

Understanding Subterranean Hydrology in the Delineation of Wetlands – an Ephemeral Hillslope Wetland on Basement Granite in South Africa

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DECLARATION AND ACKNOWLEDGEMENTS

I, Nelda Breedt, student number 04382528, submit this dissertation to the Department of Geology, University of Pretoria, in accordance with the full requirements and prerequisites for the degree Masters in Sciences (M.Sc. Hydrogeology). I declare that everything contained in this dissertation is my own work unless noted otherwise. All external sources have been referenced diligently and all credit for previously published work is acknowledged to the respective authors. I furthermore acknowledge the following people and/or institutions:

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ABSTRACT

Wetlands are multi-disciplinary ecosystems defined and classified in many different ways across the world, due to their high variability in hydrological conditions, location, size and human influence. In South Africa the only legislative definition of a wetland is held by the National Water Act 36 of 1998, which was derived from the United States Fish and Wildlife Service (USFWS) Classification System for Wetlands and Deepwater Habitats in the USA, by Cowardin *et al.* (1979). This Act introduced the first legislation in South Africa directly addressing wetlands, and a manual for wetland delineation was only published in 2005 by the then Department of Water Affairs (DWA). Before the late 1990's environmental legislation was not very specific on the identification or development of these ecosystems, resulting in their destruction by development. Today still, wetland indicators, as specified by DWA 2005, are often missed in temporary systems during dry periods, and development commences on these wetlands. Not only do these developments cause harm or destroy these ecosystems, but cause major post-development problems such as contamination through surface water-groundwater interaction and seepage of shallow subsurface water through building foundations.

GLOSSARY

CARA	Conservation of Agricultural Resources Act
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECA	Environment Conservation Act
NEMA	National Environmental Management Act
NEMAQA	National Environmental Management: Air Quality Act
NEMBA	National Environmental Management: Biodiversity Act
NEMICMA	National Environmental Management: Integrated Coastal Management Act
NEMPAA	National Environmental Management: Protected Areas Act
NEMWA	National Environmental Management: Waste Act
NWA	National Water Act
NWCS	National Wetland Classification System
s.l.	sensu lato
s.s.	sensu stricto
SABS	South African Bureau of Standards
SANBI	South African National Biodiversity Institute
SANParks	South African National Parks Board
SEMA	Specific Environmental Management Act
TDS	Total Dissolved Solids
USFWS	United States Fish and Wildlife Service
WMA	Water Management Area
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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1. INTRODUCTION

1.1. Rationale

As explained by Cowan (1995), wetlands are the connection between marine, aquatic and terrestrial environments, creating a place where animals from these environments meet and interact. A wide variety of plants, invertebrates, fish, reptiles, birds and mammals are dependent on wetlands, some of which provide food or medicine for people. Wetlands are natural filters, regulating water quantity and quality. They have a vast capacity for storing water and can therefore offset floods, trap sediments and recharge groundwater. Additionally, by recycling nutrients and oxygenating water, they slowly release purified water back into the system. Wetlands are water resources which provide water for agriculture, industry and domestic use.

South Africa is an arid country, with an average annual rainfall of 450 mm, compared to the world average of 860 mm. Approximately 65% of the country receives less than 500 mm and 21%, less than 200 mm. Rainfall is generally unreliable and unpredictable; therefore wetlands are often strongly seasonal, causing wetlands of no apparent importance to become significant at certain times (Cowan, 1995). Due to the varying climate and topography in different places across the country, South Africa has a large variety of wetland types. Cowan (1995) explains that the large variety of bird species found in South African wetlands are an indication of the wide variety of wetland types, rather than the overall amount of wetland. Inland wetlands include permanent systems, such as reedbeds (vleis) in river channels, floodplains, swamps and marshes; and seasonal or ephemeral pans and ponds. Tidal salt and mud flats as well as mangroves occur along the coast (Day, 2009).

Water resources in South Africa are under increasing stress due to overutilization and development. Increasing urbanization over the past fifty years has caused increasing development and expanding of cities and towns, often into, and at the cost of, environmentally sensitive areas such as wetlands. This damage not only has environmental consequences, but also causes major problems for humans, such as floods, deterioration of water quality causing health problems and constructional problems such as wet foundations of structures.

1.2. Objectives

The objectives of this study were to: (a) review the evolution of wetland governance in South Africa to better understand decisions made regarding these ecosystem, both in the past and presently; (b) summarise some recent contributions to anthropogenic impacts on wetlands; (c) evaluate an ephemeral hillslope wetland to adequately understand the hydrological processes governing its occurrence; and (d) address considerations resulting in the inadequate delineation and potential destruction of ephemeral wetlands resulting from inadequate hydrological understanding.

2. LITERATURE REVIEW

2.1. Hillslope Wetlands

Despite several wetland classification schemes across the world including slope wetlands (Brinston *et al.*, 1993; Dini and Cowan, 2000; Ewart-Smith *et al.*, 2006; Kotze *et al.*, 2005; Maxwell *et al.*, 1995; Semenuik and Semenuik, 1995; Ward and Lambie, 1999), very little work has been done on these wetlands. Cole *et al.* (1997) categorised a set of reference wetlands by hydrogeomorphic subclass in order to better characterise wetland hydrology, as there is often a lack of hydrologic data. In this study they note that even though riparian depressions and slope wetlands are frequently seen as a single wetland type, there is enough distance between them to be different in hydrologic behaviour and thus in their functional capacity. Furthermore, they differ in terms of hydrogeomorphism, causing riparian depressions to be almost completely groundwater fed, and slopes to be a combination of surface and groundwater. Nelson *et al.* (2011) characterised the water chemistry of slope wetlands and neighbouring headwater streams in the Colorado subalpine forests. They compared sites situated on crystalline bedrock with sites situated on a mixture of crystalline and sedimentary bedrock and found that the hydrochemistry of both the slope wetlands and headwater streams in their study is sensitive to relatively small changes in underlying bedrock, which also influenced the plant species cover and composition at the study sites. Gao *et al.* (2012) used satellite images to assess how topography and proximity to channels affect wetland change. They found that even though wetlands can be found on slopes of 0-19°, they were more prominent, and less prone to wetland loss, on hill slopes around 3°.

2.1.1. What are wetlands?

Wetlands are characterised by a number of distinguishing features, most notably the presence of stationary water above the ground surface for a specific period of time, together with particular organisms (specifically vegetation) and unique soil conditions (Mitsch and Gosselink, 2000). Due to the high variability in hydrological conditions, the occurrence along slope margins as well as deep-water systems, and due to their high variability in location, size and human influence, defining wetlands are not very straightforward (Brison, 1993).

Mitsch and Gosselink (2000) suggest a three-tiered approach to defining wetlands based on hydrology, the physiochemical environment and biota as shown in Figure 1.

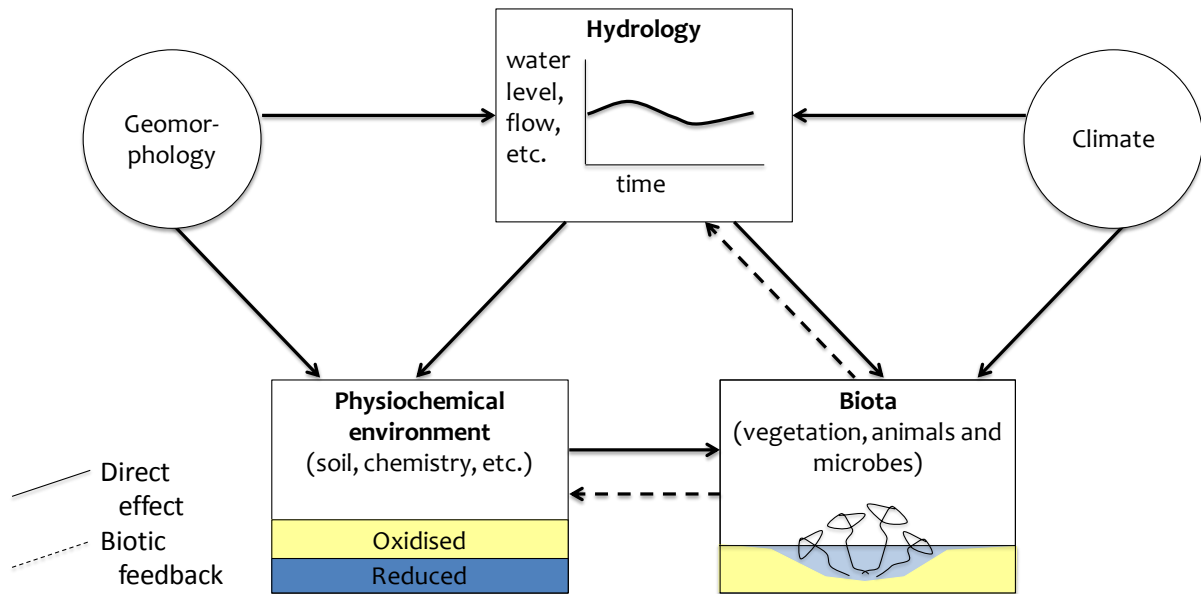


Figure 1. Defining wetlands based on hydrology, the physiochemical environment and biota (adapted from: Mitsch & Gosselink, 2000)

The adapted definition for the National Wetland Classification System (NWCS) states that a wetland is “... an area of marsh, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed ten metres” (Ewart-Smith et al., 2006) or, as stated by the South African National Biodiversity Institute (SANBI, 2009), as “... lakes and rivers, swamps and marshes, wet grasslands and peatlands, oases, estuaries, deltas and tidal flats, near-shore marine areas, mangroves and coral reefs, and human-made sites such as fish ponds, rice paddies, reservoirs, and salt pans.”

However, in South Africa, the definition stipulated by our National Water Act no 36 of 1998 apply, viz. that a wetland is “... land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil.” Identification of the vegetation might seem readily achievable, but in South Africa these species are often absent during the dryer months or are removed for a variety of reasons. Yet, this is often seen as the primary indicator despite being present due to the subsurface hydrological processes, and not vice versa.

Typical types of wetlands are as follows (Ewart-Smith et al., 2006):

- Seeps and springs (where rivers originate)
- Marshes and swamps (low-lying wetlands)
- Floodplains (areas flooded when a river exceeds its banks)
- Lakes (permanent bodies of fresh water)
- Estuaries (tidal mouths of rivers)
- Mangrove swamps (tropical coastal swamps where mangrove shrubs and trees grow).

2.1.1.1. Ephemeral Wetlands

Ephemeral wetlands are temporary or cyclic wetlands which are fed by the inflow of surface water after heavy rain, and vary in size from less than a metre to tens of kilometres in diameter (Day *et al.*, 2010). These cycles of wet and dry periods can be seasonal, but often also occur over longer time periods. In some cases dry periods may last for several years, while wet conditions only last for relatively short periods of time (Tiner, 1999). Groundwater does not contribute to these wetlands, but in permeable areas, they may recharge the groundwater (Colvin, 2002). Ephemeral wetlands are favourable for the breeding of certain amphibians and invertebrates, as they are free of fish (TCF, 2001). These wetlands are most common in arid and semi-arid regions (Tiner, 1999).

Day *et al.* (2010) investigated methods of identifying temporary wetlands during dry conditions. They discuss several vegetation and invertebrate indicators as well as abiotic indicators which may be present during dry periods and state that temporarily inundated wetlands may be easier to identify than those which are only temporarily saturated. The abiotic indicators are summarised below:

- The occurrence of a clay or other impervious layer within 50 cm below the surface;
- Deep polygonal cracks present on surfaces of thick, clay-rich substrata;
- Inorganic fines collecting on the surface, forming thin, curled polygons;
- The presence of a thin layer of highly decomposed organic matter (“muck”) on the upper surface of the site;
- The presence of biotic crusts consisting of dried algae, cyanobacteria and benthic microflora;
- The occurrence of algal markers;
- Water marks visible on fixed objects, indicating previous inundation;
- The remains of aquatic invertebrates occurring in surface sediment (although this may also be an indication of a previous wetland that no longer exist, as these may remain *in situ* for some time, and should therefore be used cautiously).

Ephemeral wetlands are important to protect, as they are connected to the surrounding upland habitat and are critical for many wildlife species. Furthermore, they play a central role in flood control and water quality (TCF, 2001).

2.1.2. Delineating Wetlands

Wetland classification is usually based on the environmental driving functions and most notably on hydrology and, as discussed by Ewart-Smith *et al.*, 2006, is based on its biophysical characteristics and is labelled the hydrogeomorphic classification.

The primary goal of classifying wetlands, according to Cowardin *et al.* (1979) in (Mitsch & Gosselink, 2000), is “... to impose boundaries on natural ecosystems for the purposes of inventory, evaluation, and management.” From, this, four primary objectives of the classification system are defined:

- To describe ecological systems with certain homogeneous natural characteristics
- To arrange these systems in a unified framework for the characterisation and description of wetlands, that will help resource management decisions
- To identify classification systems for inventory and mapping
- To provide evenness in concepts and nomenclature.

Landforms and hydrology are two fundamental features that determine the existence of all wetlands (Ewart-Smith et al., 2006), both of which are included in the hydrogeomorphic (HGM) approach. The structure of this classification system is hierarchical and progresses from Systems through Subsystems to Functional, Structural and Habitat Units where each level in the hierarchy focuses on the discriminators that distinguish between different types of wetlands (Figure 2).

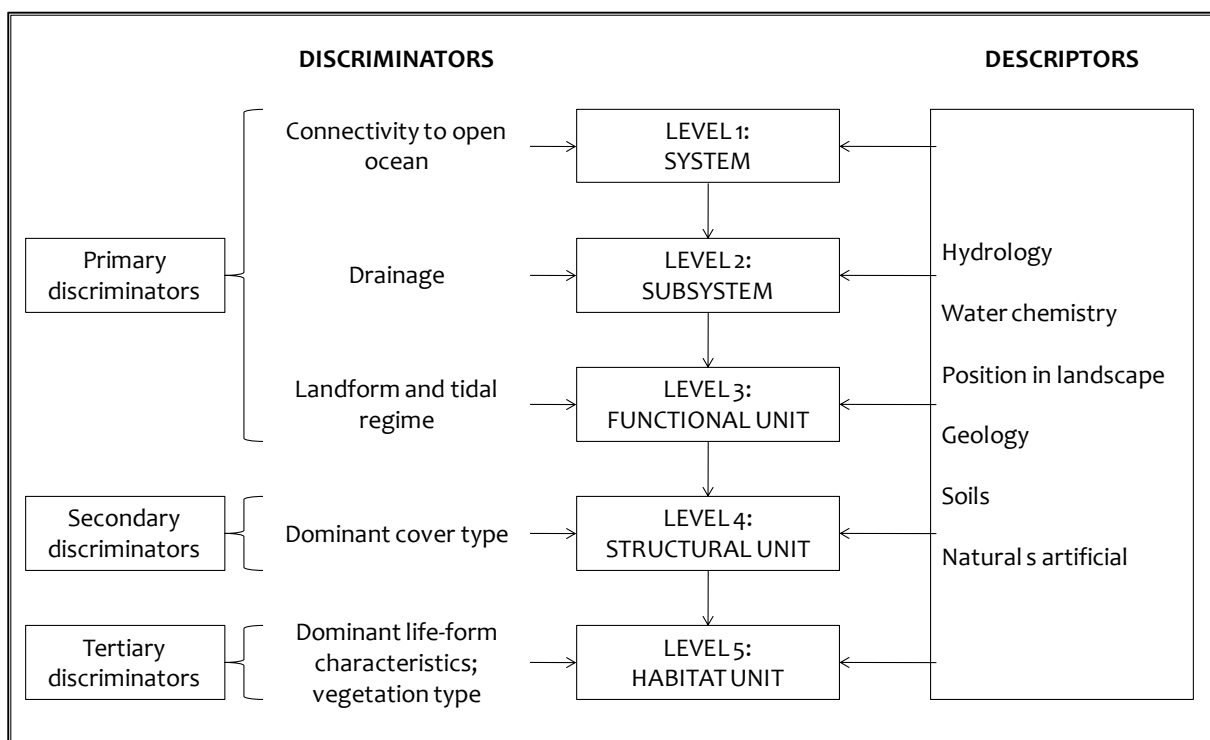


Figure 2. Proposed hydrogeomorphic (HGM) wetland classification system. (adapted from: Ewart-Smith et al., 2006)

Based on this, Ewart-Smith et al. (2006) recommend distinction between three types of systems based on Level 1, viz. marine systems (along the coastline); estuarine systems (permanently or periodically connected to ocean, influenced by tidal action and of which the water is at least occasionally diluted by freshwater); and inland systems (permanently or periodically inundated or saturated and with no existing connection to the ocean).

Level 2 refers to the level of drainage and applies only to estuarine systems (permanently open or temporarily closed) and inland systems (non-isolated or isolated). Following this, Level 3 relates to the landform and tidal discriminators; Level 4 to the substratum, surface/ subsurface vegetation and/ or emergent vegetation, including unvegetated areas; and Level 5 relating to specific habitats (e.g. dominant vegetation characteristics).

Wetland delineation is typically based on at least two of the following indicators (DWA, 2005):

- Terrain Unit Indicator to outline probable portions of the landscape for the occurrence of wetlands
- Soil Form Indicator to identify soils subjected to prolonged and frequent periods of saturation
- Soil Wetness Indicator relating to morphological signs developing in the soil profile due to prolonged and frequent periods of saturation
- Vegetation Indicator identifying the hydrophilic vegetation commonly associated with such frequently saturated soils.

Additional to the abovementioned four indicators and according to DWA (2005), wetlands should contain at least one of the following:

- Hydromorphic soils exhibiting characteristics due to prolonged saturation
- Occasional (or more frequent) presence of hydrophytes (water-loving plants)
- High water table resulting in saturation of surface or shallow subsurface and evident by anaerobic conditions in upper 0.50 m of the soil.

Day et al. (2010) additionally suggest the following abiotic indicators (to be used in conjunction with a variety of biotic determinants):

- Shallow clay or impervious layer within 50 cm of the surface
- Deep polygonal cracks on thick clayey substrata
- Thin curled polygons of inorganic fines on the surface
- Thin muck layers, often overlying sandy soil
- Sediment deposits on plants, rocks and other objects
- Biotic crusts
- Algal markers
- Water marks on rocks or any other fixed structures
- Shells, exoskeletons and bodies of aquatic vertebrates.

The four indicators (terrain, soil form, soil wetness and vegetation) are mostly applied in wetland delineation. The first – the terrain unit indicator – relates to those parts of landscapes where wetlands are more likely to occur, but should not be used as a sole indicator of a wetland. Typical terrain units likely for wetland occurrence are valley bottoms and valley bottoms connected crests, midlopes and footslopes as per Figure 3 (DWA, 2005).

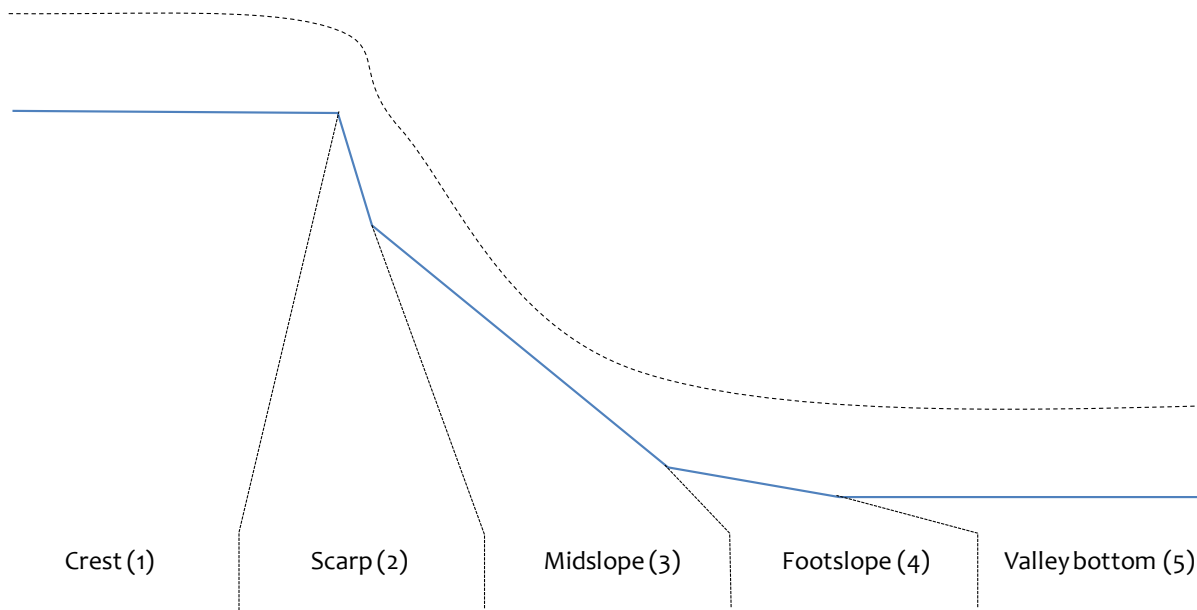


Figure 3. Typical terrain units of wetlands. (adapted from: DWA, 2005)

The second – the soil form indicator – identifies soil forms specifically associated with prolonged and/ or frequent saturation. This prolonged and repeated saturation leads to microorganisms gradually consuming the oxygen present in pore spaces, resulting in anaerobic conditions in these so-called hydromorphic soils. These anaerobic conditions are also associated with the leaching of iron and manganese, resulting in a typical change from reddish and brownish colour due to iron to greyish, greenish or bluish. This is called gleying and is interpreted as representing a zone which is temporarily or seasonally saturated (Tiner, 1999).

Water table lowering subsequently leads to aerobic conditions once again and dissolved iron becomes insoluble again. Precipitation is typically in the form of patches or mottles, also a typical indicator of wetlands. This soil wetness indicator identifies morphology signatures developed throughout the soil profile due to prolonged and frequent saturation. This is one of the most practical indicators with the increasing length and regularity of periods of saturation in a profile, the more distinctly grey the colours become. A grey soil matrix and/ or mottles must be present to support the soil being wet in the temporary, seasonal and permanent zones (DWA, 2005). This accentuates the importance of proper description of colour during soil profiling and the inclusion of this in, for instance, the MCCSSO system (§3.2.1).

Finally a vegetation indicator is applied to identify hydrophilic vegetation requiring frequently saturated soil. Vegetation in an untransformed state is a beneficial field guide in identifying the wetland boundaries as the plant species change from the centre of the wetland towards its edges. Due to the saturated conditions, plant roots cannot behave in its normal metabolic function and certain nutrients become unavailable to the plants, leading to certain elements being in elevated concentrations in the soil. Due to extensive morphological, physiological and/ or reproductive adaptation, these plant species are able to persist in these anaerobic soil conditions (DWA, 2005).

Whether a particular area is classified as a wetland is subject to the number of identified wetland indicators. The edges of a wetland are established at the point where these indicators are no longer present. The presence of all indicators provide a logical, defensible and technical basis for

identifying an area as a wetland, but an area should display a minimum of either soil wetness or vegetation indicators in order to be classified as a wetland. Verification of the terrain unit and soil form indicators increases the level of confidence in deciding the boundary and therefore, the more indicators present, the higher the confidence in the delineation (Tiner, 1999).

2.2. Hillslope Hydrology and Hillslope Wetlands

2.2.1. Catena

Brady and Well (2002) define a catena as a set of soils that form in a place where all the soils form from the same parent materials, but differ from each other in terms of drainage and relief. The catena concept is explained in much detail by Schaetzl and Anderson (2010), with emphasis on the important role of groundwater in the development of a catena: Malo *et al.* (1974, cited in Schaetzl and Anderson, 2010) explain that two main reasons for soils to vary along catenas are: (1) due to the effects of slope on fluxes of water and matter, which are normally, but not always in a downslope direction; and (2) water table fluctuations, causing debris fluxes (sediment and organics) and moisture fluxes. Schaetzl and Anderson (2010) further discuss three types of aquic conditions, *viz.* endosaturation, episaturation and anthric saturation.

Endosaturation occurs where all soil layers are saturated, from the upper boundary of the water table to a depth of ≥ 200 cm. This suggests saturation below a regional or at least local water table, with the saturated zone continuing to some depth.

Episaturation occurs within the upper 200 cm, when one or more soil layers are saturated, and one or more of the soil layers below are unsaturated. The water is perched on top of a relatively impermeable layer, with underlying layers remaining unsaturated. Episaturation is likely to cause mottling. On slopes, episaturated water may travel as throughflow along the top of an aquitard (Gile, 1958, Evans and Franzmeier, 1986 both cited in Schaetzl and Anderson, 2010).

Anthric Saturation is a human-induced aquic occurrence in cultivated and irrigated (especially by flood irrigation) soils, such as treatment wetlands.

Water tends to infiltrate or slowly run off on crests, whereas the most runoff, and thus also erosion, occur on the upper back slope and shoulder slope areas, as these have the steepest slopes. Consequently, these areas also exhibit the thinnest soil profiles and are the most likely areas for rock outcrops or free faces (Gregorich and Anderson, 1985 cited in Schaetzl and Anderson, 2010).

Fey (2010) explains that the “*red-yellow-grey plintinc catena*” is a commonly observed toposequence in South Africa, comprising of “*red soils on well drained crests, grading via yellow soils on mid-slopes to grey soils in poorly drained bottomlands*”. A plinthic horizon is generally found in soil profiles of the yellow and grey members, but is sometimes found throughout the sequence.

2.2.2. *Pedogenesis and Translocation*

Fey (2010) describes plinthic soils in detail, from its chemical and physical properties, to its classification and genesis. Plinthite is defined differently in different parts of the world, but is fundamentally “where iron oxides are found segregated and concentrated in soil in the form of mottling and cementation”. The iron oxides have a strong pigmenting effect and are cemented as either hard nodules or a variegated, vesicular hardpan. The plinthic soil group is defined either by a soft or hard plinthic B horizon and is typically a sign of a fluctuating water table, bearing valuable information about the seasonal soil water status. When the plinthite is not well developed, only showing mottling and incipient cementation, it is often difficult to differentiate between a soft plinthic B horizon and some E or G horizons or other materials with signs of wetness. When well developed, plinthite is roughly the same as what geologists call laterite or ferricrete. A plinthic soil profile comprises an orthic A horizon, grading into a soft or hard plinthic B horizon either directly or indirectly, through a red apedal B, yellow-brown apedal B or E horizon. Therefore, in many ways, the properties of plinthic soils are analogous to those of either oxidic soils and/or gleyic soils. Differentiation between soft and hard plinthic layers, not only informs about the degree of pedogenic expression, but also suggests different practical considerations of land use.

Plinthic soils are associated with sub-humid rather than a humid climate, which suggests that a distinct dry season is required of plinthite formation, together with an adequately wet season to induce saturation with water and mobilisation of reduced iron. There are roughly two different plinthite forming processes (Fey, 2010):

- i) Residual iron enrichment, mainly through weathering and removal of silica and basis, causing resistant oxides of Al, Ti and Zr to be co-enriched with iron, forming laterite or, if the Al enrichment is strong enough, bauxite. In this case, the term plinthite refers to materials in which the iron has separated into mottles and cement due to a contemporaneous or subsequent fluctuating water table. This kind of plinthite is usually linked with areas of relatively hindered drainage on old land surfaces.
- ii) Imported iron enrichment, in groundwater after mobilisation by reduction, followed by oxidation within that portion of the intermittently aerated zone that most commonly hosts an influx of dissolved Ferrous iron. In this case, manganese is the only other element which may show substantial co-accumulation, depending on its concentration in the parent material from which the iron was derived. Most plinthic soils in South Africa have formed by this process (Figure 4).

Fey (2010) further summarises the redox transformations associated with the genesis of plinthic and other hydromorphic soils.

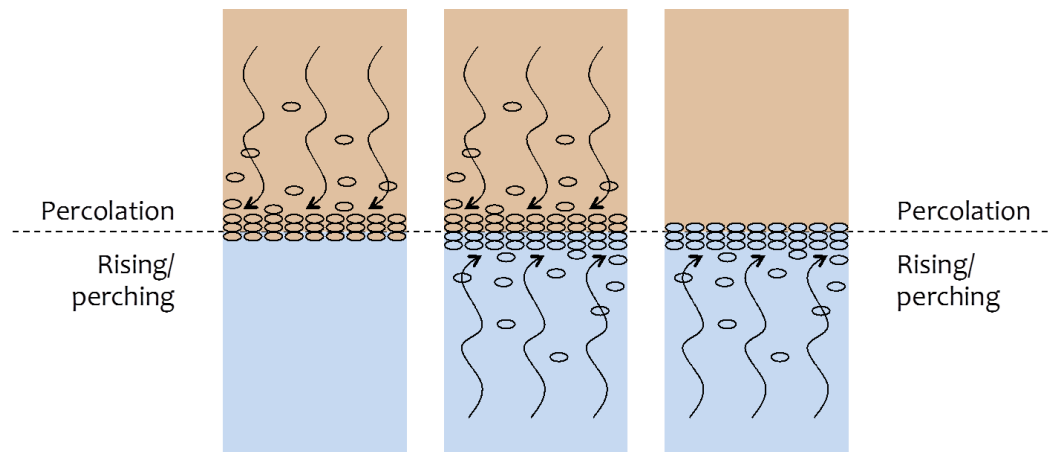


Figure 4. Ferricrete formation with Fe source from perched rising water and interflow (McFarlane 1976).

2.3. Wetland Governance

2.3.1. Historical Water Law and Wetlands

The Water Act 54 of 1956 replaced the Irrigation and Conservation of Waters Act 8 of 1912 in order to shift water supply from agriculture to the fast-growing mining and industry sector. This act was based on a riparian rights system which led to major restrictions in water access for most of the population. Consequently, the single largest reason for death and illness amongst the poor in South Africa was due to unsanitary water (Kidd, 1997). Water supply was focussed mainly on providing water for white farmers (Day, 2009; Funke et al., 2007; Kidd, 2011); however, it is important to note that even though the Act was passed during the development of the South African government's apartheid regime, it was not dominantly part of the structure (Kidd, 2011). The Act also did not provide for sustaining a basic quantity of water for the needs of the environment (Kidd, 1997).

The Water Act differentiates between private water, public water and public stream as follows (Water Act 54 of 1956 cited in Kidd, 2011):

- Private water: *"All water which rises or falls naturally on any land or naturally drains or is led onto one or more pieces of land which are the subject of separate original grants, but is not capable of common use for irrigation purposes."*
- Public water: *"Any water flowing or found in or derived from the bed of a public stream whether visible or not."*
- Public stream: *"Natural stream of water which flows in a known and defined channel, whether or not such a channel is dry during any period of the year and whether or not its conformation has been changed by artificial means, if the water therein is capable of common use for irrigation on two or more piece of land, riparian thereto which are the subject of separate original grants or on one such piece of land and also on [state] land which is riparian to such stream, provided that a stream which fulfils the foregoing*

conditions in part only of its course shall be deemed to be a public stream as regards that part only.”

Apart from a lack of knowledge regarding wetland conservation and protection at the time, one of the main reasons for the poor legislative protection, was the fact that wetlands were often regarded as being on privately owned land and was therefore treated as private water, the use and enjoyment of which was exclusive to the owner of the land on which they occurred. He was just not allowed to pollute it (O’Keeffe et al., 1992; Kidd, 2011).

As wetlands derive their water from natural drainages, springs or rainfall, it could not contain public water, according to this Act, unless the water was derived from a public stream. In other words, a wetland could only be seen as containing public water in a case where a public stream spread out and stopped flowing in a “known and defined channel”, forming the wetland (O’Keeffe et al., 1992).

The rights of a public water user were restricted in terms of using water for industrial purposes without a permit, and were subject to the strict requirements of this Act in terms of pollution. These restrictions, however, were not sufficient to ensure the conservation and protection of wetlands on privately owned land, which posed major threats to these ecosystems during urban and agricultural development (O’Keeffe et al., 1992).

2.3.2. Historical Environmental Law and Wetlands

The early 1970s are viewed worldwide as the dawn of a new era in environmental law. Even though environmental laws existed before this time, environmental issues now received a lot more political and legislative attention (Kidd, 1997; Kidd, 2011). The earliest reference to providing water explicitly for “managing the environment” was in the discussions of the Commission of Inquiry into Water Matters in 1970 (DWA, 1986 cited in Day, 2009), where it was vaguely proposed that a small percentage of water be allocated for the maintenance of floodplains and estuaries, with a small amount also being reserved for drinking water for wildlife. This was likely due to rivers of the Kruger National Park, lying downstream of large irrigated farmlands, often ran dry during summer (Day, 2009). Throughout the 1970s and 1980s South Africa had a number of laws that could protect certain wetlands in a fragmented manner, but these were all laws with different objectives and could therefore not protect wetland ecosystems as a whole (Cowan, 1999).

The first of these laws was the Mountain Catchment Areas Act 63 of 1970. The objective of this Act is to “*provide for the conservation, use, management and control of land situated in mountain catchment areas, and to provide for matters incidental thereto*”, because these areas are vital sources of water. As rivers often originate from sponges on mountain slopes, these wetlands could be protected. However, as this Act could not be applied to the catchment as a whole, it could not protect wetlands occurring on flats (O’Keeffe et al., 1992).

The Lake Areas Development Act 39 of 1975 followed, which could protect a wetland if it formed part of a declared lake area as by Section 2 of this Act: the State President could declare, by notice in the Government Gazette, any land comprising or adjoining a tidal lagoon, a tidal river or any

part thereof, or any other land comprising or adjoining an natural lake or a river or any part thereof, which is within the immediate vicinity of a tidal lagoon or a tidal river, to be a lake area (these duties were transferred to the Minister of Environment Affairs in 1986). Subsequent to this declaration, lake areas were transformed to national parks or parts thereof (Hanks and Glavovic, 1992).

The Conservation of Agricultural Resources Act 43 of 1983 (CARA) was the furthest-reaching Act in terms of wetland conservation during this time. This was the only legislation directly addressing wetland conservation. Even though the objective of this Act is the conservation of agricultural resources, in effect, it still protects the wetland in question. The Act forbids the use of vegetation in wetlands that may cause harm or deterioration to agricultural resources. Further, it prohibits the removal of an obstruction which could result in increased soil erosion during floods, especially since wetlands often occur as a result of natural barriers. Regulations also instruct land users to remove vegetation in watercourses which could cause obstruction during floods, resulting in soil erosion. This might serve to protect river banks, but could have detrimental effects further downstream (O’Keeffe et al., 1992). Furthermore, users are forbidden, without written permission, to drain or cultivate any vleij, marsh or water sponge or portion thereof on their land, or to cultivate any land within the flood area of a watercourse.

The Forest Act 122 of 1984 mainly aimed to control the making of open veld fires, but also prohibited afforestation or reforestation on certain land in order to protect any water resource (Kidd, 1997), and was therefore able to control the distance of forested areas from wetlands (O’Keeffe et al., 1992).

The Environment Conservation Act 73 of 1989 (ECA) repealed Act 100 of 1982 with the same name. In spite of the all-encompassing title, the 1982 Act only controlled a few environmental facets (Rabie, 1992), and was therefore regarded as inadequate legislation for the environmental obligations that were becoming increasingly important (Kidd, 1997). The 1989 Act significantly increased the scope of the older Act, but still had major shortcomings, and thus the title remained misleading (Rabie, 1992). According to the ECA’s long title, it aims to provide “*for the effective protection and controlled utilization of the environment and for matters incidental thereto*”. Rabie, 1992 explains that “effective protection” indicates a non-utilitarian ecocentric perspective, whereas “controlled utilization” indicates a utilitarian, anthropocentric emphasis. Kidd, 1997 describes these goals as mutually exclusive and suggests that the long title would have been better phrased as “effective conservation”. Nevertheless, Section 2(1) of the Act stated that:

“Subject to the provisions of subsection (2), the Minister may by notice in the Gazette determine the general policy, including policy with regard to the implementation and application of a convention, treaty of agreement relating to the environment which has been entered into or ratified, or to be entered into or ratified, by the Government of the Republic, to be applied with a view to:

- a) the protection of ecological processes, natural systems and the natural beauty as well as the preservation of biotic diversity in the natural environment;*
- b) the promotion of sustainable utilization of species and ecosystems and the effective application and re-use of natural resources;*

- c) *the protection of the environment against disturbance, deterioration, defacement, poisoning, pollution or destruction as a result of man-made structures, installations, processes or products or human activities;*
- d) *the establishment and maintenance of acceptable human living environments in accordance with the environmental values and environmental needs of communities;*
- e) *the promotion of the effective management of cultural resources in order to ensure the protection and responsible use thereof;*
- f) *the promotion of environmental education in order to establish an environmentally literate community with a sustainable way of life; and*
- g) *the execution and co-ordination of integrated environmental monitoring programmes.”*

The ECA provided the first attempt to define the term ‘environment’ and provided regulations for environmental impact assessments. Acting under Section 2 of the Act, the Minister of Environmental Affairs issued a notice (No 51 of 1994, published in Government Gazette 15428 of 21 January 1994) containing the general policy determined by him thereunder. This stated the following:

“All responsible government institutions must apply appropriate measures, based on sound scientific knowledge, to ensure the protection of designated ecologically sensitive and unique areas, for example...wetlands...”

