

**Geotechnical analysis of dolomitic terrain to assess the probability  
of sinkhole formation: A case study of Centurion, South Africa**

By

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## Declaration

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## **Dedication**

To my beloved wife, for your unwavering support, endless patience, and steadfast belief in me.

To my two precious daughters, you are my greatest inspiration and the joy of my life.

To my mother, for your sacrifices, wisdom, and unconditional love that shaped who I am today.

To my entire Mavhetha's family and friends, for your encouragement, understanding, and support throughout this journey. This achievement is as much yours as it is mine.

## **Abstract**

Dolomitic terrain in the Gauteng Province of South Africa presents significant geotechnical challenges for urban development. This is primarily due to subsurface dissolution processes that create void networks susceptible to sinkhole formation and ground subsidence. This research study explores the case of Cornwall Hill in Centurion where numerous sinkhole incidents have caused infrastructure damage and imposed severe development constraints.

A multi-method investigation approach was employed, combining gravity geophysical surveys, test pit excavations, rotary percussion boreholes, dynamic cone penetrometer tests, and laboratory analysis. Gravity surveys comprised 105 measurement stations on a 50 m × 50 m grid. Five test pits were excavated while four rotary percussion boreholes were drilled to depths between 10 and 25 m. Five dynamic cone penetrometer tests were also carried out on site and rotary percussion drilling was done to complement gravity surveys. Lastly, a comprehensive laboratory geotechnical analysis programme was done on field samples collected on site.

Results revealed that the site is underlain by Malmani Subgroup dolomites overlain by a consistent three-layer stratigraphic sequence comprising colluvium, residual soil, and dolomite bedrock. The residual soils exhibited consistent classification as low plasticity clay with plasticity indices of 11 – 14% and a gravel-rich composition at 50 – 60%. However, the soils displayed significant spatial variability in thickness (0.70 – 2.70 m) and bearing capacity (152 – 320 kPa at 0.7 – 0.8 m depth). Rotary percussion drilling confirmed the presence of shallow competent dolomite beneath chert layers at 2 m depth and colluvium overlying interbedded chert and dolomite from 3 m depth. A cavity located within the peripheral low-density gravity zone and extending from 2 m to 13 m depth before competent material was also reached.

Gravity survey results defined the subsurface density contrast, with high-density areas (covering 60% of the site) indicating shallow competent bedrock at 1.0–1.6

m depth and low-density areas (covering 40% of the site) indicating deep weathering profiles exceeding 2.7 m; the cavity intersected in BH01 directly correlates with low gravity in the peripheral zone. The site was described into Zone A (central D3 area of the site suitable for development with raft foundations at 600–900 mm depth) and Zone B (peripheral D4 area of the site unsuitable for development owing to the presence of a cavity, gravity lows indicating solution features, and high collapse potential) based on the results of integrated geophysical, intrusive, and laboratory investigation. The study meets the requirements of SANS 1936-2:2012 and proves the potential of integrated characterization of complex terrain, including the application of Rotary Percussion Drilling (RPD) as ground truth, for making informed decisions regarding development of difficult terrain such as this dolomitic environment, while providing valuable geotechnical data for the Centurion region.

**Keywords:** Dolomitic terrain; Geotechnical characterization; Sinkhole susceptibility; Geophysical surveying; Rotary percussion drilling

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## List of abbreviations, acronyms and symbols

<b>AASHTO</b>	American Association of State Highway and Transportation Officials
<b>ACI</b>	American Concrete Institute
<b>ASTM</b>	American Society for Testing and Materials
<b>BS EN</b>	British Standard European Norm
<b>CBR</b>	California Bearing Ratio [%]
<b>CBD</b>	Central Business District
<b>CL</b>	Low plasticity clay (Lean clay), as classified by the Unified Soil Classification System (USCS)
<b>COLTO</b>	Committee of Land Transport Officials
<b>CV</b>	Coefficient of variation [%]
<b>DCP</b>	Dynamic Cone Penetrometer
<b>DGPS</b>	Differential Global Positioning System
<b>DTH</b>	Down-the-hole
<b>EC</b>	Electrical Conductivity [mS/cm or dS/m]
<b>Ek</b>	Geological map symbol for the Eccles Formation (shale), Pretoria Group, Transvaal Supergroup
<b>ERT</b>	Electrical Resistivity Tomography
<b>FI</b>	Foundation Indicator
<b>GIS</b>	Geographic Information Systems
<b>GPR</b>	Ground-Penetrating Radar
<b>GPS</b>	Global Positioning System

<b>IEC</b>	International Electrotechnical Commission
<b>IHC</b>	Inherent Hazard Class
<b>ISO</b>	International Organization for Standardization
<b>LL</b>	Liquid Limit measured as part of the Atterberg Limit tests [%]
<b>MDD</b>	Maximum dry density [kg/m <sup>3</sup> ]
<b>Min</b>	Minimum value of an array of numbers
<b>Max</b>	Maximum value of an array of numbers
<b>N</b>	Number of sinkholes [-]
<b>N</b>	N-value obtained from the Standard Penetration Test [blows/300 mm]
<b>NACE</b>	National Association of Corrosion Engineers
<b>NHBRC</b>	National Home Builders Registration Council
<b>OMC</b>	Optimum Moisture Content [%]
<b>pH</b>	Potential of Hydrogen (measure of soil acidity or alkalinity) [-]
<b>PI</b>	Plasticity Index measured as part of the Atterberg Limit tests [%]
<b>PL</b>	Plastic Limit measured as part of the Atterberg Limit tests [%]
<b>RPD</b>	Rotary Percussion Drilling
<b>SAICE</b>	South African Institution of Civil Engineering
<b>SANRAL</b>	South African National Roads Agency Limited

<b>SANS</b>	South African National Standards
<b>SPT</b>	Standard Penetration Test
<b>Std Dev</b>	Standard Deviation
<b>TLB</b>	Tractor Loader Backhoe
<b>TMH1</b>	Technical Methods for Highways 1
<b>USCS</b>	Unified Soil Classification System
<b>ZAV</b>	Zero Air Voids

## Definitions of key terms

**Blanketing Layer:** The blanketing layer refers to the unconsolidated residual or transported soil material overlying the dolomitic bedrock. This layer acts as a protective cover above cavities and weathered zones within the dolomite and plays a major role in controlling sinkhole susceptibility and ground stability.

**Dolomite:** Dolomite is a carbonate sedimentary rock composed mainly of calcium magnesium carbonate  $[\text{CaMg}(\text{CO}_3)_2]$ .

**Dolomitic Terrain:** Dolomitic terrain refers to land underlain by dolomite rock that may be prone to ground instability due to dissolution processes and subsurface cavity development.

**Sinkhole:** A sinkhole is a surface depression or collapse feature formed when overlying soil or rock material subsides into underlying cavities or voids within dolomitic or karstic bedrock.

**Subsidence:** Subsidence refers to gradual downward movement or settlement of the ground surface caused by subsurface erosion, cavity formation, or collapse of underlying materials.

**Karstification:** Karstification is the geological process whereby carbonate rocks such as dolomite dissolve through interaction with acidic groundwater, resulting in cavities, conduits, caves, and other karst features.

**Inherent Hazard Class (IHC):** The Inherent Hazard Class (IHC) is a classification system used to indicate the natural hazard potential of dolomitic land prior to implementation of mitigation measures. The classification is based on geological, hydrogeological, and geotechnical conditions associated with sinkhole and subsidence risk.

**Doline:** A doline is a shallow closed depression formed by gradual subsidence or dissolution within dolomitic or karstic terrain.

**Dolomite Area Designation (D1–D4):** Dolomite Area Designations are classifications defined in SANS 1936 used to indicate the suitability of dolomitic land for development and the level of precautionary measures required.

**D3 Area:** A D3 designation represents a medium-risk dolomitic area where development may proceed subject to precautionary engineering measures, groundwater control, and appropriate foundation design.

**D4 Area:** A D4 designation represents a high-risk dolomitic area where significant instability hazards may exist and where stringent site-specific mitigation measures are required before development can proceed safely.

**Gravity Survey:** A gravity survey is a geophysical investigation method used to detect subsurface density variations by measuring changes in the Earth's gravitational field. Low-density anomalies may indicate cavities, voids, or highly weathered zones.

**Gravity Anomaly:** A gravity anomaly refers to a variation in measured gravitational values caused by differences in subsurface density relative to surrounding geological materials.

**Rotary Percussion Drilling (RPD):** Rotary Percussion Drilling is an intrusive geotechnical investigation technique that uses compressed air and percussion action to penetrate rock formations and obtain information regarding lithology, cavities, weathering, and groundwater conditions.

**Residual Soil:** Residual soil is soil formed in situ through weathering of the underlying parent rock without significant transportation.

**Colluvium:** Colluvium refers to loose, unconsolidated soil or rock material transported downslope mainly by gravity and surface runoff.

**Weathering Profile:** A weathering profile describes the vertical sequence of weathered materials from surface soils down to competent bedrock.

**Vadose Zone:** The vadose zone is the unsaturated zone between the ground surface and the groundwater table where pores contain both air and water.

**Phreatic Zone:** The phreatic zone is the saturated subsurface zone below the groundwater table where all voids and fractures are filled with water.

**Dynamic Cone Penetrometer (DCP):** The Dynamic Cone Penetrometer is an in-situ testing device used to assess soil strength and bearing capacity through penetration resistance measurements.

**California Bearing Ratio (CBR):** The California Bearing Ratio is a laboratory or field test used to evaluate the strength and load-bearing capacity of subgrade and pavement materials.

**Atterberg Limits:** Atterberg Limits are index properties used to define the consistency and plasticity characteristics of fine-grained soils, including the liquid limit, plastic limit, and plasticity index.

**Bearing Capacity:** Bearing capacity refers to the ability of soil or rock to safely support structural loads without excessive settlement or failure.

**Hydraulic Conductivity:** Hydraulic conductivity is the ability of soil or rock to transmit water through its pore spaces or fractures.

**Groundwater Fluctuation:** Groundwater fluctuation refers to changes in the groundwater table level caused by climatic conditions, infiltration, pumping, or dewatering activities.

**Water Ingress:** Water ingress refers to the concentrated infiltration of water into the ground through leaking services, stormwater systems, or surface runoff, often contributing to subsurface erosion and sinkhole formation in dolomitic terrain.

**Differential Settlement:** Differential settlement refers to uneven ground movement beneath a structure resulting from variable soil conditions or subsurface instability.

**Geotechnical Investigation:** A geotechnical investigation is the systematic assessment of subsurface conditions through fieldwork, laboratory testing, and geophysical methods to evaluate engineering suitability for development.

## **Chapter 1. Introduction**

### **1.1. Background**

Dolomitic areas are found in many parts of the world. They are often seen as problem areas for building cities. The rock's high solubility promotes the development of subsurface voids, which results in ground instability and sinkhole formation (Dippenaar et al., 2018). In South Africa, the Proterozoic dolomites, particularly those located in the Gauteng Province, have been very well-documented for their complex geological history, including multiple phases of karstification, which makes them highly prone to such geohazards (Buttrick et al., 2001; Dippenaar et al., 2018). The Malmani Subgroup is part of the Transvaal Basin. It lies under much of South Africa's main economic area. As cities grow, the risk of ground instability increases (Richardson, 2013).

Development is further complicated by the unique hydrogeological characteristics of these dolomitic aquifers, which function not only as vital storage for groundwater in a semi-arid country but also influence karstic processes through circulating fluids and dissolution (Montjane et al., 2020; Abiye, 2023). The stability of these terrains, which must be evaluated through comprehensive geotechnical assessments to prevent hazards, is influenced by the intricate interplay of bedrock mineralogy, overburden characteristics, and hydrological flow paths. This issue becomes particularly critical in regions such as Gauteng, where significant urban expansion occurs over dolomitic formations, specifically the Malmani Subgroup and its correlation to the Ghaap Group in more arid areas. This expansion heightens the risk of ground instability, thereby necessitating the implementation of effective risk mitigation strategies (Dippenaar et al., 2018).

Historically, dewatering operations for gold mining in the Far West Rand during the 1960s precipitated numerous catastrophic sinkhole events, leading to extensive research and the relocation of entire communities at significant financial cost (Ferentinou et al., 2020). More recently, urban expansion over these dolomitic areas, particularly around major metropolitan centres like Pretoria and

Johannesburg, has introduced new triggers for surface instability, primarily through compromised water infrastructure leading to concentrated ingress (Brink, 1979; Dippenaar et al., 2018). This scenario, in which concentrated water ingress promotes erosion of material into subsurface cavities or regional groundwater dewatering reduces overburden stability, accounts for a significant proportion of recorded sinkholes in Gauteng (Oosthuizen and Richardson, 2011; Dippenaar et al., 2018). Evidence suggests that sinkhole development is predominantly controlled by focused vadose zone flow processes rather than groundwater management alone (Kleinhans and Van Rooy, 2016).

Human-related factors, particularly leaking pipelines, are responsible for approximately 98% of recorded sinkholes in urbanized karst areas of South Africa, emphasizing the importance of effective surface water management in mitigating such hazards (De Bruyn and Bell, 2001; Youssef et al., 2016). Although there is substantial evidence correlating water ingress with the formation of sinkholes, particularly due to leaking pipelines, the precise mechanisms responsible for the erosion of overburden into deeper cavities remain insufficiently examined (Kleinhans and Van Rooy, 2014; Gutiérrez et al., 2014). This process primarily involves the weathering of overburden material by infiltrating water, which subsequently transports these sediments into pre-existing underground voids or newly formed dissolution features within the dolomite (Ferentinou et al., 2020). Understanding vadose zone processes, particularly the downward erosion of overburden into cavities due to precipitation or leaking infrastructure, is critical, as these mechanisms account for most sinkhole occurrences in Gauteng (Brink, 1979; Buttrick et al., 2001).

In view of these acute challenges of the dolomitic terrains, especially in growing urban areas like Centurion, this study presents a detailed geotechnical characterization of a dolomitic area located within Cornwall Hill in Centurion. Gauteng is an industrialized province with a high population density and restricted room for infrastructure development owing to geological formations in most places. Carbonate rocks including limestone and dolomites, which are prone to

dissolution and sinkhole formation, cover over 2 576 km<sup>2</sup> (14%), of Gauteng. (SAICE, 2019). However, granting building and exploration permissions in regions where these rocks predominate now requires thorough study and creative construction techniques. This study employs a desktop study, gravity geophysical surveying, test pitting, drilling, and laboratory geotechnical testing to evaluate the engineering behaviour of the residual soils and assess the implications for development planning.

The results of this project are expected to provide critical perspectives on land-use planning and infrastructure development with the aim of minimizing the risks associated with dolomitic dissolution and ensuring long-term structural integrity.

## **1.2. Problem statement**

Centurion is situated in a dolomitic region, historically recognized for its susceptibility to soil surface subsidence, which manifests as sinkholes. A notable incident occurred in January 2022, when heavy rainfall triggered sinkhole formation along the N1 and R21 highways near the Flying Saucer Interchange. These sinkholes caused significant traffic congestion and resulted in an estimated repair cost of approximately R424 million, with the restoration process extending over two years (SANRAL, 2024). Although the development of dolomite land in South Africa is regulated by various standards, such as SANS 1936, mere compliance with these standards, without conducting further site-specific investigations, is inadequate to ensure ground stability. Comprehensive site-specific investigations are essential for acquiring precise knowledge of a site's physical condition. In developing regions, insufficient investigation exacerbates uncertainty in the establishment of new infrastructure, increasing the likelihood of construction on unstable ground with a high risk of collapse (Buttrick et al., 2001). Insufficient assessment of site stability can significantly reduce the reliability and usefulness of a geotechnical study, to the extent that the findings provide limited value for development or construction decision-making. Frequent

sinkhole occurrences in Centurion associated with underlying dolomitic geology indicate a significant geotechnical hazard and emphasize the risks of inadequate pre-construction stability assessment (Buttrick et al., 2015). While SANS 1936 specifies site stability analysis, the investigation varies in terms of the value or depth of the knowledge. Evidence indicates an approximate 93% rate of sinkhole occurrences due to human error, but the investigation fails to fully assess the influence of load on water conditions.

### **1.3. Research questions**

This study addresses the following questions:

- What are the geotechnical and geological characteristics of the dolomitic terrain and residual soils in the study area?
- What karst-related features and geotechnical variability, such as cavities, voids, and weathered zones, are present across the site as identified through geophysical and intrusive investigations?
- How suitable is the site for the proposed development based on integrated geotechnical and geophysical findings?

### **1.4. Aim and objectives of the research**

The main aim of the research is to carry out detailed sub-surface characterization of dolomitic terrain in Centurion for development planning, using a combination of geophysical, geological, and geotechnical methods.

The specific research objectives are to

- Perform gravity geophysical surveys to identify possible subsurface anomalies using a Scintrex CG-5 gravimeter and Trimble Differential GPS (DGPS) system.
- Determine soil stratigraphy and weathering profiles of the area using test pits and rotatory percussion boreholes.

- Analyse geotechnical properties of soil through laboratory testing, including Atterberg limits, grain size distribution, compaction, and bearing capacity (CBR).

### **1.5. Significance of the study**

The significance of this study lies in the residential development planning in dolomitic areas. This study provides site-specific geotechnical data essential for appropriate foundation design and supports compliance with dolomite land-use regulations such as SANS 1936. A key gap in dolomitic land development practice is the frequent absence of comprehensive pre-construction geotechnical investigations, which limits the ability to accurately assess subsurface stability and sinkhole risks (Brink, 1979; Buttrick et al., 2001). In response, institutions such as the NHBRC, Council for Geoscience, and municipalities have strengthened requirements for compliance, emphasising the need for detailed dolomite stability assessments prior to development approval (NHBRC, 2019; Council for Geoscience, 2020).

By characterising the residual soil behaviour and its engineering properties, the study enhances understanding of subsurface conditions in dolomitic terrain and identifies localised zones of weaker ground that may require targeted engineering interventions. Within this context, the application of integrated investigation methods is essential to improve the reliability of subsurface characterisation and support evidence-based design decisions in dolomitic terrains.

The results also contribute to reducing the risk of sinkhole formation during and after development by guiding water management, foundation placement, and construction practices. Overall, the findings provide a reliable technical basis for planners, engineers, and developers operating in Centurion and other dolomitic regions, enabling more informed and safer development decision-making.

## **1.6. Structure of the dissertation**

The dissertation is organized as follows:

- Chapter 1 introduces the research background, problem, aim, and objectives.
- Chapter 2 reviews the available literature on dolomite geology, sinkhole formation, blanketing layers, and geotechnical behaviour.
- Chapter 3 describes the research methodology adopted, including study area description, gravity surveying, test pitting, drilling, and laboratory testing.
- Chapter 4 presents and discusses the results of geotechnical and geophysical investigations.
- Chapter 5 provides a summary of the conclusions and recommendations based on the findings from this research study.

## **Chapter 2. Literature review**

This section provides a comprehensive literature review based on peer-reviewed journal articles, academic books, technical reports, and prior research relevant to dolomite stability analysis in the study area. The nature of dolomite, sinkhole and subsidence creation, sinkhole formation mechanisms, and techniques for locating subterranean cavities will all be covered in this succinct literature review.

### **2.1. Stability and sinkhole formation in dolomite**

The dolomitic bedrock of the Malmani Subgroup, which underlies significant urban areas in Gauteng Province, represents one of the most extensive dolomite sequences globally (Constantinou and Van Rooy, 2018; Mndaweni, 2022). This geological formation is characterized by a complex network of subsurface voids, including caves, caverns, and interconnected conduit systems (Eriksson and Altermann, 1998; Ford and Williams, 2007). These formed through intensive karstification, weathering, and erosion of the rock over long geological periods (Brink, 1979). These geological features significantly reduce the mechanical integrity of the rock mass, thereby posing serious geotechnical challenges and substantial geohazard risks to urban development and infrastructure planning (Ahmad et al., 2025). Moreover, the increasing urban development in Gauteng, particularly in the densely populated areas between Pretoria and Johannesburg, significantly enhances the potential for surface subsidence and the development of sinkholes, in most cases triggered by human activities such as malfunction of urban infrastructure and artificial changes in subsurface water infiltration (Veress, 2021; Dastpak et al., 2023; Ahmad et al., 2025).

Dolomite stability given less than adequate evaluation during construction has resulted in serious consequences in terms of structural collapse, extensive property damage, and even loss of life (Yassin et al., 2020; Lendo-Siwicka et al., 2021; Mevoli et al., 2024; Srivastava et al., 2025). Assessment of dolomite stability evaluates the ability of overlying materials to resist collapse into underlying cavities, thereby informing decisions regarding the suitability of a particular

proposed development site. Some of the key factors identified as initiating the occurrence of sinkholes include infrastructure failures such as burst water pipes, faulty drainage networks, and irrigation systems, as well as human activities such as draining swimming pools, which are responsible for initiating subsurface erosion and cavity enlargement (Veress, 2021; Dastpak et al., 2023; Ahmad et al., 2025). Understanding these triggering mechanisms is essential for proper risk reduction and careful planning of development in areas underlain by dolomitic rocks.

The Cornwall Hill study site in Centurion falls squarely within this type of hazardous dolomitic landscape. The site is located at coordinates 28°14'10.97"E, 25°52'56.78"S in the Irene region of Centurion, Gauteng Province, within the Cornwall Hill development zone adjacent to established residential areas including Irene Country Lodge and the Cornwall Hill residential estates. The site occupies predominantly flat to gently undulating terrain characteristic of the Centurion dolomite regions, with drainage features including the Rietvlei system observable to the east of the site. The site locality is presented in Figure 2.1.

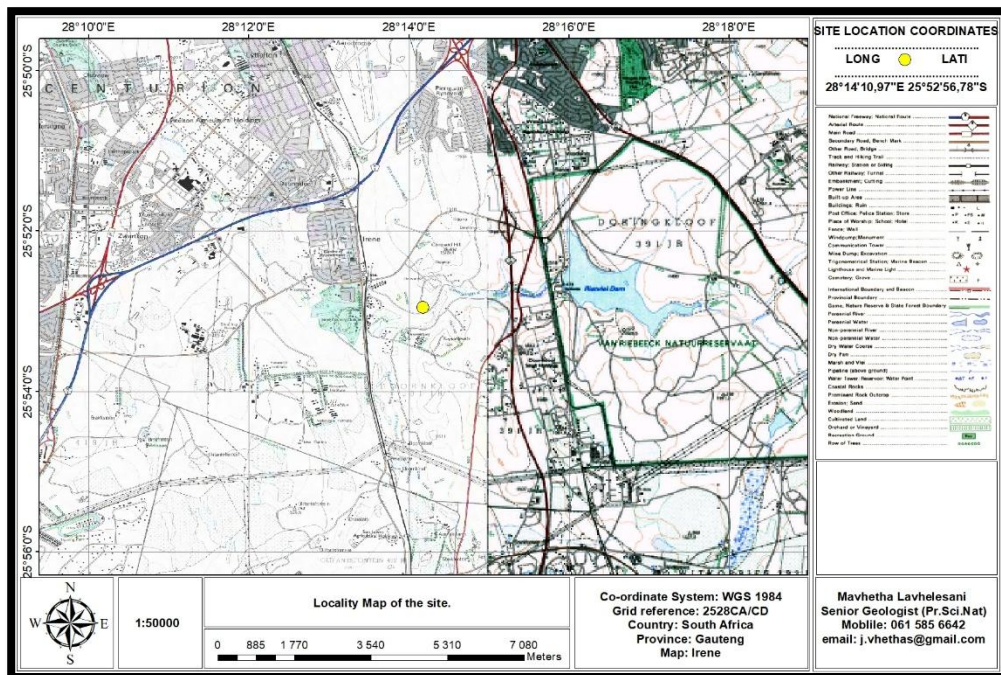
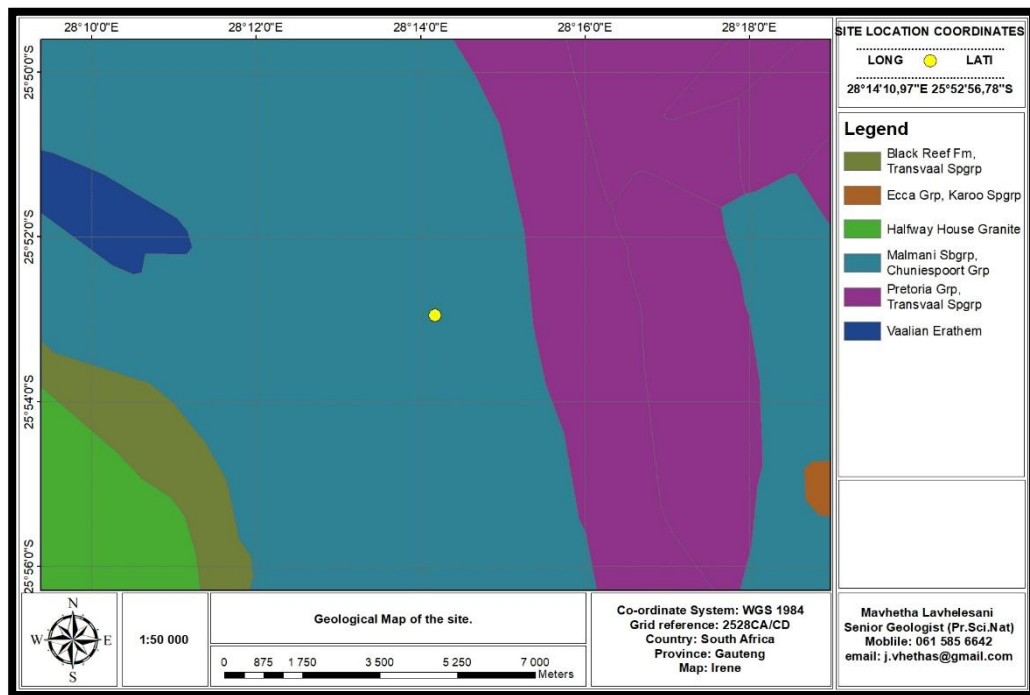


Figure 2.1: Site locality map

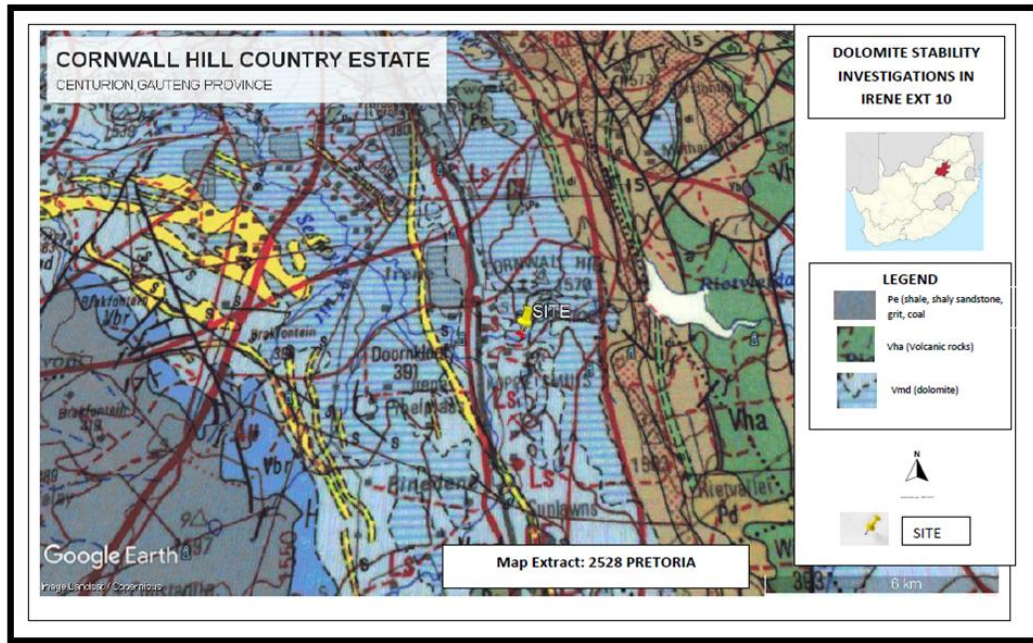
Desktop geological mapping confirmed that the site is located within the Late Archaean to Early Proterozoic Malmani Subgroup of the Chuniespoort Group, part of the Transvaal Supergroup, comprising dolomites and limestones dated to approximately 2.6 to 2.5 billion years ago (Constantinou and Van Rooy, 2018; Mndaweni, 2022). The Malmani Subgroup dolomites occur over an area of 2,576 km<sup>2</sup>, representing 14% of the total surface area of Gauteng Province, while dolomitic terrain defined as areas where dolomite occurs at depths of between 60 and 100 m constitutes approximately 4,005 km<sup>2</sup> or 24% of the province (Constantinou and Van Rooy, 2018). The regional geological map presented in Figure 2.2 confirms the location of the site predominantly within the Malmani Subgroup.



**Figure 2.2:** Regional geological map

The site is situated near the contact zone between multiple geological formations, including the Pretoria Group (Transvaal Supergroup) to the east. The dolomite rock comprises alternating bands of insoluble chert and soluble dolomite with small amounts of iron and manganese carbonates, and possesses a system of discontinuities fractures, joints, and faults which act as preferential solution

passages for water ingress. The proximity to volcanic rocks (Vha) and shale formations (Ek), visible on the local geological map Figure 2.3, adds further geological complexity to the site characterization.



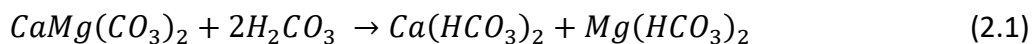
**Figure 2.3:** Local geological map

A detailed dolomite stability desktop investigation was conducted using Council for Geoscience mapping datasets. The dolomite stability investigation map Figure 2.3 confirms that the site falls within a dolomite hazard area classified as Vmd. The map illustrates dolomitic terrain with multiple documented sinkhole features and subsidence areas across the Cornwall Hill Country Estate, demonstrating that the proximity of the site to mapped dolomitic instability features is extensive. The spatial distribution of these features across the broader Cornwall Hill development indicates that ground instability is a pervasive concern throughout this residential area. A study compiled for the Centurion region documented a database of 287 sinkholes for the Gautrain Rapid Rail Link design, which passes through approximately 15 km of dolomitic ground in this area. Thousands of sinkholes, subsidence, and crack events have occurred in Gauteng over the past 50 years, with Centurion being one of the most severely affected of the area. The extensive historical record of ground instability in the immediate vicinity of the site,

combined with ongoing residential development pressure in the area, underscores the significant geotechnical challenges associated with this location.

## **2.2. Geological setting and dolomite nature**

Dolomitic terrains are primarily shaped by the chemical dissolution of carbonate rocks, which results in characteristic subsurface and surface features typical of karst environments. These geological conditions strongly influence ground stability and subsurface structure, particularly in regions where dolomite underlies urban development (Brink, 1979; Ford and Williams, 2007; Dippenaar et al., 2018). These features can pose significant geohazards in urbanized regions (Strzałkowski, 2019; Ahmad et al., 2025). Karst systems have complex three-dimensional structures formed by interconnected voids and preferential groundwater flow paths, which create significant challenges for engineering design and construction (Brink, 1979; Ford and Williams, 2007; Lendo-Siwicka et al., 2021; Ahmad et al., 2025). Discontinuities in dolomite rock, such as flaws, joints, and fractures, serve as preferred pathways for solutions. Moreover, rainwater, enriched with carbon dioxide during its passage through the atmosphere and soil, flows along these discontinuities and gradually dissolves the rock, despite relative imperviousness (porosity less than 0.3%) and insolubility in pure water of dolomite (Brink, 1979). The process may be represented as follows:



This solution causes the expansion of joints and cracks above the water table (vadose zone) into grykes or slots. Below the water table (phreatic zone), the passage of carbon dioxide-charged water leads to the formation of a network of cavities or caverns, with these slots potentially continuing to develop. Dolomite rock eventually forms pinnacles as steep valleys erode within the shear zones of faults. Some underground valleys have been reported to reach depths of up to 200 meters (Kleinhans and Van Rooy, 2016). The residual products, including

weathered dolomite, wad, chert, and residual chert, typically follow the hard rock dolomite and may be intruded or covered by younger strata (Brink, 1979).

Chert (SiO<sub>2</sub>), iron from ferruginous dolomite layers, and wad are the principal insoluble by-products of dolomite weathering. Dolomite appears as wads when there is a slight concentration of manganese present. Wad, also known as manganiferous earth, is an insoluble, highly compressible substance composed mainly of iron and manganese oxides with trace impurities. The compression of wad can lead to noticeable ground movement at the surface when the water table drops. A doline, a shallow, confined depression in the ground surface, is a manifestation of this ground movement. The length of a doline can range from over one kilometre to just a few metres (Nel and Haarhoff, 2011).

The karstic vadose zone, which often lacks a dominant epikarst layer in South African dolomites, plays a crucial role in mediating water movement and solute transport between the surface and aquifer systems (Dippenaar et al., 2018). This zone often exhibits highly variable permeability characteristics, which can significantly influence groundwater recharge processes and the potential for subsurface erosion leading to sinkhole development (Veress, 2021; Dastpak et al., 2023; Ahmad et al., 2025).

### **2.3. Factors governing dolomite stability**

The stability of dolomitic terrain is governed by complex interactions among geological, hydrological, geotechnical, and anthropogenic factors. Geological factors include the inherent properties of dolomite bedrock – its dissolution susceptibility (Buttrick and Van Schalkwyk, 1998), structural features such as joints and fractures that facilitate water ingress (Kleinhans and Van Rooy, 2016), and the thickness and composition of residual weathering products (Swart et al., 2019). Hydrological factors encompass both natural groundwater fluctuations and anthropogenic water inputs, with Richardson and Van Rooy (2018) documenting that over 90% of sinkholes in developed dolomitic areas of Gauteng result from

leaking water infrastructure. Geotechnical factors include the properties of residual dolomite (wad) and chert rubble at the soil-bedrock interface, particularly their bearing capacity, permeability, and susceptibility to subsurface erosion under variable saturation conditions (Swart et al., 2021). The mechanical stability of void-spanning soil arches depends critically on these residual soil properties, with collapse occurring when water ingress reduces matric suction and disrupts the bonded chert-clay structure (Ferentinou et al., 2020; Waltham et al., 2005).

### 2.3.1 Geological and geotechnical controls on sinkhole formation

Sinkhole formation in dolomitic terrain is controlled by both bedrock characteristics and overlying soil properties. At the bedrock level, the intrinsic geochemical susceptibility of dolomite to dissolution, coupled with structural discontinuities, establishes the foundation for instability. Ford and Williams (2007) demonstrated that although dolomite dissolves at a slower rate than calcite due to its magnesium content, it remains susceptible to acidic waters, particularly along joints, faults, and bedding planes that act as preferential flow paths. The spatial distribution of these structural features creates zones of enhanced dissolution within the bedrock mass (Kleinhans and Van Rooy, 2016). At the soil level, the thickness, composition, and mechanical properties of overlying materials critically determine whether subsurface cavities propagate to the surface. Retshedisitswe and Saheed (2024) demonstrated that thin residual soil profiles (< 2 m) offer limited buffering capacity and tend to fail rapidly through direct collapse, whereas thicker transported soil profiles (> 5 m) are more susceptible to progressive internal erosion, whereby water infiltration mobilizes fine particles into underlying voids, progressively weakening the soil from depth toward surface. The mechanical properties of these residual and transported materials particularly cohesion and internal friction.

### 2.3.2 Hydrogeological controls on stability

Fluctuations in groundwater levels are a critical factor influencing the stability of dolomitic terrains, with both increases and decreases in water tables capable of inducing instabilities through distinct mechanisms. Ferentinou et al. (2020)

documented that rising groundwater levels can destabilize the ground by increasing hydrostatic loading, reducing effective stress in overlying soils, and enhancing dissolution and internal erosion rates. Conversely, they demonstrated that falling water tables, resulting from dewatering or excessive pumping, remove buoyant support, thereby increasing effective stresses and potentially triggering the mechanical collapse of previously stable soil bridges. Day (1988) as well as Kleinhans and Van Rooy (2016) highlighted the importance of groundwater management in South African dolomitic areas, noting that cyclic wetting and drying associated with water table fluctuations induce volume changes in clay-rich residual soils, progressively weakening soil structure through repeated stress cycles.

### 2.3.3 Anthropogenic controls on sinkhole formation

Human activities, particularly urban development, excessive groundwater extraction, and infrastructure leakage, have fundamentally altered baseline geohazard rates in dolomitic terrains (Dippenaar et al., 2018). Buttrick et al. (2001) identified point-source infiltration from leaking water mains, sewer lines, and stormwater infrastructure as the primary driver of contemporary sinkhole formation in developed South African dolomitic areas. These anthropogenic water inputs create localized zones of intense subsurface erosion that dramatically exceed natural infiltration rates, thereby accelerating both bedrock dissolution and the hydraulic mobilization of residual materials.

Additional human activities triggers include poor maintenance of wet services, inadequately backfilled service trenches, and ground vibrations from heavy machinery or construction activities (Kleinhans and Van Rooy, 2016). These factors destabilize otherwise marginally stable soil arches above subsurface cavities, triggering collapse mechanisms. To address these risks, South Africa has developed integrated risk management frameworks incorporating precautionary water management measures, specialized foundation solutions, and pro-active infrastructure maintenance protocols (Watermeyer et al., 2008; SANS 1936, 2012). Richardson and Van Rooy (2018) documented strong spatial correlation

between infrastructure networks and sinkhole occurrence in Gauteng Province, confirming that anthropogenic factors now dominate contemporary hazard distributions in urbanized dolomitic settings.

#### **2.4. Protective role of blanketing layers in dolomitic terrain**

In a karst environment, the blanketing layer (A layer above a dolomitic bedrock) is a key factor in determining the stability of the area influencing sinkhole formation. The geotechnical properties of this layer are significant factors affecting the behaviour of the terrain (Constantinou and Van Rooy, 2018).

Here are some key geotechnical properties of the blanketing layer and their effects on sinkhole formation: The weathered residual materials overlying dolomite bedrock constitute a critical protective barrier against the upward propagation of subsurface cavities to the ground surface. The protective capacity of these overlying materials is governed by the complex interplay of four interdependent parameters: thickness, mechanical strength, composition, and hydraulic conductivity (Dippenaar et al., 2018). These properties collectively determine whether the layer can effectively bridge subsidence voids in the underlying bedrock while simultaneously supporting imposed surface loads without progressive collapse. When the blanketing layer is either insufficiently thick or has undergone substantial degradation, the protective function becomes compromised, thereby increasing the probability of rapid subsidence and hazardous sinkhole development at the ground surface.

