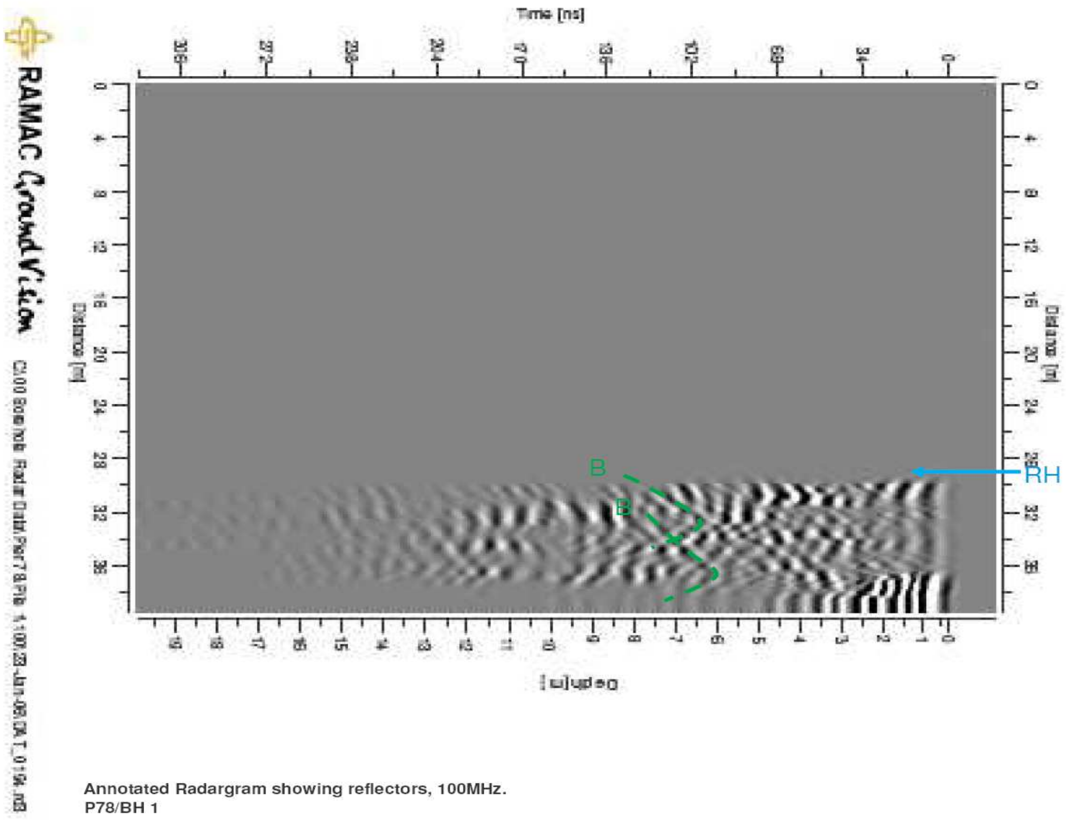
The borehole radar used during site investigation consisted of a 250 MHz radar transmitter and receiver built into separate probes, and these probes were in turn connected in series and linked to a control unit via an optical cable. The control unit was used for time signal generation and data acquisition and the data storage and display unit was either a laptop computer or display monitor.

The transmitter sends out radar waves down inside the borehole. These waves travel omni directional and are capable of picking up reflectors 12 m away from the investigating borehole wall. Reflectors like fractures, voids and other boreholes are recorded by the receiver as a result of the difference in electrical conductivity of the medium. A standard approach for the processing of the borehole radar results was developed for the Gautrain to ensure that the results from different piers could be compared. Groundvision® software was used to process the results and produce radargram plots. Vital information concerning the local geologic conditions is obtained from the amplitude of the first arrival and arrival time of the transmitted wave. The reports for each borehole included an annotated radargram plot (Figure 14) and factual report sheet to categorise different wave trace properties with depth (Tosen et al. 2009), to describe:

- First wave arrival time and attenuation which correlates with rock quality.
- Signal transmission from borehole which provides a measure of rock quality away from borehole
- Reflector types:
    - Patch (small cavity, irregular discontinuity)
    - Parabola (cavity)
    - Linear (rockhead, discontinuity [fault/joint]
    - Linear BH (borehole)

Interpretation of the radargrams for boreholes surveyed at each pier location enabled for the position, attitude (dip and strike) and proximity of features to be determined.

The radargram comprises a plot of wave traces resolved in grey scale plotted transverse to the borehole depth axis. In portrait format two horizontal axis formats are presented. The wave trace for each depth increment is plotted relative to the recorded time (ns) axis. This is resolved for a signal penetration depth on the basis of a propagation speed in dolomite of 125 micrometres per second (um/sec) which was established as an average during trials at the start of the survey. On this basis the signal penetration length is shown on the chart bottom axis and limited to a distance approximately 12 metres away from the borehole. The borehole survey depth extends along the vertical axis of the chart labelled distance (m), (Bergstrom, 2000).



Annotated Radargram showing reflectors, 100MHz.
P78/BH 1

Figure 14: Annotated Radargram plot showing reflectors (RH-Rockhead. B-Parabola)

Signal attenuation (absorption) is dependent upon the electrical conductivity of the subsurface materials, and is higher in materials with high electrical conductivity such as clay and lower in relatively low-conductivity materials such as dry sand or rock.

The single-hole reflection borehole radar survey mode was used at pier positions during the survey as shown in Figure 15. The survey is carried out by lowering the probe in a PVC pipe installed to the full depth of the borehole to protect the probe from sidewall collapse. At each pier position surveys were carried out in between 3 to 6 boreholes depending on the number of boreholes drilled at a particular pier.

Borehole radar surveys were carried out simultaneously with the drilling of boreholes at pier locations so that additional boreholes could be drilled where features were detected that may influence the foundation design. Examples of borehole radargram surveys are shown in Figure 16 which includes a geological stem plot (hard rock black grading to light grey for soils) and graph showing the drill penetration rate with depth (grid interval is 1 min/m) as described by Tosen et al. (2009). Radargram labels “A” indicate wave traces with longer intervals for first arrival time which also have a smaller amplitude (correlating with faster penetration zones and weathered rock or soil) compared with wave traces labelled “C” (correlating with rock having much slower drill penetration rates).

The high resolution detection capability of the borehole radar method is shown by the ability for surveys to detect adjacent boreholes located next to the survey borehole. The positions of adjacent boreholes appear as reflectors with black and white parallel lines as shown in Figure 17 labelled “T” and “U”. These reflectors show two boreholes dipping away from the survey borehole located 6 to 12 m from the survey borehole. The same borehole reflector trace may also show apparent deviation from the survey borehole as labelled at two locations “V1” and “V2”. The curvilinear shape results from a difference in the conductivity of the rock. The drill penetration rates confirms a gradual difference in the rock with slower drill penetration rates at “V1” associated with a slower signal propagation time compared to “V2”

Radargram interpretation should include reference to drill records and logged samples to prevent misinterpretation, since the curvilinear trace may be incorrectly delineated as a parabolic type reflector which is indicative of voids or highly weathered zones in rock.

Figure 15: Borehole radar survey at pier location

The reflectors of adjacent boreholes confirm the nature of the rock between the two boreholes as voids or highly weathered zones between the boreholes would result in high signal attenuation (loss of the reflector or change in propagation speed.

The reflector patterns for both grykes and subhorizontal weathered zones generally have a parabolic shape (Tosen et al. 2009), with axis of symmetry perpendicular to the borehole.

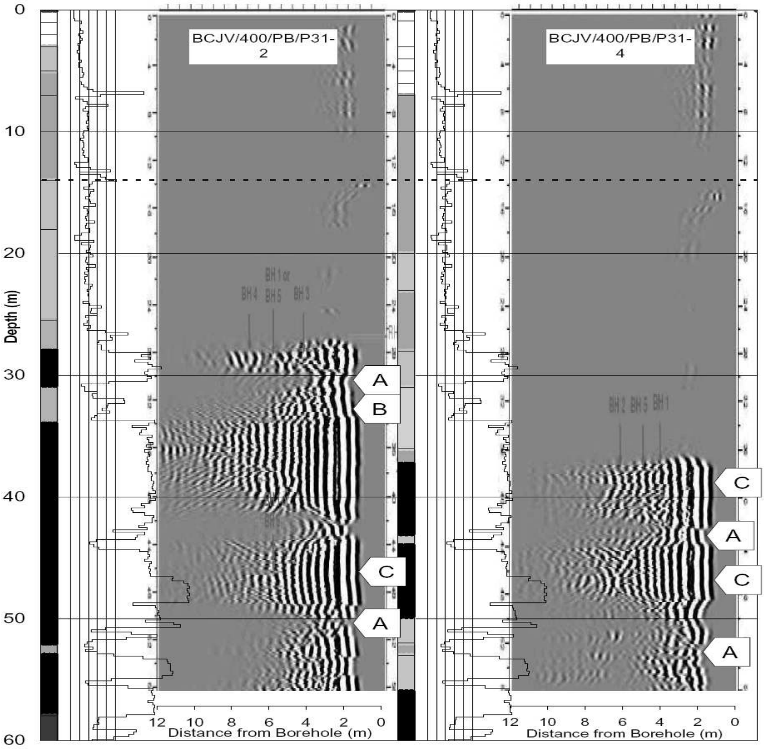


Figure 16: Borehole radargram survey results showing correlation of wave trace first arrival time and amplitude with soil and different grades of rock weathering (after Tosen et al. 2009).

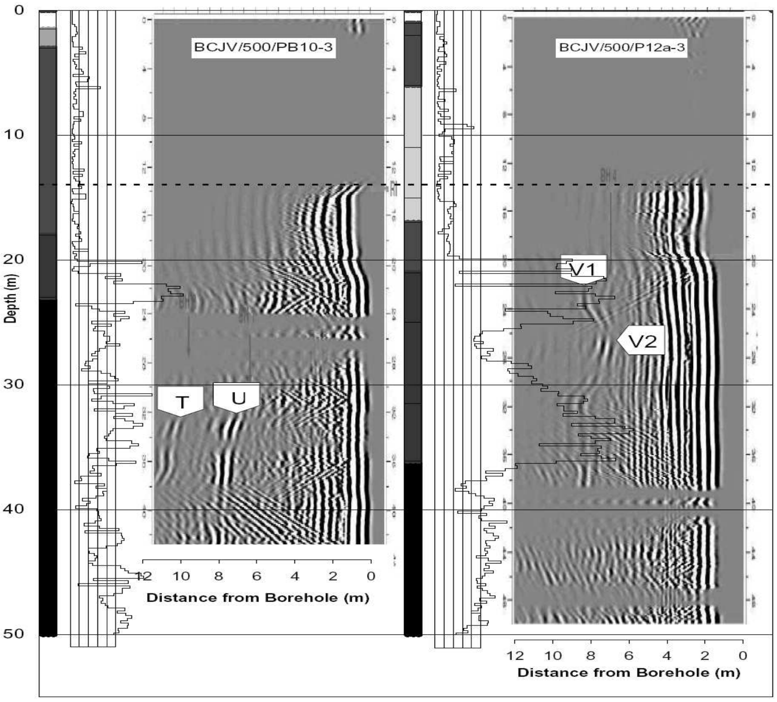


Figure 17: Borehole radargram survey results showing adjacent borehole reflectors (after Tosen et al. 2009).

Figure 18 shows the results of a borehole radar survey with several parabolic reflectors, borehole stem plots and drill penetration rate results for two boreholes drilled 6 and 9 m from the survey hole. These boreholes intersect the cavity zones delineated by the radar survey. The labels “P, Q, R and X” are situated at the inflexion points of the parabolic reflectors indicating that the cavity zones are 2 to 6m away from the survey borehole.

The results of borehole radar survey carried out along the dolomite route alignment showing the annotated radargram plots, factual and close-out reports are enclosed in Appendix G.

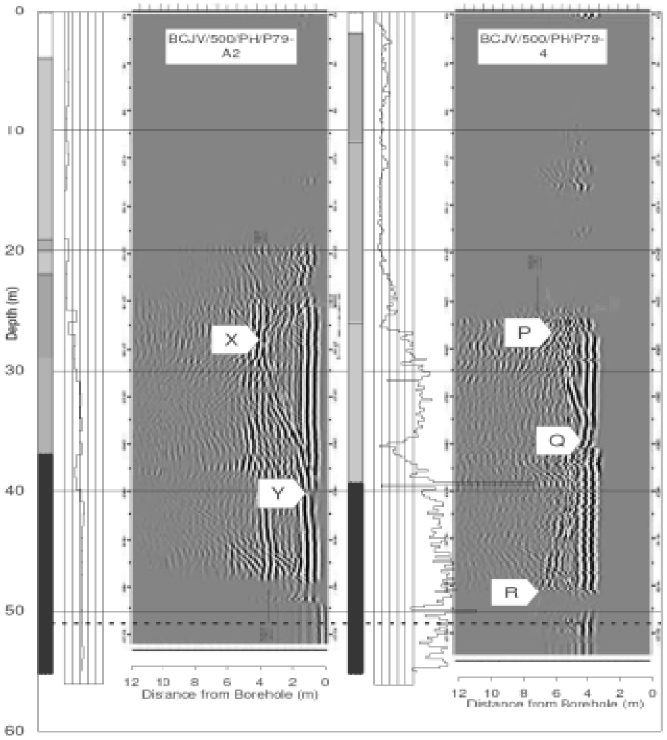


Figure 18: Borehole radargram survey results showing dipping linear reflectors intersected by survey boreholes (after Tosen et al. 2009).

3.2.2.3 Continuous Surface Wave (CSW) Test

This is a quick and less expensive technique for determining ground stiffness by measuring the velocity of Rayleigh wave propagation along the ground surface. This test is non-intrusive and non-destructive thus making it attractive for civil engineering applications (Heymann, 2008).

The continuous surface wave test uses a shaker to generate Rayleigh waves that travel along the surface of the soil by applying a vertical sinusoidal force of known frequency, with high frequencies producing short Rayleigh waves which penetrate only a shallow depth while low frequencies produce long wavelengths which penetrate to greater depths. Testing at a range of frequencies allows a Rayleigh wave velocity profile to be established. Rayleigh wave propagation is detected by an array of geophones placed at the surface in a line radiating away from the shaker. The response of the geophones determines both the wavelength and the velocity of the Rayleigh wave at any particular frequency (Heymann, 2008).

For the purpose of this project, two shakers were used as the seismic energy source in the study section. An 80 kg shaker was used at relatively high frequencies ranging from 10 to 90Hz to sample shallow depths while a low frequency shaker of 250 kg, operating in the frequency range 7 to 22 Hz was used for deeper measurements as documented by Heymann, (2008). Both shakers were counter rotating balanced eccentric weight shakers driven by a three phase motor subjected to angular velocity control. An array of five 4.5 Hz surface geophones as displayed in Figure 19 was used to measure the seismic response of the shakers. A geophone spacing of 0.5 m was used for the 80 kg shaker and a spacing of 1.0 m was used for the 250 kg shaker.

Processing of the geophone output was aimed at determining the wave length and velocity of the Rayleigh wave for each vibration frequency. This was achieved by calculating the phase difference between geophones for the continuous wave generated by the shaker (Heymann, 2008).

The shear stiffness of the soil at very small strains (G_0) is related to the bulk density (P) and the shear wave velocity (V_S) :

$$G_0 = pV_S^2 \quad \text{---} \quad (3)$$

According to Heymann, (2008), at a depth of about half to one third of the wavelength both the vertical and horizontal components of the Rayleigh wave amplitude reaches a maximum and diminishes below this depth. As a result of this, the simplifying assumption is often made that the effective depth of penetration of a Rayleigh wave is between half to one third of the wavelength. This inversion technique is called simplified inversion and allows an average stiffness to be determined for the material to a particular depth. For highly heterogeneous soil profiles such as those commonly found in dolomitic areas this inversion technique is the only practical inversion technique available (Heyman, 2008).

The CSW technique has a number of limitations (Heyman, 2008):

- Due to the fact that the source and receivers are all located at the ground surface, the CSW method becomes less accurate with depth.
- The CSW method is not ideal for “profiling” applications where the layering of the soil profile is required
- In a layered profile where large contrasts exist between the stiffness of layers, the CSW method using the simplified inversion technique will not exhibit the contrast in stiffness accurately.
- Where soft layers are present at depth, or below a stiff layer, the simplified inversion method may not detect these soft layers.

When applying the CSW technique in dolomitic areas as was the case for the Gautrain rapid link project, two further limitations should be recognized (Heyman, 2008):

- The CSW technique is not suitable for detection of cavities.
- When hard rock pinnacles are present within the depth of measurement, the profile is heterogeneous in a lateral direction. The CSW method which relies on a constant Rayleigh wave velocity for the extent of the geophone trace is clearly not suitable. For this reason the CSW technique should ideally only be applied in cases where the bedrock is sufficiently deep as not to influence the Rayleigh waves.

A total of 70 stiffness profiles were measured throughout the study area from Viaduct 5T (Techno Park), Viaduct 5C and the military area towards Eeufees Road. A full report and test results from this technique are enclosed in Appendix H.

Figure 19: Continuous Surface Wave testing showing geophones and a shaker

3.2.3 SOIL PROFILING

3.2.3.1 Test Pits

The use of test pits as an investigation technique provides a quick and economical method for obtaining reliable geotechnical information (Byrne, et al. 1995). The soil profile obtained using a TLB is only for the upper two to three metres and deeper with an excavator. Test pits cannot be used in areas of shallow water table.

A standard procedure of soil profiling for civil engineering purposes was developed by Jennings et al. (1973). A test pit is excavated and field inspections are made of useful descriptors, namely moisture, colour, consistency, structure, soil type and origin (MCCSSO) (AEG/SAIEG, SAICE, 2002). Disturbed and undisturbed samples can be recovered for laboratory tests. A soil profile is then drawn up and provides important information to decide on foundation solutions (Wagener, 1982).

On a dolomite site with near-surface pinnacles and boulders it has been found that test pits can give false information (Wagener, 1982). Such test pits are usually excavated at points of least resistance and a true picture of the distribution of pinnacles and boulders is not obtained. For this reason it is recommended that trenches be excavated instead of pits on a dolomite site with near-surface pinnacles and boulders (Wagener, 1982). It is also necessary that such trenches be excavated at right angles to the strike of the geological features.

On a site with shallow pinnacles and boulders the length of trench should be in the region of 20 m whereas it can be as short as 5 m on a site with thick chert gravel and sand (Wagener, 1982).

It is necessary that the trenches are profiled as soon as possible after excavation by an experienced engineering geologist. A ladder is used for access and for safety reasons the work should not be done without somebody in attendance at the surface. If a hole appears to be unstable, it should not be entered but rather assessed from the surface (Wagener, 1982).

A total of 152 test pits were excavated along the Gautrain route over the dolomite area from the John Vorster interchange, through the Military area to Eeufees Road using a tractor mounted loader backhoe (TLB) and following the safety procedures as set out in the SAICE Code of Practice (2003, updated 2007). Soil profiling was carried out on each of these pits according to the accepted South African Standard (AEG/SAIEG/SAICE, 2002) and samples were taken for foundation indicator testing to determine the geotechnical properties of the soil.

3.2.3.2 Large Diameter Auger

This involves the drilling of large diameter auger holes using typical piling rigs as shown in Figure 20. An experienced engineering geologist is lowered down the hole by means of a small winch on a boatswain’s chair to profile the hole by inspecting the sidewalls and the base. Undisturbed samples from the sidewalls or base of the hole can also be taken for laboratory testing and horizontal plate load tests can also be performed on site. For the successful application of this technique, it is important that the sidewalls of the auger holes remain stable during drilling and profiling. This method is ideally suited to sites with deeply weathered profiles and it is not suited to areas with a high water table where collapse of the sidewall is most likely.

During site investigation in the study area, a total of 48 auger holes, each with diameter of 900 mm were drilled along the Gautrain route, 42 in the military area towards Eeufees Road and 6 around the Techno Park area. Figure 21 is a photograph of an engineering geologist on a boatswain's chair, being lowered down a hole, supported with a temporary steel casing, for a profiling session. Results from both field and laboratory test are contained in Appendix I.

Figure 20: Large Diameter Auger Rig drilling in the Military area

Figure 21: An engineering geologist being lowered down a hole for profiling

3.2.4 Cone Penetration Test

The Cone Penetration Testing (CPT) was also used as one of the methods during the geotechnical investigation. One of the important applications of the CPT test is to evaluate variations in soil type within the profile without test pitting or trenching to expose the in-situ profile.

A CPT test is carried out by pushing a 60^0 cone having a cross sectional area of 1 000 mm^2, usually equipped with a friction sleeve which is of the same diameter of the cone and has a surface area of 1.5 x 104 mm^2, into the ground at a rate of 20 mm/sec. Separate measurements of cone penetration resistance (point resistance), total penetration resistance and the side friction resistance of the friction sleeve are made continuously throughout the test (Byrne et al. 1995).

The major advantage of this method is the fact that the testing procedure is relatively simple and repeatable, and the test results are more amenable to a rational analysis rather than relying entirely on empirical correlation. The CPT also gives a virtually continuous record of soil resistance values throughout the depth of penetration.

The data obtained from the Cone Penetration Test may be employed to (Byrne et al. 1995):

- Assist in the evaluation of the type and stratigraphy of the soil present
- Interpolate ground conditions between control boreholes
- Evaluate engineering parameters of soils (relative density, shear strength, compressibility characteristics, liquefaction potential).
- Assess driveability, bearing capacity and settlement of piled foundations

A total of 29 CPT tests, four at Techno Park, ten at Viaducts JV/JA, twelve in the Military area, and three at the viaduct crossing Eeufees Road were conducted on gravelly sand, clayey sand, silt and subordinate chert layers, wad and sandy clay soil with results enclosed in Appendix J.

3.2.5 Pressuremeter Test (PMT)

This test as documented by Byrne et al. (1995) was originally developed by Menard in 1956 and comprises a horizontal in-situ loading test carried out in a borehole by means of a cylindrical expandable probe. There are two broad categories of tests which can be distinguished based on the method of installation of the device in the ground

- Menard type pressuremeter (MPM) test in which the device is installed in a borehole.
- Self-boring pressuremeter (SBP) test in which the device bores its own way into the ground usually from the bottom of a borehole.

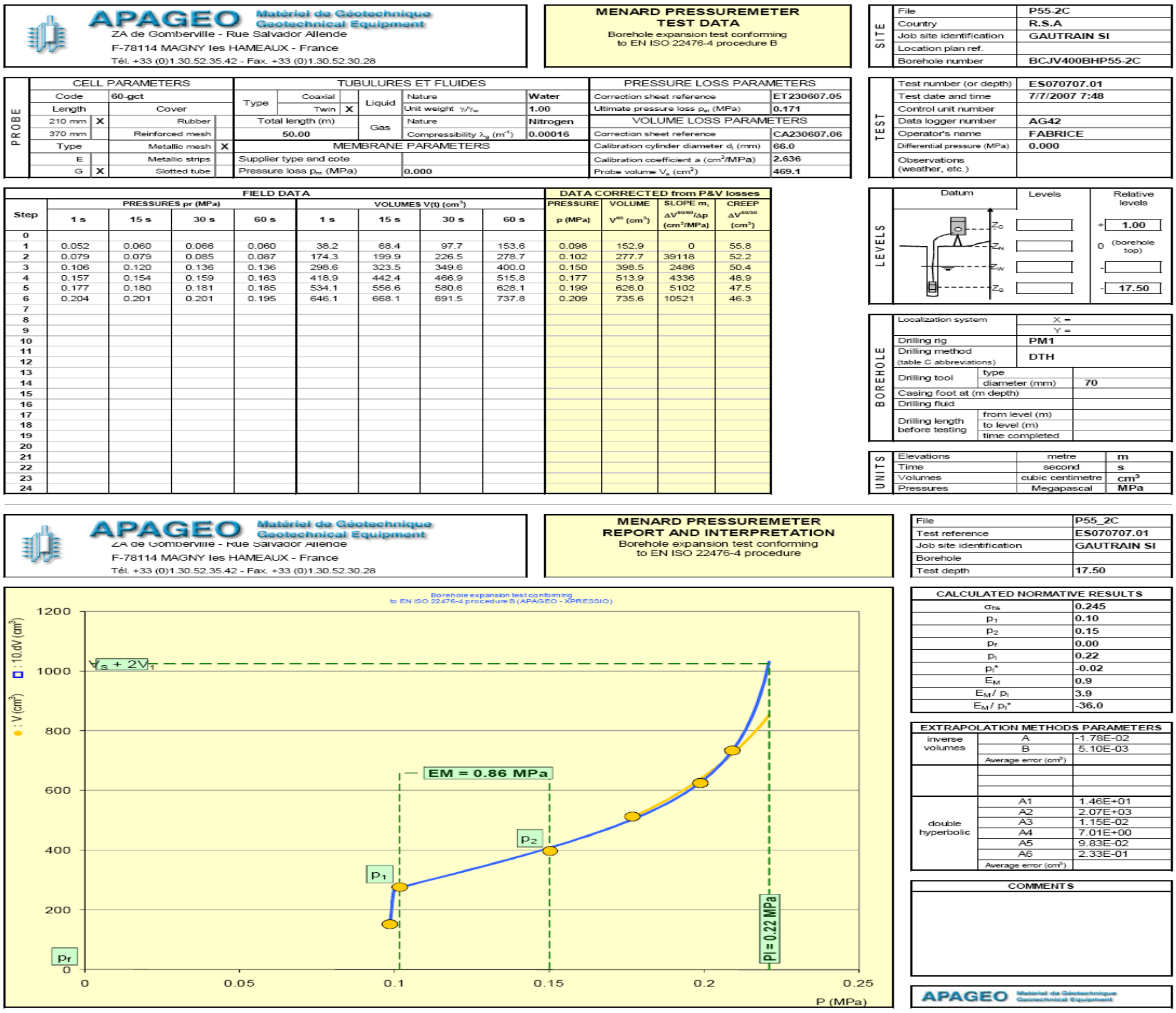
The following parameters can be deduced from Pressuremeter Test results (Byrne et al. 1995):

- Deformation modulus (i.e. compressibility)
- Undrained shear strength for clays or weak rocks.
- Effective angle of friction for sands
- In-situ total horizontal stress.