Through this policy wetlands could be protected, as in the case of Van Huyssteen & others NNO v Minister of Environmental Affairs and Tourism & others, 1996, summarised in Kidd, 1997.

2.3.3. The Ramsar Convention

The Convention on Wetlands of International Importance especially as Waterfowl Habitat, generally known as the Ramsar Convention (named after the town of Ramsar, Iran, where the first meeting was held), is an intergovernmental treaty drawn up in 1971. It aims to conserve wetlands and waterfowl across international boundaries, as these habitats often transcend these boundaries. South Africa became the fifth signatory to the Convention in 1975 (Cowan, 1995). According to Article 3.1 and 4.1 of the Convention, the objectives include the reduction of wetland loss; promotion of wise use of all wetlands; promoting special protection of listed wetlands; encouraging the training of personnel; and encouraging the enactment of responsibilities of parties under the Convention (cited in Cowan, 1999). Wetlands are here defined as: “areas of marsh, fen, peat land or water, whether natural artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres”. According to the Convention, wetlands must be selected for inclusion on the List of Wetlands of International Importance (“the List”) according to their international significance in terms of ecology, botany, zoology, limnology or hydrology, and wetlands that are of international importance to waterfowl in any season have to be included. Cowan, 1999 lists all the criteria for a wetland to be included in the List and explains when a wetland should be considered as internationally important.

In South Africa, the Department of Environmental Affairs and Tourism (DEAT, now known as DEA, Department of Environmental Affairs) is responsible on a national level for implementation of

the Convention. Management of any particular wetland can fall under the responsibility of a number of departments or under any of the nine provincial governments; however, the South African National Parks Board (SANParks) takes full responsibility of all national parks (Cowan, 1995; Kidd, 2011). A national inventory was starting to be developed in the mid to late 1990's, but is by no means comprehensive yet (Day, 2009). In 1998 the new National Water Act included wetlands in the definition of 'watercourse', which strengthened the protection and conservation of wetlands significantly on a legislative basis.

To date South Africa has 21 sites on the Ramsar List (Table 1) and two more sites designations are planned for the next Ramsar triennium (2012-2015), *viz.* Zwartkops Estuary and False Bay Ecology Park (CBD-COP11, 2012). The Montreux Record is an inventory of wetlands on the List of Wetlands of International Importance which have undergone, are undergoing or are likely to undergo changes in ecological character due to technological developments, pollution or other anthropological interference. South Africa currently has two sites on the Montreux Record, *viz.* Orange River Mouth and Blesbokspruit. According to the Convention on Biological Diversity (COP11, 2012), significant progress has been made in the case of Orange River Mouth in terms of addressing the threats affecting the ecological character of the site. In addition, a process is in motion to declare the site a Nature Reserve under National Legislation and a management plan will be established for the protection, conservation and management of the site. A report regarding Blesbokspruit will be submitted at the next meeting of the Standing Committee.

Table 1: South African Ramsar sites from 1975 to 2013 (adapted from Ramsar, 2013).

Ramsar Site No.	Site Name	Date Added to List	Province	Size (ha)	Reserve Type	Montreux Record
35	Baberspan	1975/03/12	North-West	3 118	Provincial Nature Reserve	-
34	De Hoop Vlei	1975/03/12	Western Cape	750	Provincial Nature Reserve	-
343	Blesbokspruit	1986/10/02	Gauteng	1 858	Nature Reserve	Added: 1996/05/06
342	De Mond (Heuningnes Estuary)	1986/10/02	Western Cape	918	Nature Reserve	-
345	St. Lucia System	1986/10/02	Kwazulu-Natal	155 500	Wetland Park; State Forest Reserve	Added: 1990/07/04 Removed: 1996/03/11
344	Turtle Beaches / Coral Reefs of Tongaland	1986/10/02	Kwazulu-Natal	39 500	Marine Reserve	-
398	Langebaan	1988/04/25	Western Cape	6 000	National Park	-
527	Kosi Bay	1991/06/28	Kwazulu-Natal	10 982	Nature Reserve	-
528	Lake Sibaya	1991/06/28	Kwazulu-Natal	7 750	Research Station	-

526	Orange River Mouth	1991/06/28	Northern Cape	2 000	In process of being declared a Nature Reserve	Added: 1995/09/26
525	Verlorenvlei	1991/06/28	Western Cape	1 500	-	-
524	Wilderness Lakes	1991/06/28	Western Cape	1 300	National Park; Wilderness Area; Nature Reserve	-
886	Natal Drakensberg Park	1997/01/21	Kwazulu-Natal	242 813	Wilderness Area; Nature Reserve; Game Reserve; Provincial Park; State Forest	-
887	Ndumo Game Reserve	1997/01/21	Kwazulu-Natal	10 117	Nature Reserve	-
888	Seekoeivlei Nature Reserve	1997/01/21	Freestate	4 754	Nature Reserve	-
952	Nylsvley Nature Reserve	1998/07/07	Limpopo	3 970	Nature Reserve	-
1110	Verloren Valei Nature Reserve	2001/10/06	Mpumalanga	5 891	Nature Reserve	-
1687	Makuleke Wetlands	2007/05/22	Limpopo	7 757	National Park	-
1688	Prince Edward Islands	2007/05/22	Western Cape	37 500	Protected National Habitats; Research Station	-
1904	Ntsikeni Nature Reserve	2010/02/02	Kwazulu-Natal	9 200	Nature Reserve	-
2132	uMgeni Vlei Reserve	2013/03/19	Kwazulu-Natal	958	Nature Reserve	-

2.3.4. Current Legislation

With the change in government in 1994, after the first democratic elections in South Africa, came the need for a new Constitution. The new government set out to change the republic's philosophy, priorities and approach to water resource management. It became a high priority to provide the majority of South Africans with basic water supply and sanitation along with the equal allocation of water and the benefits of water use (Funke et al., 2007). The Constitution of the Republic of South Africa Act 108 of 1996 includes the environmental right in Chapter 2. According to Section 24 of the Act, everyone has the right:

- a) to an environment that is not harmful to their health or well-being; and
- b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:
 - i. prevent pollution and ecological degradation;

- ii. *promote conservation; and*
- iii. *secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.*

It is not uncommon to have an environmental right included in the Constitution, but most countries that have a well-developed environmental law system do not have such a right (Kidd, 2011). Sustainable development is strongly emphasised in the constitutional environmental right. It unambiguously refers to the fact that environmental, social and economic aspects must be taken into account with the way the environment is protected; and states that this must be done in a balanced way to guarantee sustainable development beyond the lifetime of the present generation (du Plessis and du Plessis, 2011).

The National Water Act 36 of 1998 (NWA) along with the Water Services Act 108 of 1997 were ground-breaking in the reformation of the law in terms of water supply, water use and water resource management. For the first time, anywhere in the world, the water needs of aquatic ecosystems were given precedence, together with basic human needs, over other contending water users. The NWA was the first in the world to provide legislative protection for 'water resources' (Day, 2009). The definitions, according to the NWA, of water resource, watercourse and wetland are as follows:

Water resource: "includes a watercourse, surface water, estuary or aquifer."

Watercourse: "(a) a river or spring; (b) a natural channel in which water flows regularly or intermittently; (c) a wetland, lake or dam into which, or from which, water flows; and (d) any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks."

Wetland: "means land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports vegetation typically adapted to life in saturated soil."

Furthermore, Section 2 provides the purpose of the Act, which is to *"ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors:*

"...

- g) protecting aquatic and associated ecosystems and their biological diversity;*
 - h) reducing and preventing pollution and degradation of water resources;*
- ..."*

In essence, nothing with negative effects to a wetland can be done without a valid licence (Kidd, 2011). In spite of the theory behind the NWA being comprehensive; a lot of difficulty is still experienced with the implementation. This is due to a lack of human and technical capacity and the need new innovative ways of managing people, water and ecosystems (Day, 2009; Funke et al., 2007). In 2005 the Department of Water Affairs and Forestry (DWAF, since known as DWA, Department of Water Affairs, and now known as DWS, Department of Water and Sanitation) published a manual describing indicators and methods for determining whether an area is a wetland or riparian area and

how to delineate the area. The manual “*provides authorities with a standardised, affordable and auditable method of spatially defining these hydrologically sensitive areas*” (DWAF, 2005).

The National Environmental Management Act 107 of 1998 (NEMA) was promulgated as the framework legislation for protecting the environment, and gives effect to the environmental right guaranteed in Section 24 of the Constitution. This Act repealed the greater part of the Environment Conservation Act 73 of 1989 and sets the fundamental principles that apply to environmental decision making in Section 2. The core environmental principle is the promotion of sustainable development. Principle 4(r) states the following: “*Sensitive, vulnerable, highly dynamic or stressed ecosystems, such as coastal shores, estuaries, wetlands and similar systems require specific attention in management and planning procedures, especially where they are subject to significant human usage and development pressure.*” The Act also provides a new framework for environmental impact assessments, discussed in detail by Walmsley and Patel, 2011. Numerous other environmental framework acts have been promulgated since NEMA, referred to as the Specific Environmental Management Acts (SEMAs) as defined in Section 1 of NEMA. These include:

- i) The National Environmental Management: Protected Areas Act 57 of 2003 (NEMPAA);
- ii) The National Environmental Management: Biodiversity Act 10 of 2004 (NEMBA);
- iii) The National Environmental Management: Air Quality Act 39 of 2004 (NEMAQA);
- iv) The National Environmental Management: Waste Act 59 of 2008 (NEMWA); and
- v) The National Environmental Management: Integrated Coastal Management Act 24 of 2008 (NEMICMA).

SEMAs (i), (ii) and (v) above, have relevance to wetland conservation and protection and are further discussed below.

The Protected Areas Act repealed the National Parks Act 57 of 1976 and deals with protecting the country’s biodiversity, with keeping social and cultural concerns in account and providing for nature-based tourism (du Plessis and du Plessis, 2011). The Act is described in its long title as “*[providing] for the protection and conservation of ecologically viable areas representative of the country’s biological diversity, its natural landscapes and seascapes. It further provides for the establishment of a national register of protected areas, the management of these areas, co-operative governance, public participation and matters related to protected areas.*” The objectives of the Act are listed in Section 2. Section 9 lists the kinds of protected areas in South Africa as follows:

- a) *Special nature reserves, national parks, nature reserves (including wilderness areas) and protected environments;*
- b) *World heritage sites;*
- c) *Marine protected areas;*
- d) *Specially protected forest areas, forest nature reserves and forest wilderness areas declared in terms of the National Forests Act 84 of 1998; and*
- e) *Mountain catchment areas declared in terms of the Mountain Catchment Areas Act 63 of 1970.*

Furthermore, Section 17 lists the purposes of declaring protected areas, which include, amongst other things “to protect ecologically viable areas representative of South Africa’s biological

diversity and its natural landscapes and seascapes in a system of protected areas; to protect the ecological integrity of those areas; to conserve the biodiversity of those areas (Section 17 (a)-(c)), as well as “to rehabilitate and restore degraded ecosystems and promote the recovery of endangered and vulnerable species” (Section 17 (l)). As most of the Ramsar sites fall under the categories in Section 9 (see Table 1), these wetlands, as well as any other wetland inside a protected area, will be regulated by this Act.

The Biodiversity Act aims to provide for the conservation of South Africa’s biological resources within the NEMA framework. It regulates the use of the country’s indigenous biological resources to ensure sustainability, provides for equity in bioprospecting and the establishment of a regulatory body on biodiversity- South African Biodiversity Institute. Furthermore, the objectives in Section 2 of the Act include giving effect to ratified international agreements relating to biodiversity, such as the Convention on Biological Diversity and the Ramsar Convention. Even though the text of the Act doesn’t specifically mention wetlands, the provisions concerning the conservation of ecosystems, include, amongst others, the conservation of wetlands (Kidd, 2011). As mentioned before, many of the high profile wetlands (such the Ramsar sites) are in protected area and thus protected under the NEMPAA, but many smaller wetlands are outside of protected areas and on privately owned land. These wetlands are often under threat as landowners do not necessarily see their value (Kidd, 2011).

The Integrated Coastal Management Act establishes a system of coastal and estuarine management. It aims to conserve the coastal environment and preserve the natural characteristics of coastal landscapes and seascapes. The Act also has an approach of maintaining ecological sustainability during development of coastal zones, and the use of natural resources. It ensures that these activities are both socially and economically justifiable. In addition to this, Section 2 of the Act also regulates pollution and waste disposal activities at sea and in coastal zones. Section 1 defines a coastal wetland as follows:

- a) *“any wetland in the coastal zone; and*
- b) *includes:*
 - i. *land adjacent to coastal waters that is regularly or periodically inundated by water, salt marshes, mangrove areas, inter-tidal sand and mud flats, marshes, and minor coastal streams regardless of whether they are of a saline, freshwater or brackish nature; and*
 - ii. *the water, the subsoil and substrata beneath, and bed and banks of any such wetland”.*

The term ‘wetland’ is defined as in the NWA 36 of 1998. Section 16 lists the composition of coastal protection zone, which includes, inter alia:

“...

- d) *Any land unit situated wholly or partially within one kilometre of the high-water mark which, when this Act came into force:*
 - i) *Was zoned for agriculture or undetermined use; or*
 - ii) *...*

- e) Any land unit not referred to in paragraph (d) that is situated wholly or partially within 100 metres of the high-water mark;
- f) any coastal wetland, lake lagoon or dam which is situated wholly or partially within a land unit referred to in paragraph (d)(i) or (e);...

Additionally, Section 27(1)(c) determines that Minister must take into account “the importance of ensuring the natural functioning of dynamic coastal processes and of extending the coastal boundaries of coastal public property to include the littoral active zone and sensitive coastal ecosystems, including coastal wetlands”, when determining or adjusting the inland coastal boundary of coastal public property.

Granting that South Africa has a world class environmental legislative framework which seems to be sufficiently comprehensive in its conservation of wetlands, implementation still poses significant political and technical challenges (Day, 2009; Kidd, 2011). However, du Plessis and du Plessis (2011) remain positive and applaud the country for its design of the legal framework since 1996 and state that they are comfortable in the knowledge that if all laws, policies, plans and decisions can pass the constitutional and NEMA principles benchmark, South Africa can achieve continual sustainability. Day (2009) concludes that in spite of difficulties, the groundwork has been done and positive developments are under way.

2.4. Anthropogenic Impacts on Wetlands

Due to the increasing human population, and subsequent increasing urban development worldwide, sensitive ecosystems such as wetlands and other freshwater resources are increasingly under pressure. Humans impact wetlands in many direct and indirect ways: Zalidis *et al.* (1997), Walters *et al.* (2006) and Cabezas *et al.* (2009) reported on wetland disturbances by agricultural practices, construction of irrigation schemes, diversion of water courses, and pollution, as well as the impact of human disturbances on water quality and hydrochemistry. Furthermore, the expansion of urban areas, landscaping, reduction of catchment permeability and additional abstraction from water resources to feed the growing population, causes these environments to rapidly decrease (Liyang *et al.*, 2010; Wang *et al.*, 2010; Chu and Molano-Flores, 2013).

Riddell *et al.* (2012) considered rehabilitation techniques for a semi-arid headwater wetland in the Sand River, South Africa, which was subject to severe erosion due to poor agricultural practices. They found that the wetland hydrology is strongly governed by the distribution of clays within the wetland and that placement of rehabilitating engineering structures are crucial to the restoration of the wetland hydrology. Lunde and Resh (2012) developed and validated a macro-invertebrate index of biotic integrity in order to assess urban impacts on freshwater wetlands, however, Bird *et al.* (2013) discourages the use of macro-invertebrates as indicators of human disturbance, particularly in areas with prominent natural environmental heterogeneity, as their study shows that assemblage composition is mainly determined by environmental and spatio-temporal features, free from human influences, while human disturbances were negligible.

In the following case study, an urban ephemeral wetland was excavated as part of a building footprint. In this case, apart from the obvious destruction of the ecosystem, the anthropogenic impacts also include water quality disturbances. Furthermore, the development project has since been abandoned, partially due to the challenges posed by the subsurface hydrology to any building, now leaving an aesthetically displeasing, exposed site.

3. CASE STUDY

Due to the exposure of an ephemeral inland perched water wetland system through excavation, this site gives us a view into the systems and processes governing this wetland ecosystem. This makes research essential, since this system is presently not considered in classical wetland classification systems. Generally classification requires a shallow groundwater table or influence from surface water. As this system forms in the vadose zone it is presently not considered a wetland. However, this hydrological system needs consideration in water quality of the contiguous stream and biodiversity, as well as consequences that will need to be addressed when developing the land, as water will undoubtedly influence foundations.

3.1. Study Area Description

3.1.1. Locality

The study site is situated on Part of the Remainder of Portion 442 of the Farm Randjesfontein 405-JR, Midrand, Gauteng Province. The investigated area is bounded to the east by the N1 Highway, Olifantsfontein Road to the south, Lever Road to the west and the Development Bank of Southern Africa to the north (open land indicated on Figure 5; note the excavation in the northern portion and the visible evidence of gullies or seep areas indicated by dashed lines). This site has since been classified as a wetland, following evidence of wetland soils, waterlogged conditions and fauna and flora associated with wetlands. The wetland is temporary, seasonal to intermittent, situated on a hillslope underlain by tonalitic gneiss and occurs perched in ferricrete. The reason for being investigated in terms of vadose zone hydrology is based on the permanent water table being significantly deeper than the perched water table and because the wetland conditions are less detectable in winter when precipitation is low. The area around the site ranges from commercial to light industrial land use in the north, east and south, to residential land use in the west and south-west.

The following technical reports were available for inclusion in the study:

- Van Rooy, J. L. (2006). Report on a Phase 1 Geotechnical Site Investigation for Headway Hill Extension 1 on Part of Re/Portion 442 of the Farm Randjesfontein 405-JR, Midrand, Gauteng Province. Report Number 671. Prepared for Zoning Solutions.
- Van Rooy, J. L. (2008). Report on a Phase 1 Geotechnical Site Investigation for Headway Hill Extension 2 on Part of the Remainder of Portion 442 of the Farm Randjesfontein 405-JR, Midrand, Gauteng Province. Report Number 858. Prepared for Zoning Solutions.
- ARQ (Pty) Ltd. (2009). Geotechnical Investigation Report: Development Bank of southern Africa – Access Road. Report Number 5260/10947. Prepared for Wedge Projects.

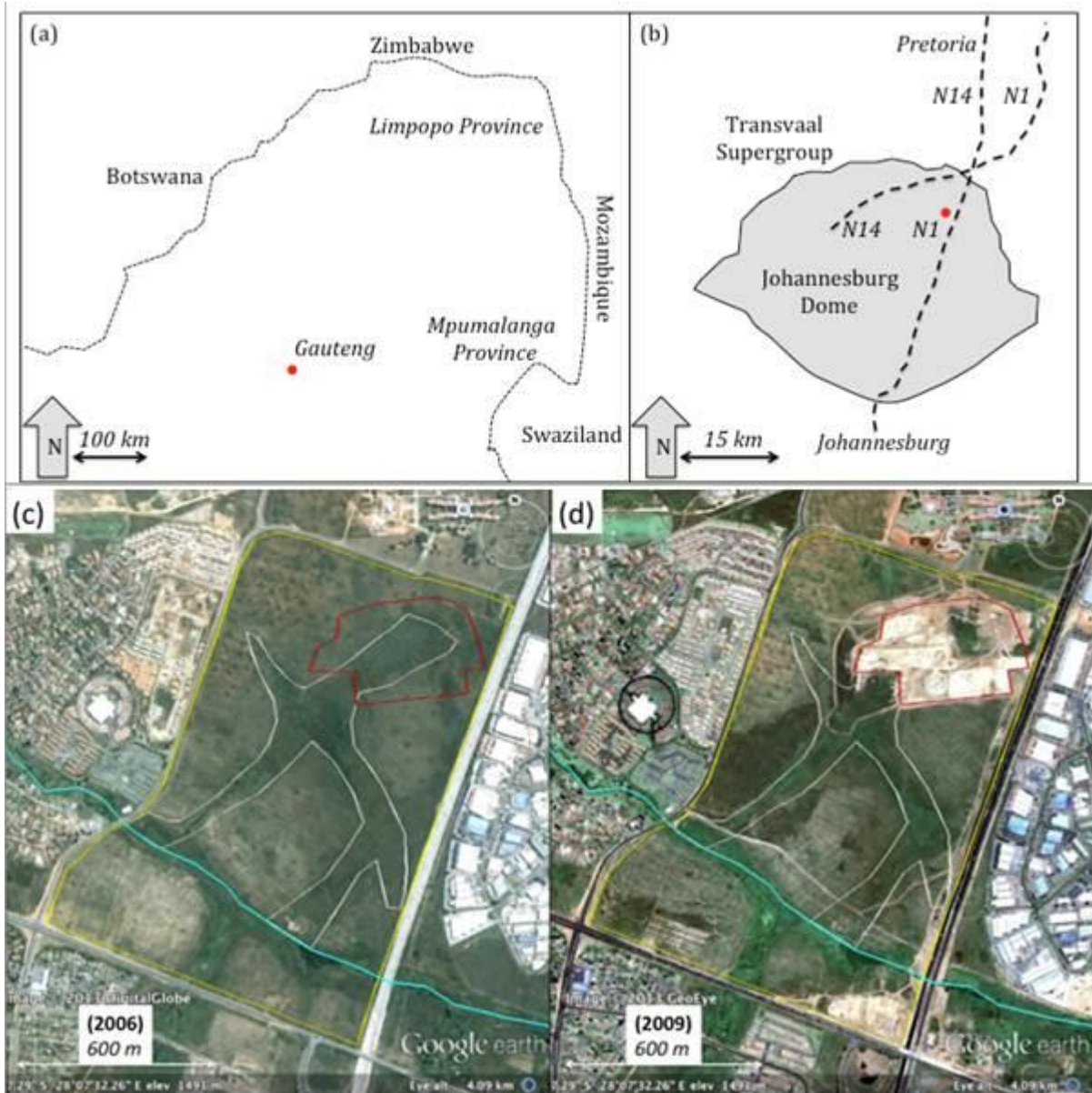


Figure 5. (a) Locality of the study site in South Africa, (b) locality and extent of Johannesburg Dome Granite in Gauteng, (c) satellite imagery before excavation and (d) satellite imagery after excavation with the proximate stream and wet areas indicated.

3.1.2. Geology

The study area is underlain by Swazian granite-gneiss, granite in places and occasional gneiss and amphibolites (1:250 000-scale 2528 Geological Sheet) of the Johannesburg Dome Granite which was previously referred to as the Halfway House Suite (Figure 6, denoted by dark grey shade Z).

The Johannesburg Dome Granite comprises various stratigraphic units of near-granitic composition. The area of interest is situated in the northern portion of the dome and underlain by trondjemitic and tonalitic gneiss and migmatite with mafic and ultramafic xenoliths (Lanseria Gneiss; #3 on Figure 7). The granite composition becomes more granodioritic to the south (Linden Gneiss,

Bryanston Granodiorite, Honeydew Granodiorite and Victory Park Granodiorite) and the outcrop is occasionally obscured by younger sediments or volcanics of the Karoo, Transvaal, Witwatersrand and Ventersdorp Supergroups, or Quaternary unconsolidated sediments (Robb et al., 2009).

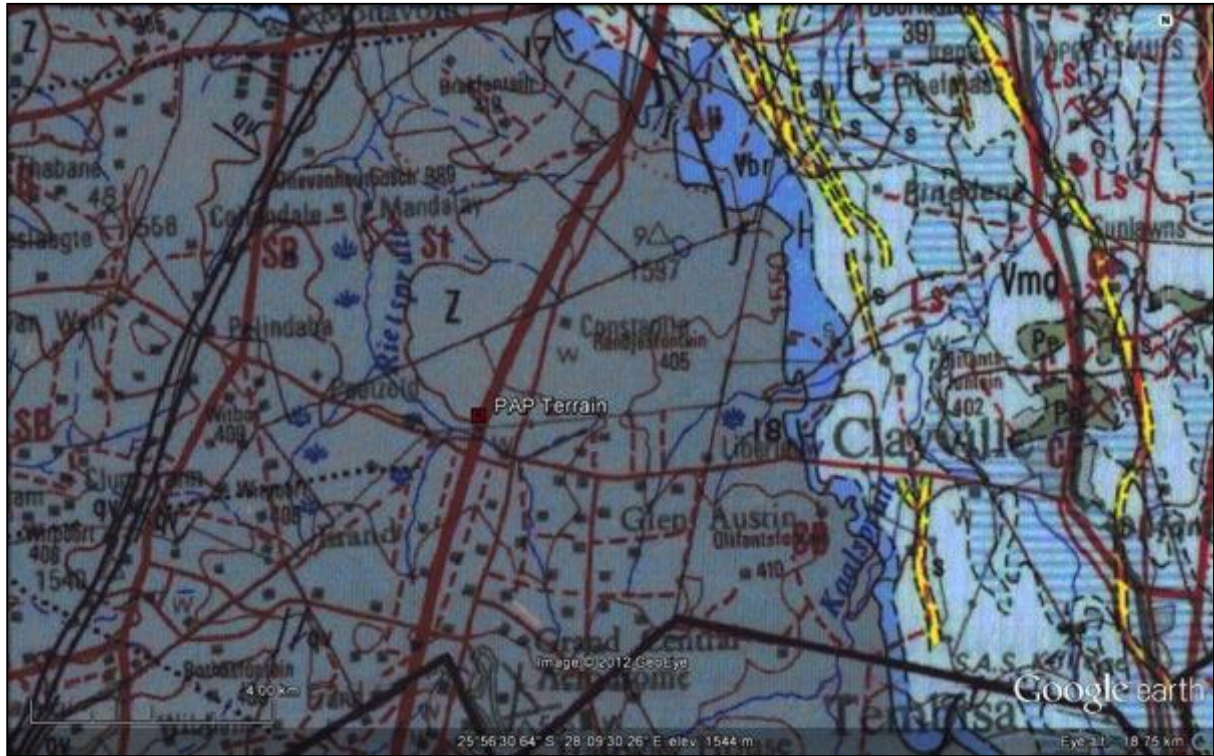


Figure 6. Regional geology of the) study area. (1:250 000-scale 2528 Geological Sheet represented on Google Earth imagery, 2012)

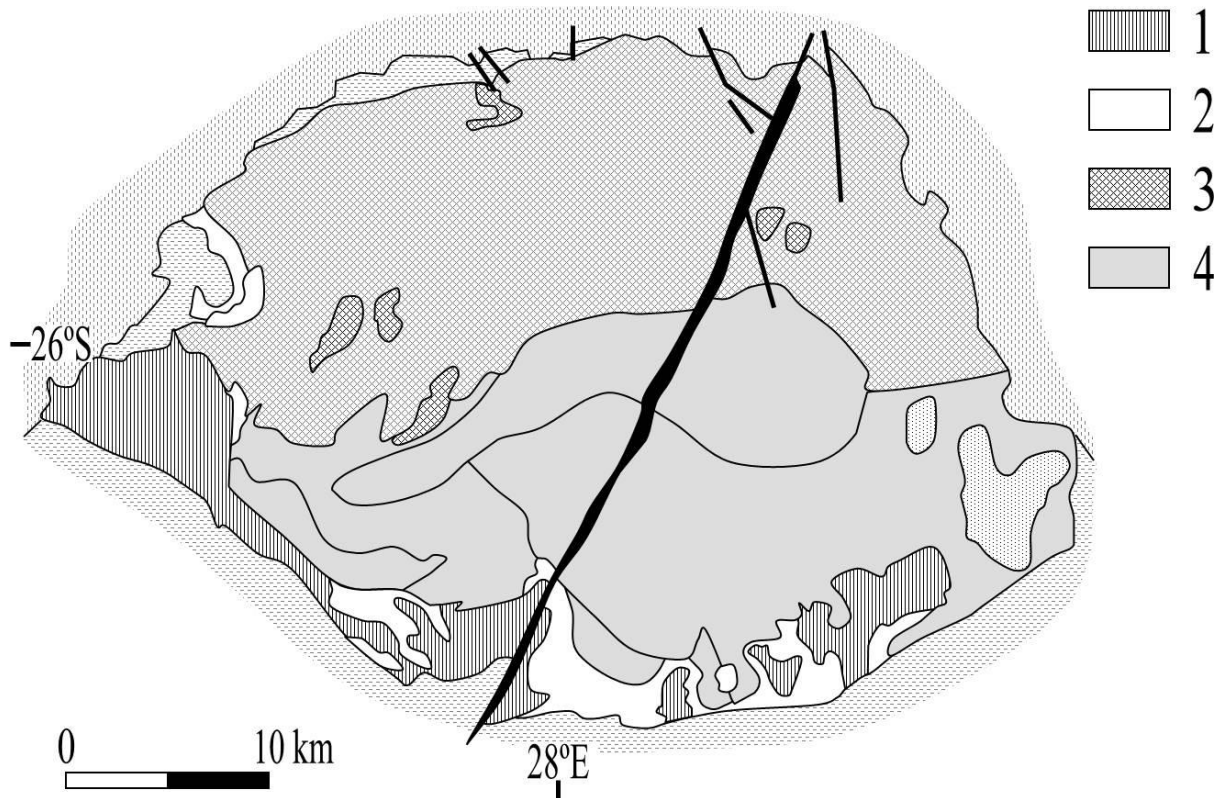


Figure 7. Geology of the Johannesburg Granite Dome with (3) Lenasia Gneiss in the northern portions. (adapted from: Robb *et al.*, 2009)

Tonalites have plagioclase as major feldspar as opposed to potassium feldspar in most common granites (Figure 8). This change in mineralogy has certain influences on the behaviour of the residual soils and weathering products, most notably being potential dispersive behaviour resulting in piping, donga formation and significant erosion.

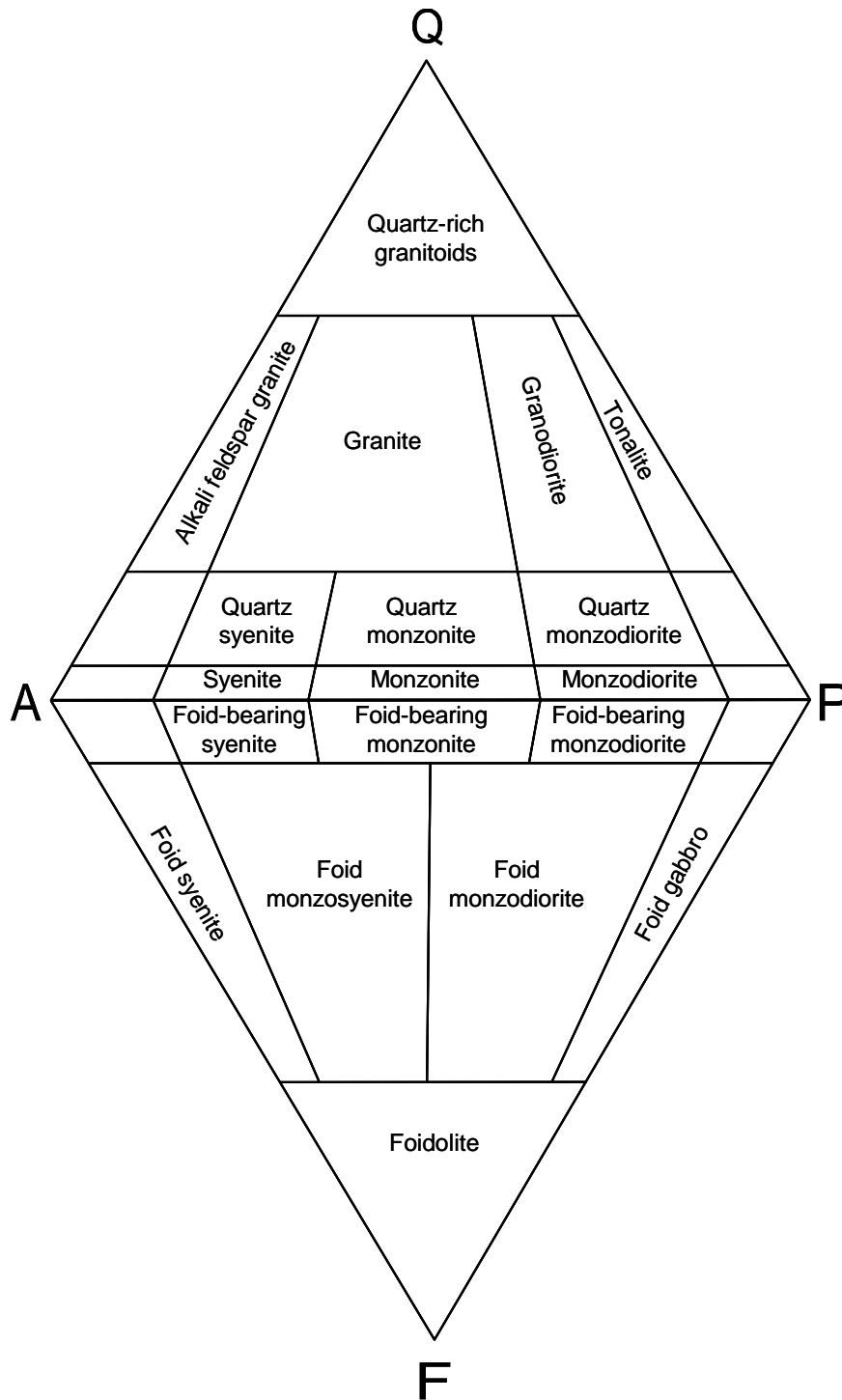


Figure 8. Quartz (Q) – Alkali feldspar (A) – Plagioclase (P) – Foid (F) diagram depicting plutonic igneous rock composition. (after: Blatt & Tracy, 1997).

3.1.3. Local Geology and geological processes

The site is underlain by yellowish white to white, coarse-grained granite (s.s.) to tonalite with distinct bands of essentially only well-crystallised quartz, microcline or albite, or darker bands of

foliated muscovitic melanogneiss. The distinct well-crystallised acid phase and foliated mafic phase forms a migmatite with alternating bands of light coloured leucogranite (granite to tonalite, coarse-grained, well-crystallised) and dark coloured melanogneiss (micaceous, foliated, medium-grained) at a large scale of 10s to 100s of metres. Bedrock is intricately fractured at shallow depth and is expected to become more intact with depth.

Quartz is weathering resistant and is expected to break down to finer fragments of SiO₂. Quartz sand is present over bulk of the site, sourced from the underlying granite. The feldspars (both albite and microcline) are fairly resistant to chemical decomposition, but will – over long periods of exposure – eventually change to clay minerals. Limited expansive clays are expected from the leucogranite phase of the migmatite and bulk of the clay minerals is typically inert kaolinite.

Iron and manganese are sourced from the melanogneiss phases and may precipitate – under changing redox conditions – as ferricrete.