##### **2.4.1 Blanketing thickness as the primary control on sinkhole risk**

Among the various parameters influencing blanketing layer performance, thickness emerges as the most critical factor in determining the likelihood of surficial manifestation of subsurface voids. This parameter forms the foundation of South African dolomite risk classification systems, which fundamentally relate blanketing thickness to development suitability (Bunk, 2023). The relationship is intuitive: thicker blanketing sequences provide enhanced arching capability

through increased overburden weight and load distribution capacity, while simultaneously affording longer time periods for cavity detection and remediation before surface failure occurs (Buttrick and Van Schalkwyk, 1998).

Recent studies have shown that even substantial blanketing thicknesses may be undermined by localized thinning or heterogeneous material properties, increasing susceptibility to sudden ground collapse (Buttrick and Van Schalkwyk, 1998; Avutia and Kalumba, 2014; Parise, 2015; Galve et al., 2022). Boo et al. (2020) demonstrated that even substantial blanketing thicknesses can be compromised by localized thinning or heterogeneous material properties, leading to heightened susceptibility to sudden ground collapse. This heightened susceptibility arises through two distinct mechanisms. First, localized zones of reduced thickness create stress concentration points where the vertical overburden stress exceeds the arching capacity of the thinned material, causing preferential failure at these locations despite adequate average thickness elsewhere (Waltham et al., 2005). Second, heterogeneous material properties result in differential strength distribution across the blanketing layer, with weaker zones (lower cohesion, reduced friction angle, or higher compressibility) failing progressively under load while stronger adjacent zones remain stable. These discontinuities in either thickness or mechanical properties create preferential pathways for upward cavity migration, effectively negating the protective function of thicker or stronger portions of the blanketing sequence.

This discovery highlights an important issue in development planning: the need to check not just the average thickness but also how it varies in different areas and the lowest points on a site. The recognition that thickness alone provides an incomplete picture of protective capacity has led to increased emphasis on multi-parameter assessment approaches (Brink, 1979; Day, 1987). The mechanical properties (strength, stiffness, density) govern the ability of the material to sustain arching stresses, while hydraulic properties (permeability, erosion resistance) control susceptibility to subsurface erosion and cavity enlargement (Trollip et al., 2010).

#### 2.4.2 Mechanical strength and load-bearing capacity

The mechanical strength characteristics of the blanketing layer determine its capacity to support overlying soil, vegetation, infrastructure, and imposed surface loads without failure. Strong, stable blanketing materials facilitate more uniform distribution of applied stresses and demonstrate greater capability to span subsurface voids. Whereas weak or poorly consolidated materials without sufficient cohesion remain vulnerable to progressive collapse mechanisms (Ferentinou et al., 2020). The hydraulic properties of dolomite-derived residual soils significantly influence stability through their control on moisture infiltration and erosion potential. Dippenaar et al., (2018) documented that these materials exhibit elevated hydraulic conductivity and storage capacity due to relict dissolution features and inherited porosity structures. This enhanced permeability facilitates rapid water transmission to underlying cavities, accelerating subsurface erosion, while high storage capacity increases vulnerability to saturation-induced strength reduction during rainfall events. These hydraulic characteristics interact with mechanical properties to alter stress distribution around subsurface voids. Al-Halbouni et al. (2018) demonstrated that residual material presence modifies stress concentration patterns around cavities, with stiffness contrasts between soil layers creating preferential load paths that amplify peak stresses by 15 – 40%. This coupled hydro-mechanical behaviour necessitates integrated characterization approaches that assess both strength and hydraulic parameters under field moisture conditions. This research highlights the critical need to characterize not only the strength parameters themselves but also how these parameters interact with the karst-specific hydrogeological conditions.

#### 2.4.3 Soil composition controls on blanketing layer performance

The compositional characteristics of blanketing materials, such as sediment grain size distribution, clay mineralogy, chert content, and organic matter, significantly influence geotechnical properties and susceptibility to both erosion and dissolution processes (Waltham et al., 2005). Clay-rich blanketing layers typically exhibit high cohesion but may demonstrate substantial volume change in

response to moisture fluctuations, whereas sandy or gravelly materials display low cohesion but generally maintain higher permeability (Brink, 1979). The presence of chert fragments, iron oxide cementation, and other binding agents can substantially enhance mechanical stability (Ferentinou et al., 2020). In the absence of such stabilizing components, residual layers may remain poorly consolidated with highly variable stiffness characteristics, thereby contributing to instability.

This compositional heterogeneity presents particular challenges in South African dolomitic terrains, where spatial variability in chert fragment concentration and residual dolomite (wad) content creates markedly different geotechnical conditions across short lateral distances. Some areas contain abundant angular chert fragments that provide internal reinforcement and increase shear strength, while adjacent zones may be dominated by clay-rich wad with minimal chert content and correspondingly lower bearing capacity (Waltham et al., 2005). This spatial variability in composition, often occurring over distances of meters rather than kilometres, adds significant uncertainty to stability assessments and necessitates comprehensive site-specific characterization rather than reliance on regional data.

#### 2.4.4 Hydraulic conductivity controls on blanketing layer stability

Hydraulic conductivity emerges as a parameter of complexity in environments characterized by carbonate-dolomite transition zones. This is due to its direct influence on water transmission beneath or across these overlaying layers, which subsequently has significant implications for overall stability (Waltham et al., 2005). Its interaction, in a classic example of dual controls for sinkhole risk, has important implications for sinkhole susceptibility based on whether it is low or high. A high value of this parameter, for instance, tends to facilitate rapid vadose zone saturation, which in turn has important implications for acceleration of dissolution rates at rockhead boundaries for potential internal soil erosion via particle transport in these shallow, unsaturated environments (Buttrick and Van Schalkwyk, 1998; Kleinhas et al., 1999). A clearly low value, on the other hand, tends to create conditions conducive to surface water accumulation or surface

saturation near shallow depths, thus reducing effective stress, altering soil structure, or even causing increased shallow slope failures, particularly for shallow subsidence events (Jennings et al., 1965; Brink, 1979).

Beyond absolute conductivity values, lateral contrasts in hydraulic conductivity between adjacent materials create conditions conducive to preferential groundwater flow and accelerated subsurface erosion. When high-permeability zones (such as sandy lenses or fractured horizons) are adjacent to low-permeability materials (such as clay-rich residuum), hydraulic gradients concentrate flow into the more permeable pathways, dramatically increasing flow velocities and erosive forces along these conduits (Trollip et al., 2010). Low-permeability materials such as clay-rich residuum function as effective barriers to regional-scale infiltration but inadvertently concentrate flow into specific fractures, relict dissolution features, or zones of structural weakness, creating focused erosion hotspots. In contrast, high-permeability materials permit rapid drainage but offer considerably less resistance to particle transport. Under sustained flow conditions, fine particles are progressively removed from the soil matrix in a process known as piping, whereby continuous subsurface voids or tunnels form through backward erosion along the flow path. These pipes can propagate upward toward the surface, eventually leading to sudden collapse when the remaining soil arch becomes too thin to support the overburden load (Cooper and Saunders, 2002; Waltham et al., 2005). Perrotti et al. (2021) and Park et al. (2024) emphasized that understanding these spatial patterns of hydraulic conductivity and their interaction with material strength properties remains crucial for accurate risk assessment and the development of effective mitigation strategies against sinkhole formation. This parameter thus requires characterization of both magnitude and spatial distribution within the broader hydrogeological and geotechnical context rather than evaluation in isolation.

## **2.5. Formation process of sinkholes**

### **2.5.1 Fundamental prerequisites for sinkhole development**

Sinkholes, defined as surface depressions resulting from subsurface material collapse, arise from complex interactions between natural geological processes and anthropogenic activities. Multiple researchers have established that sinkhole formation is unequivocally contingent upon three fundamental conditions being simultaneously satisfied (Buttrick, 1992; Day et al., 1999; Culshaw, 2005). These prerequisites collectively establish the foundational conceptual framework for understanding sinkhole susceptibility and risk assessment in dolomitic terrain.

First, soluble bedrock must be present. The dissolution of carbonate rocks, primarily limestone and dolomite, by carbonic acid creates interconnected subterranean voids and conduits, forming characteristic karst landscapes (Oberhelman et al., 2024). These karst environments are inherently susceptible to various geohazards, including sinkholes and ground subsidence, due to the presence of highly soluble rocks and underlying cavernous structures (Gutiérrez et al., 2014; Soltanpour et al., 2022; Bonetto et al., 2023).

Second, an overlying unconsolidated cover material must exist. This requirement relates directly to the blanketing layer discussed previously, which provides both protective functions and, paradoxically, the material that can be transported into voids (see Section 2.4; Trollip et al., 2010).

Last, a mechanism for progressive removal of cover material into bedrock voids must operate (Brink, 1979; Buttrick, 1992; Culshaw and Waltham, 2005). Dippenaar et al., (2018) emphasized that this third requirement has become increasingly critical in contemporary South African contexts, where human activities influence now dominate natural processes as the primary trigger mechanisms.

### 2.5.2 Geological controls: Bedrock depth and structural configuration

The depth to dolomite bedrock significantly influences potential sinkhole dimensions, with deeper bedrock generally associated with larger collapse features (Buttrick and Van Schalkwyk, 1998; Kleinhans and Buttrick, 2012). However, bedrock depth represents only one component of the geological control system. The structural configuration of the bedrock, including the presence of major faults, joint systems, and bedding plane orientations, exerts strong control over void distribution and preferential groundwater flow pathways (Constantinou and van Rooy, 2018).

Areas characterized by intensive fracturing and fault intersection zones exhibit elevated sinkhole susceptibility due to enhanced dissolution potential and reduced structural continuity. Such geological discontinuities facilitate concentrated water ingress, directly leading to accelerated dissolution rates within the soluble bedrock and enhanced soil erosion in the overlying blanketing layers. This relationship between structural geology and sinkhole susceptibility highlights the necessity of incorporating detailed structural mapping into risk assessment protocols, as localized high-risk zones may exist even within areas of generally favourable conditions (Buttrick et al., 2001; SANS 1936-2:2012).

### 2.5.3 Hydrogeological influences Groundwater position and fluctuation

The position of the groundwater level within the dolomite profile, particularly in relation to the overlying layer, significantly affects the vulnerability of overburden materials to subsurface erosion and, consequently, the formation of sinkholes (Buttrick, 1992; Culshaw, 2005). Materials located within the zone of groundwater fluctuation experience repeated cycles of saturation and drainage, which progressively weaken the soil structure and facilitate particle mobilization through both mechanical and chemical processes (Park et al., 2024).

Groundwater level changes, particularly declining water tables associated with dewatering, significantly accelerate natural sinkhole development processes (Buttrick, 1992; Culshaw, 2005). The Bapsfontein area provides compelling

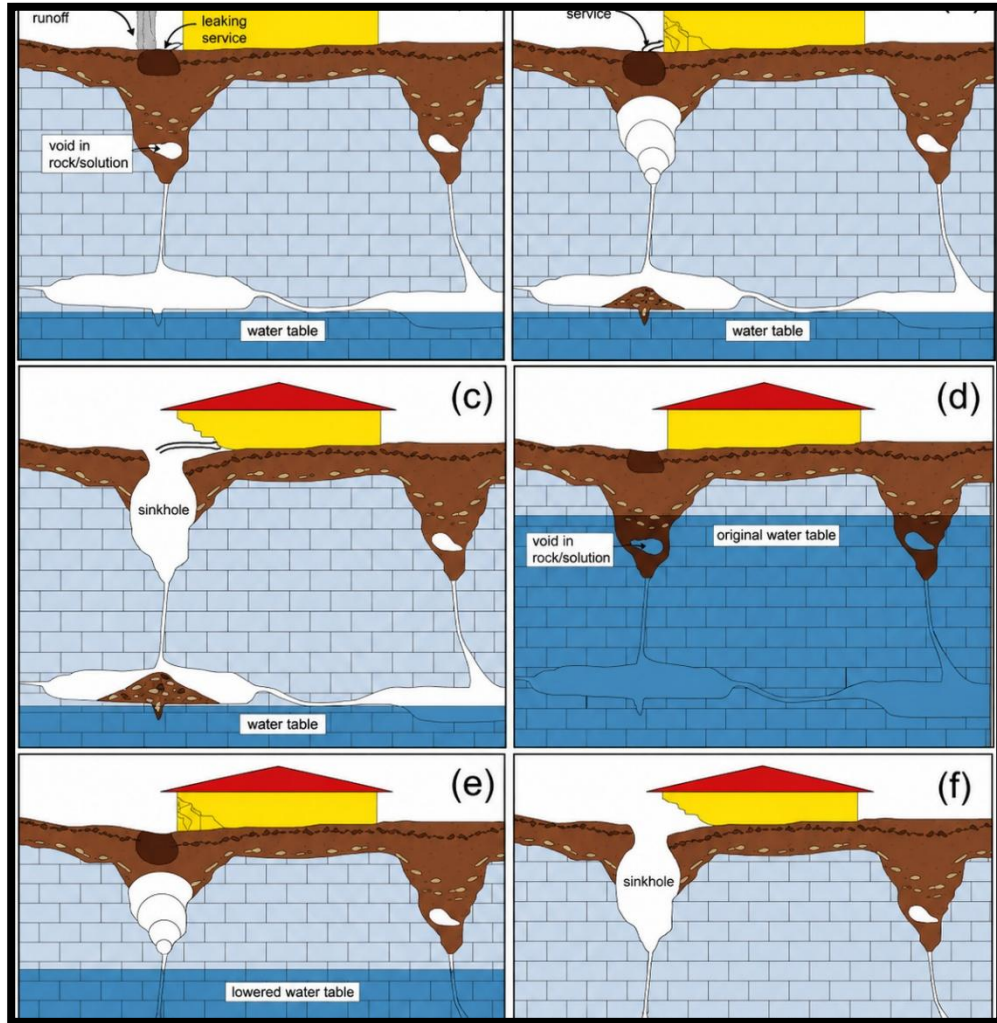
empirical evidence of this mechanism, having experienced approximately 28 new sinkholes following extensive groundwater abstraction for mining operations. The physical mechanism underlying this phenomenon involves drainage and settlement of previously saturated materials, which can cause ground subsidence and cavity roof collapse when insufficient structural support exists (Dippenaar et al., 2018; Park et al., 2024). This historical precedent established important awareness of dewatering impacts on dolomitic terrain stability.

#### 2.5.4 Triggering mechanisms of water ingress

Two principal mechanisms trigger sinkhole development in dolomitic terrain: water ingress and dewatering (Buttrick, 1992; Culshaw, 2005). While both mechanisms remain theoretically significant, contemporary research has revealed that their relative importance has shifted dramatically in modern South African contexts. Water ingress occurs when concentrated surface water infiltrates through the blanketing layer, eroding fine particles and transporting them into underlying cavities. This process is particularly prevalent in urban areas, where infrastructure failures create point sources of water introduction, generating high hydraulic gradients that drive rapid subsurface erosion (Richardson, 2013; Kleinhans, 2017).

Active subsurface erosion resulting from concentrated stormwater runoff or leaking services induces progressive material transport down available slots or fractures, culminating in material loss and void propagation toward the surface (De Waele and Gutiérrez, 2022; Park et al., 2024). The rate and extent of this process depend on water flow volumes, hydraulic gradients, soil erodibility, and the geometry of available flow pathways through the blanketing sequence (Oosthuizen and van Rooy, 2015; Liu et al., 2024). Critically, Dippenaar et al., (2018) documented that in regions like Gauteng, more than 90% of sinkholes form due to water ingress from leaking pipelines, fundamentally shifting the focus from historical dewatering concerns to contemporary infrastructure management issues. This finding has profound implications for risk mitigation strategies, as it identifies specific, controllable anthropogenic factors as the primary sinkhole

triggers in urbanized dolomitic areas. Figure 2.4 illustrates the various sinkhole formation mechanisms in dolomitic terrain, showing the interplay between water ingress (Figures 2.4a-c) and dewatering processes (Figures 2.4d-f).



**Figure 2.4:** Conceptual models of sinkhole formation mechanisms in dolomitic terrain (Adapted from Council of Geoscience, 2012)

Note in Figure 2.4, conceptual models of sinkhole formation mechanisms in dolomitic terrain showing: (a) initial stable conditions with intact blanketing layer; (b) water ingress from leaking services initiating subsurface erosion; (c) progressive void development and material transport; (d) elevated water table

conditions; (e) dewatering scenario with groundwater level decline; and (f) ultimate surface collapse and sinkhole manifestation.

## **2.6. Sinkhole characteristics and causative factor analysis**

Field data from the Centurion Central Business District (CBD) reveal distinctive patterns in sinkhole size distribution, with medium-sized features predominating in the documented inventory (Dippenaar et al., 2018; Ferentinou et al., (2020)). The most significant finding from causative factor analysis is that sinkhole formation in developed dolomitic areas is predominantly anthropogenic, with approximately 93% of documented events attributed to human-related activities (Ferentinou et al., 2020; Mndaweni, 2022). This finding contrasts with earlier conceptual models that mainly associated sinkhole occurrence with natural geological processes and groundwater dewatering related to mining activities (Buttrick and Van Schalkwyk, 1995; Constantinou and Van Rooy, 2018).

Within the anthropogenic category, leaking water-bearing services constitute the most significant trigger mechanism, accounting for approximately 40% of sinkhole occurrences. Poor stormwater management contributes 29% of recorded events, while inadequate construction practices account for 22%. In contrast, poor natural subsurface conditions and improperly sealed boreholes contribute only 7% and 2%, respectively (Ferentinou et al., 2020; Dippenaar et al., 2018). These findings identify critical intervention points for dolomite risk management and demonstrate that improved infrastructure maintenance, effective stormwater control, and appropriate construction practices can substantially reduce sinkhole occurrence in dolomitic terrain (SANS 1936-1: 2012; Mndaweni, 2022).

## **2.7. Spatial distribution of inherent hazard classifications**

In practice, the assessment of dolomitic terrain is commonly framed using the system of Inherent Hazard Classes (IHCs), also referred to as Inherent Risk Classes,

which are routinely applied in South African geotechnical investigations to provide an initial indication of sinkhole and subsidence susceptibility. This classification approach, formalized in the SANS 1936 suite of standards, is widely used by engineering geologists and geotechnical practitioners as a starting point for land-use planning, site investigation scoping, and risk-informed design on dolomite land.

The inherent hazard class assigned to a site reflects both the anticipated likelihood of instability and the expected scale of potential surface manifestation, based on geological setting, historical performance, and subsurface conditions typically encountered in similar environments. For consistency across studies, sinkhole and subsidence features are described using standardized size terminology based on the maximum diameter of surface manifestation, as set out in Table 2.1. This size-based classification is routinely used in practice to communicate the likely severity of ground movement and to contextualize potential consequences for buildings and services.

**Table 2.1:** Sinkhole size definitions

<b>Maximum diameter of surface manifestation (in m)</b>	<b>Terminology</b>
< 2	Small size
2 – 5	Medium-size
5 – 15	Large size
> 15	Very large size

Hazard distribution analysis across Centurion CBD reveals that the majority of terrain falls within Inherent Hazard Class (IHC) 2, indicating medium-hazard conditions (Oosthuizen and Van Rooy, 2015). Notably, when combined with higher hazard classifications, 70% of the area is classified as either inherently unstable or hazardous, underscoring the pervasive risk associated with development on dolomitic landscapes (Nealer, 2020).

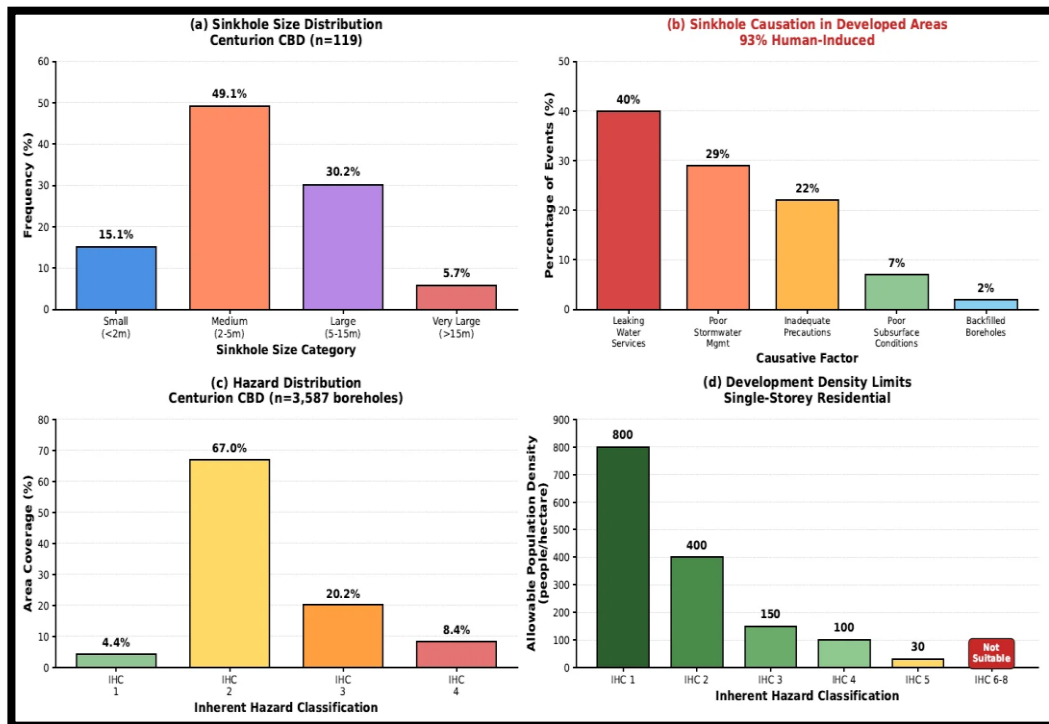
The predominance of Inherent Hazard Class (IHC) 2 terrain indicates that while development remains generally feasible across much of the area, comprehensive site investigation and appropriate engineering design measures are essential rather than optional (SANS 1936-2:2012; Buttrick et al., 2011). The substantial proportion of Inherent Hazard Class (IHC) 3 and Inherent Hazard Class (IHC) 4 terrain representing higher hazard levels underscores the critical importance of detailed geotechnical assessment prior to development approval, particularly for high-density or critical infrastructure projects (Buttrick and Van Schalkwyk, 1998; Kleinhans and Van Rooy, 2016). This empirical distribution provides planners and developers with realistic expectations regarding the challenges of dolomitic development and the necessary investment in site characterization and risk mitigation (Buttrick et al., 2001; SANS 1936-1:2012).

## **2.8. Empirically derived development density limitations**

Development density limits for single-story residential development exhibit progressive restrictions with increasing hazard classification, thereby providing quantitative guidance for land-use planning in dolomitic terrain (Buttrick et al., 2001; Oosthuizen and Van Rooy, 2015). Inherent Hazard Class (IHC) 1 terrain permits population densities of up to 800 people per hectare, reflecting minimal geotechnical constraints. Inherent Hazard Class (IHC) 2 allows 400 people per hectare, while Inherent Hazard Class (IHC) 3 restricts density to 150 people per hectare. Inherent Hazard Class (IHC) 4 terrain limits development to 100 people per hectare, and Inherent Hazard Class (IHC) 5 permits only 30 people per hectare. Terrain classified as Inherent Hazard Class (IHC) 6–8 is considered unsuitable for conventional residential development without extensive ground improvement measures (Council for Geoscience, 2010; Oosthuizen and Van Rooy, 2015).

These empirically derived density limits are based on observed performance of existing developments, sinkhole occurrence records, and dolomite risk management practices in South Africa (Buttrick and Van Schalkwyk, 1995; Buttrick

et al., 2001). The classification system provides objective criteria for land-use decision-making by ensuring that development intensity remains compatible with prevailing ground conditions and acceptable risk levels (SANS 1936-1: 2012; SANS 1936-2: 2012). Consequently, the approach represents an evidence-based framework for sustainable development and hazard mitigation in dolomitic areas. Figure 2.5 presents the empirical dataset illustrating these relationships.



**Figure 2.5:** Dolomite stability characteristics from Gauteng Province

Figure 2.5 illustrates the key stability relationships derived from empirical studies of dolomitic terrain in Gauteng Province. (a) Sinkhole size distribution showing predominance of medium-sized features (n = 119 sinkholes); (b) Sinkhole causation revealing 93% human-induced events with leaking water services as primary trigger (40%); (c) Inherent Hazard Class distribution across 3,587 boreholes showing 67% medium-hazard terrain (IHC 2); (d) Development density limits for single-storey residential development showing progressive restrictions from 800 people/hectare (IHC 1) to unsuitable classifications (IHC 6-8). Data from Oosthuizen and Van Rooy (2015).

## **2.9. Implications for development planning and risk management**

The empirical evidence from Gauteng Province demonstrates several critical findings with direct applicability to development planning strategies. First, the overwhelming predominance of human-induced sinkhole triggers, accounting for 93% of documented events in the Centurion CBD area (Constantinou and van Rooy, 2015) and up to 98% across broader Gauteng Province (Council for Geoscience, cited in Brown, 2014), indicates that most failures are preventable through proper infrastructure design, construction practices, and maintenance protocols (Buttrick et al., 2011; Richardson, 2013). These findings shift responsibility from accepting natural hazards as inevitable to actively managing anthropogenic risk factors.

Second, the concentration of causation in leaking water services and poor stormwater management identifies specific, high-impact intervention points for risk mitigation (Heath and Oosthuizen, 2008; Buttrick et al., 2011). Council for Geoscience investigations have consistently demonstrated that deteriorating infrastructure, particularly aging water-bearing services, represents the dominant trigger mechanism in urbanized dolomitic areas (Richardson, 2013; Kleinhans and Van Rooy, 2016). These are not diffuse, difficult-to-control factors but rather specific infrastructure systems that are amenable to improved design, quality control, and maintenance protocols.

Third, the quantified relationship between hazard classification and allowable development density, evidenced by progressively restrictive limits from 800 people per hectare in Inherent Hazard Class (IHC) 1 terrain to unsuitable classifications in Inherent Hazard Class (IHC) 6 – 8, provides objective criteria for land-use decision-making (SANS 1936-1:2012; Kirsten et al., 2014). This framework, codified in the Method of Scenario Supposition (Buttrick et al., 2001) and incorporated into national standards (SANS 1936-2:2012), removes subjectivity from planning decisions and enables consistent application of risk-based development controls across different geological contexts (Constantinou and van Rooy, 2015).

These findings collectively underscore the paramount importance of comprehensive site investigation (SANS 1936-2:2012), rigorous infrastructure design standards (Buttrick et al., 2011), and ongoing monitoring and maintenance programs in dolomitic areas (Kleinhans, 2017). The data also highlight that while natural geological conditions establish baseline hazard levels (Buttrick and Van Schalkwyk, 1998), human activities represent the primary trigger mechanism. This suggests that effective engineering and management interventions can substantially reduce sinkhole occurrence even in inherently hazardous terrain (Richardson, 2013; Constantinou and van Rooy, 2018), providing optimism that dolomitic development can be conducted safely with appropriate precautions.

## **2.10. Investigation methodologies for subsurface cavity detection**

Detecting underground cavities in dolomitic terrain presents significant geotechnical challenges, primarily due to inherent subsurface heterogeneity and advanced karstified complexity. A fundamental principle established through decades of South African experience is that a single investigation method proves demonstrably insufficient for comprehensive characterization of all relevant geohazards (Constantinou and Van Rooy (2018)). Consequently, integrated multi-method approaches, combining complementary techniques, have become imperative for achieving optimal and reliable characterization. The strategic selection of investigation methods must meticulously consider site-specific conditions, project requirements, budgetary constraints, and the inherent limitations of each technique.

## **2.11. Geophysical survey techniques**

### **2.11.1 Gravity surveys: Density contrast detection**

Gravity surveys represent a well-established geophysical method that precisely measures subtle variations in gravitational field of the earth arising from subsurface density contrasts (Tuckwell et al., 2008; Jacob et al., 2022; Linzer and

Linzer, 2025). Cavities, voids, or low-density weathered zones invariably generate localized gravity anomalies that can be consistently detected and mapped through systematic measurement campaigns (Tuckwell et al., 2008; Dezert et al., 2019).

The technique demonstrates significant depth penetration capability, enabling effective identification of large features at considerable depths (Butler, 1984). However, resolution inherently diminishes with increasing depth and decreasing target dimensions, representing an important constraint on applicability. Successful interpretation necessitates meticulous consideration of regional gravity gradients, terrain corrections, and potential interference from non-target density variations. The efficacy of gravity surveys is particularly enhanced when integrated with other geophysical methods, offering more robust characterization of subsurface anomalies and reducing interpretational ambiguities (Wadas et al., 2022). This complementary approach addresses the inherent limitations of individual methods while capitalizing on their respective strengths.

#### 2.11.2 Electrical resistivity tomography: Subsurface electrical properties

Electrical Resistivity Tomography (ERT) assesses the subsurface distribution of electrical resistivity by injecting current through electrode arrays and subsequently measuring potential differences. This technique produces two-dimensional or three-dimensional resistivity cross-sections revealing subsurface structure, with air-filled cavities exhibiting extremely high resistivity values relative to surrounding materials. ERT demonstrates particular effectiveness in detecting shallow to intermediate-depth voids and mapping weathering profiles (Wadas et al., 2022), establishing it as a widely applied method for investigating karst networks, sinkholes, and subsurface instabilities (Grechi et al., 2024).

However, important limitations constrain ERT applicability in certain settings. Accuracy decreases in highly resistive formations or electrically noisy environments. Urban or industrialized settings present particular challenges due to electromagnetic interference or the presence of ferroconcrete, which can disrupt measurements (Pazzi et al., 2018). Furthermore, exceptionally high

resistivity conditions or the presence of mineral-conductive layers surrounding cavities can complicate precise delineation (Baghzendani et al., 2024). These limitations necessitate careful consideration of site conditions when selecting ERT as an investigation tool and typically require integration with complementary methods for robust interpretation.

### 2.11.3 Ground-penetrating radar: High-resolution shallow imaging

Ground-Penetrating Radar (GPR) employs high-frequency electromagnetic waves to image shallow subsurface features, with reflections occurring at interfaces between materials of contrasting dielectric properties. This method excels at detecting shallow voids, bedrock irregularities, and stratigraphic variations in the upper few meters of the subsurface, making it widely applied for investigating karst networks, sinkholes, and subsurface instabilities (Grechi et al., 2024; Pazzi et al., 2018). However, GPR effectiveness is severely limited in clay-rich materials and saturated conditions due to signal attenuation.

Maximum penetration depth rarely exceeds a few metres; it is typically 10 – 15 m in highly favourable conditions restricting application in deeper investigations (Pazzi et al., 2018). Despite these limitations, GPR remains a powerful tool for accurately determining the size of anomalies in homogeneous, low-conductive media, often complementing ERT for comprehensive cavity detection (Boubaki, 2013). The method's strength lies in high-resolution imaging of shallow features, making it particularly valuable when combined with deeper-penetrating techniques in integrated investigation programs.

### **2.12. Direct investigation: Rotary percussion drilling**

Rotary percussion drilling stands as the most definitive and indispensable method for characterizing dolomitic subsurface conditions, providing continuous, direct lithological information through systematic chip recovery (Buttrick et al., 2001; SANS 1936-2:2012). This technique efficiently penetrates hard, fractured dolomite, offering irrefutable physical evidence of material composition,

weathering degree, cavity locations, and groundwater conditions (Kleinhans and Van Rooy, 2016; Constantinou and van Rooy, 2018). Standard drilling programs consistently establish blanketing layer thickness, bedrock quality, and void distribution with high confidence, thereby enabling robust quantitative hazard classification in accordance with established protocols (Buttrick et al., 2001; SANS 1936-2:2012).

Despite limitations in sample continuity compared to core drilling, the efficiency of the rotary percussion drilling in hard, fractured dolomite makes it the preferred investigation method for routine site characterization (Kleinhans, 2017). The technique provides ground-truth data against which geophysical interpretations can be calibrated, addressing a critical limitation of indirect investigation methods (Momberg et al., 2011; Kubayi et al., 2025). Integration of drilling data with geophysical surveys and near-surface investigations provides comprehensive site characterization, balancing cost, time requirements, and information quality to support engineering design and risk assessment (Buttrick et al., 2011; Kleinhans and Van Rooy, 2016). This multi-method integration represents current best practice in South African dolomitic investigations (SANS 1936-2:2012; Ferentinou et al., (2020)).

### **2.13. Regulatory framework: Hazard classification and development guidelines**

The South African National Standard 1936 (SANS 1936:1991) provides the primary regulatory framework for development on dolomitic ground in South Africa. This standard establishes a risk-based classification system that categorizes dolomite terrain into four distinct hazard designations (D1 – D4), each requiring progressively stringent precautionary measures and development controls. Sites on or near dolomite ground must have formal Dolomite Area Designations assigned to establish appropriate risk management protocols. Table 2.2 summarizes the four designation categories and their associated development

implications, based on the frameworks established by Buttrick et al. (2001) and Watermeyer et al. (2008).

**Table 2.2:** Dolomite area designations (after Buttrick et al., 2001; Watermeyer et al., 2008)

<b>Dolomite area designation</b>	<b>Description</b>
D1	Precautions do not need to be taken.
D2	Precautionary measures that are meant to stop concentrated water intrusion into the ground are needed, in compliance with SANS 1936-3 regulations.
D3	Precautionary measures in compliance with the applicable requirements of SANS 1936-3 are necessary, in addition to those related to the prevention of concentrated intrusion of water into the ground.
D4	There is little chance that the safety precautions needed to comply with SANS 1936-3 will cause a hazard that is intolerable. Precautions that are peculiar to the site are needed.

The SANS 1936 standard implements a tiered approach to risk management based on these designations. D1 areas require only standard engineering practices appropriate for stable ground conditions, representing the lowest risk category. D2 areas demand specialized precautions including adequate site investigation and foundation design consideration of potential ground instability, with particular emphasis on comprehensive geotechnical investigation, foundation systems capable of accommodating differential movement, and provision for ongoing monitoring. D3 areas require enhanced measures beyond those mandated for D2 sites, necessitating more intensive investigation protocols and sophisticated foundation solutions to address elevated sinkhole risk. The guidelines specifically emphasize preventing concentrated water intrusion into

the ground as a critical risk mitigation measure across D2 and D3 designations, recognizing the role of water infiltration in triggering dolomite subsidence.

D4 areas are deemed unsuitable for conventional development without extensive ground treatment or specialized foundation solutions, as the inherent risk for mobilization of the blanketing layer and potential sinkholes on such sites cannot be adequately managed through standard precautionary measures alone.

The framework incorporates eight Inherent Hazard Classes (IHC), providing finer gradation of risk levels (Department of Public Works, 2017). Inherent Hazard Class (IHC) designations are determined primarily by blanketing layer thickness, bedrock conditions, and groundwater level position, with classification protocols well-established through decades of experience in South African dolomitic terrain. These classification systems enable systematic risk assessment and provide objective criteria for determining appropriate foundation measures, development density limits, and infrastructure design standards.

The SANS 1936 framework represents a culmination of South African expertise in dolomitic development, codifying best practices into enforceable standards that balance development needs with safety requirements. The likelihood of a sinkhole or subsidence happening increases with the Inherent Hazard Class number, as does the potential size of the feature should it materialize. Table 2.3 displays the definition for every Inherent Hazard Class.

**Table 2.3:** Description of classes and associated risk (after Buttrick et al., 2001; Watermeyer et al., 2008)

<b>Class</b>	<b>Description of expected risk</b>	<b>General foundation recommendation</b>
Class 1 Regions	Regions where there is a minimal inherent risk of sinkhole and doline formation (of all sizes) due to water intrusion	Suitable for most types of construction, Shallow foundations with proper drainage, Minimal ground preparation required

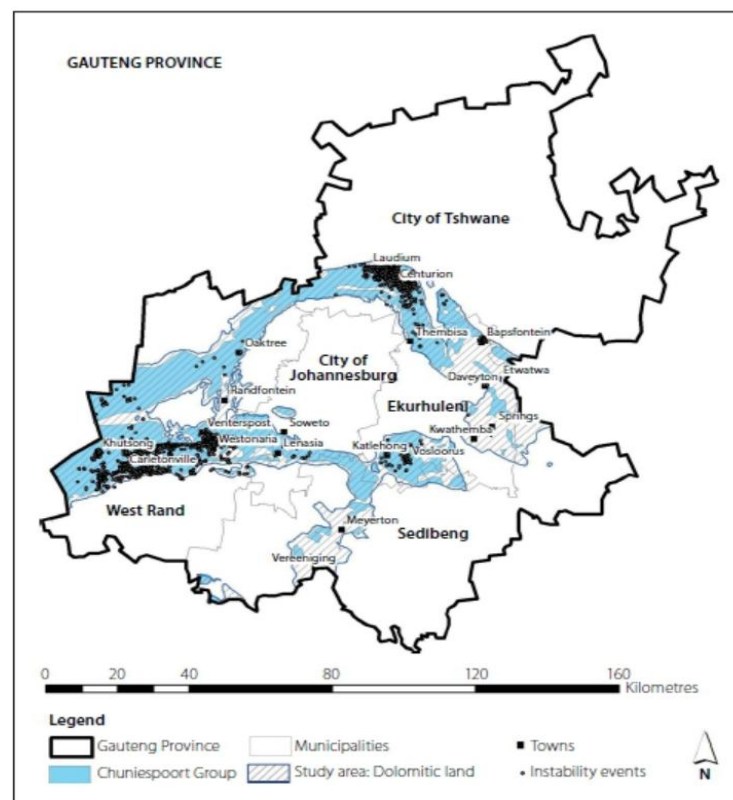
Class 2 Regions	Regions classified as having a medium inherent risk of developing dolines and small sinkholes due to water intrusion	Consider deeper foundations, Implement periodic monitoring for ground movement
Class 3 Regions	Areas characterized as reflecting a medium Inherent Risk of medium sinkhole and doline formation with respect to ingress of water	Employ reinforced foundations, Implement ground stabilization measures
Class 4 Regions	Regions that, in terms of water intrusion, are classified as having a medium inherent risk of major sinkhole and doline formation	Use pile foundations for increased stability, Conduct thorough geological surveys
Class 5 Regions	Regions that are classified as having a high inherent risk of small sinkhole and doline formation (of all sizes) due to water intrusion	Avoid major constructions. Implement ground reinforcement techniques
Class 6 Areas	Regions that are classified as having a high inherent risk of developing dolines and medium-sized sinkholes due to water intrusion	Implement deep foundations with extensive reinforcement, Continuous ground monitoring and maintenance required
Class 7 Areas	Regions that are classified as having a high inherent risk of developing dolines and sinkholes due to water intrusion	Utilize specialized engineering solutions, Develop emergency response plans
Class 8 Areas	Regions that are classified as having a high inherent risk of developing dolines and sinkholes of considerable size due to water intrusion	Conduct detailed risk assessment before construction, Consider alternative site locations if possible

## 2.14. Regional geological context: the Centurion study area

### 2.14.1 Regional geological setting

Centurion is situated within the broader Transvaal Supergroup, characterized by extensive dolomitic rock formations notorious for susceptibility to karst processes and associated geohazards (Brink, 1979; Ford and Williams, 2007). The study area lies within the Centurion dolomitic compartment, bounded by major geological structures that influence groundwater flow patterns and void distribution.