The degree of success in obtaining any of these parameters is mainly dependent upon the type of test and the interpretation of the data (Byrne, et al. 1995). Consideration must also be given to possible differences in the properties of soil horizons measured in a horizontal direction by the pressuremeter, and those required for many design problems which are more concerned with vertical properties (Byrne, et al. 1995).

A total of 22 Pressuremeter Tests were conducted on the wad profile along the Rail Route alignment using the Menard type Pressuremeter test with a cylindrical expandable probe as shown in Figure 22**,** and the results are enclosed in Appendix K. The test data was recorded and calculations made with Apageo® software and presented in the format as shown in Figure 23**.**

Figure 22: Pressuremeter Monitoring Box and expandable probe



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MENARD PRESSUREMETER TEST DATA
Borehole expansion test conforming to EN ISO 22476-4 procedure B

SITE	
File	P55-2C
Country	R.S.A
Job site identification	GAUTRAIN SI
Location plan ref.	
Borehole number	BCJV400BHP55-2C

PROBE

CELL PARAMETERS			
Code	60-gct		
Length		Cover	
210 mm	X	Rubber	
370 mm		Reinforced mesh	
Type		Metallic mesh	X
E		Metallic strips	
G	X	Slotted tube	

TUBULURES ET FLUIDES					
Type	Coaxial		Liquid	Nature	Water
	Twin	X		Unit weight γ_l/γ_w	1.00
Total length (m)			Gas	Nature	Nitrogen
50.00				Compressibility λ_g (m^{-1})	0.00016

MEMBRANE PARAMETERS	
Supplier type and cote	
Pressure loss p_m (MPa)	0.000

PRESSURE LOSS PARAMETERS	
Correction sheet reference	ET230607.05
Ultimate pressure loss p_{el} (MPa)	0.171

VOLUME LOSS PARAMETERS	
Correction sheet reference	CA230607.06
Calibration cylinder diameter d_i (mm)	66.0
Calibration coefficient a (cm^3/MPa)	2.636
Probe volume V_s (cm^3)	469.1

TEST	
Test number (or depth)	ES070707.01
Test date and time	7/7/2007 7:48
Control unit number	
Data logger number	AG42
Operator's name	FABRICE
Differential pressure (MPa)	0.000
Observations (weather, etc.)	

FIELD DATA									DATA CORRECTED from P&V losses			
	PRESSURES pr (MPa)				VOLUMES V(t) (cm^3)				PRESSURE	VOLUME	SLOPE m_i	CREEP
Step	1 s	15 s	30 s	60 s	1 s	15 s	30 s	60 s	p (MPa)	V^{60} (cm^3)	$\Delta V^{60/60}/\Delta p$ (cm^3/MPa)	$\Delta V^{60/30}$ (cm^3)
0												
1	0.052	0.060	0.066	0.060	38.2	68.4	97.7	153.6	0.098	152.9	0	55.8
2	0.079	0.079	0.085	0.087	174.3	199.9	226.5	278.7	0.102	277.7	39118	52.2
3	0.106	0.120	0.136	0.136	298.6	323.5	349.6	400.0	0.150	398.5	2486	50.4
4	0.157	0.154	0.159	0.163	418.9	442.4	466.9	515.8	0.177	513.9	4336	48.9
5	0.177	0.180	0.181	0.185	534.1	556.6	580.6	628.1	0.199	626.0	5102	47.5
6	0.204	0.201	0.201	0.195	646.1	668.1	691.5	737.8	0.209	735.6	10521	46.3
7												
8												
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15												
16												
17												
18												
19												
20												
21												
22												
23												
24												

LEVELS		
Datum	Levels	Relative levels
Z_C		+ 1.00
Z_N		0 (borehole top)
Z_W		-
Z_S		- 17.50

BOREHOLE		
Localization system		X = Y =
Drilling rig		PM1
Drilling method (table C abbreviations)		DTH
Drilling tool	type	
	diameter (mm)	70
Casing foot at (m depth)		
Drilling fluid		
Drilling length before testing	from level (m)	
	to level (m)	
	time completed	

UNITS		
Elevations	metre	m
Time	second	s
Volumes	cubic centimetre	cm^3
Pressures	Megapascal	MPa

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MENARD PRESSUREMETER REPORT AND INTERPRETATION
Borehole expansion test conforming to EN ISO 22476-4 procedure

File	P55_2C
Test reference	ES070707.01
Job site identification	GAUTRAIN SI
Borehole	
Test depth	17.50

CALCULATED NORMATIVE RESULTS	
σ_{hs}	0.245
p_1	0.10
p_2	0.15
p_f	0.00
p_l	0.22
p_l^*	-0.02
E_M	0.9
E_M / p_l	3.9
E_M / p_l^*	-36.0

EXTRAPOLATION METHODS PARAMETERS		
inverse volumes	A	-1.78E-02
	B	5.10E-03
	Average error (cm^3)	
double hyperbolic	A1	1.46E+01
	A2	2.07E+03
	A3	1.15E-02
	A4	7.01E+00
	A5	9.83E-02
	A6	2.33E-01
	Average error (cm^3)	

COMMENTS

Figure 23: Pressuremeter data record for PMT hole at Pier 55

3.2.6 Dynamic Probe Super Heavy (DPSH)

The test equipment comprises of a 60^0 disposable cone, 50 mm in diameter and fitted to the bottom of an “E” size rod (Figure 24) that is driven into the ground by a 63.5 kg hammer falling through 762 mm (Byrne et al. 1995). The number of blows required to drive the cone through each successive 300 mm of penetration is recorded and this gives an indication of consistency. Once refusal depth is reached (more than 100 blows per 300 mm), the driving rods are pulled up by 600 mm. The disposable cone remains at the base of the hole. The rods are then re-driven with the number of blows per 300 mm being recorded. The re-drive blow counts provide an indication of the skin friction acting on the drive rods.

Figure 24: Dynamic Probe Super Heavy testing in Techno Park

4 RESULTS

This chapter deals with the detailed information obtained from ground investigations carried out along the Gautrain Rapid Rail Link in the study section and the presentation of each dataset. The ground investigation results show the viaduct alignment is underlain by soils comprising transported material and residual soils formed by the weathering of predominantly dolomite and chert. The ground profile includes both weathered and unweathered syenite occurring in the form of dykes and sills, with skarn at the dolomite contact ranging from centimeters to metres in thickness observed at some deep excavations.

The dolomite bedrock topography is highly variable as reflected in Figure 25, with differences in depth to solid bedrock of 20 to 30m delineated between boreholes drilled at a pier location. Drilling parameters for the boreholes were recorded with Jean Lutz drill parameter recorders. These measurements helped to facilitate the characterisation of the various material types (Tosen et al. 2009) and enabled an assessment of the extent of zones according to the drilling penetration rate. A summary of the various types of ground investigations conducted in different sections along the Gautrain Route over the area underlain by dolomite bedrock is shown in Table 3, while the main material types intersected is summarised in Table 4.

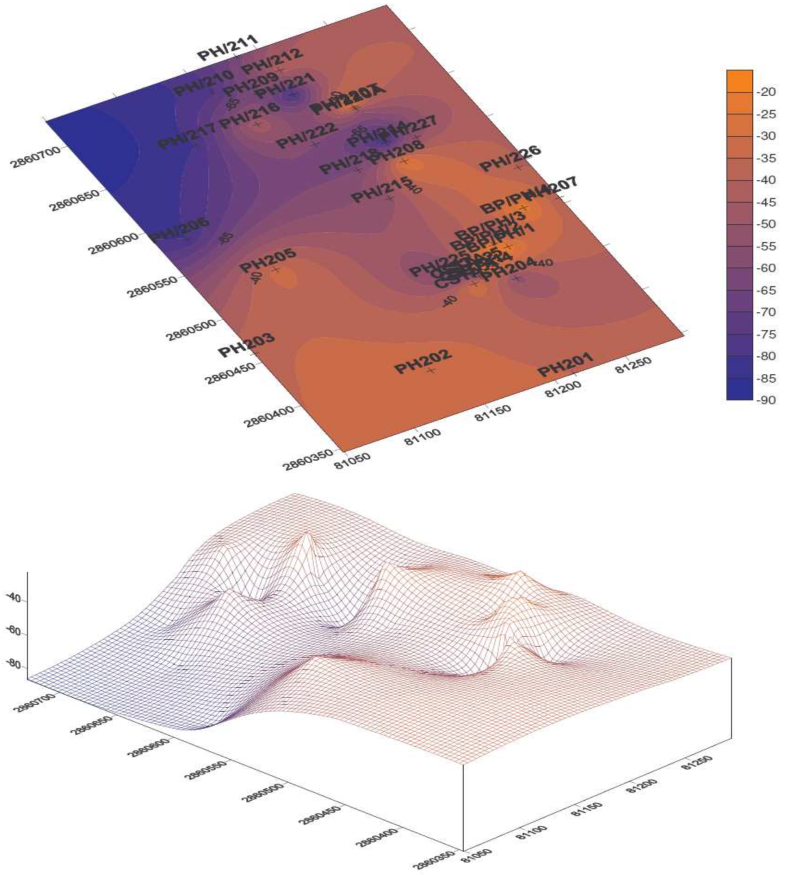
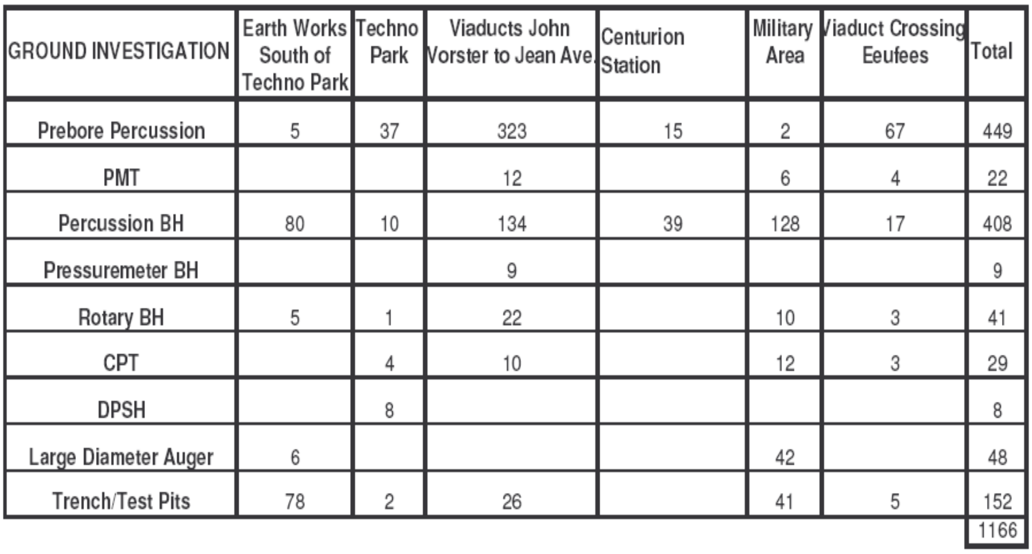


Figure 25: schematic diagram showing variable rock head for boreholes drilled at Centurion Station.

Low density or voided sections are delineated by high penetration zones (Table 4) on the profile. These low density zones as documented by Tosen et al. (2009), represent zones of relative instability in the profile, which may be linked to form preferential pathways for ingress of water to solution cavities in the bedrock and hence comprise a necessary component for sinkholes development.

Table 3: Summary of Ground investigation works along the Gautrain Rapid Rail Link



GROUND INVESTIGATION	Earth Works South of Techno Park	Techno Park	Viaducts John Vorster to Jean Ave	Centurion Station	Military Area	Viaduct Crossing Eeufees	Total
Prebore Percussion	5	37	323	15	2	67	449
PMT			12		6	4	22
Percussion BH	80	10	134	39	128	17	408
Pressuremeter BH			9				9
Rotary BH	5	1	22		10	3	41
CPT		4	10		12	3	29
DPSH		8					8
Large Diameter Auger	6				42		48
Trench/Test Pits	78	2	26		41	5	152
							1166

Table 4: Summary of main dolomite profile material types (after Tosen et al. 2009)

Lithology	Thickness (m)	Drill Rate (mm:ss/m)
Colluvium	0 - 3	00:20 to 01:00
Chert Gravel (matrix: Or/Br Sand and Silt)	1 - 30	00:20 to 01:30
Chert and Wad (matrix: Black Wad Silt)	1 - 40	00:20 to 01:30
Wad	1 - 30	00:05 to 00:20
Residual Syenite	1 - 20	00:20 to 00:45
Syenite	Sills and dykes	02:00 to 05:00
Dolomite (incl. Chert)	Bedrock	01:45 to 03:00

4.1 Percussion Drilling

A total of 449 Prebore holes were drilled along all 96 piers using both the symmetrix and reverse circulation methods while an additional 408 holes were drilled using “down the hole” (DTH) hammer. The results for boreholes drilled along pier positions on each section of the viaduct, showing depth to bedrock, average mean as well as standard deviation are presented in Tables 5 (Appendix N), while summary of borehole logs is presented in Table 6 (Appendix N). These tables show the variability in rock head encountered during percussion drilling in the study area. Each borehole was drilled at least 15 m into the rock in order to confirm that bedrock has been found and not a large “floater” which might be present in the overburden above bedrock level. Typical variations of 20 m or more were delineated over distances of 3 m along the route alignment underlain by dolomite as shown in tables with standard deviations ranging from 9.5 to 19.5.

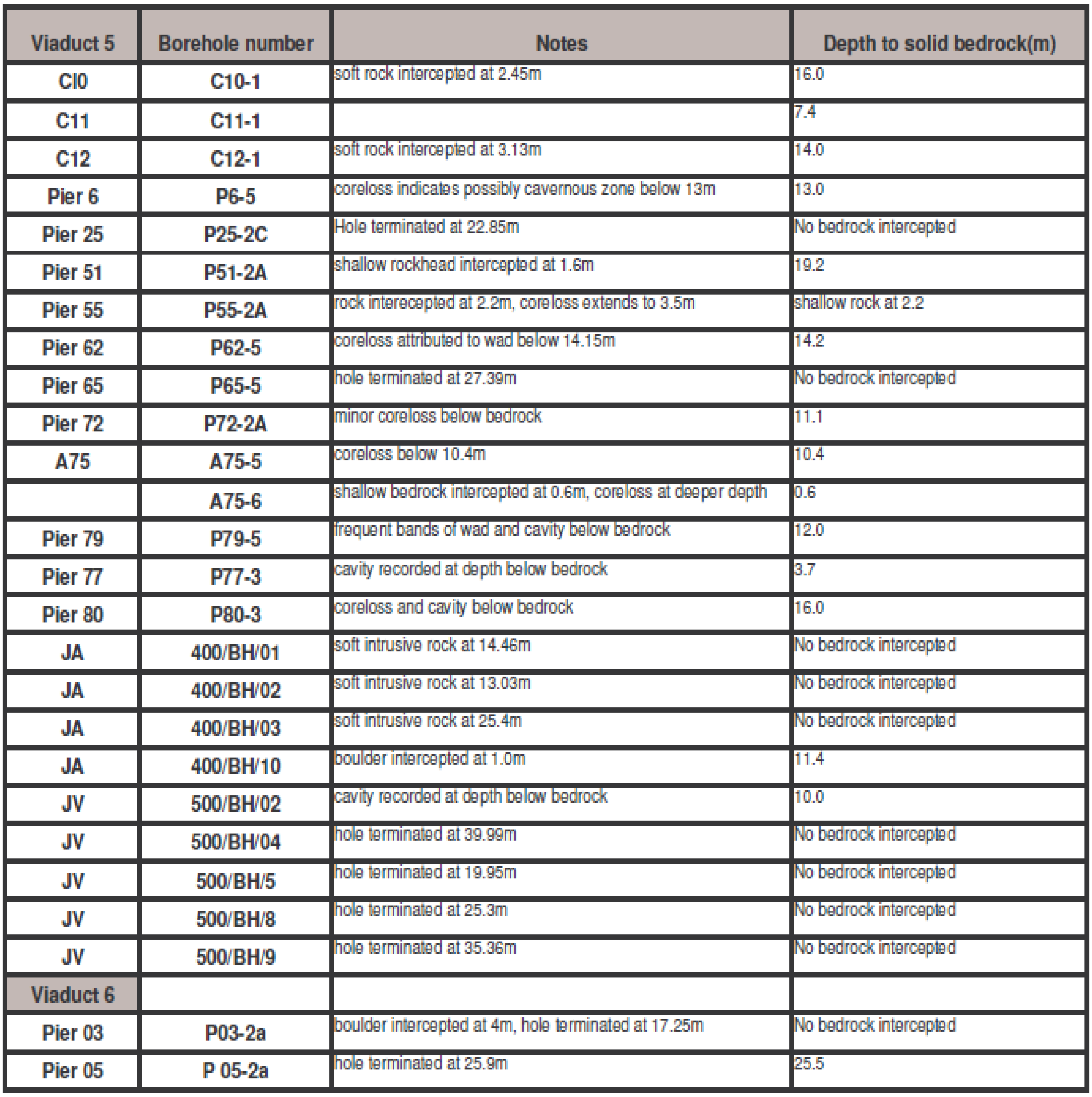
4.2 Rotary Drilling

Rotary drilling was carried out in selected pier positions where shallow bedrock has been delineated along the viaduct around Centurion from John Vorster Interchange crossing the N1 in the south, through Centurion to Jean Avenue Interchange crossing the Ben Schoeman highway in the north, to compliment the percussion boreholes.

Point load tests and Uniaxial Compressive Strength tests were performed on both dolomite and igneous intrusive core samples to determine the strength of the rock, while in-situ test (Standard Penetration Tests) was performed on both cohesive and cohensionless overburden soil material at intervals of between 1.5 m and 2.0 m during drilling to evaluate the soil consistency. Shelby tube sampler was used in some of the boreholes to recover undisturbed material from soft to very soft cohesive soils for laboratory testing.

Samples recovered from boreholes were logged by an experienced engineering geologist. A summary of depth to solid bedrock for rotary boreholes drilled along the Gautrain Rail Route is shown in Table 7.

TABLE 7: ROTARY BOREHOLE DEPTH TO BEDROCK (DD6A AND DD6B)



Viaduct 5	Borehole number	Notes	Depth to solid bedrock(m)
CI0	C10-1	soft rock intercepted at 2.45m	16.0
C11	C11-1		7.4
C12	C12-1	soft rock intercepted at 3.13m	14.0
Pier 6	P6-5	coreloss indicates possibly cavernous zone below 13m	13.0
Pier 25	P25-2C	Hole terminated at 22.85m	No bedrock intercepted
Pier 51	P51-2A	shallow rockhead intercepted at 1.6m	19.2
Pier 55	P55-2A	rock interecepted at 2.2m, coreloss extends to 3.5m	shallow rock at 2.2
Pier 62	P62-5	coreloss attributed to wad below 14.15m	14.2
Pier 65	P65-5	hole terminated at 27.39m	No bedrock intercepted
Pier 72	P72-2A	minor coreloss below bedrock	11.1
A75	A75-5	coreloss below 10.4m	10.4
	A75-6	shallow bedrock intercepted at 0.6m, coreloss at deeper depth	0.6
Pier 79	P79-5	frequent bands of wad and cavity below bedrock	12.0
Pier 77	P77-3	cavity recorded at depth below bedrock	3.7
Pier 80	P80-3	coreloss and cavity below bedrock	16.0
JA	400/BH/01	soft intrusive rock at 14.46m	No bedrock intercepted
JA	400/BH/02	soft intrusive rock at 13.03m	No bedrock intercepted
JA	400/BH/03	soft intrusive rock at 25.4m	No bedrock intercepted
JA	400/BH/10	boulder intercepted at 1.0m	11.4
JV	500/BH/02	cavity recorded at depth below bedrock	10.0
JV	500/BH/04	hole terminated at 39.99m	No bedrock intercepted
JV	500/BH/5	hole terminated at 19.95m	No bedrock intercepted
JV	500/BH/8	hole terminated at 25.3m	No bedrock intercepted
JV	500/BH/9	hole terminated at 35.36m	No bedrock intercepted
Viaduct 6			
Pier 03	P03-2a	boulder intercepted at 4m, hole terminated at 17.25m	No bedrock intercepted
Pier 05	P 05-2a	hole terminated at 25.9m	25.5

4.3 Soil Profiles

152 test pits or trenches were excavated, at selected positions along the Gautrain route over the dolomite area using a tractor mounted loader backhoe (TLB). The selected test pit locations were located on undeveloped or open properties and excavation was carried out prior to BCJV utilities team confirmation that no underground services existed within test pit section.

The purpose of these test pits was to obtain detailed engineering description of the soil profile and to enable recovery of disturbed and undisturbed samples for laboratory analysis regarding geotechnical properties of the soil material.

The individual soil profiles were recorded by an engineering geologist in accordance with the guidelines for soil profiling proposed by Jenning et al. (1973) and the profile sheets, together with the laboratory results are included in Appendix L. Summary of soil profiles with soil material encountered are shown in Table 8 as enclosed in Appendix N, while summary of indicator test results are displayed in Table 9 of Appendix N.

As expected the soil profiles revealed the Guatrain Route alignment to be underlain by predominantly residual dolomite along the Viaduct 5 section with residual shale occurring in some profiles on Viaduct 5 and also in Viaduct 6, while residual chert was also profiled in almost all piers along this Viaduct, which is indicative of the Eccles Formation. Residual syenite dominates the profile along Viaduct 5B and also occurs in some section along Viaduct 5C to 5D extending to section of Viaduct 6, dominating on profiles from pier V6-A16.

The soil profiles along the Gautrain Rapid Rail Route generally contain upper horizon of fill or transported material and a lower horizon which can either be of transported or residual material. The uppermost horizon is only visible on eight profiles from viaduct 5C and seven profiles from viaduct 6. This horizon consists of light pinkish grey to pinkish brown clayey silty sand, silty gravel to clayey gravelly sand with loose to medium dense consistency, predominantly shale and siltstone fragments with roots in some sections, and containing up to (40%) angular weathered shale gravel in profile from Viaduct 6. In viaduct 5 this horizon ranges from dark to reddish brown clayey gravelly sand with medium dense consistency and occasional small chert boulder. This horizon is interpreted as the fill and has been introduced by human activity.

The second horizon occurs in almost all profiles along the Rail Route and consists of brown to orange brown clayey sandy gravel with consistency ranging from dense to medium dense, with TLB refusal recorded at BCJV/400/TP/19A. This horizon is interpreted as Hillwash/Transported material.

Underlying this horizon is reddish brown silty clay with a firm to stiff consistency. This acts as matrix material to variety of inclusions along the route. Dark grey ferricrete and manganocrete nodules and yellow white and grey, moderately to highly weathered chert are mostly present in this horizon and in places form as two separate layers with different inclusions speckled yellow, black and white, grey with medium dense to very dense, stiff to very stiff consistency, while in other section, could be silty gravelly sand with traces of ferricrete nodules, highly to moderately weathered soft rock. This is interpreted as ferruginised residual rock

Refusal was experienced in most of the test pits along the route and this is assumed to be due to the presence of shallow dolomite floaters, chert breccia, shale gravel or highly weathered syenite.

4.4 Dynamic Probe Super Heavy (DPSH)

These tests were conducted at 8 locations along the Gautrain route in the Techno Park area, to evaluate the consistency of the soil overlying the bedrock. The depth of refusal at 300mm/100 blows corresponds to the level where soft to hard rocks were encountered on boreholes drilled on these sections, as displayed in Table 10, while comprehensive test data is presented in Appendix M.

