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Geomorphology of a portion of Mariepskop, South Africa

by

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Abstract

Hillslopes usually have high heterogeneity in terms of landscape processes. Interactions occur between geology, geomorphological processes, and vegetation distribution on a hillslope. This study was undertaken to assess the processes and interactions of geology, regolith production, geomorphological processes, channel formation and how these are influenced by the vegetation on a portion of Mariepskop. Mariepskop forms part of the Drakensberg Escarpment, but is a separate hillslope within the Mpumalanga Province. A north-eastern portion of the Mariepskop forms the study site, with a drainage line located within the site. Deciduous bush covers most of the study site, and grassland patches occur on the southern parts of the study site. Quartz-feldspar-biotite gneiss dominates most of the area with the cliff and higher parts consisting of feldspar-rich schist. Three site visits were undertaken where bedrock geology, weathering, soil formation, erosion, mass movement processes and the drainage channel were assessed. Maps of these processes as well as slope profiling and plan forms were compiled. According to the results, Mariepskop shows heterogeneous processes both laterally and vertically, with various degrees of interactions taking place. Underlying geology, mass movements on higher altitudes, and soil creep on lower altitudes occur on both the northern and southern parts. Processes mainly occurring on the northern part are rockfall from drainage channel incision, weathering, rill erosion and fluvial erosion within the drainage channel. Main processes on the southern part are mass movement in term form of slumping/debris flow, and erosion, in particular rainsplash and overland flow. Soil is deeper on northern part than on southern part of the study site. Geomorphological processes interact with the vegetation distribution over the study area. Grassland patches on the southern part of the study site are mainly due to slumping/debris flow, rainsplash erosion, convexity of the plan form (therefore no valleys) and oxidic soils occurrence. Similar geomorphological processes will probably influence grassland patches over the rest of Mariepskop.

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Chapter 1: Introduction

1.1 Geomorphological interactions on a hillslope

The correlation between geology, geomorphological processes, and vegetation distribution on a hillslope has been well studied and documented. Hillslope shape is a result of elevation patterns, geology, slope angle, aspect and geomorphic processes and features (Swanson *et al*., 1988; Marston, 2010). The influence of geomorphological processes and features on a hillslope is as important as the influence of a hillslope on these geomorphological processes and features, making it interacting as well as dependant on each other (Marston, 2010).

Bedrock characteristics, such as rock strength and fracturing, influence the hillslope through erosion (Clarke & Burbank, 2010), weathering (Aristizábal *et al*., 2005) and the fluvial properties of the hillslope (Gabrielli *et al*., 2012). Soil characteristics influenced by hillslope and hillslope position are moisture content (Beven & Kirkby, 1979; Ticehurst *et al*., 2007), temperature, and erosion or deposition (Hancock *et al*., 2010). Soil erosion due to water flow is an important part of a hillslope and depends on the type of soil and water flow, as well as the topography and climate (Cochrane & Flanagan, 2001; Saadat *et al*., 2008). The type of hillslope, being depositional or transportational, depends on the weathering and erosional processes working on the slope (Yoo *et al*., 2009). Slope profile influences the fluvial characteristics (Hilberts *et al*., 2004) and erosional characteristics (Koulouri & Giourga, 2007) of a hillslope. Fluvial geomorphology is a vital aspect to consider, such as sediment and water transport. This is typically through the workings of erosion rill channels on the hillslopes (Petts & Foster, 1985).

Vegetation is dependent on the hillslope position and the soil characteristics (Gessler *et al*., 1995; Hancock *et al*., 2010). According to Marston (2010), biodiversity is dependent on geomorphological disturbances as well as heterogeneity. A geomorphological disturbance provides areas for different vegetation growth, creating diversity (Reice, 1994). Because hillslope geomorphology leads to different soil formation, this leads to a diversity of soil properties (Brubaker *et al*., 1993), which in turn influences vegetation (Phillips *et al*., 2008).