The spatial extent of dolomite occurrence in Gauteng Province is shown in Figure 2.6, illustrating the widespread distribution of potentially hazardous terrain across the region. As depicted in the figure, Centurion falls within one of the major dolomitic belts in Gauteng, positioned among municipalities including the City of Tshwane, City of Johannesburg, and Ekurhuleni, where historical instability events have been documented. This regional context places the Cornwall Hill study site within a well-established zone of dolomite-related geotechnical concern.



**Figure 2.6:** Distribution of dolomitic land in Gauteng Province – Municipal boundaries, study area location, and recorded instability events are also shown

Figure 2.6 illustrates the extensive dolomite occurrence across the Gauteng Dolomitic Group and Chuniespoort Group formations. Regional geological mapping reveals complex structural relationships including fault systems, dolerite intrusions, and contact zones that substantially influence local geotechnical conditions (Council for Geoscience, 2012; Martini et al., 2001). Understanding this regional context provides essential framework for interpreting site-specific investigations and recognizing patterns of hazard distribution (Buttrick and Van Schalkwyk, 1998; Constantinou and Van Rooy, 2018). These structural features control groundwater compartmentalization and preferential dissolution pathways, directly affecting sinkhole susceptibility at the local scale.

#### 2.14.2 Lithostratigraphic complexity of dolomitic formations

Dolomitic formations, particularly those of the Chuniespoort Group, exhibit complex petrographic composition characterized by interbedded chert layers and nodules. This inherent heterogeneity significantly contributes to highly variable weathering susceptibility and unpredictable geotechnical behaviour. The local stratigraphy comprises multiple dolomite units with distinctly different geotechnical properties, often separated by chert marker horizons that critically affect groundwater flow and dissolution patterns, thereby directly impacting karstic development potential and associated geohazards such as sinkhole formation (Dippenaar et al., 2018).

This profound stratigraphic and petrographic complexity necessitates detailed investigation programs to accurately delineate unit boundaries, precisely characterise property variations, and enable robust risk assessment. The variability inherent in these formations means that conditions can change dramatically over short distances, requiring high-density investigation programs and conservative application of site characterization data. This geological complexity represents one of the fundamental challenges in dolomitic development, as it introduces substantial uncertainty even with comprehensive investigation programs.

### 2.14.3 Hydrogeological regime and dynamic conditions

The hydrogeological regime in dolomitic terrains, such as Centurion, is characterized by highly complex groundwater flow paths, fundamentally shaped by extensive secondary porosity resulting from dissolution processes. These intricate pathways directly influence terrain susceptibility to geohazards, particularly sinkhole formation. The regional aquifer system exhibits significant variability in water table depths, marked seasonal fluctuation patterns, and frequent occurrence of localized perched water conditions, all critically impacting geotechnical stability.

Historical groundwater level trends reveal dynamic shifts: long-term declines in some areas due to abstraction pressures contrast with rising water tables in other localities, often driven by urban recharge from leaking infrastructure. These highly dynamic and often unpredictable hydrogeological conditions, especially concentrated water ingress exacerbated by urban development and inadequate stormwater management, are now recognized as primary triggers for sinkhole occurrences in regions like Gauteng (Dippenaar et al., 2018). Continuous monitoring is essential to assess and mitigate evolving risk profiles inherent to dolomitic development, as changes in groundwater conditions can rapidly alter stability conditions across affected areas.

### 2.14.4 Knowledge gaps and research imperatives

Numerous geotechnical investigations conducted in Centurion have established a comprehensive database of subsurface conditions, documented sinkhole occurrence patterns, and validated hazard classification methodologies. These investigations provide crucial baseline data for comparative analysis and help identify temporal trends in hazard distribution and development effects on geotechnical stability. However, despite extensive efforts, critical gaps in understanding persist regarding exact processes by which water infiltrates and erodes overlying material into subsurface voids.

This gap in knowledge assumes particular significance because these processes account for a substantial majority of recorded sinkholes in regions like Gauteng, directly impacting infrastructure stability and public safety. Comprehensive understanding of water movement through the unsaturated zone in karstic dolomites has become essential, especially since recent sinkhole occurrences in South Africa are primarily attributed to concentrated water ingress frequently exacerbated by urban development and inadequate stormwater management rather than historical mine dewatering scenarios (Dippenaar et al., 2018).

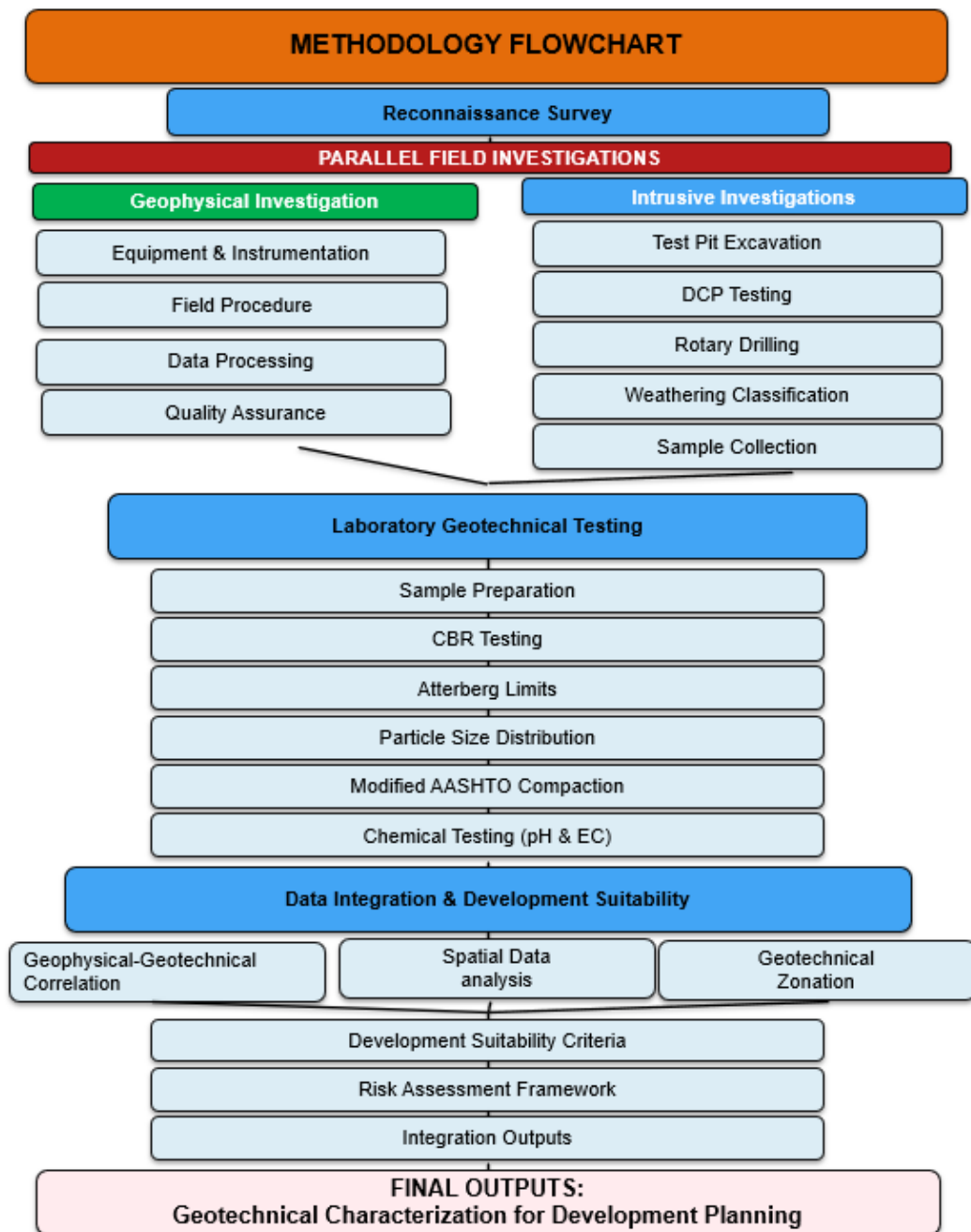
Addressing this research imperative is vital for developing more effective risk mitigation strategies and ensuring sustainable development in dolomitic regions. This highlights the necessity for advanced vadose zone assessment protocols that account for unique hydrogeological and geotechnical properties of dolomitic karst systems, which differ fundamentally from non-karst systems. Future research must focus on quantifying vadose zone flow processes, understanding particle transport mechanisms during water ingress events, and developing predictive models that can identify high-risk conditions before surface failure occurs. Such advances would enable transition from reactive response to sinkhole formation toward proactive identification and mitigation of hazardous conditions.

## **Chapter 3. Research methodology**

### **3.1. Introduction**

This chapter presents the methodology employed to characterize the geotechnical properties of dolomitic terrain in Centurion, Gauteng Province, South Africa. The study adopts an integrated multi-method approach combining geophysical surveys, intrusive ground investigations, and laboratory testing to achieve comprehensive site characterization for development planning purposes. The methodology directly addresses the research aim by systematically evaluating subsurface conditions, identifying dissolution features, and assessing foundation suitability on dolomitic land. Each investigative method is described in detail, including equipment specifications, field procedures, applicable standards, and quality control measures implemented throughout the investigation. The methodology follows South African National Standards for dolomite land development (SANS 1936-2:2012) and adheres to international best practices for geotechnical site investigation (SANS 633:2009; SAICE, 2009).

This structured approach ensures systematic addressing of all research objectives with clear traceability between objectives and methods, ultimately supporting the provision of reliable geotechnical data for informed development planning in dolomitic terrain. The methodology flowchart presented in Figure 3.1 illustrates the sequential flow and integration of the various investigative components.



**Figure 3.1:** Methodology flowchart showing the integrated investigation approach for dolomitic terrain characterization at Cornwall Hill

## **3.2. Presentation of the study area**

### **3.2.1 Location and extent**

The study area is located in Centurion, Gauteng Province, South Africa, within the Tshwane Metropolitan Municipality. Centurion forms part of the larger Pretoria-Witwatersrand-Vereeniging metroplex and occupies a strategic position along the N1 highway corridor connecting Johannesburg and Pretoria. The site is situated within the Chuniespoort Group dolomites of the Transvaal Supergroup, which underlie extensive portions of southern Gauteng (Eriksson et al., 2006).

### **3.2.2 Regional geological setting**

The study area lies within the southern portion of the Transvaal Basin, underlain by Malmani Subgroup dolomites of Archaean to Proterozoic age (approximately 2.6 to 2.5 billion years old). These carbonate rocks, comprising primarily of dolomite [ $\text{CaMg}(\text{CO}_3)_2$ ] with subordinate limestone and chert bands. They are characterized by extensive karstification resulting from prolonged chemical weathering and groundwater circulation (Brink, 1979). The karstification process has created a terrain highly susceptible to subsidence and sinkhole formation, presenting significant geotechnical challenges for infrastructure development (Ford and Williams, 2007).

The dolomite bedrock is overlain by a variable thickness blanketing layer consisting of residual soils, transported materials, and weathered rock. This blanketing layer plays a critical role in the stability of dolomitic terrain, as it provides founding support for infrastructure while simultaneously being prone to collapse into underlying cavities (Day and Wagener, 2010).

### **3.2.3 Topography and drainage**

The site exhibits gently undulating topography typical of dolomitic terrain, with localized depressions and mounds reflecting differential weathering of the underlying bedrock. Surface gradients are generally mild, facilitating natural drainage toward local drainage lines. However, the presence of karstified dolomite

beneath creates complex subsurface drainage patterns independent of surface topography.

Surface water management is a critical consideration in dolomitic terrain due to the risk of sinkholes triggering by concentrated water infiltration. Leaking water infrastructure, ponding, or uncontrolled surface runoff can lead to erosion of blanketing materials into subsurface voids, potentially causing catastrophic collapse (Day, 1988). The regional groundwater table depth varies seasonally and is influenced by both natural recharge and anthropogenic factors, including urban water distribution systems and wastewater infrastructure.

### **3.3. Reconnaissance survey**

A reconnaissance survey was conducted to obtain an initial on-site understanding of surface conditions, access constraints, and features that could influence the planning and execution of subsequent geophysical and geotechnical investigations. Reconnaissance surveys form a routine component of geotechnical practice and are used to familiarise the investigator with site conditions that may not be fully captured through desktop data alone (Brink and Bruin, 2002; SAICE, 2009).

In this study, the reconnaissance survey played a critical role in identifying physical obstacles that could interfere with borehole drilling, equipment setup, and gravity survey execution. It also provided an opportunity to become familiar with the study area and evaluate conditions that could affect data collection. Key observations included the general terrain morphology, evidence of previous slope instabilities, the presence of surface water bodies, vegetation cover, and man-made structures. These insights were essential for refining the fieldwork strategy, optimizing equipment placement, and ensuring the safety and effectiveness of on-site activities. The findings from the reconnaissance survey informed the planning of subsequent fieldwork investigations described in the following sections.

### **3.4. Geophysical investigation**

The primary objective of the gravity survey was to identify possible subsurface anomalies, specifically cavities, sinkholes, and zones of low density, which are commonly associated with karstic features in dolomitic terrain (Tucker and Smith, 2020). These anomalies pose significant geotechnical risks, including ground instability and subsidence, which must be assessed before infrastructure development. A systematic grid layout with a spacing of 50 m by 50 m was employed to provide suitable resolution for identifying subsurface density variations at the site scale. While higher resolution surveys (10 – 30m spacing) are optimal for detailed cavity detection, the 50m grid spacing was selected to balance comprehensive site coverage with practical survey constraints and has proven effective for identifying significant karstic features in dolomitic terrain (Nabighian et al., 2005; Hinze et al., 2013).

#### **3.4.1 Equipment and instrumentation**

A Scintrex CG-5 Autograv gravimeter was used to measure gravity variations at each survey point (Figure 3.2). The CG-5 is a relative gravimeter that uses a quartz spring and an electrostatic system to measure changes in gravity. When gravity varies, the force on an internal mass changes, which the instrument balances with an electric force and records in microGals. Its high stability and low drift make it suitable for microgravity surveys targeting shallow subsurface features such as sinkholes and unstable ground (Table 3.1). Sinkholes typically produce gravity anomalies of only a few hundred microGals or less (Tuckwell et al., 2008), requiring instruments with high sensitivity and repeatability, which the CG-5 provides.



**Figure 3.2:** Scintrex CG-5 Autograv gravimeter (Scintrex Limited, 2018)

The gravimeter was factory-calibrated with a manufacturer-supplied calibration factor linking the electrostatic signal to gravity values. However, the scale factor and drift of the CG-5 can change over time, particularly after transport (Sermiagin et al., 2024). To manage drift, a base station was established on stable ground and measured at the start of each day and at regular intervals. These repeated readings allowed drift tracking and correction during data processing, following standard microgravity procedures (Tuckwell et al., 2008; Sermiagin et al., 2024).

At each grid point, the gravimeter was levelled on a tripod using built-in tilt sensors and allowed to stabilise before measurement. Multiple readings were taken at each point to reduce noise and verify repeatability. The CG-5 automatically corrected for Earth tides, tilt, temperature, and seismic noise. Readings affected by vibration were rejected and repeated. The instrument recorded corrected gravity values, along with timing and standard deviation data, following standard CG-5 protocols (Sermiagin et al., 2024). The final dataset provided quality gravity measurements suitable for identifying anomalies associated with sinkholes and weak ground (Table 3.1).

**Table 3.1:** CG-5 specifications

Parameter	Specification	Relevance to sinkhole surveys
Sensor type	Fused quartz spring with electrostatic nulling	Provides stable measurements of very small gravity variations caused by voids and weakened ground
Measurement resolution	1 $\mu$ Gal	Required to resolve low-amplitude gravity lows associated with sinkholes
Field repeatability	< 5 $\mu$ Gal	Ensures consistent station values, as required in microgravity case studies (Tuckwell et al., 2008)
Long-term drift	< 0.02 mGal/day	Allows reliable daily surveys using base-station drift correction
Automated corrections	Earth tides, tilt, temperature, seismic noise	Removes non-geological effects that can mask shallow anomalies
Tilt compensation	$\pm$ 200 arc-seconds	Reduces errors from uneven ground common in karst terrain
Data recording	Digital storage of corrected gravity and statistics	Allows quality control and rejection of noisy readings
Portability	$\sim$ 8 kg, self-contained	Enables dense station spacing required for sinkhole surveys

In conjunction with the gravimeter, a Trimble DGPS (Figure 3.2) was utilized to acquire precise spatial coordinates, including latitude, longitude, and elevation, for each gravity station. The elevation data were particularly crucial for calculating free-air and Bouguer corrections, thereby ensuring that observed gravity anomalies were accurately referenced to the site's topography (Van der Westhuizen et al., 2019). The integration of DGPS technology provided centimetre-level accuracy, which significantly improved terrain correction models.



**Figure 3.3:** Trimble Differential GPS (DGPS) system

#### 3.4.2 Field setup and positioning for gravity measurements

To ensure uniform spatial coverage, a physical survey grid was established across the site, with gravity stations spaced at 50 m intervals. The position and elevation of each station were recorded using a Trimble DGPS system with an accuracy of approximately  $\pm 5$  m to achieve the positional precision required for gravity data corrections.

The DGPS base station was installed at a fixed reference point with clear satellite visibility and operated continuously during the survey. A rover unit was used to capture corrected coordinates at each gravity station, with the antenna positioned directly above the gravimeter location. Differential corrections were applied in real

time, and antenna heights were measured to allow accurate ground-level elevation adjustments. Satellite geometry and signal quality were monitored throughout the survey, and any stations with inadequate accuracy were re-measured. Following fieldwork, GPS data were downloaded and post-processed to confirm positional consistency. The final coordinates were used to apply elevation-dependent gravity corrections, including free-air and Bouguer corrections.

Gravity measurements were recorded at each station using a gravimeter in accordance with standard field procedures (Lowrie, 2007). Data quality was maintained through duplicate readings at selected stations, measurements conducted under stable weather conditions, and detailed field notes documenting surface conditions and potential sources of interference. A gravity base station was established within the survey area to allow regular drift corrections, accounting for temporal variations in the gravimeter and improving overall data accuracy (Telford et al., 1990).

#### 3.4.3 Data processing and corrections

Raw gravity data underwent several corrections to enhance precision and reliability. Drift correction was applied to compensate for gradual changes in gravimeter sensitivity. Free-air and Bouguer corrections were performed to adjust for gravity variations due to elevation differences and uniform subsurface masses, respectively (Hofmann-Wellenhof and Moritz, 2005).

Topographic corrections were incorporated using DGPS-derived elevation data to refine the gravity anomaly interpretation. The processed data were then used to generate Bouguer anomaly maps, which highlight density variations within the subsurface. These maps served as the primary tool for delineating potential geotechnical risks such as voids and loosened zones (Blakely, 1995).

#### 3.4.4 Quality assurance

To ensure the reliability of the collected data, several quality control measures were implemented:

- Duplicate readings were taken at critical grid points to assess consistency.
- Daily field data reviews helped identify errors promptly.
- Anomalous data points were revisited and re-measured where necessary to confirm findings.

By implementing these rigorous methodological steps, the survey results were optimized to provide a detailed and reproducible assessment of subsurface anomalies in the study area.

### 3.5. Intrusive geotechnical investigations

This section covers Intrusive Geotechnical Investigations, which include methods such as test pits and drilling to assess soil layers and weathering patterns. To accomplish this, a structured field investigation program was carried out. Figure 3.4 below illustrates the layout of the Test Pit positions.



**Figure 3.4:** Layout and position of the test pit

Aerial photograph showing the spatial distribution of test pit locations (TP1-TP5) across the study area. The site boundary is delineated in red. Test pits were strategically positioned to investigate different gravity anomaly zones and provide

comprehensive spatial coverage for subsurface characterization. Base imagery: Google Earth.

### 3.5.1 Test pit excavation and soil profiling

As depicted in Figure 3.5, test pits were dug using a Tractor Loader Backhoe (TLB) to thoroughly inspect the conditions of the near-surface soil, groundwater, and bedrock (Jennings et al., 1973). These excavations allowed direct observation and recording of soil stratigraphy, detailing layer thicknesses, boundaries, and transitions between horizons. The excavations also enabled characterization of the weathering profile from the topsoil down to the bedrock or the point of refusal.



**Figure 3.5:** Excavation of the test pit

The layout of the pits was carefully planned, with positions and dimensions marked on the ground. Pit widths were measured as 0.75 m, which is the size of the TLB Bucket. Depths ranged from 1 to 3 m or refusal. Safety precautions were strictly observed during excavation. To prevent collapse, pit sides were appropriately sloped or shored. Access and egress were facilitated using ladders or other suitable

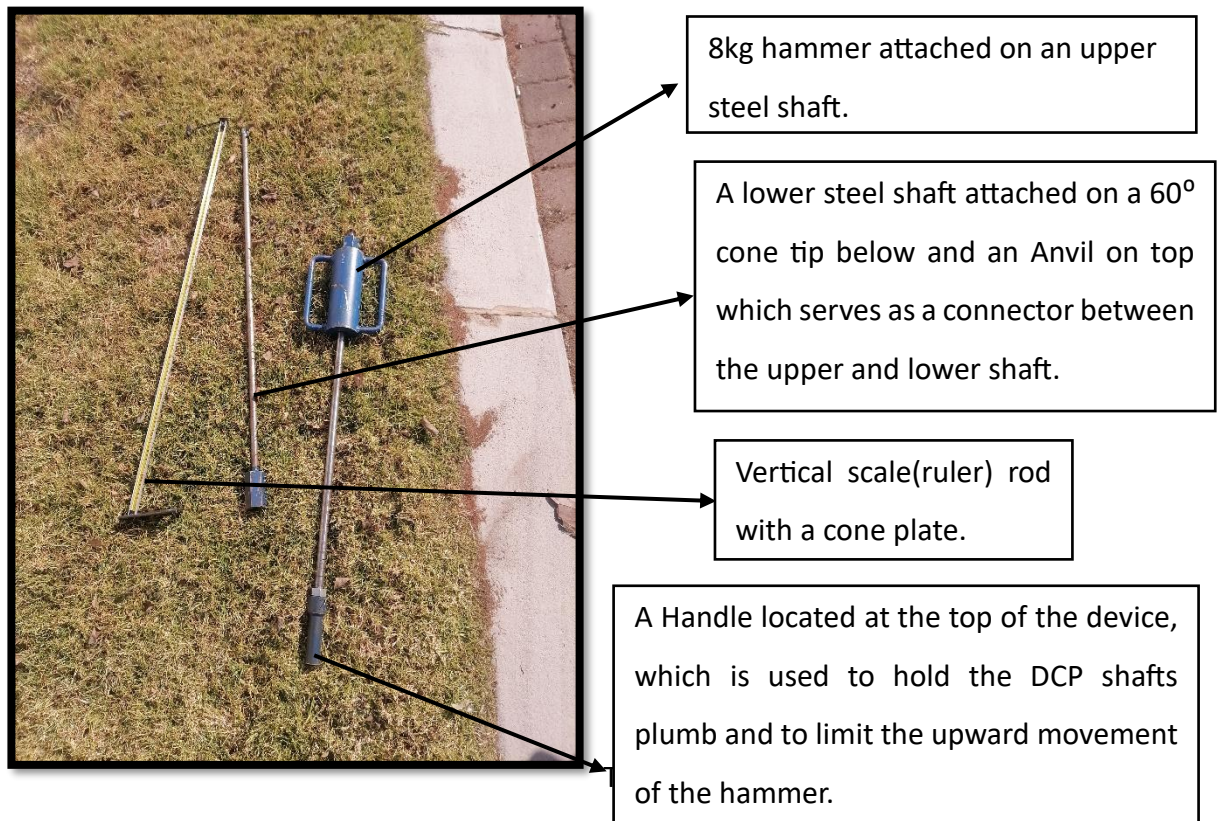
measures to ensure worker safety. Upon completion of sampling and inspection, the pits were backfilled with excavated material. Soil was compacted in layers to restore the site to its original condition, ensuring proper closure of the pits.

### 3.5.2 Dynamic cone penetrometer testing

Although the research objectives did not specifically mention Dynamic Cone Penetrometer (DCP) testing, it was incorporated as an additional in-situ test to support the intrusive investigation program. The DCP offers continuous profiles of penetration resistance, which help to fill the gaps between the widely spaced test pits and boreholes, thereby improving the spatial characterization of near-surface soil strength (Amir et al., 2021).

The DCP is a straightforward tool for determining soil characteristics in situ, offering advantages in cost-effectiveness and speed compared to traditional methods of soil boring and geotechnical research. It is particularly useful for studying soil layers when the necessary depth is not too large. The Dynamic Cone Penetrometer used in this research conformed to ASTM standard D 6951-18. The device consisted of a 15.8 mm diameter steel rod attached to a cone with a 20-mm base diameter and 60-degree cone angle. The device was driven into the soil by successive blows of the 8 kg hammer, falling from a height of 575 mm.

Figure 3.6 shows the DCP equipment configuration used in this investigation. The device comprises four main components: an 8 kg hammer attached to an upper steel shaft, a lower steel shaft with a 60° cone tip and anvil connector between the upper and lower shafts, a vertical scale (ruler) rod with cone plate for measuring penetration depth, and a handle at the top for maintaining vertical alignment and limiting upward hammer movement during operation.



**Figure 3.6:** Dynamic Cone Penetrometer (DCP) equipment showing the main components: 8 kg hammer on upper shaft, lower shaft with 60° cone tip and anvil connector, vertical measuring scale with cone plate, and top handle for operational control

In terms of test procedure, conducting a DCP test involves raising and dropping the hammer to drive the cone on the lower shaft through the ground. After each hammer blow, the penetration of the cone is measured and recorded. Each test takes approximately 5 to 10 min but may take up to 20 or 30 min if the ground is hard.

#### Step by step

- Record the coordinates.
- Place your DCP vertical on the ground at the DCP station.
- Raise the hammer to its upper limit and let it fall freely to strike the anvil.  
(Using the caution to not lift the shaft and break the contact between the

cone and the ground. Be careful not to influence the drop by forcing the hammer down or gripping the upper handle too tight).

- Record the penetration following each hammer drop by recording the reading and blow count by reading the shaft to the nearest 0.1 m. Record it as penetration for blow number 1.
- Repeat the procedure until the cone is driven to the full depth of the lower shaft.
- Blow for consecutive drops until it reaches 38 drops or blows, as that is recorded as refusal.
- If the lower shaft has penetrated full depth, remove the DCP from the hole. Move to the next DCP station. If done, wipe off the upper and lower shafts and inspect the cone for any damage. Disassemble and pack it nicely in its bag.



**Figure 3.7:** Dynamic Cone Penetrometer test

DCP tests were conducted at multiple points across the site to assess soil resistance, stability, and compaction characteristics (Figure 3.7). The standardized cone attached to a steel rod was driven into the ground using a standard weight

dropped from a specific height. The number of blows required for each 100 mm penetration increment was recorded at varying depths to capture vertical soil variations. Real-time data logging enabled accurate measurement of penetration resistance at each depth, with results analysed to identify stability patterns and potential zones of weakness.

### 3.5.3 Rotary percussion drilling

Rotary percussion drilling is a subsurface investigation technique that combines rotary grinding and high-frequency percussive impacts to penetrate hard rock formations such as dolomite (Day and Wagener, 2010; Buttrick, 1992). This method was selected for its efficiency in drilling through competent geological materials and for producing accurate subsurface profiles in challenging ground conditions. The primary objective of employing this method was to assess dolomitic ground conditions and identify cavities, voids, or unstable zones that could pose a geotechnical risk to future development.



**Figure 3.8:** Rotary-percussion drilling

Four (4) rotary percussion boreholes were drilled by JK Drilling (Pty) Ltd using a percussion drilling rig equipped with a 165 mm down-the-hole (DTH) hammer operated with an 18 bar, 27.6 m<sup>3</sup>/min air compressor. The rotary percussion drilling method combines rotary motion with percussive hammering to penetrate hard rock formations. Compressed air was used to operate the hammer mechanism and flush cuttings from the borehole to maintain a clear drilling path.

The number and positions of the boreholes were informed by the gravity survey results and strategically selected to investigate gravity highs, lows, and intermediate zones across the site. This approach ensured representative subsurface coverage and allowed correlation between geophysical anomalies and intrusive investigation results.

The process involved transmitting energy pneumatically through the drill rod to the bit, resulting in a repeated hammering motion that dislodged rock. Simultaneously, the drill bit rotated at approximately 10–30 rpm, forming a straight, circular hole. The holes were terminated at depths of 25 m, 11 m, 10 m, and 11 m respectively, based on geotechnical refusal.

Drilling was conducted in accordance with the SANS 633:2009 and SANS 1936-2:2012 standards. Chip samples were collected at 1 m intervals and retained for lithological logging. These were supported by the driller's logs to construct geological profiles for each borehole, following the procedures outlined in the (Brink and Bruin, 1990)

Chip logging and lithological profiling at 1-m intervals enabled detailed characterization of the weathering profile and stratigraphic succession. Weathering grades were classified following the procedures proposed by Brink and Bruin (1990), with particular attention to the transition from residual soils through partially weathered dolomite to competent bedrock.

Twenty-four hours after the completion of drilling, all boreholes were dipped to determine the depth to the groundwater table. After this hydrogeological assessment, the boreholes were backfilled using in-situ material, and a concrete

plug was installed to seal the boreholes as per standard practice and environmental safety requirements. This method proved effective in achieving the investigation objectives, ensuring accurate characterization of the dolomitic subsurface and enabling informed geotechnical analysis for future land-use planning.

#### 3.5.4 Weathering profile classification

All intrusive investigations included systematic documentation of weathering profiles. The weathering classification system adopted for this study follows the (Brink and Bruin, 1990), which recognizes six weathering grades:

- **Grade VI:** Residual soil (completely weathered)
- **Grade V:** Completely weathered rock (rock structure destroyed)
- **Grade IV:** Highly weathered rock (>50% rock mass decomposed)
- **Grade III:** Moderately weathered rock (staining and discoloration)
- **Grade II:** Slightly weathered rock (slight staining on discontinuities)
- **Grade I:** Fresh rock (no visible weathering)

Each test pit and borehole log included weathering grade designations, enabling three-dimensional reconstruction of the weathering profile across the site. This systematic approach ensured that soil stratigraphy and weathering profiles were comprehensively determined (Trollip et al, 2010; Day and Wagener, 2010).

Weathering boundaries were identified by:

- Changes in rock colour and texture
- Degree of decomposition and friability
- Preservation of rock structure
- Ease of excavation or drilling
- Moisture conditions

Documentation included:

- Depth of each weathering grade transition
- Thickness of each weathering zone

- Lateral variations observed between investigation points
- Photographic evidence of weathering features

### 3.5.5 Sample collection and preservation

To assess the geotechnical characteristics of soils within the study area, a systematic sampling approach was employed during fieldwork following the excavation of test pits. The objective was to collect representative foundation indicator and California Bearing Ratio (CBR) samples for laboratory analysis, which are essential for evaluating soil suitability for infrastructure development on dolomitic land. No rock samples were collected, as the investigation focused solely on soil profiling and rotary percussion borehole drilling.



**Figure 3.9:** Chip logging and soil sampling

After the excavation of test pits to the desired depth typically between 1.5 m and 3 m undisturbed soil layers were visually inspected and logged according to the (Brink and Bruin, 1990). Samples were collected from natural soil horizons free of contamination, organic matter, or inclusions.

For foundation indicator tests, which include Atterberg limits, particle size distribution, linear shrinkage, and hydrometer analysis, a minimum of 5 kg of soil was collected from each relevant soil horizon. The samples were extracted using a hand shovel or spade, ensuring that material was taken from the full depth and width of the horizon to obtain a representative sample. The soil was placed into

clean, labelled plastic bags with detailed information, including GPS coordinates, depth, soil description, and date of collection.

For CBR testing, which requires a larger volume of material due to compaction and penetration resistance testing, a minimum of 80 kg of soil was collected. This sample was taken from the same test pits but from zones that exhibited homogenous soil conditions typical of anticipated founding levels. The soil was extracted manually and placed into large, clean polypropylene sacks or containers. Care was taken to avoid mixing materials from different layers or disturbed areas.

All samples were sealed, clearly labelled, and transported to an accredited geotechnical laboratory under standard protocols to prevent moisture loss or contamination. The sampling and handling procedures adhered to the specifications outlined in SANS 3001 GR series and TMH1 (Department of Transport, 1986) to ensure data integrity and reproducibility of results.

Chip logging was conducted to create a detailed subsurface geological record. As drilling progressed, dolomite chips (cuttings) were brought to the surface by the drilling fluid and collected at regular depth intervals of every 1 m. These cuttings were washed to remove drilling fluid and fine particles, air-dried, and then sieved to sort by size. Observations were systematically recorded in a chip log, with detailed descriptions and photographs of the cuttings at each depth interval, serving as a comprehensive record of the subsurface geological conditions. Processed cuttings were stored in labelled chip trays, each compartment corresponding to a specific depth interval, and securely stored for future reference.

### **3.6. Laboratory testing for soil classification and foundation assessment**

The laboratory testing programme was designed in accordance with the SANS 3001 series and relevant geotechnical testing standards. The selection of tests was guided by the anticipated subsurface soil conditions, the engineering requirements for foundation design on dolomitic land, and the need to classify the

soil materials and evaluate their behaviour under anticipated field loading conditions.

The primary aim of the laboratory testing was to determine key foundation indicator properties and bearing characteristics of the near-surface materials. These parameters are essential for assessing the engineering suitability of the soils for supporting infrastructure and for identifying potential dolomitic risks associated with collapsible or expansive soil behaviour (Das, 2010; Bowles, 1996).

The laboratory testing programme was designed in accordance with the guidelines outlined in SANS 3001 series and relevant geotechnical testing standards. The tests were selected based on the anticipated soil conditions, engineering requirements, and the need to classify and assess the material behaviour under field and loading conditions. The results of these tests provided critical input into the foundation design, site classification, and evaluation of ground improvement requirements.

Nine laboratory tests were performed on the bulk samples obtained from test pits to examine their geotechnical properties. These tests included:

- Three (3) Atterberg Limit tests to determine the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), which aid in the classification of fine-grained soils and evaluation of their plasticity and compressibility.
- Three (3) particle size analyses for grading, performed by mechanical sieving and hydrometer methods to assess the distribution of coarse and fine particles, essential for determining soil classification and compaction characteristics.
- Two (2) Modified AASHTO (MOD AASHTO) compaction tests, to evaluate the maximum dry density and optimum moisture content of the soils for compaction control.
- Two (2) CBR tests, conducted on samples compacted to MOD AASHTO specifications, to assess the strength and bearing capacity of the in-situ materials for pavement and subgrade design.

- One (1) pH and Electrical Conductivity (EC) test, to evaluate the chemical aggressiveness of the soil towards buried concrete and metal infrastructure, this additional test is essential for comprehensive development planning assessment on dolomitic terrain, as sulphates and acidic conditions common in dolomite residual soils can severely affect foundation durability (Schwartz and Yates, 1980; Day and Wagener, 2010).

All laboratory testing was carried out in accordance with the South African National Standards (SANS) and relevant industry protocols, ensuring consistent, accurate, and comparable results. The interpretations of these tests directly informed the geotechnical design recommendations presented in the subsequent chapters of this report.

### 3.6.1 Sample preparation

The procedure begins with sample preparation, where soil specimens from designated test sites are collected and transported to the laboratory. Each soil sample was initially air-dried. Stainless steel trays were then cleaned, dried, and weighed to determine their tare mass. The soil samples were placed into the trays, and the combined mass of the tray and sample was recorded. Thereafter, the trays were placed in a laboratory drying oven, which remained sealed throughout the drying period to minimize temperature fluctuations. The oven was set to 105°C. After 24 h, the oven was opened, and the trays containing the dried soil samples were removed and reweighed to determine the mass loss due to moisture evaporation, as shown in Figure 3.10. The dried samples were subsequently sieved to remove particles larger than 19 mm, ensuring a consistent particle-size distribution for further testing. The soil moisture content is adjusted to the optimum level determined by a Proctor compaction test (ASTM D698 or ASTM D1557) to enhance accuracy in load-bearing capacity evaluation. The optimum moisture content (OMC) varies depending on the method used, with ASTM D698 typically yielding values between 10% and 20%, while ASTM D1557, which applies greater compactive effort, results in an OMC ranging from 8% to 15%. These values are experimentally determined for each soil type based on grain size, plasticity

characteristics, and compaction properties. By adhering to these established procedures, the test ensures reliable assessment of soil stability and suitability for foundation construction.



**Figure 3.10:** Sample drying oven

### 3.6.2 California Bearing Ratio (CBR) and Foundation Indicators

The California Bearing Ratio (CBR) and Foundation Indicators (FI) test were conducted to evaluate the bearing capacity and strength of subgrade and base course materials, following the ASTM D1883-16 standard. This test assesses the resistance of soil to penetration under controlled conditions, providing critical data for geotechnical engineering and foundation design.

In terms of compaction and soaking, compacted soil specimens were prepared using a standard mould. The soil was compacted in five layers, each receiving 56 blows from a standard compaction hammer. After compaction, the specimens were soaked in water for 96 hours to simulate field conditions.