TABLE 10: DYNAMIC PROBE SUPER HEAVY (DPSH) SUMMARY TABLE

TEST LOCATION	**DEPTH (m)**	**NUMBER OF BLOWS**	**MATERIAL DESCRIPTION**		
			HILLWASH (m)	**RESIDUAL ROCK (m)**	**SOFT TO HARD ROCK (m)**
BCJV/400/DPSH/RE-1	0.0	0	0.0		
	0.3	22	0.0-0.3		
	0.6	24	0.3-0.6		
	0.9	25	0.6-0.9		
	1.2	100	0.9-1.1		1.1-1.2
BCJV/400/DPSH/RE-2	0.0	0	0.0		
	0.3	38	0.0-0.3		
	0.6	38	0.0-0.6		
	0.9	40	0.6-0.9		
	1.2	28	0.9-1.2		
	1.5	21		1.2-1.5	
	1.8	30		1.5-1.8	
	2.1	20		1.8-2.1	
	2.4	29		2.1-2.4	
	2.7	30		2.4-2.7	
	3.0	24		2.7-3.0	
	3.3	49		3.0-3.3	
	3.6	100		3.3-3.6	
BCJV/400/DPSH/RE-3	0.0	0	0.0		
	0.3	41	0.0-0.3		
	0.6	49	0.3-0.6		
	0.9	100	0.6-0.9		
BCJV/400/DPSH/RE-4	0.0	0		0.0	
	0.3	38		0.0-0.3	
	0.6	60		0.3-0.6	
	0.9	100		0.6-0.9	
BCJV/400/DPSH/RE-5	0.0	0		0.0	
	0.3	21		0.0-0.3	
	0.6	76		0.3-0.6	
	0.9	100		0.6-0.9	
BCJV/400/DPSH/RE-6	0.0	0		0.0	
	0.3	41		0.0-0.3	
	0.6	100		0.3-0.6	
BCJV/400/DPSH/C13-2	0.0	0	0.0		
	0.3	21	0.0-0.3		
	0.6	14	0.3-0.6		
	0.9	23	0.6-0.9		
	1.2	25			0.9-1.2
	1.5	41			1.2-1.5
	1.8	76			1.5-1.8
	2.1	94			1.8-2.1
	2.4	100			2.1-2.4

TABLE 10: DYNAMIC PROBE SUPER HEAVY (DPSH) SUMMARY TABLE (cont.)

TEST LOCATION	DEPTH (m)	NUMBER OF BLOWS	MATERIAL DESCRIPTION		
			HILLWASH (m)	RESIDUAL ROCK (m)	SOFT TO HARD ROCK (m)
BCJV/400/DPSH/C11-2	0.0	0		0.0	
	0.3	12		0.0-0.3	
	0.6	21		0.3-0.6	
	0.9	65		0.6-0.9	
	1.2	100		0.9-1.0	1.0-1.2

5 APPLICATION / USE IN DESIGN

There are three major foundation problems in dolomite areas as listed below:

- Large variation in rock head identified with cavities or large slabs of dolomite
- Wad is mainly iron and manganese oxides, it is compressible and highly erodible.
- Sinkhole and subsidence formation

The dolomites underlying the Gautrain alignment present a sinkhole risk for the project and advance ground investigation works were undertaken in order to evaluate superficial deposits and bedrock conditions (Storry et al. 2009). The route from Viaduct 5B (John Vorster), down through Viaduct 5C to Viaduct 5D (Jean Avenue) is underlain by dolomite of the Monte Christo Formation. Rock head varies from shallow outcrop ranging from 0 m at Pier 49 to areas of generally deeper bedrock of up to 79.5 m at Pier 64 as shown in Table 5. This formation further extends beyond Pier A81 through the Military area, where it is overlain by the Lyttelton Formation, which is in turn overlain by the youngest Eccles Formation at Viaduct 6, as earlier illustrated in Appendix B.

The presence of chert layers and wad in the dolomite of the Chuniespoort Group has a major impact on the engineering performance of the weathered material. According to Kotze and Vorster (2009), the sharp difference between the extremely hard dolomite with a Uniaxial Compressive Strength of up to 300MPa and the residual soil at the rock interface, which may only have stiffness in the order of 5 to 10MPa, makes it difficult to design suitable foundation options on the dolomite.

In order to investigate these ground conditions for the Gautrain, Bombela Civils Joint Venture utilised borehole radar equipment to survey drilled percussion boreholes and provide the design team with a more comprehensive picture of the ground conditions. It provided high resolution omni-directional data indicating steeply dipping rockhead, lithological changes and voids for distances up to 12 m around the surveyed boreholes. It confirmed the presence of fissures that were intersected during drilling and identified features around the boreholes that were not intersected by drilling. The borehole radar results have been used in combination with borehole logs and Jean Lutz data to interpret the ground conditions. The combination of the data has allowed for the determination of zones of good and poor quality rock as well as the locality of cavities.

The data presented in the previous chapter have been interpreted and utilised to overcome the challenges in the design of the various foundations and structures for the Gautrain Rapid Rail Link over the dolomite terrain in the Centurion area. The depth to bedrock for each borehole drilled at a pier position, variability in bedrock, problematic subsurface conditions such as karst formation, and different in-situ and laboratory tests were analysed and the interpretations have been applied in the various design methods.

These interpretations led to the use of five different suitable foundation options as shown in (Figure 26), in order to mitigate the possibility of sinkhole formation and to overcome construction challenges at minimal costs along the Gautrain Rapid Rail Route over the sections underlain by dolomite. At pier positions where the bedrock depth was in the range 5 to 30m below the natural ground level the viaduct piers were founded on shafts and spread footings or large diameter piles (Tosen et al. 2009), depending on the groundwater level relative to the founding level.

These design options, as described below, were utilised at piers along the viaduct route as displayed in Table 11.

1. Shafts: This option was used where obstructions such as boulders had to be penetrated in order to found on solid bedrock. This is a deep foundation where each shaft is 7 m in diameter and socketed on competent bedrock with RMR ≥70. Drilling using the pneumatic rig from the base assures that founding conditions were consistent. It was geologically controlled by a site geologist.

2. Spread footing: Footings were used where ground investigation delineated shallow bedrock with less variability in rockhead. Drilling and grouting were carried out to confirm adequate founding was used. It was geologically controlled by the site geologist.

3. Floating Foundation: Used on piers where difficulties have been envisaged founding on rock, either due to very deep competent bedrock or where there are voids or wad filled cavities within the bedrock and which sometimes extends to the bottom of boreholes.
    - Piled Raft: This involved preloading a 20 m x 20 m area. The stability and bearing capacity of the subsoil was then improved by compaction grouting of possible voids and cavities. The grout mix consisted of cement, fly ash, bentonite, water, iron oxide pigment and sand, with 28 days cube grout strength of 5 Mpa. Friction piles of 600 mm diameter to a depth of 15 m were then installed within the grouted column, followed by casting of a pile cap over the piles. This was used for the first time in South Africa to overcome the challenges on the dolomites, especially on piers with thin or no chert gravel layer.
    - Raft: Raft on soil with or without soil improvement as above and grouting of voids and cavities to reduce the risk of sinkhole occurrence.

- Large Diameter Piles: This foundation consisted of 1.5 m diameter circular reinforced concrete piles embedded into the bedrock. It is important to emphasise that piled foundations to rock are generally not favoured for dolomite conditions due to constraints regarding the installation of piles. These constraints are mainly due to presence of chert bands and floaters within the dolomite residuum, piling below the water table, and also due to pinnacled nature of the bedrock. These challenges were overcome by advance drilling and predrilling with interpretation of percussion boreholes to define rockhead and socket length.

- Concrete U Shaped Sections: These were used where the risk of sinkhole formation was significant. The train will run inside the U Shaped sections designed to span over a 15 m cavity diameter. These were constructed over sections in the Military Area, where the substrata have been improved by Dynamic Compaction over the footprint of the embarkment

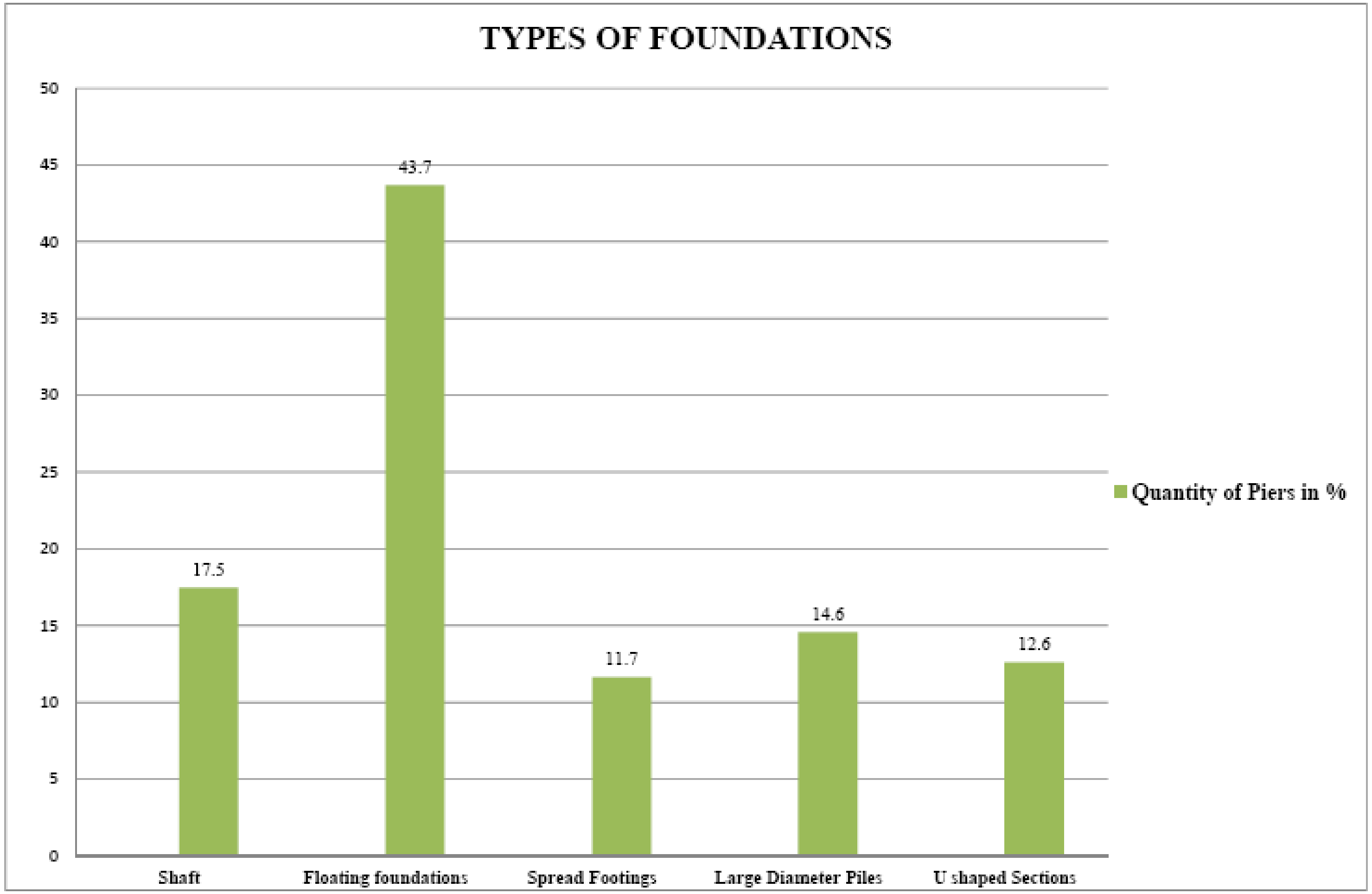


Figure 26: Types of Foundation Options in Percentage

5.1 Shaft

This foundation option was used on 17.5% of the total piers along the study section as shown in Figure 26, where there was variability in rockhead, very dense intermediate strata had to be penetrated or where obstructions such as boulders must be penetrated before competent rockhead (Table 5) as established from the original ground investigation was encountered. Also at piers where cavities or soft zones have been delineated to occur in between boulders and competent rock. The option involved blasting the pinnacles in order to set up the foundation on flat uniform bedrock.

Sidewall stabilization was maintained by shotcreting or casting concrete ring after every 1.5 m depth of sinking the shaft through excavation or blasting depending on the type of material encountered (soil/rock) as confirmed by the geologist during shaft sinking.

In piers where wad filled cavities or void have been detected at certain depth during the original ground investigation, shaft sinking was interrupted between 3.0 m to 5.0 m above the expected cavity/void. This was followed by drilling and grouting in sequence from primary to tertiary boreholes depending on the grout take (volume) and the pumping pressure during grouting. A grout mix with 1:1 ratio water to cement and 1:0.083 bentonite was used which yielded 72 hours cube strength of 15 Mpa. This was carried out to either increase the bearing capacity of the soil or fill any void within the rock, thereby preventing sidewall collapse or instability resulting from depression as work progressed.

In pier locations where groundwater was encountered (Table 6), above solid bedrock or shaft founding levels, ingress from both sidewall and shaft floor was controlled by continuous pumping and shotcreting.

The impact on traffic and right of way was also considered in choosing this option as most suitable compared to the floating foundation option, due to the fact that the installation of this foundation can effectively be carried out in areas/sections with restricted space and without much interfering with traffic flow, or completely blocking off the highway. A total of 18 shafts as shown in Table 11 were constructed on the dolomites of the Monte

Christo Formation, from Viaduct 5B (John Vorster Interchange) through Viaduct 5C down to Viaduct 5D (Jean Avenue).

Competent rockhead occurs at similar depth in eight of the eighteen piers, with less variability along viaduct 5B, where rockhead difference, not exceeding 5 m, was observed (Table 5), with the maximum dip ranging from 30° to 45° in a NW-SW trend in viaduct 5B, while in viaduct 5D, steeply dipping rockhead as high as 77° to 78° has been delineated at Pier 69 and Pier A75 with trend towards SW-SSE.

Zones of sample loss were recorded at 5 piers as shown on the borehole logs (Appendix D), which ties in with relatively high penetration rates as indicated in the Jean Lutz data and this correlates with signal attenuation on the radargram (Appendix G). The borehole radar indicated possible cavernous zones at three piers (Pier 77 to Pier 79) on Jean Avenue (viaduct 5D) which were not intercepted during exploratory drilling of these boreholes.

Geological stem plot shows thicknesses of weathered dolomite above and within competent rock ranging from 0.5 m at Pier 6 up to 10 m at Pier 5.

Borehole radar indicated a high signal attenuation zone at Pier 7 BH1, from 35 m to 46 m, which ties in with relatively low penetration rates shown in the Jean Lutz data, (Appendix C), and correlates with the borehole log for BH1, indicating hard rock chert between 35 m to 39 m (Table 6). A linear reflector was picked in Pier 8 BH3, as shown on the radargram, which is indicative of a dip in rockhead between BH3 and BH1 from 17 m to 24 m at distance from BH3 between 1 m to 3.7 m.

Borehole radar shows a loss of signal from 16 m to 28 m in Pier 9 BH4, due to the presence of wad and wad gravel as shown on the geological stem plot and correlates with very high penetration rate in the Jean Lutz data. Attenuation between 22 m to 24 m (Pier 9) ties in with the contact zone between dolomite and syenite, characterised by weathered dolomite and weathered syenite on the geological stem plot (Appendix E), and correlates with high penetration rates in the Jean Lutz data. High signal attenuation, due to the presence of unweathered, intrusive syenite from 24 m to 40 m and between 5 m to greater than 11.5 m away from BH1, ties in with low penetration rates from the Jean Lutz data in boreholes BH1, BH2, BH3 and BH4.

The presence of both closely spaced joints and minor joints, logged in Pier 41 BH2, ties in with linear reflectors shown on the radagram between 1 m to 9 m and at a distance of 2.4 m to 3.4 m away from BH2 and also from 37 m to 40 m at a distance of 8.4 m to 9.1 m away from BH2.

Although no cavity was intercepted by the boreholes during drilling at Pier 78, the borehole radar survey picked up possible cavities at 33 m in BH1, at a distance of 6 m away from the borehole, and also at 37 m at a distance of 5.5 m away from the borehole. This also ties in with high penetration rates recorded in the Jean Lutz data, while at Pier 79, the radar shows complete loss of signal from 0 m to 25 m due to the presence of weathered material, which correlates with BH2 and ties in with relatively high penetration rates recorded in the Jean Lutz data.

5.2 Spread Footings

A footing on rock was used at piers where bedrock has been encountered at shallow depth and without residual rock within or below the competent rock to ensure the bearing capacity and limit settlements. There was no occurrence of groundwater in these pier locations.

Competency is confirmed by the geologic mapping of the footing floor by the site geologist and where a rock mass class (RMR) of more than 70 is obtained. This is followed by drilling and grouting to ensure adequate founding conditions.

This option was used on a total of 5 piers as shown in Table 11. Competent rockhead at these piers ranges from depths of 4 m to depth of 18m as indicated on the geological stem plots (Appendix E), with a maximum dip of 23° towards the NE from BH1 to BH4 at Pier 48, while at Pier 49 the, general dip direction is NE from BH3 to BH4 at 72° and NW from BH3 to BH1 at 63°. At pier 72, the maximum dip is 68° at a general trend to the NE from BH3 to BH2.

Geological stem plots indicate sample loss in BH4 of Pier 48, which was not recorded in other boreholes at this Pier and the cavity extent was confined to the NE corner of the cap, while at Pier 72, a cavity was intersected in BH1, which was also not found in the other boreholes. This was confined to the NW corner of the cap.

Weathered dolomite occurs in all 5 Piers and ranges in thickness from 0.3 m in Pier 70 to 14.5 m in Pier 49, while syenite is incorporated as part of the competent rock at Pier 70 to Pier 72 where it occurs at similar depths at each of the piers. Depths range from 11 m at Pier 70 to 22.8 m at Pier 72 with exceedingly high penetration rates recorded by the Jean Lutz method across these piers. It also correlates with zones of signal attenuation on the radargram.

There was no record of ground water strikes noticed in any of the borehole across the piers according to the borehole logs.

The borehole radar surveys picked up linear reflectors at some of the piers, which correlate to minor joints logged in boreholes. Cavity anomalies in the radar data that are not intercepted in the boreholes are attributed to the presence of poor material.

TABLE 11: FOUNDATION DESIGN OPTIONS

VIADUCT SECTION	PIERS	FOUNDATION OPTION				
		SHAFT	FLOATING FOUNDATION	SPREAD FOOTINGS	LARGE DIAMETER PILES	U SHAPED SECTIONS
5B	A5	X				
	P06	X				
	P07	X				
	P08	X				
	P09	X				
	P10	X				
	P11				X	
5C	P12A				X	
	P12B				X	
	P13				X	
	P14				X	
	P15		X			
	P16		X			
	P17		X			
	P18		X			
	P19		X			
	P20				X	
	P21		X			
	P22		X			
	P23		X			
	P24		X			
	P25		X			
	P26		X			
	P27		X			
	P28		X			
	P29		X			
	P30		X			
	P31		X			
	P32		X			
	P33		X			
	P34		X			
	P35				X	
	P36				X	
	P37		X			
	P38		X			
	P39		X			
	P40		X			
	P41	X				
	P42			X		
	P43		X			
	P44		X			
	P45		X			
	P46		X			
	P47		X			

Table 11: FOUNDATION DESIGN OPTIONS (continued)

VIADUCT SECTION	PIERS	FOUNDATION OPTION				
		SHAFT	**FLOATING FOUNDATION**	**SPREAD FOOTINGS**	**LARGE DIAMETER PILES**	**U SHAPED SECTIONS**
5C	P48			X		
	P49			X		
	P50	X				
	P51	X				
	P52	X				
	P53		X			
	P54		X			
	P55		X			
	P56		X			
	P57	X				
	P58		X			
	P59		X			
	P60		X			
	P61		X			
	P62		X			
	P63		X			
	P64		X			
	P65		X			
	P66	X				
	P67		X			
	P68		X			
	P69	X				
	P70			X		
	P71			X		
	P72			X		
	P73		X			
	P74A		X			
	P74B		X			
5D	A75	X				
	P76	X				
	P77	X				
	P78	X				
	P79	X				
	P80					X
	P81					X
MILITARY ALLIGNMENT	MILITARY					X
6	V6-A0					X
	V6-P01					X
	V6-P02					X
	V6-P03					X
	V6-P04					X
	V6-P05					X
	V6-P06					X

TABLE 11: FOUNDATION DESIGN OPTIONS (continued)

VIADUCT SECTION	PIERS	FOUNDATION OPTION				
		SHAFT	FLOATING FOUNDATION	SPREAD FOOTINGS	LARGE DIAMETER PILES	U SHAPED SECTIONS
6	V6-P07					X
	V6-P08					X
	V6-P09					X
	V6-P10				X	
	V6-P11				X	
	V6-P12				X	
	V6-P13				X	
	V6-P14				X	
	V6-P15				X	
	V6-P16				X	

5.3 FLOATING FOUNDATIONS

This option was utilised at piers with deep bedrock, where depth to competent rockhead in some boreholes extended to below 40 m, e.g. Pier 60, where no bedrock was encountered in some boreholes, and where cavities extended to the bottom of a borehole at 80 m. This option was also applied at piers with high variability in rockhead, or steeply dipping rockhead and with very thick layers of impurities such as wad and wad filled cavities underlying chert gravels. Due to these subsoil conditions, founding on rock was extremely difficult, hence this option was considered the most economical and practical solution. This foundation option was preferred from a construction point of view, provided that the sinkhole risk as well as foundation settlement could be addressed (Kotze and Vorster, 2009). Sinkhole risk was reduced along the Gautrain Rapid Rail Route by using this option as well as compaction grouting to minimise the formation of sinkholes below or adjacent to the pier.

This was also the most favoured construction solution with 43.7% of all the piers, as shown on Figure 26, from viaduct 5C through to viaduct 5D being founded in this manner. Competent rockhead at these piers ranges from 3 m in Pier 67 to 79.5 m in Pier 64 as shown in Appendix F, with a maximum dip of up to 83° in Pier 31, and with trends in SW, NE, E-NE, NW and SE directions in most of the piers.

Cavernous zones were recorded during the drilling of the original ground investigation boreholes as indicated by zones of sample loss on the borehole logs (Appendix D), in 18 of the total of 46 piers, where floating foundations were constructed. These tie in with relatively high penetration rates from the Jean Lutz data and high signal attenuation zones on the radagrams, e.g. Pier 38 (Appendix E).

The borehole radar survey also picked up cavity reflectors at varying depths in and at varying distances from the boreholes which were attributed to poor material and also presence of cavernous wad in the original boreholes. These zones on the radargrams tie in with areas of relatively high penetration rates in the Jean Lutz data as shown on the geological stem plots, in Appendix E. High signal attenuation zones on the radargrams are correlated to areas where poor material has been recorded on the borehole logs e.g. Pier 24.

Weathered dolomite is present in borehole profiles at most of the piers with this foundation option and occurs both within the competent rock and above the competent rock and correlates with zones of signal attenuation on the radargrams. Thicknesses of weathered dolomite range from 0.1 m (Pier 33 BH1A) up to 28 m (Pier 24 BH2), while at Pier 28 BH3, it occurs in the last 0.5 m of the borehole as shown on the geological stem plots.

Wad layers occurred in all piers with this foundation option and vary in thickness, in boreholes from 0.4 m in Pier 33 BH2A and extend up to 45 m in Pier 63. The wad layers correlate with zones of relatively high penetration rates in the Jean Lutz data and also tie in with zones of high signal attenuation on the radargrams.

5.4 LARGE DIAMETER PILES

This option is cost effective where depth to competent rock is large (e.g. more than 30 m). Intermediate strata and boulders were penetrated before socketing on solid bedrock. Additional ground investigations prior to pile construction and proper selection of pile positions were important to minimise construction difficulties. The nature of the steeply dipping pinnacled rockhead led to opting for larger diameter piles rather than smaller diameter piles.

Four piles were socketed into solid bedrock at each pier position. Rock head and pile socket length were established on each pile position by open hole drilling of a minimum of four boreholes around the circumference of each proposed pile and coring the rock at the pile centre to a minimum of 7 m below the pile base to confirm that bedrock was consistent.

A total of 16 piers from Viaduct 5 to Viaduct 6, (Table 11) have been constructed using this design option. Competent rockhead at these piers range from as shallow as 1 m in Pier 42-BH1, to as deep as 32m in Pier 20-BH1, as shown on the geological stem plots. The maximum rockhead dip was 73° and a variation of 17.5 m was delineated in Pier 42. This pier was originally designed with a shallow foundation, but a socket on competent rockhead could not be intercepted on the south-eastern section of the footing, hence additional ground investigation was conducted to confirm large diameter piling as an alternative design method.

Piles were socketed on intrusive syenite in Piers 11 to 14, with rockhead occurring at similar depths and, no sample loss recorded, while at Piers 35, 36 and 42 sample losses were recorded in boreholes (Appendix D) with the extent of the cavity confined to the NE corner of the cap at Pier 36.

Weathered dolomite occurred both within and above competent rockhead in 9 Piers, with thicknesses ranging from 0.5 m in Pier 42 (Viaduct 5C) and Pier 11 (Viaduct 6), up to 8 m in Pier 10 (Viaduct 6).