Hillslope geomorphology not only influences vegetation patterns, but is also influenced by vegetation patterns and properties. The study of the influence vegetation has on the geomorphology is relatively new (Marston, 2010) thus not much information exists on the topic. A few noteworthy influences of vegetation on the hillslope geomorphology, as tabled by Marston (2010), will be mentioned. Modification of soil moisture may be due to vegetation, intercepting raindrops, and the loss of moisture to transpiration (Haneberg, 1991;

Harden, 2006). Leaves and vegetation litter dissipates the erosive energy of raindrops (Walsh & Voight, 1977; Parsons *et al*., 1996; Marston & Dolan, 1999; Keim & Skaugset, 2003). Organic matter increases water storage, infiltration, and percolation. This in turn encourages vegetation growth and reduces erosion (Bryan, 2000). Soil piping, erosion and shallow mass movement are inhibited by root binding (Greenway, 1987; Schmidt *et al*., 2001). Biomass affects overland flow (Abrahams *et al*., 1994; 1995, Parsons *et al*., 1996; Wainwright *et al*., 2000; Stavi *et al*., 2009) and tree-fall increases the potential for soil erosion (Gabet *et al*., 2003). The last example Marston (2010) used in this report was that vegetation canopy and surface cover influences sediment yield (Lane *et al*., 1997).

In September 2010, Ferguson & Rautenbach (2012) described the drivers of long term vegetation change at Mariepskop, South Africa. During this discussion, the changes in vegetation on parts of Mariepskop were highlighted. This included the spatial location and change in size over a duration ranging from 1938 to 2008. According to Ferguson and Rautenbach (2012), the grassland areas situated on the northern slope of Mariepskop are reducing in size. The location of these grassland patches as well as the change over time is anticipated to be due to environmental and/or geomorphological actions, and could also be from human induced impacts.

1.2 Research aims and objectives

The question then is: what are the relations between different geomorphological processes on a site and how do these processes influence or are influenced by the vegetation? It is envisaged that Mariepskop will be a suitable site to study different geomorphological processes, as hillslopes usually have a high heterogeneity in landscape properties (Hopp & McDonnell, 2009). For this reason, and due to the study done by Ferguson and Rautenbach (2012), a portion of Mariepskop was used as a study site for this research.

This research is focused on the interrelationships between different geomorphological processes, where after the information could be used to determine whether any of these geomorphological processes influence the occurrence of grassland on the Mariepskop area, and which of these processes influence the grassland vegetation. The aim of this study is thus to describe and assess the geomorphological properties on a portion of the northern slope of Mariepskop. In order to ascertain the interactions of the geomorphology, the following objectives of the research were undertaken:

1. To assess geological processes and regolith production, hillslope processes and formation, and channel classification within the study site.

2. To discuss the interaction between the different geological processes and regolith production, and hillslope processes and formation. This includes an integrated geomorphological map.
3. To discuss the interaction between all the geomorphological processes and vegetation growth on the study site. This will then be added to the integrated geomorphological map.

1.3 Thesis outline

Chapter 2 provides an overview of the general area in which Mariepskop is situated, the geological and geomorphological background, climate and general vegetation. This chapter is concluded with a brief overview of the specific study site on Mariepskop, its boundaries, the drainage channel located within the site and a motivation for the decision to use the specific site. The literature review in chapter 3 is a short description in terms of the research history, formation, processes and application of the geological, geomorphological, and fluvial processes on a hillslope. This chapter is concluded with a description on how geomorphological mapping is used as a tool in hillslope research, and the formation and characteristics of the bedrock geology is given. Weathering formation and processes due to weathering are described; which is then followed by erosional and wash processes. Soil description, as an associated attribute of geology, includes its formation and processes on a hillslope. The second part of the literature review is a description of hillslope form and mass movement processes associated with hillslopes. Mass movement includes a history on the classification of mass movement and a short overview of the types of mass movements. Hillslope form includes slope profile and plan descriptions. The slope profile is described in terms of slope units, angles, and slope models. A drainage channel review contains a description of the types of channel classifications which then link with hillslope formation. This chapter is concluded with a description of Geographic Information Systems (GIS) and geomorphological mapping as a tool to interpret hillslope processes.