3.1.4. Climate and Drainage

Midrand is situated in an area of subtropical climate with summer rainfall, and receives an average of 537 mm of rainfall per year. The peak of the rainy season is reached during January (on average 101 mm), after which rainfall decreases, to the peak of the dry season in June (0 mm). Midday temperatures range on average between 17.2°C in June to 26.8°C in January. The lowest temperatures are reached in July with an average night temperature of 1.1°C (SAExplorer, 2011).

The site falls within the A21C Quaternary Drainage Region of the previous Marico/Crocodile (West) Management Area (WMA 3), now part of the Limpopo Water Management Area, WMA 1, near the water divide with the A21B Quaternary Drainage Region to the northeast. The main drainage feature on the site is the Rietspruit, in the south of the site, flowing towards the west, changing direction to the north through the Kosmosdal wetland system, situated northwest of the study site and ultimately joining the the Hennops river(DWAF, 2007).

Water is expected to infiltrate from surface and follow surface topography. Being a wetland, the connection with the permanent water table is not confirmed and water probably flows as interflow, daylighting to form the wetland and flowing as sheetflow to the stream in the southern portion of the site.

Classification of the site as a wetland contradicts many conventions, notably due to the distinct absence of shallow groundwater or surface water. The perched water table does not satisfy the majority of the international classification systems; however, the site has since been identified as such and is treated as a special type of ephemeral inland wetland sourced from perched water.

The aquifer in this area is intergranular and fractured in nature with a groundwater harvest potential of 10 000-15 000 m³/km³/annum (DWAF, 1996). The size of the aquifer significantly exceeds the volume of mean annual recharge, of 110-160 mm/a (DWAF, 1995, 1996), and may therefore restrict the available harvest. The mean depth to the groundwater level is between 10-20m and

potential borehole yield ranges between 1.5-3.0 L/s, calculated as the geometric mean of the blow yield. The groundwater is considered fresh, with a geometric mean concentration of TDS of less than 200 mg/L and is not at risk of Nitrate and Fluoride pollution (DWAf, 1995, 1996). On average, groundwater forms 25-50 mm of baseflow annually (DWAf, 1996).

The site is located on a hillslope with elevations ranging from 1 560 mamsl in the northeastern corner to 1 495 mamsl in the southwest (Figure 9).

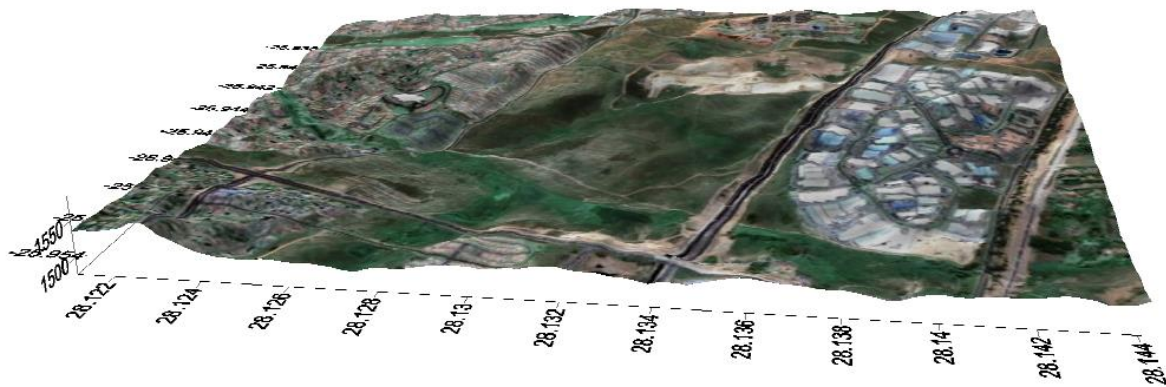


Figure 9. Topography of the study area.

3.1.5. Pedology

The area is located within the borders of the Bb1 land type on the 1:250 000-scale Land Type Map 2528 Pretoria. The soils are part of a plinthic catena in which upland duplex and marginalitic soils are rare. In the Bb1 land type specifically, dystrophic and/or Mesotrophic soils are dominant over eutrophic soils of the same forms and red soils are not wide spread.

As the climate, geology, drainage conditions and soil types of this site is the same as that of the Kosmosdal wetland; it can be assumed that the soil forms will be the same on both sites. According to Van Riet and Louw Landscape Architects (1998) the prevailing landforms on the crest are Hutton, Avalon and Glencoe; on the midslope, Mispah, Glenrosa and Glencoe with some overlapping Wasbank and Longlands soil forms; on the footslope, Wasbank and Longlands with some overlapping of Kroonstad and Westleigh soil forms; and on the valley bottom, Kroonstad, Westleigh and Dundee.

Hutton, Mispah and Glenrosa soil forms represent drier soil conditions; whereas Wasbank, Longlands, Avalon and Glencoe represent intermediate soil moisture conditions; and Kroonstad, Westleigh and Dundee represent wet soil conditions. The wet condition soil forms characterise the wetland or aquatic system, while the dry condition soil forms characterise the dry or terrestrial ecosystem, with the intermediate condition soil forms characterising a transition zone between the two ecosystems (Van Riet and Louw Landscape Architects, 1998).

3.1.6. Vegetation

The vegetation of this area is considered as typical Bakenveld or “false grassland” as by Acocks (1953, 1988), who describes this vegetation as a grassland sustained by fire, which would change into a savanna if fire was excluded. This vegetation occurs as “islands of temperate mountain Bushveld within the Grassland biome”, characteristically containing numerous woody species typical of Sour Bushveld, whereas grass species have a definite Drakensburg similarity and are limited to bare areas, on rocky soils in the uneven, rolling high-altitude landscape, particularly on the crests of quartzite hills. Due to the large variation in topography, a great diversity of plant communities occurs in this area (O’Connor & Bredenkamp, 1997).

3.1.7. Prevailing Conditions

The site is shown in Figure 10 prior to excavation. Images (a) and (d) represent the wet season in 2005 and 2009 respectively, whereas (b) and (c) were during the drier winter months of 2007 and 2008 respectively. Note the colouring on the satellite images indicating – irrespective of seasons – possible wetter areas as outlined on Figure 12.

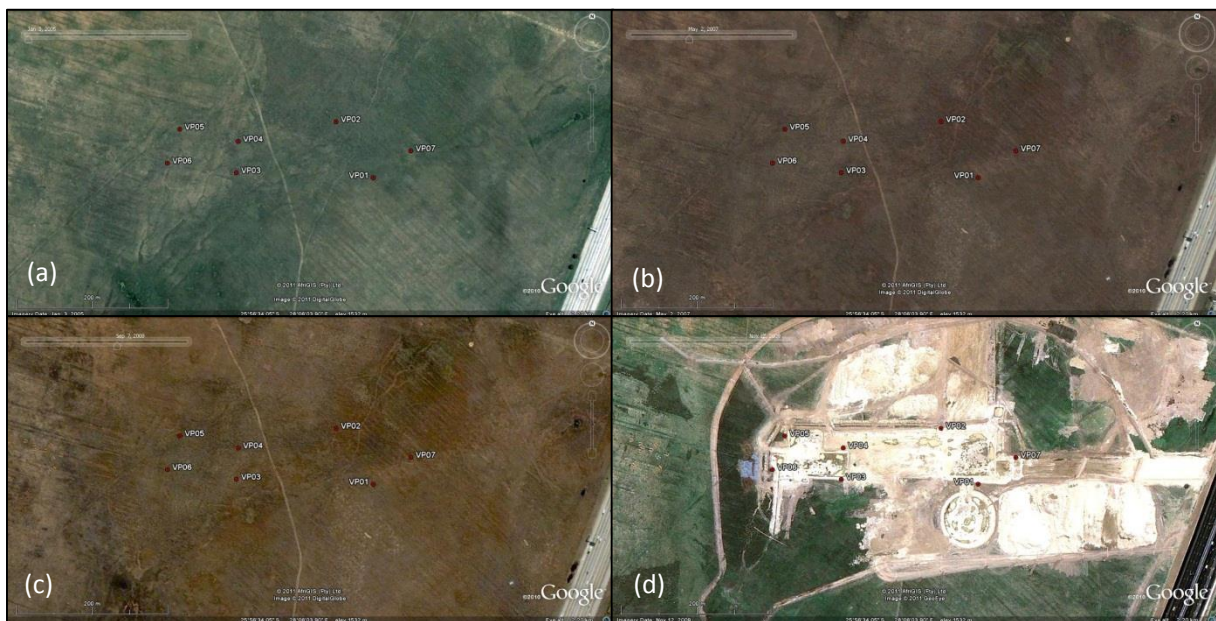


Figure 10. Historical imagery of the site: (a) January 2005, (b) May 2007, (c) August 2008 and (e) November 2009. (Google Earth imagery, 2011)

The site has since been excavated for the proposed footprint, although the development has since moved to another locality (Figure 11). Note the wet conditions prevailing despite the dry winter months and how a new wetland appears to be forming despite the vast area excavated.



Figure 11. View towards the south showing the excavation and wet conditions during the dry winter months (June 2011).

3.2. Materials and Methods

Field work was conducted on several occasions during 2011 and 2012. The field work included collation of historical reports, soil profile descriptions and a number of laboratory tests on retrieved samples to evaluate the physical, chemical, mineralogical and hydraulic properties of the site materials.

For the sake of simplification, the study area was subdivided based on the position on slope as follows (Figure 12):

- Upper slope higher than 1550 mamsl
- Upper to midslope 1540-1550 mamsl
- Midslope 1525-1540 mamsl
- Middle to lower slope 1500-1525 mamsl
- Lower slope <1500 mamsl
- Drainage features.



Figure 12. Land forms: northernmost shaded yellow – upper slope; central shaded yellow – midslope; southern shaded yellow – lower slope; drainage feature and wet areas indicated.

3.2.1. Profile Descriptions and Physical Properties

Soil profiles were described according to the MCCSSO system described in draft SABS 633: 2009 and involve the parameters in the sequence of the acronym:

- Moisture – dry, slightly moist, moist (near optimal moisture content), very moist (near saturation) and wet (saturated usually with seepage)
- Colour – based on primary and secondary colour with additional comments on discolouration (including speckling, mottling, blotching and staining)
- Consistency – very loose, loose, medium dense, dense and very dense for non-cohesive soils; very soft, soft, firm, stiff and very stiff for cohesive soils
- Soil structure – e.g. intact (structureless), pinholed, open, voided, honeycombed, jointed, fissured, foliated, open root channels, shattered, microshattered, slickensided, etc. and reference to manner of clast disposition, e.g. matrix-supported or clast-supported
- Soil type – estimated clay (< 0.002 mm), silt (< 0.06 mm), sand (< 2 mm), gravel (< 60 mm), cobble (< 200 mm) and boulder (over 200 mm) fractions in ascending order of dominance
- Soil origin – transported (e.g. colluvium, alluvium, pebble marker), pedogenic materials (ferricrete) residual (in-situ weathered bedrock) and bedrock (completely weathered to fresh).

Additional descriptors were also noted, including seepage from profile sides, sidewall instabilities, termite or ant burrows, root channels and any other noticeable and relevant feature.

Particle size analyses and Atterberg limits are determined as a foundation indicator test combination to supply basic parameters relevant to founding. The test comprises the following:

- Grading through sieves to 0.074 mm fraction and hydrometer to 0.002 mm fraction
- Grain size distribution and soil texture
- Moisture content – consistency relationships (Atterberg Limits), namely plasticity index, linear shrinkage and liquid limit
- Grading modulus and uniformity coefficient to address material grading
- Estimated soil activity based on clay fraction and plasticity (Van der Merwe’s method, 1964)
- AASHO and Unified soil classification.

Bulk of the foundation indicator analyses were done at Soillab (Pty) Ltd in Pretoria.

At present, the following data points relating to material descriptions are available (Figure 13):

- Seven test pits TP01 – TP07 described for the geotechnical investigation for the DBSA access road
- Seven test pits HH01 – HH07 and three auger profiles AH11 – AH13 described during the geotechnical investigation for the PAP site
- Seven open profiles VP01 – VP07 described during 2011 and 2012.

The profile logs for the abovementioned excavations are shown in Appendix A.



Figure 13. Distribution of historical and new profile description positions overlain by slopes as defined. (Google Earth imagery, 2012)

3.2.2. *Chemical Properties*

A total of 39 samples were retrieved from VP01 and VP07 to characterise the vertical variation of the seven profiles down the hillslope in the excavated wetland. Chemical analyses included XRF and XRD on selected samples.

The samples for X-Ray Diffraction (XRD) were prepared for XRD analysis using a back loading preparation method. They were analysed using a PANalytical X'Pert Pro powder diffractometer with X'Celerator detector and variable divergence and receiving slits with Fe-filtered Co-K α radiation. The phases were identified using X'Pert Highscore plus software. The relative phase amounts (weight %) were estimated using the Rietveld method (Autoquan Program) and errors are on the 3 sigma level. Amorphous phases, if present, were not taken into consideration in the quantification.

The X-Ray Fluorescence spectroscopy (XRF) samples were prepared as pressed powder briquettes. The ARL9400 XP+ Sequential XRF and Uniquant software was used for analyses. The software analysed for all elements in the periodic table between Na and U, but only elements found above the detection limits were reported. The values were normalised as no LOI was done to determine crystal water and oxidation state changes. All elements were expressed as oxides.

Bulk of the XRD and XRF analyses were conducted and partly funded by the Analytical Facility of the Geology Department (University of Pretoria).

3.2.3. *Hydraulic Properties*

Field percolation tests were conducted in accordance with the SABS standard (1993) for french drains to relate field values to empirical and laboratory results. Fourteen such tests were conducted and tests were repeated until consistent percolation rates were achieved. The positions of these test sites are shown on Figure 14.



Figure 14. Positions of fourteen percolation tests depicted on surface contours inferred from Google Earth (© 2013); north-eastern contour 1 550 mamsl, decreasing by 5 m intervals to 1 500 mamsl in the southwest.

4. DATA

All soil profiles and laboratory results are shown in Appendix B.

4.1. Physical Properties

The soil profiles from existing reports (numbered AH, HH and TP) and as described in the excavation (numbered VP) are summarised in Table 2. The soil textures for each horizon in profiles VP01 – VP07 are shown in Figure 15.

The profile varies in thickness with the following typical horizons:

- Slightly moist to wet, light or reddish brown, loose to dense, open, silty sand – colluvium with roots in places.
- Slightly moist, brown, medium dense, intact, silty sand with varying amounts of gravel – pebble marker with roots in places (occasionally ferruginized).
- Hardpan ferricrete formed in pebble marker and/ or residual granite (occasionally present)
- Slightly moist, yellowish brown or orange brown, loose to dense, pinholed, clayey silty sand– residual granite (occasionally ferruginized).
- Slightly moist, light yellowish brown or white to grey, dense, jointed clayey silty sand to silty sandy gravel – completely weathered granite.

Descriptors vary significantly over the site and the abovementioned summary should only serve as a broad generalisation of the site materials.

Table 2: Generalised soil profile descriptions and depths to different horizons.

Profile	Colluvium	Pebble Marker	Ferricrete	Residual Granite	Completely Weathered	End of Profile
AH11	0.80	1.20	—	3.50	> 6.80	6.80
AH12	0.31	0.41	—	2.40	> 5.91	5.91
AH13	0.50	0.70	1.45	(1.45) 2.40	X	2.40
HH01	0.60	1.45	—	2.15	> 2.50	2.50
HH02	0.50	0.65	—	1.35	> 2.00	2.00
HH03	0.60	0.70	—	1.40	> 2.20	2.20
HH04	0.50	0.70	> 1.10	(1.10)	X	1.10
HH05	0.50	0.70	—	1.00	> 1.30	1.30
HH06	0.30	0.45	—	—	> 0.90	0.90
HH07	0.40	0.50	—	0.70	> 1.30	1.30
TP01	> 1.20	—	—	—	—	1.20
TP02	0.70	—	—	> 1.00	—	1.00
TP03	0.70	—	—	(1.10) > 1.10	—	1.10
TP04	0.80	—	—	(1.20) > 1.20	—	1.20
TP05	0.20	—	—	(1.20) > 1.20	—	1.20
TP06	> 1.20	—	—	—	—	1.20
TP07	0.60	—	—	(1.10) > 1.10	—	1.10
VP01	0.46	0.75	1.90	(1.90)	3.20	6.20
VP02	1.47	—	2.94	(2.94) 4.20	5.50	6.74
VP03	1.27	—	—	2.20	> 3.40	3.40
VP04	Stripped	Stripped	1.14	(1.14)	1.99	4.69
VP05	1.07	—	2.63	(2.630)	> 4.26	4.26
VP06	1.14	—	2.49	(2.49)	3.83	4.97
VP07	0.85	—	2.48	(2.48)	> 3.26	3.26

- horizon not identified
- X end of excavation prior to possible occurrence of horizon
- () depth of extensive ferruginization of indicated horizon

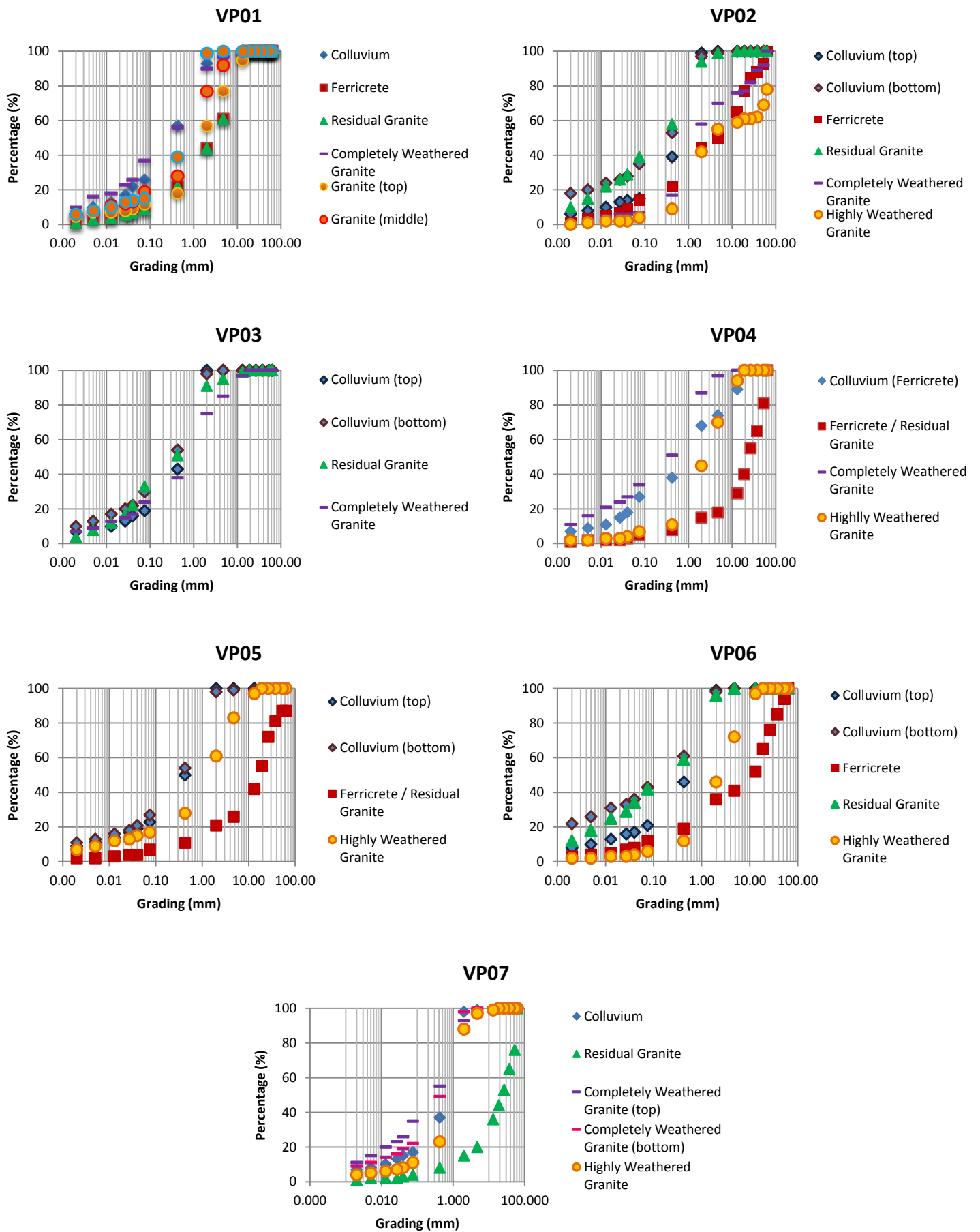


Figure 15. Soil textures for each horizon in profiles VP01 – VP07.

4.2. Chemical Properties

The XRD results for seven profiles in the excavation are shown in Figure 16.

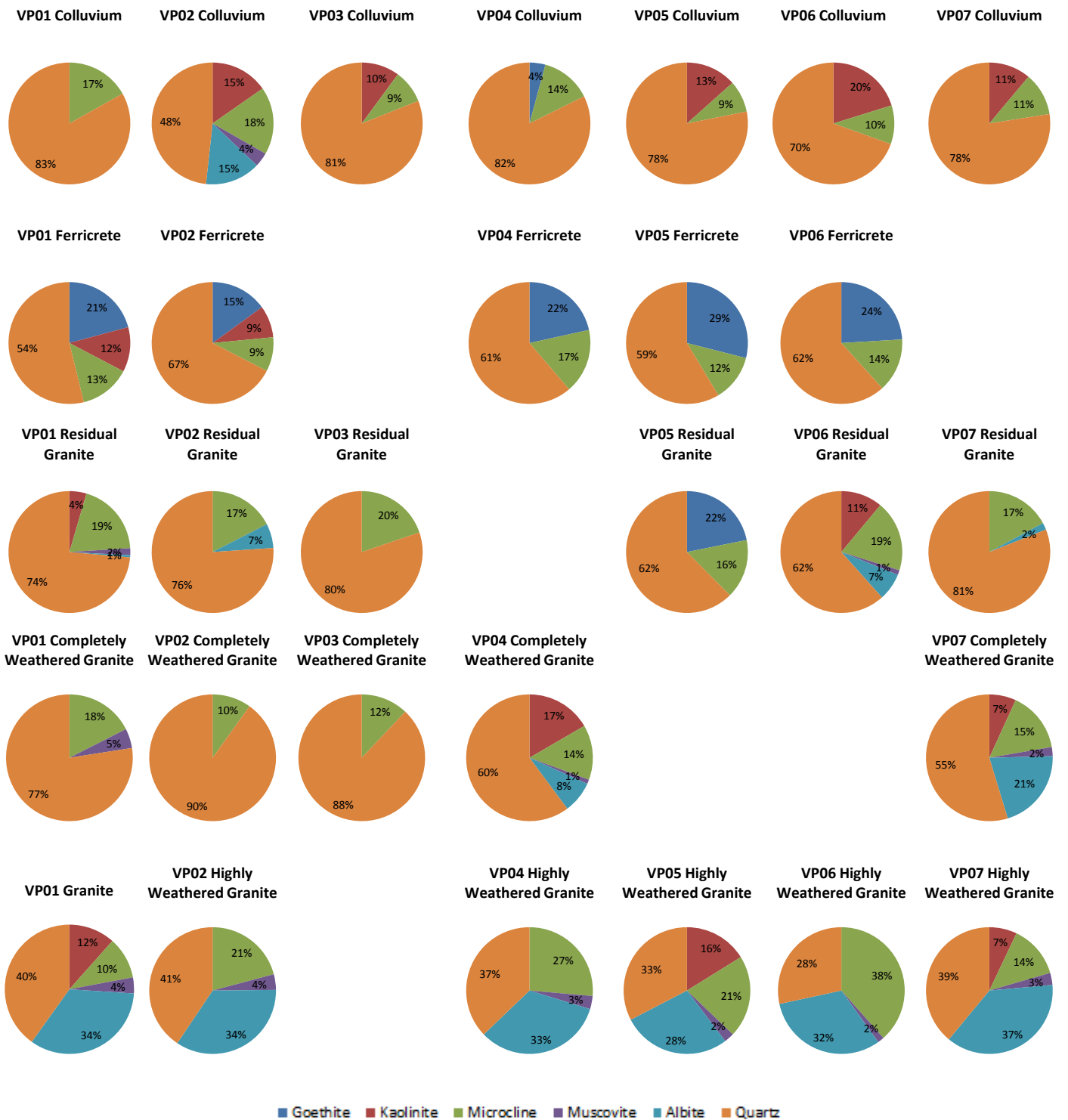


Figure 16. Mineral compositions (XRD) for each horizon in profiles VP01 – VP07.

XRF results are shown per soil origin in Figure 17.

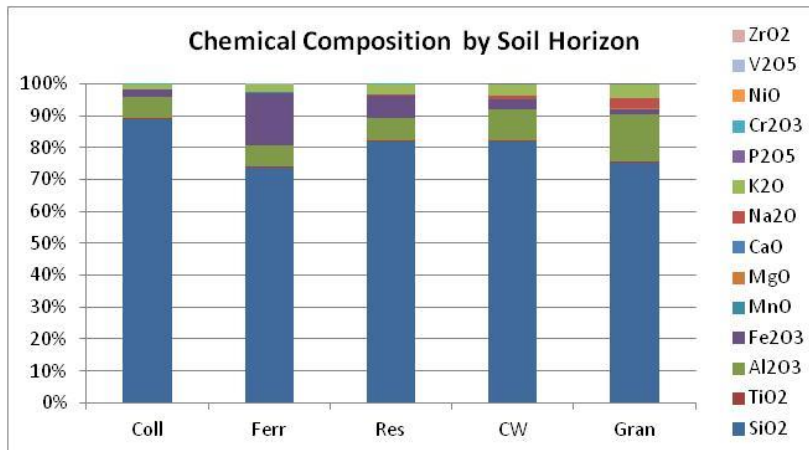


Figure 17. Chemical compositions (XRF) for each soil origin in profiles VP01 – VP07 (Coll=colluvium; Ferr=ferricrete; Res=residual granite; CW=completely weathered granite; Gran=granite).

4.3. Hydraulic Properties

Fourteen field percolation tests were conducted over the site to estimate saturated vertical hydraulic conductivity (Table 3). Tests were grouped into three major groups based on the landform in which the test was conducted. The upper to middle reaches of the hillslope (in the vicinity of the excavation) has an average vertical saturated hydraulic conductivity of the colluvial materials in the order of 6.9×10^{-5} m/s. This increases to 1.8×10^{-4} m/s on the middle to lower slope below the excavation.

Table 3: Field percolation test results.

Landform	Test	K (m/s)	Mean	St. Dev	n
Upper - Mid	Perc01	1.55E-05	6.94E-05	6.54E-05	8
	Perc07	2.13E-04			
	Perc09	3.07E-05			
	Perc10	6.21E-05			
	Perc11	9.52E-05			
	Perc12	8.77E-05			
	Perc13	1.96E-05			
	Perc14	3.15E-05			
Mid - Lower	Perc02	1.14E-04	1.81E-04	5.93E-05	6
	Perc03	1.96E-04			
	Perc04	2.38E-04			
	Perc05	1.25E-04			
	Perc06	2.56E-04			
	Perc08	1.54E-04			

5. ANALYSES / RESULTS

5.1. Conceptual Model

The conceptual model is presented in Appendix C and D, showing a cross section along the slope, though the excavated area and displaying soil grading and mineralogy, respectively, for each horizon at profile positions labelled VP. The section is drawn from the upper reaches of the slope where no ferricrete was found at profiles labelled TP, AH and HH. Further downslope in HH4 and AH13 ferricrete or ferruginization is found, as well as in VP02, VP05 and VP04. VP07 is located just downslope of this zone and is characterised by an absence of ferricrete. Further downslope, on the midslope, VP03 also shows no ferricrete, while ferricrete is present in the area between the upper- and midslopes, as well as just below the midslope. Therefore, areas of deeper percolation are indicated on the upper reaches of the slope as well as in the areas surrounding VP07 and VP03. Inferred flow directions as well as zones of infiltration and perching are also indicated.

5.2. Data Interpretation

Soil textures (Figure 15) become distinctly more coarse-grained with depth, from silty sand in the colluvium to gravel in the pebble marker and ferricrete. Weathered granite bedrock horizons are also typically more coarse-grained than surface horizons, which relates to the mineralogy. From Figure 16 it is clear that quartz dominates all horizons and that goethite is absent in VP03, situated along the midslope, and VP07, situated on the upper slope, indicating an absence of the ferruginized horizon at these positions on the slope. Goethite and kaolinite are the two major variables in the profiles, their occurrence depending on depth and position along the slope, where soil profiles were altered due to imported iron enrichment and pedogenetic processes. The variation in these two constituents may cause markedly different porosities, void sizes and connectivity in the various horizons, possibly effecting the occurrence of the perched water table system.

Figure 17 shows an increase of iron oxide from the bottom upward, towards the ferricrete (or plinthite). The overburden is generally waterlogged and not iron depleted, therefore the iron source must be from perched rising water and interflow as shown in Figure 4.

Figure 18 shows a panorama of the excavated wetland with a schematic section depicting the transported material (where infiltration occurs), the ferruginized horizons (in which the water is perched) and the fractured gneiss bedrock. The panorama and section are along the exposed excavation in Figure 11 and depicts the maximum visible heterogeneity, therefore excluding portions where no significant excavations are available such as the hill crest and the flood plain. From this one can see that bedrock weathering topography is very uneven – as is typical of granites and gneisses – and the ferruginization is commonly associated with the coarser grained pebble marker and leached residual granite horizons. The darker patches indicate thickening of the ferruginized horizon in deeper weathered granite and is mostly associated with seeps. Water seepage appears to be through distinct

“channels” rather than the bulk of the material as shown in Figure 19. Furthermore, the water discharging from these seep faces in the excavation, as well as water logged on surface, particularly in the wet season, contain distinctly visible films of metal precipitate (presumably iron and manganese), which is an indication of the dynamic nature of the system.

Figure 20 shows a conceptual section of the formation of the ferruginized zones through leaching and iron depletion processes which occur on the crest and midslope, as well as in the weathered bedrock below the ferricrete. Ferric iron is reduced during leaching and accumulates as ferrous iron downslope of areas of infiltration. These interruptions in the ferricrete suggest a connection between the perched and permanent water tables.

Percolation tests indicate higher hydraulic conductivity of the transported material on the mid to lower slope as compared to those on the upper to mid slope, indicating slightly more water logged conditions in the vicinity of the excavation, which is consistent with the areas of ferruginization and thus, the occurrence of the wetland. This further supports the idea of areas of deeper percolation where ferricrete is absent, and thus areas of interaction between the surface- and intermediate vadose zone.

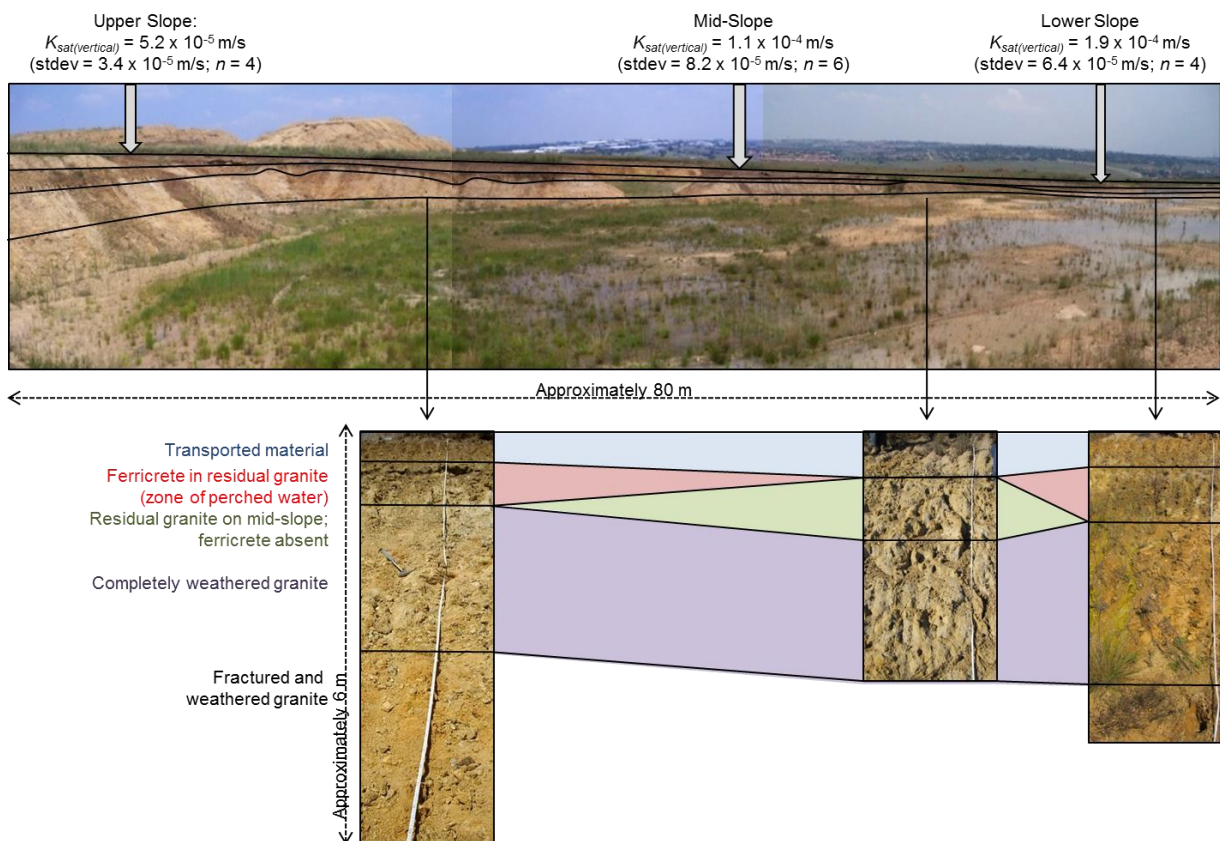


Figure 18. Panorama of the southern excavation and a simplified schematic section indicating the main horizons (September 2011).



Figure 19. Seepage from the more porous ferruginized horizon near VP04.

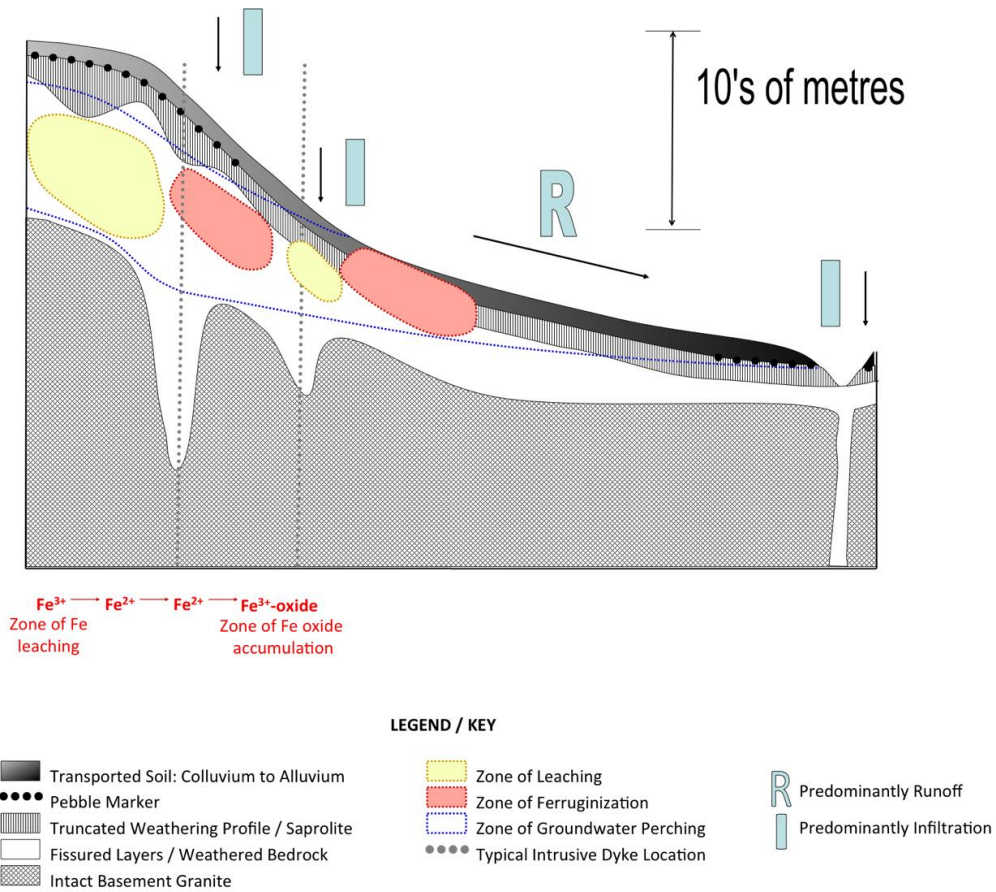


Figure 20. Conceptual section showing leaching in the crest and midslope with contiguous zones of ferruginization.