Borehole radar data indicated high signal attenuation due to the presence of unweathered intrusive syenite and correlates with relatively low penetration rates as shown in the Jean Lutz data, e.g. Pier 11. Linear features were picked up by the radar at depths of 8 m to 12 m in Pier 35-BH5 and at a distance of 5.2 m to 8.4 m away from the borehole and at depths of 14.5 m to 18 m in Pier 15 (Viaduct 6) at a distance of 3.1 m to 4.9 m away from the borehole. This correlates with oxide stained joints logged in boreholes from these piers. Attenuation from depths of 33 m to 37 m in Pier 20, extending from the borehole up to more than 11.5m away from the borehole, ties in with carbonaceous shale encountered in boreholes around this Pier (Appendix D). Moreover, high signal attenuation in P42-BH 4, from depths of 17 m to 18 m tie in with a zone of high penetration in the Jean Lutz data and correlates with a cavity zone in the geological stem plot.

5.5 CONCRETE U SHAPED SECTIONS

The Gautrain Rapid Rail Link is aligned on the ground surface where the rail is running in these U shaped sections. Earthworks were carried out over these sections from Pier A81, through the Military area up to Pier 9 (Viaduct 6). This design option was chosen due to very deep bedrock/or no encountered bedrock, presence of very thick wad layers, cavities or very loose ground.

Roadbed treatment was carried out to stabilise the ground, thereby providing a homogenous foundation under the railway platform by densifying the soils below the platform and collapsing any shallow cavities through the following processes:

- Dynamic compaction: Carried out across the Military area on Lyttelton Formation where thick layers of soft material (wad) are located in shallow areas.
- Standard compaction: Dynamic loading of impact rollers was used across areas where there are no occurrences of shallow wad, but rather thick layers of chert gravel (Eccles Formation). Compaction methods were controlled by settlement measurements and plate load testing.
- Pinnacle breakouts/soil replacement: Where rock was close to surface.
- Slope Stabilisation: Carried out in cut and cover sections.

A total of 12 piers (Tables 11), have been constructed based on this design option. Laboratory analysis from Table 9, shows that sections with chert gravel at shallow depths has higher percentages of gravel sized materials, which indicates that thick layers of this material, belonging to the Eccles Formation, was profiled as shown in Table 8. There is no competent bedrock at some of these piers as indicated on the geological stem plots (Appendix E) e.g. pier 5 (viaduct 6), while at other piers depth to bedrock occurred below 60 m e.g. pier 7-BH4 (viaduct 6), which made it not feasible to found on rock.

6 CONCLUSION

The Gautrain rapid rail route is underlain by dolomite for approximately 15 km in the Centurion section with nearly 6 km elevated on viaducts.

Design and construction challenges were associated with the dolomite terrain. Major risk to the rail project was envisaged along the dolomite section due to the geohazards associated with the karstification of the dolomite. These geohazards could include: high variability in rockhead depths within closely spaced boreholes due to steeply dipping pinnacles, low density compressible and highly erodible wad material and presence of cavities and floaters within weathered dolomite and chert. These challenges could lead to surface instability in the form of sinkholes and compaction subsidence.

More rigorous and advanced ground investigation methods were utilised along this section.

- Percussion drilling involved drilling between 4 to 6 boreholes spaced 5 m to 9 m apart, in a single pier location to fully establish the variation of the rock profile.
- A combination of symmetrix and reverse circulation drilling advanced the borehole with casing and enabled drilling above and below ground water table without sample contamination from sidewall collapse. Stability of the borehole for later testing and instrumentation was also maintained.
- The use of Jean Lutz drilling parameters recording system to assess consistency of superficial deposits and rock hardness. The use of this system eradicated irregularities which existed over interpretation of the data introduced by different drilling rigs and the rig operators.
- Borehole radar survey to establish and verify the extent of voids, occurrence of floaters, rock quality and steeply dipping rockheads. Borehole radargram confirmed significant voids which might have been missed by the conventional drilling investigation. This survey therefore helped in the validation of founding conditions.
- Borehole verticality was measured to confirm that the drill string had not deviated off a rock pinnacle.

- ❖ Auger rig equipped with a 900 mm flight and capable of excavating down to 20 m in the wad material was used to obtain large undisturbed samples from wad for laboratory testing which was not possible with conventional percussion drilling airflush.
- ❖ Specialised field testing included Pressuremeter testing, Cone Penetration testing and Continuous Surface Wave testing. These techniques were used to gain more information for geotechnical design parameter, particularly for the soft wad materials, the stiff clay and chert layers.

The advanced geotechnical investigation methods used, led to more comprehensive knowledge of the geotechnical properties of the underlying materials and the selection of suitable design solutions at each pier location for the dolomite sections depending on the local geological conditions encountered.

- Spread footing on dolomite bedrock/pinnacles with specially constructed mass concrete mattress was used at pier locations where geotechnical investigation delineated shallow depth to solid bedrock. Small diameter drill holes confirmed founding on rooted bedrock. This foundation option was best suited for this geology and outweighed other available options in terms of financial cost and time constraint.
- Floating foundations were chosen for pier locations where difficulty was envisaged founding on rock due to absence of solid bedrock, or bedrock occurring at deep depth (either below or above the water table) with presence of cavities within bedrock. This option was considered most suitable at those pier locations where it was used, since it involved pre-treatment of the soil mass in order to improve its density and strength thereby reducing the risk of sinkhole occurrence to an acceptable level and therefore required large work space for machines and equipment.
- Large diameter shafts to rock were mostly suited for the balanced cantilever viaducts (John Vorster and Jean Avenue viaducts) where foundation loads are higher due to their greater spans, and also at piers with variability in bedrock. These are 7 m diameter shafts which have been excavated to bedrock and socketed into hard dolomite bedrock up to 42 m below ground surface.
- Large Diameter Pile to rock was used at piers with variable rockhead and where solid bedrock is located above the water table. It was the best option in areas where space

was a significant constraint e.g. road intersections, pier close to road or other major services.

7 RECOMMENDATION

It is necessary to carry out appropriate geotechnical investigations in all construction projects specifically in a dolomite environment, in order to obtain required geotechnical design parameters for suitable foundation options.

Although cost and time consuming equipment and methods may be necessary in some instances during geotechnical investigations, the cost of using such equipment and methods could be far less compared to the savings gained in adopting a suitable solution for design and construction. Advanced geotechnical investigations also ensure that a suitable foundation design option has been utilise hence eliminating possibility of delays in the construction phase.

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APPENDIX N

SUMMARY TABLES OF RESULTS

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS

	JOHN VORSTER VIADUCT 5B (MONTE CHRISTO FORMATION)									
	BH NO	PIER								
		5	6	7	8	9	10	11		
Depth to bedrock (m)	1	19	22	21	22	24	21	14		
	2	21	23	12	16	26	20	15		
	3	19	19	22	16	26	21	15		
	4	21	17	12	17	26	21	16		
	5									
	6									
MEAN AVERAGE		20	20	17	18	26	21	15		
STANDARD DEVIATION		1.15	2.75	5.50	2.87	1.00	0.50	0.82		
COEFFICIENT OF VARIATION		5.77	13.60	32.84	16.18	3.92	2.41	5.44		

	CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)									
	BH NO	PIER								
		12A	12B	13	14	15	16	17	18	19
Depth to bedrock (m)	1	18	3	23	24	24		26	27	34.2
	2	20	30.9	24	25	19	25	26.7		33
	3	2	28	22.5	17	26				31
	4	18	30	22	24	23.9	30		31	
	5									
	6									
MEAN AVERAGE		15	23	23	23	23	28	26	29	33
STANDARD DEVIATION		8.39	13.37	0.85	3.70	2.98	3.54	0.49	2.83	1.62
COEFFICIENT OF VARIATION		57.84	58.20	3.73	16.43	12.82	12.86	1.88	9.75	4.94

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS (continued)

		CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)								
	BH NO	**PIER**								
		20	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Depth to bedrock (m)	**1**	31	20	31.8	26	47	40	36	39	21
	2	22	32	32.5	26.5	36	32	36	25.2	25.2
	3	32	18	22	25	48	45.6	21.2	26	23
	4	33.5	19	24	34	30	27	39	62.2	9.5
	5						35			9.4
	6									
MEAN AVERAGE		30	22	28	28	40	36	33	38	18
STANDARD DEVIATION		5.19	6.55	5.35	4.13	8.73	7.18	8.03	17.27	7.60
COEFFICIENT OF VARIATION		17.51	29.44	19.41	14.82	21.69	19.98	24.28	45.32	43.16

		CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)								
	BH NO	**PIER**								
		30	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Depth to bedrock (m)	**1**	36	23	39	13.5	9	2	24		
	2	53	28	3	5.5	6	23	24	25.5	25
	3	32	34	34	11	2				
	4	18	20	41	55.6	5		8	49	8.5
	5	32		20			4.2	13	39	4
	6									
MEAN AVERAGE		34	26	27	21	6	10	17	38	13
STANDARD DEVIATION		12.54	6.13	15.92	23.04	2.89	11.54	8.06	11.79	11.06
COEFFICIENT OF VARIATION		36.66	23.35	58.09	107.68	52.49	118.58	46.71	31.17	88.45

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS (continued)

	CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)									
	BH NO	**PIER**								
		39	**40**	**41**	**42**	**43**	**44**	**46**	**47**	**48**
Depth to bedrock (m)	**1**	3	5		1	19.4	26.1	23.5	8	1.4
	2	1.2	16	32	1	2	28.5	18	11	1
	3		3			28	20	27	43.8	3
	4	6	5	12	1	4.6	30	31	8	7
	5	7.8	6	32	3.2					
	6									
MEAN AVERAGE		5	7	25	2	14	26	25	18	3
STANDARD DEVIATION		2.96	5.15	11.55	1.10	12.34	4.40	5.51	17.46	2.74
COEFFICIENT OF VARIATION		65.77	73.54	45.58	70.97	91.38	16.84	22.16	98.63	88.38

	CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)									
	BH NO	**PIER**								
		49	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**
Depth to bedrock (m)	**1**	3	24	24	16	2	8	24	24	2.6
	2	1	24	25	15	7	5	32	14	
	3	0		24	22	5.2	9	33	14	23
	4	3	22	24	25	4	33.5	22	18	
	5			24		21	9.5	24		
	6							23	18	6
	8									6
	9									4
MEAN AVERAGE		2	23	24	20	8	13	26	18	8
STANDARD DEVIATION		1.50	1.15	0.45	4.80	7.58	11.59	4.84	4.10	8.33
COEFFICIENT OF VARIATION		85.71	4.95	1.85	24.59	96.66	89.17	18.40	23.29	100.14

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS (continued)

		CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)								
	BH NO	**PIER**								
		58	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**
Depth to bedrock (m)	**1**	52		58	61.5	29	36	18..5	40.6	16
	2	48	52		52.2	60	61	49	47.2	11
	3	56	53	54	57.5	26	39	22.1	55	13
	4	23				52.3	65	79.5	48	14
	5									16
	6									
MEAN AVERAGE		45	53	56	57	42	50	50	48	14
STANDARD DEVIATION		14.86	0.71	2.83	4.67	16.88	14.86	34.35	5.89	2.12
COEFFICIENT OF VARIATION		33.21	1.35	5.05	8.17	40.36	29.58	68.42	12.35	15.15

		CENTURION VIADUCT 5C (MONTE CHRISTO FORMATION)								
	BH NO	**PIER**								
		67	**68**	**69**	**70**	**71**	**72**	**73**	**74A**	**74B**
Depth to bedrock (m)	**1**	22.8		17	7	9	0	5	23.8	14.5
	2		23	16	5	11.5	3	1	15.8	3.9
	3	3		11	3	7	1.5	1.5	14	17
	4			32	8	7	1	1	10	21
	5		22.5	34						
	6									
MEAN AVERAGE		13	23	22	6	9	1	2	16	14
STANDARD DEVIATION		14.00	0.35	10.32	2.22	2.14	1.25	1.93	5.80	7.31
COEFFICIENT OF VARIATION		108.53	1.55	46.91	38.56	24.77	90.91	90.88	36.46	51.83

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS (continued)

JEAN AVENUE VIADUCT 5D (MONTE CHRISTO FORMATION)								
	BH NO	**PIER**						
		A75	**76**	**77**	**78**	**79**	**80**	**81**
Depth to bedrock (m)	**1**	32	6		30	23		
	2	33.5	10		20	22		28
	3		8	10	18		15	
	4	6.5	10	10	31	39	16	7
	5							
	6							
	A1							
	A2							
	A4							
	A3							
MEAN AVERAGE		24	9	10	25	28	16	18
STANDARD DEVIATION		15.17	1.91	0.00	6.70	9.54	0.71	14.85
COEFFICIENT OF VARIATION		63.22	22.53	0.00	27.08	34.07	4.56	84.85

	JEAN AVENUE VIADUCT 6 (MONTE CHRISTO FORMATION)									
	BH NO	**PIER**								
		V6-A0	**V6-P01**	**V6-P02**	**V6-P03**	**V6-P04**	**V6-P05**	**V6-P06**	**V6-P07**	**V6-P08**
Depth to bedrock (m)	**1**		NONE	NONE	37	39	NONE	NONE	NONE	15
	2	55	NONE	NONE	55	34	NONE		NONE	23.5
	3	NONE	NONE	NONE	37	33	NONE	NONE	NONE	
	4			NONE		45	NONE	NONE	61	59
	5							NONE		14.5
	6									
MEAN AVERAGE		55			43	38			61	28
STANDARD DEVIATION		38.89	0.00	0.00	10.39	5.50	0.00	0.00	30.50	21.08
COEFFICIENT OF VARIATION		70.71			24.17	14.57			50.00	75.27

TABLE 5: BOREHOLE DEPTH TO BEDROCK (m) SHOWING GEOLOGICAL FORMATIONS AT PIER POSITIONS (continued)

	JEAN AVENUE VIADUCT 6 (MONTE CHRISTO FORMATION)									
Depth to bedrock (m)	**BH NO**	**PIER**								
		V6-P09	**V6-P10**	**V6-P11**	**V6-P12**	**V6-P13**	**V6-P14**	**V6-P15**	**V6-A16**	
	1		16.5	14	12.5	9	12	10	25	
	2	27	26	16	19	14	9.5	11	24	
	3			17.2	12.5		16	6	26	
	4	28	26	20	12	8.5	10	7		
	5	12	26							
	6									
MEAN AVERAGE		22	24	17	14	11	12	9	25	
STANDARD DEVIATION		8.96	4.75	2.51	3.34	3.04	2.95	2.38	1.00	
COEFFICIENT OF VARIATION		40.13	20.11	14.93	23.87	28.97	24.88	28.01	4.00	

TABLE 6: SUMMARY OF BOREHOLE LOGS

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM (m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5B/500	**A5**	**BCJV/500/PH/ A5-1**	**0.0-1.6**			**1.6-9.0, 38.0-39.0**	**12.1-38.0 39.0-45.0**	**21.0**
		BCJV/500/PH/ A5-2	**0.0-3.0**			**3.0-8.0 34.0-36.0**	**8.0-34.0 36.0-48.0**	**20.0**
		BCJV/500/PH/ A5-3	**0.0-2.0**			**2.0-7.0 34.0-36.0**	**7.0-15.0, 16.0-21.0 22.0-34.0, 36.0-42.0**	**21.0**
		BCJV/500/PH/ A5-4	**0.0-1.6**		**8.0-10.0**	**1.6-8.0**	**10.0-57.0**	**20.0**
5B/500	**P6**	**BCJV/500/PH/ P6-1**			**16.0-20.0**	**0.0-16.0**	**20.0-62.0**	**40**
		BCJV/500/PH/ P6-2	**0.0-1.3**			**1.3-13.0 36.0-38.0**	**13.0-17.0, 22.0-36.0 38.0-60.0**	**27**
		BCJV/500/PH/ P6-3		**18.1-19.7**		**0.0-16.0**	**19.7-64.0**	
		BCJV/500/PH/ P6-4	**0.0-1.0**			**1.0-13.3, 36.0-38.0, 50.0-51.0**	**13.3-36.0, 38.0-50.0, 51.0-68.0**	**49**
5B/500	**P7**	**BCJV/500/PH/ P7-1**	**0.0-1.8**	**35.0-39.0**		**1.8-20.4 63.0-73.0**	**20.4-35.0, 39.0-63.0**	
		BCJV/500/PH/ P7-2	**0.0-1.0**			**1.0-12.0**	**12.0-61.0**	**45.0**
		BCJV/500/PH/ P7-3	**0.0-1.0**			**1.0-16.0 18.0-22.0, 34.0-38.0, 64.0-76.0**	**16.0-18.0, 22.0-34.0 38.0-64.0**	
		BCJV/500/PH/ P7-4	**0.0-9.0**		**21.0-21.5**	**0.9-12.5, 37.0-39.0**	**12.5-21, 21.5-37, 39.0-71**	**24**
5B/500	**P8**	**BCJV/500/PH/ P8-1**	**0.0-1.5**		**20.0-22.5**	**1.5-20.0**	**22.5-63.0**	**22**
		BCJV/500/PH/ P8-2	**0.0-1.5**		**14.0-15.0**	**1.5-14.0, 63.0-76.0**	**15.0-63.0**	**17**
		BCJV/500/PH/ P8-3	**0.0-1.5**		**14.0-16.0**	**1.5-14.0, 63.0-76.0**	**16.0-63.0**	**61**
		BCJV/500/PH/ P8-4	**0.0-1.2**			**1.2-17.0, 57.0-76.0**	**17.0-57.0**	**41.5**
5B/500	**P9**	**BCJV/500/PH/ P9-1**	**0.0-3.0**	**4.0-6.0, 11.0-12.0**	**3.0-4.0**	**6.0-11, 23.0-43.0**	**12.0-23.0**	**24.0**
		BCJV/500/PH/ P9-2	**0.0-2.0**	**6.0-11.0**	**11.0-13.0**	**2.0-6.0, 26.0-43.0**	**13.0-26.0**	**25**
		BCJV/500/PH/ P9-3	**0.0-2.0**	**2.0-3.0, 6.0-8.0**	**10.0-13.0**	**3.0-6.0, 8.0-10.0, 25.0-44.0**	**13.0-25.0**	**24**
		BCJV/500/PH/ P9-4	**0.0-1.4**	**7.0-9.0**	**11.0-14.0, 19.0-22.0 25.0-26.0**	**1.4-7.0, 9.0-11.0 26.0-43.0**	**14.0-19.0**	**24**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5B/500	**P10**	**BCJV/500/PH/ P10-1**	**0.0-1.0**	**1.5-3.0**		**3.0-22.0**	**22.0-36.0**	**18**
		BCJV/500/PH/ P10-2	**0.0-1.0**			**1.5-22.0**	**22.0-36.0**	**19**
		BCJV/500/PH/ P10-3	**0.0-1.5**	**1.5-3.0**		**3.0-23.0**	**23.0-50.0**	**20**
		BCJV/500/PH/ P10-4	**0.0-2.0**	**2.0-3.0**		**3.0-24.0, 38.0-40.0, 41.0-42.0**	**24.0-38.0, 40.0-41.0, 42.0-50.0**	**17**
5B/500	**P11**	**BCJV/500/PH/ P11-1**	**0.0-1.0**			**1.0-27.0**	**27.0-35.0**	
		BCJV/500/PH/ P11-2	**0.0-2.0**			**2.0-29.0**	**29.0-25.0**	**15**
		BCJV/500/PH/ P11-3			**0.0-2.5**	**2.5-28.0**	**28.0-35.0**	**17**
		BCJV/500/PH/ P11-4			**2.0-5.5**	**0.0-2.0, 5.5-28.9**	**28.9-32.0**	**15**
5C/400	**P12A**	**BCJV/400/PB/ P12A-1**	**0.0-3.0**	**3.0-6.0**	**6.0-18.0**	**18.0-38.0**	**38.0-45.0**	**18**
		BCJV/400/PB/ P12A-2	**0.0-1.3**	**1.3-6.0**	**6.0-12.5**	**12.5-37.0**		**21**
		BCJV/400/PB/ P12A-3	**0.0-1.0**		**6.0-17.0**	**1.0-6.0, 17.0-36.1**	**36.1-50.0**	**20**
		BCJV/400/PB/ P12A-4	**0.0-1.0**		**1.0-12.0**	**12.0-36.0**		**18**
5C/400	**P12B**	**BCJV/400/PB/ P12B-1**	**0.0-3.0**	**6.0-16.0, 17.0-20.0**	**20.0-30.0**	**3.0-6.0, 16.0-17.0 30.0-45.0**		
		BCJV/400/PB/ P12B-2	**0.0-12.0**	**13.0-28.0**	**12.0-13.0, 20.0-30.9**	**30.9-52.0**	**52.0-55.0**	**29**
		BCJV/400/PB/ P12B-3	**0.0-3.0**	**3.0-15.0, 18.0-22.5**	**22.5-28.0**	**15.0-18.0, 28.0-49.0**		
		BCJV/400/PB/ P12B-4	**0.0-3.0**	**7.0-16.0**	**16.0-30.0**	**3.0-7.0, 30.0-47.0**		**29**
5C/400	**P13**	**BCJV/400/PB/ P13-1**	**0.0-1.5**		**1.5-23.0**	**23.0-43.0**		**22**
		BCJV/400/PB/ P13-2	**0.0-1.5**		**8.0-24.0**	**1.5-8.0, 24.0-40.0**		**23**
		BCJV/400/PB/ P13-3	**0.0-2.0**	**5.0-11.0**	**11.0-19.0, 21.0-22.5**	**2.0-5.0, 22.5-42.0**		**26**
		BCJV/400/PB/ P13-4	**0.0-1.8**		**1.8-22.0**	**22.0-43.0**		**21**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	**P14**	**BCJV/400/PB/P14-1**	**0.0-2.0**		**2.0-19.0, 20.0-24.0**	**28.0-44.0**	**24.0-28.0**	**21.0**
		BCJV/400/PB/P14-2	**0.0-1.5**		**3.0-25.0**	**1.5-3.0 27.4-44.0**	**25.0-27.5**	**24.0**
		BCJV/400/PB/P14-3	**0.0-2.0**		**2.0-16.0**	**27.5-38.0**	**17.0-27.5**	**18.0**
		BCJV/400/PB/P14-4	**0.0-1.5**		**1.5-14.0, 17.0-24.0**	**27.0-43.0**	**24.0-27.0**	**18.0**
5C/400	**P15**	**BCJV/400/PB/P15-1**	**0.0-1.0**	**1.0-6.0**	**6.0-24.0 26.5-28.0**	**32.0-47.0**	**24.0-26.5, 28.0-32.0**	**19.0**
		BCJV/400/PB/P15-2	**0.0-2.0**	**2.0-3.0**	**3.0-19.0, 21.0-24.0**	**31.0-40.0**	**19.0-21.0, 24.0-31.0**	**21.0**
		BCJV/400/PB/P15-3	**0.0-2.0**	**2.0-7.0**	**7.0-26.0**	**31.0-45.0**	**26.0-31.0**	**21.0**
		BCJV/400/PB/P15-4	**0.0-1.5**	**1.5-4, 17.0-19.0 22.8-23.9**	**4.0-17.0 19.0-22.8**	**32.0-46.0**	**23.9-32.0**	**21**
5C/400	**P16**	**BCJV/400/PB/P16-2**	**0.0-1.5**	**1.5-7.0**	**7.0-25.0**	**37.0-56.0**	**25.0-37.0**	**24**
		BCJV/400/PB/P16-4	**0.0-1.5**	**1.5-7.0, 25.0-30.0**	**7.0-25.0**	**37.0-56.0**	**25.0-37.0**	**24**
5C/400	**P17**	**BCJV/400/PB/P17-1**	**0.0-1.0**	**1.0-10.1, 23.2-24.5**	**10.1-23.2, 24.5-26, 29.2-33.5**	**43.5-67.0**	**26.0-29.2, 33.5-43.5**	**20.0**
		BCJV/400/PB/P17-2	**0.0-3.0**	**3.0-6.8, 30.0-30.3**	**6.8-26.7, 30.3-35.5**	**26.7-30.0, 46.2-68.0**	**35.5-46.2**	**25**
5C/400	**P18**	**BCJV/400/PB/P18-1**	**0.0-1.2**	**3.0-14.0**	**1.2-3.0, 14.0-27.0**	**47.95-57.0**	**27.0-47.95**	**26.0**
		BCJV/400/PB/P18-2	**0.0-1.0**	**1.0-9.8 21.8-22.6 27.2-31.0**	**9.8-21.8 22.6-27.2**	**46.9-58.93**	**31.0-46.9**	**27.0**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	**P19**	**BCJV/400/PB/ P19-1**	**0.0-2.0**	**2.0-4.5, 9.2-10.5 34.2-37.4**	**4.5-9.2, 10.5-34.2**	**50.0-53.0**	**37.4-50.0**	**31.0**
		BCJV/400/PB/ P19-2	**0.0-1.0**	**1.0-6.0, 7.0-8.0 10.1-12.0, 30.4-33.0**	**6.0-7.0, 8.0-10.1, 12.0-30.4**	**52.0-54.0**	**33.0-52.0**	**32.0**
		BCJV/400/PB/ P19-3	**0.0-1.0**	**35.0-39.0**	**1.0-31.0, 39.0-39.3**	**52.0-56.0**	**31.5-35.0, 39.3-52.0**	**30**
5C/400	**P20**	**BCJV/400/PB/ P20-1**	**0.0-3.0**	**29.0-31.0**	**4.5-29.0**	**3.0-4.5, 37.0-38.5**	**31.0-37.0, 38.5-48.0**	**22.0**
		BCJV/400/PB/ P20-2	**0.0-3.0**	**3.0-18.0**	**18.0-22.0**	**36.0-37.0**	**22.0-36.0, 37.0-45.0**	**24.0**
		BCJV/400/PB/ P20-3	**0.0-1.2**	**3.0-11.0, 19.0-25.0 28.0-32.0**	**11.0-19.0 27.0-28.0**	**1.2-3.0, 25.0-27.0 52.0-54.0**	**32.0-52.0**	**23.0**
		BCJV/400/PB/ P20-4	**0.0-1.47**	**4.0-27.0, 29.0-33.5**		**1.47-4.0, 27.0-29.0 36.0-38.0**	**33.5-36.0, 38.0-54.0**	**24.0**
5C/400	**P22**	**BCJV/400/PB/ P22-1**	**0.0-3.0**		**3.0-20.0 28.3-34.0**		**20.0-28.3, 34.0-56.0**	**19.0**
		BCJV/400/PB/ P22-2	**0.0-3.5**	**7.0-11.0, 13.0-19.0 25.0-31.0**	**19.0-25.0, 31.0-32.0**	**3.5-7.0, 11.0-13.0**	**32.0-56.0**	**20.0**
		BCJV/400/PB/ P22-3	**0.0-0.7**	**0.0-2.0, 2.0-4.0 5.0-9.0**	**9.0-11.0, 16.0-18.0**	**4.0-5.0, 11.0-16.0**	**18.0-48.0**	**19.0**
		BCJV/400/PB/ P22-4	**0.0-1.5**	**1.5-3.0, 3.0-9.0**	**10.5-19.0**	**9.0-10.5, 44.0-45.0**	**19.0-44.0, 45.0-55.0**	**19**
5C/400	**P23**	**BCJV/400/PB/ P23-1**		**1.5-6.0, 30.0-31.0**	**0.0-1.5, 8.0-30.0 31.0-31.8**	**6.0-8.0**	**31.8-51.0**	**23.0**
		BCJV/400/PB/ P23-2		**27.0-30.0**	**0.0-1.5, 3.0-27.0 30.0-32.5 37.0-41.0**	**1.5-3.0**	**32.5-37.0, 41.0-56.0**	**18**
		BCJV/400/PB/ P23-3	**0.0-3.0**		**6.0-22.0**	**3.0-6.0**	**22.0-48.0**	
		BCJV/400/PB/ P23-4	**0.0-6.0**	**49.0-51.0**	**6.0-24.0**		**24.0-49.0**	**27.0**
5C/400	**P24**	**BCJV/400/PB/ P24-1**	**0.0-3.0**	**47.5-53.0**	**7.0-26.0**	**3.0-7.0**	**26.0-38.0, 44.0-47.5 53.0-59.0**	**26.0**
		BCJV/400/PB/ P24-2	**0.0-1.4**	**1.4-13.0**	**13.0-26.5, 27.7-29.3**		**26.5-27.7, 29.3-51.0**	**27.0**
		BCJV/400/PB/ P24-3	**0.0-3.0**		**3.0-25.0**	**39.0-41.0**	**25.0-39.0, 41.0-63.0**	**25.0**
		BCJV/400/PB/ P24-4	**0.0-1.2**	**1.2-5.0**	**7.0-34.0**	**5.0-7.0**	**34.0-50.0**	**26.0**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	P25	BCJV/400/PB/ P25-1	0.0-3.0	34.0-47.0	3.0-34.0		47.0-68.0	35.0
		BCJV/400/PB/ P25-2	0.0-3.0	3.0-8.5, 34.0-36.0, 53.0-55.0, 56.0-59.0	8.5-34.0		36.0-53.0, 55.0-56.0, 59.0-60.0	33.0
		BCJV/400/PB/ P25-4	0.0-3.0	3.0-10.0, 25.0-29.0, 36.0-48.0	10.0-25.0, 29.0-36.0		48.0-64.0	33.0
		BCJV/400/PB/ P25-5	0.0-2.5	2.5-17.0	17.0-30.0		30.0-56.0	29.0
5C/400	P26	BCJV/400/PB/ P26-1	0.0-3.0	3.0-4.0, 60.0-62.0	7.0-40.0	4.0-7.0	40.0-60.0, 62.0-63.0	20.0
		BCJV/400/PB/ P26-2	0.0-3.0	3.0-5.0, 33.7-39.0	7.0-32.0	5.0-7.0	32.0-33.3, 39.0-61.0	20.0
		BCJV/400/PB/ P26-3	0.0-3.0	37.0-45.6	3.0-6.0, 11.0-37.0	6.0-11.0	45.6-62.0	28.0
		BCJV/400/PB/ P26-4	0.0-3.0	3.0-11.0, 15.0-18.0, 38.0-42.5	11.0-15.0, 18.0-27.0, 29.5-31.7		27.0-29.5, 31.7-38, 42.5-61.0	25.0
		BCJV/400/PB/ P26-5	0.0-4.0	4.0-14.0, 34.0-35.0	14.0-34.0, 37.0-42.0, 46.0-48.0	36.0-37.0	35.0-36.0, 42.0-46.0, 48.0-64.0	33.0
5C/400	P27	BCJV/400/PB/ P27-1	0.0-4.0		4.0-28.0, 33.4-36.0		36.0-53.0	-
		BCJV/400/PB/ P27-2	0.0-3.4		3.4-36.0		36.0-48.8	-
		BCJV/400/PB/ P27-3	0.0-6.0		6.0-21.2, 25.4-36.5		21.2-25.4, 36.5-58.0	20.0
		BCJV/400/PB/ P27-4	0.0-2.0	10.0-15.0	2.0-10.0, 15.0-39.0		39.0-55.0	27.0
5C/400	P28	BCJV/400/PB/ P28-1	0.0-4.0	15.0-24.0	4.0-15.0, 24.0-39.0		39.0-55.0	26.0
		BCJV/400/PB/ P28-2	0.0-5.0	5.0-7.0	7.0-25.2, 30.5-33.5, 36.0-48.7		25.2-30.5, 33.5-36.0, 48.7—64.0	28.0
		BCJV/400/PB/ P28-3	0.0-5.0	5.0-13.0, 63.0-64.0, 65.0-66.5	13.0-26.0, 30.5-48.0, 53.0-59.0		26.0-30.5, 48.0-52.0, 59.0-63.0, 64.0-65.0, 66.5- 73	25.0
		BCJV/400/PB/ P28-4	0.0-4.0	50.0-62.2, 67.0-69.0	4.0-50.0		62.2-67.0, 69.0-78.0	36.0
5C/400	P29	BCJV/400/PB/ P29-1	0.0-11.0,		11.0-21.0, 40.8-47.0		21.0-40.8, 47.0-65.0	-
		BCJV/400/PB/ P29-2	0.0-13.0		13.0-25.2		25.2-66.0	
		BCJV/400/PB/ P29-3	0.0-13		14.0-23.0, 33.0-36.7, 38.0-39.4		23.0-33.0, 36.7-38.0, 39.4-46.5, 48.0-67.0	23.0
		BCJV/400/PB/ P29-4B	0.0-7.0		21.0-26.5	7.0-9.5, 20.0-21.0	9.5-20.0, 26.5-67.0	21.0
		BCJV/400/PB/ P29-5	0.0-9.4	13.0-15.0, 47.0-52.5		34.0-39.3	9.4-13.0, 15.0-34.0, 39.3-47.0, 52.5-63.0	20.0