Chapter 4 provides the methodology followed for this thesis. This chapter is also compiled according to the different processes outlined in the literature review, such as: geological processes, hillslope processes, channel classification and geomorphological mapping of the study site. Results and observations follow in chapter 5. Bedrock geology is differentiated into rocks from rockfall and the underlying bedrock. Geology is described in terms of rock type and characteristics. Observations of weathering as well as comparison between the weathering on the northern and southern parts of the study site are given. Similarly to weathering, erosional and wash processes are discussed. Soil description results include type of soil classification, texture, chemical composition, depth and colour. Mass movement processes observed on the site are also linked to literature and is then followed by a description of the hillslope form due to above-mentioned processes. A drainage line classification follows, which is then linked to the hillslope form and geological and hillslope processes in a geomorphological map. A discussion and conclusion follow as chapter 6 and 7 to this thesis.

Chapter 2: General study area

2.1 Mariepskop location and general overview of the area

Mariepskop is situated adjacent on the southern part of Kampersrus Agricultural Holdings, forming part of the town Hoedspruit (Maruleng Local Municipality) in the Mpumalanga Province; on the border with the Limpopo Province. Mariepskop is situated on six original farms namely: Bedford 419 KT, Glenlyden 424 KT, Magalieskop 421 KT, Mariepskop 420 KT, Blyderivierpoort 595 KT, and Driehoek 417 KT (South Africa, 2007b). Fig. 1 indicates the general location of Mariepskop and Fig. 2 indicates the 1:50 000 topocadastral map of study site and boundaries.

The Blyde River Canyon Nature Reserve, also known as the Motlatse Canyon Provincial Nature Reserve, surrounds Mariepskop to the north-west, west to south-west. The Blyde River Canyon Nature Reserve is located against the Greater Drakensberg escarpment and incorporates the Blyde River Canyon, which extends 50km along the escarpment (Siyabona Africa Travel, 2012) and falls within the farms Driehoek 417 KT, Blyderivierspoort 595 KT and, to a certain extent, Mariepskop 420 KT. The Blyde River Canyon Nature Reserve is administered by the Mpumalanga Parks Board. Farming took place in this area since the 1870s and sheep grazing during winter took place up to the 1950s (Rowe, 2009), and the nature reserve was established in 1965 (Rowe, 2009). According to the Mpumalanga Tourism and Parks Agency, this reserve is one of the most visited reserves in Mpumalanga (Prosperosa, n.d.).

The south-eastern part of Mariepskop falls within the Mariepskop Forest; situated on the remainder of the farm Mariepskop 420 KT, as well as Magalieskop 421 KT and Glenlyden 424 KT. Historically, this area was a stronghold of the Pedi tribe, named after one of their chiefs, Maripe, who defended this area against the Swazi tribe in 1864 during the battle of Moholoholo (Mogologolo) (Rowe, 2009; Groundspeak, 2000). In 1935, Col Deneys Reitz bought the farm Glenlyden 424 KT. Farming took place during the years 1935 to 1942 (Rowe, 2009), and the area has been extensively planted under forestry. Towards the east is the Madrid Game Farm. Moholoholo Wildlife and Forest Camps owns the north-eastern parts of Mariepskop, which includes a wildlife rehabilitation centre, forest camps, and other tourist attractions.