5.2.1. *Post-excavation influences*

Reports from the geotechnical investigations done prior to the excavation provided sufficient indications of the possible presence of a wetland, with the ferricrete layer and occurrence of mottling noted in some of the soil profiles, as well as the soil wetness in certain areas of the site. These investigations were done during the rainy season, whereas investigations by the EIA specialist were done during the dry season, who subsequently did not observe the soil wetness reported in the geotechnical investigation. As the vegetation, which in industry is often relied on for the identification of wetlands, was removed by veld fires during the dry season, the EIA specialist did not recognise the need for a wetland delineation to be done.

The approximated extent of the excavation is shown in Figure 21, showing the interruption of the ferricrete layer and ponding and subsequent regeneration of the wetland on the bedrock. As interflow occurred within the ferricrete, perched water which used to feed into the river downslope, now flow down seep faces (Figure 19) and accumulate inside the excavation. Bedrock at the depth of the excavation floor is considered to be largely impermeable (depending on the nature of fracturing which occurs in the unweathered bedrock), however induced infiltration may occur due to ponding of water during the rainy season.

The excavation of the wetland not only disturbed the ecology, vegetation and downslope hydrology, but also significantly increased the vulnerability of the underlying aquifer, as the thickness of the vadose zone below the area of induced infiltration, is drastically decreased, decreasing the capacity of the vadose zone to filter out any contaminants before it reaches to permanent groundwater table. Periodic fluctuation of water ponding on top of fresh bedrock, may cause increase deeper weathering as well as ferruginization, due to the continuing presence of iron and manganese in the perched water (Figure 22).

Most of the indicators listed in Section 2.1.1.1 were observed in and around the excavation during the dry seasons following excavation of the site. Exposed profiles also show mottling of the soil as well as soil forms associated with intermediate to wet conditions. Ponding may occur for extended periods of time in certain small areas on site, as some drainage features were installed in an attempt to minimise water flow into the excavation, prior to the termination of the development project (Figure 23).

Poor (or no) access control to the wetland following the court case, has led to increased exposure of the site to direct anthropogenic impacts such as dirt biking in the excavation and dumping of domestic waste.

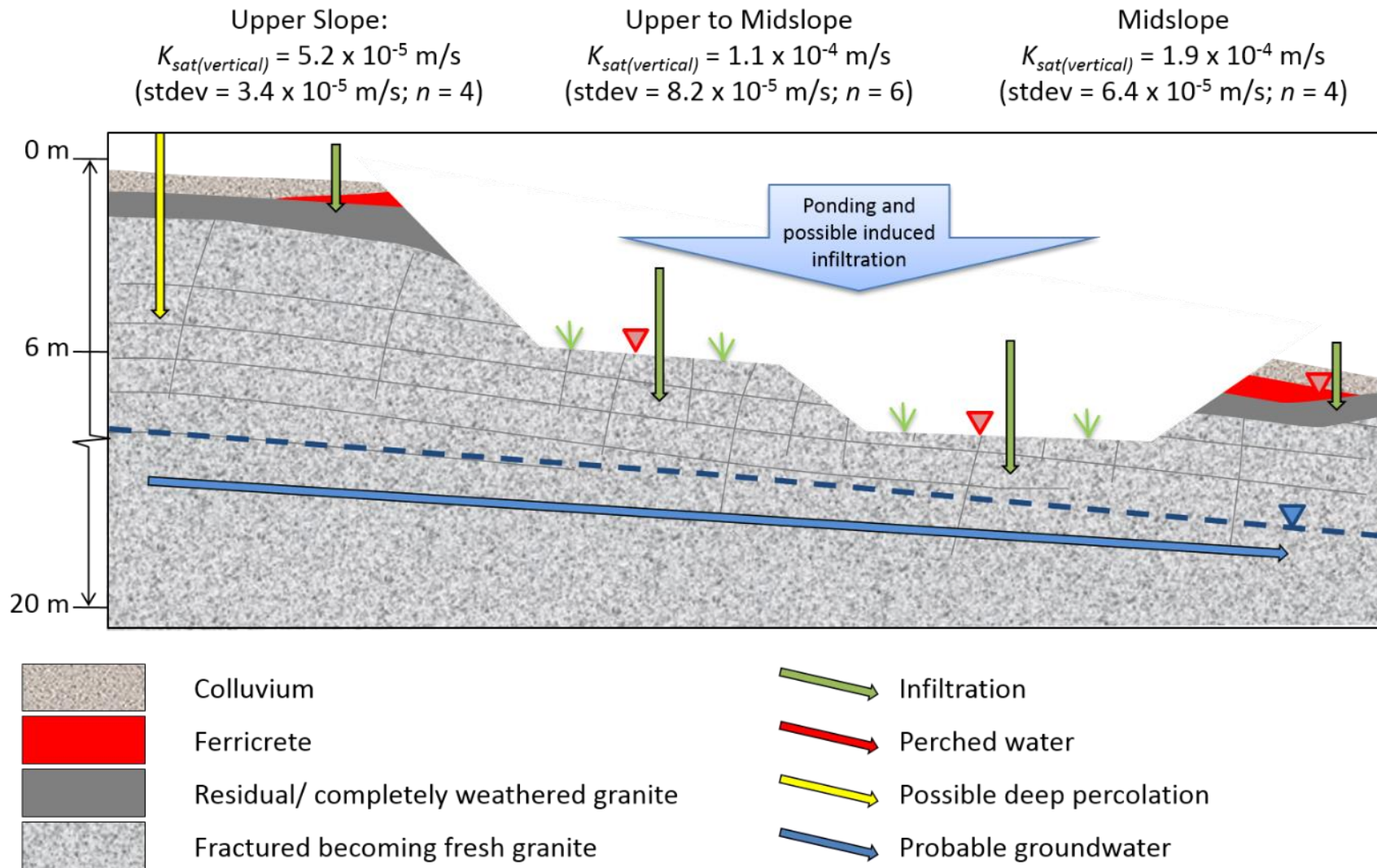


Figure 21: Conceptual model of study site post-excavation.



Figure 22: Metal (presumably iron and manganese) precipitate on the perched water inside the excavation.



Figure 23: Ponding in excavation as part of drainage features installed during the development project.

6. FINDINGS / CONCLUSIONS

6.1. Legislation

The old Water Act 54 of 1956 was very limited in terms of management of water resources and provision of water to people and no provision was made for sustaining a basic quantity of water for the environment. During this time, a large part of the population experienced major restrictions with regards to access to water. Although this Act did control water use for industrial purposes and protected water resources against pollution, it did not provide for the protection or conservation of wetlands. Wetlands were generally regarded as “private water” as they were often on privately owned land and therefore, as per this Act, the land owner could use and enjoy the water as he saw fit, with no regard to any environmental impact.

The 1970s dawned a new era in environmental law, in which environmental issues received a lot more political and legislative attention. During the 1970s and 1980s South Africa had a number of laws which could protect wetlands in a fragmented manner, as these laws all had different objectives which by no means included all wetlands. These were:

- The Mountain Catchment Areas Act 63 of 1970, which could only protect wetlands situated within mountain catchments;
- The Lake Areas Development Act 39 of 1975, which only protected wetlands that were part of a declared lake area;
- The Conservation of Agricultural Resources Act 43 of 1983, which protected wetlands against alien vegetation, soil erosion and draining or cultivation, as part of the agricultural resource;
- The Forest Act 122 of 1984, which protected wetlands in terms of the effect of forested areas on the water resource;
- The Environmental Conservation Act 100 of 1982, followed by the Environmental Conservation Act 73 of 1989, which in spite of the all-encompassing title covered very few environmental aspects, but provided the first attempt to define the term “environment” and introduced environmental impact assessment policies. Only after notice in the *Government Gazette* by the Minister of Environmental affairs in 1994, were wetlands specifically named as ecologically sensitive areas, and had to be protected as such.

Even though South Africa became the fifth signatory to the Ramsar Convention, in 1975, not much was done in terms of legislative wetland protection until the 1990s. To present, South Africa has 21 wetlands on the Ramsar List of Wetlands of International Importance, two of which are on the Monraux Record. The St. Lucia System was put on the Monraux Record in 1990, but was removed six years later, after sufficient rehabilitation.

The Ramsar Convention currently plays an important role in the conservation of South African biodiversity. South Africa remains an active member of the Convention, with new sites being designated for inclusion on the List, regularly. The Convention undoubtedly played a role in the way

of thinking around environmental conservation and the importance of wetlands across the world, which furthermore influenced the environmental legislation we have today.

The new Constitution (Act 108 Of 1996), after the change in government in 1994, changed the priorities and approach to water resource management and included the environmental right in Chapter 2, Section 24, providing for a safe and protected environment for everyone.

The National Water Act 36 of 1998 (NWA) and the Water Services Act 108 of 1997 were revolutionary pieces of legislation in terms of water supply, water use and water resource management. The NWA includes the only legislative definition of a wetland, in South Africa. Wetlands are also included in the definition of a water course, ensuring its protection and conservation along with other water resources, such as rivers, springs, lakes, dams, etc. In 2005 DWAF published a manual for identifying and delineating wetlands and riparian areas.

The National Environmental Management Act 107 of 1998 (NEMA) is the framework legislation for protecting the environment and gives effect to the environmental right guaranteed in Section 24 of the Constitution. From this Act, numerous other “specific environmental management acts” have been promulgated, viz.:

- NEMPAA (Act 57 of 2003), which protects the country’s biodiversity, keeping social and cultural concerns in account and providing for nature-based tourism;
- NEMBA (Act 10 of 2004), which provides for the conservation of South Africa’s biological resources within the NEMA framework. It also gives effect to international treaties such as the Ramsar Convention and protects smaller wetlands, outside of protected areas and often under threat on privately owned land;
- NEMICMA (Act 24 of 2008) which provides for the management and conservation of the coastal environment, maintaining ecological sustainability during development of coastal zones and use of natural resources. It also defines the term “coastal wetland” and protects them as sensitive coastal ecosystems;
- NEMAQA (Act 39 of 2004) and NEMWA (Act 59 of 2008) regulate air quality and disposal of waste, respectively, and do not have a direct influence on wetlands, and are therefore not discussed here.

South Africa certainly has world-class water and environmental legislation and over the past 50 years, remarkable progress has been made in the conservation of wetlands. However, implementation of legislation still poses significant challenges, largely due to lack of human and technical capacity. It is therefore important to educate and create awareness of people on the value of aquatic ecosystems and wetlands as well as the impact of poor understanding of subsurface hydrology on construction. Furthermore, continuous research is important for the understanding of natural processes in order to keep developing adequate legislation, guidelines and best practices.

Anthropogenic influences on wetlands are a world-wide problem, mainly due to population growth and urban development, but are not extensively researched. Apart from the destruction of sensitive ecosystems, it is important to understand influences and their effects on physical and geochemical properties as well as on subsurface hydrology. Changes to the water source may dry wetlands through removal or canalisation and redirection or, conversely, create wetlands through

addition of water to the system through irrigation or reallocation of water. When these systems are not isolated, these influences will inevitably affect downstream water courses and ecosystems.

Aquifer vulnerability and impacts on water quality are essential to consider in urbanised areas where sources of pollution are often closely situated and determining the point of contamination is very difficult. The influences on wetlands of agricultural practices, construction of irrigation schemes, diversion of water courses, pollution, urban development, landscaping, reduction of urban catchment permeability, and increased abstraction of water resources, have all been reported on internationally and remain a growing concern as populations continually grow.

6.2. Randjiesfontein Wetland

The significance of land use change to urban ecosystems was investigated at the hand of the Randjiesfontein wetland during which the following were noted:

- Ephemeral wetlands are ecologically important ecosystems and are essential for flood control and water quality;
- It is imperative to recognise areas which are prone to the occurrence of ephemeral wetlands due to the regional climate, geology and topography and to be attentive in these regions to indicators of the presence of ephemeral wetlands, especially during the dry season or dry years;
- Although not all project time frames allow for environmental investigations to stretch over more than one season and include the evaluation of seasonal variation across a site, or to be selective of the season during which studies should be conducted, it is still important understand the value of data collected during a rainy season, as opposed that collected during the dry season. Simply because ephemeral systems are significantly easier to identify during the wet season;
- Knowing and understanding the processes which govern the existence of ephemeral wetlands as well as the indicators which may occur during the dry season is imperative for the successful identification and delineation of these systems;
- Aquatic ecosystems, regardless of their size and topographical position, remain important land features, particularly in an urban environment when decisions are made regarding land use. As noted before, these systems are highly dynamic, and as seen in Figure 11, while these systems are undeniably ecologically sensitive, they can also be regenerative to some extent, as the processes governing the system are on-going;
- When poor land use decisions are made on such sites, implications can be drastic. In urban settings periodically saturated soils can cause wet foundations and subsequent instability in structures. Additionally, as urban environments are prone to pollution, due to a high density of various sources such as underground fuel storage facilities, industrial works, underground fuel, gas and sewage pipelines etc., the presence of a high or perched water table can drastically increase the risk of water pollution;
- In a system which is not isolated, such as in this case study, surface water - groundwater interaction further increases the area which can be affected by pollution, therefore

increasing the vulnerability of the surface water drainage network and underlying aquifer(s);

- Understanding and being able to identify terrain units where wetlands are likely to occur provide a good starting point of investigation for the presence of wetlands, as topography plays a role in the movement of water and fines down slope, as well as in soil forming processes as indicated in Figure 20;
- Soil types, their properties, and the processes by which they form, play a significant role in the occurrence of the wetland. Therefore, a detailed understanding of the geology and pedology with regards to material textures and mineralogy is imperative in order to understand the processes currently taking place and/or which could take place during recurring periods of increased precipitation. The colluvium, although predominantly sandy, contains most of the clay material (kaolinite) in the profile and is underlain by the largely impermeable ferricrete, hence causing the perching of water and periodically saturated conditions in specific areas along the slope;
- Through land use change, processes governing natural water movement are often disturbed due to changing of soil and hydraulic properties in the vadose zone. Changes such as loosening or compaction of soil, changes the porosity of the soil, which influences the hydraulic properties. Similarly, addition of imported material with varying physical and chemical properties may influence the movement of subsurface water. Furthermore, the removal of soil above the bedrock can significantly decrease the thickness of the vadose zone and subsequently decrease the filtering or purifying effect it has on water reaching the permanent water table;
- A good comprehension of the hydraulic properties across the site provides a better understanding of areas more prone to saturation or inundation during periods of increased precipitation, which can aid in the delineation of the wetland, even during dry periods;
- Furthermore, excavation and construction may interrupt flow paths, disrupt the associated movement of ions and fines, decrease groundwater recharge and increase evaporation due to impermeable surfaces or increase the aquifer vulnerability to pollution where infiltration through the bedrock fracture network is induced through ponding.
- Finally, it is essential to recognise the importance compulsory data, such as geotechnical investigations, from both an engineering and environmental point of view. Careful consideration should be taken of this data and the information it provides in terms of soil profiles (and thus the properties of the different soil horizons) and soil wetness.

6.3. Conclusions and Recommendations

The Randjiesfontein wetland provided an uncommon and unique opportunity to observe an exposed urban ephemeral wetland and investigate the processes that govern the occurrence of this wetland which was previously not perceived to be there. This case study highlights the importance of thorough investigation on multiple cross-disciplinary levels, before decisions on land use change are made. Furthermore, it is seen that even though certain wetland indicators, as described in DWA

(2005), can at times be used as sole indicators, their absence do not always confirm the absence of an ephemeral wetland and deeper investigation is always recommended.

Due to the overly generic nature of legislation pertaining to wetlands, these temporary systems are often not recognised and therefore not delineated and protected. The damage or destruction of a wetland through urban development is unfortunately not an uncommon occurrence. However, by taking an investigative approach, such as done in this case study, before any development or construction takes place, the risk of damage or destruction of ecosystems, damage to urban structures, pollution of water courses as well as monetary loss can be minimised.

It is recommended that these systems which are not linked to surface or groundwater, and are thus perched water wetlands, be included in wetland terminology, especially in arid climates, such as South Africa, where wetlands (s.s.) are uncommon and scattered. Investigations should be detailed and focus on the distinct indicators of these special systems, which may be present in the absence of the four conventional indicators.

Moreover, it is recommended that compulsory data for developments, such as geotechnical investigations, be used to infer possible ephemeral wetland conditions and that the hydraulic properties of the materials present in soil profiles be carefully considered in order to conceptualise possible flow paths and areas of temporary saturation or inundation and the effects this will have on the development project in question.

Additionally, a fifth indicator is recommended, which relates to the intermittent water logging of deeper soils and includes lateral and vertical upward water logging, sourcing water from the intermediate vadose zone, between the water table and plant root zone. In order to do this, detailed soil profile descriptions should be made along with geochemical and physical characterisation of soils. Although landform, soil wetness and soil form all have the ability to indicate these systems, the common disruption of surface materials or landscaping easily masks some of these indicators. Identification based on markers at depth or upslope, such as comprehensive hydrological understanding, can therefore aid where these alternative abiotic identifiers may be absent, obscured or disrupted.

Hillslope hydrology should be considered as complex systems which are temporally and spatially variable. Therefore, creating a conceptual model which includes the physical, geochemical and hydrological properties is essential when developing a site, in order to understand the processes at hand. This is useful for site selection, positioning of the desired development on a site, as well as for construction design purposes.

Where these systems are identified and construction is to be done within close proximity to these systems, environmental specialist should be consulted with regards to the design of the project, in order to avoid future damage or contamination of the wetland.

7. REFERENCES

- Acocks, J.P.H. (1953). Veld Types of South Africa. Botanical Survey of South Africa. Memoir No.28. Government Printer, Pretoria
- Acocks, J.P.H. (1988). Veld Types of South Africa. 3rd Edition. Memoirs of the Botanical Survey of South Africa 57:1-146. Government Printer, Pretoria
- ARQ (Pty) Ltd. (2009). Geotechnical Investigation Report: Development Bank of southern Africa – Access Road. Report Number 5260/10947. Prepared for Wedge Projects.
- Bird, M.S., Mlambo, M.C. and Day, J.A. (2013). Macroinvertebrates as unreliable indicators of Human disturbance in Temporary Depression Wetlands of South-Western Cape, South Africa. Springer Science + Business Media Dordrecht. 2013. Hydrobiologia. Vol. 720:19-37.
- Blatt, H. and Tracy, R.J. (1997). Petrology: Igneous, Sedimentary and Metamorphic (2nd ed.). W.H Freeman and Company. USA.
- Brady, N.C. and Well, R.R. (2002). The Nature and Properties of Soils. 13th Ed. Pearson Education Inc. India. 976pp.
- Brinson, M.M. (1993). A Hydromorphic Classification for Wetlands. Technical Report WRP-DE-4, US Army Engineer Waterways Experiment Station. Vicksburg, MS.
- Cabezas, A., Garcia, M., Gallardo, B., Gonzalez, E., Gonzalez-Sanchis, M. and Comin, F.A. (2009). The Effect of Anthropogenic Disturbance on the Hydrochemical Characteristics of Riparian Wetlands at the Middle Ebro River (NE Spain). Springer Science + Business Media B.V. 2008 Hydrobiologia. Vol. 617: 101-116.
- CBD-COP11 (Convention on Biological Diversity, 11th Conference of the Contracting Parties). (2012). National Report on Implementation of the Ramsar Convention on Wetlands. Ramsar. Available online at: ramsar.org/pdf/cop11/nr/ccp11-nr.southafrica.pdf. Accessed 16 April 2013.
- Chu, S. and Molano-Flores, B. (2013). Impacts of Agricultural to Urban Land-Use change on Floristic Quality Assessment Indicators in Northeastern Illinois Wetlands. Springer Science + Business Media, LLC. 2012. Urban Ecosystems. Vol. 16: 235-246.
- Cole, C.A., Brooks, R.P. and Wardrop, D.H. (1997). Wetland Hydrology as a Function of Hydrogeomorphic (HGM) Subclass. The Society of Wetland Scientists. Wetlands. Vol. 17 (4): 456-467.
- Colvin, C., Le Maitre, D. and Huges, S. (2002). Assessing Terrestrial Groundwater Dependent Ecosystems in South Africa. WRC Report No. 1090-2/2/03. Water Research Commission. Pretoria.

- Cowan, G.I. (1995). South Africa and the Ramsar Convention, *In: Cowan, G.I. (Ed.) Wetlands of South Africa*. Department of Environmental Affairs and Tourism, Pretoria, 1-20.
- Cowan, G.I. (1999). The Development of a National Policy and Strategy for Wetland Conservation in South Africa. PhD Thesis, University of Pretoria.
- Cowardin, C.M., Carter, V. Golet, F.C., LaRoe, E.T. (1979). Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service Report No. FWS/OBS/-79/31. Washington, D.C.
- Day, J., Day, E., Ross-Gillespie, V. and Kettley, A. (2010) Wetland Health and Importance Research Programme: The Assessment of Temporary Wetland During Dry Conditions (Vol. 2). WRC Report No. TT 434-09. Water Research commission. Pretoria.
- Day, J.A. (2009). Rivers and Wetlands. *In: Strydom, H.A. and King, N.D. (Eds.), Environmental Management in South Africa*. 2nd ed. Juta Law, Cape Town, 842-867.
- Dini, J.A. and Cowan, G.I. (2000). Classification System for the South African Wetland Inventory. Second Draft, June 2000. South African Wetlands Conservation Programme, Department of Environmental Affairs and Tourism, Pretoria.
- Du Plessis, W. and Du Plessis A.A. (2011). Striking the Sustainability Balance in South Africa. *In: Faure, M. and Du Plessis, W. (Eds.) The Balance of Interests in Environmental Law in Africa*. Pretoria University Law Press (PULP), 413-458.
- DWA [Department of Water Affairs]. (1986) Management of the Water Resources of the Republic of South Africa. Department of Water Affairs. Pretoria.
- DWAF (Department of Water Affairs and Forestry). (2005). A Practical Field Procedure for Identification and Delineation of Wetlands and Riparian Areas. Edition 1. DWAF, South Africa, Pretoria.
- DWAF [Department of Water Affairs and Forestry] Directorate: Spatial and Land Information Management. (2007). WMA 3: Crocodile (West) & Marico. 1:1 000 000. Ref: GM07_217. Department of Water Affairs. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1995). Groundwater Resources of the Republic of South Africa. Sheet 2: Mean Annual Recharge. 1:7 500 000. Water Research Commission. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1995). Groundwater Resources of the Republic of South Africa. Sheet 2: Groundwater Component of River Flow (Baseflow). 1:7 500 000. Water Research Commission. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1995). Groundwater Resources of the Republic of South Africa. Sheet 2: Depth to Groundwater Level. 1:7 500 000. Water Research Commission. Pretoria.

- DWAF [Department of Water Affairs and Forestry]. (1995). Groundwater Resources of the Republic of South Africa. Sheet 2: Hydrochemical Types. 1:7 500 000. Water Research Commission. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1996). Groundwater Harvest Potential of South Africa. 1:3 000 000. Department of Water Affairs and Forestry. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1996). Groundwater Harvest Potential of South Africa: Factors Restricting Available Harvest. 1:8 500 000. Department of Water Affairs and Forestry. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1996). Groundwater Harvest Potential of South Africa: Potential Borehole Yield. 1:8 500 000. Department of Water Affairs and Forestry. Pretoria.
- DWAF [Department of Water Affairs and Forestry]. (1996). Groundwater Harvest Potential of South Africa: Groundwater Quality. 1:8 500 000. Department of Water Affairs and Forestry. Pretoria.
- Evans, C.V. and Franzmeier, D.P. (1986). Saturation, Aeration, and Color Patterns in a Toposequence of Soils in North-Central Indiana. *Soil Science Society of America Journal*. Vol. 50: 975-980.
- Ewart-Smith, J.L., Ollis, D.J., Day, J.A. and Malan, H.L. (2006). National Wetland Inventory: Development of a Wetland Classification System of South Africa. April 2006. Report No. KV 174/06. Prepared for the Water Research Commission and South African National Biodiversity Institute.
- Fey, M. (2010). *Soils of South Africa*. Cambridge University Press. Cape Town, South Africa. 287pp.
- Funke, N., Nortje, K., Findlater, K., Burnes, M., Turton, A., Weaver, A. and Hatting, H. (2007). Redressing Inequality: South Africa's New Water Policy. *Environment*, 49(3): 10-23.
- Gao, J., Xilai, L.I. and Brierley, G. (2012). Topographic Influence of Wetland Distribution and Change in Maduo County, Qinghai-Tibet Plateau, China. *Science Press and Institute of Mountain Hazards and Environment, CAS and Springer-Verlag, Berlin, Heidelberg. Journal of Mountain Science*. Vol. 9: 362-371.
- Gile, L.H. (1958). Fragipan and Water-Table Relationships of some Brown Podzolic and Low Humig-Gley Soils. *Soil Science Society of America Proceedings*. Vol 22: 560-565.
- Gregorich, E.G. and Anderson, D.W. (1985). Effects of Cultivation and Erosion on Soils of Four Toposequences in the Canadian Prairies. *Geoderma*. Vol. 36:343-354.
- Hanks, J. and Glavovic, P.D. (1992). Protected Areas. In: Fuggle, R.F. and Rabie, M.A. (Eds.) *Environmental Management in South Africa*, 1st ed. Juta & Co. Ltd., Kenwyn, 690-714.
- Kidd, M. (1997). *Environmental Law: A South African Guide*. Juta & Co. Ltd., Cape Town, 193pp.

- Kidd, M. (2011). *Environmental Law*. 2nd ed. Juta & Co. Ltd., Cape Town, 368pp.
- Kotze, D.C., Marneweck, G.C., Batchelor, A.L., Lindley, D.S. and Collins, N.B. (2005). *Wet-Ecoservices, A Technique for Rapidly Assessing Ecosystem Services Supplied by Wetlands*. Unpublished Report, May 2005.
- Liyan, R., Wenze, Y., Jaillin, L. and Cifang, W. (2010). *Impact of Economic Development on Wetlands in Hangzhou Bau Industrial Belt*. Science China Press and Springer-Verlag. *Journal of Geographical Science*. Vol. 20 (3): 406-416.
- Lunde, K.B. and Resh, V.H. (2012). *Development and Validation of a Macroinvertebrate Index of Biotic Integrity (IBI) for Assessing Urban Impacts to Northern California Freshwater Wetlands*. Springer Science + Business Media B.V. 2011. *Environmental Monitoring Assessment*. Vol. 184: 3653-3674.
- Malo, D.D., Worcester, B.K., Cassel, D.K., *et al.* (1974). *Soil-Landscape Relationships in a Closed Drainage System*. *Soil Science Society of America Proceedings*. Vol. 38:813-818.
- Maxwell, J.R., Edwards, C.J., Jensen M.E., Paustian S.J., Parrott, H. and Hill, D.M. (1995). *A Hierarchical Framework of Aquatic Ecological Units in North America (Nearctic Zone)*. General Technical Report NC-176, Forest Service, United States, Department of Agriculture.
- McFarlane, M.J. (1976) *Laterite and Landscape*. Academic Press. Kent. p. 151.
- Mitsch, W.J. and Grosselink, J.G. (2000). *Wetlands* (3rd ed.). John Wiley & Sons Inc. New York.
- Nelson, M.P., Rhoades, C.C. and Dwire, K.A. (2011). *Influence of Bedrock Geology on Water Chemistry of Slope Wetlands and Headwater Streams in the Southern Rocky Mountains*. *Society of Wetland Scientists. Wetlands*. Vol. 31: 251-261.
- O'Keeffe, J.H., Uys, M. and Burton M.N. (1992). *Freshwater Systems*. *In: Fuggle, R.F. and Rabie, M.A. (Eds.) Environmental Management in South Africa*, 1st ed. Juta & Co. Ltd., Kenwyn, 277-315.
- O'Connor TG & Bredenkamp GJ 1997. *Grassland*. *In: Cowling RM, Richardson DM & Pierce SM (eds). Vegetation of South Africa*. Cambridge University Press, Cambridge.
- Rabie, M.A. (1992). *Environmental Conservation Act*. *In: Fuggle, R.F. and Rabie, M.A. (Eds.) Environmental Management in South Africa*, 1st ed. Juta & Co. Ltd., Kenwyn, 99-119.
- Riddell, E.S., Lorentz, S.A. and Kotze, D.C. (2012). *The Hydrodynamic Response of a Semi-Arid Headwater Wetland to Technical Rehabilitation Interventions*. *Water Research Commission. Water SA*. Vol. 38 (1): 55-66.
- Robb, L.J., Brandl, G., Anhaeusser, C.R., and Poujol, M. (2009). *Archaeoan Granitoid Intrusions*. *In: Johnson, M.R., Anhaeusser, C.R. and Thomas, R.J. The Geology of South Africa*. Johannesburg/ Pretoria: Geological Society of South Africa/ Council for Geoscience. 57-94.

- SA Explorer. (2000-2011; viewed 27 March 2012). SA Explorer South Africa. Internet: www.saexplorer.co.za/south-africa.climate/midrand_climate.asp
- SANBI [South African National Biodiversity Institute]. (2009). Further Development of a Proposed National Wetland Classification System for South Africa. Pretoria: Freshwater Consulting Group (FCG) of South African National Biodiversity Institute (SANBI).
- SANS [South African National Standards]. (1993). Code of Practice: Water Supply and Drainage for Buildings. Part 2: Drainage Installations for Buildings. SANSn10252-2. South African Bureau of Standards. Pretoria.
- SANS [South African National Standards]. (2009a). Profiling, and Percussion and Core Borehole Logging in Southern Africa for Engineering Purposes. Draft SANS 633. South African Bureau of Standards. Pretoria.
- Schaetzl, R.J. and Anderson, S. (2005). Soils: Genesis and Geomorphology. Cambridge University Press. New York. 817pp.
- Semeniuk, C.A. and Semeniuk, V. (1995). A Geomorphic Approach to Global Classification for Inland Wetlands. *Vegetatio*. Vol. 118: 103-124.
- South Africa (1994) General Policy in terms of the Environment Conservation Act 1989 (Act No. 73 of 1989) *Government Gazette* 15428:51, January 21.
- TCF [The Conservation Foundation]. (2001). Midwestern Ephemeral Wetlands: A Vanishing Habitat. U.S. Environmental Protection Agency. Grant No. CD97501001-1. Available online at: herpcenter.ipfw.edu/outreach/EphWetBrochure/EphemeralWetlandsBrochure.pdf.
- The Ramsar Convention on Wetlands (2013). The Annotated Ramsar List: South Africa. Available online at: www.ramsar.org/cda/en/ramsar-news-archives-2010-annotated-ramsar-16187/main/ramsar/-26-45-437%5E16187_4000_0__. Accessed 16 April 2013.
- Tiner, R.W. (1999). Wetland Indicators: A Guide to Wetland Identification, Delineation, Classification, and Mapping. Lewis Publishers. United States.
- Van Riet and Louw Landscape Architects (1998). Environmental Impact Assessment Scoping Report and Environmental Management Plan for Blue Valley Golf and Country Estate. Unpublished. Van Riet and Louw Landscape Architects.
- Van Rooy, J. L. (2006). Report on a Phase 1 Geotechnical Site Investigation for Headway Hill Extension 1 on Part of Re/Portion 442 of the Farm Randjesfontein 405-JR, Midrand, Gauteng Province. Report Number 671. Prepared for Zoning Solutions.
- Van Rooy, J. L. (2008). Report on a Phase 1 Geotechnical Site Investigation for Headway Hill Extension 2 on Part of the Remainder of Portion 442 of the Farm Randjesfontein 405-JR, Midrand, Gauteng Province. Report Number 858. Prepared for Zoning Solutions.

- Walmsley, B. and Patel, S. (2011). Handbook of Environmental Legislation in the SADC Region. 3rd ed. Pretoria: Development Bank of Southern Africa (DBSA) in collaboration with the Southern African Institute for Environmental Assessment (SAIEA).
- Walters, D.J.J., Kotze, D.C. and O'Connor, T.G. (2006). Impact of Land Use on Vegetation Composition, Diversity, and Selected Soil Properties of Wetlands in the Southern Drakensburg Mountains, South Africa. Springer. Wetland Ecology and Management. Vol. 14: 329-348.
- Wang, M., Qin, D., Lu, C., Li, Y. (2010). Modelling Anthropogenic Impacts and Hydrogeological Processes on a Wetland in China. Springer Science + Business Media B.V. 2010. Water Resource Management. Vol. 24: 2743-2757.
- Ward, J.C., and Lambie, J.S. (1999). Monitoring Changes in Wetland Extent: An Environmental Performance Indicator for Wetlands. Coordinated Monitoring of New Zealand Wetlands. A Ministry for the Environment SMF Funded Project. Final Report_Project Phase 1, October 1999. Lincoln Environmental. Lincoln University, Canterbury.
- Zalidis, G.C., Mantzavelas, A.L. and Gourvelou, E. (1997) Environmental Impacts on Greek Wetlands. The Society of Wetland Scientists. Wetlands. Vol. 17 (3): 339-345.

Legislation:

CARA [Conservation of Agricultural Resources Act], 43 of 1983. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Constitution of the Republic of South Africa, Act 108 of 1996. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

ECA [Environment Conservation Act], 73 of 1989. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

ECA [Environment Conservation Act], 100 of 1982. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Forest Act, 122 of 1984. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Irrigation and Conservation of Waters Act, 8 of 1912. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Lake Areas Development Act, 39 of 1975. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Mountain Catchment Areas Act, 63 of 1970. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NEMA [National Environmental Management Act], 107 of 1998. *Government Gazette*, Republic of

South Africa. Government Printer: Pretoria.