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/ SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	**P30**	**BCJV/400/PB/P 30-1A**	**0.0-4.0**		**4.0-36.0, 40.5-43.0, 48.0-64.0**		**36.0-40.5, 43.0-48.0, 64.0-77.0**	**13.0**
		BCJV/400/PB/P 30-2	**0.0-7.0**		**7.0-53.0**		**53.0-74.0**	**33.0**
		BCJV/400/PB/P 30-3	**0.0-6.0**		**6.0-32.0, 35.0-37.0, 40.0-46.0, 47.5-54.0, 57.0-58.0**		**32.0-35.0, 37.0-40.0, 46.0-47.0, 54.0-57.0, 58.0-75.0**	**26.0**
		BCJV/400/PB/P 30-4	**0.0-8.0**		**8.0-18.0, 19.0-33.6, 40.0-51.5**		**18.0-19.0, 33.6-40.0, 51.5-72.0**	**38**
		BCJV/400/PB/P 30-5	**0.0-6.0**		**6.0-32.0, 35.0-45.5, 49.0-52.5**		**32.0-35.0, 45.5-49.0, 52.5-71.0**	**34.0**
5C/400	**P31**	**BCJV/400/PB/P 31-1**	**0.0-13.5**		**13.5-23.0, 26.5-28.5, 31.5-34.0**		**23.0-26.5, 28.5-31.5, 34.0-73.0**	**-**
		BCJV/400/PB/P 31-2	**0.0-3.0**	**3.0-14.0**	**14.0-28.0**		**28.0-74.0**	**-**
		BCJV/400/PB/P 31-3	**0.0-5.0**	**5.0-20.5, 50.0-55.0, 60.0-62.0**	**20.5-34.0, 37.0-50.0, 55.0-60.0**		**34.0-37.0, 62.0-77.0**	
		BCJV/400/PB/P 31-4	**0.0-7.0**	**7.0-20.0, 23.0-28.0**	**28.0-37.3**		**20.0-23.0, 37.3-77.0**	**30.0**
5C/400	**P32**	**BCJV/400/PB/P 32-1**	**0.0-1.1**	**6.0-16.0, 32.0-34.0**	**1.1-6.0, 16.0-29.0, 30.0-32.0, 35.0-44.5, 57.5-62.5**		**29.0-30.0, 34.0-35.0, 44.5-57.5, 62.5-80.0**	**30.0**
		BCJV/400/PB/P 32-2	**0.0-1.1**	**1.1-3, 4.2-13.0, 32.7-34.0, 39.0-40.0**	**13.0-32.7, 34.0-39.0, 40.0-56.0**		**3.0-4.2, 56.0-78.0**	**28.0**
		BCJV/400/PB/P 32-3	**0.0-2.0**	**2.0-15.0, 36.8-38.1, 40.0-41.2**	**13.0-32.7, 34.0-39.0, 40.0-56.0**		**3.0-4.2, 56.0-78.0**	**28.0**
		BCJV/400/PB/P 32-4	**0.0-1.2**	**1.2-13.0, 51.0-52.5**	**13.0-15.0, 16.0-41.0, 62.0-67.6**		**41.0-51.0, 52.5-62, 67.6-80.0**	**28.0**
		BCJV/400/PB/P 32-5	**0.0-6.0**	**6.0-14.0**	**14.0-20.0, 22.0-28.0, 33.0-34.0, 63.5—66.7**		**20.0-22.0, 28.0-33.0, 34.0-63.5, 66.7-80.0**	**33.0**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK(m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	**P33**	**BCJV/400/PB/P33-1**	**0.0-1.1**	**1.1-7.0**	**7.0-13.5, 18.0-38.0**		**13.5-18.0**	**18.0**
		BCJV/400/PB/P33-1A	**0.0-1.2**	**1.2-9.0**	**9.0-33.2, 46.8-48.1**		**33.2-46.8, 48.1-69.0**	**19.0**
		BCJV/400/PB/P33-2A	**0.0-3.0**	**3.0-5.5**	**8.1-13.0, 17.8-21.0, 24.0-32.0, 44.5-50.0, 51.0-53.5, 60.4-60.8**		**5.5-8.4, 13.0-17.8, 21.0-24.0, 32.0-44.5, 50.0-51.0, 53.5-60.4, 60.8-63.5, 66.5-80.0**	**18**
		BCJV/400/PB/P33-3A	**0.0-1.5**	**1.6-8.0, 9.0-11.0**	**8.0-9.0, 27.0-49.3,49.5-8.5**		**11.0-27.0, 58.5-76.0**	**26.0**
		BCJV/400/PB/P33-4	**0.0-2.0**	**2.0-9.0**	**9.0-24.0, 35.0-55.6, 60.0-66.0**		**55.6-60.0, 66.0-76.0**	**30.0**
5C/400	**P34**	**BCJV/400/PB/P34-1**	**0.0-2.0**	**2.0-9.0, 12.0-14.0**	**14.0-17.0, 20.5-24.0, 27.0-30.5**		**9.0-12.0, 17.0-20.5, 30.5-78.0**	**18.0**
		BCJV/400/PB/P34-2	**0.0-2.0**		**16.9-23.2**	**2.0-6.0**	**6.0-16.9, 23.2-70.0**	**21.0**
		BCJV/400/PB/P34-3	**0.0-1.2**		**8.0-36.0**		**2.0-8.0, 36.0-78.0**	**18.0 & 50.0**
		BCJV/400/PB/P34-4	**0.0-1.0**	**1.0-3.0**	**3.0-5.0, 21.0-29.0**		**5.0-21.0, 29.0-66.0**	**17.0**
5C/400	**P35**	**BCJV/400/PB/P35-1A**	**0.0-1.0**				**1.0-17.0, 18.0-37.0**	**18.0**
		BCJV/400/PB/P35-1T	**0.0-1.4**		**1.4-2.0**		**2.0-12.2, 13.0-17.0**	**-**
		BCJV/400/PB/P35-2		**0.0-11.0, 20.7-23.0**	**11.0-20.7**		**23.0-41.0**	**18.0**
		BCJV/400/PB/P35-5	**0.0-1.5**	**1.5-4.2**			**4.2-12.0, 15.3-32.0**	**-**
5C/400	**P36**	**BCJV/400/PB/P36-1**	**0.0-2.0**	**2.0-6.0**	**6.0-16.0, 18.0-24.0**		**24.0-40.0**	**24.0**
		BCJV/400/PB/P36-2	**0.0-3.0**	**3.0-7.0**	**7.0-18.2, 21.0-24.0**		**24.0-40.0**	**23.0**
		BCJV/400/PB/P36-4		**3.0-4.0**	**6.5-8.0, 9.6-10.5, 14.0-17.0**	**0.0-3.0, 4.0-6.5**	**8.0-9.6, 10.5-14.0, 17.0-39.0**	**20.0**
		BCJV/400/PB/P36-5	**0.0-1.2**	**1.2-6.0**	**6.0-13.0**		**13.0-46.0**	**-**
5C/400	**P37**	**BCJV/400/PB/P37-2**	**0.0-1.4**	**1.4-14.0, 53.5-59.0**	**14.0-25.5, 35.0-36.0, 39.0-42.0, 49.0-50.0**		**25.5-35.0, 36.0-39.0, 42.0-49.0, 50.0-53.5, 59.0-80.0**	**18.0**
		BCJV/400/PB/P37-4	**0.0-1.2**	**1.2-14.0, 55.0-56.0**	**14.0-28.0**	**30.0-49.0, 50.0-52.0**	**49.0-50.0, 52.0-55.0, 56.0-80.0**	**39.0**
		BCJV/400/PB/P37-5	**0.0-1.2**	**1.2-33.0, 38.0-39.0**	**49.0-51.0**	**33.0-38.0**	**39.0-49.0, 51.0-55.0, 58.4-80.0**	**37.0**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL(m)
5C/400	P38	BCJV/400/PB/P38-2	0.0-1.4	1.4-12.0	12.0-14.0, 15.0-25.0, 38.0-40.0, 56.0-61.0		25.0-38.0, 40.0-56.0, 62.0-80.0	18.0
		BCJV/400/PB/P38-4	0.0-2.0	2.0-5.0, 39.0-40.0	5.0-8.5,16.0-18.5,20.5-3.0, 35.8-39.0, 40.0-44.0, 55.0-56.0	44.0-51.5	8.5-14.0, 18.5-20.5, 33.0-35.8, 51.5-55.0, 56.0-57.0, 58.0-78.0	52.0
		BCJV/400/PB/P38-5	0.0-1.4	1.4-4.0, 6.0-7.0, 8.0-12.0, 13.3-14.0, 43.0-49.0, 52.2-59.0	14.0-34.0, 35.7-43.0	49.0-52.5	4.0-6.0, 7.0-8.0, 12.0-13.3, 34.0-35.7, 59.0-75.0	-
5C/400	P39	BCJV/400/PB/P39-1		0.0-3.0	27.3-28.0, 32.0-35.0	18.8-19.8	3.0-15.5, 19.8-27.3, 28.0-32.0, 35.0-54.0	-
		BCJV/400/PB/P39-2	0.0-1.2		21.0-22.0, 22.0-28.0		1.2-19.0, 28.0-43.0	25
		BCJV/400/PB/P39-4	0.0-1.1	1.1-6.0	16.5-28.0		6.0-10.5, 12.0-16.5, 28.0-38.5, 41.0-48.0	-
		BCJV/400/PB/P39-5		0.0-6.0	6.0-7.8		7.8-27.0	-
5C/400	P40	BCJV/400/PB/P40-1	0.0-1.2	1.2-5.0	15.0-16.0, 20.0-26.0		5.0-15.0, 16.0-20.0, 26.0-42.0	-
		BCJV/400/PB/P40-2	0.0-2.0	2.0-9.0, 12.0-14.0	9.0-11.0, 14.0-16.0, 23.0-24.0		16.0-20.5, 24.0-42.0	23.0
		BCJV/400/PB/P40-3	0.0-2.0	2.0-3.0	9.0-25.5		3.0-8.0, 25.5-42.0	26.0
		BCJV/400/PB/P40-4	0.0-2.0	2.0-4.0, 6.0-25.0	4.0-5.0, 25.0-30.0		5.0-6.0, 30.0-47.0	30.0
		BCJV/400/PB/P40-5	0.0-0.9	0.9-6.0	18.0-26.0		6.0-18.0, 26.0-42.0	-
5C/400	P41	BCJV/400/PB/P41-1	0.0-1.0	13.0-17.5, 29.5-33.0			Check	-
		BCJV/400/PB/P41-2	0.0-1.0				1.0-9.0, 10.0-12.0, 17.5-29.5, 33.0-49.0	27.0
		BCJV/400/PB/P41-4	0.0-1.4		27.0-30.0		1.4-27.0	-
		BCJV/400/PB/P41-4A	0.0-0.7		2.0-3.0, 14.0-16.5		0.7-2.0, 3.0-12.8,16.5-39.0	-
		BCJV/400/PB/P41-5	0.0-1.0	4.0-5.0	1.0-4.0, 7.0-8.0		8.0-48.0	-
5C/400	P42	BCJV/400/PB/P42-1	0.0-1.0	16.8-17.2	2.0-3.0		1.0-2.0, 3.0-16.8, 17.2-29.0	-
		BCJV/400/PB/P42-2	0.0-1.0				1.0-25.0	8
		BCJV/400/PB/P42-4	0.0-1.0				1.0-16.8, 18.0-35.0	-
		BCJV/400/PB/P42-5	0.0-1.0	1.0-3.2			3.2-17.9, 19.8-25.0	-

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	P43	BCJV/400/PB/ P43-1	0.0-1.5	2.0-8.0	8.0-10.0, 11.0-19.4, 21.0-24.3		19.4-21.0, 24.3-40.0	
		BCJV/400/PB/ P43-2	0.0-1.0	1.0-2.0	15.3-20.4, 21.5-24.0		2.0-10.0, 14.0-15.3, 20.4-21.5, 24.0-39.0	
		BCJV/400/PB/ P43-3	0.0-2.0	2.0-13.0	14.0-28.0		28.0-48.0	31.0
		BCJV/400/PB/ P43-4	0.0-2.0	2.0-4.6	15.0-16.8, 17.8-19.5		4.6-15.0, 16.8-17.8, 19.5-39.0	-
5C/400	P44	BCJV/400/PB/ P44-1	0.0-2.0	2.0-3.0, 4.0-10.0	10.0-20.5, 24.0-26.1	20.5-24.0	26.1-33.3, 33.6-48.0	-
		BCJV/400/PB/ P44-2	0.0-1.2	1.2-6.0, 7.0-11.0	6.0-7.0, 11.0-24.0, 24.0-28.5		28.5-51.0	40.0
		BCJV/400/PB/ P44-3	0.0-1.0	1.0-8.0	8.0-20.0, 21.0-33.0	33.0-36.0	20.0-21.0, 36.0-53.0	37.0
		BCJV/400/PB/ P44-4	0.0-1.0	1.0-9.0, 29.0-30.0	9.0-29.0		30.0-45.0	27.0
5C/400	P46	BCJV/400/PB/ P46-1	0.0-3.0		3.0-23.5		23.5-43.0	-
		BCJV/400/PB/ P46-2	0.0-2.0	2.0-4.5	4.5-14.0, 15.0-18.0	14.0-15.0	18.0-20.0, 25.0-41.0	-
		BCJV/400/PB/ P46-3	0.0-2.0		2.0-27.0, 31.0-32.0		27.0-31.0, 32.0-48.0	-
		BCJV/400/PB/ P46-4	0.0-1.3	1.3-6.8	7.0-19.0, 27.3-31.0	6.0-7.0	31.0-48.0	
5C/400	P47	BCJV/400/PB/ P47-1	0.0-2.0	2.0-5.0	5.0-8.0, 14.0-43.0		8.0-14.0, 43.0-65.0	-
		BCJV/400/PB/ P47-2	0.0-2.0	2.0-6.5	6.5-11.0, 15.0-42.3		11.0-15.0, 42.3-60.0	-
		BCJV/400/PB/ P47-3	0.0-2.0	2.0-5.0	6.0-43.8		43.8-63.0	
		BCJV/400/PB/ P47-4	0.0-3.0	3.0-7.0	7.0-8.0, 12.0-48.0		8.0-12.0, 48.0-67.0	
5C/400	P48	BCJV/400/PB/ P48-1	0.0-1.4				1.4-37.0	-
		BCJV/400/PB/ P48-2	0.0-1.0				1.0-38.0	
		BCJV/400/PB/ P48-3	0.0-1.2	1.2-3.0			3.0-36.0	
		BCJV/400/PB/ P48-4	0.0-2.0	2.0-6.0, 11.0-12.0			7.0-11.0, 12.0-37.0	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