According to the testing procedure, after soaking, the specimens were placed in a loading frame. A standard plunger with a 50 mm diameter was used to penetrate

the soil at a rate of 1.27 mm/min. The force required to achieve penetrations of 2.5 mm and 5.0 mm was recorded. The CBR value was calculated as the percentage of the measured force relative to the standard force at each penetration depth. The higher value from the two penetrations was used for reporting.

### 3.6.3 Atterberg limits

The Atterberg Limits, comprising the Liquid Limit and Plastic Limit, are fundamental tests used to evaluate the consistency and plasticity characteristics of fine-grained soils (O'Kelly, 2021). These tests were conducted in accordance with ASTM D4318, which provides standardized procedures for determining these limits.

The soil samples were first sieved to remove coarse particles, ensuring that the portion selected for testing was representative of the fine-grained soil. The soil was then mixed with water to form a uniform paste suitable for testing. This paste was placed in a Casagrande cup, an apparatus designed for the Liquid Limit test, where a groove was made through its centre using a standardized tool.

During the test, the cup was lifted and dropped in a controlled manner, allowing the groove in the soil paste to close over a specified distance. The number of blows required to close the groove was carefully recorded. The moisture content corresponding to 25 blows was used to determine the Liquid Limit (LL) of the soil, indicating the point at which the soil changed from a liquid to a plastic state. This process was repeated multiple times to ensure accuracy, and the average number of blows at the Liquid Limit was calculated and reported.

In contrast, the Plastic Limit test began with similarly prepared soil samples that had been air-dried and sieved to remove coarse particles. The fine-grained soil was rolled into threads on a glass plate until the threads began to crumble at a diameter of 3 mm. The water content of the soil at this critical point, where the threads started to crumble, determined the Plastic Limit (PL). The Plastic Limit indicated the moisture content at which the soil changed from a plastic to a semi-solid state

and was crucial for understanding the behaviour of the soil under different moisture conditions.

The difference between LL and PL is known as the Plasticity Index (PI). This index provided valuable information about the plasticity characteristics of the soil. Soils with higher PI values were highly plastic and exhibited significant volume changes with variations in moisture content, whereas soils with lower PI values were less plastic and more stable under varying conditions.

#### 3.6.4 Particle size distribution

Grain size analysis (or particle size analysis) is a key test for determining the particle size distribution of soil, significantly influencing its compaction and stability properties. This test was conducted in accordance with ASTM D422, which outlines the standard method for performing sieve analysis. The soil samples were weighed to obtain total dry mass, and any clumps were gently broken up without crushing individual soil particles to maintain sample integrity.

For the sieve analysis, a series of 15 sieves with progressively smaller mesh openings, ranging from 100 mm to 0.075 mm, were stacked in descending order, with the largest aperture at the top and the smallest at the bottom. The prepared soil sample was placed in the top sieve, and the entire stack was securely placed on a mechanical sieve shaker. The sieve stack (Figure 3.11) was subjected to vibration for approximately 10–15 min, allowing soil particles to pass through the sieves according to their size, with larger particles retained on the top sieves and finer particles passing through to the lower sieves. After shaking, each sieve was carefully removed, and the soil retained on each sieve was weighed and recorded to ensure accurate measurements.



**Figure 3.11:** Sieves of different aperture sizes

### 3.6.5 Modified AASHTO compaction testing

Modified AASHTO compaction tests were performed to determine the maximum dry density (MDD) and optimum moisture content (OMC) of soil samples. These parameters are essential for evaluating compaction requirements and predicting field performance under loading conditions. The testing followed ASTM D1557 standard procedures, applying higher compactive effort than standard Proctor tests to simulate conditions under heavier structural loads.

### 3.6.6 Chemical testing (pH and electrical conductivity)

pH and Electrical Conductivity testing were conducted to assess the chemical properties of soils that could affect the durability of buried infrastructure. Acidic conditions (low pH) and high sulphate content (indicated by elevated EC) can lead to accelerated deterioration of concrete foundations and corrosion of metal pipes and reinforcement. This test provided essential data for specifying appropriate protective measures for foundations and buried services in the dolomitic environment.

Soil pH determination employed a glass electrode-equipped pH meter. Sample preparation involved air-drying the soil followed by sieving through a 2-mm mesh. A soil-water mixture was prepared at a 1:2.5 ratio and thoroughly agitated before allowing equilibration for approximately 30 min. Prior to measurement, the pH

meter underwent calibration using standard buffer solutions at pH 4, 7, and 9. The calibrated electrode was then immersed in the equilibrated suspension, and pH values were documented upon reading stabilization.

Electrical conductivity (EC) was measured using a calibrated EC meter equipped with a conductivity probe. Following air-drying and sieving through a 2 mm sieve, soil samples were mixed with distilled water at a 1:5 soil-to-water ratio and thoroughly agitated to ensure homogeneity prior to measurement. The suspension underwent a 30 – 60 min equilibration period to facilitate dissolution of soluble salts. After calibrating the EC metre against standard conductivity solutions, the probe was positioned in the clarified supernatant and electrical conductivity readings were recorded in mS/cm or dS/m.

### **3.7. Integrated geotechnical data analysis for dolomitic land development suitability**

A structured integration framework was developed in accordance with SANS 1936-2:2012 standards for dolomitic land development to combine geophysical and geotechnical findings and evaluate development potential. The integration methodology combined multiple datasets to provide comprehensive site characterization: gravity survey results (Bouguer anomaly maps identifying subsurface density variations), intrusive investigation data (borehole and test pit stratigraphic logs, weathering profiles), laboratory test results (CBR values, Atterberg limits, particle size distribution), and hydrogeological observations (groundwater depth and seasonal fluctuations). Geographic Information Systems (GIS) facilitated spatial overlay and analysis of these datasets, enabling correlation between geophysical anomalies and ground-truthed subsurface conditions. Areas exhibiting negative Bouguer anomalies indicating potential voids or highly weathered zones were cross-referenced against borehole logs to verify subsurface features characteristic of dolomitic terrains (Buttrick et al., 2001; Dippenaar et al., 2018).

The integrated data were used to subdivide the study area into distinct geotechnical zones, each characterized by blanketing layer thickness and composition, soil engineering properties (shear strength, bearing capacity, compressibility), presence or absence of subsurface anomalies, weathering profile characteristics, and groundwater conditions. This zonation follows the classification approach outlined by Day et al. (1999) and SANS 1936-2:2012 for dolomitic land development assessment. Development suitability for each zone was evaluated using three primary criteria: foundation design requirements (minimum blanketing thickness, bearing capacity, collapse potential, shrink-swell susceptibility), dolomitic hazard rating (gravity anomalies indicating voids, depth to bedrock, groundwater conditions, proximity to historical sinkholes), and required engineering interventions (ground improvement techniques, foundation type recommendations, water management strategies). A risk matrix approach (Ferentinou et al., 2020) was applied to assign risk classifications (low, moderate, high, very high) to each zone based on the likelihood of sinkhole or subsidence occurrence and the consequence severity for proposed development.

The integration process produced five key deliverables: a Geotechnical Zonation Map spatially delineating zones with distinct subsurface conditions and foundation recommendations, a Development Suitability Classification providing zone-specific construction feasibility assessments, a Risk Register identifying and rating dolomitic hazards by location, Mitigation Recommendations detailing engineering solutions tailored to each zone, and Monitoring Requirements specifying ongoing surveillance protocols for high-risk areas. This systematic integration methodology ensures comprehensive amalgamation of geophysical and geotechnical data to assess site development suitability (Buttrick et al., 2011; Dippenaar et al., 2018; SANS 1936-2:2012).

### **3.8. Concluding remarks**

#### **3.8.1 Data processing procedures**

All collected data underwent systematic processing to ensure accuracy and reliability for subsurface characterization. Gravity survey data were corrected for instrumental drift using repeated base station measurements recorded at the start, midpoint, and end of each field day. Free-air corrections accounted for elevation differences between measurement stations, while Bouguer corrections removed the gravitational effect of material between the station and reference datum. Terrain corrections were applied using high-resolution digital elevation models derived from DGPS measurements to account for topographic irregularities. These corrections followed standard microgravity processing protocols (Hinze et al., 2013).

Borehole and test pit logs were compiled following standardized geological logging procedures, with lithological descriptions, weathering grades, and stratigraphic boundaries systematically recorded. Weathering classification followed the scheme outlined in SANS 1936-2:2012, ranging from fresh rock (Grade I) through completely weathered material (Grade VI). Laboratory test results were interpreted according to SANS 3001 and ASTM standards, with appropriate classification systems applied (USCS for soil classification, AASHTO for pavement materials). Where multiple tests were conducted on similar materials, statistical analysis including mean, standard deviation, and coefficient of variation was performed to assess data consistency and identify outliers.

#### **3.8.2 Quality control measures**

Quality control was implemented throughout all investigation phases to ensure data integrity and reliability. For the gravity survey, duplicate measurements were conducted at randomly selected stations representing 10% of the total survey points, with acceptable repeatability defined as differences less than 20  $\mu\text{Gal}$  between duplicate readings. Base station drift monitoring was performed at minimum 4-h intervals throughout each field day, with linear drift interpolation

applied during post-processing. Field data were reviewed daily to identify anomalous readings requiring remeasurement before leaving the site.

Intrusive investigations incorporated photographic documentation of all test pit profiles and borehole core samples, providing visual records for subsequent verification and reinterpretation if required. Weathering grade assignments and lithological descriptions were independently verified by a second geologist to minimize subjective bias in classification. Standardized sample labelling and chain-of-custody procedures ensured traceability from field collection through laboratory testing to final reporting.

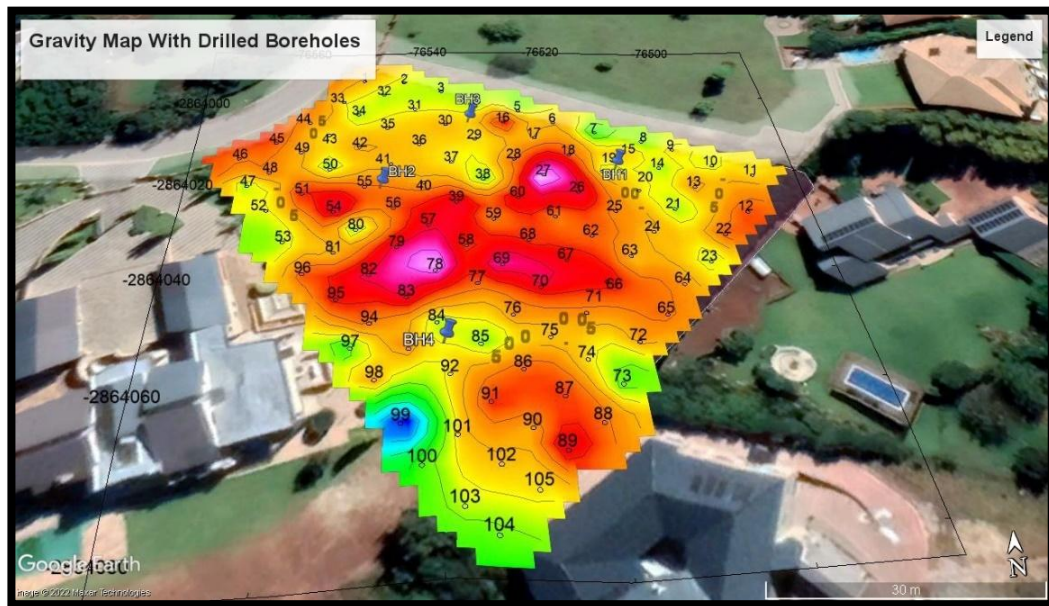
Laboratory testing was conducted by a SANS-accredited facility operating under ISO/IEC 17025:2017 quality management standards, ensuring internationally recognized analytical competence. All testing equipment underwent regular calibration following manufacturer specifications and quality system requirements. Selected samples representing approximately 10% of the total were tested in duplicate to verify repeatability, with results reviewed by senior laboratory staff before release. Test result interpretations were peer-reviewed by experienced geotechnical engineers to ensure consistency with site observations and regional geological knowledge.

## **Chapter 4. Results and discussion**

This chapter outlines the analysis and discussion of the results obtained through the methodologies described in Chapter 3. The results follow the methodological sequence, beginning with non-intrusive geophysical assessments and advancing through intrusive geotechnical investigations, laboratory analyses, rotary percussion drilling, and hydrogeological characterization. The discussion synthesizes findings from these complementary investigation techniques, highlighting the significance of an integrated approach to the characterization of dolomite landscapes. Buttrick et al (2001) highlighted that the characterization of dolomitic terrain based on a single investigative technique may result in an incomplete understanding of subsurface conditions. Consequently, an integrated site investigation approach incorporating gravity surveys, intrusive test pitting, and borehole drilling was adopted to facilitate a more comprehensive assessment of the subsurface profile and associated geotechnical conditions (Buttrick et al., 2001). Supporting tables, figures, and interpretive discussions are presented within the relevant sections to aid in the evaluation and correlation of the investigation results.

### **4.1. Gravity survey results**

A detailed gravity survey comprising 105 measurement stations distributed on a 50 m × 50 m grid was conducted across the study area to delineate subsurface density variations associated with dolomitic terrain. The survey methodology and data acquisition procedures are detailed in chapter 3. A residual gravity map (Figure 4.1) was generated by removing the first-order regional trend from the Bouguer anomaly grid, thereby isolating localized gravitational variations potentially indicative of subsurface voids, cavities, zones of differential weathering, or variations in overburden thickness characteristic of dolomitic environments (Buttrick and Van Schalkwyk, 1998).



**Figure 4.1:** Residual gravity anomaly map of the study area

Numbers 1 – 105 represent gravity measurement station locations on the 50 m × 50 m survey grid. The colour gradient indicates relative residual gravity anomaly magnitude, with warmer colours (purple, red, orange) representing higher gravity values and cooler colours (yellow, green, blue) representing lower gravity values. Grid coordinates displayed along the map boundaries are expressed in meters using the local coordinate system. The 'BH' markers indicate borehole locations used for ground-truth correlation. A scale bar and north arrow are provided for spatial reference.

The residual gravity map reveals a distinct spatial pattern of subsurface density variations across the site. The colour gradient represents relative gravity anomaly magnitudes measured at each station, providing insight into the three-dimensional geometry of the subsurface geology. Detailed quantitative gravity data including absolute anomaly values in milligals (mGal), drift corrections, and signal-to-noise ratios were processed by the geophysical contractor. The spatial distribution patterns and relative anomaly magnitudes for geotechnical interpretation, correlated with direct ground-truth investigations from boreholes and test pits.

Very high gravity anomalies, represented by dark purple coloration, are observed in the north-central portion of the site, particularly in the vicinity of station 26. These anomalies represent the highest residual gravity values recorded across the survey area and suggest the presence of very shallow competent dolomitic bedrock with minimal overburden thickness. Alternatively, these zones may indicate dense accumulations of chert fragments within the residual soil profile, as chert possesses significantly higher density than surrounding weathered dolomite materials. The presence of such anomalies typically correlates with favourable foundation conditions due to the proximity of competent bearing strata to the surface.

High gravity anomalies, displayed in red to pink coloration, dominate the central portion of the study area, concentrated around stations 26 – 27, 56 – 60, 66 – 70, and 77 – 78. These anomalies indicate shallow, relatively unweathered dolomitic bedrock with limited overburden development. The spatial distribution of these high anomalies suggests that the central area of the site is characterized by competent bedrock at shallow depths, representing zones of greatest geotechnical stability. Buttrick and Van Schalkwyk (1998) demonstrated that residual gravity mapping is an effective non-invasive technique for identifying such zones of dense, unweathered bedrock in South African dolomite terrains. These areas typically exhibit favourable engineering properties including high bearing capacity and minimal settlement potential, making them suitable for development with conventional shallow foundation systems.

Moderate gravity anomalies, represented by orange to yellow coloration, form transitional zones surrounding the central gravity highs and extend across much of the northern and eastern portions of the site. These intermediate anomaly values suggest moderate overburden thickness overlying the dolomitic bedrock, or zones where the bedrock has undergone partial weathering. The gradational nature of these anomalies between the central heights and peripheral lows indicates a progressive increase in either overburden thickness or degree of bedrock weathering moving away from the site centre. From a geotechnical perspective,

these moderate anomaly zones require careful evaluation through direct investigation methods to determine precise overburden depths and bedrock quality for foundation design purposes.

Low gravity anomalies, displayed in light green to yellow-green coloration, are distributed along the western periphery of the site, particularly around stations 45 – 48, 50 – 53, 80 – 82, and 95 – 98, as well as in the northeastern corner encompassing stations 1-11. These anomalies indicate zones of deeper soil profiles, more extensive bedrock weathering, or increased fracturing within the underlying dolomite. In dolomitic environments, such low gravity anomalies are frequently associated with advanced karstification processes, including the development of thick residual soil profiles (wad), extensive fracture networks, or potentially the presence of subsurface voids (Jennings, 1965; Brink, 1979). The identification of these zones is critical for geotechnical stability assessments, as they may represent areas of reduced bearing capacity, increased compressibility, or elevated sinkhole susceptibility.

Very low gravity anomalies, represented by dark blue coloration, are concentrated in the southwestern corner of the site, particularly around stations 99 – 100 and 103 – 104. These anomalies represent the lowest residual gravity values recorded across the entire survey area and are of geotechnical significance. The anomalously low gravity readings suggest zones of maximum overburden thickness, extensively weathered dolomite bedrock, deeply fractured zones, or the potential presence of subsurface cavities associated with karst development (Kleinhans et al., 1999; Buttrick et al., 2001). In the context of dolomitic terrain stability, such anomalies warrant detailed investigation as they indicate areas where the competent bedrock lies at greater depth and where the overlying materials may be susceptible to collapse or subsidence. These zones represent the highest sinkhole risk areas on the site and require either ground improvement measures or avoidance in development planning to ensure long-term structural stability.

The wavelength characteristics of the observed anomalies provide additional insight into the depth and lateral extent of the causative density contrasts. The broad, long-wavelength nature of the central gravity high suggests a relatively deep-seated feature, likely to represent the gently undulating upper surface of competent dolomite bedrock. In contrast, the shorter-wavelength anomalies observed along the site peripheries indicate more localized, shallow features such as isolated weathered zones or discrete void spaces. The amplitude variations, ranging from the dark blue minima to dark purple maxima, indicate substantial density contrasts across the site, consistent with the variable overburden thickness and differential weathering patterns characteristic of South African dolomitic terrains (Van Rooy and Dippenaar, 2013).

From a geotechnical engineering perspective, the gravity survey results enable the preliminary zonation of the site into areas of varying development suitability. The central high gravity zone represents the most favourable area for development, characterized by shallow competent bedrock and minimal sinkhole risk. The moderate anomaly zones require standard geotechnical investigation and potentially deeper foundations or ground improvement measures. The low and very low gravity zones, particularly the southwestern dark blue anomaly, represent areas of elevated geotechnical risk that warrant either avoidance in development planning, comprehensive ground improvement, or implementation of specialized foundation systems designed to accommodate potential ground instability.

The spatial distribution of gravity anomalies at Cornwall Hill is consistent with patterns reported in previous dolomitic investigations in the Gauteng region. The central gravity high, correlating with shallow competent bedrock, and the peripheral gravity lows, correlating with deeper weathered profiles and the cavity intersected in BH01, are in agreement with findings by Buttrick and Van Schalkwyk (1998), who demonstrated, as discussed in the literature review, that residual gravity mapping is an effective technique for delineating zones of dense, unweathered bedrock in South African dolomitic terrains. The low gravity values recorded in the southwestern zone are consistent with the interpretation of

Kleinhans et al. (1999) and Buttrick et al. (2001) that anomalously low gravity readings in dolomitic settings are indicative of subsurface dissolution features or deeply weathered material rather than simple overburden thickening. These findings support the use of microgravity surveys as a guide for targeted intrusive investigation in heterogeneous dolomitic terrain, as advocated by Oosthuizen and Van Rooy (2015).

#### **4.2. Test pit and soil profile analysis**

Five test pits (TP1–TP5) were excavated across the study area to characterise near-surface geotechnical conditions and to enable correlation with the gravity survey interpretation. The integration of intrusive and geophysical methods aligns with established approaches for investigating dolomitic terrain, where subsurface variability is commonly inferred through combined datasets (Buttrick et al., 2001; Richardson, 2013).

The test pit results indicate a broadly consistent near-surface profile across the site, characterised by topsoil overlying residual soils derived from dolomitic bedrock. Variations in soil thickness, consistency, and moisture conditions were observed locally, reflecting the heterogeneous nature of weathering processes typically associated with dolomitic environments (Buttrick et al., 2001). These variations do not suggest significant stratigraphic discontinuity but rather localised changes in material properties.

Correlation with the gravity survey interpretation shows that subtle differences in near-surface conditions correspond with identified anomaly zones, supporting the geophysical interpretation of underlying subsurface variability (Council for Geoscience, cited in Brown, 2014). Furthermore, comparison with borehole data confirms general agreement between shallow soil profiles and deeper stratigraphy, thereby strengthening the reliability of the integrated geological model developed for the site (Buttrick et al., 2001).

**Table 4.1:** Location correlation between test pits and borehole

Test Pit ID	Borehole ID	Longitude	Latitude	Altitude (m)
TP1	BH1	28°24'11.8" E	25°52'56.3" S	1464
TP2	BH2	28°14'10.5" E	25°52'56.4" S	1467
TP3	BH3	28°14'10.9" E	25°52'55.7" S	1470
TP4	BH4	28°14'10.6" E	25°52'57.6" S	1465
TP5		28°14'11.12"E	25°52'56.92"S	1462

Table 4.1 indicate the location correlation between test pits and boreholes. The site altitudes range from 1462 m to 1470 m above mean sea level, with an average elevation of 1465.6 m. This modest topographic variation of 8 m across the site reflects the gently undulating terrain characteristic of the Centurion dolomitic landscape. The relatively uniform elevations suggest subdued relief, which has implications for natural drainage patterns and potential water movement across the site that could influence sinkhole susceptibility and ground stability.

### **4.3. Integration with gravity anomaly zones**

The test pit locations were deliberately distributed to intersect the range of gravity anomalies identified in the geophysical survey, enabling validation of geophysical interpretations through direct observation. Test pits TP1 and TP3 were positioned within the central high gravity anomaly zone (red to purple colours in Figure 4.4), where elevated residual gravity values suggest shallow competent dolomitic bedrock. Test pit TP4 was located in the northeastern portion of the site within a moderate gravity anomaly zone (orange to yellow colours), representing transitional conditions between the central highs and peripheral lows. Test pits TP2 and TP5 were excavated along the western periphery of the site in low gravity anomaly zones (green to blue colours), where reduced gravity values indicate

either thicker overburden sequences, more extensively weathered bedrock, or potential subsurface void development associated with karstification processes.

This spatial distribution strategy enables assessment of how subsurface conditions vary across the gravity anomaly spectrum observed on site. By excavating test pits in zones representing the full range of geophysical signatures from very high (dark purple) through moderate (orange) to very low (dark blue) gravity anomalies, the investigation provides ground-truth data for validating the geophysical interpretations and refining the understanding of subsurface conditions relevant to development suitability. The correlation between test pit observations and gravity anomaly patterns is essential for establishing confidence in the geophysical survey as a tool for delineating zones of varying sinkhole risk and geotechnical stability across the site (Buttrick and Van Schalkwyk, 1998).

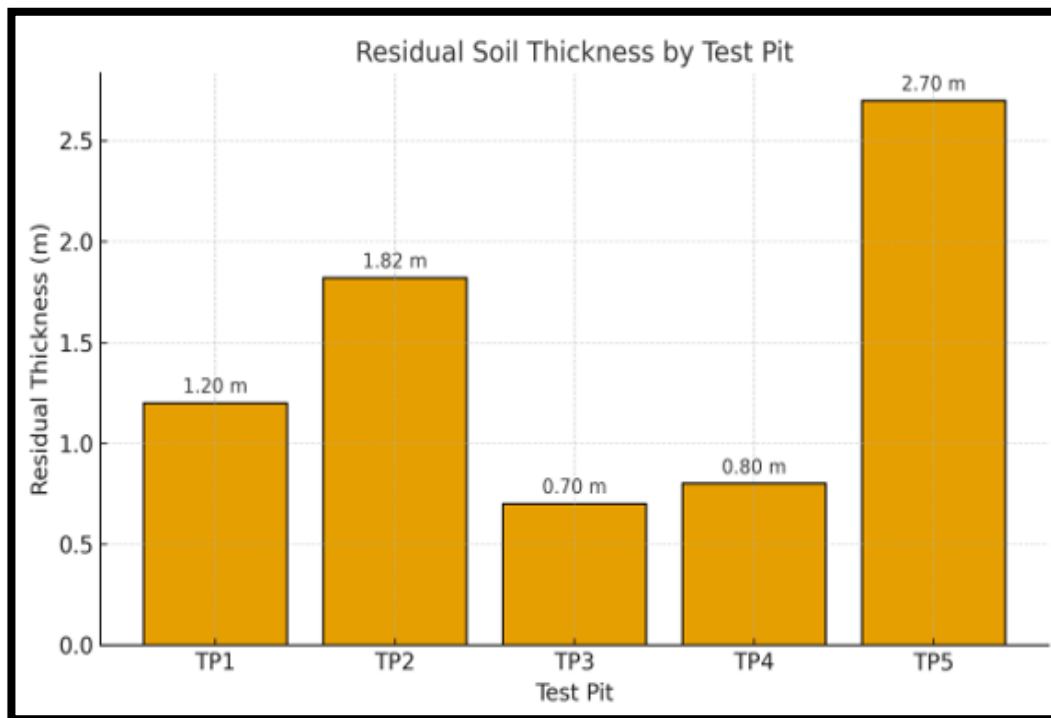
#### 4.3.1 Subsurface stratigraphy

Test pit excavations revealed a consistent three-layer stratigraphic sequence comprising topsoil (colluvium), residual soil, and dolomite bedrock. This vertical succession is typical of weathered dolomitic profiles in the Malmani Subgroup dolomites of Gauteng Province (Brink, 1979; Jennings, 1965). Each geological unit is described below in terms of lithological characteristics, engineering properties, and spatial distribution.

##### 4.3.1.1. Topsoil Layer (Colluvium)

The uppermost unit consists of loose to slightly compacted colluvial topsoil characterized by dark brown to reddish-brown coloration, high organic content, and root penetration throughout. This material comprises silty clay with scattered angular chert fragments ranging from gravel to cobble size. The colluvium exhibits soft to firm consistency when moist and demonstrates minimal structural strength. Texture is friable with visible root channels and organic matter concentrated in the upper portions. The presence of vegetation debris and disturbed fabric indicates recent soil-forming processes and limited consolidation history.

Topsoil thickness was measured across all five test pits, ranging from 0.30 m (TP3 and TP5) to 0.55 m (TP4), with a mean thickness of 0.39 m and standard deviation of 0.11 m. This relatively uniform thickness distribution (coefficient of variation = 28%) suggests consistent surficial weathering and soil accumulation processes across the site. TP1 exhibited 0.40 m of topsoil, TP2 showed 0.38 m, TP3 and TP5 both displayed 0.30 m, while TP4 presented the greatest thickness at 0.55 m. The colluvial layer maintains relatively consistent characteristics throughout the site despite minor thickness variations, indicating stable surface conditions and uniform recent weathering history. The spatial variability in residual soil thickness across the five test pits is illustrated in Figure 4.2, which shows values ranging from a minimum of 0.70 m at TP3 to a maximum of 2.70 m at TP5.



**Figure 4.2:** Thickness of the residual soil estimated from the test pits

Given its low bearing capacity, high compressibility, and organic content, this unit is unsuitable for direct foundation support and requires removal prior to construction activities. This finding is consistent with standard South African geotechnical practice for foundation preparation on dolomitic sites (SANS 1936-2:2012).

#### 4.3.1.2. Residual soils

Beneath the colluvium lies a residual soil horizon derived from in-situ weathering of the underlying dolomite bedrock. This material is characterized by reddish-brown to orange-brown coloration with pale whitish mottling, reflecting oxidation of iron-bearing minerals during weathering. The soil matrix consists predominantly of sandy silt to silty sand with clay content varying from low to moderate. Medium dense packing was observed through manual excavation resistance and standard penetration behaviour. The material is matrix-supported with scattered chert fragments, angular dolomite boulders (up to 300 mm diameter), and gravel-sized rock fragments distributed throughout. Moisture content was observed as slightly moist to moist, with no evidence of saturation or perched water tables within this horizon. The reddish coloration indicates oxidizing conditions and weathering under vadose zone conditions, while the presence of angular chert fragments reflects selective dissolution of carbonate minerals from the parent dolomite. The matrix-supported fabric suggests advanced weathering with loss of original rock structure. Visual and tactile examinations during excavation revealed homogeneous characteristics throughout the site, with consistent grain size distribution, colour, density, and plasticity across all test pit locations. This uniformity indicates stable weathering processes operating consistently across the investigation area.

Residual soil thickness exhibits significant spatial variability across the site, ranging from 0.70 m (TP3) to 2.70 m (TP5), with a mean thickness of 1.59 m and standard deviation of 0.92 m Figure 4.3. This substantial coefficient of variation (58%) reflects the heterogeneous nature of dolomitic weathering profiles characteristic of the Malmani Subgroup. At TP1, residual soil thickness measured 1.20 m, increasing to 1.82 m at TP2. TP3 exhibited the thinnest profile at 0.70 m, while TP4 showed 0.80 m. TP5 displayed the greatest thickness at 2.70 m, where bedrock was not encountered within the 3.0 m excavation depth limit. This thickness variability reflects differential weathering patterns controlled by bedrock topography, structural discontinuities, and historical groundwater circulation

patterns (Buttrick and Van Schalkwyk, 1998). Areas of thinner residual soil (TP3, TP4) suggest proximity to less weathered bedrock highs, while thicker profiles (TP5) may indicate deeper weathering zones or potential dissolution features requiring further investigation. The residual soil horizon represents the primary zone for foundation support consideration and was targeted for detailed sampling and laboratory characterization at TP2, TP3, and TP5 to capture the range of thickness and property variations observed.

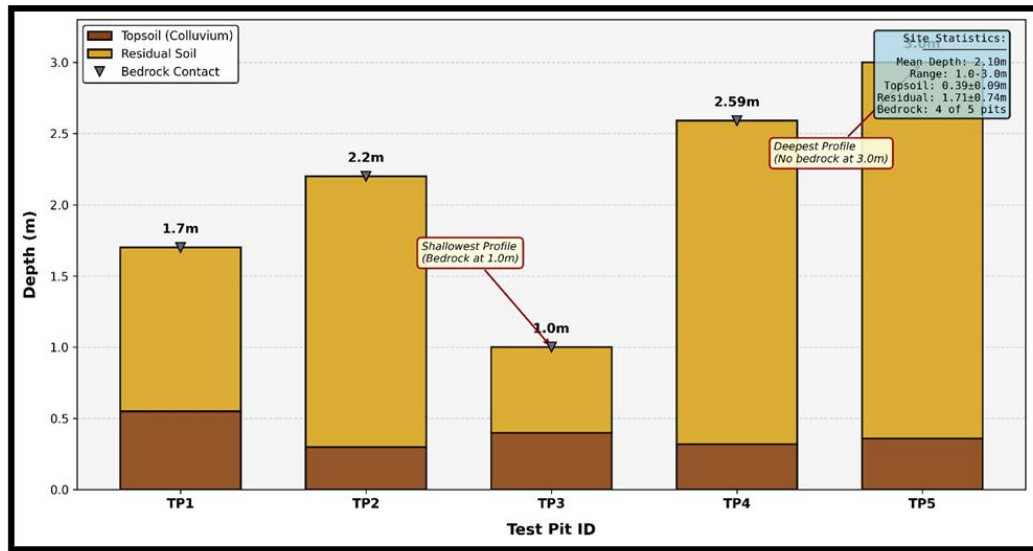
The three-layer stratigraphic sequence identified across all five test pits, comprising colluvium, residual soil, and dolomite bedrock, is characteristic of the Malmani Subgroup weathering profile described by Brink (1979) and Jennings et al. (1965). The residual soil thickness varied considerably across the site, ranging from 0.70 m at TP3 to 2.70 m at TP5, with a coefficient of variation of 58%. This degree of variability is consistent with the heterogeneous weathering profiles typical of dolomitic terrains in the Gauteng region, as discussed in the literature review (Buttrick et al., 2001). Blanketing thickness is the primary control on sinkhole risk, with thinner profiles providing limited arching capacity above underlying voids (Buttrick and Van Schalkwyk, 1998; Dippenaar et al., 2018).

The shallow residual soil at TP3 corresponds to the central high gravity zone, indicating relatively competent near-surface conditions, while the deep profile at TP5 coincides with the peripheral low gravity anomaly, which is consistent with zones of advanced weathering or karstification. Boo et al. (2020) further noted that localized thinning creates preferential failure points even where average blanketing thickness appears adequate. The variability observed at this site supports this interpretation and highlights the importance of distributed investigation rather than reliance on average thickness values alone.

#### 4.3.1.3. Dolomite bedrock

Competent dolomite bedrock of the Malmani Subgroup was encountered at four of five test pit locations (TP1, TP2, TP3, TP4), marking the base of the weathered profile. The bedrock surface is characterized by light grey to pale yellowish-grey

medium to coarse-crystalline dolomite with occasional chert bands and nodules. Where exposed, the rock surface exhibited irregular topography with dissolution features including minor cavities and weathering pockets along bedding planes. The material demonstrated very high strength, resisting mechanical excavation and requiring specialized equipment (hydraulic breakers or percussion drilling) for penetration beyond the bedrock contact.



**Figure 4.3:** Stratigraphic profile – Thickness of the soil layer estimated from the test pits

Depth to bedrock shows considerable spatial variation across the site Figure 4.3. At TP3, bedrock was encountered at the shallowest depth of 1.0 m below ground surface, representing a bedrock high beneath the site. TP4 intersected bedrock at 1.35 m depth, followed by TP1 at 1.60 m and TP2 at 2.20 m depth. At TP5, bedrock was not encountered within the maximum TLB excavation depth of 3.0 m, indicating either a localized bedrock depression or enhanced weathering extending beyond this depth. The mean depth to bedrock for the four pits where it was encountered is 1.54 m with a standard deviation of 0.52 m.

The variable bedrock surface topography reflects the irregular dissolution and weathering characteristic of carbonate terrains (Jennings, 1965). Shallow bedrock zones (TP3, TP4) may provide favourable foundation conditions with reduced

settlement potential, while deeper weathered profiles (TP5) require additional investigation to verify subsurface conditions and assess potential for concealed dissolution features. In all cases where encountered, bedrock contact marked excavation refusal, defined as the point beyond which mechanical excavation cannot proceed without specialized rock-breaking equipment. This excavation termination indicates competent bedrock suitable for founding purposes where accessible at suitable depths.

#### 4.3.2 Comparative analysis

The complete stratigraphic succession across all five test pits is presented in Figure 4.3 and summarized in Table 4.2. The data reveals a consistent three-layer profile with systematic variations in layer thickness. The surficial colluvium (brown in Figure 4.3) maintains relatively uniform thickness (0.30 – 0.55 m) across the site, while the residual soil layer gold in Figure 4.3 exhibits substantial thickness variability (0.70 – 2.70 m).

**Table 4.2:** Summarised results of the soil profiles from the test pits

Test Pit ID	Depth (m)			Comment
	Topsoil (Colluvium)	Residual Soil	Bedrock	
TP1	0 – 0.4	0.4 – 1.6	1.6 – 2	No sampled
TP2	0 – 0.38	0.38 – 2.2	2.2 – 2.5	Sampled between a depth of 0.38 m to 2.2 m
TP3	0 – 0.3	0.3 – 1.0	1.0 – 1.25	Sampled between a depth of 0.3 m to 1.0 m
TP4	0 – 0.55	0.55 – 1.35	1.35 – 1.8	No sampled
TP5	0 – 0.3	0.3 – 3	TLB can only excavate up to 3 m	Sampled between a depth of 0.3 m to 3 m. No bedrock encountered

TP3 represents the shallowest overall profile with bedrock at 1.0 m depth and only 0.70 m of residual soil, suggesting a localized bedrock high. Conversely, TP5 exhibits the deepest profile investigated, with 2.70 m of residual soil and no bedrock encountered within the 3.0 m excavation limit, indicating a potential bedrock depression or enhanced dissolution zone. TP2 displays an intermediate condition with 1.82 m of residual soil and bedrock at 2.20 m depth, while TP1 and TP4 show relatively thin residual soil covers (1.20 m and 0.80 m respectively) over bedrock.

This thickness variability in the residual soil horizon is characteristic of differential weathering in dolomitic terrains, reflecting spatial variations in bedrock dissolution rates, structural controls (faults, fractures, bedding), and historical groundwater infiltration patterns (Buttrick et al., 2001). The deeper profile observed at TP5 correlates spatially with negative gravity anomalies identified during geophysical surveying, supporting interpretation of deeper weathering or potential subsurface dissolution features in this area requiring further investigation through deeper drilling.

Bulk samples were collected from the residual soil horizon at TP2 (0.38 – 2.2 m depth), TP3 (0.3 – 1.0 m depth), and TP5 (0.3 – 3.0 m depth) to capture the range of geotechnical conditions present. These sampling locations encompass both shallow bedrock zones (TP3) and deeper weathered profiles (TP5), ensuring representative characterization of site variability for subsequent laboratory testing and foundation design development.

#### **4.4. Dynamic cone penetrometer (DCP) test results**

A total of 5 DCP tests were conducted adjacent to each test pit location with DCP1 positioned close to TP01 and continuing sequentially up to DCP 5 near TP05 to evaluate the densities of the subsurface soils. The test data were used to estimate equivalent Standard Penetration Test (SPT) N-values, which were then correlated

with allowable bearing capacities across various depths at the site. This section presents quantitative comparisons of penetration resistance, SPT N-values, and bearing capacities, along with statistical analyses to characterize site-wide trends and identify zones of geotechnical concern. The analysis is essential for understanding the heterogeneity typical of dolomitic terrain and informing foundation design strategies.