NEMAQA [National Environmental Management: Air Quality Act], 39 of 2004. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NEMBA [National Environmental Management: Biodiversity Act], 24 of 2004. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NEMICMA [National Environmental Management: Integrated Coastal Management Act], 24 of 2008. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NEMPAA [National Environmental Management: Protected Areas Act], 57 of 2003. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NEMWA [National Environmental Management: Waste Act], 59 of 2008. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

NWA [National Water Act], 36 of 1998. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Water Act, 54 of 1956. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

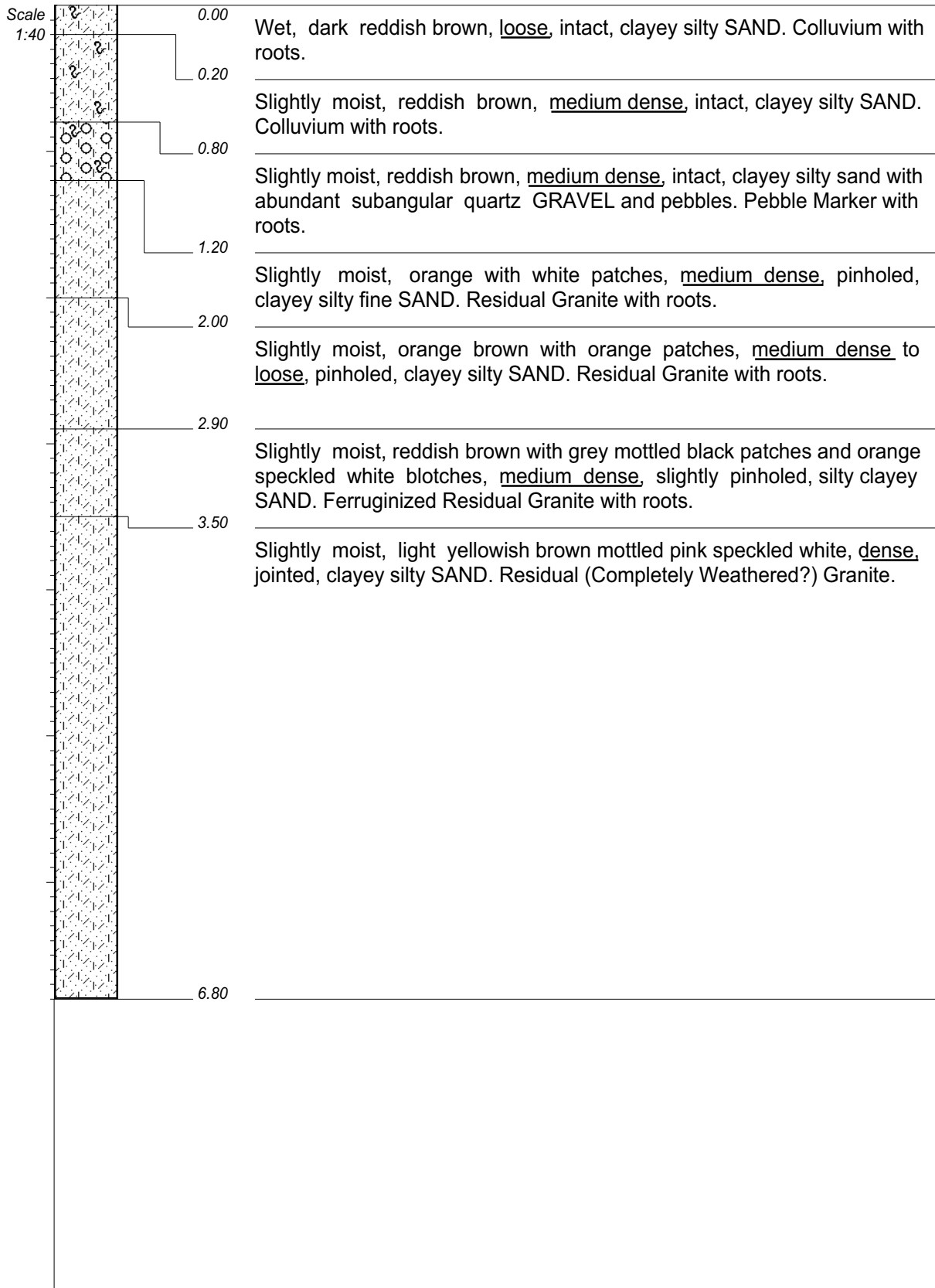
Water Services Act, 108 of 1997. *Government Gazette*, Republic of South Africa. Government Printer: Pretoria.

Cases:

The State v Frylinck and Another, Case number 14/1740/2010, judgement granted on 6 April 2011 per Magistrate Patterson in the Regional Division of North Gauteng. Available online at gssc.gpg.gov.za/gautengemi/docs/judgement.pdf. Accessed 16 April 2013.

Van Huyssteen and others NNO v Minister of Environmental Affairs and Tourism and others 1996 (1) SA 283 (C).

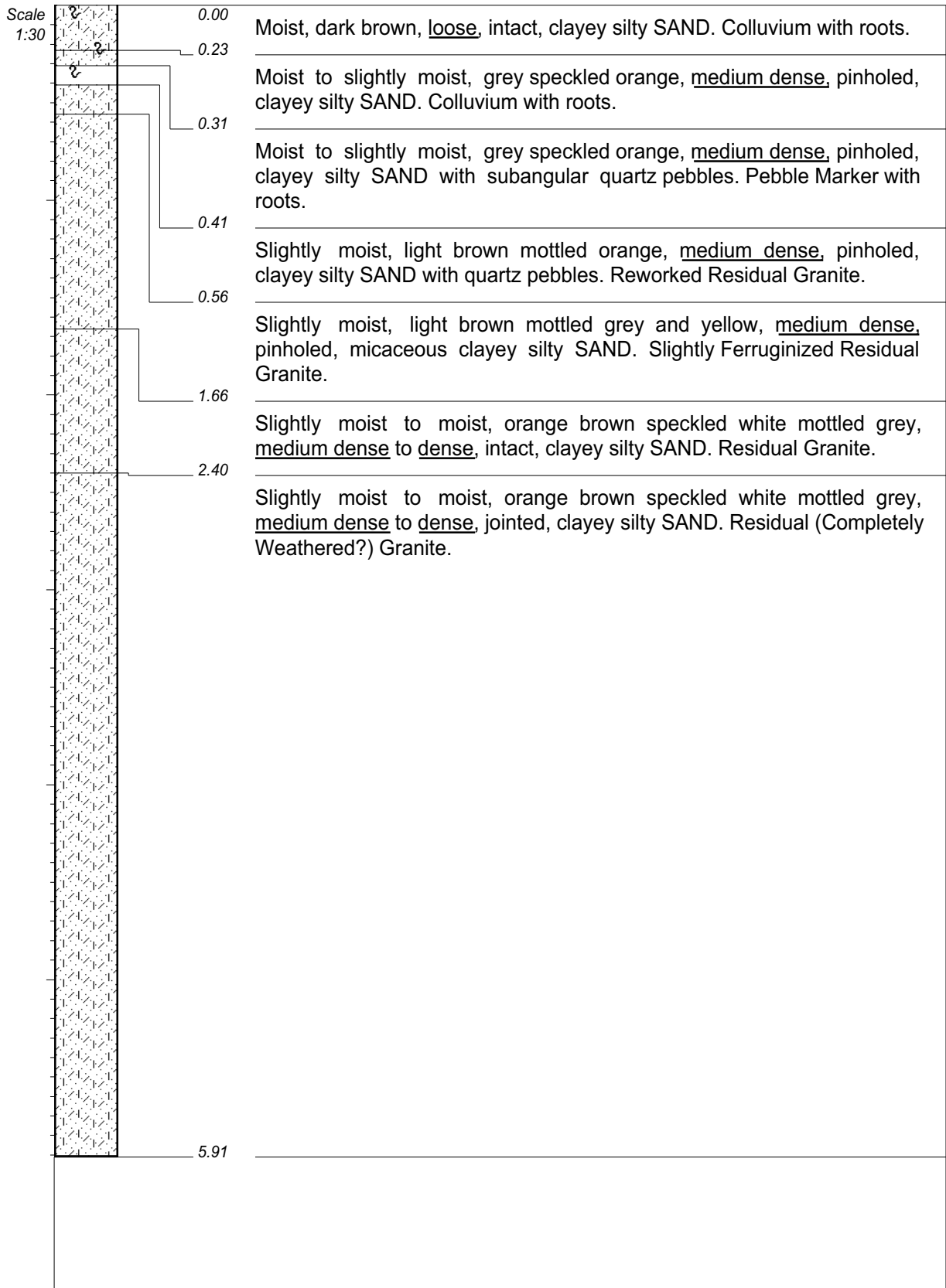
APPENDIX A: Soil Profile Logs



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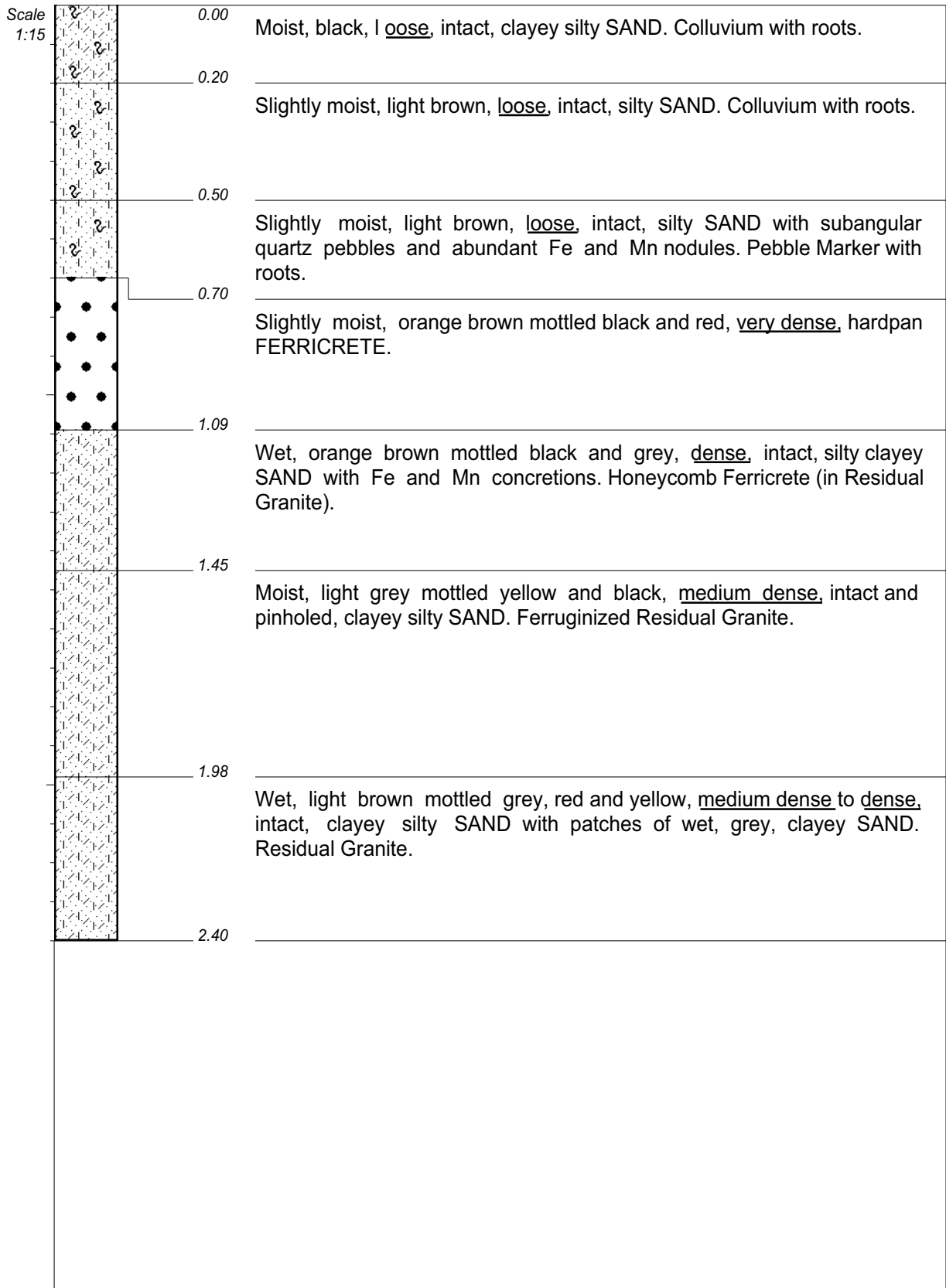
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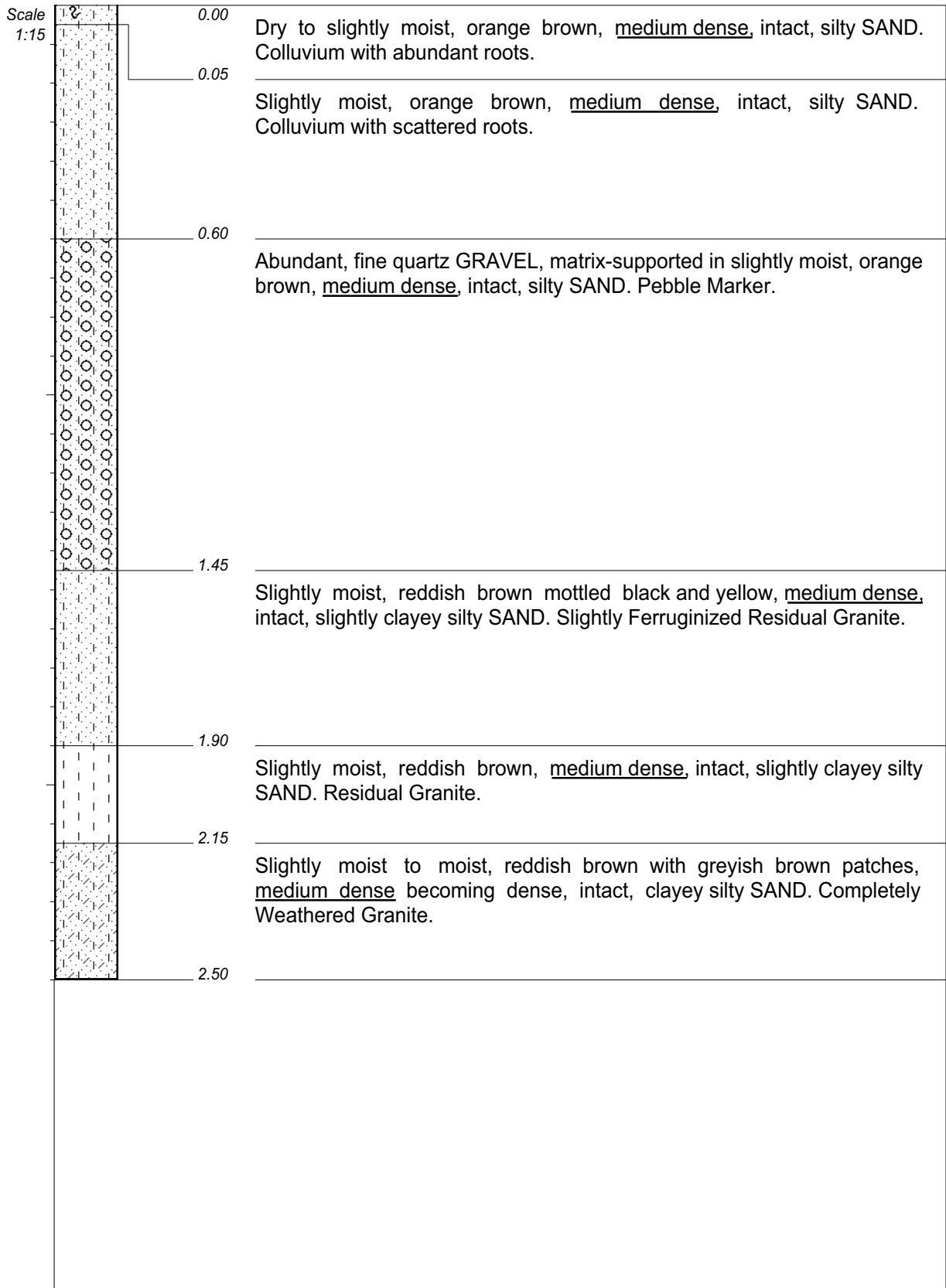
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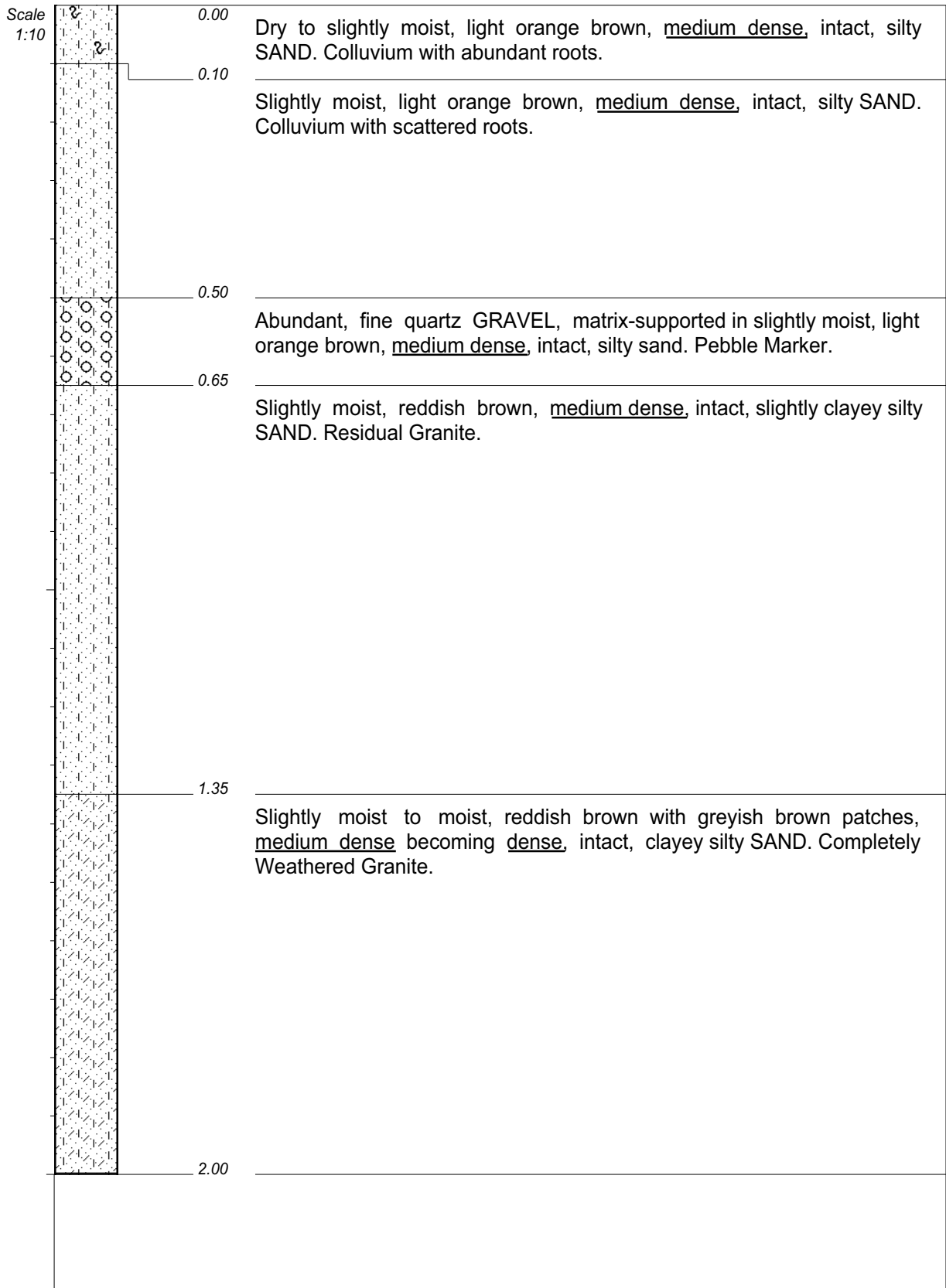
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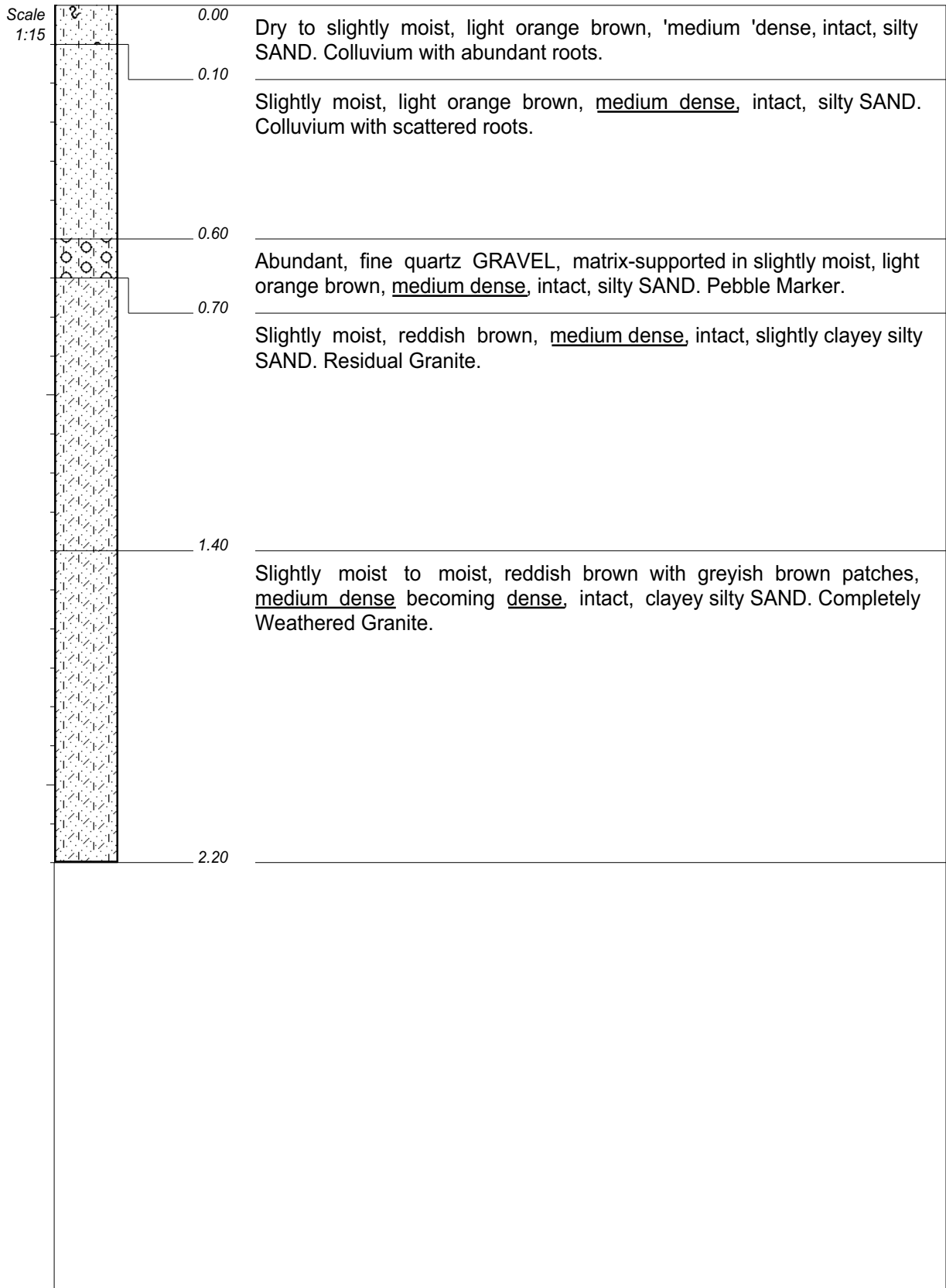
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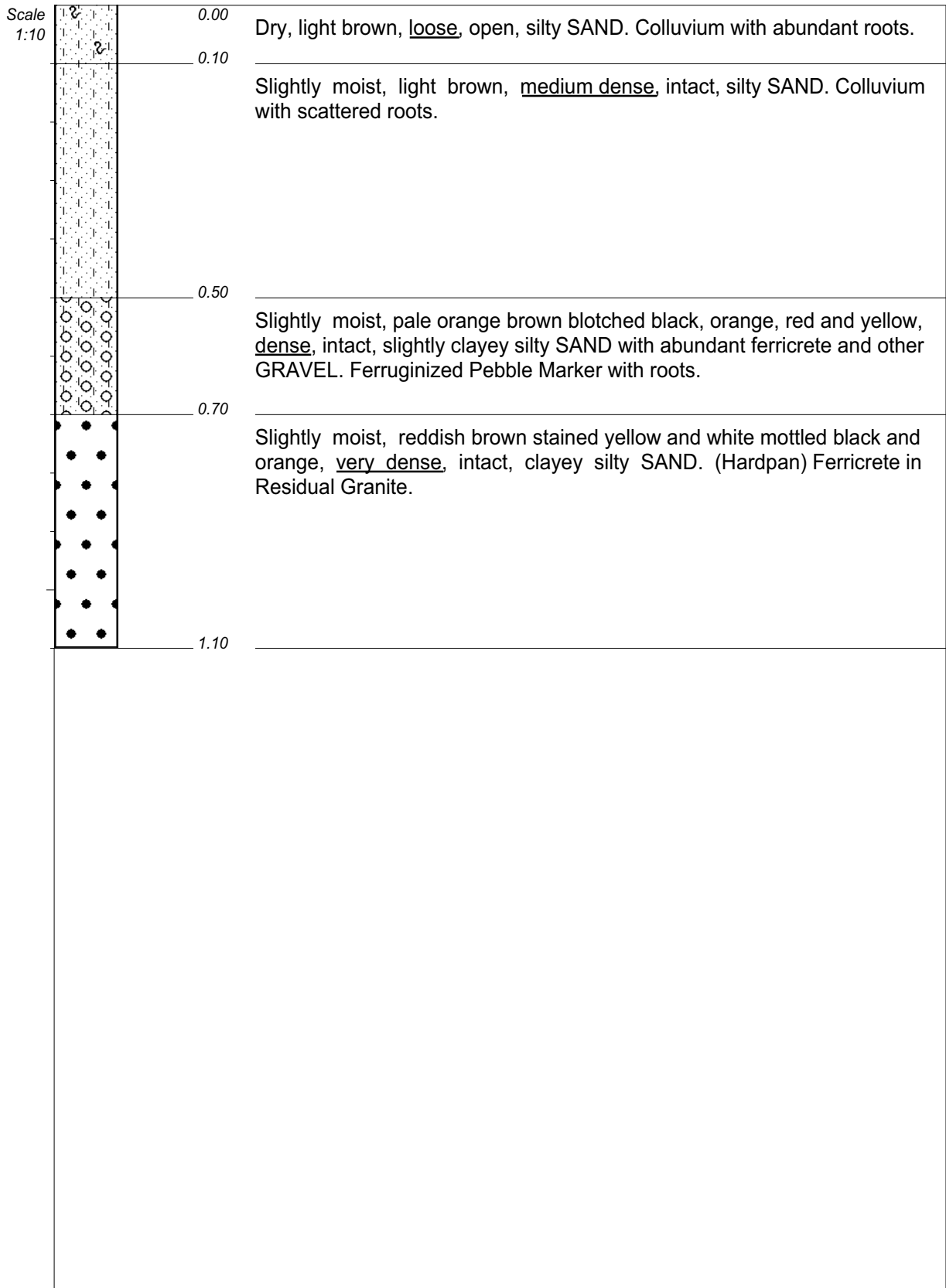
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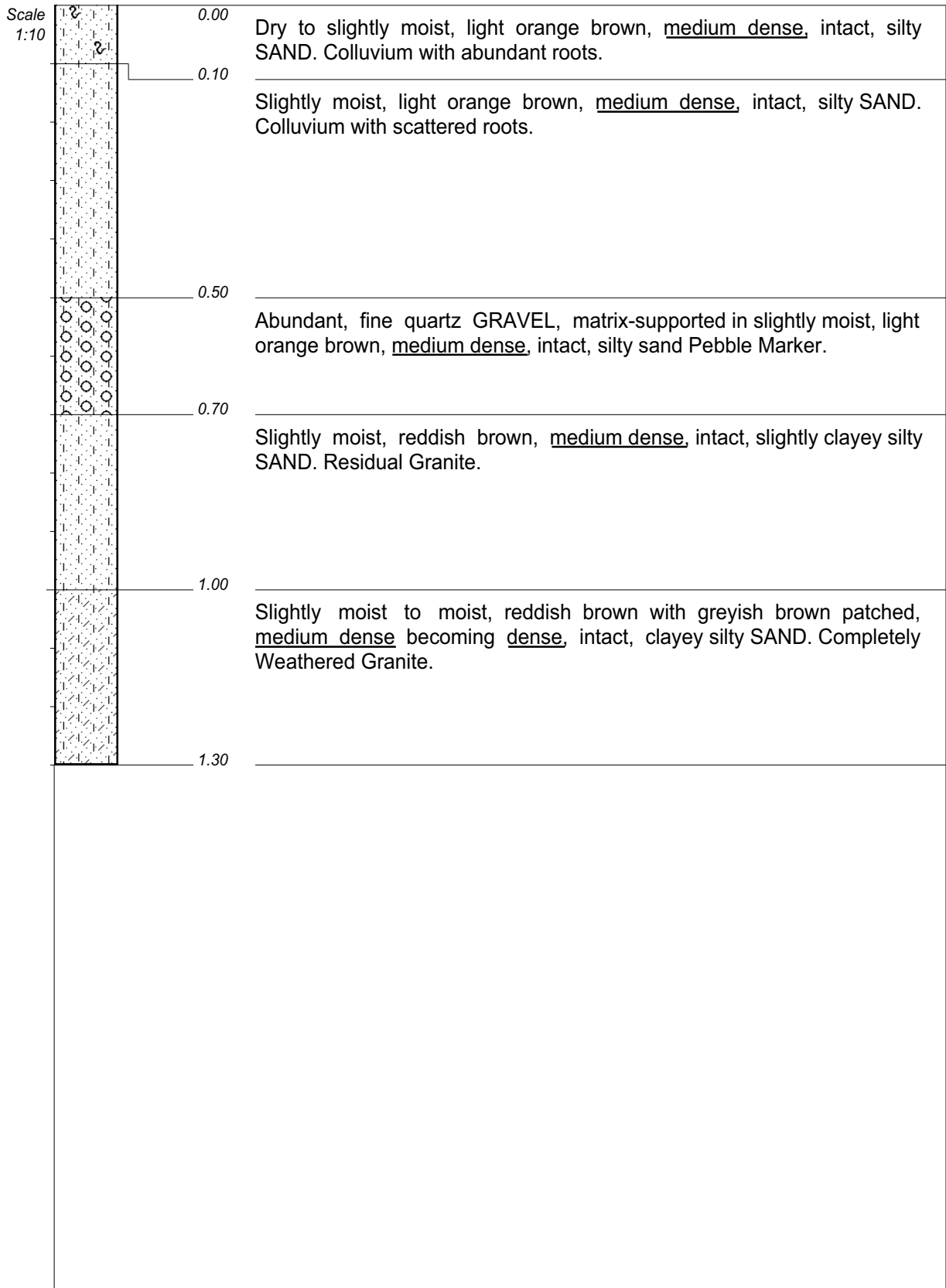
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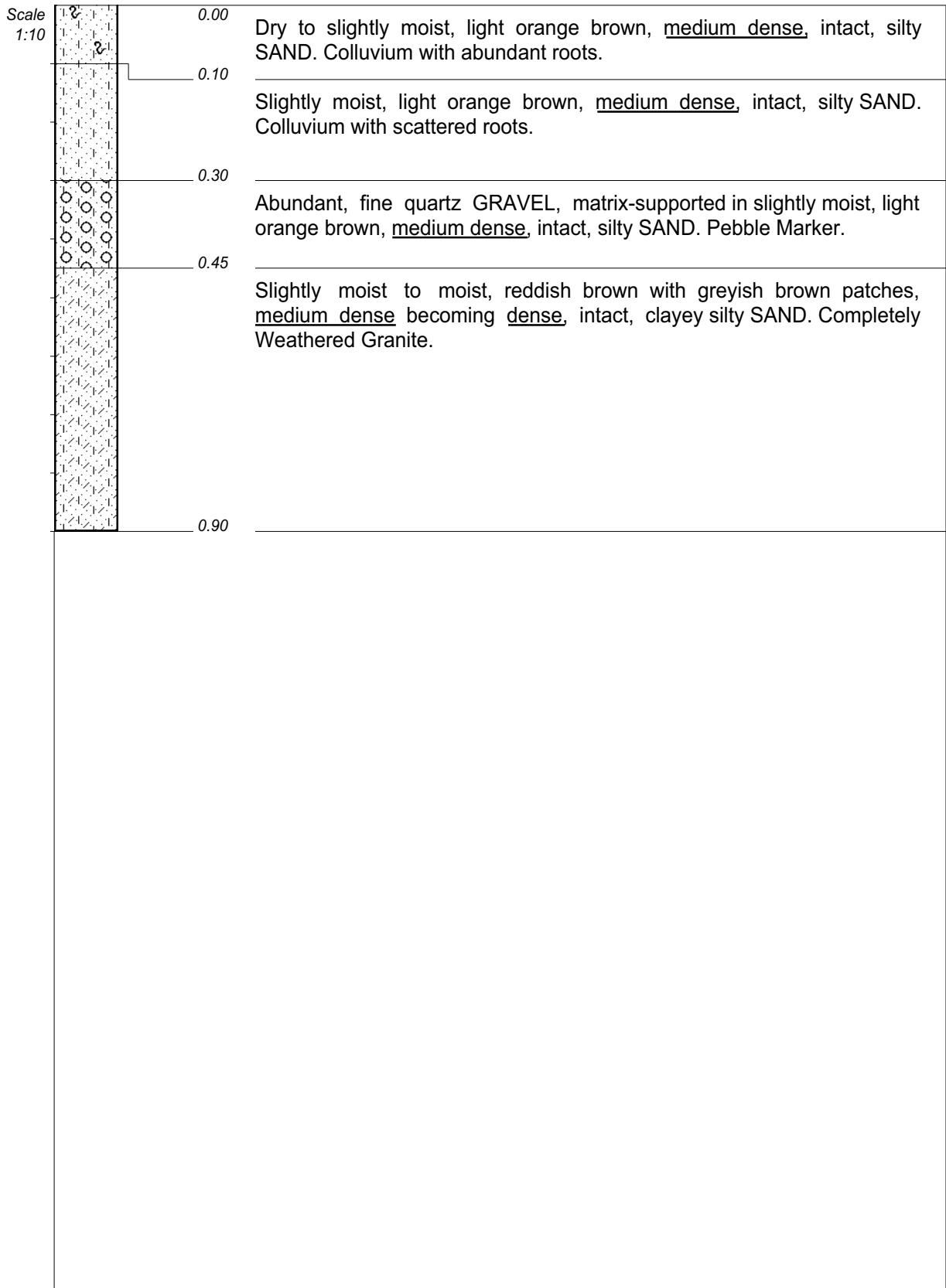
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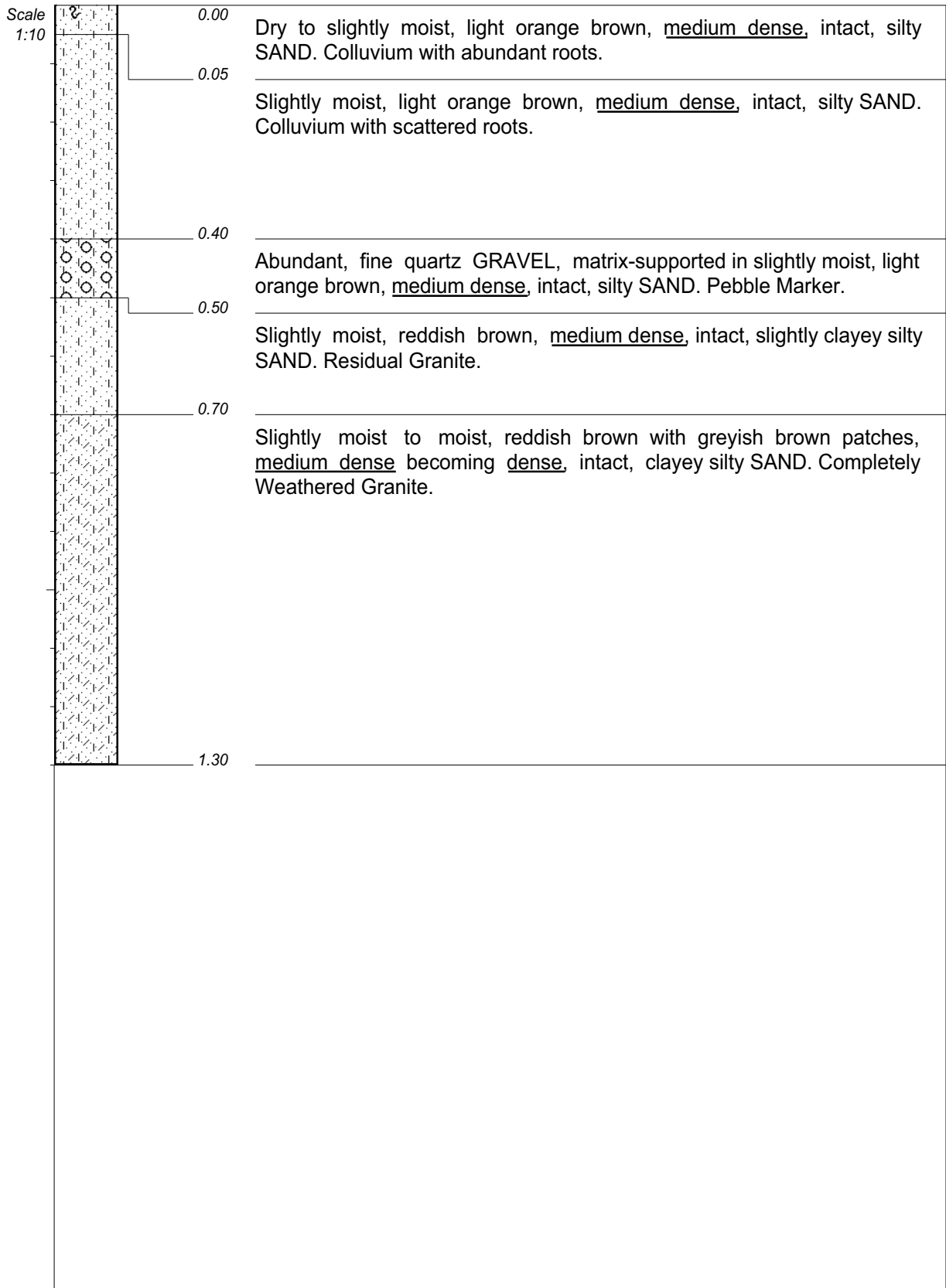