5C/400	P49	BCJV/400/PB/P49-1		0.0-3.0			3.0-6.0, 6.0-30.0	
		BCJV/400/PB/P49-2	0.0-1.0				1.0-30.0	
		BCJV/400/PB/P49-3					0.0-38.0	
		BCJV/400/PB/P49-4	0.0-1.2	1.2-3.0			3.0-33.0	
5C/400	P50	BCJV/400/PB/P50-1	0.0-1.0	1.0-4.0	16.0-23.0		4.0-16.0, 23.0-39.0	
		BCJV/400/PB/P50-2	0.0-1.0	1.0-4.0		18.3-18.7	4.0-18.3, 18.7-38.0	
		BCJV/400/PB/P50-4	0.0-1.0	1.0-7.0	7.0-15.0, 19.0-22.0		15.0-16.2, 22.0-39.0	
5C/400	P51	BCJV/400/PB/P51-1	0.0-1.0				1.0-21.0, 23.0-40.0	29
		BCJV/400/PB/P51-2	0.0-1.5	1.5-7.0	7.0-12.0, 14.0-16.0		16.0-42.0	26.85
		BCJV/400/PB/P51-3	0.0-3.0				3.0-40.0	-
		BCJV/400/PB/P51-4	0.0-1.3				1.3-40.0	
		BCJV/400/PB/P51-5	0.0-2.0	2.0-3.0, 24.2-24.8			4.0-24.2, 24.8-40.0	
5C/400	P52	BCJV/400/PB/P52-1	0.0-2.0	2.0-3.5	3.5-15.0		15.0-33.0	
		BCJV/400/PB/P52-2	0.0-1.5	1.5-5.0, 12.0-13.0	5.0-12.0		13.0-30.0	
		BCJV/400/PB/P52-3	0.0-1.8	1.8-7.0	7.0-20.0		20.0-36.0	
		BCJV/400/PB/P52-4	0.0-2.0	2.0-6.0	6.0-25.0		25.0-42.0	
5C/400	P53	BCJV/400/PB/P53-1B	0.0-0.5		0.5-2.0		2.0-6.0, 7.7-35.0	
		BCJV/400/PB/P53-2	0.0-2.0		2.0-7.0, 8.0-14.0, 25.0-27.8, 31.0-45.0		7.0-8.0, 14.0-25.0, 27.8-31.0, 45.0-60.0	33.0
		BCJV/400/PB/P53-2A	0.0-1.5		1.5-6.0, 9.0-11.0, 12.2-14.0, 25.0-38.0, 51.5-54.5		6.0-7.6, 11.0-12.2, 14.0-22.0, 24.0-25.0, 38.0-51.5	38.0
		BCJV/400/PB/P53-2B	0.0-2.0	2.0-5.0	5.0-22.0, 23.0-31.0, 33.0-39.0		39.0-61.0	33.5
		BCJV/400/PB/P53-3	0.0-2.0		2.0-5.2, 7.8-11.12		5.2-7.8, 11.2-39.0	
		BCJV/400/PB/P53-4	0.0-2.0		2.0-4.0, 6.4-14.2		4.0-6.4, 14.2-34.0	
		BCJV/400/PB/P53-5	0.0-2.0	2.0-5.0	18.0-21.0	5.0-6.0	21.0-44.0	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	**P54**	**BCJV/400/PB/ P54-1**	**0.0-3.0**		**3.0-8.0, 12.0-14.0, 18.0-33.0**		**8.0-12.0, 14.0-18.0, 33.0-48.0**	**28**
		BCJV/400/PB/ P54-2	**0.0-2.0**		**3.5-5.0, 16.0-19.0, 20.0-23.0, 28.0-29.0**	**2.0-3.5**	**5.0-16.0, 19.0-20.0, 23.0-28.0, 29.0-48.0**	**27.25**
		BCJV/400/PB/ P54-3	**0.0-1.1**	**1.1-5.0**	**5.0-9.0, 19.0-24.0, 29.2-30.0**		**9.0-19.0, 24.0-29.2, 30.0-48.0**	**29.1**
		BCJV/400/PB/ P54-4	**0.0-2.5**	**2.5-5.0**	**5.0-10.0, 16.0-21.0, 23.0-24.0, 25.0-33.5, 36.8-40.5**		**33.5-36.0, 40.5-57.0**	**30**
		BCJV/400/PB/ P54-5	**0.0-1.2**	**1.2-5.0**	**5.0-9.5, 15.3-23.0, 29.0-30.0**		**9.5-15.3, 23.0-29.0, 30.0-49.0**	**28**
5C/400	**P55**	**BCJV/400/PB/ P55-1**	**0.0-2.0**	**2.0-6.5, 17.0-25.0**	**6.5-12, 14.5-17.0, 25.0-28.0**		**12.0-14.5, 28.0-46.0**	
		BCJV/400/PB/ P55-2	**0.0-2.0**	**6.0-7.5, 14.0-17.0**	**2.0-6.0, 7.5-14.0, 17.0-24.0, 25.0-31.0**		**24.0-25.0, 31.0-57.0**	**27.0**
		BCJV/400/PB/ P55-3	**0.0-2.0**	**2.0-5.0**	**5.0-15.0, 16.0-24.9**		**24.9-25.3, 32.5-49.0**	**26.0**
		BCJV/400/PB/ P55-4		**0.0-6.0, 11.0-14.5**	**6.0-11.0, 14.5-22.0, 34.0-35.0**		**22.0-23.0, 30.0-34.0, 35.0-49.0**	
		BCJV/400/PB/ P55-5	**0.0-3.0**		**3.0-23.5**		**23.5-46.0**	
		BCJV/400/PB/ P55-6	**0.0-2.0**		**2.0-23.0**		**23.0-45.0**	**33.0**
5C/400	**P56**	**BCJV/400/PB/ P56-1**	**0.0-1.5**		**1.5-21.0**		**21.0-36.0**	
		BCJV/400/PB/ P56-2	**0.0-2.0**		**2.0-14.1**		**14.1-30.0**	
		BCJV/400/PB/ P56-3	**0.0-2.0**	**2.0-3.0**	**3.0-14.0, 20.0-22.0**		**14.0-20.0, 22.0-36.0**	
		BCJV/400/PB/ P56-3A	**0.0-3.0**		**3.0-15.0, 20.9-23.1**		**15.0-20.9, 23.1-38.0**	
		BCJV/400/PB/ P56-4	**0.0-1.5**		**1.5-7.0, 10.0-18.0**	**7.0—10.0**	**18.0-33.0**	**30.0**
		BCJV/400/PB/ P56-5	**0.0-1.5**	**2.0-4.0**	**1.5-2.0, 4.0-6.9, 10.0-24.0, 29.0-49.0**	**6.9-10.0**		**24.0**
		BCJV/400/PB/ P56-5A	**0.0-1.0**	**1.0-3.0, 7.0-8.9**	**3.0-7.0, 8.9-17.0**			**15.0**
		BCJV/400/PB/ P56-6	**0.0-1.1**	**1.1-3.0, 5.0-7.0**	**3.0-5.0, 9.0-25.8**		**25.8-33.0**	**31.0**

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/ SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK(m)	GW LEVEL (m)
5C/400	P57	BCJV/400/PB/P 57-1	0.0-2.0				3.0-33.0	30.0
		BCJV/400/PB/P 57-3	0.0-1.5		1.5-8.0, 18.0-22.5, 28.0-29.0		8.0-14.0, 22.5-28.0, 29.0-36.0	
		BCJV/400/PB/P 57-6	0.0-1.5				1.5-14.4, 18.4-36.0	16.0
		BCJV/400/PB/P 57-8	0.0-1.5				1.5-19.0	
		BCJV/400/PB/P 57-9	0.0-1.5		1.5-2.0		2.0-19.0	
5C/400	P58	BCJV/400/PB/P 58-1	0.0-1.0	9.0-10.0	1.0-9.0, 10.0-13.3, 29.5-30.5, 49.0-52.0		13.3-25.07, 36.5-43.0, 52.0-66.0	
		BCJV/400/PB/P 58-2	0.0-2.0		2.0-17.5		17.5-32.0	
		BCJV/400/PB/P 58-3	0.0-2.0	2.0-6.0, 7.0-11.0	6.0-7.0, 11.0-17.0		17.0-31.6	
		BCJV/400/PB/P 58-3A	0.0-1.0	1.0-8.0	8.0-11.0, 13.2-16.0, 50.2-52.0	11.0-13.2	16.0-32.1, 36.9-39.9, 49.7-50.2, 52.0-54.0, 56.3-70.0	57.0
		BCJV/400/PB/P 58-4	0.0-2.0		2.0-22.0		22.0-24.0	
5C/400	P59	BCJV/400/PB/P 59-2	0.0-2.0	51.0-52.0	2.0-28.0, 36.0-39.0, 40.5-51.0		28.0-34.2, 52.0-70.0	43.0
		BCJV/400/PB/P 59-3	0.0-2.0	2.0-24.0	24.0-51.0		51.0-68.0	45.0
5C/400	P60	BCJV/400/PB/P 60-1	0.0-1.2	1.2-20.0	20.0-58.0		58.0-79.0	40.0
		BCJV/400/PB/P 60-3	0.0-1.25	7.2-25.0	1.25-7.2, 25.0-54.0, 68.0-70.0		54.0-65.3, 67.7-68.0	40.0
5C/400	P61	BCJV/400/PB/P 61-1	0.0-9.0	9.0-20.0	20.0-61.5		61.5-65.0	34.0
		BCJV/400/PB/P 61-2	0.0-2.0	19.0-22.0, 32.5-38.0, 67.0-68.0	10.5-19.0, 22.0-32.5, 38.0-57.2	2.0-10.5	57.2-67.0, 68.0-80.0	39.0
		BCJV/400/PB/P 61-3	0.0-1.0	2.0-12.5, 15.0-16.0, 34.0-42.0, 54.0-57.5	1.0-2.0, 12.5-15.0, 16.0-34.0, 42.0-54.0		57.5-75.0	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE ROCK (m)	GW LEVEL (m)
5C/400	P62	BCJV/400/PB/ P62-1	0.0-2.0	31.0-39.0	12.0-28.0	2.0-12.0, 28.0-31.0	39.0-56.0	39.0
		BCJV/400/PB/ P62-2	0.0-2.0	15.0-16.0	18U.0-33.0, 36.0-60.0, 65.0-66.0	2.0-15.0, 16.0-18.0, 33.0-36.0	60.0-61.8, 66.0-84.0	47.0
		BCJV/400/PB/ P62-3	0.0-1.5	47.0-49.0	14.5-26.0, 28.5-47.0	1.5-14.5, 26.0-28.5	49.0-64.0, 66.3-90.0	37.0
		BCJV/400/PB/ P62-4	0.0-2.0	23.5-25.0	15.0-23.5, 25.0-29.8, 36.0-52.3	2.0-15.0, 29.8-36.0	52.3-72.0	49.0
5C/400	P63	BCJV/400/PB/ P63-1	0.0-1.3	1.3-9.0, 11.0-12.0	9.0-11.0, 12.0-36.0, 41.0-54.0	36.0-41.0	54.0-58.7	
		BCJV/400/PB/ P63-2	0.0-2.0	15.0-16.0	14.0-15.0, 16.0-61.0	2.0-14.0	61.0-89.0	
		BCJV/400/PB/ P63-3	0.0-1.3	19.5-21.0, 60.0-62.0	11.0-19.5, 21.0-39.0, 44.0-60.0, 62.0-65.0	1.3-11.0, 39.0- 44.0	65.0-76.8	
		BCJV/400/PB/ P63-4	0.0-1.3	52.6-55.0	17.0-52.6, 55.0-65.0	1.3-17.0	65.0-71.9, 73.5-80.0	
5C/400	P64	BCJV/400/PB/ P64-1	0.0-1.0	2.0-6.0	1.0-2.0, 6.0-18.5		18.5-24.0	
		BCJV/400/PB/ P64-2	0.0-2.0	2.0-3.0, 14.0-15.0, 16.0-20.0, 21.5-49.0	3.0-14.0, 15.0-16.0, 20.0-21.5		49.0-66.0	51.0
		BCJV/400/PB/ P64-3	0.0-1.5	1.5-3.0	3.0-22.1, 27.4-30.0		22.1-27.4	
		BCJV/400/PB/ P64-3A			30.0-32.2, 35.8-37.0		32.2-35.8, 39.0-65.0	39.0 & 59.0
		BCJV/400/PB/ P64-4	0.0-2.0	2.0-5.0,15.0-16.0	5.0-15.0,16.0-64,9,76.0-79.5		79.5-83.0	82.0
5C/400	P65	BCJV/400/PB/ P65-1	0.0-1.4	14.0-15.0	1.4-9.0, 23.0-24.0, 25.0-40.6	9.0-14.0,15.0-23.0,24.0-25.0	40.6-63.0	
		BCJV/400/PB/ P65-2	0.0-4.0	25.0-27.0	27.0-47.2	4.0-25.0	47.2-65.0	42.0, 45.0, 47.0
		BCJV/400/PB/ P65-3	0.0-3.0		3.0-55.0		55.0-72.0	45.0
		BCJV/400/PB/ P65-4	0.0-3.0		3.0-5.0, 19.0-48.0, 49.0-50.0	5.0-19.0, 48.0-49.0	50.0-69.0	
5C/400	P66	BCJV/400/PB/ P66-1	0.0-1.0	1.0-4.5	4.5-11.2		11.2-14.2,15.3-35.0	
		BCJV/400/PB/ P66-2		0.0-8.0	8.0-9.3		9.3-35.0	
		BCJV/400/PB/ P66-4	0.0-1.5	1.5-6.0			6.0-28.0	
		BCJV/400/PB/ P66-5	0.0-0.9	0.9-2.0, 14.0-15.0	2.0-3.4, 3.4-4.9		4.9-14.0, 15.0-35.0	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT /SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL(m)
5C/400	**P67**	**BCJV/400/PB/ P67-1**	**0.0-2.0**	**2.0-14.0**	**14.0-22.0**		**22.0-42.0**	**33.0**
		BCJV/400/PB/ P67-3	**0.0-1.2**	**1.2-2.0,21.0-22.0**	**2.0-3.0**		**3.0-21.0,22.0-39.0**	**20.0**
5C/400	**P68**	**BCJV/400/PB/ P68-2**	**0.0-2.0**	**2.0-11.0, 14.0-23.0, 25.0-40.5**	**11.0-14.0, 40.5-63.0**		**23.0-25.0, 63.0-79.0**	**36.0**
		BCJV/400/PB/ P68-5	**0.0-1.5**	**1.5-2.5,5.0-9.0,19.0-21.0**	**2.5-5.0,14.0-19.0,21.0-22.5,32.0-50.6,58.0-59.0**	**9.0-14.0**	**22.5-32.0, 50.6-58.0, 59.0-77.0**	**56.0**
5C/400	**P69**	**BCJV/400/PB/ P69-1**	**0.0-0.9**	**0.9-1.6, 6.0-17.5, 33.0-34.0**		**12.5-16.0**	**1.6-12.5, 17.5-33.0, 34.0-36.0**	
		BCJV/400/PB/ P69-2	**0.0-2.0**			**11.0-17.2**	**2.0-11.0,17.2-31.0**	
		BCJV/400/PB/ P69-3	**0.0-1.5**	**1.5-3.0, 31.0-32.0**	**4.0-10.0**	**10.0-14.5**	**3.0-4.0, 14.5-31.0, 32.0-46.0**	
		BCJV/400/PB/ P69-4	**0.0-1.5**		**1.5-6.0**	**6.0-13.0**	**13.0-50.0**	
5C/400	**P70**	**BCJV/400/PB/ P70-1**	**0.0-2.0**	**2.0-7.0**		**12.0-16.5**	**7.0-12.0,16.5-32.0**	
		BCJV/400/PB/ P70-2	**0.0-5.0**			**11.8-17.2**	**5.0-11.8,17.2-25.0**	
		BCJV/400/PB/ P70-3	**0.0-1.4**	**1.4-3.0**		**11.0-16.0**	**3.0-11.0,16.0-25.0**	
		BCJV/400/PB/ P70-4	**0.0-2.0**		**2.0-8.0**	**11.8-17.8**	**8.0-11.8,17.8-25.0**	
5C/400	**P71**	**BCJV/400/PB/ P71-1**	**0.0-2.0**	**2.0-6.0**	**6.0-9.0**	**11.5-20.0**	**9.0-11.5, 20.0-30.0**	
		BCJV/400/PB/ P71-2	**0.0-2.0**	**2.0-6.0**	**6.0-11.5**	**11.5-17.6**	**17.6-30.0**	
		BCJV/400/PB/ P71-3	**0.0-2.0**	**2.0-5.0**	**5.0-7.0**	**11.0-18.0**	**7.0-11.0,18.0-36.0**	
		BCJV/400/PB/ P71-4	**0.0-2.0**	**2.0-5.0, 6.0-7.0**	**5.0-6.0**	**11.5-16.5**	**7.0-11.5,16.5-36.0**	
5C/400	**P72**	**BCJV/400/PB/ P72-2**	**0.0-1.5**	**1.5-3.0**		**17.2-23.5**	**3.0-17.2,23.5-33.0**	
		BCJV/400/PB/ P72-3	**0.0-1.5**	**3.0-5.0**	**5.0-5.7**	**17.0-21.9**	**1.5-3.0, 5.7-17.0, 21.9-41.0**	
		BCJV/400/PB/ 72-4	**0.0-1.5**	**1.5-3.0**		**16.0-22.8**	**3.0-16.0,22.8-36.0**	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/ SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5C/400	P73	BCJV/400/PB/ P73-1	0.0-2.0	2.0-4.0	4.0-5.0,6.0-10.0	23.0-29.0	5.0-6.0, 10.0-23.0, 29.0-37.0	
		BCJV/400/PB/ P73-2	0.0-1.0		7.3-11.5		1.0-7.3,11.5-19.0	
		BCJV/400/PB/ P73-2A	0.0-0.5			23.0-25.0	0.5-23.0,25.0-49.0	
		BCJV/400/PB/ P73-3	0.0-1.5		8.0-9.0, 16.0-17.0, 18.0-20.5	20.5-28.0	1.5-8.0, 9.0-16.0, 28.0-37.0	
		BCJV/400/PB/ P73-4			0.0-1.0	23.0-29.0	1.0-23.0,29.0-34.0	
5C/400	P74	BCJV/400/PB/ P74A-1	0.0-1.0	1.0-11.0	11.0-23.8	27.0-42.0	23.8-27.0	
		BCJV/400/PB/ P74A-2	0.0-1.2	1.2-3.0,5.0-7.0,9.0-12.0	3.0-5.0,7.0-9.0,12.0-15.8	28.9-34.0	15.8-28.9,34.0-40.0	
		BCJV/400/PB/ P74A-3	0.0-1.0	1.0-8.0	8.0-14.0	28.2-34.0	14.0-28.2,34.0-40.0	
		BCJV/400/PB/ P74A-4	0.0-2.0		2.0-10.0, 11.0-13.5	28.0-35.0	10.0-11.0, 13.5-28.0, 35.0-40.0	
5D/400	P75	BCJV/400/PB/ P75-1	0.0-2.0	2.0-3.0	17.9-24.0	35.0-42.0	3.0-17.9, 24.0-31.0, 32.0-35.0	
		BCJV/400/PB/ P75-2	0.0-1.0		1.0-2.0, 22.0-24.0	33.0-34.0, 37.0-43.0	2.0-22.0, 24.0-37.0, 43.0-45.0	
		BCJV/400/PB/ P75-4	0.0-1.0	1.0-2.0	2.0-3.0		3.0-24.0	
5D/400	P76	BCJV/400/PB/ P76-1	0.0-0.5				0.5-26.0	
		BCJV/400/PB/ P76-2	0.0-2.0	2.0-4.5	4.5-6.0, 7.0-8.0		6.0-7.0, 8.0-29.0, 29.0-30.0	
		BCJV/400/PB/ P76-3	0.0-1.6		1.6-4.0		4.0-24.0	
		BCJV/400/PB/ P76-4	0.0-2.0		2.0-4.0, 4.7-8.0		4.0-4.7, 8.0-31.0	
5D/400	P77	BCJV/400/PB/ P77-3	0.0-2.0				2.0-22.0	
		BCJV/400/PB/ P77-4	0.0-1.3				1.3-26.0	
5D/400	P78	BCJV/400/PB/ P78-1	0.0-4.0	4.0-8.0	8.0-11.0, 26.8-27.6		11.0-26.8, 27.6-43.0	34.0
		BCJV/400/PB/ P78-2	0.0-3.0	11.0-12.0, 21.0-25.0		16.8-19.8	3.0-11.0, 12.0-16.8, 19.8-21.0, 25.0-41.0	
		BCJV/400/PB/ P78-3	0.0-2.0	10.0-11.0		25.0-28.0	2.0-10.0, 11.0-25.0, 28.0-49.0	
		BCJV/400/PB/ P78-4A	0.0-1.4	1.4-5.0	23.0-31.0		5.0-12.5, 17.0-18.0, 31.0-49.0	
		BCJV/400/PB/ P78-4T	0.0-4.5			19.0-22.6	4.5-11.8	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
5D/400	P79	BCJV/400/PB/P79-1	0.0-2.5	6.0-7.0	2.5-6.0, 10.5-17.0, 21.0-23.0		7.0-10.5, 17.0-21.0, 23.0-39.0	
		BCJV/400/PB/P79-2	0.0-2.0	7.0-10.0, 18.0-22.0	10.0-18.0, 22.0-27.0	2.0-7.0	27.0-45.0	
		BCJV/400/PB/P79-4	0.0-2.0		14.0-39.5	2.0-14.0	39.5-55.0	
5D/400	P80	BCJV/400/PB/P80-3	0.0-1.5			1.5-15.0	15.0-33.3	
		BCJV/400/PB/P80-4	0.0-1.5			1.5-16.0	16.0-48.0	
		BCJV/400/PB/P80-4A	0.0-1.5			1.5-18.5	18.5-34.0	
5D/400	P81	BCJV/400/PB/P81-2	0.0-1.2	1.2-2.0, 46.0-49.0	26.0-28.0	2.0-26.0	28.0-42.0	
		BCJV/400/PB/P81-4	0.0-1.5	40.0-43.0		1.5-29.0	29.0-40.0, 51.0-52.0, 72.0-73.0	
6/400	V6-A00	BCJV/400/PB/V6-A00-2A	0.0-1.8		21.7-54.5		1.8-21.7, 54.5-72.0	58.0
		BCJV/400/PB/V6-A00-3	0.0-1.5	1.5-3.0, 59.5-66.0, 74.0-80.0	20.0-23.0, 24.0-47.2, 69.0-70.2, 71.5-74.0		3.0-20.0, 23.0-24.0, 47.2-59.5, 66.5-69.0, 70.2-71.5	50.0
6/400	V6-P01	BCJV/400/PB/V6-P01-1	0.0-2.0	77.0-81.0	5.0-7.0, 26.7-33.5, 65.7-66.0, 67.0-68.3, 74.5-76.0		2.0-5.0, 7.0-26.7, 33.5-65.7, 66.0-67.0, 68.3-74.5, 76.0-77.0	43.0
		BCJV/400/PB/V6-P01-2	0.0-1.4	1.4-3.0, 58.0-59.6	3.0-11.0, 20.0-50.8, 53.0-56.2, 65.8-69.0		11.0-20.0, 50.8-53.0, 56.2-58.0, 59.6-65.8, 69.0-74.0	
		BCJV/400/PB/V6-P01-3	0.0-3.0	3.0-7.0	7.0-20.0, 26.0-35.8, 36.5-38.2, 40.2-46.0, 50.3-53.0, 56.0-58.0, 67.0-69.0		20.0-26.0, 35.8-36.5, 38.2-40.2, 46.0-50.3, 53.0-56.0, 58.0-67.0, 69.0-75.0	39.0

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
6/400	**V6-P02**	**BCJV/400/PB/V6-P02-1A**	**0.0-1.0**	**2.0-5.0, 7.0-11.0**	**1.0-2.0, 5.0-7.0, 11.0-15.0, 23.4-39.0, 41.5-42.5, 44.0-46.0, 56.5-75.0**		**15.0-23.4, 39.0-41.5, 42.5-44.0, 46.0-56.5**	**39.0**
		BCJV/400/PB/V6-P02-2	**0.0-1.5**	**1.5-7.5**	**7.5-11.8, 17.3-20.1, 23.5-24.0, 36.2-49.0, 57-58.5, 63.0-65.0, 67.0-70.5, 73.0-81.0**		**11.8-17.3, 20.1-23.5, 24.0-36.2, 49.0-57.0, 58.5-63.0, 65.0-67.0, 70.5-73.0**	**50.0**
		BCJV/400/PB/V6-P02-3	**0.0-1.6**	**1.6-7.5, 41.0-42.0**	**7.5-8.7, 29.0-41.0, 64.0-77.0, 79.5-81.0**		**8.7-29.0, 42.0-64.0, 77.0-79.5**	**44.0**
		BCJV/400/PB/V6-P02-4	**0.0-1.5**	**1.5-6.0, 7.0-16.5, 72.0-74.0**	**6.0-7.0, 29.0-45.0, 62.0-71.0, 74.0-81.0**		**16.5-29.0, 45.0-62.0, 71.0-72.0**	**47.0**
6/400	**V6-P03**	**BCJV/400/PB/V6-P03-1**	**0.0-1.8**	**1.8-12.0**	**12.0-32.0**		**32.0-52.0**	
		BCJV/400/PB/V6-P03-2	**0.0-2.0**	**2.0-13.0**	**13.0-35.0**		**35.0-70.0**	**36.0**
		BCJV/400/PB/V6-P03-3	**0.0-1.3**	**1.3-8.0**	**8.0-9.0, 10.0-14.0, 19.0-30.0, 34.0-35.0**		**9.0-10.0, 14.0-19.0, 35.0-52.0**	**43.0**
		BCJV/400/PB/V6-P03-4	**0.0-1.0**	**1.0-11.0**	**11.0-48.0, 66.0-81.0**		**48.0-66.0**	**37, 41**
6/400	**V6-P04**	**BCJV/400/PB/V6-P04-1**	**0.0-3.5**		**3.5-30.5**		**30.5-54.0**	**33.0**
		BCJV/400/PB/V6-P04-2	**0.0-5.0**		**5.0-20.0**		**20.0-54.0**	**38.0**
		BCJV/400/PB/V6-P04-3	**0.0-3.0**	**3.0-5.0**	**5.0-24.0**		**24.0-48.0**	
		BCJV/400/PB/V6-P04-4	**0.0-4.0**	**4.0-7.0**	**7.0-34.0**		**34.0-60.0**	