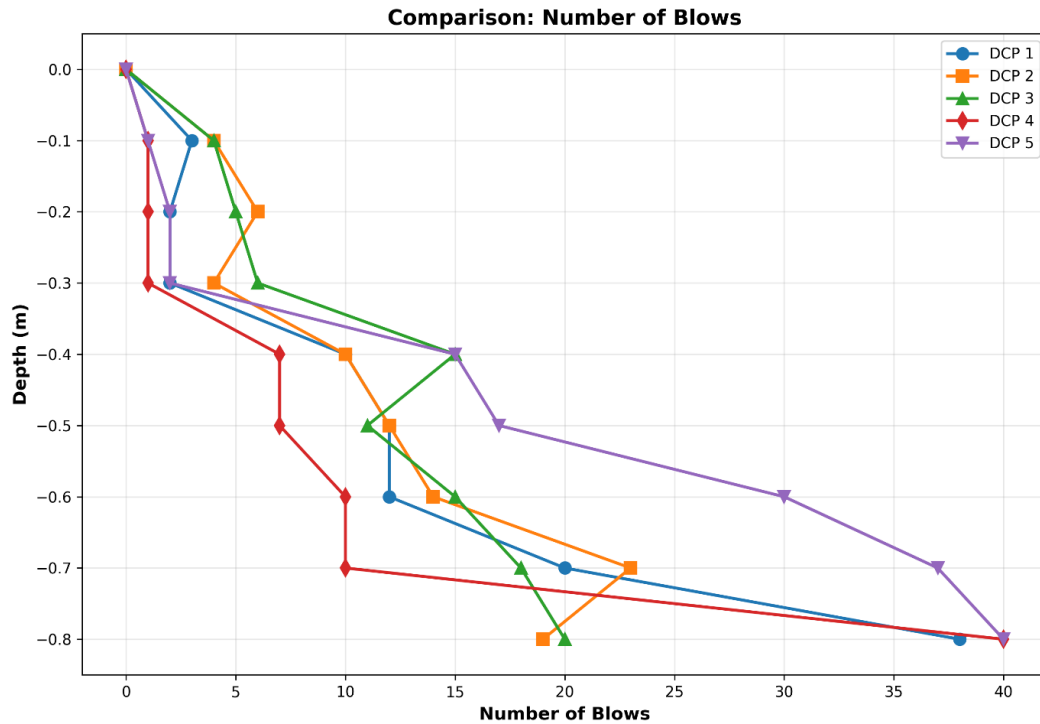
#### 4.4.1 Depth-wise comparison of penetration resistance

Following the execution of the DCP test, the data were compiled in Table 4.3. As observed in Table 3, all five DCPs exhibit notably low blow counts within the upper 0.3 m, indicative of a weak, highly weathered near-surface layer characteristic of dolomitic soils (Jennings et al., 1965; Brink, 1979). Specifically, DCP 1 registers 0 – 2 blows per 100 mm in this zone, after which its resistance markedly increases from 10 – 12 blows at 0.4 – 0.6 m to 20 blows at 0.7 m and 38 blows at 0.8 m. Although DCP 2 and DCP 3 were extended to -1.0 m during field testing, the statistical analysis particularly the computation of the mean and standard deviation was standardized to a maximum depth of -0.8 m. This decision was made to ensure consistency across all test points and improve the reliability of comparative interpretations, as not all DCPs reached depths beyond 0.8 m.

**Table 4.3:** Comparative Blow Count Data for All DCP Tests

Depth (m)	DCP 1	DCP 2	DCP 3	DCP 4	DCP 5	Mean	Std Dev	Min	Max
0	0	0	0	0	0	0.0	0.0	0	0
-0.1	3	4	4	1	1	2.6	1.5	1	4
-0.2	2	6	5	1	2	3.2	2.0	1	6
-0.3	2	4	6	1	2	3.0	2.0	1	6
-0.4	10	10	15	7	15	11.4	3.4	7	15
-0.5	12	12	11	7	17	11.8	3.8	7	17
-0.6	12	14	15	10	30	16.2	8.0	10	30
-0.7	20	23	18	10	37	21.6	10.6	10	37
-0.8	38	19	20	40	40	31.4	11.2	19	40

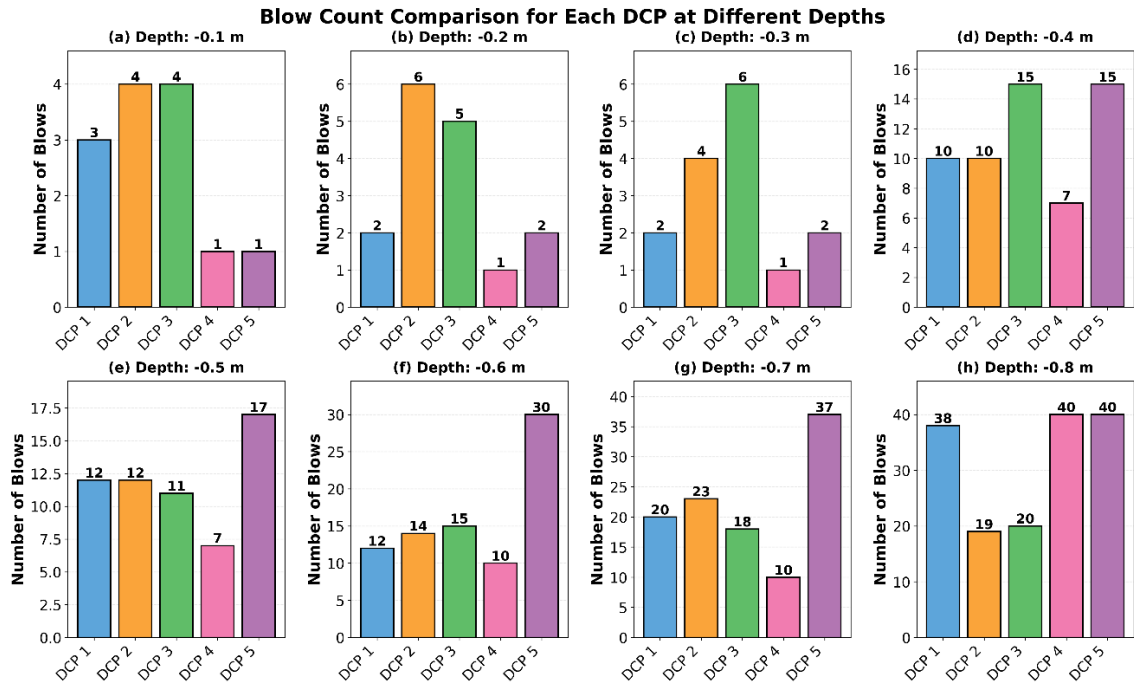
This distinct upward trend, as illustrated in Figure 4.4, signifies a transition from soft residuum to a considerably stiffer, partially cemented material, approaching refusal conditions at greater depths. DCP 2 exhibits a comparable surface pattern (2 – 6 blows); however, its increase in resistance is less pronounced, with 10 – 14 blows at 0.4 – 0.6 m, 23 blows at 0.7 m, and a slight decrease to 19 blows at 0.8 m. In contrast to DCP 1, DCP 2 does not attain high refusal-type resistance, suggesting that the competent horizon is either deeper or transitions more gradually at this location.



**Figure 4.4:** Comparative profile of blow counts across all test locations

DCP 3 also shows low resistance in the upper 0.3 m (4 – 6 blows), but from 0.4 m downward, the blow counts increase more steadily than DCP 2, reaching 11 – 15 blows at 0.4 – 0.6 m, 18 blows at 0.7 m, and 20 blows at 0.8 m (Table 3). This suggests a moderately stiff subsurface profile that continues to strengthen with depth, though without the abrupt increase characteristic of imminent refusal. DCP 4 records some of the lowest surface values (1 – 2 blows), indicating extremely weak material. Resistance then increases modestly to 7 – 10 blows at 0.4 – 0.6 m, followed by a sharp rise from 10 blows at 0.7 m to 40 blows at 0.8 m (Figure 4.4).

This abrupt jump suggests a thin, weathered layer overlying a shallow competent horizon, potentially associated with pinnacled bedrock or cemented chert-rich material (Wagener, 1982; Day, 2012). DCP 5 displays the highest resistance overall. After initial low surface counts (1 – 2 blows), blow counts rise rapidly to 15 at 0.4 m, 17 at 0.5 m, 30 at 0.6 m, 37 at 0.7 m and 40 at 0.8 m. The steep increase from 0.4 m downward (Figure 4.4) indicates very shallow competent material, characteristic of dolomitic terrains with resistant pinnacles beneath relatively thin overburden (Brink, 1979; Buttrick et al., 2001).



**Figure 4.5:** Comparison of blow count at each depth interval

The depth-specific results shown in Figure 4.5 indicate a generally weak near-surface layer across the site. From ground level to approximately 0.3 m depth, all DCP tests recorded low blow counts, reflecting soft, weathered materials with little resistance to penetration. This condition is typical of dolomitic terrains where residual soils are affected by prolonged weathering, surface runoff, and local disturbance, and is consistent with materials that offer limited bearing support in their natural state.

Below about 0.4 m depth, the DCP profiles begin to separate, with notable differences in penetration resistance between test points. DCP 1, DCP 4, and DCP 5 show a rapid increase in blow counts with depth, in some cases approaching practical refusal. This suggests the presence of shallower competent horizons or localized zones of denser material. In contrast, DCP 2 and DCP 3 exhibit a more gradual increase in resistance, indicating a thicker weathered profile and a deeper transition to more competent material.

This variability reflects lateral changes in the thickness of the overburden and the depth to competent dolomitic material, which are commonly encountered in karst

environments due to differential dissolution and irregular bedrock morphology. Such conditions are specifically recognized in SANS 1936, which cautions that dolomitic sites may display abrupt changes in ground conditions over short distances and that ground classification and development decisions should not be based on isolated investigation points.

The observed divergence in DCP response therefore reinforces the requirements of SANS 1936 for site-specific and adequately spaced investigation data to inform risk zoning and foundation design. It further highlights the limitation of relying solely on shallow or widely spaced tests in dolomitic areas, where localized zones of weakness or competence may significantly influence development suitability.

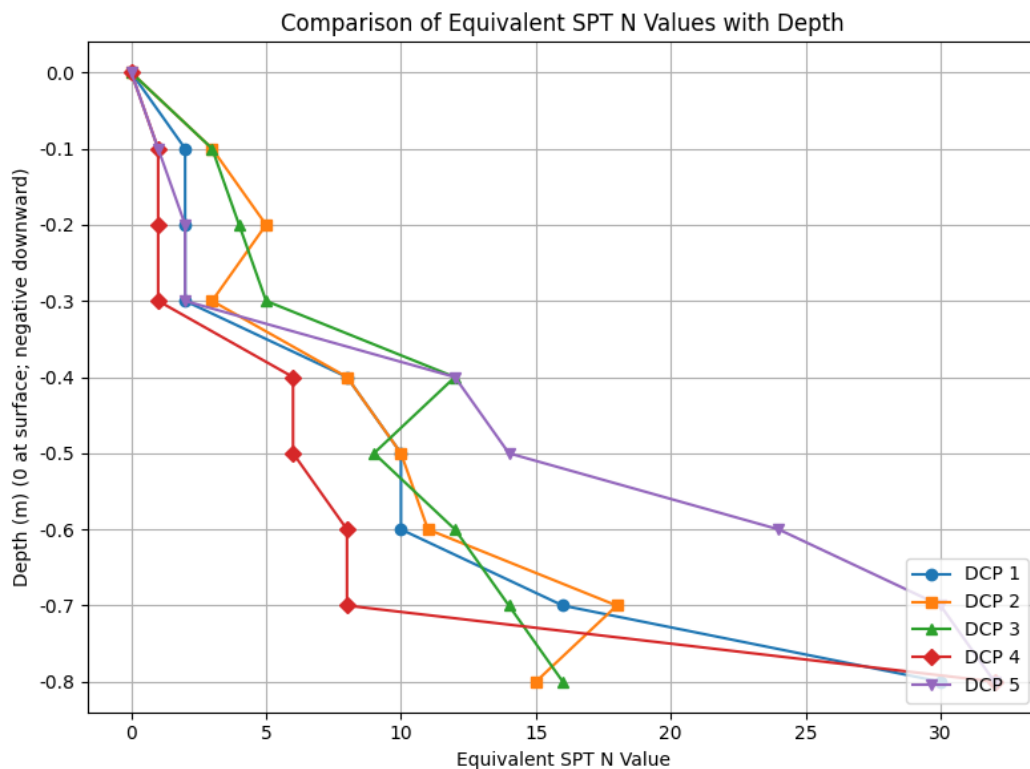
#### 4.4.2 SPT N-value correlation and classification

Equivalent SPT N-values derived from the DCP blow counts using established South African correlations (Kleyn, 1975; TMH7, 1981) are presented in Table 4.4 and illustrated in Figure 4.6, showing the variation in subsurface stiffness across the five test points. Across all profiles, the upper 0.3 m consistently exhibits very low N-values, classifying the near-surface material as very loose to loose granular soil or very soft cohesive soil (ASTM D1586; BS 5930).

**Table 4.4:** Comparative SPT N-values across all DCP tests

Depth (m)	DCP 1	DCP 2	DCP 3	DCP 4	DCP 5	Mean	Std Dev	Min	Max
0	0	0	0	0	0	0.0	0.0	0	0
-0.1	2	3	3	1	1	2.0	1.0	1	3
-0.2	2	5	4	1	2	2.8	1.5	1	5
-0.3	2	3	5	1	2	2.6	1.5	1	5
-0.4	8	8	12	6	12	9.2	2.7	6	12

Depth (m)	DCP 1	DCP 2	DCP 3	DCP 4	DCP 5	Mean	Std Dev	Min	Max
-0.5	10	10	9	6	14	9.8	2.9	6	14
-0.6	10	11	12	8	24	13.0	6.4	8	24
-0.7	16	18	14	8	30	17.2	8.5	8	30
-0.8	30	15	16	32	32	25.0	9.0	15	32



**Figure 4.6: Equivalent SPT N-value profiles with depth for all five DCP test locations.**

As shown in Figure 4.6, all DCPs record very low penetration resistance in the upper 0.3 m, with N-values generally between 1 and 5. This confirms the presence of a weak near-surface layer across the site, likely comprising soft residual soils or loose transported material. These values are well below those typically required for shallow foundation support and are therefore unsuitable for direct bearing.

Between depths of approximately 0.3 m and 0.6 m, a gradual increase in resistance is observed across most profiles (Figure 4.6), with mean N-values ranging from about 9 to 13 (Table 4.4). This zone represents a transition from soft to medium dense or stiff material. While an improvement in stiffness is evident, the noticeable spread in N-values indicates variable ground conditions, suggesting that settlement behaviour would be difficult to predict without conservative design or ground improvement.

At depths of 0.7 – 0.8 m, Figure 4.6 clearly shows a divergence in behaviour between the DCPs. DCPs 1, 4 and 5 exhibit sharp increases in N-values, reaching between 30 and 32, which is indicative of very dense material or the onset of refusal against shallow competent horizons. In contrast, DCPs 2 and 3 continue to penetrate material with moderate resistance, with N-values remaining below 20. This contrast points to significant lateral variability in the thickness of the weathered profile and the depth to competent material.

The observed pattern is characteristic of dolomitic terrains, where irregular bedrock geometry and differential weathering commonly result in abrupt changes in founding conditions over short distances. The variability highlighted in Figure 4.6, when considered alongside the statistical spread in Table 4.4, supports classification of the site within higher dolomite hazard zones and reinforces the need for cautious foundation design and targeted subsurface investigation.

#### 4.4.3 Bearing capacity distribution and implications on foundations

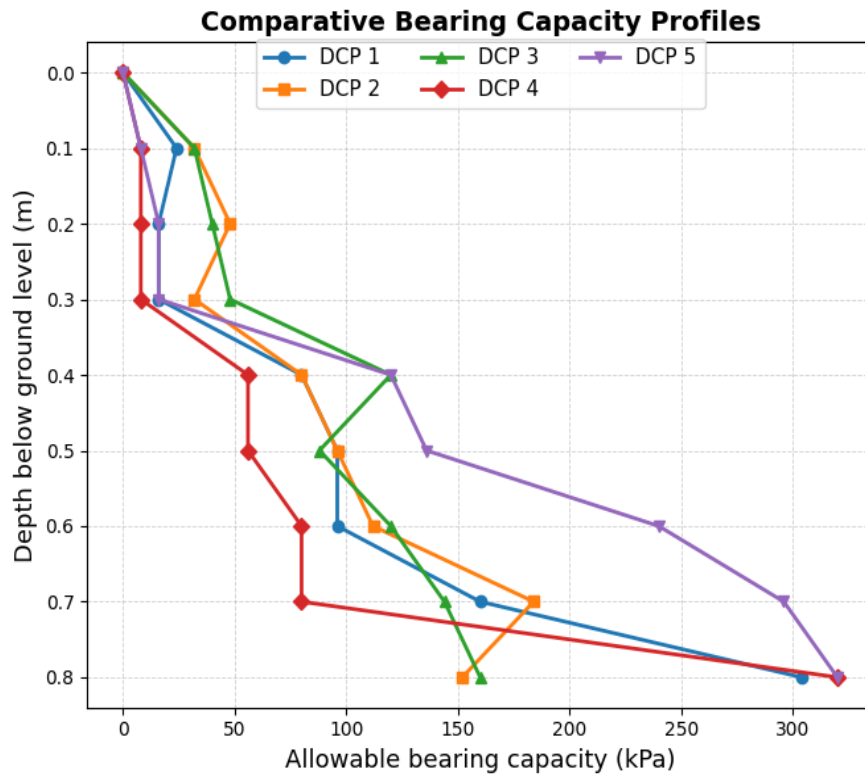
Allowable bearing capacities estimated from the DCP results using established South African correlations (Kleyn, 1975; TMH7, 1981) are presented in Table 4.5 and plotted in Figure 4.7, showing clear depth-dependent changes in soil strength across the site.

**Table 4.5:** Bearing capacities across all DCP tests

Depth (m)	DCP 1	DCP 2	DCP 3	DCP 4	DCP 5	Mean	Std Dev	Min	Max
0	0	0	0	0	0	0	0	0	0
-0.1	24	32	32	8	8	20.8	12.2	8	32
-0.2	16	48	40	8	16	25.6	17.9	8	48
-0.3	16	32	48	8	16	24.0	16.4	8	48
-0.4	80	80	120	56	120	91.2	27.5	56	120
-0.5	96	96	88	56	136	94.4	30.7	56	136
-0.6	96	112	120	80	240	129.6	64.2	80	240
-0.7	160	184	144	80	296	172.8	85.0	80	296
-0.8	304	152	160	320	320	251.2	89.6	152	320

As shown in Figure 4.7, DCP 1 records a bearing capacity of approximately 24 kPa at 0.1 m, reducing slightly to 16 kPa between 0.2 and 0.3 m. Capacities then increase to 80 – 96 kPa between 0.4 and 0.6 m, followed by a pronounced rise to 160 kPa at 0.7 m and 304 kPa at 0.8 m. This profile reflects very weak near-surface material, marginal intermediate support, and adequate bearing capacity only at depths approaching 0.8 m, where competent material is encountered.

DCP 2 exhibits weak surface capacities of 32 – 48 kPa within the upper 0.3 m. Bearing capacity improves to approximately 80 – 112 kPa between 0.4 and 0.6 m and increases further to 184 kPa at 0.7 m, before decreasing slightly to 152 kPa at 0.8 m. Although an improvement with depth is evident, the maximum capacity achieved remains notably lower than those recorded at DCP 1, DCP 4 and DCP 5, suggesting a deeper or less well-developed competent horizon.



**Figure 4.7:** Bearing capacity profiles

DCP 3 shows a similar response, with low surface capacities of 32 – 48 kPa up to 0.3 m. Capacities increase to 120 kPa at 0.4 m, reduce slightly to 88 kPa at 0.5 m, and then rise progressively to 120 – 144 kPa between 0.6 and 0.7 m, reaching 160 kPa at 0.8 m. While stronger than the near-surface material, these values remain significantly lower than the 300 kPa capacities observed at the stiffer locations, indicating a thicker weathered zone.

DCP 4 records the lowest near-surface bearing capacities, with values of approximately 8 kPa between 0.1 and 0.3 m. Capacities increase to 56 – 80 kPa between 0.4 and 0.6 m, before rising sharply to 320 kPa at 0.8 m. This abrupt increase indicates a thin weak overburden overlying shallow competent material or a cemented horizon.

DCP 5 also shows extremely weak surface conditions, with capacities of 8 – 16 kPa within the upper 0.3 m. However, a rapid increase in bearing capacity is observed with depth, rising to 120 – 136 kPa at 0.4 – 0.5 m, 240 kPa at 0.6 m, and 296 – 320 kPa at 0.7 – 0.8 m. This profile represents the stiffest conditions encountered

below 0.4 m and is consistent with shallow competent dolomite or strongly cemented residual material.

A comparative assessment of all profiles in Table 4.5 and Figure 4.7 identifies three distinct depth zones. In the surface zone (0.1 – 0.3 m), bearing capacities range from 8 to 48 kPa, with a mean of approximately 23 kPa and high variability. These values fall well below the typical allowable bearing pressures for strip or raft foundations (generally  $\geq 100 - 150$  kPa; NHBRC, 2007; SANS 10400-H, 2011), confirming that this zone is unsuitable for direct foundation support.

The transition zone between 0.3 m and 0.6 m shows improved mean bearing capacities of approximately 90 – 130 kPa. However, the relatively high variability (standard deviation  $\approx 28 - 64$  kPa; coefficient of variation of roughly 30 – 50%) indicates inconsistent ground conditions and unreliable performance for shallow foundations without ground improvement or conservative design measures (Day, 2012).

In the deeper zone (0.7 – 0.8 m), bearing capacities display a clear bifurcation. DCPs 1, 4 and 5 achieve high values between 304 and 320 kPa, which are suitable for light to medium structural loads, whereas DCPs 2 and 3 record more moderate capacities of 152 – 184 kPa, which are marginal and may require deeper founding levels or engineered ground improvement. Importantly, even where competent material occurs at shallow depth, the presence of a 0.3 – 0.4 m thick weak overburden layer remains problematic. This layer would require removal, stabilisation, or bypassing through deeper foundations (Webster and Maartens, 2000; Buttrick et al., 2001). In dolomitic terrain, such weak overburden overlying competent material is also a recognised factor contributing to sinkhole susceptibility, reinforcing the need for cautious and conservative foundation design.

The allowable bearing capacities estimated from DCP testing ranged from 152 kPa to 320 kPa at 0.7–0.8 m depth across the five test locations. These values are broadly consistent with those reported by Swart et al. (2021) for dolomitic

residuum in the Pretoria–Centurion region, where similar spatial variability in bearing capacity was attributed to heterogeneous chert content and differential weathering, both of which were observed at this site. As discussed in the literature review, the mechanical strength of the blanketing layer is governed by material composition and moisture conditions, with zones of reduced strength typically associated with more weathered horizons (Ferentinou et al., 2020).

The lower bearing capacities at DCP1 and DCP4 correspond to areas of thinner and more weathered residual soil, which is in agreement with this interpretation. The higher values recorded at 0.7–0.8 m depth at most DCP locations indicate that competent founding horizons are accessible at relatively shallow depths, even within terrain classified as D3 to D4, provided that the dolomite-specific precautions required by SANS 1936-2:2012 are observed.

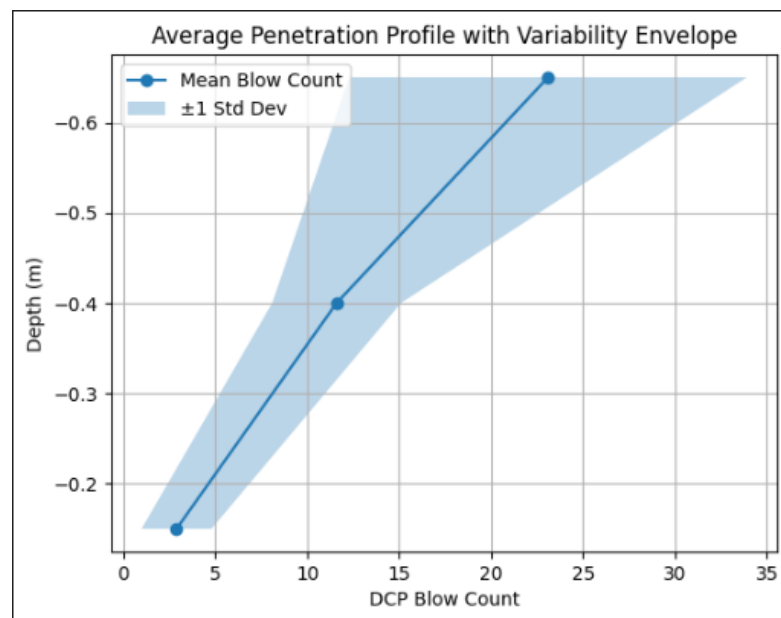
#### 4.4.4 Statistical characterization and variability analysis

The statistical summary of blow counts and derived bearing capacities for each depth zone is presented in Table 4.6, while the corresponding mean penetration profile and associated variability envelope are illustrated in Figure 4.8.

**Table 4.6 : Statistical summary of DCP blow counts, bearing capacities, and soil consistency classification across three depth zones (0 – 0.8 m).**

Depth zone	Blow count range	Mean	Std Dev	Bearing capacity range (kPa)	Mean	Std Dev	Consistency	Engineering significance
<b>0-0.3 m (Surface)</b>	1.0 – 6.0	2.9	1.9	8 – 48	23.5	17.1	Very Loose	Critical weak zone requiring removal/improvement
<b>0.3-0.5 m (Transition)</b>	7.0 – 17.0	11.6	3.5	56 – 136	92.8	29.0	Loose to Medium Dense	Transitional weathering zone
<b>0.5-0.8 m (Deep)</b>	10.0 – 40.0	23.1	10.8	80 – 320	184.5	86.2	Medium Dense to Dense	Increasing competence with depth

Statistical analysis of the complete DCP dataset reveals systematic trends in both central tendency and variability that have significant implications for site characterization and foundation design. The surface zone (0 – 0.3 m) exhibits the lowest absolute resistance (mean blow count 2.9) but moderate relative variability (CV = 65%), indicating that while the material is consistently weak, the degree of weakness varies substantially. This pattern is characteristic of surficial dolomitic residuum subjected to variable weathering processes, as documented by Jennings et al. (1965) and subsequently confirmed in regional studies across the Gauteng dolomite belt (Brink, 1979; Buttrick et al., 2001).



**Figure 4.8:** Average penetration profile with variability envelope

The transition zone (0.3 – 0.5 m) shows increased absolute resistance (mean blow count 11.6) with moderate variability (CV = 30%), suggesting more uniform material properties in this weathering horizon. This zone likely represents a transitional boundary between highly weathered surface residuum and progressively less weathered material at depth. According to Wagener (1982), such transitional zones in dolomitic profiles often contain reworked materials, weathering-resistant chert fragments, or partially leached dolomite, creating locally improved but still heterogeneous conditions.

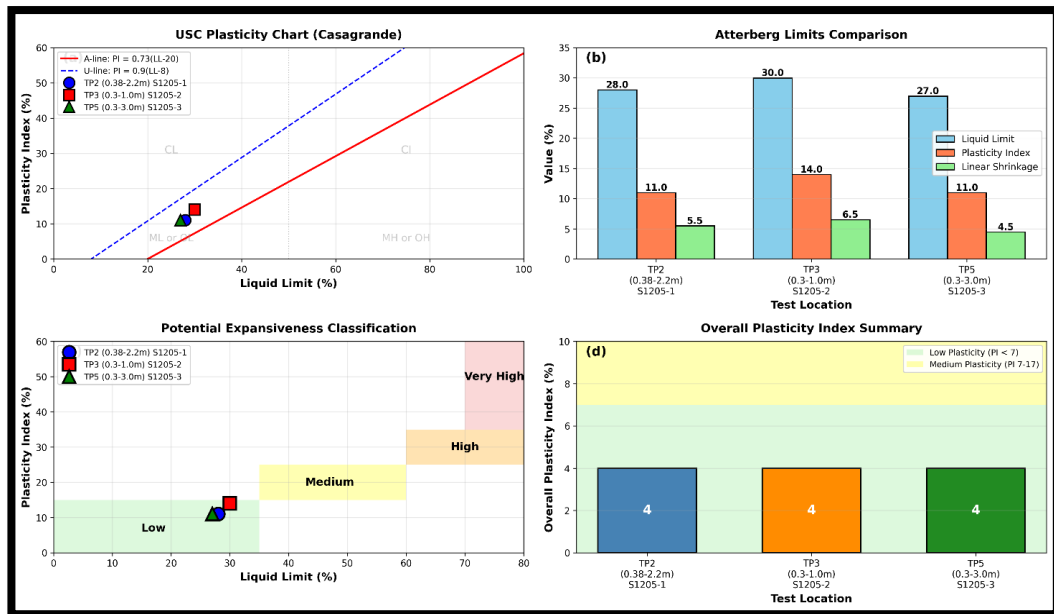
The deep zone (0.5 – 0.8 m) exhibits the highest mean resistance (23.1 blows) but also the greatest absolute variability (standard deviation 10.8, CV = 47%). This high deep-zone variability is the most significant finding from a foundation engineering perspective, as it indicates pronounced spatial heterogeneity at depths where foundations would typically be embedded. The large variability envelope shown in Figure 4.8 quantifies the uncertainty in predicting subsurface conditions between investigation points, a critical consideration for foundation design in dolomitic terrain.

From a geotechnical risk assessment perspective, the bearing capacity statistics are particularly informative. The surface zone shows mean bearing capacity of only 23.5 kPa with a coefficient of variation of 73%, well below any acceptable foundation design threshold. Even at 0.5 – 0.8 m depth where mean bearing capacity reaches 184.5 kPa, the standard deviation of 86.2 kPa (CV = 47%) indicates that actual bearing capacity could range from approximately 100 – 270 kPa within this zone. This variability exceeds the  $\pm 20 - 30\%$  variation typically considered acceptable for uniform foundation design (Terzaghi and Peck, 1967; Day, 2012). The implications are clear: foundations across this site will experience differential performance unless ground conditions are either improved to reduce variability or foundation systems are designed to accommodate significant spatial variation in support capacity. According to NHBRC (2007) and SANS 634 (2012), sites exhibiting such high geotechnical variability in dolomitic terrain should be classified as requiring special foundation measures, which may include deep strip footings, raft foundations with adequate flexibility, or piled foundation systems that extend to more competent and consistent bearing strata.

#### **4.5. Plasticity characteristics and soil classification**

Figure 4.9 shows the results obtained for plasticity characteristics and soil classification. The Atterberg limits test showed that all three test sites in this study had low plasticity characteristics, as illustrated in in Figure 4.9(b). The plasticity

indices were between 11% and 14%, and the liquid limits were between 27% and 30%. This means that all the samples were in the CL (low plasticity clay) zone according to the Unified Soil Classification System (USCS), as seen in Figure 4.9(a). This classification aligns with the characteristics of residual dolomitic soils commonly found in the Gauteng region (Buttrick et al., 2001; Brink, 1979).



**Figure 4.9:** Atterberg Limits and Plasticity characteristics of the site

The low plasticity exhibited by these materials suggests favourable engineering properties for construction purposes. According to Holtz and Kovacs (1981), soils with plasticity indices below 15% generally exhibit minimal volume change behaviour, which is advantageous for foundation stability. The observed plasticity characteristics align well with previous studies of dolomitic residuum in the Pretoria area, where Oosthuizen and Richardson (2011) reported similar low to medium plasticity indices ranging from 8% to 18%.

The potential expansiveness classification (Figure 4.9c) indicates all three samples fall within the 'Low' expansion category, with plasticity indices below 15% (Van der Merwe, 1964). This low expansion potential significantly reduces the risk of heave-related foundation distress, which is particularly relevant for the residential development context at Cornwall Hill. Studies by Schwartz and Yates (1980) have

demonstrated that residual dolomite soils with low plasticity typically exhibit acceptable volume change behaviour under moisture fluctuations.

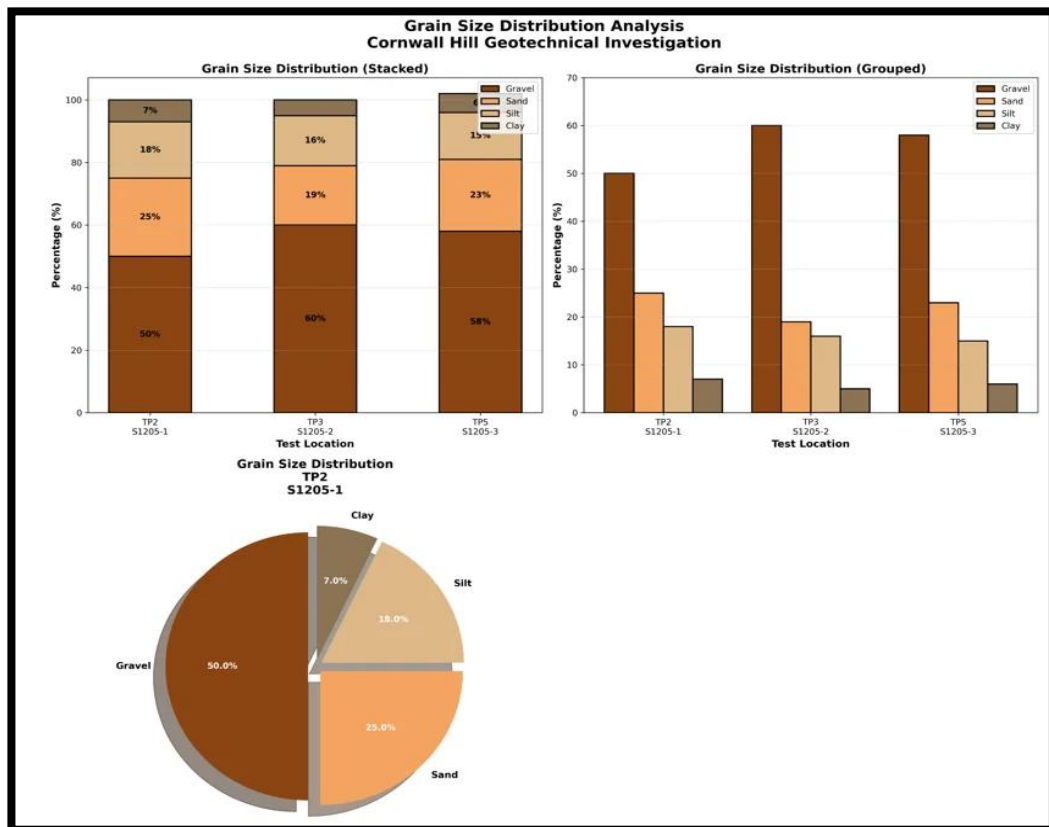
Interestingly, the slight variation in plasticity characteristics between test locations (PI = 11%, 14%, and 11% for TP2, TP3, and TP5 respectively, as shown in Figure 4.9d) may reflect differences in weathering profiles or the degree of clay mineral development within the residual soil matrix. TP3, located at a shallower depth (0.3 – 1.0 m), exhibited marginally higher plasticity, possibly indicating greater weathering intensity near the surface. This observation is consistent with weathering profiles described by Jennings et al. (1973) for South African dolomitic terrains. The plasticity characteristics, while important for understanding clay behaviour, represent only one aspect of the soil composition. A more complete understanding of the engineering properties requires examination of the complete particle size distribution across the soil profile.

The plasticity indices measured for the residual soils ranged from 11% to 14%, placing them in the low plasticity category. These values are consistent with those reported by Buttrick et al. (2001) for stable dolomitic sites in Centurion and Pretoria, where plasticity indices between 10% and 20% were typical, as discussed in the literature review. The Cornwall Hill values fall at the lower end of this range, indicating a less plastic material with lower susceptibility to volume change under moisture fluctuation.

Clay-rich blanketing layers with high plasticity are more prone to weakening through cyclic wetting and drying (Day, 1988; Kleinhans and Van Rooy, 2016), and the measured clay content of 5–7% and low PI values suggest that the residual soil at this site is not dominated by expansive clay minerals. By comparison, Trollip et al. (2010) reported clay fractions exceeding 15% at more intensely weathered dolomitic sites, indicating that the blanketing material at Cornwall Hill is in generally better condition than that at some comparable sites in the region. These characteristics support the suitability of the residual soils for foundation purposes, subject to adequate management of surface water infiltration.

#### 4.6. Particle size distribution and soil composition

The study looked at the particle size distribution and Grain size distribution analysis revealed predominantly coarse-grained soils across all test locations, with gravel comprising 50 – 60% of the soil mass (Figure 4.10a). This gravel-dominated composition is characteristic of residual dolomitic soils where the insoluble fraction accumulates during carbonate dissolution (Brink, 1979; Day, 1988). The relatively high gravel content provides favourable load-bearing characteristics and enhanced drainage properties, both of which are beneficial for foundation performance.



**Figure 4.10: Grain size distributions measured from samples collected on site**

The sand content ranged from 19% to 25%, with finer fractions (silt and clay) constituting 23 – 25% of the total mass (Figure 4.10b). This gradation places the materials in the well-graded category, which typically provides good mechanical interlock and higher shear strength compared to uniformly graded soils (Das, 2010). According to the South African National Standard SANS 1200 DB (2012),

these materials would classify as G5 to G6 gravel, suitable for subbase and selected subgrade applications in road construction.