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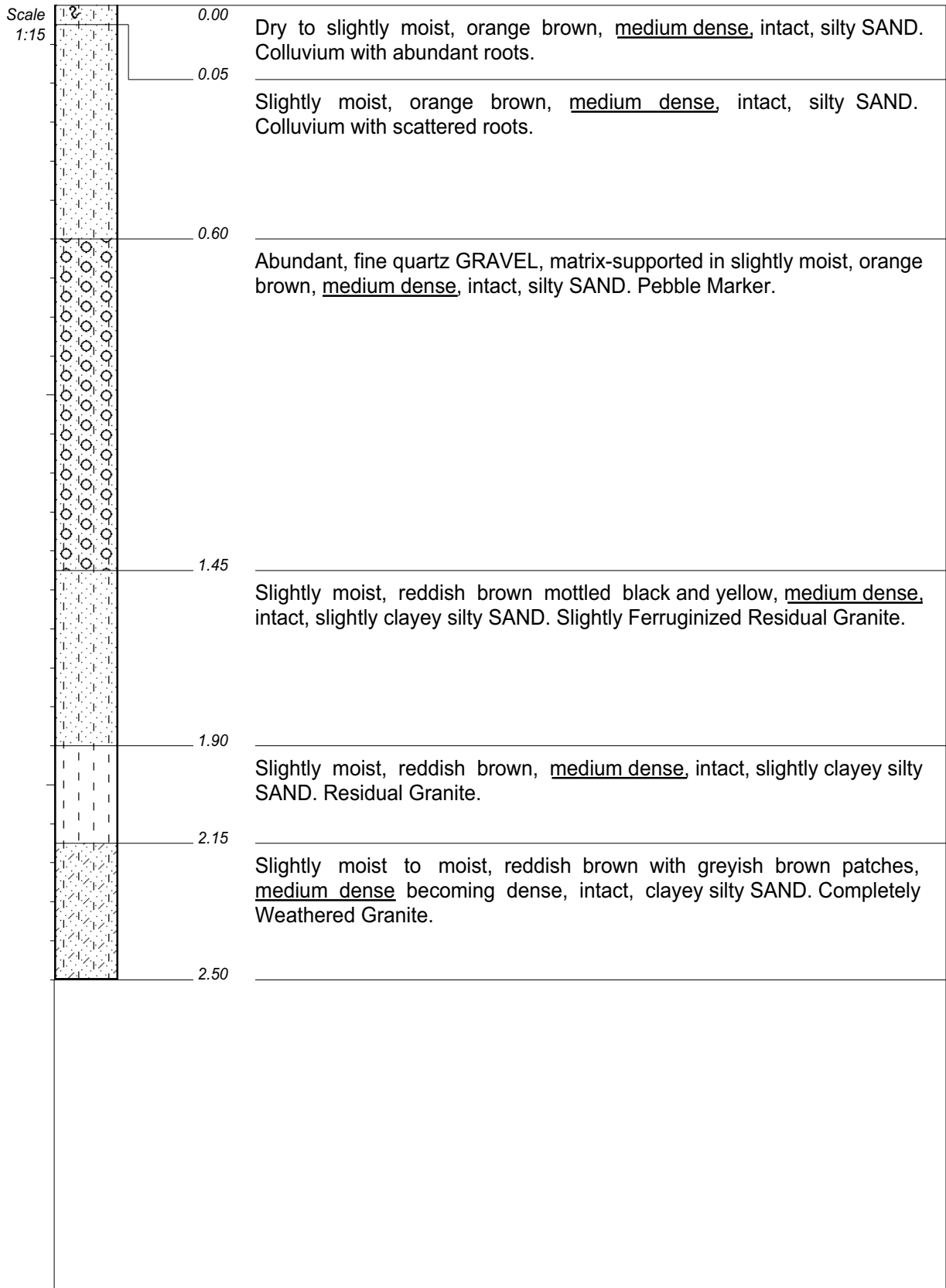
TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:06
TEXT : C:\dot7000\txt\1PAP2012.txt

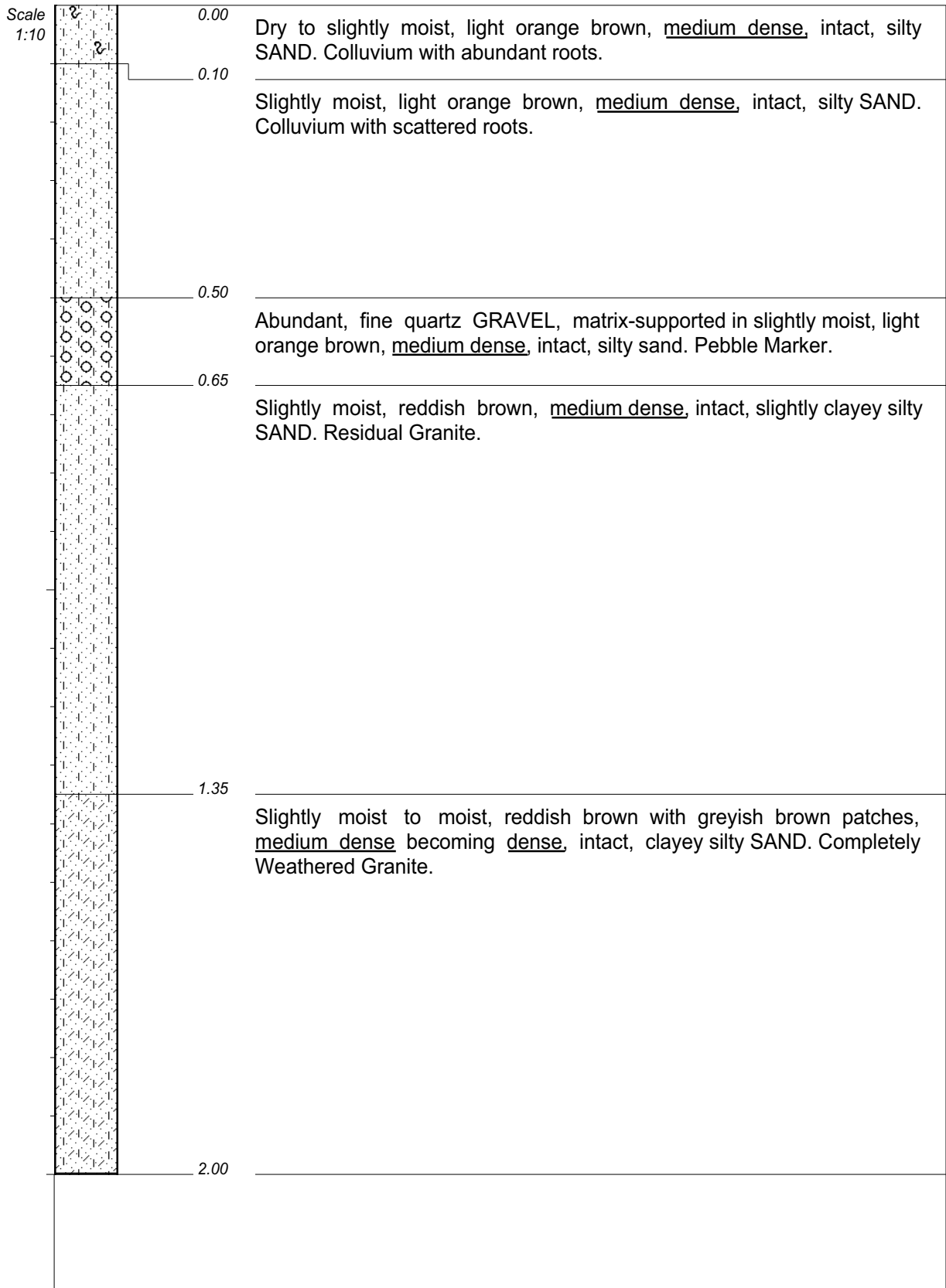
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
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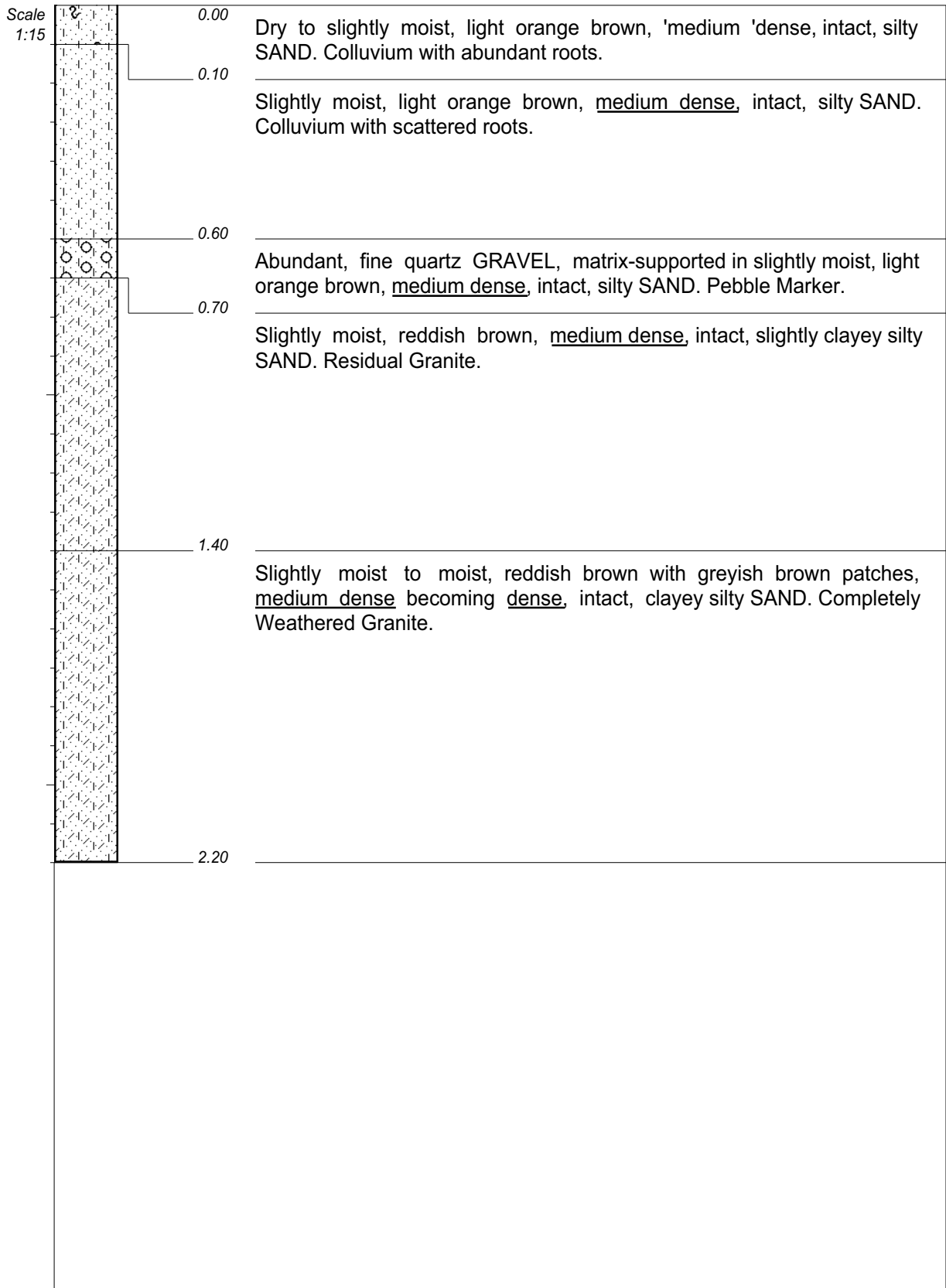
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
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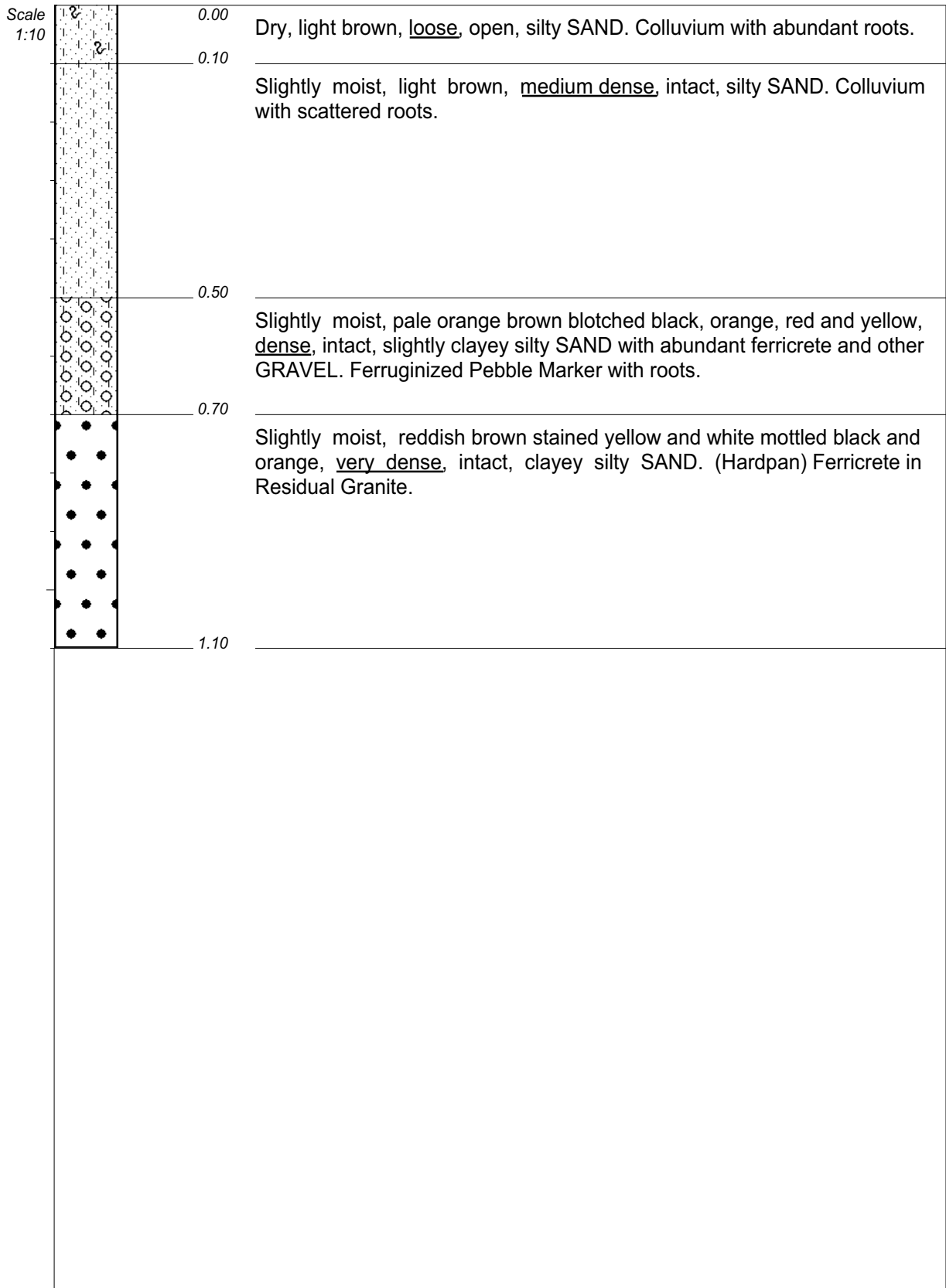
ELEVATION :
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Y-COORD :



CONTRACTOR :
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DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
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ELEVATION :
X-COORD :
Y-COORD :

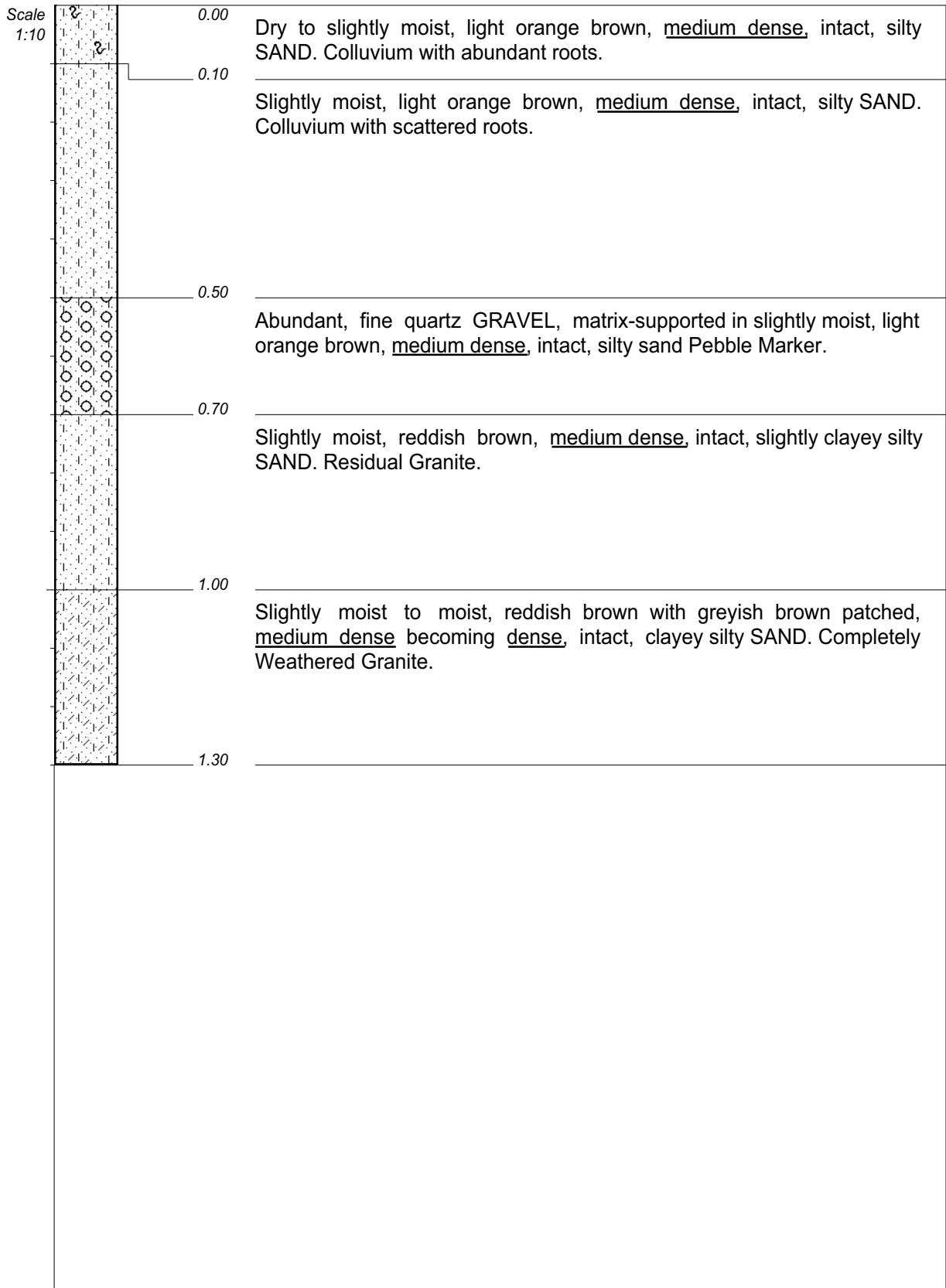


CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :
HOLE No: HH4

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



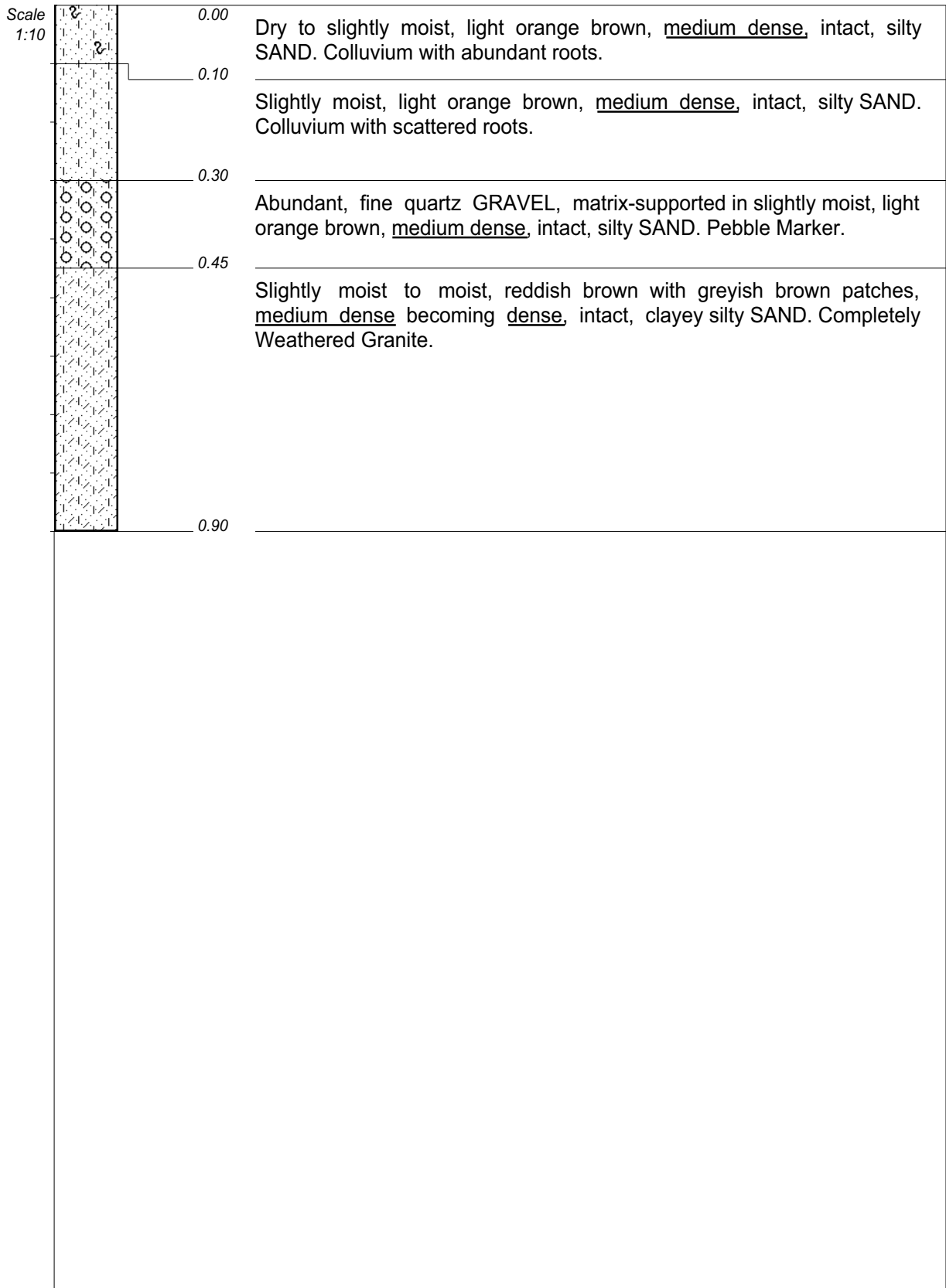
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DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
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DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

HOLE No: HH5

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET

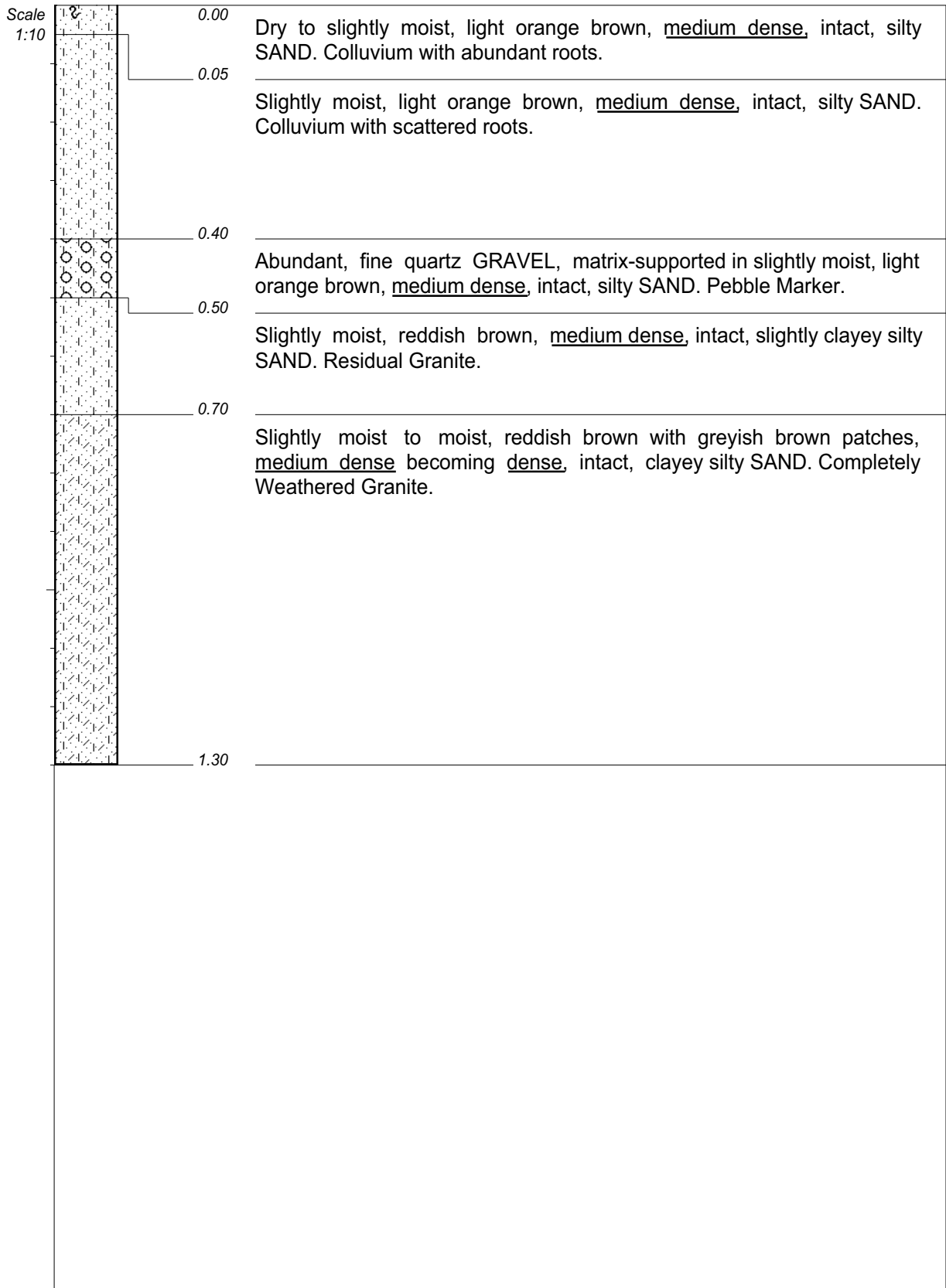


CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :
HOLE No: HH6

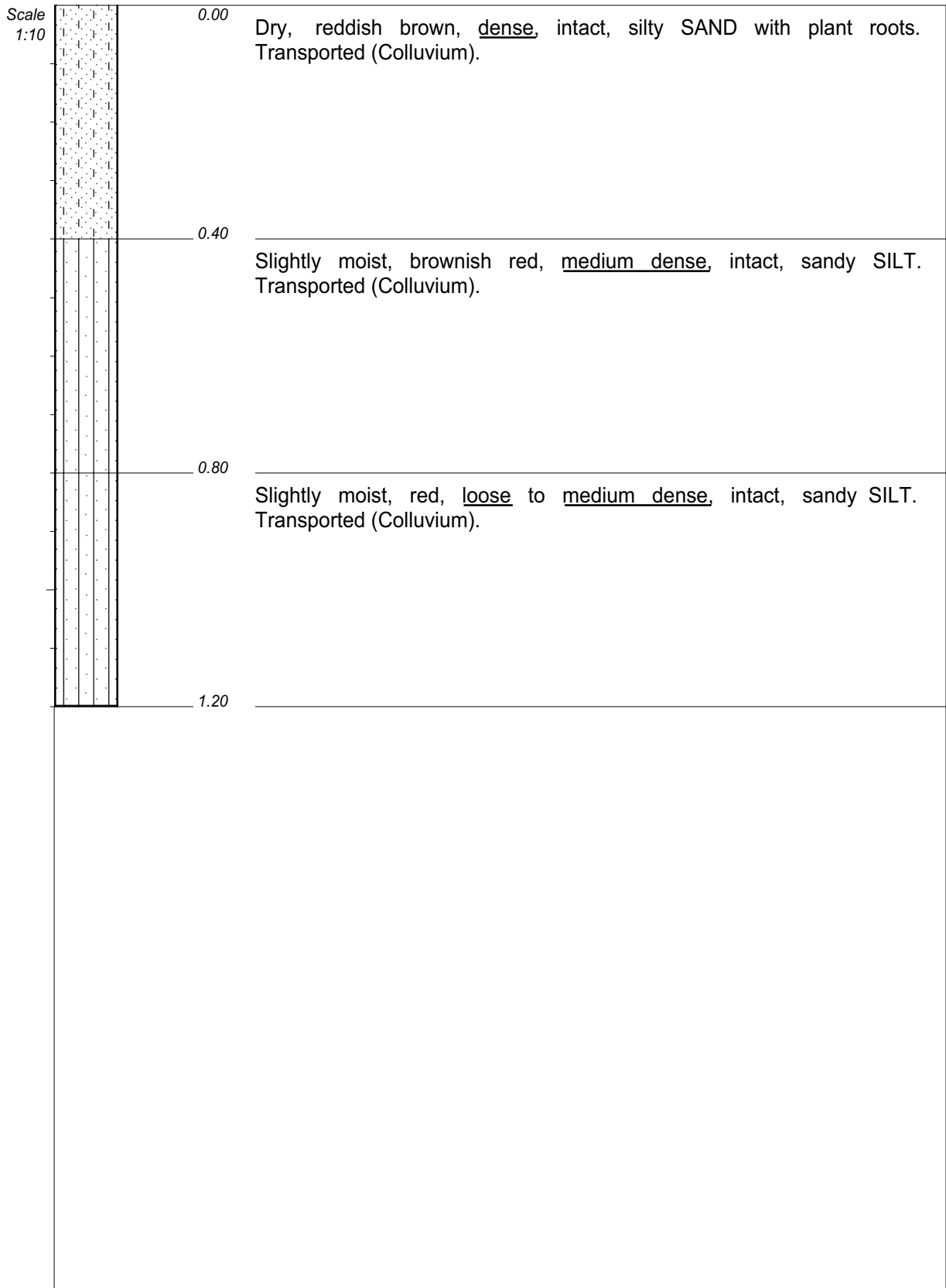
TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
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ELEVATION :
X-COORD :
Y-COORD :



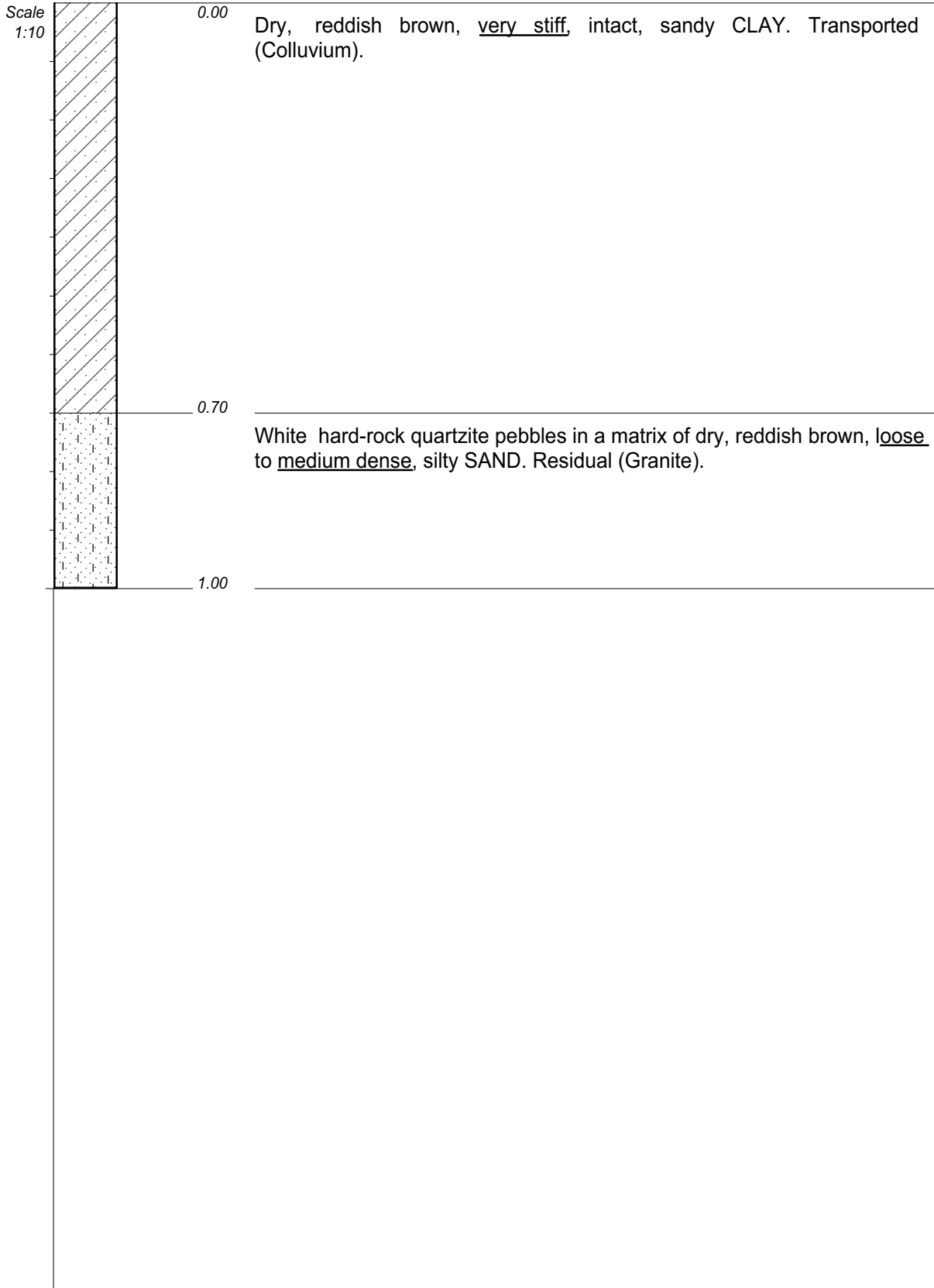
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DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