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/ SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
6/400	V6-P05	BCJV/400/PB/V6-P05-1A	0.0-3.0		3.0-27.7, 34.8-37.5, 41.0-43.0, 54.3-54.9, 63.0-65.6, 68.4-81.0		27.7-34.8, 37.5-41.0, 43.0-54.3, 54.9-63.0, 65.6-68.4	36.0
		BCJV/400/PB/V6-P05-2	0.0-2.5	42.0-45.4	2.5-24.0, 38.0-42.0, 45.4-72.0, 75.5-81.0		72.0-75.5	
		BCJV/400/PB/V6-P05-3	0.0-3.0	39.0-40.0, 44.0-46.9, 51.0-53.0, 68.0-81.0	3.0-39.0, 40.0-44.0, 46.9-51.0, 53.0-68.0			
		BCJV/400/PB/V6-P05-4	0.0-1.0	1.0-9.0, 67.0-74.0	9.0-43.5, 47.9-49.3, 55.5-57.0, 60.0-67.0		43.5-47.9, 49.3-55.5, 57.0-60.0, 79.0-80.0	31.0
6/400	V6-P06	BCJV/400/PB/V6-P06-1	0.0-1.4	2.0-11.0, 34.5-41.5, 69.0-80.0		11.0-34.5, 41.5-69.0	80.0-81.0	34.0
		BCJV/400/PB/V6-P06-3	0.0-2.0	2.7-6.5, 31.0-32.0, 49.0-52.0, 54.5-62.5	6.5-21.0, 23.0-28.0, 32.0-35.0, 40.0-45.2, 71.3-80.0		2.0-2.7, 35.0-40.0, 45.2-49.0, 52.0-54.5, 62.5-71.3	
		BCJV/400/PB/V6-P06-4A	0.0-2.0	2.0-19.0, 56.8-63.0	29.0-40.0, 48.0-56.8, 71.0-80.0	19.0-29.0, 40.0-48.0	63.0-71.0	
6/400	V6-P07	BCJV/400/PB/V6-P07-1	0.0-2.0	22.5-23.7	2.0-22.5, 23.7-33.8, 37.2-41.5, 45.9- 62.5, 74.5-80.0		33.8-37.2, 41.5-45.9, 62.5-74.5	31.0
		BCJV/400/PB/V6-P07-2	0.0-1.5	1.5-15.0	15.0-16.0, 52.2-54.8		16.0-52.2, 54.8-80.0	32.0
		BCJV/400/PB/V6-P07-4	0.0-2.0	2.0-5.0, 21.5-22.0, 38.5-44.0, 46.0-53.0	5.0-21.5, 22.0-34.5		34.5-38.5, 44.0-46.0, 53.0-78.0	32.0
6/400	V6-P08	BCJV/400/PB/V6-P08-1	0.0-1.2	1.2-6.0, 29.0-30.0	6.0-14.0		14.0-29.0, 30.0-39.0	
		BCJV/400/PB/V6-P08-2	0.0-1.0	1.0-4.0, 38.0-42.0	4.0-23.5		23.5-38.0, 42.0-48.0	38.0
		BCJV/400/PB/V6-P08-4	0.0-1.5	1.5-4.0, 44.8-48.0, 58.0-59.0	4.0-21.0, 23.0-33.0, 37.6-44.8, 54.0-58.0		33.0-37.6, 48.0-54.0, 59.0-69.0	28.0
		BCJV/400/PB/V6-P08-5	0.0-2.0	2.0-3.5	3.5-14.5		14.5-36.0	24.0

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM(m)	RESIDUAL DOLOMITE(m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
6/400	V6-P09	BCJV/400/PB/V6-P09-1	0.0-1.3	1.3-6.0, 42.0-45.0	6.0-16.8, 22.8-27.0, 28.8-30.0, 33.0-42.0, 45.0-52.0, 54.6-57.0		16.8-22.8, 27.0-28.8, 52.0-54.6, 57.0-69.0	
		BCJV/400/PB/V6-P09-2	0.0-1.3	1.3-6.0, 39.0-47.0	6.0-27.0		27.0-39.0, 47.0-64.0	25.0
		BCJV/400/PB/V6-P09-4	0.0-2.0	2.0-6.0	6.0-28.0, 31.0-36.5, 54.0-55.0		28.0-31.0, 36.5-54.0, 55.0-71	26.0
		BCJV/400/PB/V6-P09-5	0.0-1.0	1.0-7.0, 27.0-28.0	7.0-12.0, 13.0-27.0, 34.0-35.0		12.0-13.0, 28.0-34.0, 35.0-66.0	27.0
6/400	V6-P10	BCJV/400/PB/V6-P10-1	0.0-1.5	1.5-6.0	6.0-21.5		32.0	19
		BCJV/400/PB/V6-P10-2	0.0-1.4	1.4-5.0	5.0-12.4, 16.0-18.5, 20.2-26.3		12.4-16.0, 18.5-20.2, 26.3-41.0	20.0
		BCJV/400/PB/V6-P10-4	0.0-2.0	2.0-7.0	7.0-26.5		26.5-4.2	21.0
		BCJV/400/PB/V6-P10-5	0.0-1.6	2.0-3.0, 4.5-6.0	1.6-2.0, 3.0-4.5, 6.0-27.0	29.0-30.0	27.0-29.0, 30.0-42.0	22.0
6/400	V6-P11	BCJV/400/PB/V6-P11-1	0.0-1.5	1.5-6.0	6.0-15.5		15.5-33.0	17.0
		BCJV/400/PB/V6-P11-2	0.0-1.5	1.5-7.0	7.0-16.0		16.0-30.0	21.0
		BCJV/400/PB/V6-P11-3	0.0-1.5	1.5-7.0	7.0-17.2		17.2-33.0	18.0
		BCJV/400/PB/V6-P11-4	0.0-1.5	1.5-8.0, 15.4-19.0	8.0-15.4, 19.0-20.5		20.5-30.0	21.0
6/400	V6-P12	BCJV/400/PB/V6-P12-1	0.0-1.2	1.2-3.0	3.0-5.5, 12.9-13.5		5.5-12.9, 13.5-36.0	23.0
		BCJV/400/PB/V6-P12-2	0.0-1.2	2.0-6.0	1.2-2.0, 6.0-19.0		19.0-37.0	33.0
		BCJV/400/PB/V6-P12-3	0.0-1.5	1.5-3.0	3.0-5.5, 11.8-12.5		5.5-11.8, 12.5-30.0	17.0
		BCJV/400/PB/V6-P12-4	0.0-1.3	1.3-3.0	3.0-13.5		13.5-30.0	
6/400	V6-P13	BCJV/400/PB/V6-P13-1	0.0-0.9	0.9-7.0	7.0-9.0		9.0-24.0	7.0
		BCJV/400/PB/V6-P13-2		1.2-5.8	5.8-9.5, 12.0-14.0		9.5-12.0, 14.0-25.0	9.0
		BCJV/400/PB/V6-P13-4	0.0-0.9	0.9-5.0	5.0-8.5		8.5-24.0	9.0

TABLE 6: SUMMARY OF BOREHOLE LOGS (continued)

VIADUCT/SECTION	PIER	BH NO	TRANSPORTED SOIL (m)	CHERT ROCK/RESIDUUM (m)	RESIDUAL DOLOMITE (m)	INTRUSIVE ROCK (m)	DOLOMITE HARD ROCK (m)	GW LEVEL (m)
6/400	V6-P14	BCJV/400/PB/V6-P14-1	0.0-3.0			3.0-26.3	26.3-28.0	27.0
		BCJV/400/PB/V6-P14-2	0.0-3.0			3.0-22.0	22.0-35.0	15.0
		BCJV/400/PB/V6-P14-3	0.0-1.3			1.3-35.0		
		BCJV/400/PB/V6-P14-4	0.0-1.1			1.1-26.0		
6/400	V6-P15	BCJV/400/PB/V6-P15-1	0.0-3.2		3.2-10.0		10.0-25.0	
		BCJV/400/PB/V6-P15-2	0.0-1.0		2.0-3.8, 5.0-11		3.8-5.0, 11.0-27.0	24.0
		BCJV/400/PB/V6-P15-3	0.0-2.3		2.3-6.0		6.0-24.0	
		BCJV/400/PB/V6-P15-4	0.0-1.5		1.5-6.1		6.1-24.0	
6/400	V6-A16	BCJV/400/PB/V6-A16-1			14.5-19.5	0.0-14.5	19.5-40.0	23.0
		BCJV/400/PB/V6-A16-2		2.0-6.0	18.0-24.0	0.0-2.0, 6.0-18.0	24.0-38.0	21.0
		BCJV/400/PB/V6-A16-3			20.0-21.0	0.0-20.0	21.0-36.0	22.0

TABLE 8: SUMMARY OF SOIL PROFILES

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/V6 -A0		0-0.8 (md)	0.8-2.0 (d) 2.0-2.5 (vs-hr)R			None		
BCJV/400/TP/V6 -P01A		0-0.6 (md) 0.6-1.0 (d)	1.0-1.9 (d) 1.9-3.0 (f-st)R			None		
BCJV/400/TP/V6 -P2A		0-1.1 (md) 1.1-1.55 (d)	1.55-3.2 3.2-3.9 (f-st)R			None		
BCJV/400/TP/V6 -P3A	0-0.6 (l- md)	0.6-1.0 (md) 1.0-1.5 (d)	1.5-3.4(R)			None		
BCJV/400/TP/V6 -P4B	0-0.4 (md)	0.4-0.9 (md) 0.9-1.5 (d) 1.5-2.5 (md)	2.5-3.1 (vd)R			None		
BCJV/400/TP/V6 -P5A	0-0.2 (md)	0.2-0.7 (md) 0.7-1.1 (d)	1.1-1.8 (md) , 3.2-3.9 (f-st)R			None		
BCJV/400/TP/V6 -P6A	0-0.8 (l-md) 0.8-1.5 (d) 1.5-4.4 (md)M					None		
BCJV/400/TP/V6 -P8A	0-0.9 (l-md)		0.9-2.4 (d), 2.4-4.4 (s-hr)R			None		
BCJV/400/TP/V6 -P9A			0-1.6 (hr) 1.6-3.0 (md-d) 3.0-4.5 (f-st)M			None		
BCJV/400/TP/V6 -P10A	0-0.4(md)	0.4-0.9(md)	0.9-1.1(md-d) 1.1-2.9(vs-hr)R			None		

d-dense
f-firm
hr-hard rock
l-loose
md-medium dense
m-maximum reach of machine
R-refusal of TLB

vd-very dense
vst-very stiff
vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/V6-P11A	0-0.9(md)	0.9-1.5(md)	1.5-2.8(vs-hr)R			None		
BCJV/400/TP/V6-P15B		0-0.9(md)			0.9-1.6(st) 1.6-2.5(vst-vsr)R	None		
BCJV/400/TP/01A		0-0.45(md)				0.45-1.4(md-d) 1.4-4.4(st-vsr)M		3.0
BCJV/400/TP/02A		0-0.6(md)				0.6-1.4(md-vd) 1.4-3.9(st)M		0.6
BCJV/400/TP/02B		0-0.9(md)				0.9-2.0(md-vd) 2.0-5.0(st)M		0.9
BCJV/400/TP/04A		0-1.0(md)				1.0-2.4(md-d) 2.4-5.0(st)M		2.5
BCJV/400/TP/04B		0-0.9(md)				0.9-2.6(md-d) 2.6-5.0(st)M		2.5
BCJV/400/TP/05A		0-0.9(l-md) 0.9-1.6(md)				1.6-3.5(st) 3.5-4.9(st-vsr)M		2.0
BCJV/400/TP/05B		0-0.6(l-md) 0.6-1.3(md)				1.3-3.4(st) 3.4-4.8(st-vsr)M		2.0
BCJV/400/TP/06A		0-0.6(l-md) 0.6-1.4(md)			1.4-2.9(st) 2.9-5.0(d-vsr)M	None		2.0

d-dense	vd-very dense
f-firm	vst-very stiff
hr-hard rock	vsr-very soft rock
l-loose	vs-very soft
md-medium dense	st-stiff
m-maximum reach of machine	s-soft
R-refusal of TLB	

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/06B		0-0.4(l-md) 0.4-0.9(md)			1.4-2.9(st) 2.9-5.0(d-vsr)R	None		2.0
BCJV/400/TP/08A		0-0.4(l-md)				None	0.4-2.6(vd-vsr)	2.0
BCJV/400/TP/09A		0-0.4(l-md) 0.4-0.8(md)				0.8-1.7(f-st) 1.7-5.0(st)M		3.0
BCJV/400/TP/09B		0-0.5(l-md) 0.5-1.0(md)				1.0-1.8(f-st) 1.8-4.8(st)M		3.0
BCJV/400/TP/11A				1.5-3.1(st)	1.0-1.5(st-vsr) 3.1-5.0M	None	0-1.0(vd-vsr)	
BCJV/400/TP/11B				1.4-2.9(st)	0.5-1.4(st-vsr) 2.9-5.0(sr)M	None	0-0.5(vd-vsr)	
BCJV/400/TP/12A		0-0.6(md) 0.6-1.6(vd-vsr)		1.6-2.4(d-vsr) 2.4-4.5(st-vst)R		None		1.6
BCJV/400/TP/12B		0-0.3(md) 0.3-1.4(vd-vsr) 1.4-2.0(d-vsr)			2.0-4.5(st-vst)R	None		1.4
BCJV/400/TP/13A		0-0.5(l) 0.5-2.0(md) 2.0-3.1(d-vd)		3.1-4.5(st)		None		
BCJV/400/TP/13B		0-0.5(l) 0.5-1.9(md) 1.9-3.4(d-vd)		3.4-4.8(st)		None		

d-dense
f-firm
hr-hard rock
l-loose
md-medium dense
m-maximum reach of machine
R-refusal of TLB

vd-very dense
vst-very stiff
vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/15A		0-0.4(l) 0.4-2.9(md) 2.9-5.0(d-vd)		3.4-4.8(st)				
BCJV/400/TP/15B		0-0.4(l) 0.4-2.5(md) 2.5-5.0(d-vd)						
BCJV/400/TP/16A		0-0.5(l) 0.5-2.1(md) 2.1-3.4(d)		3.4-5.0(d) M				
BCJV/400/TP/16B		0-0.5(l) 0.5-2.4(md) 2.4-3.7(d)		3.7-5.0(d) M				
BCJV/400/TP/17A		0-0.5(md) 0.5-2.6(md) 2.6-3.4(d)		3.4-4.2(d) 4.2-5.0(d-vd) M				
BCJV/400/TP/17B		0-0.4(md) 0.4-2.2(md) 2.2-3.8(md)		3.8-4.2(d) 4.2-5.0(d-vd) M				
BCJV/400/TP/18A		0-0.2(l) 0.2-2(md) 2.0-3.3(d-vd)		3.3-5.0(st) M				
BCJV/400/TP/18B		0-0.3(l) 0.3-1.9(md) 1.9-3.1(d-vd)		3.1-5.0(st) M				
BCJV/400/TP/19A		0-0.5(l-md) 0.5-2.7(md) 2.7-4.5(d-vd) (R)						
BCJV/400/TP/19B		0-0.5(l-md) 0.5-3.7(md) 3.7-4.2(d-vd) (R)						

d-dense
f-firm
hr-hard rock
l-loose
md-medium dense
m-maximum reach of machine
R-refusal of TLB

vd-very dense
vst-very stiff
vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/20A		0-0.2(l) 0.2-2.0(md) 2.0-3.8(d-vd)		3.8-5.0(d) M				
BCJV/400/TP/20B		0-0.3(l) 0.3-2.2(md) 2.2-4.0(d-vd)		4.0-5.0(d)M				
BCJV/400/TP/30A		0-0.3(md)		0.8-3.6(st) (R)	0.2-0.8 (vs-sr)			
BCJV/400/TP/30B		0-0.2(md)		0.8-3.8(st) (R)	0.3-0.8(vs-sr)			
BCJV/400/TP/31A		0-0.4(md) 0.4-1.0(md) 1.0-2.2(l-md)		2.2-3.5(md-d)	3.5-3.7(sr-mhr)			
BCJV/400/TP/31B		0-0.3(md) 0.3-1.0(md) 1.0-2.1(l-md)		2.1-3.6(md-d)	3.6-4.0(sr-mhr) (R)			
BCJV/400/TP/33A		0-1.0(s-md)		1.0+ (R)				
BCJV/400/TP/33B		0-1.0(s-md)		1.0+ (R)				
BCJV/400/TP/34A		0-0.5(l-md) 0.5-1.2(md)		1.2+ (R)				
BCJV/400/TP/34B		0-0.5(l-md)		0.5+ (R)				

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R-refusal of TLB

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vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/35A		0-0.5(l-md)		0.5+ (R)				
BCJV/400/TP/35B		0-0.5(l-md)		0.5+ (R)				
BCJV/400/TP/37A		0-0.7(l-md)		0.7-1.5(md) 1.5+ (R)				
BCJV/400/TP/37B		0-0.7(l-md)		0.7-1.5(md) 1.5+ (R)				
BCJV/400/TP/38A		0-1.7(md)		1.7+ (R)				
BCJV/400/TP/38B		0-1.7(md)		1.7+ (R)				
BCJV/400/TP/39A		0-07(l-md) 0.7-1.4(l-md)		1.4-2.2(f-st) 2.2+ (R)				
BCJV/400/TP/39B		0-07(l-md) 0.7-1.4(l-md)		1.4-2.3(f-st) 2.3+ (R)				
BCJV/400/TP/40A		0-0.7(l-md) 0.7-1.7(md-d)		1.7-2.5(f-st) 2.5+ (R)				
BCJV/400/TP/40B		0-0.8(l-md) 0.8-1.5(md-d)		1.5-2.1(f-st) 2.1+ (R)				

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md-medium dense
m-maximum reach of machine
R-refusal of TLB

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vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/41A		0-0.5(l-md) 0.5-1.5(md-d)		1.5-3.7(f-st) 3.7+ (R)				
BCJV/400/TP/41B		0-0.5(l-md) 0.5-1.0(md-d)		1.0-4.5(f-st) 4.5+ (R)				
BCJV/400/TP/42A		0-0.5(md) 0.5-1.5(md)		1.5-4.3(md) 4.3+ (R)				
BCJV/400/TP/42B		0-0.9(md) 0.9-1.2(md)		1.2+ (R)				
BCJV/400/TP/45A		0-0.9(md)		0.9-1.7(f-st) 1.7-2.7(d)		2.7-3.4(vsr) (R)		
BCJV/400/TP/45B		0-0.7(md)		0.7-1.4(f-st) 1.4-2.1(d)		2.1+ (R)		
BCJV/400/TP/47A		0-0.6(l-md)		0.6-1.5(md-d) 1.5+ (R)				
BCJV/400/TP/47B		0-0.5(l-md)		0.5-1.6(md-d) 1.6+ (R)				
BCJV/400/TP/48A				0-0.1(hr) 0.1-1.6(md-d) 1.6+ (R)				
BCJV/400/TP/48B		0-0.7(l-md)		0.7-1.7(md-d) 1.7+ (R)				

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vs-very soft
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s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/50A		0-1.1(l-md)		1.1-2.6(md-d) 2.6+ (R)				
BCJV/400/TP/50B		0-0.7(l-md)		0.7-1.5(hr) 1.5-2.6(md-d) 2.6+ (R)				
BCJV/400/TP/51A		0-1.1(l-md)		1.1-1.8(f-st) 2.4-2.9(f-st)	1.8-2.4(sr) 2.9+ (R)			
BCJV/400/TP/51B		0-1.0(l-md)		1.0-1.6(f-st) 2.0-2.6(f-st)	1.6-2.0(sr) 2.6+ (R)			
BCJV/400/TP/52A		0-1.2(l-md)		5.0-5.4(f-st) (M)	4.3-4.6(sr) 4.6-5.0(sr)	1.6-2.9(md) 2.9-4.3(d)	1.2-1.6(md)	
BCJV/400/TP/52B		0-0.8(l-md)		1.3-4.5(f-st) 4.9-5.2(f-st)	4.5-4.9(sr) 5.2+ (M)		0.8-1.3(md)	
BCJV/400/TP/55A		0-0.3(l-md)		0.3-1.2(d-vsr)	1.2+ (R)			
BCJV/400/TP/55B		0-0.8(l-md)				0.8-1.5(d) 1.5+ (R)		
BCJV/400/TP/56A		0-0.3(d)				0.3+ (R)		
BCJV/400/TP/56B		0-0.3(d)				0.3-0.9(s-mhr) (R)		

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f-firm
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l-loose
md-medium dense
m-maximum reach of machine
R-refusal of TLB

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vst-very stiff
vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/57A		0-0.5(f)			0.5-1.3(s-mhr) (R)			
BCJV/400/TP/57B		0-0.5(f)			0.5-1.3(s-mhr) (R)			
BCJV/400/TP/63A				0-0.7(f-st)		0.7-4.7(d) (M)		
BCJV/400/TP/64A				0-1.7(st)		1.7-4.7(d) (R)		
BCJV/400/TP/64B				0-1.45(st)		1.45-3.0(d) (R)		
BCJV/400/TP/65A					2+ (sr) (R)	0-2.0(md-d)		
BCJV/400/TP/65B					1.7+(sr) (R)	0-1.7(md-d)		
BCJV/400/TP/67A				3.5+ (hr) (R)	2.4-3.5(sr)	0-2.4(s-mhr)		
BCJV/400/TP/67B				3.7 + (hr) (R)	2.4-3.7 (sr)	0-2.4 (s-mhr)		
BCJV/400/TP/69A		0.0-0.4 (md-d)		0.4 + (hr) (R)				

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md-medium dense
m-maximum reach of machine
R-refusal of TLB

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vst-very stiff
vsr-very soft rock
vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/69B		0.0-0.4(md-d)		0.4+ (hr) (R)				
BCJV/400/TP/70A		0.0-0.4(md-d)		0.4+ (hr) (R)				
BCJV/400/TP/70B		0.0-0.5 (md-d)		0.5 + (hr) (R)				
BCJV/400/TP/73A		0.0-0.8 (md)		0.8 + (hr) (R)				
BCJV/400/TP/73B		0.0-0.8(md)		0.8 + (hr) (R)				
BCJV/400/TP/75A		0.0-1.3(md)		1.3 + (hr) (R)				
BCJV/400/TP/75B		0.0-1.3 (md)		1.3 + (hr) (R)				
BCJV/400/TP/76A		0.0-1.4 (l-md)		1.4-2.0 (f-st) 2.0 + (hr) (R)				
BCJV/400/TP/76B		0.0-0.9 (l-md)		0.9-1.8 (f-st) 1.8 + (hr) (R)				
BCJV/400/TP/77A		0.0-0.5 (l-md)		0.5-1.1 (d) 1.1 + (hr) (R)				

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s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	**FILL (m)**	**HILLWASH (m)**	**CHERT RESIDUUM/CHERT(m)**	**RESIDUAL DOLOMITE/DOLOMITE BOULDER (m)**	**RESIDUAL SHALE (m)**	**RESIDUAL SYENITE/SYENITE (m)**	**PERBLE MARKER (m)**	**WATER SEEPAGE (m)**
BCJV/400/TP/77B		0.0-0.7 (l-md)		0.7 – 1.3 (d) 1.3 + (hr) (R)				
BCJV/400/TP/78A		0.0-0.6 (md-d)		0.6-1.4 (md-d) 1.4 + (hr) (R)				
BCJV/400/TP/78B		0.0-0.6 (md-d)		0.6-1.4 (md-d) 1.4 +(hr) (R)				
BCJV/400/TP/80A		0.0-0.7 (md)		0.7 – 1.3 (md-d) 1.3 + (hr) (R)				
BCJV/400/TP/82A		0.0-1.1 (md)		1.0-2.3 (s-hr) 2.3-3.0 (md 3.0 + (hr) (R)				
BCJV/400/TP/83A		0.0-0.5 (l-md) 0.5-1.3 (md-d)		1.3 (mh-hr) (R)				
BCJV/400/TP/83B		0.0-0.5 (l-md) 0.5-0.9 (md-d)		0.9 (mh-hr) (R)				
BCJV/400/TP/501		0.0-0.3 (f) 0.3-0.9 (f-st)				0.9-2.0 (md) 2.0-3.4 (d)		2.0
BCJV/400/TP/P13A		0.0-1.0 (md-d)	1.0-1.7 (st) 1.7-2.3 (vst) 2.3-3.7 (st) 3.7-5.0 (st) (M)					
BCJV/400/TP/P22A	0.0-1.2 (md)	1.2-1.8 (st)	1.8-2.8 (d-vd) (R)					

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m-maximum reach of machine
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vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/P22B	0.0-1.2 (md)	1.1-1.7 (st)	1.7-2.5 (d-vd)					
BCJV/400/TP/P24A	0.0-1.0 (md)	1.0-1.3 (f)	1.3-1.5 1.5-2.9 (d-vsr) (R)					2.0
BCJV/400/TP/P24B	0.0-1.0 (md)	1.0-1.3 (f)	1.3-1.5 1.5-2.9 (d-vsr) (R)					2.0
BCJV/400/TP/P25A	0.0-1.5 (md) 1.5-4.7 (md)							4.0
BCJV/400/TP/P25B	0.0-0.9 (md) 0.9-5.0 (md)							4.0
BCJV/400/TP/P31A	0.0-2.2 (md-d) 2.2-4.8 (l-md)							
BCJV/400/TP/P31B	0.0-2.3 (md-d) 2.3-5.0 (l-md) (M)							
BCJV/400/TP/P34A		0.0-0.55 (l-md)	0.55-2.5 (md-d) 2.5+ (mh-hr) (R)					
BCJV/400/TP/P34B		0.0-0.7 (l-md)	0.7-2.0 (md-d) 2.0 + (mh-hr) (R)					
BCJV/400/TP/P46A		0.0-0.5 (l-md)	0.5-3.4 (md-d)	3.4-3.7 (md-d) (R)				