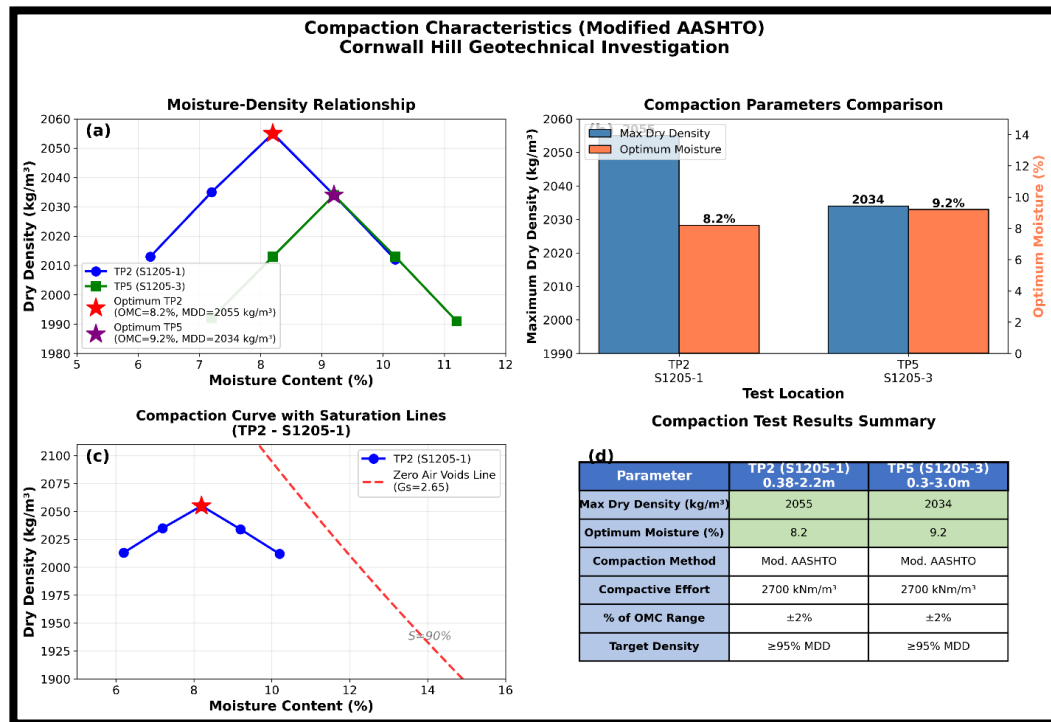
The relatively low clay content (5 – 7%) is particularly significant in the context of dolomite stability, as illustrated by the detailed composition breakdown for TP2 in Figure 4.10(c). Higher clay contents can indicate more advanced weathering and potentially weaker soil structures. The observed clay percentages fall within the range reported by (Trollip et al, 2010) for stable dolomitic soils in the Gauteng region, where clay contents below 15% are generally associated with lower sinkhole susceptibility. TP3 exhibited the highest gravel content (60%) and lowest clay fraction (5%), suggesting a relatively competent soil profile. This is consistent with the position of the location in the site stratigraphy and may indicate proximity to less weathered dolomite bedrock. The gradation curves demonstrate good particle interlocking potential, which contributes to the bearing capacity and stability of the soil mass (Terzaghi et al., 1996).

The grain size distribution also provides insights into permeability characteristics. The gravel-dominated composition suggests relatively high hydraulic conductivity, which facilitates rapid drainage and reduces the likelihood of prolonged water ponding. This is particularly important in dolomitic terrain, where sustained water infiltration can accelerate carbonate dissolution and contribute to subsidence development (Buttrick and Van Schalkwyk, 1998). While the particle size distribution reveals the inherent composition of these residual soils, their engineering performance in the field depends critically on achieving proper compaction during construction. The compaction characteristics therefore represent a crucial link between the natural soil composition and its engineered performance.

#### **4.7. Compaction characteristics and density-moisture relationships**

Modified AASHTO compaction testing yielded maximum dry densities (MDD) of 2,055 kg/m<sup>3</sup> and 2,034 kg/m<sup>3</sup> for TP2 and TP5, respectively, with corresponding

optimum moisture contents (OMC) of 8.2% and 9.2% (Figure 4.11a & b). These values are characteristic of gravel-rich soils and align well with typical compaction parameters for residual dolomitic materials reported in the South African geotechnical literature (Brink, 1979; TMH1, 1986).



**Figure 4.11:** Compaction characteristics (Modified AASHTO)

The relatively high maximum dry densities reflect the coarse-grained nature of the soils and indicate excellent compactability. According to Proctor (1933), who pioneered compaction theory, soils with higher gravel contents typically achieve greater densities at lower optimum moisture contents, which is precisely what was observed at Cornwall Hill. The moisture-density curves (Figure 4.11a) show well-defined peaks, indicating clear optimum compaction conditions that can be readily achieved during construction.

The low optimum moisture contents (8.2 – 9.2%) are particularly advantageous from a construction perspective, as they minimize the moisture adjustment required during earthworks. This is especially beneficial in dolomitic areas where excessive wetting should be avoided to prevent potential dissolution-related

subsidence (Buttrick et al., 2001). The observed OMC values are consistent with findings by Netterberg (1994) for calcrete and gravelly soils in southern Africa.

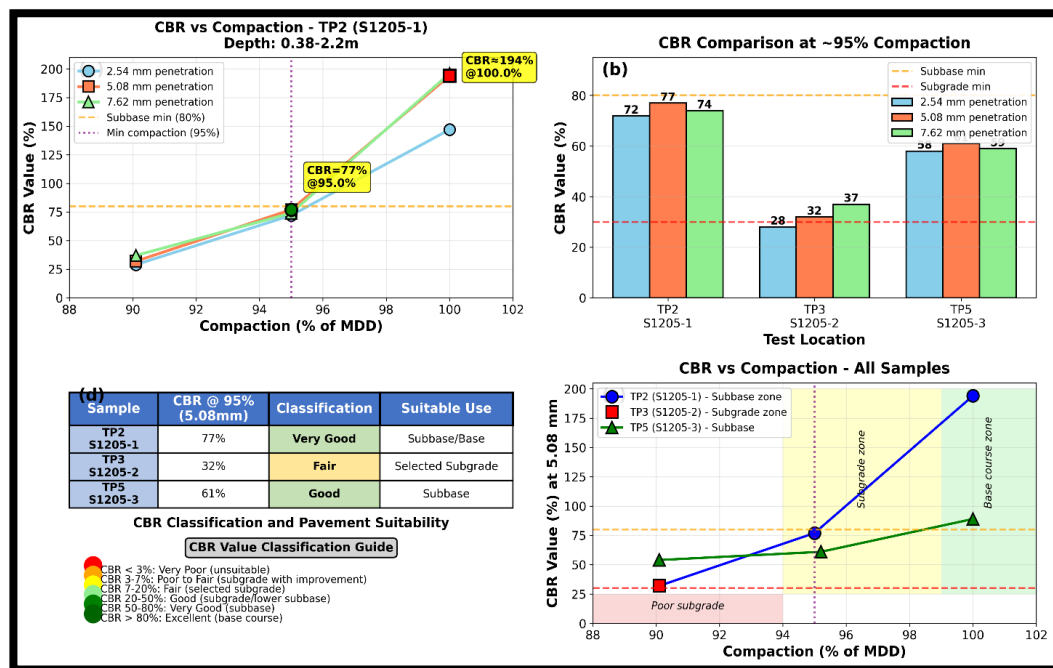
The degree of saturation at optimum compaction was calculated to be approximately 65% for both samples, based on the ZAV line shown in Figure 4.11(c). This relatively low saturation level at optimum compaction ensures adequate air void space, which is desirable for maintaining soil stability and preventing pore pressure buildup under loading (Holtz and Kovacs, 1981). The moisture-density relationships demonstrate that achieving 95 – 100% of MDD is readily attainable within a practical moisture content range. The slight difference in MDD between TP2 (2,055 kg/m<sup>3</sup>) and TP5 (2,034 kg/m<sup>3</sup>) likely reflects minor variations in particle size distribution and mineralogical composition. The higher density of TP2 correlates with its marginally higher clay and silt content, which can fill void spaces more effectively during compaction. Both values exceed the typical minimum density requirements of 1,950 kg/m<sup>3</sup> specified for selected subgrade materials in South African road design standards (COLTO, 1998).

The compaction curves show relatively flat peaks, which is advantageous as it provides a wider acceptable moisture range for achieving target densities. The moisture-density relationship, characterized by its forgiving nature, facilitates field compaction processes and diminishes sensitivity to moisture fluctuations during construction. These attributes have been identified by Sampson and Netterberg (1985) as advantageous indicators for pavement foundation materials. Nevertheless, although high compaction densities can be attained, the ultimate engineering performance of these soils is contingent upon their load-bearing capacity under field conditions. The CBR testing provides a direct measurement of this critical design parameter.

#### **4.8. Bearing capacity and CBR performance**

Figure 4.12 illustrates the CBR test results, featuring: (a) the relationship between CBR and compaction for TP2 (S1205-1) at a depth of 0.38 – 2.2m; (b) a bar chart

comparing CBR values at approximately 95% compaction, displaying values at three penetration depths across all test locations (TP2, TP3, TP5) alongside subbase and subgrade minimum thresholds; (c) a table summarizing CBR at 95% compaction, including classification (Very Good, Fair, Good) and suitable use for each sample; (d) a scatter plot depicting the relationship between compaction level and CBR for all three test locations, with zone classifications (subbase, subgrade, poor subgrade, base course).



**Figure 4.12:** Correlation between compaction and CBR values of the test site

CBR testing revealed significant variation in load-bearing capacity across the three test locations (Figure 4.12b). At 95% compaction, CBR values ranged from 32% (TP3) to 77% (TP2), with TP5 exhibiting an intermediate value of 61%. These results demonstrate that while the overall site contains competent bearing materials, spatial variability in soil quality necessitates careful foundation design.

TP2 achieved a CBR of 77% at 95% compaction, classifying the material as 'Very Good' and suitable for subbase or base course applications in pavement design (TMH1, 1986; Figure 4.12c). This high CBR value indicates excellent load-bearing characteristics and correlates well with the favourable grain size distribution and

high maximum dry density of the location. According to Yoder and Witczak (1975), CBR values above 50% are indicative of high-quality granular materials that require minimal pavement thickness for load distribution.

The relationship between CBR and compaction level at TP2 (Figure 4.12a) shows a steep increase from 77% at 95% compaction to approximately 194% at 100% compaction. This strong sensitivity to compaction degree highlights the importance of achieving adequate field compaction to realize the full bearing capacity potential of the soil. The dramatic improvement with increased compaction is characteristic of coarse-grained, well-graded materials where particle interlock and density significantly influence strength (Bowles, 1996).

In contrast, TP3 exhibited a CBR of only 32% at 95% compaction, classifying the material as 'Fair' and suitable for selected subgrade applications. This lower bearing capacity, despite the location having the highest gravel content (60%), suggests that factors beyond particle size distribution influence strength characteristics. Possible explanations include differences in particle angularity, presence of weathered or weak particles, or variations in the degree of cementation within the soil matrix (Netterberg, 1994).

The CBR value of 61% recorded at TP5 indicates that the soil at this location is of good quality and capable of adequately supporting foundations for most construction purposes. The strength of the soil was tested at three penetration depths 2.54 mm, 5.08 mm, and 7.62 mm and the results shown in Figure 4.12(b) confirm that the soil resists loading consistently at all three depths, suggesting that the soil composition is largely uniform throughout the tested layer.

However, the CBR values differ noticeably between the three test locations, ranging from low to high, with a coefficient of variation of 37%. This means that the soil bearing capacity is not the same across the site some areas are stronger than others. This variability is typical of residual dolomitic soils, where the degree of weathering and dissolution of the underlying dolomite rock can differ significantly over short distances. Figure 4.12(d) illustrates these differences

clearly, with each test location occupying a distinct zone that reflects its individual bearing capacity characteristics.

For foundation design purposes, the most conservative CBR value (32% from TP3) should be considered for initial design calculations, with site-specific adjustments based on detailed subsurface investigations at specific building locations. Using the relationship proposed by Black (1961) for estimating allowable bearing pressures from CBR values, these results suggest allowable bearing capacities ranging from 150 kPa to 350 kPa for shallow foundations, depending on location and foundation depth.

The CBR results also provide guidance for pavement design if roadways are constructed within the development. According to the South African Mechanistic-Empirical Design Method (Theyse et al., 1996), the observed CBR values would require pavement thicknesses ranging from 150 mm to 300 mm for typical residential traffic loadings, with TP3 locations requiring additional pavement thickness or soil improvement measures. While the mechanical properties assessed through Atterberg limits, grain size, compaction, and CBR testing provide essential information on soil strength and behaviour, the long-term performance of foundations and buried infrastructure also depends critically on soil chemistry and its potential effects on construction materials.

#### **4.9. Soil chemistry and corrosivity assessment**

Soil chemistry analysis was conducted on representative samples from TP2 to evaluate potential corrosion risks to buried infrastructure and foundation materials (Table 4.7). The chemical properties of soil are critical parameters that influence the long-term durability of concrete foundations, steel reinforcement, and buried utilities such as water pipes and electrical conduits. The assessment focused on three key parameters: pH, electrical conductivity, and electrical resistivity.

**Table 4.7:** Soil chemistry and engineering implications

Parameter	Value	Classification	Engineering significance
pH	6.18	Moderately Acid	Slightly acidic; may cause mild corrosion of steel/concrete over long term
Conductivity	0.01 S/m	Very Low	Low dissolved ion content; low corrosion potential
Resistivity	82.059 $\Omega$ -m	Non-Corrosive	Excellent for buried steel/concrete; no special protection needed

The measured pH of 6.18 classifies the soil as moderately acidic. This slight acidity may cause mild corrosion of steel and concrete over extended periods, particularly in the presence of moisture. According to the Portland Cement Association, concrete in contact with soils having pH values between 5.5 and 6.5 is considered to be in a mildly aggressive environment. While this does not necessitate special concrete mixes for typical residential construction, it does suggest that good construction practices should be followed, including adequate concrete cover over reinforcement (minimum 50 mm for foundations in contact with soil) and proper curing to ensure dense, impermeable concrete.

The measured electrical conductivity of 0.01 S/m is classified as very low, indicating minimal dissolved ionic content within the soil moisture. Low conductivity is associated with reduced electrochemical corrosion potential, as it reflects a scarcity of mobile ions required to sustain corrosion reactions (Roberge, 2008; Baeckmann et al., 1997). This condition limits the likelihood of galvanic corrosion in buried metallic infrastructure. Furthermore, very low conductivity values typically indicate the absence of aggressive ions such as chlorides and sulphates, which are the primary contributors to concrete deterioration and steel corrosion in soil environments (Neville, 2011; ACI 222R-01, 2001).

The measured soil resistivity of approximately 82  $\Omega\cdot\text{m}$  falls within the non-corrosive classification according to standard corrosion assessment criteria (BS EN 12501-2, 2003). Soils with resistivity values exceeding about 50  $\Omega\cdot\text{m}$  are generally considered to present a low corrosion risk to buried steel structures (Peabody and Bianchetti, 2001). The relatively high resistivity recorded at Cornwall Hill therefore indicates favourable conditions for buried steel and concrete infrastructure, with no requirement for specialised corrosion protection measures beyond standard construction practice (NACE, 2013; Broomfield, 2007).

The combination of moderately acidic pH, very low electrical conductivity, and high soil resistivity reflects an overall benign chemical environment for construction. While slightly acidic conditions warrant attention to concrete quality and reinforcement cover, the low conductivity and high resistivity significantly limit the rate of potential corrosion reactions. This electrochemical profile is characteristic of well-drained residual dolomitic soils, where extensive leaching has removed most soluble salts, resulting in chemically stable ground conditions (Brink, 1979; Buttrick et al., 2001).

It should be noted that these soil chemistry parameters represent conditions at TP2 and may vary across the site due to local variations in soil composition, moisture content, and organic matter. Additional soil chemistry testing at other locations would provide a more comprehensive assessment of chemical variability across the development. Furthermore, these measurements represent current conditions; changes in site hydrology following development (such as increased infiltration from irrigation or leaking services) could potentially alter soil chemistry over time, though the well-drained nature of the gravel-rich soils provides some protection against significant chemical changes. Having now characterized the soil profile through physical properties (Atterberg limits, grain size distribution), mechanical properties (compaction, bearing capacity), and chemical properties (pH, conductivity, resistivity), it is essential to synthesize these findings to provide an integrated assessment of dolomite stability and foundation design implications for Cornwall Hill.

#### **4.10. Implications for dolomite stability and foundation performance**

The laboratory results reveal that residual dolomitic soils characteristic of Cornwall Hill possess generally favourable engineering properties for foundation support. The combination of low plasticity (PI = 11 – 14%), high gravel content (50 – 60%), good compaction characteristics (MDD > 2000 kg/m<sup>3</sup>), predominantly good to very good bearing capacity (CBR = 61 – 77% for TP2 and TP5), and non-aggressive soil chemistry (pH = 6.18, resistivity = 82 Ω·m) indicates competent foundation conditions across much of the site. These properties collectively suggest stable, well-consolidated residual dolomite that is suitable for conventional residential development with appropriate design considerations.

However, the results also reveal important spatial variability that must be addressed in foundation design. Lower CBR (32%) and slightly higher plasticity of TP3 suggest a zone of potentially weaker material that may require localized foundation enhancement measures. This variability is characteristic of dolomitic terrains where weathering profiles are inherently heterogeneous (Day, 1988; Buttrick et al., 2001).

From a dolomite stability perspective, the low clay content (5 – 7%) and relatively high density of the residual soils are positive indicators. According to Jennings et al. (1973), residual dolomite profiles with these characteristics typically represent stable, well-consolidated conditions with lower susceptibility to sudden subsidence. The absence of high plasticity clays or very loose materials suggests that the site is not in an active dissolution zone.

The test results indicate that the subsurface conditions across most of the site are compatible with conventional shallow foundation systems, when interpreted in the context of the measured penetration resistance, bearing capacity, and observed spatial variability. The DCP and bearing capacity profiles show that, although conservative parameters are required to represent weaker zones, several locations exhibit higher bearing capacities and stiffer response at shallow depth, reflecting more competent material within the investigated depth range.

The results also demonstrate marked lateral variability in subsurface conditions. Differences in penetration resistance and bearing capacity between adjacent DCP locations indicate that soil properties vary over short distances, which is characteristic of residual dolomitic terrains. This variability is directly reflected in the spread of measured values and statistical summaries derived from the test data.

The measured soil chemistry provides additional context to the mechanical results. Low electrical conductivity and high resistivity values indicate a chemically benign soil environment, consistent with limited ionic mobility and low corrosion potential. These chemical characteristics support the interpretation that the observed ground conditions are not influenced by aggressive soil chemistry within the investigated depth range.

When considered alongside published data from comparable dolomitic sites in the Gauteng region, the Cornwall Hill results are broadly consistent with conditions associated with manageable, moderate-risk terrain. The combination of low plasticity (PI = 11–14%), high gravel content (50–60%), and high dry density (MDD > 2000 kg/m<sup>3</sup>) is characteristic of well-consolidated residual dolomite profiles that Buttrick and Van Schalkwyk (1998) associated with D3-class terrain, and the results therefore support the D3 designation assigned to Zone A. However, the spatial variability observed across the site, particularly the lower CBR at TP3 (32%) and the cavity intersected in BH01, indicates that geotechnical conditions are not uniform.

As discussed in the literature review, Boo et al. (2020) and Ferentinou et al., (2020) noted that even broadly stable dolomitic sites may contain localized zones of elevated collapse potential, and the present results are consistent with this observation. The proximity of Zone A (D3) and Zone B (D4) conditions across short lateral distances at this site further supports the findings of Oosthuizen and Van Rooy (2015), who emphasized that site-specific investigation is necessary for

accurate hazard classification in dolomitic terrain rather than reliance on regional generalizations.

#### **4.11. Comparison with regional dolomite studies**

The results obtained from Cornwall Hill show general agreement with previous investigations of dolomitic residuum in the Gauteng region. Buttrick et al. (2001) reported similar grain size distributions and plasticity characteristics for stable dolomitic sites in Centurion and Pretoria, with clay contents typically below 10% and plasticity indices ranging from 10% to 20%. The Cornwall Hill results fall within these ranges, suggesting comparable geological conditions.

However, the CBR values obtained at Cornwall Hill (32 – 77%) show a wider range than those reported by Brink (1979) for typical Gauteng dolomitic soils (CBR = 45 – 65%). This greater variability may reflect the specific geological setting of Cornwall Hill or differences in testing methodology. Nonetheless, the upper range values (61 – 77%) align well with the 'good' to 'very good' classifications established in South African pavement design manuals (TMH1, 1986).

The compaction characteristics (MDD = 2034 – 2055 kg/m<sup>3</sup>, OMC = 8.2 – 9.2%) compare favourably with data compiled by Netterberg (1994) for gravelly residual soils in Southern Africa. The observed maximum dry densities exceed typical values for standard AASHTO compaction (1900 – 2000 kg/m<sup>3</sup>), confirming the dense nature of these gravel-rich materials.

#### **4.12. Percussion borehole drilling results**

The percussion borehole drilling results provide insight into subsurface conditions at depths beyond the range investigated by test pits and DCP testing. The boreholes intersected a sequence of residual soils and weathered material overlying increasingly competent strata, with termination depths reflecting refusal against hard or very dense material.

Lithological logging based on recovered chip samples indicates that the upper portions of the boreholes are generally characterized by residual soils and weathered dolomitic material of variable thickness. These materials show progressive changes in texture and consistency with depth, transitioning from softer, more weathered horizons near surface to denser and less weathered material at greater depths. This trend is consistent with the increase in penetration resistance and bearing capacity observed in the shallow investigation results.

At greater depths, the boreholes encountered horizons interpreted as highly weathered to partially weathered dolomite, with occasional indications of cemented zones or intact rock fragments. The depth at which these more competent materials were encountered varies across the site, reflecting lateral variability in weathering depth and bedrock topography, a characteristic feature of dolomitic terrain.

The borehole profiles corroborate the DCP and bearing capacity results by confirming that competent material occurs at relatively shallow to moderate depths in some areas, while thicker weathered profiles persist elsewhere. This variability supports the interpretation of a heterogeneous subsurface profile, with irregular transitions between residual soils, weathered dolomite, and competent material.

The spatial distribution of boreholes is shown in Figure 4.13, while a summary of the borehole depths and interpreted lithological units is provided in Table 4.9. Borehole descriptions were compiled in accordance with standard South African soil and rock logging practice as outlined by (Brink and Bruin, 2002).



**Figure 4.13:** Locations and depths of the four rotary percussion boreholes (BH01 – BH04) at the Cornwall Hill study site, Centurion

**Table 4.8:** Summary of the information of individual boreholes

BH ID.	Colluvium / Transported	Chert Residuum (m)	Weathered Dolomite (m)	Cavity / Wad (m)	Dolomite Bedrock (m)	End of BH	Ground water (m)		Risk Assessment				Inherent Hazard Class (IHC)	Dolomite Designation
							Water Strike	Water Rest level	Ingres Scenario		Dewatering Scenario			
									Low	High	Low	High		
BH 01	0 - 2	-	13-15	2-13	15-25	25	-	Dry	Med-High	Med-high	Low	Low	6/(1)	D4
BH 02	-	0-2	-	-	2-11	11	-	Dry	Low-Med	Low-Med	Low	Low	5/(1)	D3

BH 03	-	0-2	-	-	2-10	10	-	Dr y	Lo w-Me d	Lo w-Me d	Lo w	Lo w	5//(1)	D3
BH 04	0-3	3-5	-	-	5-11	11	-	Dr y	Lo w	Lo w	Lo w	Lo w	5//(1)	D3

No groundwater strikes were encountered in any of the four boreholes during the investigation period. This observation suggests that the groundwater table, if present, occurs at depths greater than 25 m below ground level or is discontinuous due to the fractured nature and moderate to high drainage capacity of the dolomitic bedrock. This observation is consistent with hydrogeological studies in the Malmani Subgroup dolomites, which indicate that groundwater often occurs at considerable depths in recharge areas, while discharge zones are typically localized to topographic lows and stream channels (Enslin and Kriel, 1967; Bredenkamp et al., 1995).

The absence of shallow groundwater is advantageous from a geotechnical perspective, as it eliminates concerns related to buoyancy effects on foundations, groundwater-induced settlement, and the need for excavation dewatering (reference). The borehole profiles confirm the dominance of competent dolomite bedrock, underlain by thin veneers of colluvium or residual soil near the surface. This stratigraphic profile is typical of the weathering profile developed on dolomite bedrock in the Gauteng Province.

These findings are consistent with the results of the gravity survey and test pit profiling and serve to validate the conceptual geotechnical model developed for the site. The percussion drilling results support the assessment that the site is structurally suitable for shallow to moderately deep foundations, provided that dolomite-specific risk mitigation measures are incorporated into the foundation design, as recommended by NHBRC Guidelines (2007) and SANS 1936-1:2012.

These findings are consistent with the results of the gravity survey and test pit profiling and serve to validate the underlying geotechnical model of the site. The percussion drilling results support the assessment that the site is structurally suitable for shallow to moderately deep foundations, provided dolomitic risk mitigation is incorporated in the design. Drillers logs and borehole logging are presented in Appendix D and Appendix E respectively.

#### **4.13. Borehole lithology and stratigraphic profile**

Detailed lithological logging was carried out on chip samples retrieved from each percussion borehole at 1-m intervals. This was performed in accordance with the (Brink and Bruin,1990). The logging process aimed to classify the geological strata encountered, assess material variability, and identify zones of potential instability, such as cavities or voids that are common in dolomitic terrain.

The presence of chert layers is significant, as chert is highly resistant to dissolution and often forms protective caps that can slow or prevent downward cavity propagation (Jennings et al., 1965). The site geology confirms that the area under investigation is dominated by layers of residual chert overlying dolomite bedrock in the Malmani Subgroup. The drilling data corroborates the regional geological mapping derived from Council for Geoscience GIS datasets, confirming that the site is predominantly underlain by competent dolomite bedrock. Localised zones of deeper weathering, such as those encountered in BH01, reflect the inherent variability and unpredictable nature of dolomitic terrains.

The stratigraphic sequence observed during drilling operations is consistent with typical dolomite weathering profiles in the Gauteng Province. The sequence commences with a relatively thin surficial layer of colluvium material (generally less than 1 m thickness), described as brown sandy silty clay with abundant greyish white highly weathered chert fragments. This is underlain by a blanketing layer of chert-rich dolomitic residuum encountered at variable depths from 1 m to 24 m,

characterized as yellowish-brown clayey sandy silt with minor grey highly weathered chert fragments transitioning to grey dolomite fragments at depth.

The combined field and laboratory results indicate that the materials overlying the dolomite bedrock are generally well-graded, non-expansive sandy silt with gravel, classified as A-2-6(0) in terms of the AASHTO system. This material exhibits favourable strength characteristics at depth, as reflected by the increase in DCP-derived bearing capacities within the 0.6–1.0 m interval and the high CBR values obtained from laboratory testing. These results indicate that, from a material strength perspective, the residual soils are capable of supporting typical infrastructure loads under uniform ground conditions.

However, the interpretation of these results must be considered within the broader geological context of the site. Despite the favourable soil properties, the presence of karstic dolomite beneath the residual cover introduces inherent uncertainty associated with irregular weathering profiles and variable bedrock depth. The observed spatial variability in penetration resistance and borehole profiles demonstrates that subsurface conditions are not uniform across the site. Consequently, the behaviour of the founding materials is controlled not only by soil strength but also by the underlying dolomitic terrain, which governs the overall geotechnical response. A summary of the lithological conditions encountered in each borehole, including significant strata and termination depths, is presented in Table 4.9, which provides the basis for the interpretation of subsurface variability discussed in this section.

**Table 4.9:** Summary of rock conditions encountered during drilling

BH ID.	Colluvium	Chert	Dolomite	Cavity	Water Strike	Final Depth
<b>Depth to base of stratum (mbgl)</b>						
BH01	0 – 2	-	-	2 – 13	-	25
BH02	-	0 – 2	2 – 11	-	-	11
BH03	-	0 – 2	2 – 10	-	-	10
BH04	0 – 3	3 – 5	3 – 5	-	-	11

The cavity intersected in BH01 between 2 m and 13 m depth is the most significant geotechnical finding of the drilling. As discussed in the literature review, sinkhole development in dolomitic terrain requires three conditions to be satisfied simultaneously: the presence of soluble bedrock, an overlying unconsolidated cover layer, and a mechanism for the progressive removal of that cover into underlying voids (Buttrick, 1992; Culshaw and Waltham, 2005). All three conditions are present at the BH01 location.

The Malmani Subgroup dolomite constitutes the soluble bedrock, the 0–2 m colluvial overburden provides the cover material, and the absence of a formal stormwater drainage system, documented in Section 4.14, creates conditions conducive to concentrated water ingress. This is consistent with Richardson and Van Rooy (2018), who documented that more than 90% of sinkholes in developed dolomitic areas of Gauteng result from water ingress rather than dewatering. The cavity depth and extent are in agreement with the IHC 6 classification and D4 designation assigned to Zone B in accordance with Buttrick et al. (2001) and SANS 1936-2:2012, confirming that the geophysical and drilling results are consistent and lead to the same risk assessment outcome.

#### **4.14. Hydrogeological conditions**

Hydrogeological conditions are a critical component of geotechnical investigations, particularly in dolomitic terrains where the interaction between water and soluble carbonate rock can influence ground stability. This section presents the results and interpretation of surface drainage characteristics and groundwater observations based on both direct field measurements and inferred indicators.

##### **4.14.1 Surface Drainage and Runoff Patterns**

Field observations from the reconnaissance and detailed investigation phases indicate that the site does not have a formal stormwater management system. Surface runoff occurs along irregular, non-engineered flow paths that are largely controlled by local microtopography rather than by defined drainage infrastructure. No evidence of constructed drainage features, such as channels, catchpits, or culverts, was observed within or immediately adjacent to the proposed development area.

The absence of structured surface drainage results in localized surface water accumulation during rainfall events. Although no groundwater was encountered within the investigated depth range, such surface water accumulation can promote localized infiltration into the shallow residual soil profile. In dolomitic terrains, this form of near-surface infiltration is significant because it may enhance dissolution and erosion processes within the weathered zone above bedrock. Over time, these processes can contribute to soil ravelling and the gradual development of subsurface voids, which are recognized precursors to subsidence or sinkhole formation (Wagener, 1982; Buttrick et al., 2001).

##### **4.14.2 Groundwater Conditions**

No groundwater strikes were recorded during drilling, with all boreholes remaining dry to the maximum investigated depth of 25 m below ground level. This indicates that the groundwater table, if present, occurs at a depth greater than that investigated or is discontinuous within the fractured dolomitic bedrock. The absence of a shallow groundwater table is a relevant observation in the context of

site stability, as it implies that subsurface conditions are not influenced by groundwater-level fluctuations within the investigated depth range. This reduces the likelihood of instability mechanisms associated with rapid groundwater drawdown or dewatering-related subsidence, which have been documented in other dolomitic and mining-affected areas (Enslin and Kriel, 1967; Wagener et al., 1997).

The absence of a formal stormwater drainage system is reflected in the observed surface and near-surface conditions across the site. Borehole and test pit results, including the deeper weathering profile encountered at TP5 and BH01, together with irregular subsurface profiles, indicate that surface water ingress has influenced localized dolomite weathering. In some areas, the shallow depth to dolomite bedrock (approximately 1.0 – 2.5 m) is consistent with progressive erosion of the residual soil cover and topsoil removal associated with uncontrolled surface runoff.

The hydrogeological observations indicate that current stability conditions are not governed by a shallow groundwater table, as no groundwater was encountered within the investigated depth range. Instead, the data suggests that localized infiltration of surface water into the weathered zone represents the dominant hydrological influence on subsurface conditions. This interpretation is consistent with documented case histories from dolomitic areas in Gauteng, where instability has been associated with concentrated surface water ingress rather than regional groundwater fluctuations (Meyer et al., 2003; Joubert, 2006).

Although groundwater was not intersected during the investigation, this observation does not preclude longer-term variations in groundwater conditions related to seasonal recharge or extended periods of above-average rainfall. Within this context, the integrated hydrogeological assessment indicates that surface-related water ingress constitutes the primary contributor to potential instability mechanisms at the site, while the groundwater component reflects a lower order

of influence within the investigated depth range, as classified in terms of the Inherent Hazard Classification framework of SANS 1936-1 (2012).

The subsurface material is predominantly composed of non-cohesive sandy residual soils, which typically exhibit moderate drainage characteristics. However, these soils are susceptible to loss of capacity when saturated, due to reduced stiffness and effective confining stress. In such materials, fluctuating shallow water tables or temporary saturation due to poor drainage can result in instability or deterioration in service performance of lightly loaded structures. Furthermore, no indicators of ferricrete, silcrete, or ferruginisation were recorded during logging, which often signal the presence of a fluctuating or perched water table. However, the potential for vertical water movement through permeable sandy layers necessitates precautionary design consideration.

No groundwater was recorded in any of the four boreholes to the maximum investigated depth of 25 m. This is consistent with the hydrogeological characterization of Malmani Subgroup dolomites presented in the literature review, where Enslin and Kriel (1967) and Bredenkamp et al. (1995) noted that groundwater in recharge areas typically occurs at considerable depth, with shallow groundwater more characteristic of topographic discharge zones. The dry borehole conditions suggest that the site occupies a recharge position in the regional groundwater system.

The dewatering-related instability mechanism discussed in the literature review, whereby declining water tables remove buoyant support and promote collapse (Buttrick, 1992; Dippenaar et al., 2018), is therefore not considered the dominant stability risk at this site. Instead, the hydrogeological data support the interpretation that localised surface water ingress represents the primary hydrological influence on subsurface conditions. This is in agreement with Richardson and Van Rooy (2018) and Kleinhans and Van Rooy (2016), who identified concentrated stormwater infiltration as the dominant trigger mechanism in comparable urbanised dolomitic areas of Gauteng. The absence of

a formal stormwater management system on site, observed during the reconnaissance survey, therefore represents the most significant water-related risk factor for future development and should be addressed in accordance with the requirements of SANS 1936-1:2012 and Watermeyer et al. (2008).

## **Chapter 5. Conclusion and recommendations**

This study investigated the geotechnical characteristics of dolomitic terrain at Cornwall Hill in Centurion, South Africa, to assess sinkhole formation risk and guide safe development planning. Dolomitic areas in Gauteng Province are highly susceptible to subsurface dissolution, cavity formation, and ground subsidence, with approximately 93% of sinkholes attributed to anthropogenic water ingress. The research addressed the critical need for comprehensive site-specific characterization to support development in these geologically challenging areas where infrastructure damage from sinkhole events has resulted in significant economic losses and safety concerns.

The study successfully achieved all research objectives through a multi-method investigation approach. The ArcGIS ArcMap software generated a geological map that established the regional geological context and identified the site as underlain by Malmani Subgroup dolomites. Gravity geophysical surveys on a 50 m × 50 m grid successfully identified subsurface density variations consistent with irregular dolomite bedrock topography. Test pits and rotary percussion boreholes (10 – 25 m depth) effectively determined soil stratigraphy and weathering profiles, revealing gravel-rich residual soils of variable thickness. Comprehensive laboratory testing successfully characterized geotechnical properties including Atterberg limits, grain size distribution, compaction characteristics, and bearing capacity (CBR), providing essential data for foundation design and development planning.

This chapter synthesizes the key findings from the ArcGIS, gravity survey, test pitting, drilling, and laboratory analyses. Conclusions are drawn directly from the results presented in Chapters 3 and 4, while recommendations for guiding site development are outlined to ensure safe and sustainable construction practices. The integrated analysis successfully categorized the site into two geotechnical zones and demonstrated that development is feasible when appropriate engineering measures are implemented.

## 5.1. Conclusions

The study concluded that the site falls within a dolomitic environment characterized by residual soils overlying variably weathered dolomite bedrock. Site investigations confirmed that the Cornwall Hill development zone is an area where dolomite is prone to dissolution, cavity formation, and potential sinkhole development. The results of the gravity surveys confirmed minor density variations consistent with irregular dolomite bedrock. Limitations in DGPS accuracy and grid spacing may have left smaller anomalies undetected.

Test pits and drilling confirmed gravel-rich residual soil profiles of variable thickness, although no direct cavity interception was evident. Laboratory testing provided comprehensive characterization of soil properties. Plasticity Index values ranged from 11% to 14%, falling within the low expansion category. Grain size distributions indicated 50 – 60% gravel, 19 – 25% sand, and 23 – 25% fines, with 5 – 7% clay content, representing well-graded soils with good drainage capacity. Maximum dry densities varied between 2,034 and 2,055 kg/m<sup>3</sup> at optimum moisture contents of 8.2% to 9.2%. CBR values distinguished between stronger zones (TP2, TP5: 61 – 77%) and a notably weaker zone (TP3: 32%). Soil chemistry indicated slightly acidic pH values of 6.18 and favourable resistivity of 82 Ω·m, confirming low corrosion risk for buried infrastructure.

The site was categorized into Zone A (Inherent Hazard Class (IHC) 5//1-D3) and Zone B (Inherent Hazard Class (IHC) 6//1-D4) through geotechnical zonation, as illustrated in Appendix G. Zone A represents the more favourable portion, underlain by competent residual soils with lower plasticity, higher CBR values, and generally stable subsurface conditions. This zone is classified as moderate risk (D3), appropriate for conventional foundations with standard dolomite precautions.

Zone B was identified as the highest-risk area, coinciding with a gravity low that suggests the presence of incipient or partially infilled solution features. This zone exhibits evidence of weaker near-surface soils, reduced overburden thickness, and irregular rockhead topography, indicating heightened structural sensitivity and

elevated collapse potential consistent with its D4 hazard classification. This spatial distribution is illustrated in Appendix G, where Zone B is delineated in red on the geotechnical zonation map. In contrast, Zone A demonstrates comparatively lower susceptibility (D3 classification) with more competent subsurface conditions. Overall, the site exhibits moderate dolomite stability with manageable sinkhole susceptibility, provided that zone-specific engineering interventions including appropriate foundation design, drainage management, and ongoing monitoring protocols are implemented in accordance with the risk profile of each zone.

This study successfully characterized the geotechnical properties of dolomitic terrain at Cornwall Hill, Centurion, and demonstrated that residential and light commercial development is feasible when appropriate engineering measures are implemented.

## **5.2. Recommendations**

### **5.2.1 General development guidelines**

Development on the site is feasible but requires appropriate engineering and water-management precautions to address soil strength variability and dolomitic sensitivities. Foundation designs should be conservative, based on the weakest measured values. However, TP3 may require improvement measures such as reinforced raft foundations across the whole developable portion of the site, thicker engineered fill, or localized soil stabilization due to lower CBR values. The undevelopable portion is due to the cavity of approximately 11 m recorded in BH1 between 2 – 13 m.

Water ingress is the most common trigger of sinkhole occurrences in dolomitic terrain; therefore, stormwater management is critical. This requires avoiding ponding, sealing stormwater infrastructure, directing roof runoff away from buildings, and avoiding water-bearing services near weaker zones. Further investigations are warranted where gravity anomalies or test pit variability were

identified. Subsidence-sensitive developments require long-term groundwater monitoring.