HOLE No: TP1

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



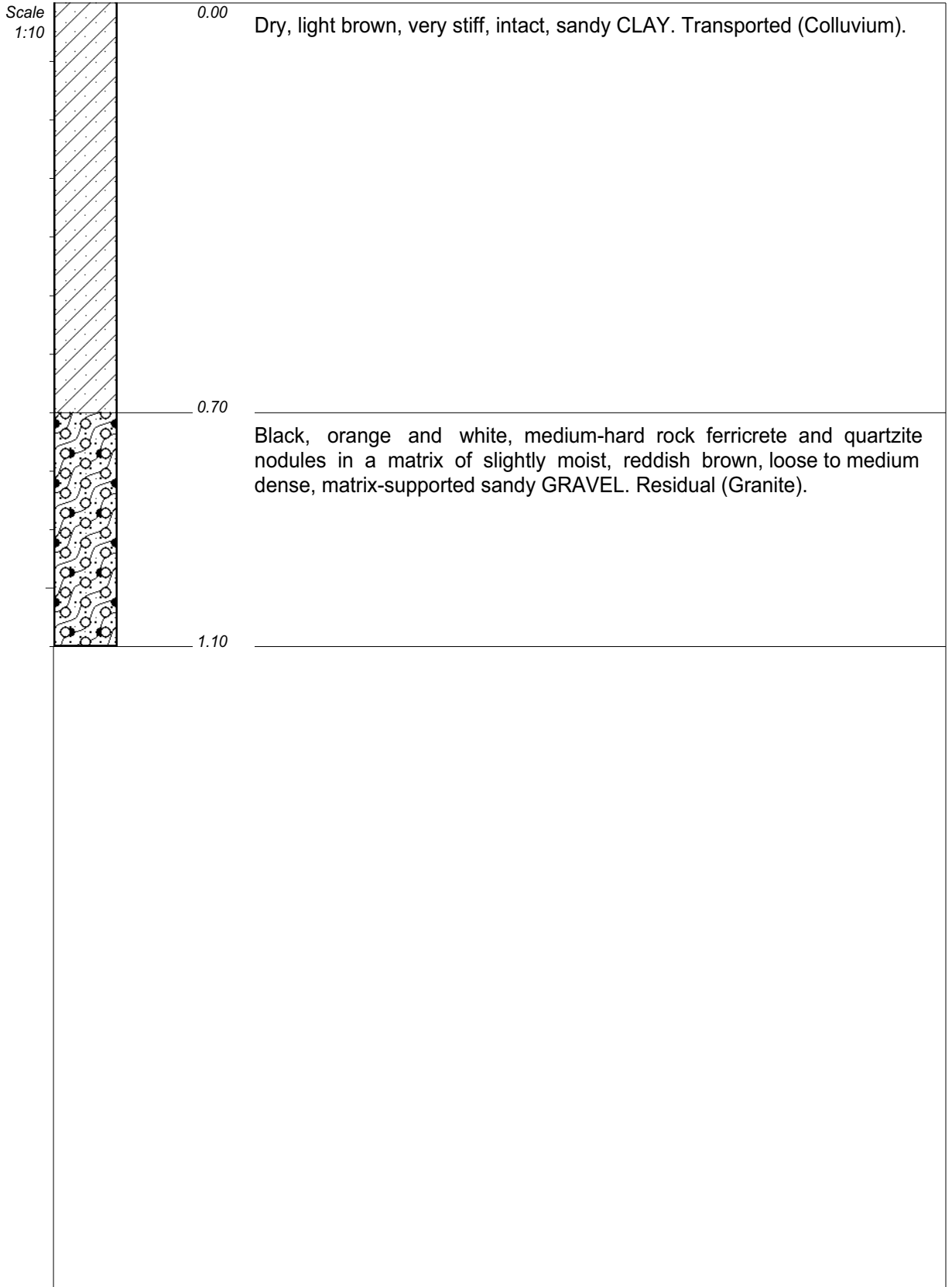
CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
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DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

HOLE No: TP2

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET

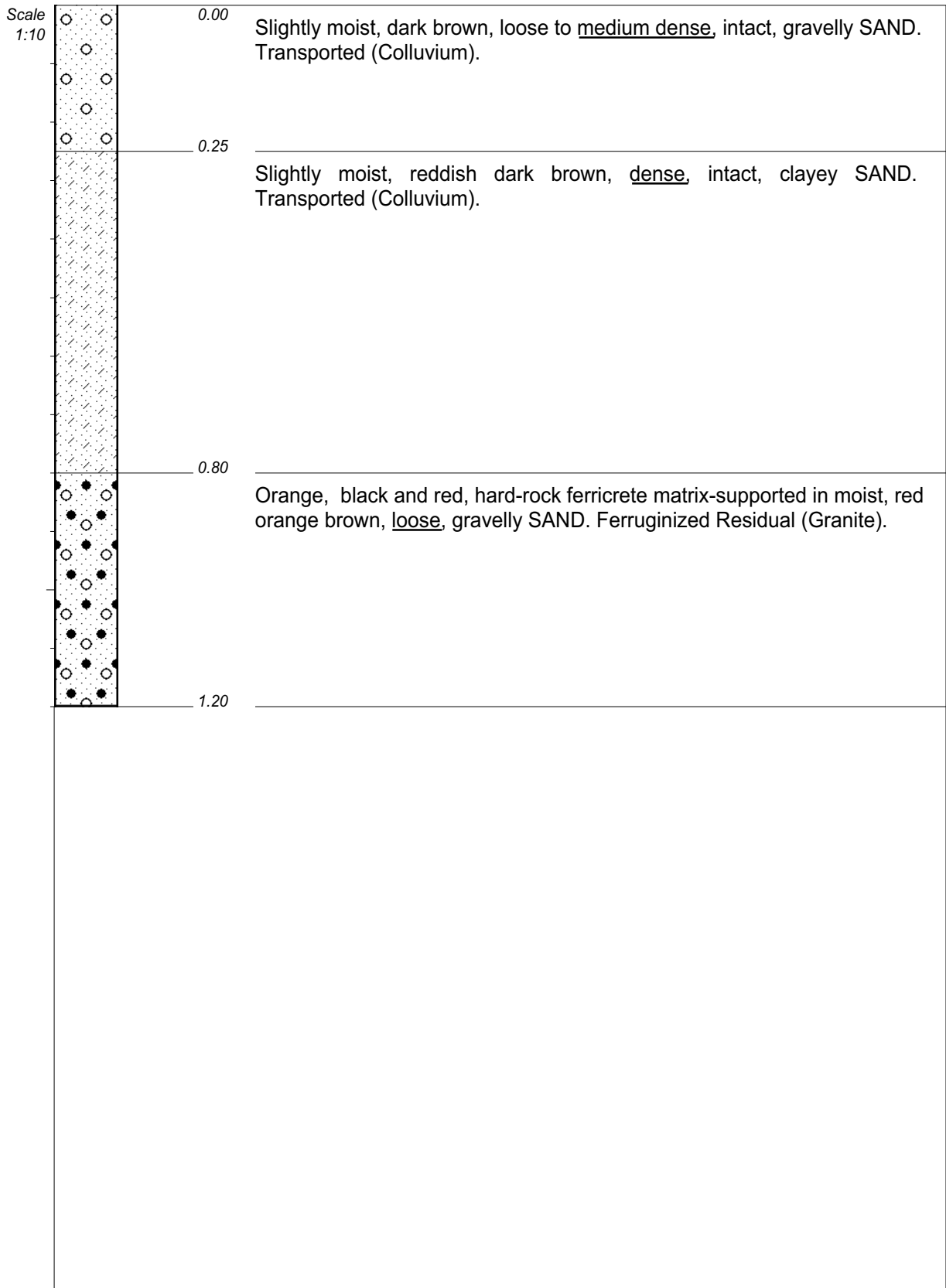


CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

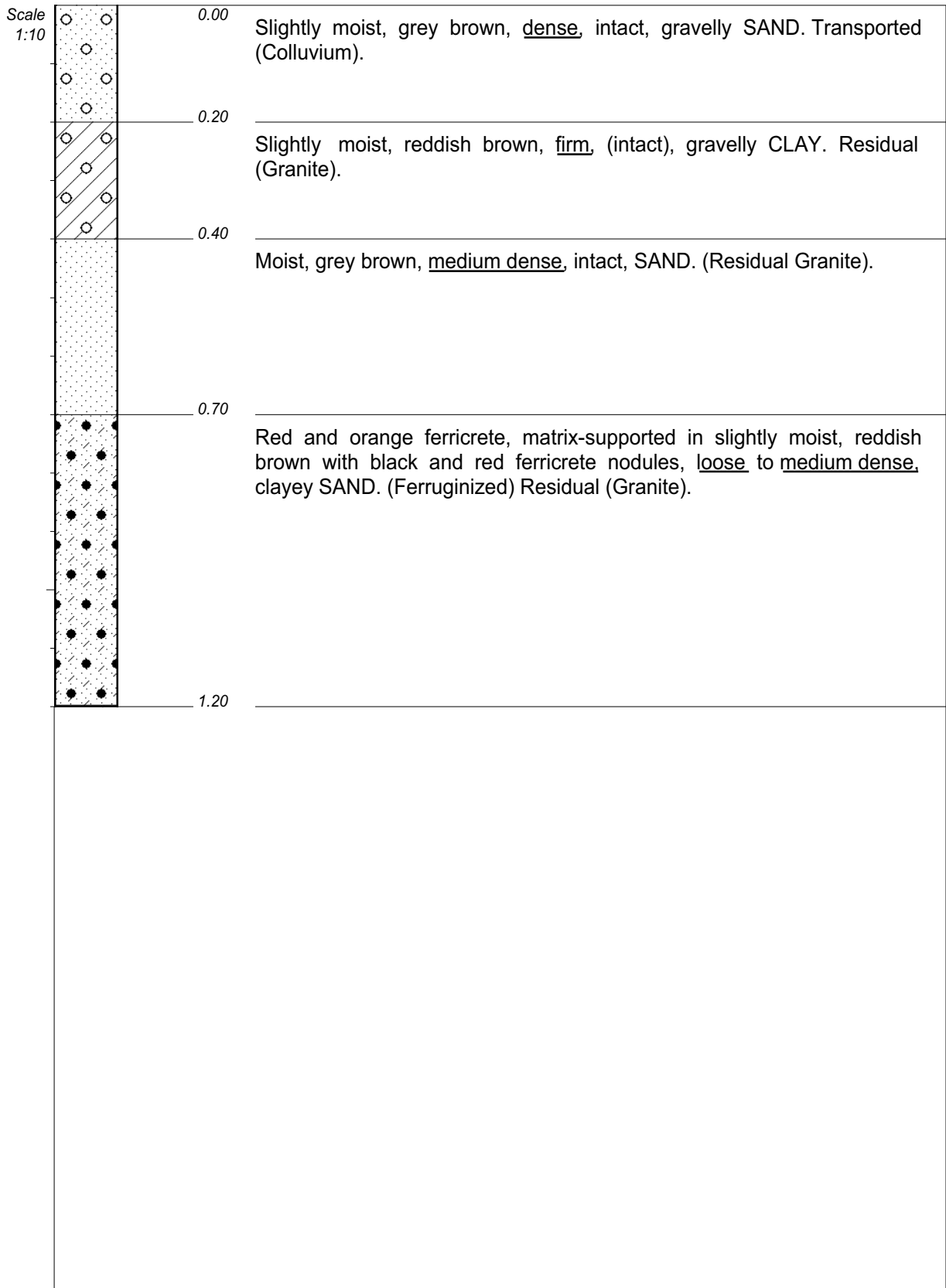
HOLE No: TP3



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

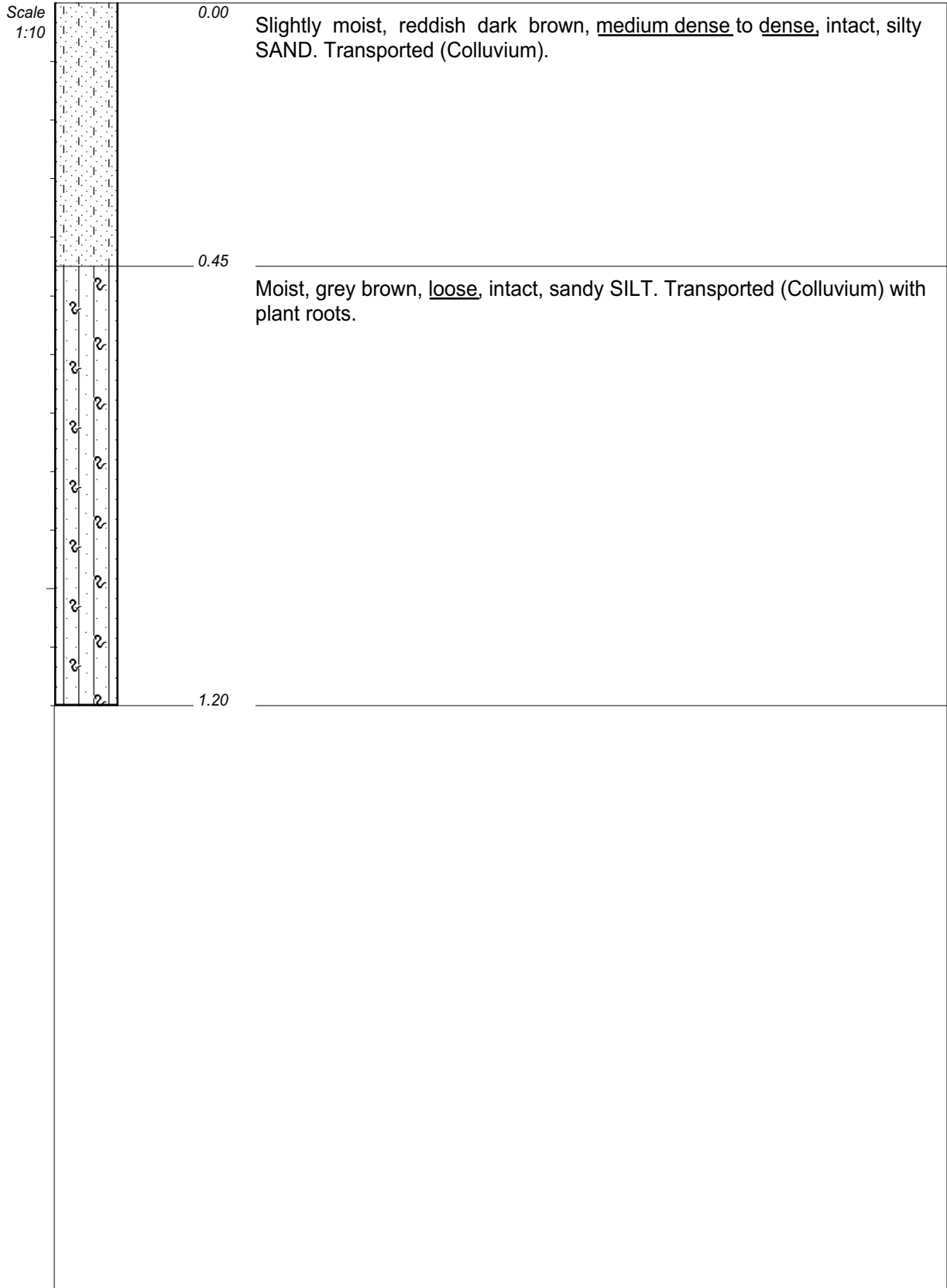
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

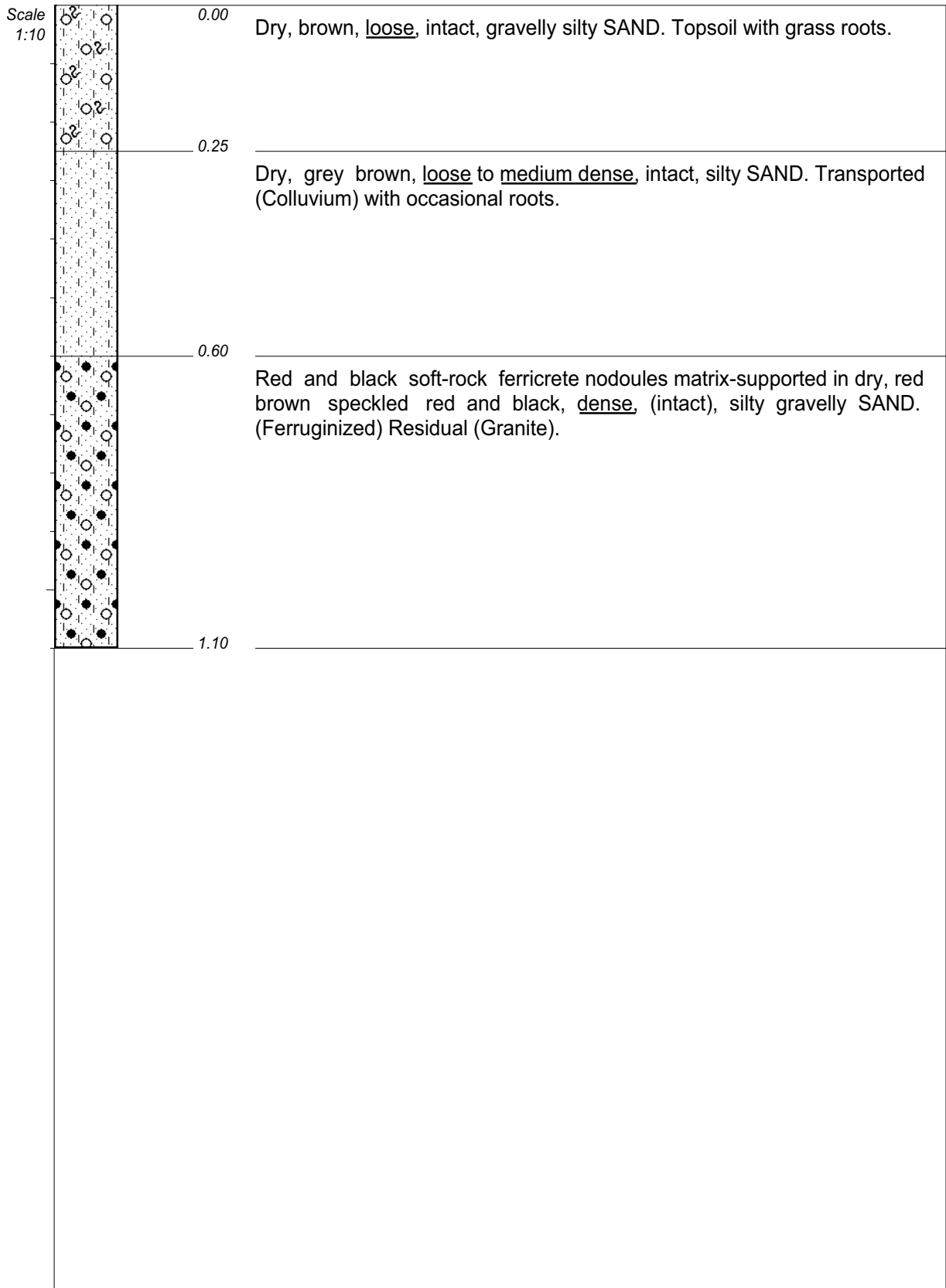
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :



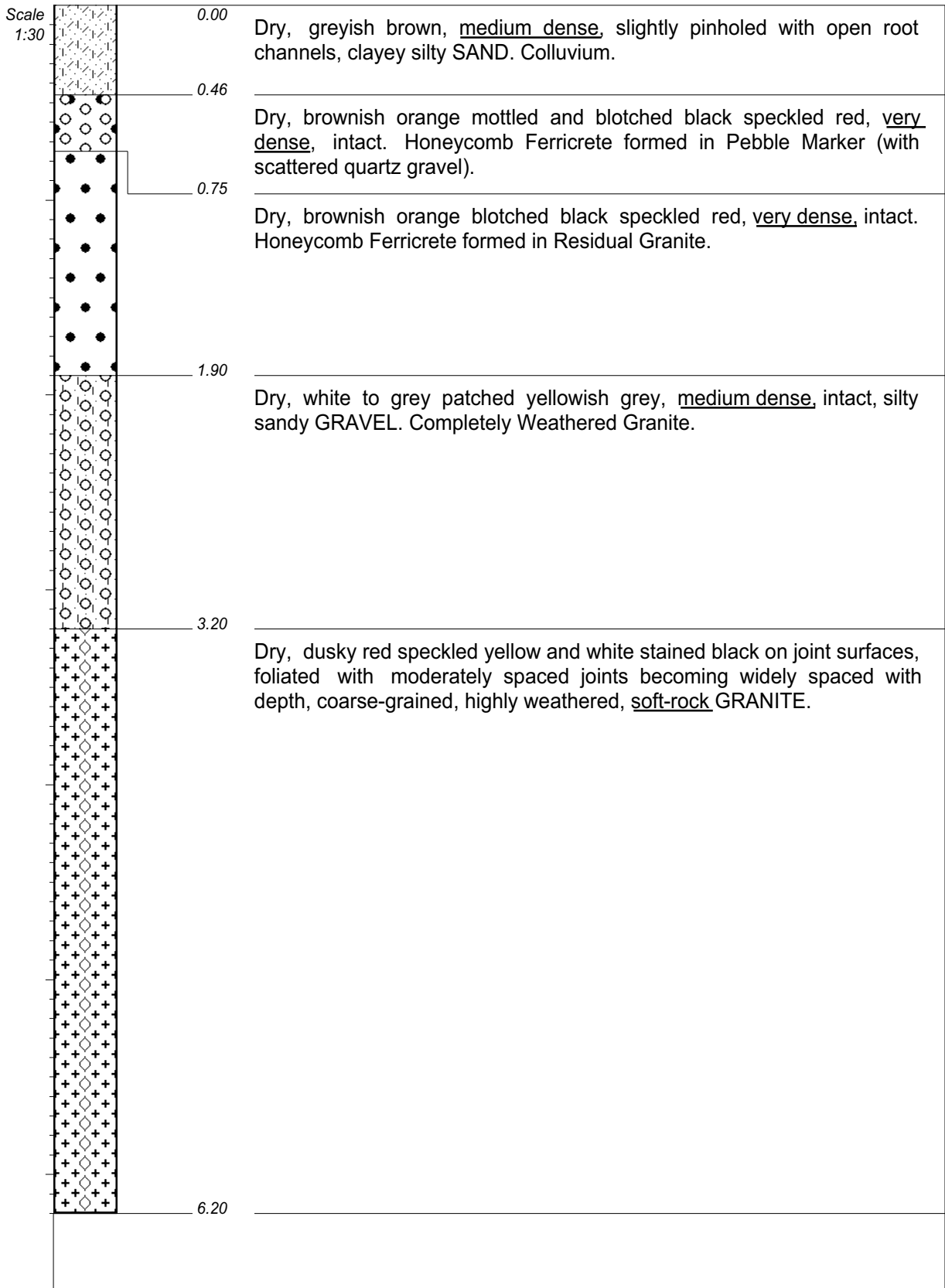
CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

HOLE No: TP7

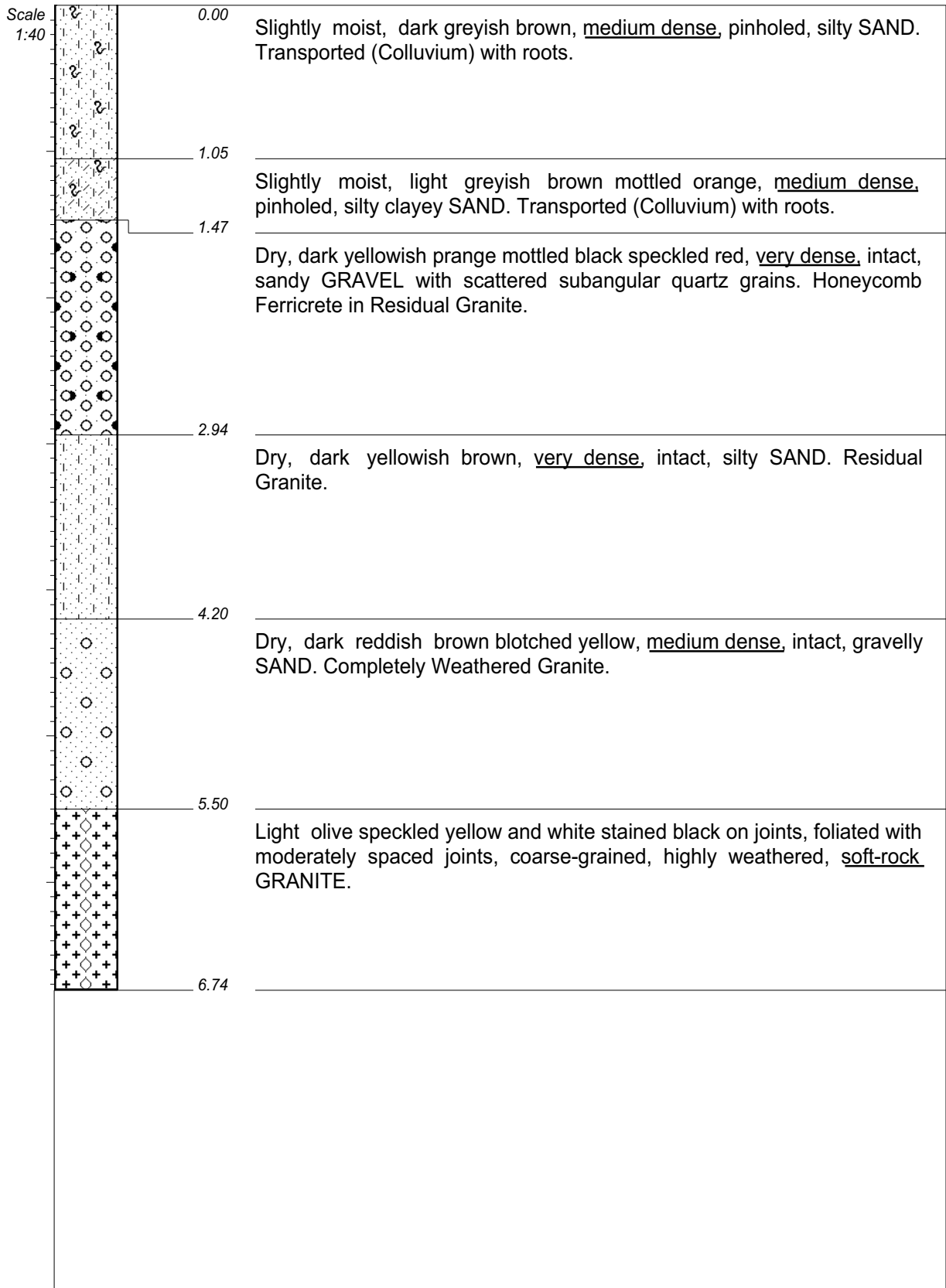
TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

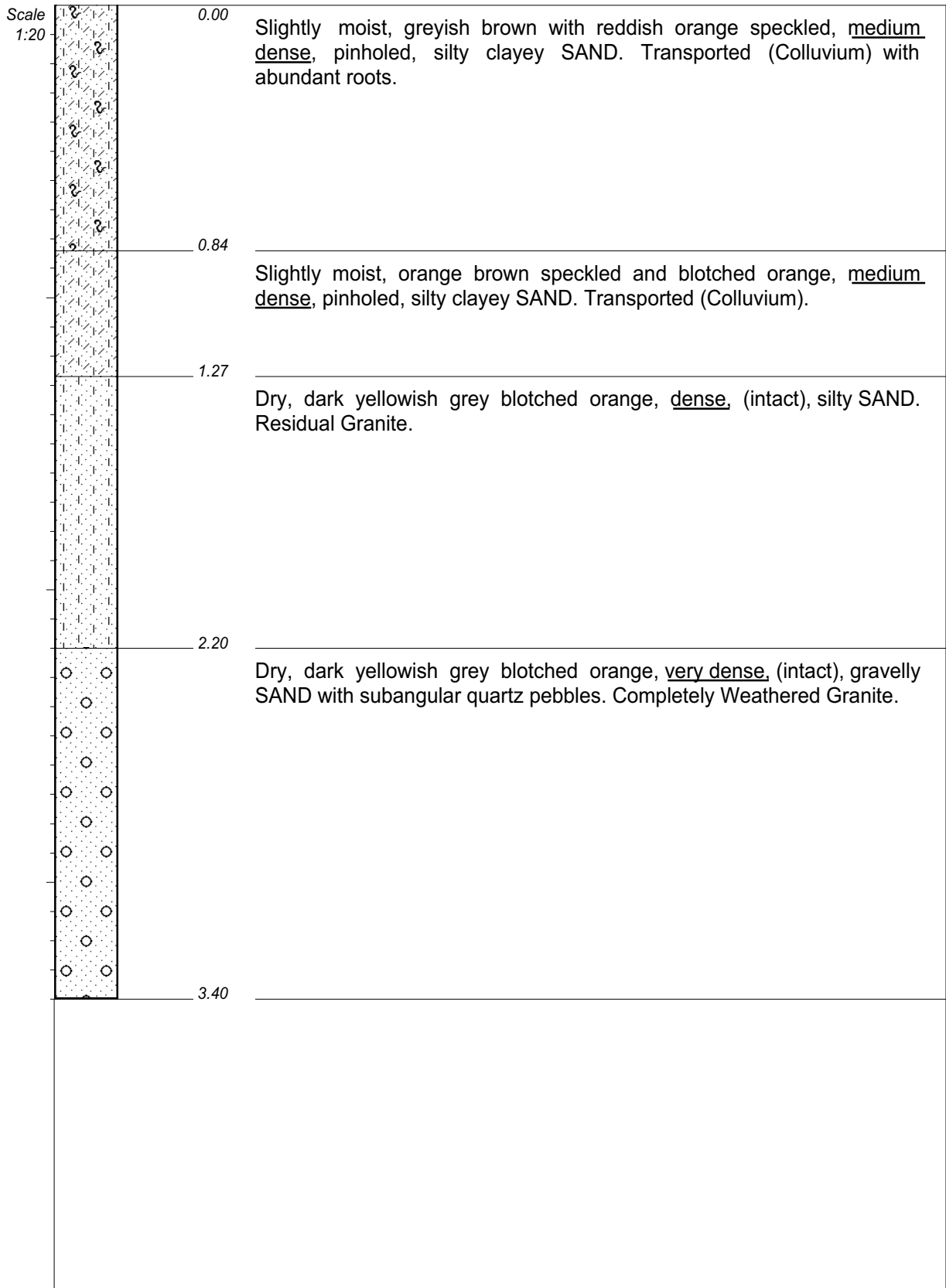
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

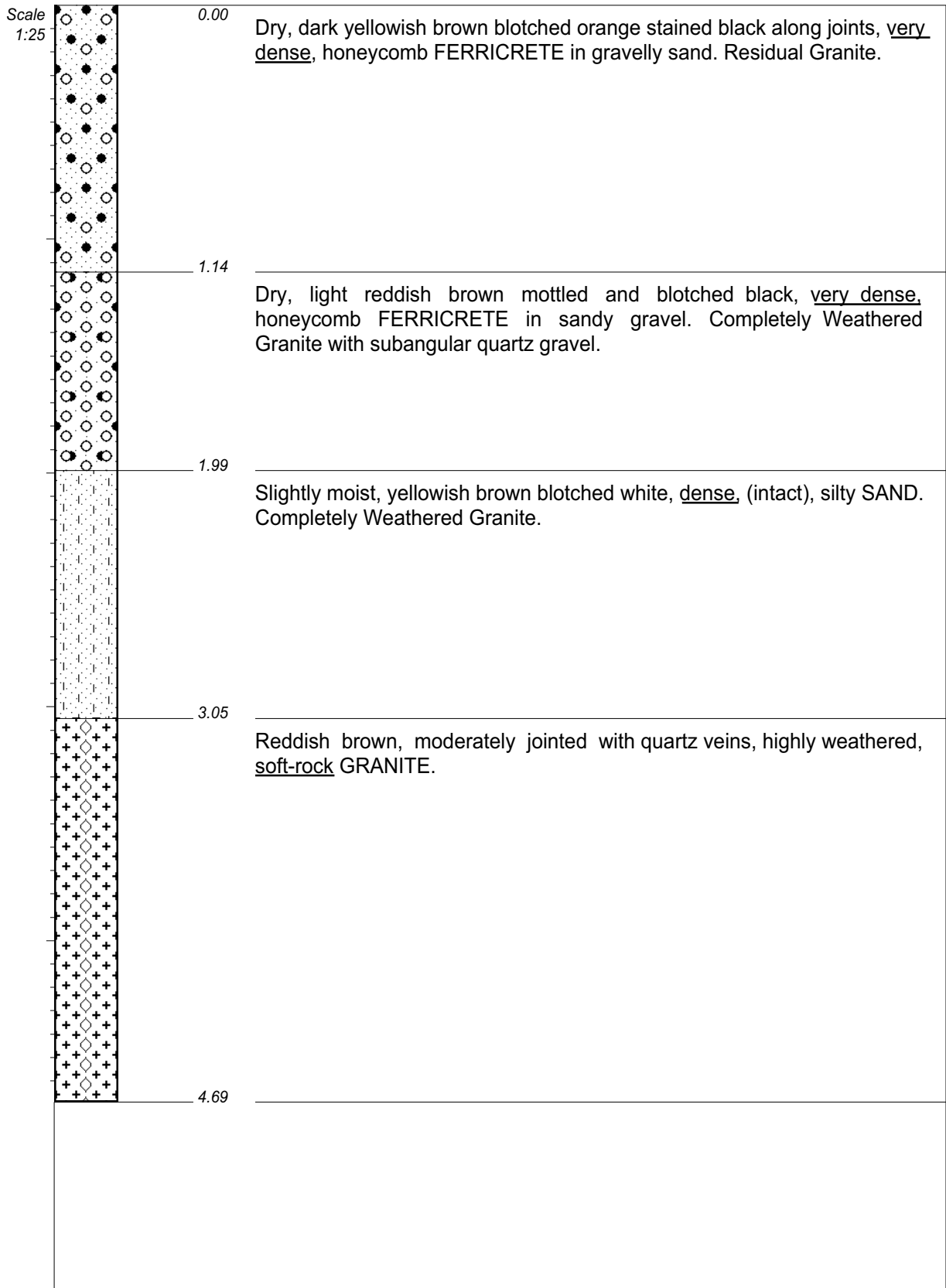


CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :
HOLE No: VP03

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



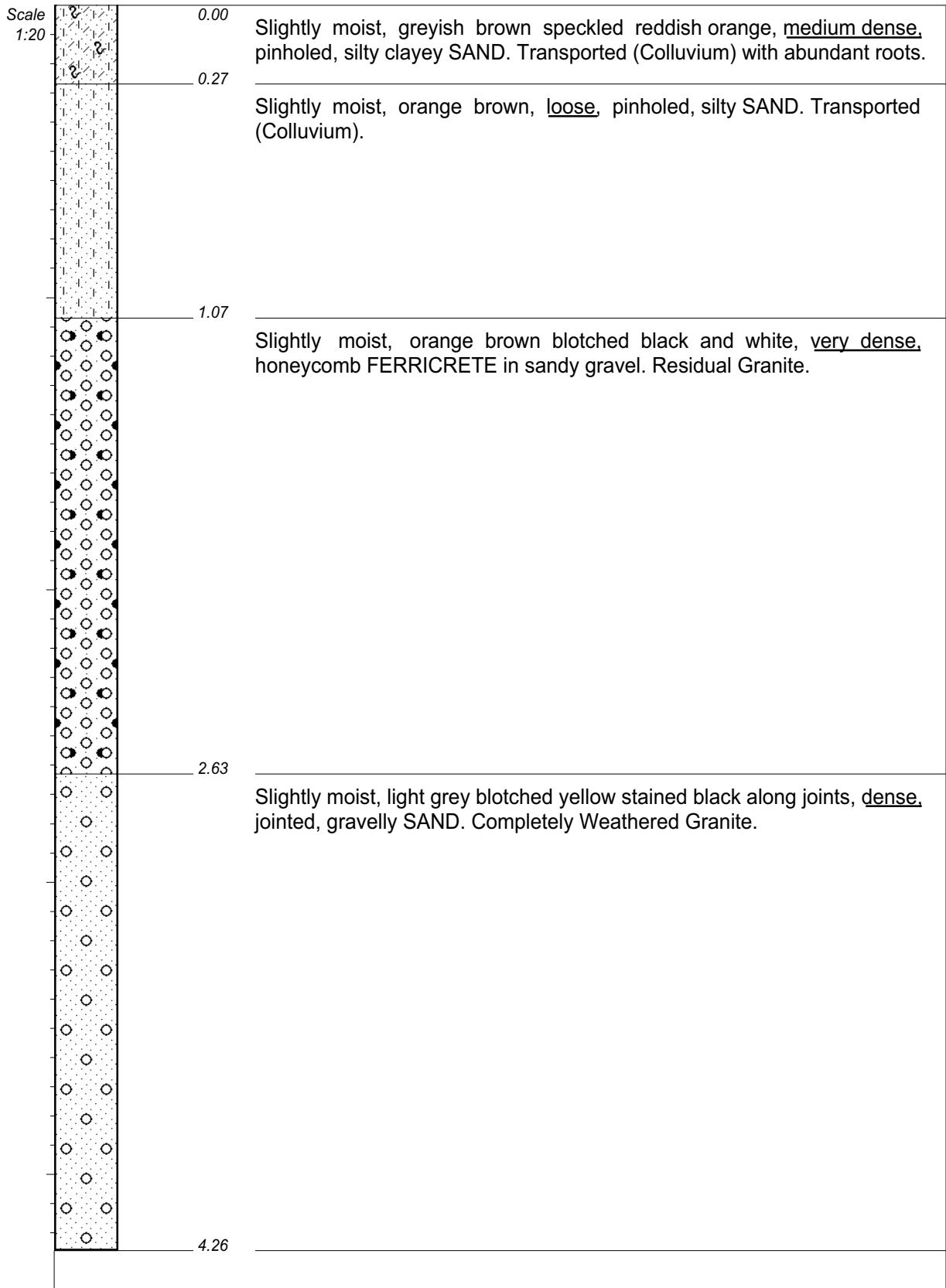
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DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