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vs-very soft
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s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/P48A		0.0-0.7 (l-md)	0.7-4.5 (md-d)	4.5-4.9 (md-d) (M)				
BCJV/400/TP/P54A		0.0-0.8 (d)	0.8-3.0 (d-vd) (R)					
BCJV/400/TP/P54B		0.0-0.5 (d)	0.5-2.9 (d-vd) (R)					
BCJV/400/TP/P55A			0.0-0.9 (md-d) 0.9-2.4 (s-hr) (R)					
BCJV/400/TP/P55B			0.0-1.4 (md-d) 1.4-2.1 (s-hr) (R)					
BCJV/400/TP/P58A		0.0-0.5 (l-md)	0.5-4.0 (d-vd)	4.0 + (hr) (R)				
BCJV/400/TP/P58B		0.0-0.4 (l-md)	0.4-3.5 (d-vd)	3.5 + (hr) (R)				
BCJV/400/TP/P65A		0.0-0.9 (l-md)	0.9-2.3 (d)			2.3-3.4 (d) 3.4-4.8 (f-st) (M)		
BCJV/400/TP/P65B		0.0-0.9 (l-md)	0.9-1.5 (d)			1.5-3.2 (d) 3.2-4.5 (f-st) (M)		
BCJV/400/TP/P72A		0.0-0.8 (l-md)	0.8-2.5 (md)	2.5-3.7 (d) 3.7-4.9 (vd-vsr) (M)				

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md-medium dense
m-maximum reach of machine
R-refusal of TLB

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vs-very soft
st-stiff
s-soft

TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/400/TP/P72B		0.0-0.6 (l-md)	0.6-1.4 (md)	1.4-1.5 (d) 1.5-3.7 (hr) 3.7-5.0 (vd-vsr) (M)				
BCJV/400/TP/P74A-A		0.0-0.9 (md)	0.9-1.7 (d-vd)	1.7-3.0 (md) 3.0 + (M)				
BCJV/400/TP/P74A-B		0.0-0.8 (md)		0.8-2.5 (md) 2.5-4.5 (f-st) (M)				
BCJV/500/TP/01		0.0-0.4 (l-md)	0.4-2.4 (md-d) (R)					
BCJV/500/TP/2		0.0-0.4 (l-md)	0.4-2.0 (md-d) (R)					
BCJV/500/TP/03		0.0-0.5 (f)	0.5 – 1.02 (st) 1.02-2.8 (d) 2.8 + (vd-hr) (R)					
BCJV/500/TP/04		0.0-0.5 (md-d)	0.5-1.4 (vd) (R)					
BCJV/500/TP/05		0.0-1.0 (md) 1.0-1.8 (md) 1.8-3.6 (st) (M)						
BCJV/500/TP/06		0.0-3.9 (md) (M)						
BCJV/500/TP/07		0.0-0.5 (md)	0.5-1.9 (md) 1.9 + (sr) (R)					

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TABLE 8: SUMMARY OF SOIL PROFILES (continued)

TEST PIT NO	FILL (M)	HILLWASH (M)	CHERT RESIDUUM/CHERT(M)	RESIDUAL DOLOMITE/DOLOMITE BOULDER (M)	RESIDUAL SHALE (M)	RESIDUAL SYENITE/SYENITE (M)	PERBLE MARKER (M)	WATER SEEPAGE (M)
BCJV/500/TP/08		0.0-1.4 (md)				1.4-2.3 (st-vsr)		
BCJV/500/TP/A 75A		0.0-0.6 (md-d)	2.8 + (hr) (R)	0.6-2.8 (d-vsr)				
BCJV/500/TP/W 18-1		0.0-0.3 (md)	0.3-0.5 (md) 0.5-1.10 (s-hr) (R)					
BCJV/500/TP/W 18-2		0.0-0.3 (md)	0.3-1.6 (md) 1.6 + (s-hr) R					
BCJV/500/TP/W 19-1		0.0-0.6 (md)	0.6-1.6 (hr) (R)					
BCJV/500/TP/W 19-2		0.0-0.4 (md)	0.4-1.4 (hr) (R)					

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s-soft

TABLE 9: SUMMARY OF INDICATOR TEST RESULTS

TEST PIT NO	DEPTH (m)	MATERIAL DESCRIPTION	ATTERBERG LIMITS			GRADING				PERCENTAGE FINER THAN (mm)			GM	CLASSIFICATION		POTENTIAL EXPANSIVENESS
			LL	PI (*)	LS	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	0.075	0.425	0.002		HRB	UNIFIED	
BCJV/400/TP-01	1.5-5.0	RESIDUAL SYENITE	31.6	8.3(5.5)	4.0	7.9	23.8	58.6	9.7	35	67	8	1.08	A-2-4	SM	LOW
BCJV/400/TP-01(2)	0.8-1.8	RESIDUAL SYENITE	31.3	9.7(7.9)	4.7	12.5	31.0	52.4	4.0	47	81	13	0.76	A-4[2]	SC	LOW
BCJV/400/TP-01(3)	1.8-5.0	RESIDUAL SYENITE	31.6	8.3(5.5)	4.0	7.9	23.8	58.6	9.7	35	67	8	1.08	A-2-4	SM	LOW
BCJV/400/TP-04(2)	2.1-2.9	RESIDEUAL SYENITE	36.3	13.6(7.0)	6.7	6.7	27.7	36.6	29.0	37.0	51	7	1.41	A-6(1)	SC	LOW
BCJV/400/TP-04(3)	2.6-5.2	RESIDEUAL SYENITE	35.4	8.3(8.0)	4.0	12.7	32.8	54.2	0.3	50	97	13	0.54	A-4(3)	SM	LOW
BCJV/400/TP-05(3)	2.9-3.7	RESIDEUAL SYENITE	35.3	10.5(7.2)	6.0	8.3	39.7	43.0	9.0	51	69	8	0.89	A-6(4)	ML/OL	LOW
BCJV/400/TP-05	1.0-1.8	RESIDEUAL SYENITE	33.9	8.8(7.1)	4.0	11.1	48.8	30.2	9.8	66	81	11	0.63			LOW
BCJV/400/TP-05(4)	3.7-5.0	RESIDEUAL SYENITE	48.6	20.7(18.5)	10.0	19.3	30.0	49.2	1.5	53	89	19	0.59	A-7-6(9)	ML/OL	MEDIUM
BCJV/400/TP-06	0.0-3.9	RESIDUAL SHALE	33.3	9.7(8.1)	4.7	12.2	45.4	35.7	6.6	68	84	12	0.55			LOW
BCJV/400/TP-06(3)	1.2-5.0	RESIDUAL SHALE	38.3	10.9(7.3)	5.3	12.2	41.6	22.8	23.4	56	67	12	0.99	A-6(5)	ML/OL	LOW
BCJV/400/TP-09(2)	1.5-2.2	RESIDUAL SYENITE	34.9	9.6(7.8)	4.7	12.1	34.1	51.8	2.1	51	81	12	0.7	A-4(3)	ML/OL	LOW
BCJV/400/TP-09(3)	2.2-5.0	RESIDUAL SYENITE	38.8	8.7(7.7)	4.0	8.7	34.5	56.2	0.7	48	89	9	0.64	A-4(3)	SM	LOW
BCJV/400/TP-10(2)	1.4-2.0	RESIDUAL GRANITE	31.4	9.1(6.3)	4.7	11.2	29.7	47.5	11.5	44	70	11	0.98	A-4[2]	SC	LOW
BCJV/400/TP-10(3)	2.0-5.0	RESIDUAL GRANITE	31.1	5.3(3.9)	2.7	4.7	18.6	75.7	1.0	27	74	5	1.00	A-2-4	SM	LOW
BCJV/400/TP-11(2)	1.3-2.0	RESIDUAL SHALE	37.8	11.7(7.3)	6.0	6.7	37.9	35.7	19.8	50	63	7	1.08	A-6(4)	SM	LOW
BCJV/400/TP-11(3)	2.8-3.9	RESIDUAL SHALE	43.8	9.5(7.5)	4.7	12.2	46.2	37.9	4.0	63	79	12	0.61	A-5(6)	ML/OL	LOW
BCJV/400/TP-12(2)	1.4-2.1	RESIDUAL SHALE	41.1	13.8(6.8)	7.3	8.9	21.5	41.8	27.8	33	50	9	1.46	A-2-6(1)	SM	LOW
BCJV/400/TP-12(4)	2.6-5.0	RESIDUAL SHALE	41.9	12.1(8.9)	6.7	11.7	42.8	34.8	10.7	59	74	12	0.77	A-7-6[6]	ML/OL	LOW

LL -LIQUID LIMIT GM-GRADING MODULUS PI(*)-PLASTICITY INDEX (PI OF WHOLE SAMPLE) NP-NON PLASTIC LS -LINEAR SHRINKAGE

TABLE 9: SUMMARY OF INDICATOR TEST RESULTS (cont)

TEST PIT NO	DEPTH (m)	MATERIAL DESCRIPTION	ATTERBERG LIMITS			GRADING				PERCENTAGE FINER THAN (mm)			GM	CLASSIFICATION		POTENTIAL EXPANSIVENESS
			LL	PI (*)	LS	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	0.075	0.425	0.002		HRB	UNIFIED	
BCJV/400/TP-73(1)	0.0-0.8	HILLWASH	28.3	5.8(3.7)	2.7	4.4	12.3	76.1	7.2	18	63	4	1.26	A-2-4	SM	LOW
BCJV/400/TP-76(1)	0.0-1.4	HILLWASH	25.9	4.2(2.5)	2.7	3.0	17.4	71.5	8.1	23	59	3	1.26	A-2-4	SM	LOW
BCJV/400/TP-76(2)	0.8-2.0	RESIDUAL DOLOMITE	37.2	8.0(5.2)	4.0	8.1	31.1	46.7	14.1	43	65	8	1.06	A-4[2]	SM	LOW
BCJV/400/TP-77(2)	0.5-1.3	RESIDUAL DOLOMITE	27.9	6.8(3.5)	3.3	4.2	10.1	63.7	22.0	16	52	4	1.55	A-2-4	SC/SM	LOW
BCJV/400/TP-82(1)	0.7-2.3	RESIDUAL DOLOMITE	28.1	8.3(5.7)	4.0	8.4	30.7	57.3	3.6	44	69	8	0.91	A-4[2]	SC	LOW
BCJV/400/TP-P13-4	2.3-3.7	CHERT RESIDUUM	46.0	22.0	10.0	23.0	26.0	43.0	8.0	60	76	23	0.72	A-7-6[11]	CL	MEDIUM
BCJV/400/TP-P22-1	1.6-2.8	CHERT RESIDUUM	42.0	19.0	8.5	5.0	4.0	14.0	78.0	9	12	5	2.57	A-2-7[0]	GP & GC	LOW
BCJV/400/TP-P25-2	1.2-5.0	RESIDUAL DOLOMITE	44.0	24.0	10.0	20.0	14.0	31.0	35.0	41	52	20	1.42	A-7-6[5]	SC	MEDIUM
BCJV/400/TP-P31-2	2.5-5.2	RESIDUAL DOLOMITE	28.0	13.0	6.5	12.0	18.0	25.0	45.0	41	48	12	1.56	A-6[2]	SC	LOW
BCJV/400/TP-P34-1	0.2-2.5	CHERT RESIDUUM	28.0	10.0	5.0	6.0	19.0	30.0	44.0	34	46	6	1.64	A-2-4[0]	SC	LOW
BCJV/400/TP-P46-2	3.4-3.7	RESIDUAL DOLOMITE	30.0	12.0	6.0	8.0	16.0	21.0	56.0	31	39	8	1.86	A-2-6[0]	SC	LOW
BCJV/400/TP-P48-2	4.5-4.9	RESIDUAL DOLOMITE	30.0	13.0	6.0	7.0	13.0	16.0	63.0	28	33	7	2.02	A-2-6[0]	GC	LOW
BCJV/400/TP-P54-1	0.8-3.3	CHERT RESIDUUM	25.0	9.0	4.0	3.0	16.0	21.0	60.0	26	33	3	2.01	A-2-4[0]	GC	LOW
BCJV/400/TP-P55-1	1.0-2.4	CHERT RESIDUUM	40.0	15.0	7.0	18.0	18.0	26.0	38.0	43	50	18	1.45	A-6[3]	SC	LOW
BCJV/400/TP-65-2	1.3-2.6	CHERT RESIDUUM	34.0	12.0	6.0	8.0	19.0	30.0	43.0	36	44	8	1.63	A-6[1]	SC	LOW
BCJV/400/TP-P72-4	4.3-5.0	RESIDUAL DOLOMITE	31.0	14.0	6.0	14.0	21.0	28.0	37.0	46	54	14	1.37	A-6[3]	SC	LOW
BCJV/400/TP-P74A-2	1.0-2.8	CHERT RESIDUUM	23.0	4.0	1.5	2.0	19.0	17.0	62.0	27	30	2	2.05	A-2-4[0]	GC & GM	LOW
BCJV/400/TP-P74A-3	2.8-4.4	RESIDUAL DOLOMITE	33.0	16.0	8.0	26.0	31.0	38.0	6.0	72	85	26	0.49	A-6[10]	CL	MEDIUM
BCJV/500/TP-A75-1	0.0-2.0	CHERT RESIDUUM	23.0	9.0	4.0	6.0	23.0	27.0	44.0	32	46	6	1.66	A-2-4[0]	SC	LOW

TABLE 9: SUMMARY OF INDICATOR TEST RESULTS (cont)

TEST PIT NO	DEPTH (m)	MATERIAL DESCRIPTION	ATTERBERG LIMITS			GRADING				PERCENTAGE FINER THAN (mm)			GM	CLASSIFICATION		POTENTIAL EXPANSIVENESS
			LL	PI (*)	LS	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	0.075	0.425	0.002		HRB	UNIFIED	
BCJV/400/TP-13-3	3.7-5.0	RESIDUAL DOLOMITE	41.0	16	8.0	32.0	33.0	33.0	1.0	73	85	32	0.43	A-7-6[10]	ML	LOW
BCJV/400/TP-18-3	3.8-5.0	RESIDUAL DOLOMITE	39.0	16.0	8.0	23.0	32.0	40.0	5.0	62	76	23	0.67	A-6[8]	CL	MEDIUM
BCJV/400/TP-19-2	3.0-5.0	GRAVELLY SAND	35.0	12	6.0	8.0	20.0	40.0	32.0	33	47	8	1.52	A-2-6[0]	SC	LOW
BCJV/400/TP-20-2	2.1-4.0	GRAVELLY SAND	40.0	13	6.5	12.0	22.0	40.0	25.0	41	54	12	1.3	A-6[2]	SC	LOW
BCJV/400/TP-20-3	4.0-5.0	RESIDUAL DOLOMITE	46.0	18	8.0	18.0	39.0	41.0	2.0	65	79	18	0.58	A-7-6[10]	ML	MEDIUM
BCJV/400/TP-22-2	0.9-1.6	RESIDUAL GRANITE	40.0	17.0	8.0	17.0	27.0	34.0	22.0	51	61	17	1.10	A-6[6]	CL	LOW
BCJV/400/TP-22-3	1.6-2.8	RESIDUAL GRANITE	44.0	20.0	10.0	16.0	39.0	40.0	4.0	63	82	16	0.59	A-7-6[10]	CL	MEDIUM
BCJV/400/TP-22-4	2.8-5.0	RESIDUAL GRANITE	35.0	13.0	6.5	4.0	30.0	60.0	7.0	42	70	4	0.95	A-6[2]	SC	LOW
BCJV/400/TP-23-4	2.3-5.0	RESIDUAL GRANITE	30.0	9.0	4.5	8.0	23.0	62.0	8.0	34	55	8	1.19	A-2-4	SC	LOW
BCJV/400/TP-30-1	0.2-0.8	RESIDUAL SHALE	38.5	6.9(3.8)	3.3	7.6	25.5	28.5	38.4	38	56	8	1.44	A-4[1]	GM	LOW
BCJV/400/TP-30-2	0.8-3.6	RESIDUAL DOLOMITE	82.6	11.6(8.1)	5.3	10.2	38.0	30.0	21.8	56	70	10	0.96	A-7-5[7]	MH/OH	LOW
BCJV/400/TP-35-1	0.0-3.0	GRAVELLY SAND	27.,5	6.6(4.4)	2.7	5.0	25.2	67.3	2.5	33	67	5	1.02	A-2-4	SC/SM	LOW
BCJV/400/TP-37-1	0.7-1.4	RESIDUAL DOLOMITE	29.3	5.6(2.8)	2.7	4.0	18.2	52.0	25.7	24	51	4	1.5	A-2-4	SM	LOW
BCJV/400/TP-39-3	1.4-2.4	RESIDUAL DOLOMITE	26.6	6.9(3.7)	3.3	6.6	25.5	43.9	23.9	35	54	7	1.35	A-2-4	SC/SM	LOW
BCJV/400/TP-48-2	0.9-1.9	RESIDUAL DOLOMITE	41.0	9.0	4.5	2.0	26.0	66.0	5.0	35	61	2	1.09	A-2-5[0]	SC	LOW
BCJV/400/TP-52-2	2.6-5.0	RESIDUAL DOLOMITE	47.0	18.0	8.0	2.0	45.0	51.0	3.0	63	87	2	0.53	A-7-6[10]	ML	LOW
BCJV/400/TP-55-3	0.6-1.5	SANDY GRAVEL	29	10.0	5.0	2.0	10.0	25.0	63.0	15	26	2	2.22	A-2-4[0]	GC	LOW
BCJV/400/TP-64-2	1.7-4.3	RESIDUAL SYENITE		NP	0.0	0.0	33.0	67.0	0.0	42	97	0	0.61	A-4[1]	SC	NONE
BCJV/400/TP-65-1	0.0-2.1	RESIDUAL SYENITE	28.0	5.0	1.5	0.0	43.0	57.0	0.0	54	97	0	0.49	A-4[4]	ML	NONE

LL -LIQUID LIMIT GM-GRADING MODULUS PI(*)-PLASTICITY INDEX (PI OF WHOLE SAMPLE) NP-NON PLASTIC LS-LINEAR SHRINKAGE

TABLE 9: SUMMARY OF INDICATOR TEST RESULTS (continued)

TEST PIT NO	DEPTH (m)	MATERIAL DESCRIPTION	ATTERBERG LIMITS			GRADING				PERCENTAGE FINER THAN (mm)			GM	CLASSIFICATION		POTENTIAL EXPANSIVENESS
			LL	PI (*)	LS	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	0.075	0.425	0.002		HRB	UNIFIED	
BCJV/500/TP-02	1.0-2.0	CHERT GRAVEL	32.4	8.1(5.2)	4.0	10.1	33.6	33.8	22.4	47	65	10	1.11	A-4[2]	SM	LOW
BCJV/500/TP-03	0.5-2.8	CHERT GRAVEL	38.2	10.7(3.8)	5.3	5.7	19.9	19.2	55.3	27	35	6	1.93	A-2-6[0]	GM	LOW
BCJV/500/TP-05	0.0-1.0	HILLWASH	23.0	10.0	4.0	5.0	19.0	41.0	35.0	31	52	5	1.52	A-2-4[0]	SC	LOW
BCJV/500/TP-05	0.1-1.8	HILLWASH	21.0	6.0	2.5	2.0	11.0	29.0	58.0	17	26	2	2.15	A-1-6[0]	SC & SM	LOW
BCJV/500/TP-05	1.8-3.6	HILLWASH	32.0	12.0	6.0	14.0	22.0	32.0	31.0	49	59	14	1.23	A-6[3]	SC	LOW
BCJV/500/TP-06	0.0-3.9	CHERT RESIDUUM	33.3	9.7(8.1)	4.7	12.2	45.4	35.7	6.6	68	84	12	0.55			LOW
BCJV/500/TP-07	0.1-0.5	HILLWASH (COLLUVIUM	24.4	6.6(4.3)	3.3	10.2	25.1	42.8	21.8	38	65	10	1.19	A-4[1]	SC/SM	LOW
BCJV/500/TP-07	0.5-1.9	CHERT RESIDUUM	26.2	5.3(2.7)	2.7	6.2	26.4	32.8	34.6	36	51	6	1.48			LOW
BCJV/500/TP-08	0.1-1.4	HILLWASH	30.0	14.0	6.5	6	17.0	25.0	52.0	32	40	6	1.80	A-2-6[1]	SC	LOW
BCJV/500/TP-08	1.4-2.3	CHERT RESIDUUM	35.0	15.0	7.0	14.0	23.0	32.0	31.0	49	58	14	1.24	A-6[5]	SC	LOW
BCJV/500/TP-W18-1	0.0-0.5	CHERT GRAVEL	21.0	6.9(2.3)	2.7	6.0	30.1	30.1	56.0	16	33	4	2.07	A-2-4	GC/GM	LOW
BCJV/500/TP-W18-1	0.5-1.1	CHERT BRECCIA	23.5	5.1(1.7)	2.7	4.3	15.3	27.7	52.7	21	34	4	1.97	A-1-6	GC/GM	LOW
BCJV/500/TP-W18-2	0.0-0.3	HILLWASH	20.0	5.6(2.8)	2.7	5.4	11.8	57.3	25.5	20	50	5	1.56	A-2-4	SC/SM	LOW
BCJV/500/TP-W18-2	0.3-1.6	CHERT GRAVEL	21.7	8.3(2.3)	8.3	2.0	13.4	23.6	61.0	17	28	2	2.16	A-2-4	GC	LOW
BCJV/500/TP-W19-1	0.01-0.6	HILLWASH	23.8	8.8(2.7)	4.0	3.4	11.9	23.5	61.3	17	30	3	2.14	A-2-4	GC	LOW
BCJV/500/TP-W19-1	0.6-1.4	CHERT RESIDUUM	30.3	11.6(2.5)	6.0	4.2	9.3	18.7	67.7	15	22	4	2.31	A-2-6[0]	GC	LOW
BCJV/500/TP-W19-2	0.01-0.4	HILLWASH	20.2	5.7(1.5)	2.7	4.5	8.1	21.5	65.9	13	27	4	2.25	A-1-a	GC/GM	LOW
BCJV/500/TP-W19-2	0.4-1.4	CHERT RESIDUUM	23.4	4.1(1.2)	2.7	3.5	15.1	22.0	59.4	20	29	4	2.1	A-1-b	GC/GM	LOW

LL -LIQUID LIMIT GM-GRADING MODULUS PI(*)-PLASTICITY INDEX (PI OF WHOLE SAMPLE) NP-NON PLASTIC LS-LINEAR SHRINKAGE

TABLE 9: SUMMARY OF INDICATOR TEST RESULTS (continued)

TEST PIT NO	DEPTH (m)	MATERIAL DESCRIPTION	ATTERBERG LIMITS			GRADING				PERCENTAGE FINER THAN (mm)			GM	CLASSIFICATION		POTENTIAL EXPANSIVENESS
			LL	PI (*)	LS	CLAY (%)	SILT (%)	SAND (%)	GRAVEL (%)	0.075	0.425	0.002		HRB	UNIFIED	
BCJV/400/TP-V6-A-01	1.5-2.0	CHERT RESIDUUM	27.5	5.8(2.1)	2.7	6.6	23.3	23.5	46.6	33	42	7	1.71			LOW
BCJV/400/TP-V6-P01-1	0.5	HILLWASH	20.9	5.9(3.4)	2.7	6.6	25.0	44.6	23.8	37	58	7	1.29			LOW
BCJV/400/TP-V6-P01-2	1.5	CHERT GRAVEL	26.4	6.5(2.7)	3.3	4.5	24.5	21.0	50.0	32	42	5	1.76			LOW
BCJV/400/TP-V6-P01-3	5.0	RESIDUAL DOLOMITE	29.3	9.8(7.9)	4.7	11.2	49.2	25.4	14.2	66	81	11	0.68			LOW
BCJV/400/TP-V6-P02-2	3.4	RESIDUAL DOLOMITE	26.6	4.5(2.3)	2.7	3.2	31.7	28.6	36.5	38	51	3	1.47			LOW
BCJV/400/TP-V6-P03-1	2.0	CHERT GRAVEL	25.7	5.3(1.3)	2.7	2.6	13.8	14.9	68.6	19	24	3	2.26			LOW
BCJV/400/TP-V6-P03-2	3.3	CHERT RESIDUUM	29.2	8.7(2.9)	4.0	5.1	17.9	18.2	58.9	26	34	5	1.99			LOW
BCJV/400/TP-V6-P04-2	1.6	HILLWASH	25.5	4.1(1.6)	2.7	4.5	21.3	22.3	51.8	28	39	5	1.85			LOW
BCJV/400/TP-V6-P05-1	0.80	HILLWASH	24.4	6.6(4.9)	3.3	7.8	36.2	45.1	11.0	48	74	8	0.89			LOW
BCJV/400/TP-V6-P05-2	1.30	CHERT GRAVEL	22.5	6.5(1.9)	3.3	3.3	15.1	19.2	62.5	20	29	3	2.14	A-2-4	GC/GM	LOW
BCJV/400/TP-V6-P05-3	2.10	RESIDUAL DOLO MITE	26.0	5.4(2.6)	2.7	5.5	27.4	27.8	39.4	36	48	6	1.55	A-4[0]	SC/SM	LOW
BCJV/400/TP-V6-P06-1	0.3	CHERT GRAVEL	25.7	5.3(1.3)	2.7	2.6	13.8	14.9	68.6	19	24	3	2.26			LOW

LL -LIQUID LIMIT GM-GRADING MODULUS PI(*)-PLASTICITY INDEX (PI OF WHOLE SAMPLE) NP-NON PLASTIC LS -LINEAR SHRINKAGE