#### 5.2.2 Zone A: Moderate risk area (D3)

Zone A is moderately suitable for development with dolomite-specific precautions. Shallow foundations (concrete raft) are acceptable at minimum founding depths of 600 – 900 mm within the denser gravelly horizon. Adequate water management is imperative: stormwater must not be allowed to collect and must be diverted away from structures; all water-bearing services must be leak-resistant and constructed from SANS 1936-compliant materials; and landscaping should eliminate ponding potential. Earthworks require  $\geq 95\%$  Modified AASHTO compaction. Visual inspections are necessary during construction for possible differential settlement or moisture concentration.

#### 5.2.3 Zone B: High risk area (D4)

Zone B represents the most sensitive area, associated with gravity lows and heterogeneous conditions at TP1, BH1, and BH3 with a cavity between 2 – 13m in BH1. No development is permissible in this zone unless the cavity identified on site is further investigated to determine its full extent and subsequently rehabilitated. This determination is based on the Inherent Hazard Classification (IHC) and Dolomite Designation classification criteria presented in Chapter 2.

Water-bearing services should avoid this zone where practicable. Where unavoidable, they must be sleeved, leak-monitored, and rerouted. Stormwater infiltration is not permitted. Zone B is not suitable for soakaways, swimming pools, or irrigation systems without specialist approval. Higher-resolution geophysical surveys (microgravity or ERT) should be undertaken to better define weathered zone limits. A Dolomite Risk Management Plan should be developed for construction monitoring and post-construction inspections.

### **5.3. Recommendations for future research**

Based on the findings and limitations of this study, the following areas warrant further investigation:

- High-resolution geophysical surveys with improved DGPS accuracy and reduced grid spacing (e.g., 10 m × 10 m) to detect smaller subsurface anomalies and better delineate cavity boundaries.
- Long-term groundwater monitoring programs to assess seasonal variations, recharge patterns, and their impact on dolomite stability and sinkhole formation mechanisms.
- Comparative studies of foundation performance across different dolomite hazard zones in the Centurion region to validate engineering interventions and develop region-specific design guidelines.
- Development and validation of predictive models for sinkhole risk assessment in urbanized dolomitic terrain, integrating geological, geotechnical, and hydrogeological parameters.
- Investigation of cost-effective ground improvement techniques specifically tailored for dolomitic residual soils in high-risk zones.

### **5.4. Methodological limitations and geographic scope**

Several limitations should be acknowledged regarding the scope and generalizability of this study. The gravity survey was constrained by DGPS positional accuracy ( $\pm 0.5$  m horizontal,  $\pm 1.0$  m vertical) and grid spacing (50 m × 50 m), which may have limited detection of smaller subsurface features typically less than 10 m in diameter. The investigation covered a specific geographic area within Cornwall Hill, Centurion, and findings may not be directly applicable to other dolomitic regions with different geological histories, weathering profiles, or hydrogeological regimes.

The study represents subsurface conditions at a specific point in time (November 2024) and does not account for long-term temporal variations in groundwater

levels, progressive dissolution processes, or climate-induced changes in moisture regimes. Additionally, while the investigation program complied with SANS 1936-2:2012 requirements, the limited number of investigation points (five test pits and four boreholes) may not have captured all subsurface heterogeneity across the site. The spatial variability inherent in dolomitic terrain suggests that localized anomalies could exist between investigation points.

Finally, laboratory testing was conducted on disturbed samples, which may not fully represent in-situ soil behaviour, particularly regarding stress-strain relationships and deformation characteristics. Despite these limitations, the multi-method investigation approach provided sufficient data to characterize the site and develop appropriate engineering recommendations for safe development.

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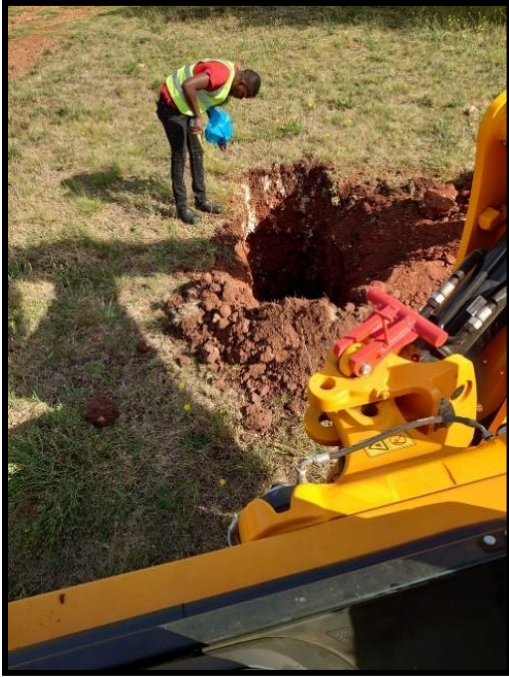
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## Appendices

### Appendix A: Site photos

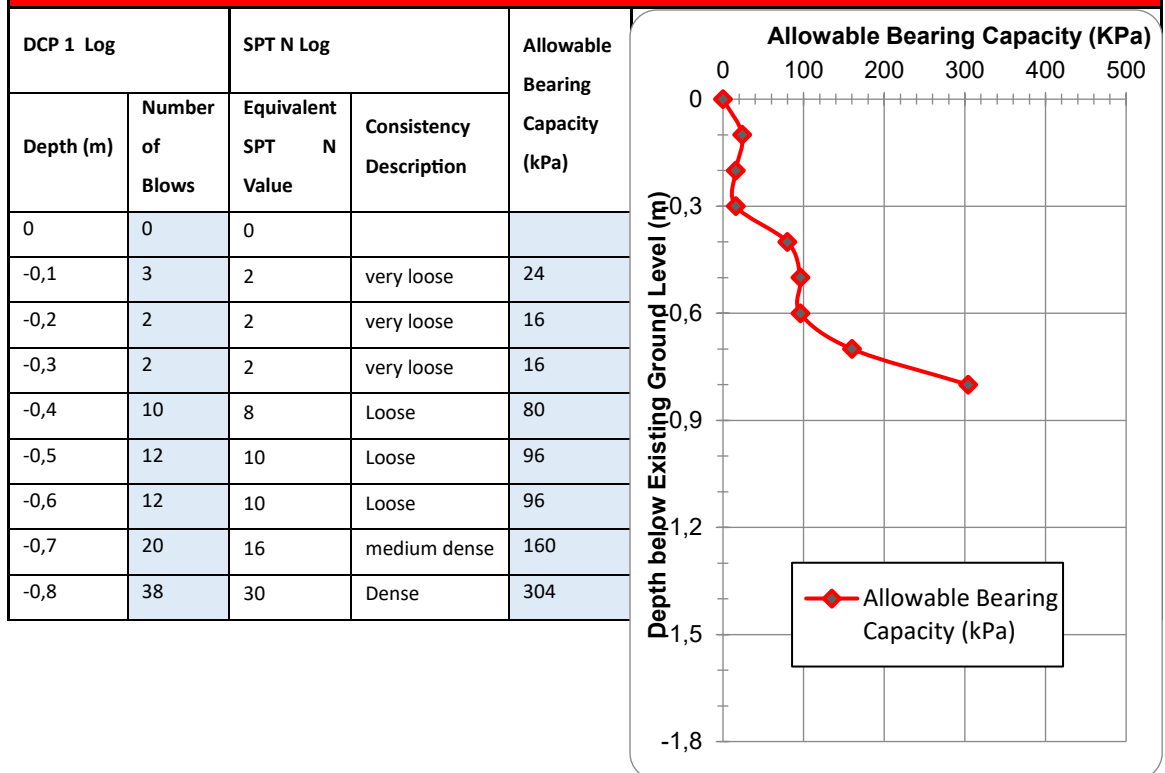




## Appendix B: DCP tests

Location	CORNWALL HILL
Date tested	12/11/2024
Operator	L Mavhetha
Final Depth	0.8m
Test Number	DCP 1

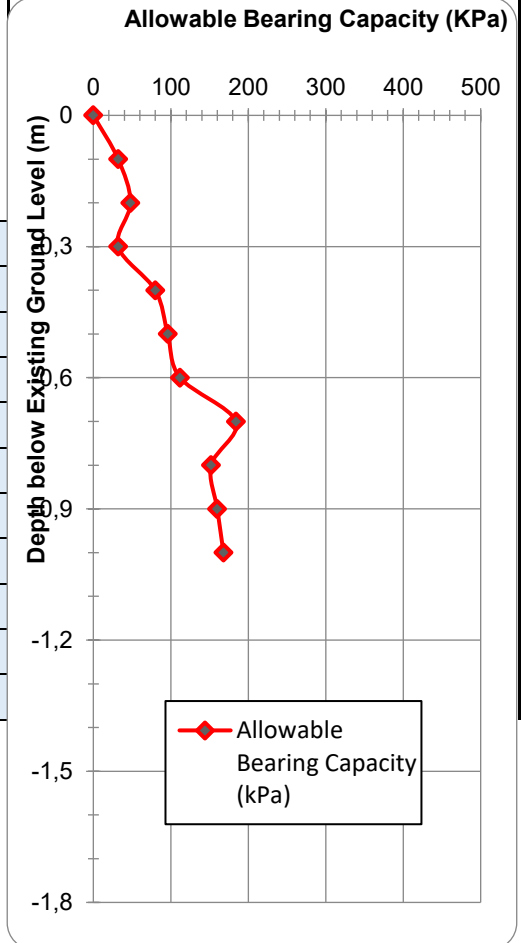
### PENETROMETER REPORT



Location	CORNWALL HILL
Date tested	12/11/2024
Operator	L Mavhetha
Final Depth	1,0m
Test Number	DCP 2

**PENETROMETER REPORT**

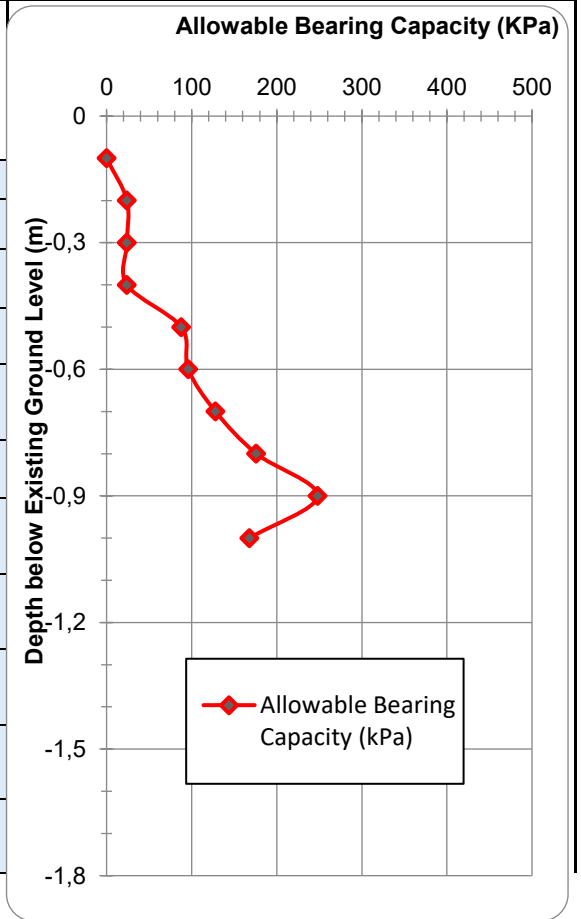
DCP 2 Log		SPT N Log		Allowable Bearing Capacity (kPa)
Depth (m)	Number of Blows	Equivalent SPT N Value	Consistency Description	
0	0	0		
-0,1	4	3	very loose	32
-0,2	6	5	very loose	48
-0,3	4	3	very loose	32
-0,4	10	8	loose	80
-0,5	12	10	loose	96
-0,6	14	11	medium dense	112
-0,7	23	18	medium dense	184
-0,8	19	15	medium dense	152
-0,9	20	16	medium dense	160
-1	21	17	medium dense	168



Location	ERF 805 CORNWALL HILL
Date tested	12/11/2024
Operator	L Mavhetha
Final Depth	1m
Test Number	DCP 3

**PENETROMETER REPORT**

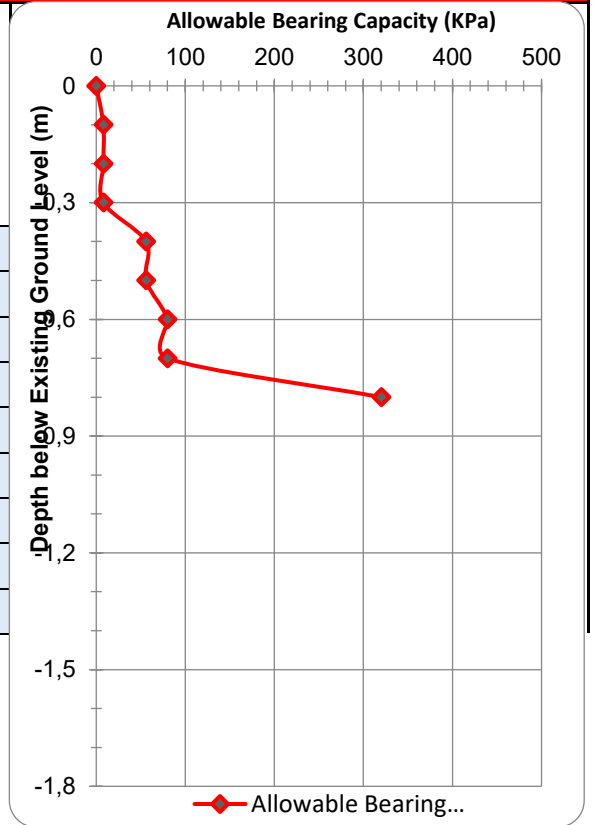
DCP 3 Log		SPT N Log		Allowable Bearing Capacity (kPa)
Depth (m)	Number of Blows	Equivalent SPT N Value	Consistency Description	
0	0	0		
-0,1	4	3	very loose	32
-0,2	5	4	very loose	40
-0,3	6	5	very loose	48
-0,4	15	12	medium dense	120
-0,5	11	9	loose	88
-0,6	15	12	medium dense	120
-0,7	18	14	medium dense	144
-0,8	20	16	medium dense	160
-0,9	21	17	medium dense	168
-1	22	18	medium dense	176



<b>Location</b>	<b>CORNWALL HILL</b>
<b>Date tested</b>	<b>12/11/2024</b>
<b>Operator</b>	<b>L Mavhetha</b>
<b>Final Depth</b>	<b>0.8m</b>
<b>Test Number</b>	<b>DCP 4</b>

**PENETROMETER REPORT**

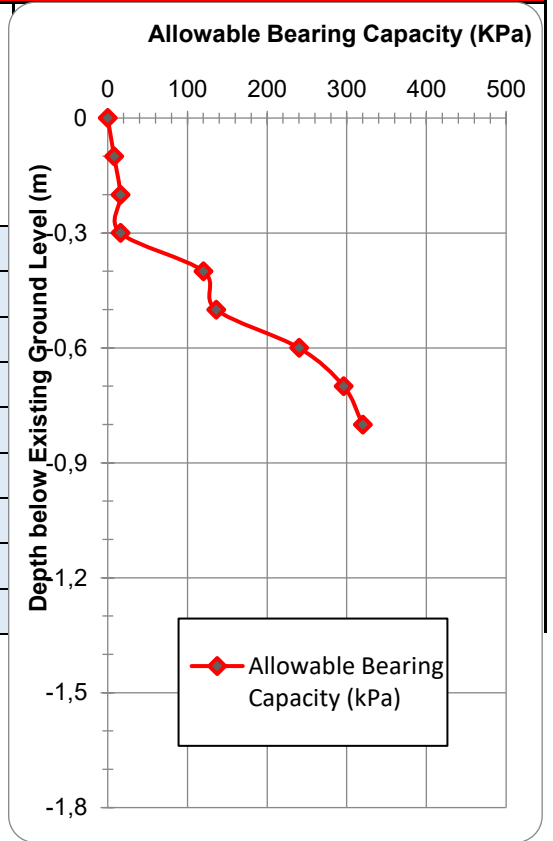
DCP 4 Log		SPT N Log		Allowable Bearing Capacity (kPa)
Depth (m)	Number of Blows	Equivalent SPT N Value	Consistency Description	
0	0	0		
-0,1	1	1	very loose	8
-0,2	1	1	very loose	8
-0,3	1	1	very loose	8
-0,4	7	6	loose	56
-0,5	7	6	loose	56
-0,6	10	8	loose	80
-0,7	10	8	loose	80
-0,8	40	32	dense	320



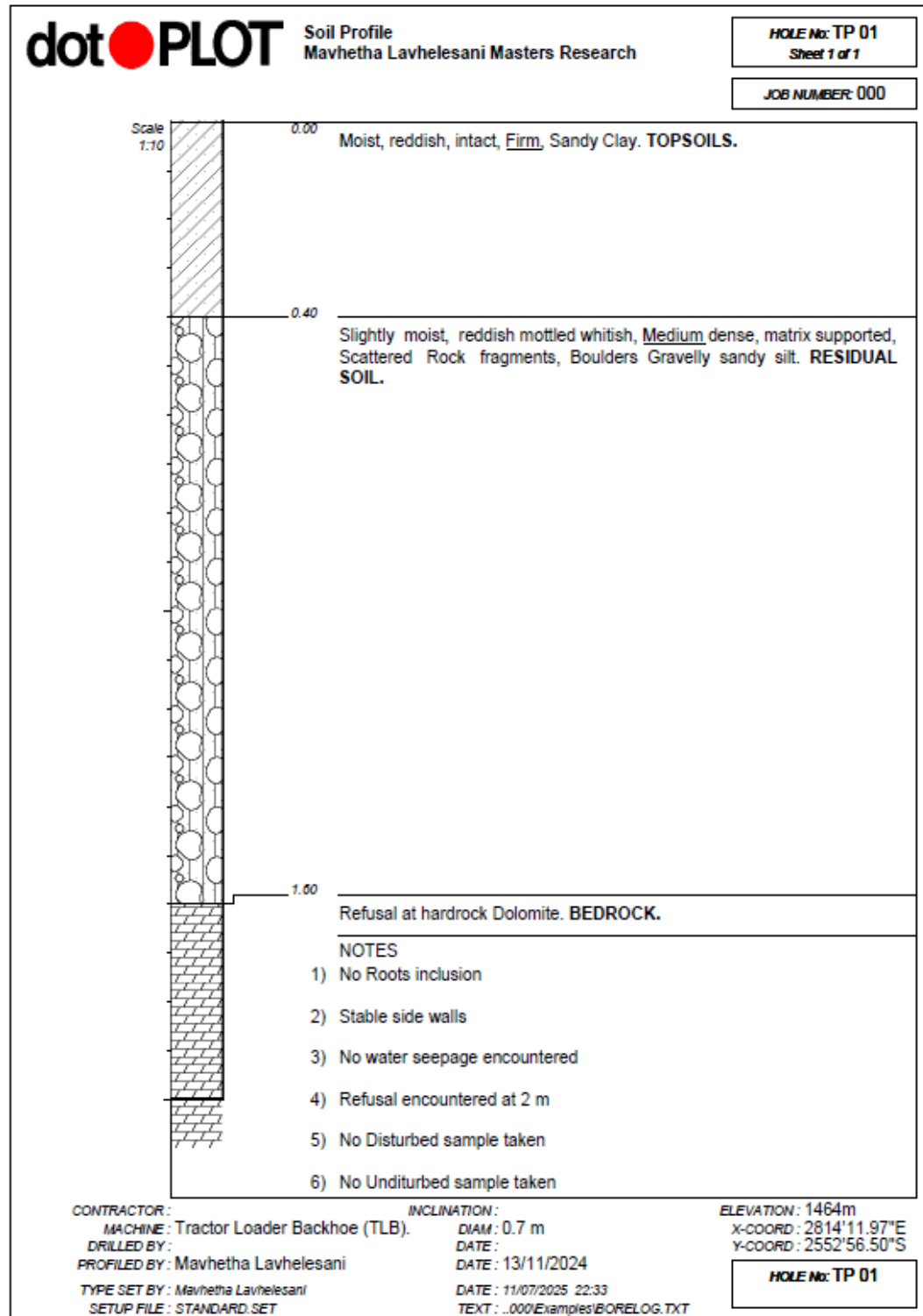
Location	CORNWALL HILL
Date tested	12/11/2024
Operator	L Mavhetha
Final Depth	0.8m
Test Number	DCP 5

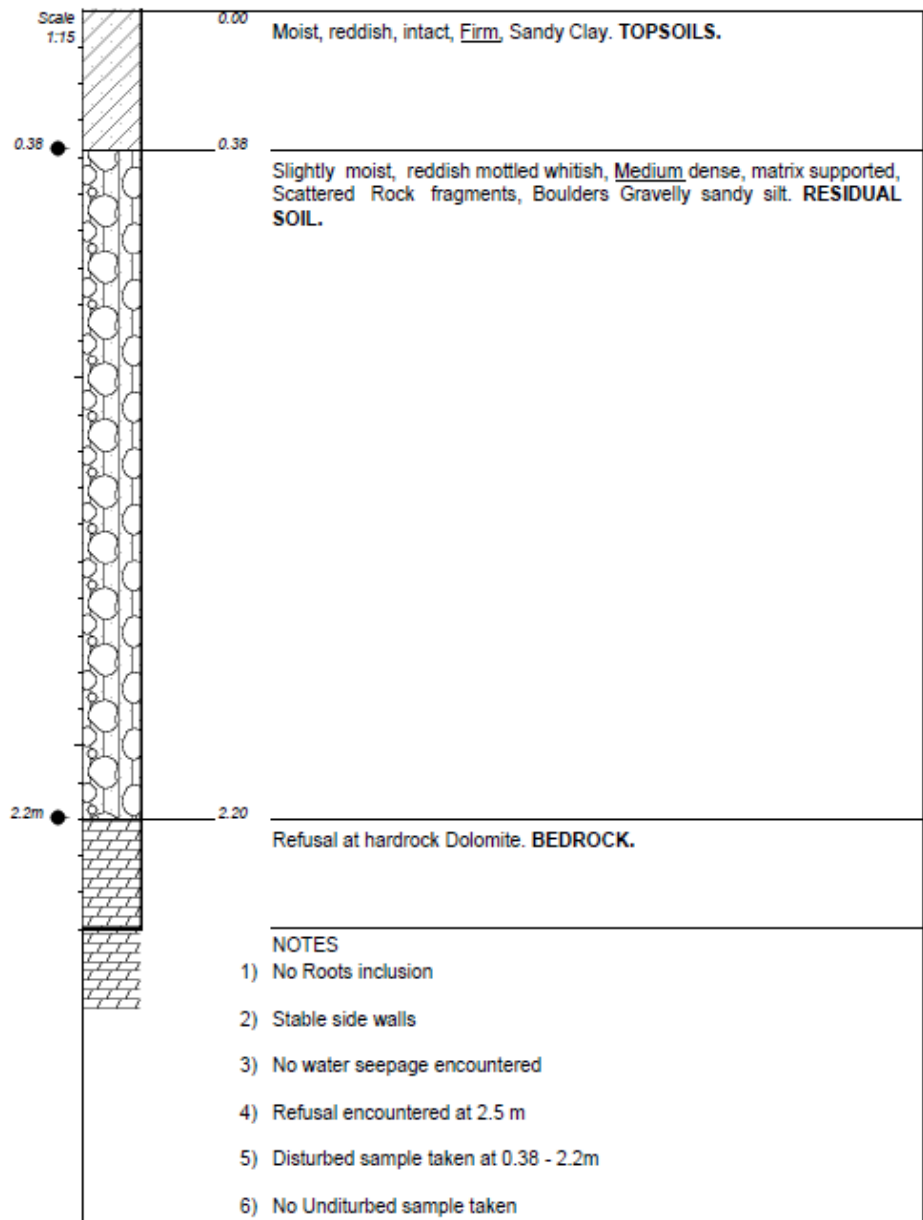
**PENETROMETER REPORT**

DCP 5 Log		SPT N Log		Allowable Bearing Capacity (kPa)
Depth (m)	Number of Blows	Equivalent SPT N Value	Consistency Description	
0	0	0		
-0,1	1	1	very loose	8
-0,2	2	2	very loose	16
-0,3	2	2	very loose	16
-0,4	15	12	medium dense	120
-0,5	17	14	medium dense	136
-0,6	30	24	medium dense	240
-0,7	37	30	medium dense	296
-0,8	40	32	dense	320



## Appendix C: Soil profile

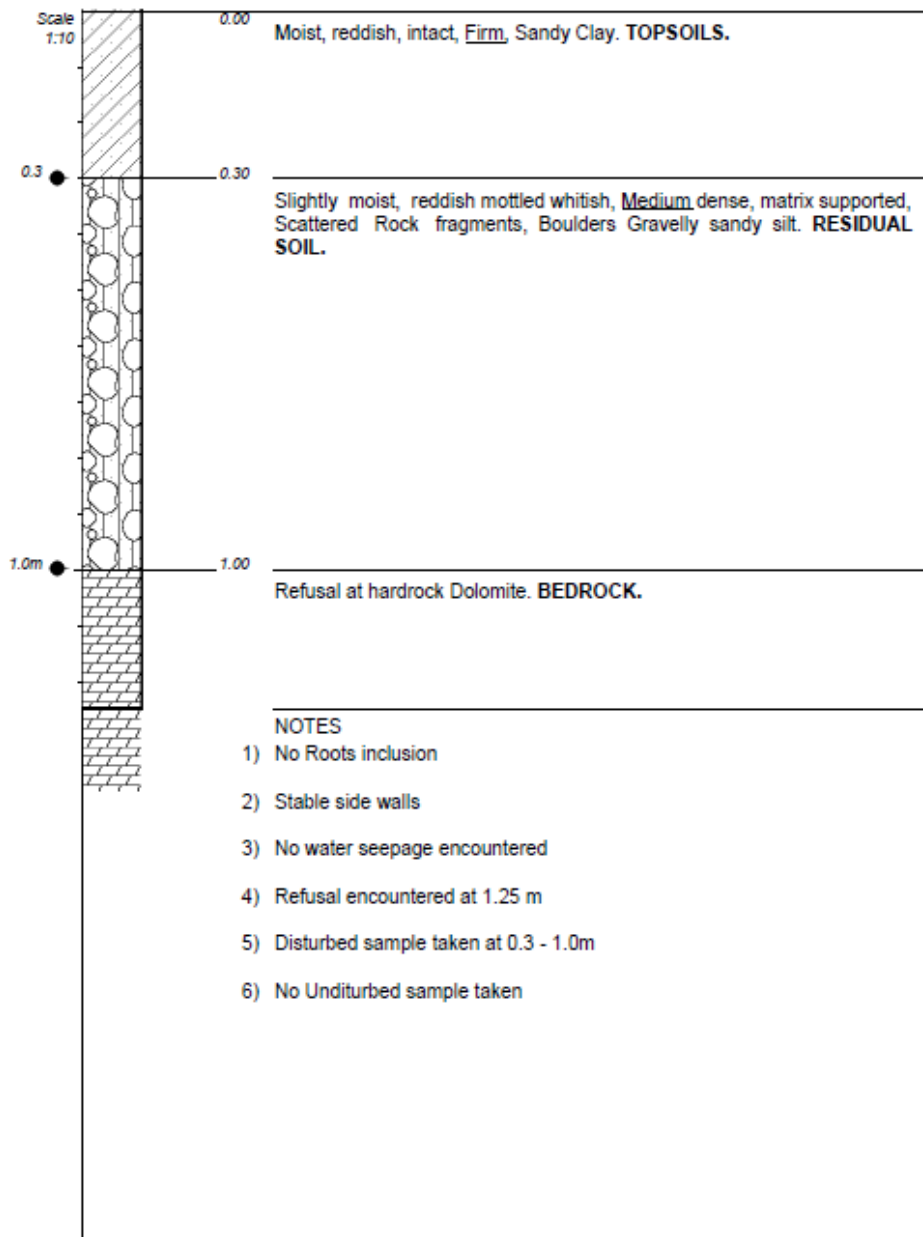




CONTRACTOR :  
MACHINE : Tractor Loader Backhoe (TLB).  
DRILLED BY :  
PROFILED BY : Mavhetha Lavhelesani  
TYPE SET BY : Mavhetha Lavhelesani  
SETUP FILE : STANDARD.SET

INCLINATION :  
DIAM : 0.7 m  
DATE :  
DATE : 13/11/2024  
DATE : 11/07/2025 22:33  
TEXT : ..000\Examples\BORELOG.TXT

ELEVATION : 1467m  
X-COORD : 2814'10.67"E  
Y-COORD : 2552'56.04"S



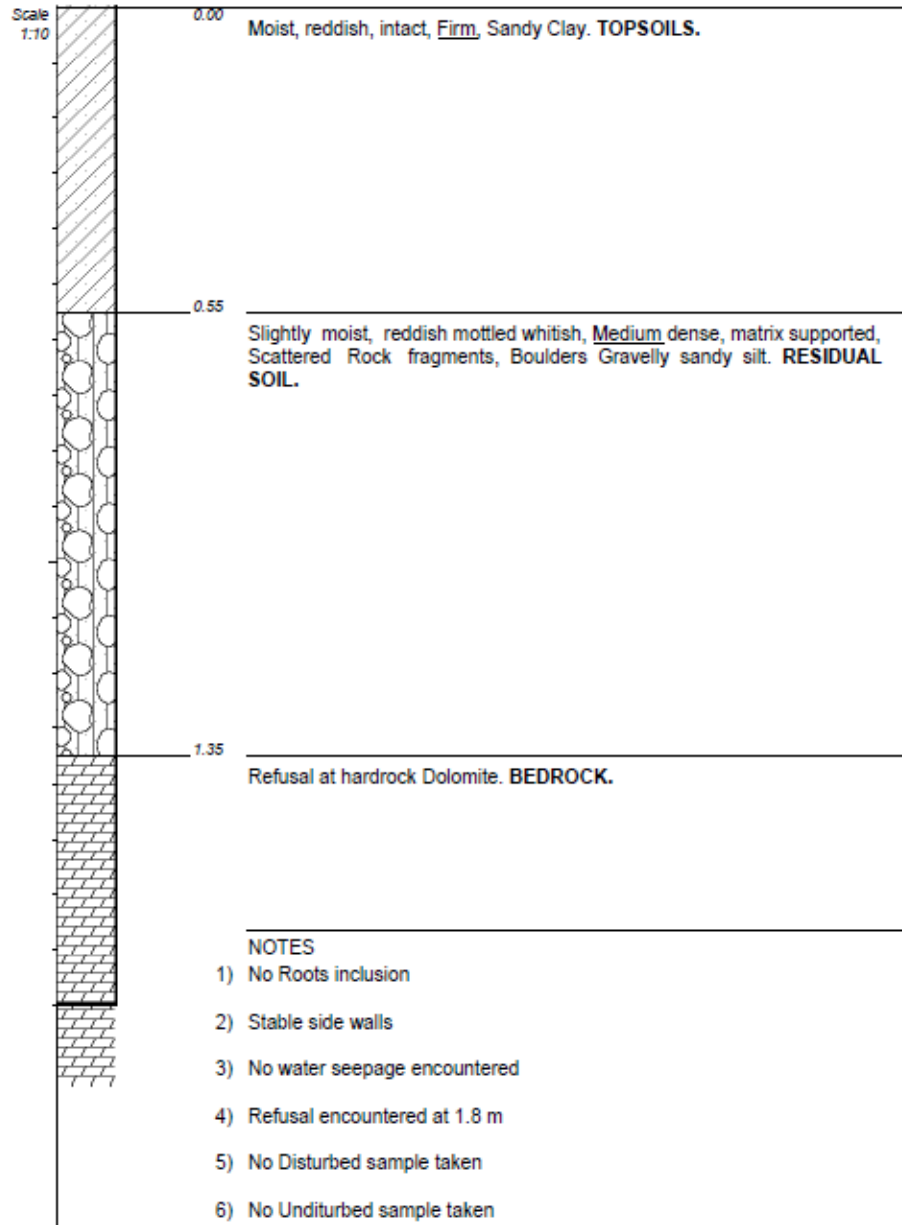
NOTES

- 1) No Roots inclusion
- 2) Stable side walls
- 3) No water seepage encountered
- 4) Refusal encountered at 1.25 m
- 5) Disturbed sample taken at 0.3 - 1.0m
- 6) No Undisturbed sample taken

CONTRACTOR :  
MACHINE : Tractor Loader Backhoe (TLB).  
DRILLED BY :  
PROFILED BY : Mavhetha Lavhelesani  
TYPE SET BY : Mavhetha Lavhelesani  
SETUP FILE : STANDARD.SET

INCLINATION :  
DIAM : 0.7 m  
DATE :  
DATE : 13/11/2024  
DATE : 11/07/2025 22:33  
TEXT : ..000\Examples\BORELOG.TXT

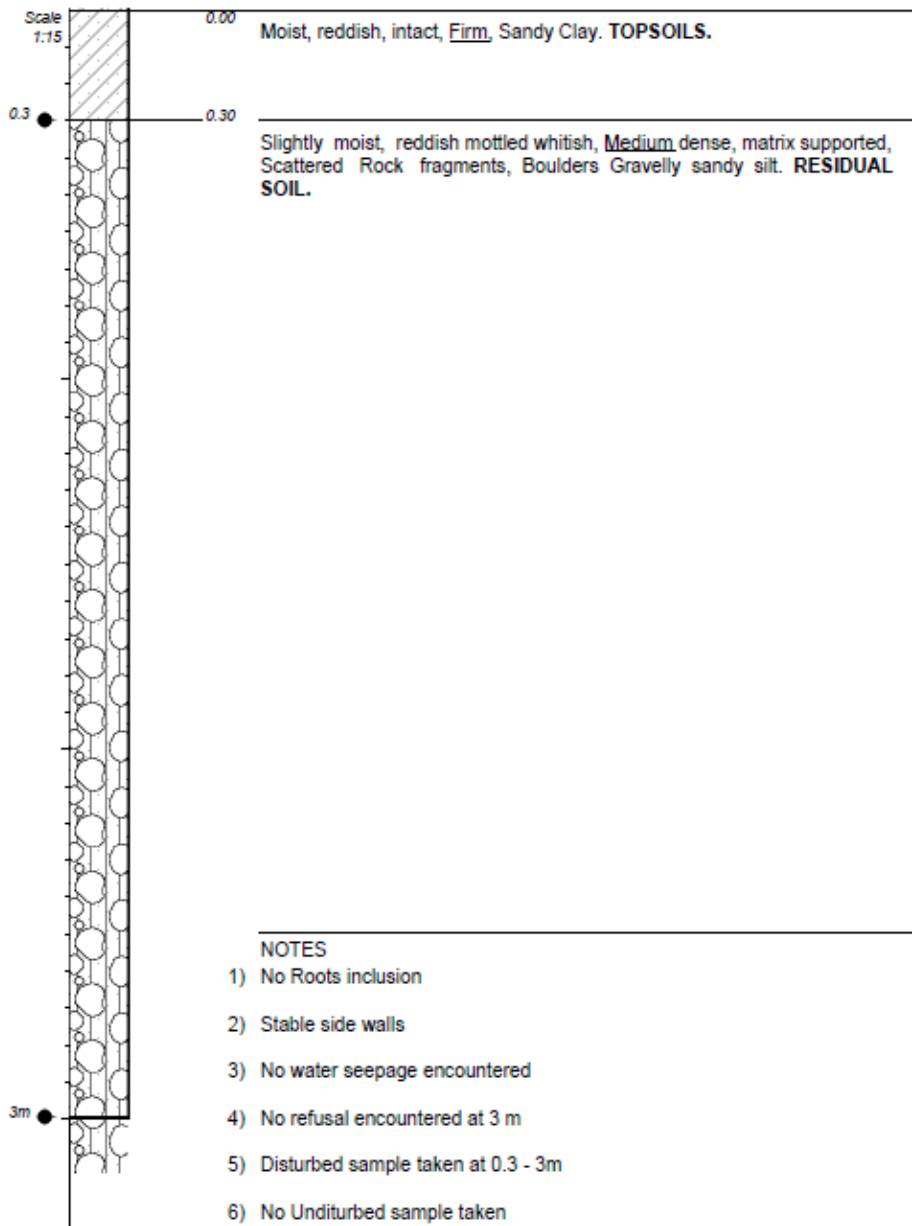
ELEVATION : 1470m  
X-COORD : 2814'10.12"E  
Y-COORD : 2552'56.63"S



CONTRACTOR :  
MACHINE : Tractor Loader Backhoe (TLB).  
DRILLED BY :  
PROFILED BY : Mavhetha Lavhelesani  
TYPE SET BY : Mavhetha Lavhelesani/  
SETUP FILE : STANDARD.SET

INCLINATION :  
DIAM : 0.7 m  
DATE :  
DATE : 13/11/2024  
DATE : 11/07/2025 22:33  
TEXT : ..000\Examples\BORELOG.TXT

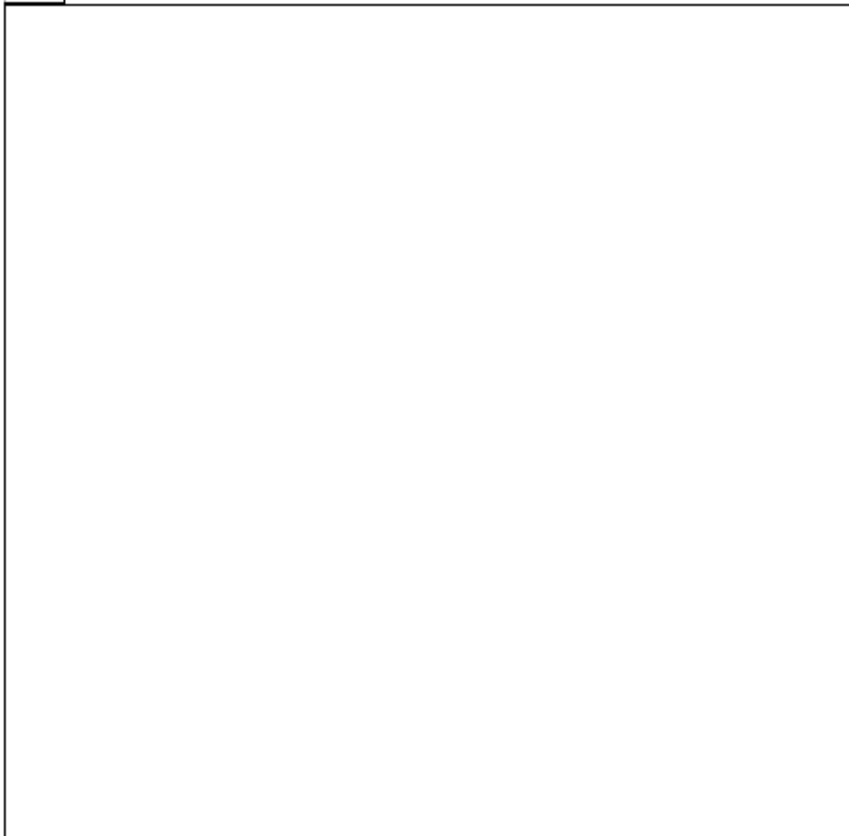
ELEVATION : 1465m  
X-COORD : 2814'10.97"E  
Y-COORD : 2552'56.78"S