HOLE No: VP04

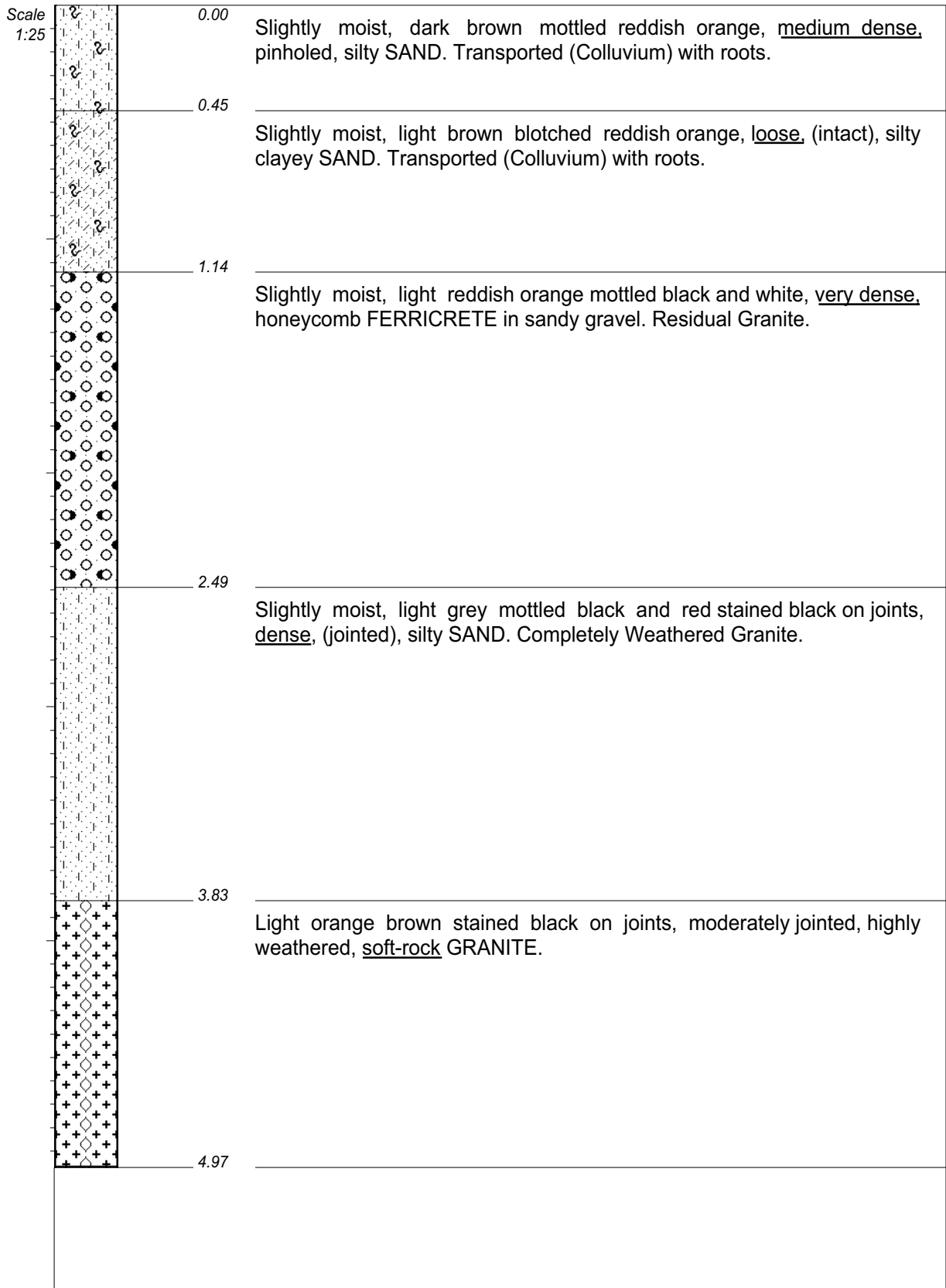
TYPE SET BY : MAD
SETUP FILE : STANDARD.SET



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
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DATE : 25/03/2012 17:08
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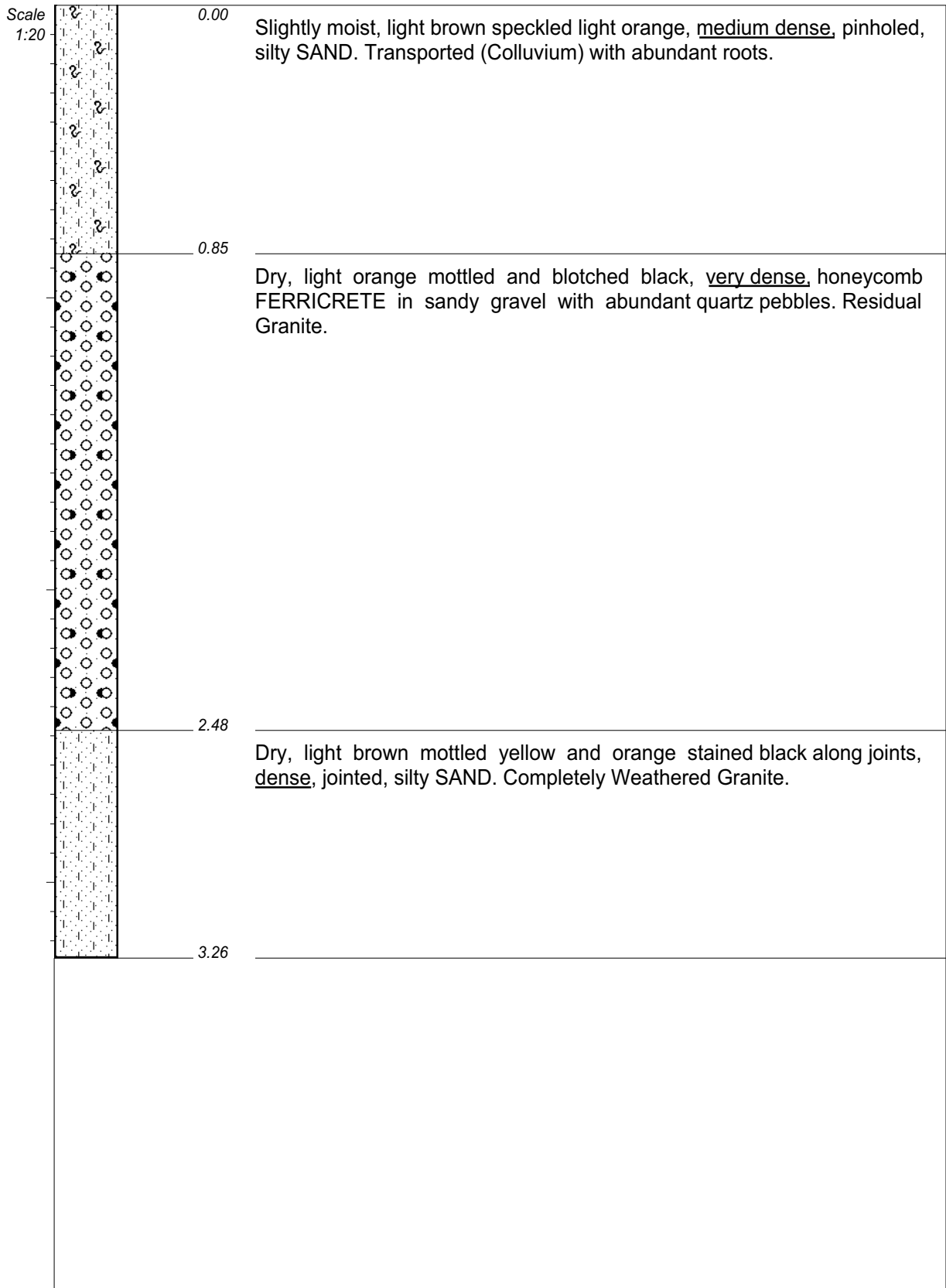
ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD
TYPE SET BY : MAD
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :



CONTRACTOR :
MACHINE : Open excavation
DRILLED BY :
PROFILED BY : MAD

INCLINATION :
DIAM :
DATE :
DATE :
DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :
HOLE No: VP07

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET

	GRAVEL	{SA02}
	GRAVELLY	{SA03}
	SAND	{SA04}
	SANDY	{SA05}
	SILT	{SA06}
	SILTY	{SA07}
	CLAY	{SA08}
	CLAYEY	{SA09}
	QUARTZITE	{SA15}
	GRANITE	{SA17}{SA44}
	FERRICRETE	{SA24}
	ROOTS	{SA40}

CONTRACTOR :
MACHINE :
DRILLED BY :
PROFILED BY :

TYPE SET BY : MAD
SETUP FILE : STANDARD.SET

INCLINATION :
DIAM :
DATE :
DATE :

DATE : 25/03/2012 17:08
TEXT : C:\dot7000\txt\1PAP2012.txt

ELEVATION :
X-COORD :
Y-COORD :

LEGEND
SUMMARY OF SYMBOLS

APPENDIX B: Soil Profile and Chemistry Laboratory Results

Ephemeral Inland Wetland (Data)

	S (dms)	E (dms)	comb coord	Elev (mamsl)
			Garmin GPS	GoogleEarth
VP01	25 56 34.6	28 08 06.8	25 56 34.6 S 28 08 06.8 E	1536
VP02	25 56 32.3	28 08 05.1	25 56 32.3 S 28 08 05.1 E	1535
VP03	25 56 34.4	28 08 00.5	25 56 34.4 S 28 08 00.5 E	1529
VP04	25 56 33.1	28 08 00.6	25 56 33.1 S 28 08 00.6 E	1531
VP05	25 56 32.6	28 07 57.9	25 56 32.6 S 28 07 57.9 E	1530
VP06	25 56 34.0	28 07 57.3	25 56 34.0 S 28 07 57.3 E	1527
VP07	25 56 33.5	28 08 08.5	25 56 33.5 S 28 08 08.5 E	1539

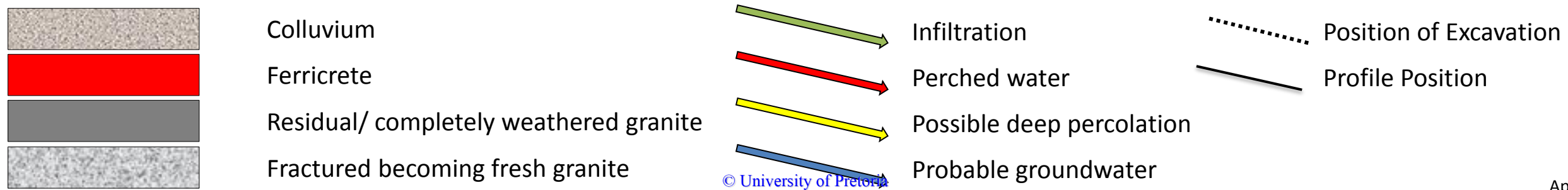
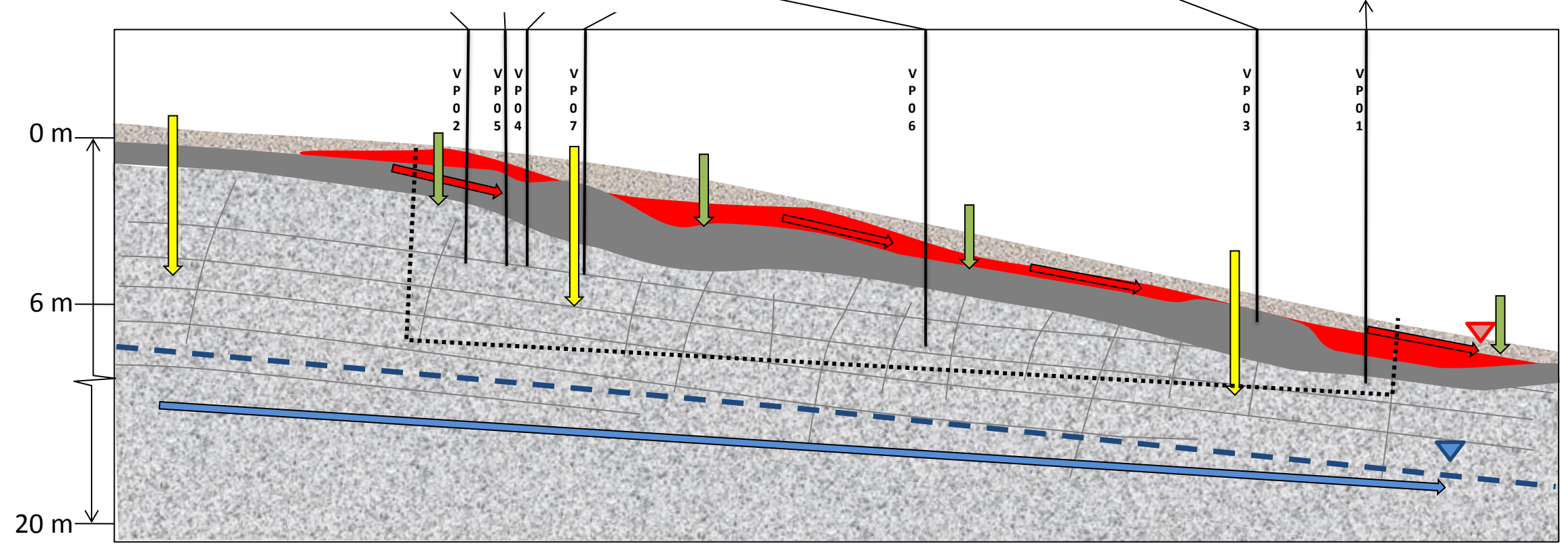
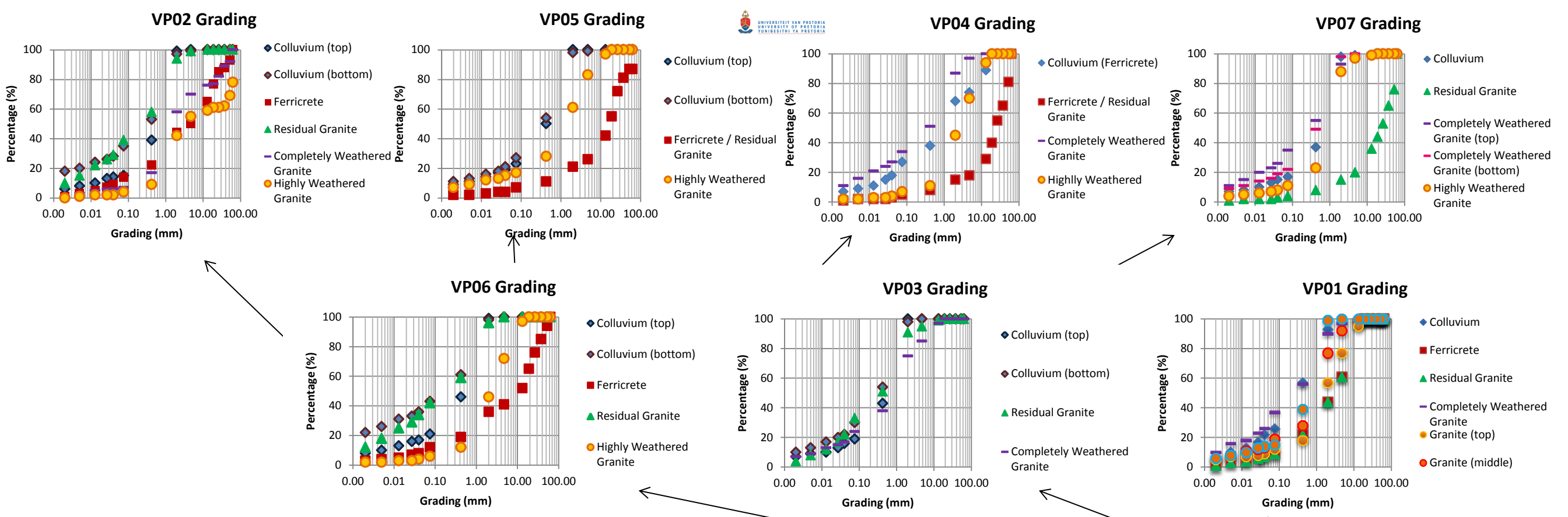
Mineral	SG *	
Alkali Feldspar (K --> Na)	2.55 - 2.63	2.56
Plagioclase (Na)	2.62	2.62
Plagioclase (Ca)	2.76	2.76
Quartz	2.65	2.65
Hematite	< 5.254	5
Gibbsite	~ 2.4	2.4
Goethite	~ 4.3	4.3
Limonite	4 - 5.5	4.75
Kaolinite	2.61 - 2.68	2.64
Illite	2.6 - 2.9	2.7
Smectite	2.0 - 3.0	2.5
Vermiculite	~ 2.3	2.3

* Deer, Howie and Zussman - The Rock-forming Minerals.

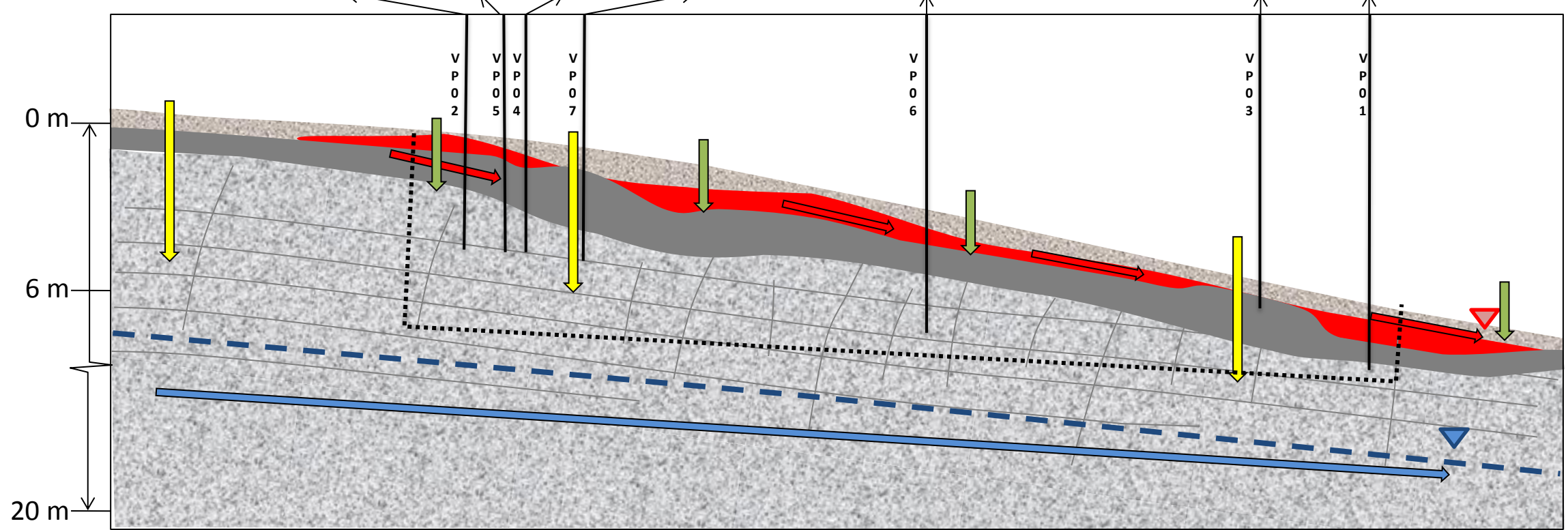
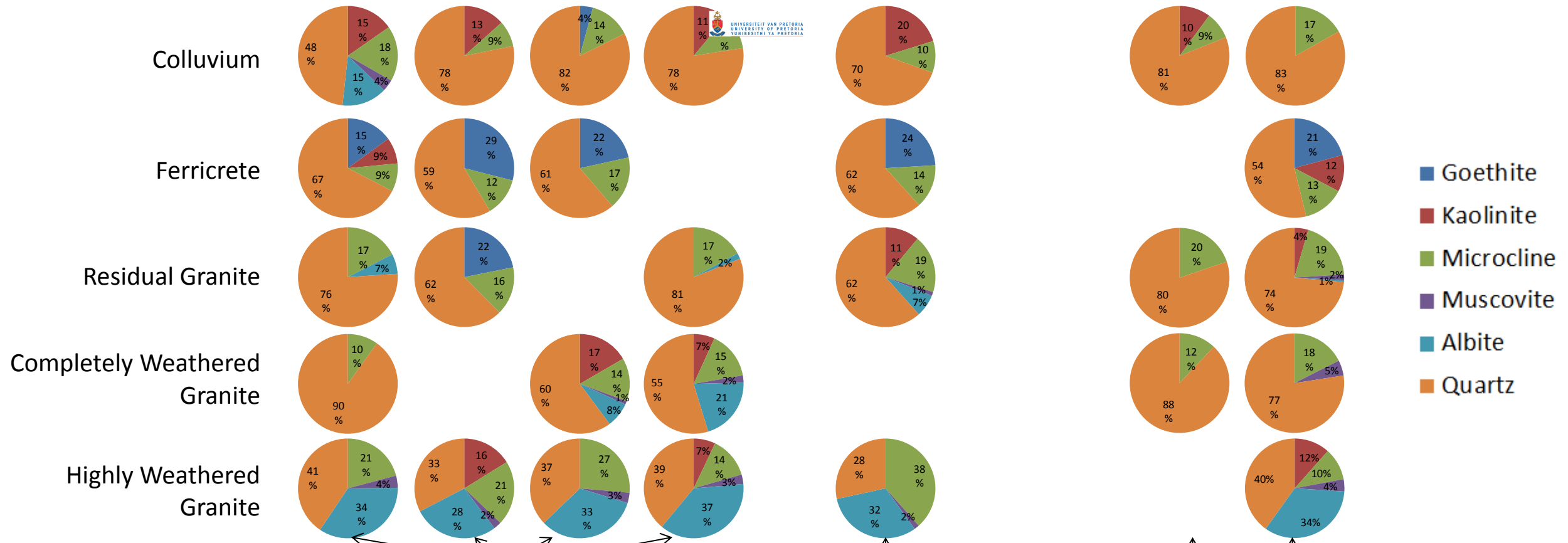
Ephemeral Inland Wetland (Data)

Sample No	Depth to	Material	Clay	Silt	Sand	Gravel	Goethite	Kaolinite	Microcline	Muscovite	Albite	Quartz	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	Cr2O3	NiO	V2O5	ZrO2		
VP01	0.46	Coll		7	17	69	7	0	16.86	0	0	0	83.14	83.79561	0.28987	6.10924	3.5203	0.02944	0.00241	0.00241	0.10557	2.23216	0.03558	0.01969	0.00329	0.00913	0.03103	
VP01	0.75	FerrPM		1	7	35	56	20.8	11.88	13.51	0	0	53.8	64.20238	0.32263	8.55611	18.70146	0.25304	0.0469	0.00237	0.03345	2.54646	0.08258	0.05834	0.00878	0.04096	0.02059	
VP01	1.2	Res		1	7	35	56	0	9.04	19.76	1.51	1.17	68.52	72.19078	0.37134	7.80512	11.91886	0.32607	0.00241	0.00241	0.09189	3.02554	0.05056	0.03267	0.00029	0.02532	0.02964	
VP01	1.9	Res		1	7	35	56	0	0	19.17	2.2	0	78.64	76.27595	0.42835	8.22797	8.36381	0.47203	0.0665	0.00242	0.15226	2.98656	0.10899	0.02493	0.00256	0.02635	0.03343	
VP01	3.2	CW		10	22	58	10	0	0	17.53	5	0	77.46	85.27728	0.40827	6.74839	2.45377	0.0152	0.01018	0.00246	0.19253	3.18048	0.02282	0.01832	0.00317	0.00774	0.03846	
VP01	4.2	Gran		5	6	46	43	0	14.03	9.84	3.83	34.46	38.84	74.47804	0.14325	14.99612	1.38026	0.03221	0.30964	0.0242	3.44219	3.06413	0.01303	0.00136	0.00337	0.002	0.02005	
VP01	5.2	Gran		6	10	60	23	0	0	16.62	4.24	28.24	50.9	75.54673	0.21314	12.7258	3.10274	0.12907	0.183	0.00245	2.52582	3.15235	0.03489	0.01059	0.00447	0.00711	0.02291	
VP01	6.2	Gran		6	8	85	1	0	20.78	5.07	3.96	39.21	30.99	71.69786	0.24055	16.23263	2.25155	0.02157	0.46461	0.56585	3.80504	1.92587	0.02618	0.00498	0.00445	0.00367	0.02461	
VP02	1.05	Coll		6	8	85	1	0	34.59	4.6	17.64	43.16	92.27526	0.19621	3.32995	0.73752	0.01153	0.00247	0.00247	0.00738	1.33454	0.01283	0.00625	0.00402	0.00532	0.02717	0.03096	
VP02	1.47	Coll		18	14	65	3	0	18.4	8.63		72.97	83.96923	0.35096	7.9512	2.47661	0.00887	0.03016	0.00242	0.0058	1.36395	0.02083	0.01373	0.00452	0.00908	0.03096	0.03096	
VP02	2.03	FerrPM		1	11	32	56	30.01	6.51			63.47	64.28351	0.42658	5.67559	22.75447	0.14825	0.00237	0.00237	0.00569	1.31043	0.11929	0.03303	0.00028	0.03211	0.02533	0.02533	
VP02	2.5	Coll-PM		1	11	32	56	0	13.01			86.99	86.81335	0.36876	3.97022	4.97718	0.06006	0.00246	0.00246	0.02669	2.19531	0.03184	0.01475	0.00114	0.01146	0.04009	0.04009	
VP02	2.94	FerrPM		1	11	32	56	17.69	8.98	9.4		63.93	48.11411	0.33003	4.30159	15.02574	0.69582	0.00239	0.00239	0.03204	1.44569	0.03775	0.0337	0.00358	0.04	0.04783	0.04783	
VP02	4.2	Res		10	24	59	6	0	17.46		6.48	76.06	85.95484	0.52373	6.03986	1.08934	0.01273	0.00247	0.00247	0.4425	3.03077	0.00975	0.00764	0.00343	0.00523	0.04523	0.04523	
VP02	5.5	CW		1	6	51	42	0	9.9			90.1	74.20487	0.16152	13.27102	1.61976	0.05987	0.2148	0.00247	1.57551	6.86288	0.02846	0.00502	0.00318	0.00321	0.01583	0.01583	
VP02	6.74	HW		0	3	38	58	0	20.86	3.97	34.58	40.59	74.66621	0.16105	14.22299	1.12763	0.01599	0.26303	0.02129	3.6665	4.1071	0.01611	0.0003	0.00325	0.00168	0.01918	0.01918	
VP03	0.84	Coll		7	11	82	0	0	5.18	9.48		85.34	0.00012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VP03	1.27	Coll		10	17	71	2	0	15.02	8.25		76.73	85.40319	0.34972	6.08954	2.56182	0.00969	0.00243	0.00243	0.00583	1.42652	0.02483	0.02035	0.00888	0.00998	0.03319	0.03319	
VP03	2.2	Res		4	24	62	9	0	19.79			80.21	82.36086	0.42123	6.10738	5.62109	0.02796	0.00245	0.00245	0.15556	3.0901	0.04561	0.04034	0.001	0.01683	0.03534	0.03534	
VP03	3.4	CW		7	14	54	25	0	12.04			87.96	81.36408	0.50817	5.30615	7.06216	0.20309	0.00244	0.00244	0.00244	2.03254	0.01961	0.01451	0.00299	0.01617	0.03745	0.03745	
VP04	1.14	FerrColl		7	16	44	32	4.21	13.45			82.34	85.69427	0.48496	4.62301	4.10121	0.03752	0.00246	0.00246	0.02738	2.05856	0.03506	0.01615	0.00352	0.01267	0.04384	0.04384	
VP04	1.99	FerrRes		1	3	11	85	21.55	17.18			61.26	69.00272	0.39363	6.79179	17.25227	0.03953	0.0024	0.0024	0.04867	2.94865	0.13183	0.03196	0.00029	0.03895	0.03021	0.03021	
VP04	3.05	CW		11	20	56	13	0	16.62	14.02	1.09	8.11	60.16	80.04897	0.5411	9.72881	3.41255	0.02408	0.07945	0.00244	0.54498	3.03468	0.04074	0.01221	0.00367	0.00904	0.03718	0.03718
VP04	4.69	HW		2	4	40	55	0	26.37	3.36	33.1	37.17	75.52941	0.11584	14.71683	0.99706	0.01001	0.16159	0.00247	3.3284	5.31004	0.01828	0.00492	0.00396	0.00096	0.0137	0.0137	
VP05	0.269	Coll		9	13	78	0	0	11.12	9.16		79.72	87.39361	0.29193	5.826	1.48626	0.01258	0.00243	0.00243	0.01284	1.52182	0.02465	0.01149	0.00443	0.00488	0.032	0.032	
VP05	1.07	Coll		11	14	73	2	0	15.69	7.75		76.56	83.62358	0.30936	6.85092	3.88556	0.01305	0.00429	0.00242	0.00581	1.52356	0.03754	0.018	0.00447	0.01136	0.03173	0.03173	
VP05	1.8	FerrRes		2	4	15	79	28.98	12.42			58.61	62.89501	0.34409	7.50657	21.31707	0.22652	0.00237	0.00237	0.00569	2.11832	0.15448	0.04347	0.00028	0.0513	0.02469	0.02469	
VP05	2.63	FerrRes		2	4	15	79	21.84	15.72			62.44	68.97339	0.37093	7.62801	16.19337	0.15972	0.0024	0.0024	0.00576	2.75017	0.07943	0.02233	0.00029	0.02551	0.02852	0.02852	
VP05	4.26	HW		7	9	45	39	0	16.15	20.98	2.55	27.7	32.61	73.37528	0.17947	15.96594	1.23523	0.04662	0.18472	0.00771	2.73188	4.88428	0.03037	0.00658	0.00438	0.0019	0.01534	0.01534
VP06	0.45	Coll		8	11	79	1	0	13.44			86.56	88.81995	0.23254	4.72972	0.68957	0.00819	0.00326	0.00245	0.02468	1.4931	0.01829	0.01356	0.00628	0.00427	0.02831	0.02831	
VP06	1.14	Coll		22	18	59	2	0	22.48	9.43		68.09	80.05003	0.40059	10.81197	2.58443	0.00976	0.07414	0.00239	0.00574	1.5531	0.02785	0.0148	0.00548	0.00895	0.03265	0.03265	
VP06	2.49	FerrRes		3	8	26	64	24.06	14.22			61.72	68.35242	0.36476	6.93187	17.1075	0.18858	0.00238	0.00238	0.00572	2.43531	0.09743	0.03479	0.00029	0.03482	0.02768	0.02768	
VP06	3.83	Res		12	27	57	4	0	11.05	18.79	1.27	7.28	61.62	81.60199	0.52526	8.70032	2.2607	0.01688	0.01933	0.00246	6.63331	3.73456	0.0371	0.00743	0.00268	0.0067	0.03959	0.03959
VP06	4.97	HW		2	3	41	54	0	38.45	1.64	31.51	28.4	69.19801	0.09022	12.81787	0.72302	0.01509	0.00424	0.00424	2.26177	7.88579	0.01819	0.0041	0.02902	0.00297	0.08038	0.08038	
VP07	0.49	Coll		7	10	82	2	0	12.82	12.13		75.05	86.16267	0.25195	5.63542	2.15766	0.03428	0.00243	0.00243	0.06094	1.81	0.02834	0.0173	0.0053	0.00651	0.02653	0.02653	
VP07	0.85	Coll		7	10	82	2	0	9.39	10.71		79.9	86.67486	0.256	5.42039	3.30745	0.03449	0.06744	0.00244	0.45728	1.82291	0.04351	0.0218	0.00564	0.01174	0.02655	0.02655	
VP07	2.48	Res		1	2	12	85	0	17.12		1.87	81.01	78.17703	0.32178	5.60971	10.17576	0.08902	0.00244	0.00244	0.16302	2.89902	0.0781	0.01926	0.00029	0.02391	0.02807	0.02807	
VP07	3.26	CW		11	20	62	7	0	18.56	1.71	5.46	74.27	85.0536	0.49764	7.25559	1.09871	0.02327	0.0188	0.00246	0.39139	3.10245	0.00941	0.00659	0.00323	0.00525	0.03913	0.03913	
VP07	4.5	CW		9	12	78	2	0	7.06	13.45	3.07	37.44	38.99	74.98878	0.12838	14.80447	0.95368	0.05377	0.12188	0.00246	3.6631	3.77595	0.01245	0.0003	0.00275	0.00129	0.01707	0.01707
VP07	5.32	HW		4	6	79	12	0	7.06	13.45	3.07	37.44	38.99	74.98878	0.12838	14.80447	0.95368	0.05377	0.12188	0.00246	3.6631	3.77595	0.01245	0.0003	0.00275	0.00129	0.01707	0.01707
HH01	0.6	Coll		20	12	64	5																					
HH01	2.15	Res		18	16	51	15																					
HH04	0.7	FerrPM		6	8	32	54																					

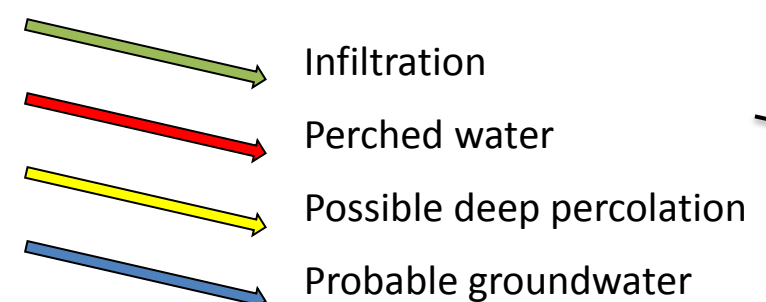
APPENDIX C: Conceptual Model: Soil Grading



APPENDIX D: Conceptual Model: Mineralogy



Colluvium
 Ferricrete
 Residual/ completely weathered granite
 Fractured becoming fresh granite



Position of Excavation (dotted line)
 Profile Position (solid line)