CONTRACTOR :	INCLINATION :	ELEVATION : 1462m
MACHINE : Tractor Loader Backhoe (TLB).	DIAM : 0.7 m	X-COORD : 2814'10.92"E
DRILLED BY :	DATE :	Y-COORD : 2552'57.49"S
PROFILED BY : Mavhetha Lavhelesani	DATE : 13/11/2024	<b>HOLE No: TP 05</b>
TYPE SET BY : Mavhetha Lavhelesani	DATE : 11/07/2025 22:33	
SETUP FILE : STANDARD.SET	TEXT : ..000\Examples\BORELOG.TXT	

	BOULDERS	{SA01}
	GRAVELLY	{SA03}
	SANDY	{SA05}
	SILT	{SA06}
	CLAY	{SA08}
	DOLOMITE	{SA13}
	DISTURBED SAMPLE	{SA38}

Name ●



CONTRACTOR :  
MACHINE :  
DRILLED BY :  
PROFILED BY :

INCLINATION :  
DIAM :  
DATE :  
DATE :

ELEVATION :  
X-COORD :  
Y-COORD :

TYPE SET BY : Mavhetha Lavhelesani  
SETUP FILE : STANDARD.SET

DATE : 11/07/2025 22:33  
TEXT : ..000\Examples\BORELOG.TXT







**PERCUSSION BOREHOLE RECORD**

Company Registration: 1015238807037

Client: DOLomite STUDY  
 Project: BH03  
 Hole No: BH03  
 Hole Position: \_\_\_\_\_

Total Depth: 10M  
 Casing In & out: \_\_\_\_\_  
 Casing installed(m): \_\_\_\_\_  
 Casing permanently damaged(m): \_\_\_\_\_

Date: 05/03/25  
 Air Pressure: \_\_\_\_\_ Air Capacity: \_\_\_\_\_  
 BH Diameter(mm): \_\_\_\_\_  
 Water Street(mm): \_\_\_\_\_  
 Rest Level(m): \_\_\_\_\_

Depth	Penetration Rate Time min	Formation				Hammer Rate			Air Loss				Moisture Condition				Casing	Sample Recovery			Remarks	
		Crumbly	Very Soft	Foamy / Hard	Solid	Very Irregular	Irregular	Regular	None	Slightly	Medium	Too	Fanned	Wet	Moist	Dry		Hole Collapsing	Depth Installed	Good		Medium
0-1	0:20																					COORDINATES N: 28° 52' 56.4" S E: 028° 14' 10.3" E
1-2	1:28																					
2-3	2:11																					
3-4	2:44																					
4-5	3:06																					
5-6	3:16																					
6-7	3:11																					
7-8	3:00																					
8-9	3:24																					
9-10	3:33																					
10-11																						
11-12																						
12-13																						
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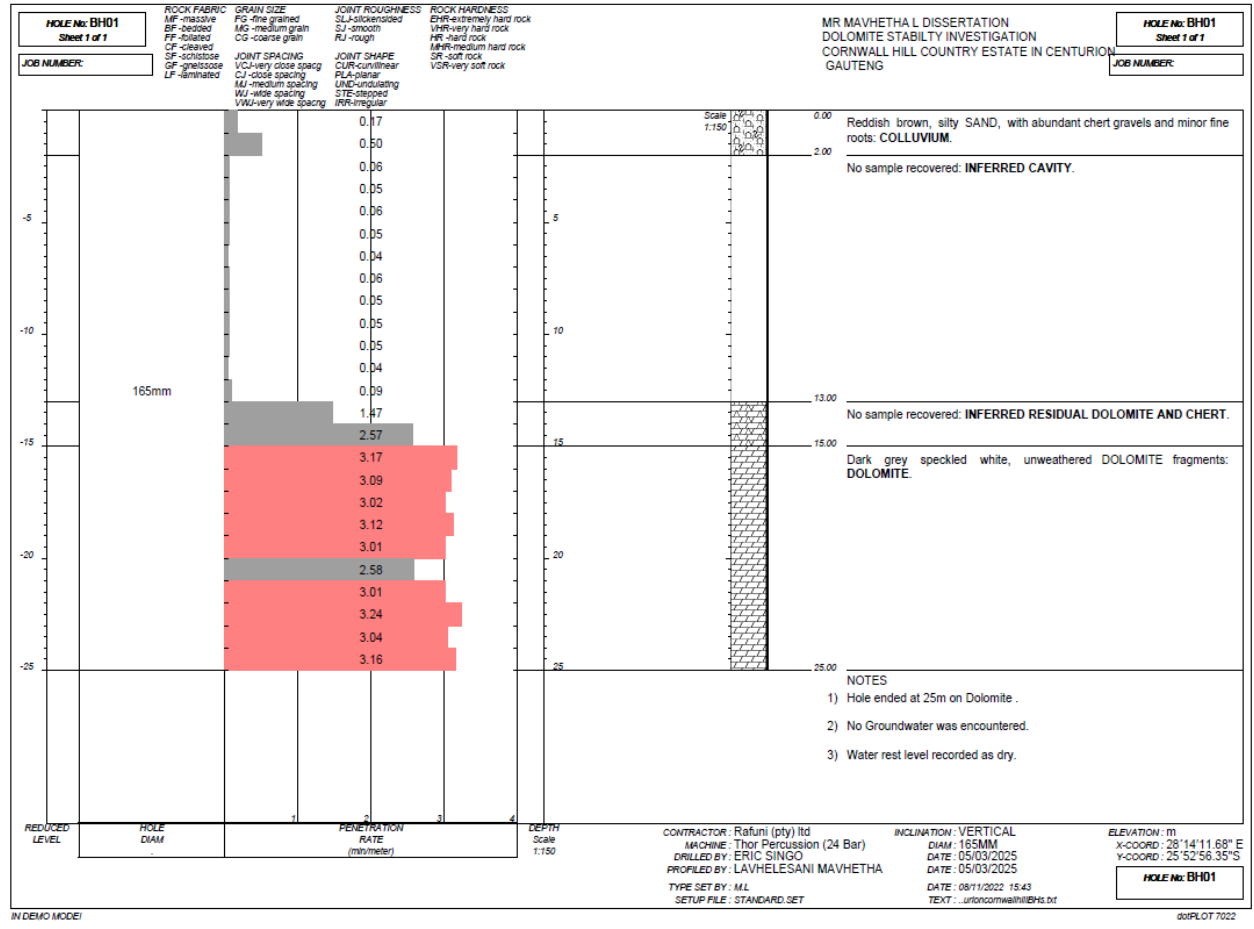
HARD ROCK

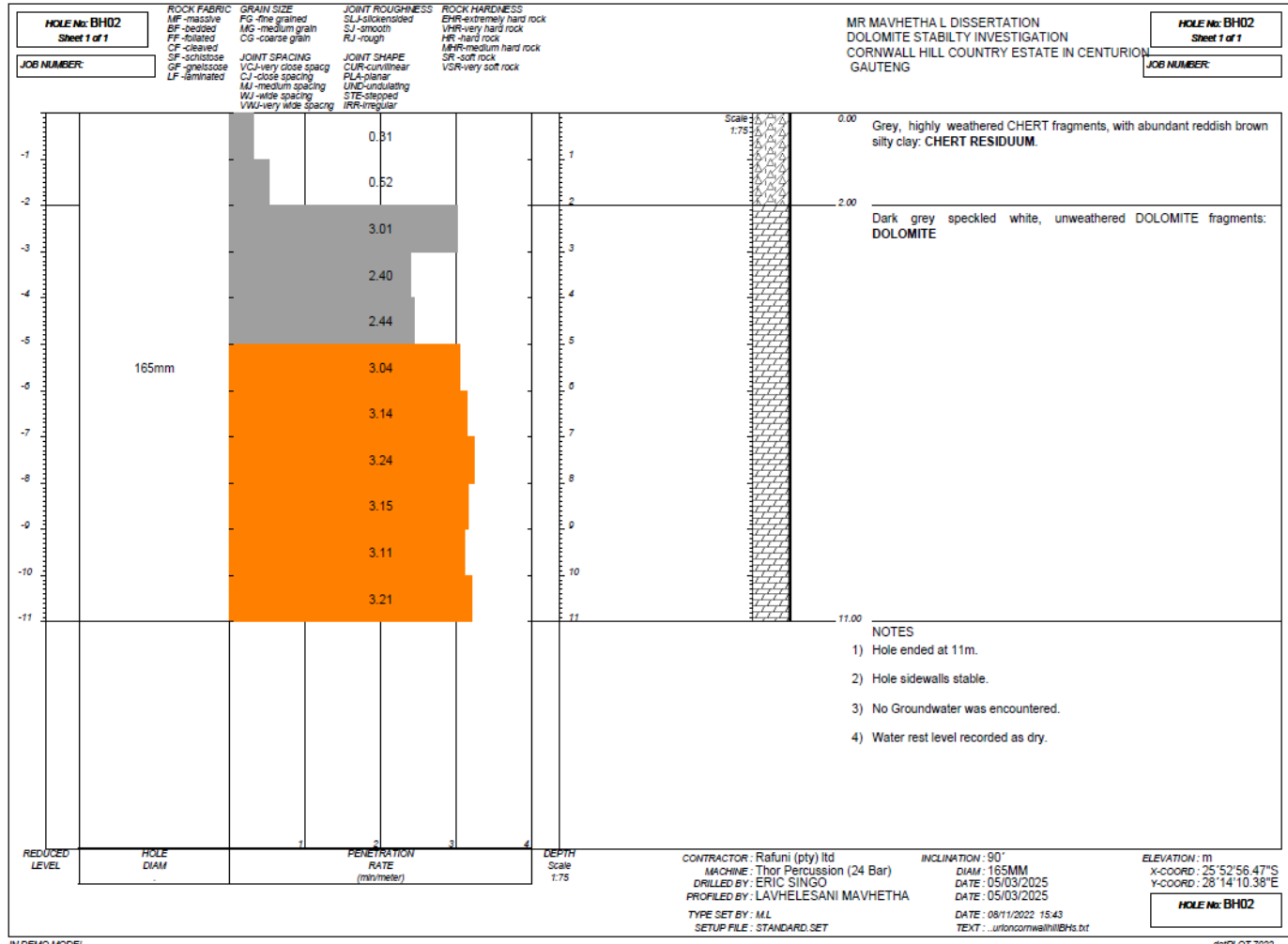
REMARKS \_\_\_\_\_  
 DATA DESCRIBED BY \_\_\_\_\_ OPERATOR \_\_\_\_\_

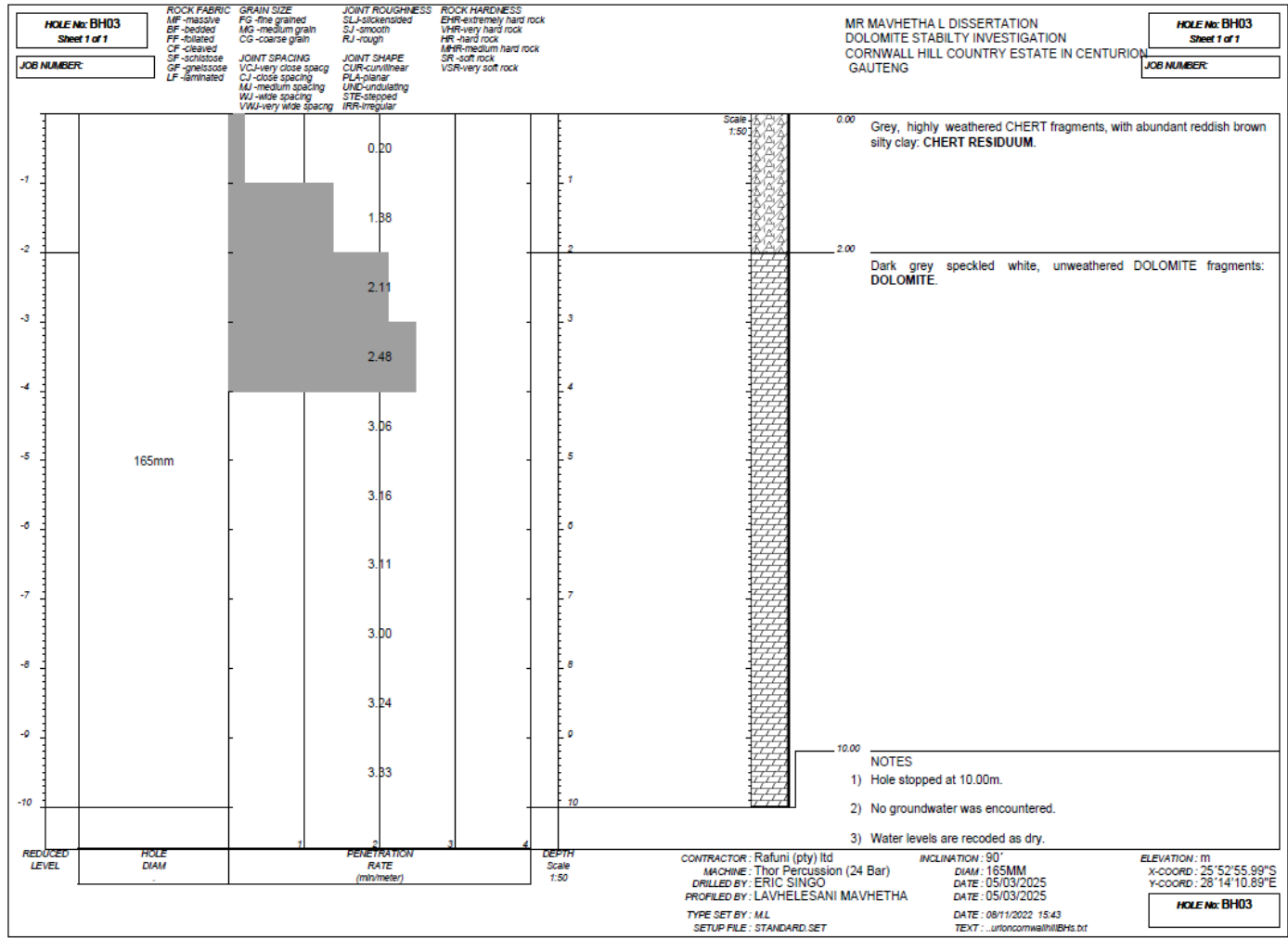
Call: 061 429 7388 | Fax: 011 41 7381  
 Email: info@rafuni.com  
 Website: www.rafuni.com  
 Address: 5, BANGKOK ROAD, PHNOM PENH



# Appendix E: Borehole logging

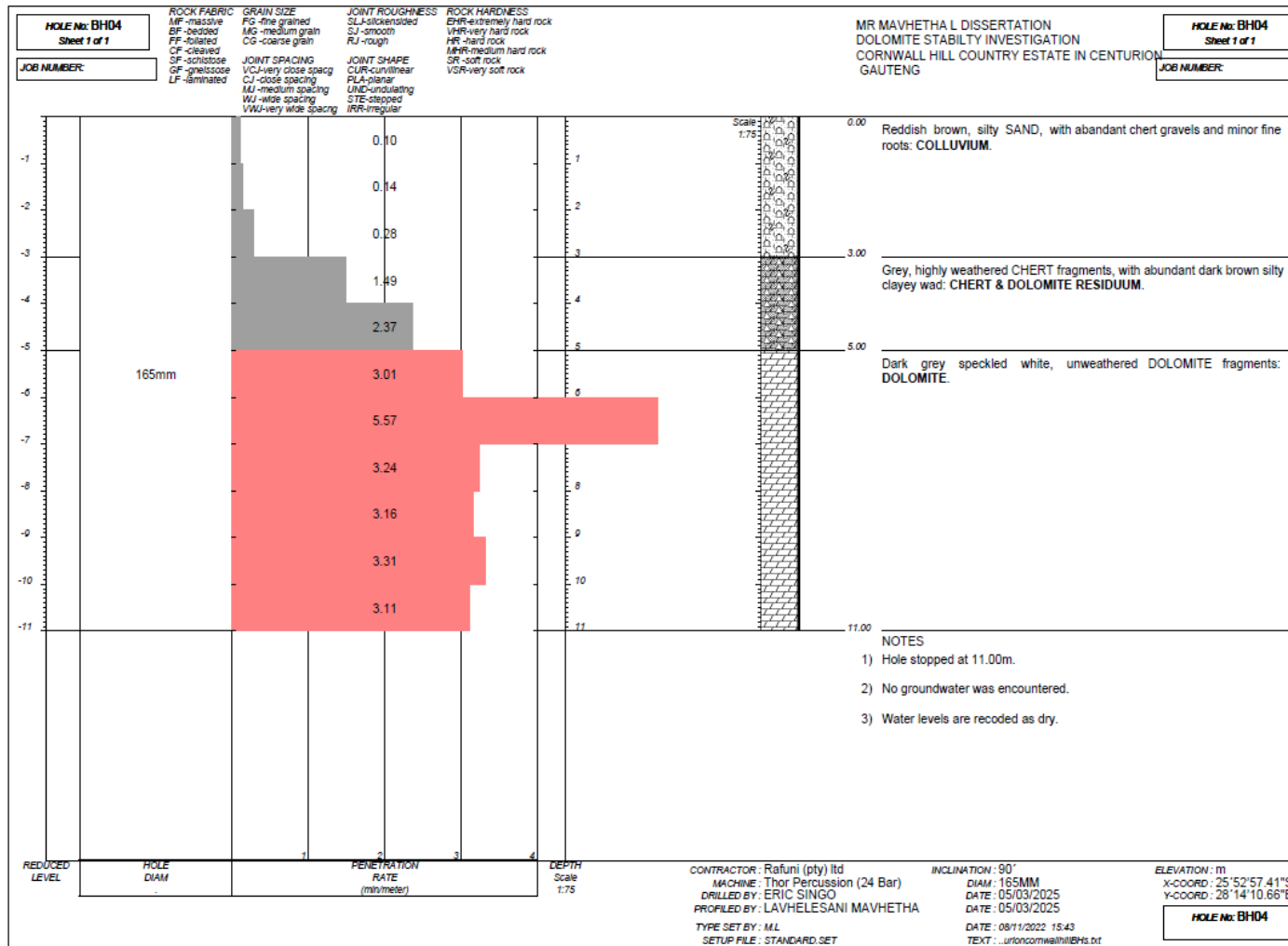






IN DEMO MODE!

dotPLOT 7022



IN DEMO MODE!

dotPLOT 7022

## Appendix F: Laboratory results

36 Fourth Street, Booyens Reserve, Johannesburg 2091  
 PO Box 82223, Southdale 2135  
 Tel: +27 (0)11 835 3117•Fax: +27 (0)11 835 2503  
 E-mail: jhb@civilab.co.za•Website: www.civilab.co.za



T0062

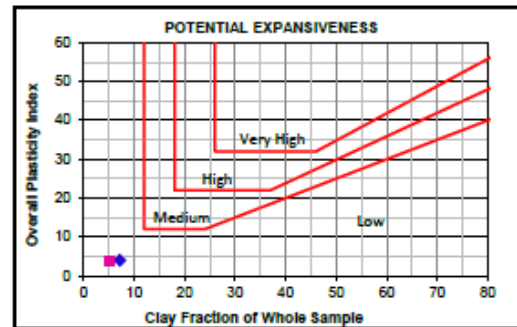
# Civilab

Civil Engineering Testing Laboratories

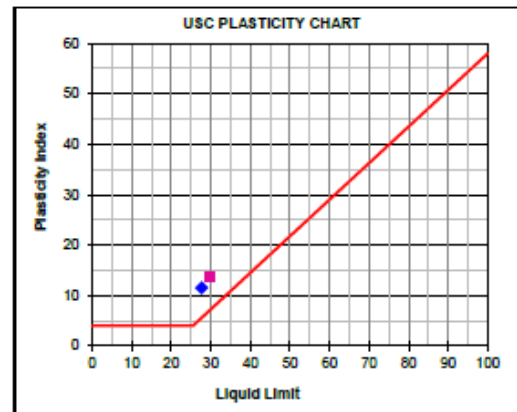
Client :	MAVHETHA LAVHELESANI	Date Received:	07/03/2025
Project :	CORNWALL HILL	Date Reported:	04/04/2025
Project No :	2022-B-1205	Page No. :	2 of 8

### FOUNDATION INDICATOR

Laboratory Number	S1205-1	S1205-2
Field Number	TP2	TP3
Client Reference		
Depth (m)	0.38-2.2	0.3-1.0
Position		
Coordinates	X	
	Y	
Description		
Additional Information		
Calcrete / Crushed Stabilizing Agent		



Moisture Content & Relative Density		
Moisture Content (%)		
Relative Density (S.G.)		



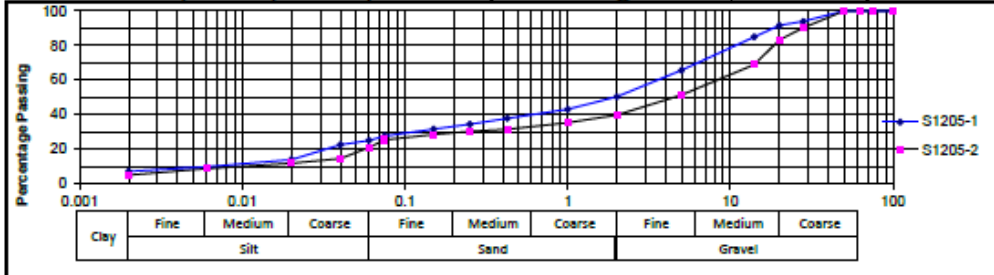
Sieve Analysis (Wet Prep)		
Percentage Passing		
100 mm	100	100
75 mm	100	100
63 mm	100	100
50 mm	100	100
37.5 mm	98	99
28 mm	94	90
20 mm	92	83
14 mm	85	69
5 mm	66	51
2 mm	50	40
1 mm	43	35
0.425 mm	38	31
0.250 mm	35	30
0.150 mm	32	29
0.075 mm	28	25
Grading Modulus	1.84	2.03

Hydrometer Analysis		
Percentage Passing		
0.060 mm	25	21
0.040 mm	23	15
0.020 mm	14	12
0.008 mm	10	9
0.002 mm	7	5
Gravel	%	50
Sand	%	25
Silt	%	18
Clay	%	7

Laboratory Number	S1205-1	S1205-2
Atterberg Limits -425µ		
Liquid Limit	%	28
Plasticity Index	%	11
Linear Shrinkage	%	5.5
Overall PI	%	4

Classifications		
HRB (AASHTO)	A-2-6(0)	A-2-6(0)
Unified (ASTM D2487)	SC	GC
Weston Swell @ 1 kPa		

Note: An assumed S.G. may be used in Hydrometer Analysis calculations



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# Civilab

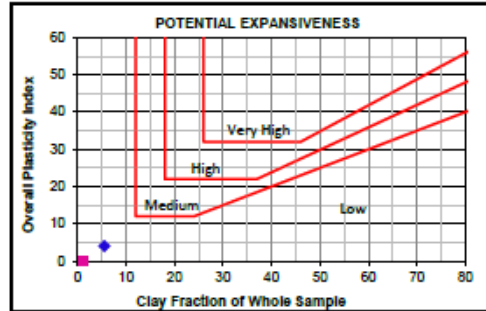
T0062

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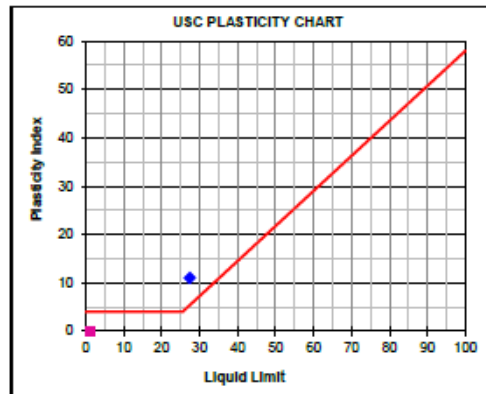
Client :	MAVHETHA LAVHELESANI	Date Received:	07/03/2025
Project :	CORNWALL HILL	Date Reported:	04/04/2025
Project No :	2022-B-1205	Page No. :	3 of 8

## FOUNDATION INDICATOR

Laboratory Number	S1205-3
Field Number	TP5
Client Reference	
Depth (m)	0.3-3.0
Position	
Coordinates	X Y
Description	
Additional Information	
Calcrete / Crushed Stabilizing Agent	



Moisture Content & Relative Density	
Moisture Content (%)	
Relative Density (S.G.)	
Sieve Analysis (Wet Prep)	

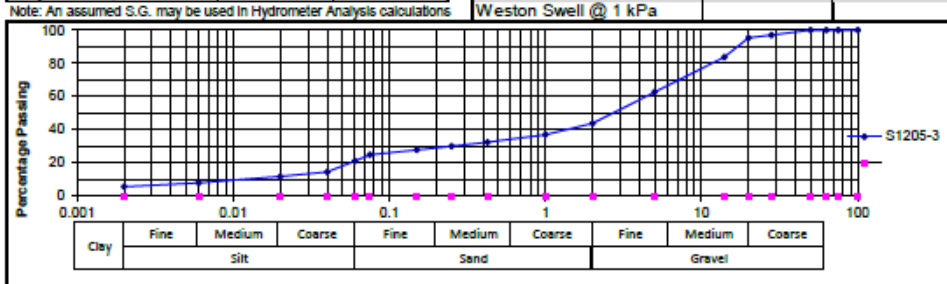


Percentage Passing	100 mm	100
	75 mm	100
	63 mm	100
	50 mm	100
	37.5 mm	100
	28 mm	97
	20 mm	95
	14 mm	84
	5 mm	63
	2 mm	44
	1 mm	37
	0.425 mm	32
	0.250 mm	30
0.150 mm	28	
0.075 mm	25	
Grading Modulus	1.99	

Laboratory Number	S1205-3
Atterberg Limits -425µ	
Liquid Limit	% 27
Plasticity Index	% 11
Linear Shrinkage	% 4.5
Overall PI	% 4

Hydrometer Analysis	
Percentage Passing	
0.060 mm	21
0.040 mm	14
0.020 mm	12
0.008 mm	8
0.002 mm	6
Gravel	% 56
Sand	% 23
Silt	% 15
Clay	% 6

Classifications	
HRB (AASHTO)	A-2-6(0)
Unified (ASTM D2487)	SC
Weston Swell @ 1 kPa	



Note: An assumed S.G. may be used in Hydrometer Analysis calculations

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Client : MAVHETHA LAVHELESANI Date Received: 07/03/2025  
 Project : CORNWALL HILL Date Reported: 04/04/2025  
 Project No: 2022-B-1205 Page No. : 4 of 8

### MOISTURE DENSITY RELATIONSHIP

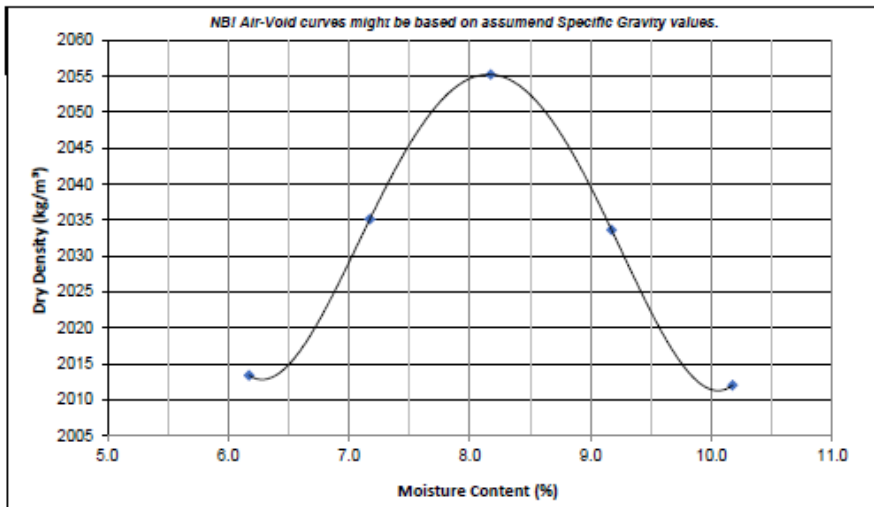
Laboratory Number	S1205-1	
Field Number	TP2	
Client Reference		
Depth (m)	0.38-2.2	
Position		
Coordinates	X	
	Y	
Description		
Additional Information		
% of Sample Scalped		
Stabilizing Agent		

**Maximum Dry Density & Optimum Moisture Content - SANS 3001 GR30**

Compactive Effort:	Modified AASHTO
--------------------	-----------------

Dry Density	kg/m <sup>3</sup>	2055	2035	2034	2013	2012	
Moisture Content	%	8.2	7.2	9.2	6.2	10.2	

Max. Dry Density	kg/m <sup>3</sup>	2055
Optimum Moisture	%	8.2



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Client : MAVHETHA LAVHELESANI Date Received: 07/03/2025  
 Project : CORNWALL HILL Date Reported: 04/04/2025  
 Project No: 2022-B-1205 Page No. : 5 of 8

**MOISTURE DENSITY RELATIONSHIP**

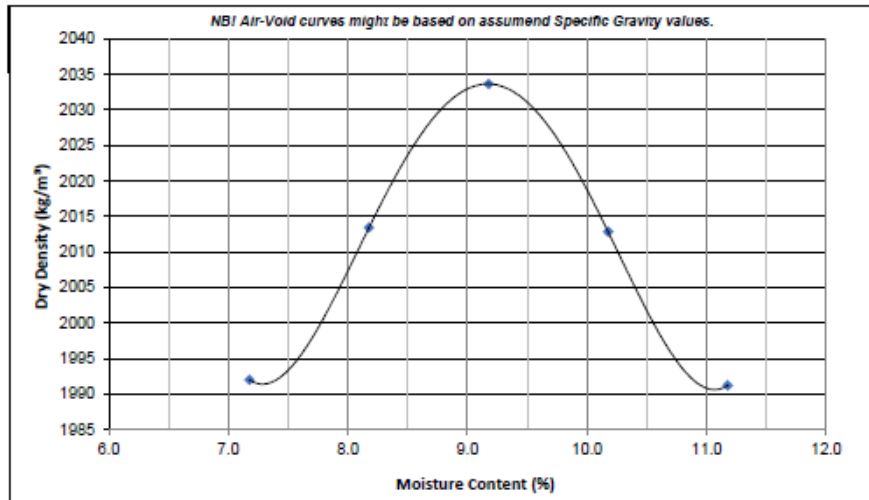
Laboratory Number		S1205-3	
Field Number		TP5	
Client Reference			
Depth (m)		0.3-3.0	
Position			
Coordinates	X		
	Y		
Description			
Additional Information			
% of Sample Scalped			
Stabilizing Agent			

**Maximum Dry Density & Optimum Moisture Content - SANS 3001 GR30**

Compactive Effort:	Modified AASHTO
--------------------	-----------------

Dry Density	kg/m <sup>3</sup>	2034	2013	2013	1992	1991	
Moisture Content	%	9.2	8.2	10.2	7.2	11.2	

Max. Dry Density	kg/m <sup>3</sup>	2034
Optimum Moisture	%	9.2



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 Project : CORNWALL HILL Date Reported : 04/04/2025  
 Project No. : 2022-B-1205 Page No. : 6 of 8

**CALIFORNIA BEARING RATIO (CBR) & ROAD INDICATOR REPORT**

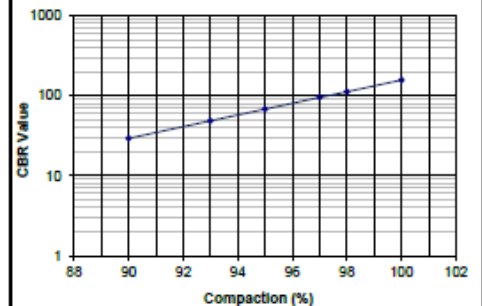
Laboratory No.	S1205-1	S1205-2
Field Number	TP2	TP3
Client Reference		
Depth (m)	0.38-2.2	0.3-1.0
Position		
Coordinates	X	
	Y	
Description		
Additional information		
Calcrete/Crushed		
Stabilizing Agent		

Laboratory No.	S1205-1	S1205-2
Maximum Dry Density & Optimum Moisture Content		
MDD	kg/m <sup>3</sup>	2055
OMC	%	8.2

California Bearing Ratio		
Compaction Data		
Moisture	%	8.1
Dry Density	kg/m <sup>3</sup>	2078 1975 1873
Compaction	%	100.0 95.0 90.1
Penetration Data		
CBR at	2.54 mm	147 72 29
	5.08 mm	194 77 32
	7.62 mm	198 74 37
Swell	%	0.0 0.2 0.3
Final Moisture (%)		11.6 13.3 15.8

**Sieve Analysis (Wet preparation)**

100 mm	100	100
75 mm	100	100
63 mm	100	100
53 mm	100	100
37.5 mm	96	99
28 mm	94	90
20 mm	92	83
14 mm	85	69
5 mm	66	51
2 mm	50	40
1 mm	43	35
0.425 mm	38	31
0.250 mm	35	30
0.150 mm	32	29
0.075 mm	28	25
Grading Modulus	1.84	2.03



**Soil Mortar Analysis**

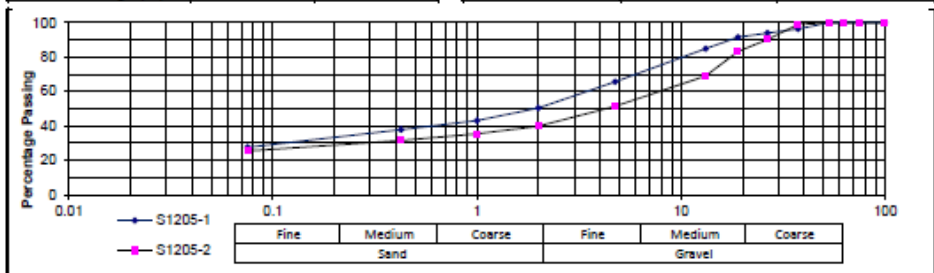
Coarse Sand	25	21
Coarse Fine Sand	7	3
Medium Fine Sand	6	4
Fine Fine Sand	8	8
Silt and Clay	55	64

**Atterberg Limits**

Liquid Limit (%)	28	30
Plasticity Index (%)	11	14
Linear Shrinkage (%)	5.5	6.5

**Classifications**

HRB (AASHTO)	A-2-6(0)	A-2-6(0)
COLTO	G7	
TRH14	G6	



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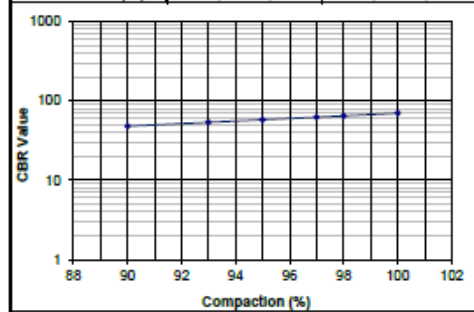
**CALIFORNIA BEARING RATIO (CBR) & ROAD INDICATOR REPORT**

Laboratory No.	S1205-3
Field Number	TP5
Client Reference	
Depth (m)	0.3-3.0
Position	
Coordinates	X Y
Description	
Additional information	
Calcrete/Crushed	
Stabilizing Agent	

Laboratory No.	S1205-3
Maximum Dry Density & Optimum Moisture Content	
MDD	kg/m <sup>3</sup> 2034
OMC	% 9.2

California Bearing Ratio			
Compaction Data			
Moisture	%	9.1	
Dry Density	kg/m <sup>3</sup>	2059	1961 1855
Compaction	%	100.0	95.2 90.1
Penetration Data			
CBR at	2.54 mm	70	58 48
	5.08 mm	89	61 54
	7.62 mm	99	59 51
Swell	%	0.1	0.2 0.2
Final Moisture (%)		11.8	13.9 18.7

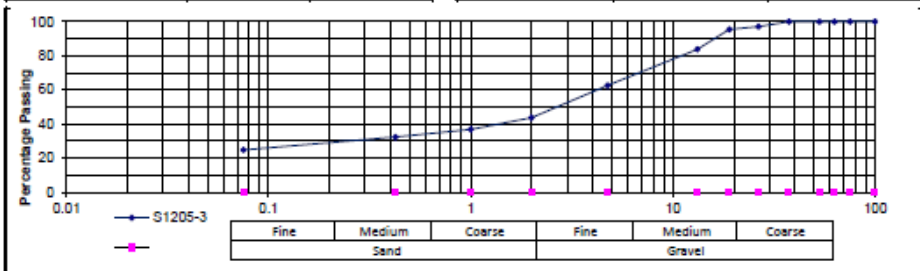
Sieve Analysis (Wet preparation)		
Percentage Passing	100 mm	100
	75 mm	100
	63 mm	100
	53 mm	100
	37.5 mm	100
	28 mm	97
	20 mm	95
	14 mm	84
	5 mm	63
	2 mm	44
	1 mm	37
	0.425 mm	32
	0.250 mm	30
	0.150 mm	28
0.075 mm	25	
Grading Modulus	1.99	



Soil Mortar Analysis	
Coarse Sand	28
Coarse Fine Sand	6
Medium Fine Sand	5
Fine Fine Sand	7
Silt and Clay	57

Atterberg Limits	
Liquid Limit (%)	27
Plasticity Index (%)	11
Linear Shrinkage (%)	4.5

Classifications	
HRB (AASHTO)	A-2-6(0)
COLTO	G6
TRH14	G6





## Appendix G: Geotechnical zonation map