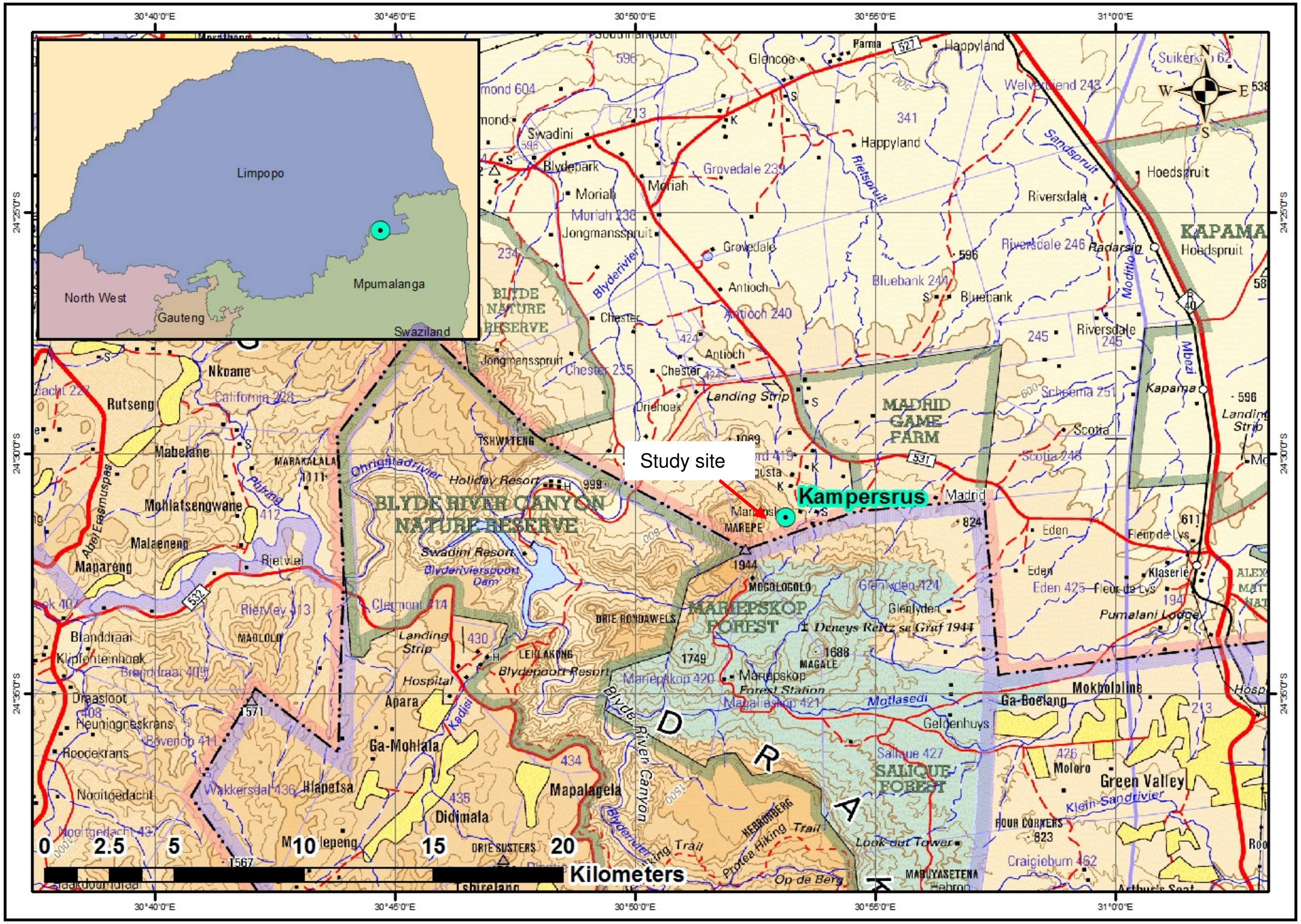

FIGURE 1: Locality of the study site as part of Mariepskop

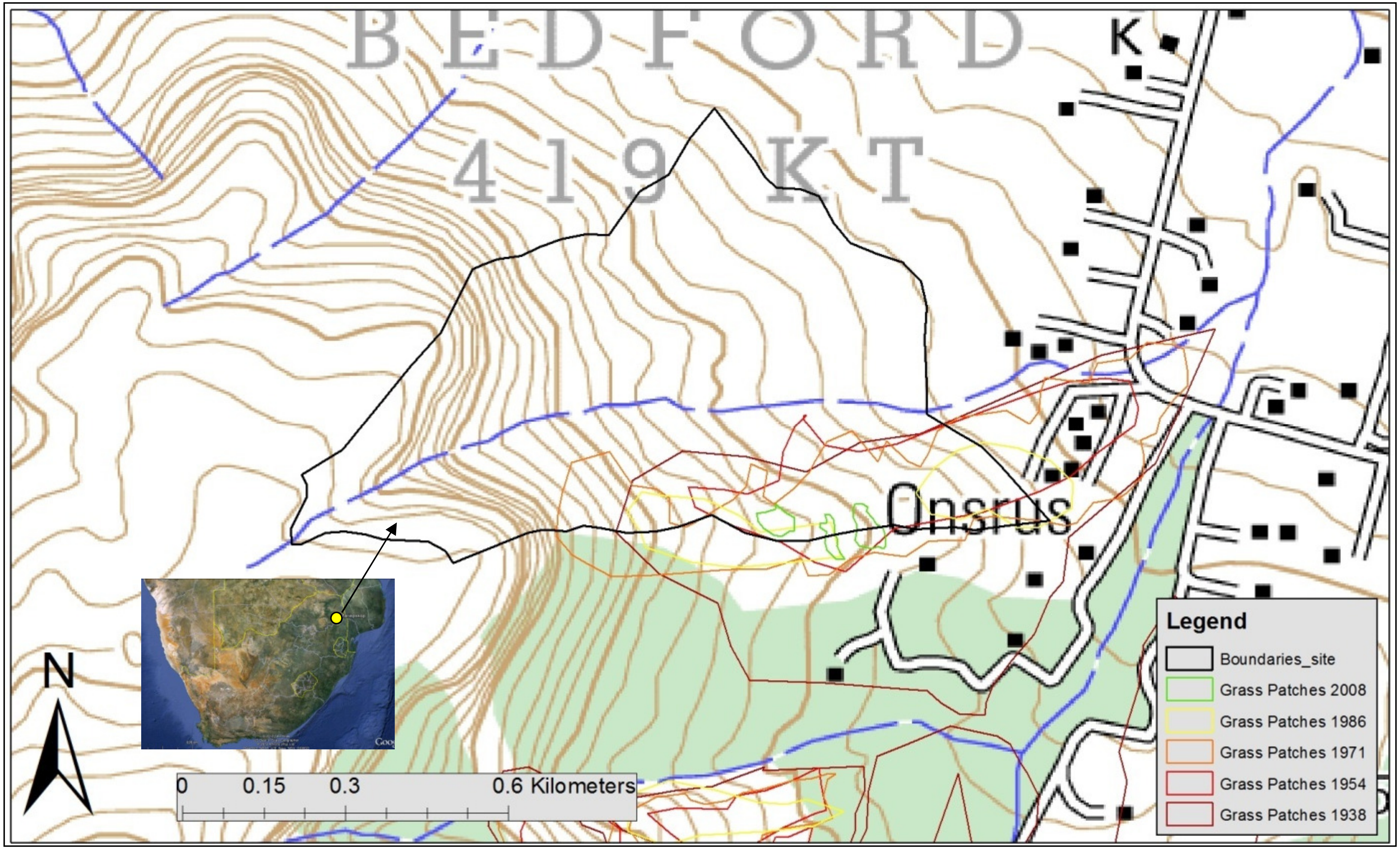

FIGURE 2: Map of study site and boundaries (Adapted from: Ferguson & Rautenbach, 2012), enlarged from 1:50 000 topocadastral map

2.2 Geological and geomorphological background of Mariepskop

Mariepskop forms part of the Drakensberg Escarpment, situated on the Swazian basement complex to the east and the Transvaal Sequence to the west (Walraven, 1989). The site itself falls only within the Swazian basement complex. Rocks encountered on the site all form part of two lithological units of the Swazian basement complex (South Africa, 1986), which are described by Walraven (1989). The eastern part of the study site falls within the lithological unit described as quartz-feldspar-biotite gneiss with mafic xenolith (Zbg), part of the Swazian basement complex, grouped under the Baberton sequence. The lithological unit occurring above the study site are a collection of quartzite (Vwk) and feldspar-rich schist rocks (Vwk) with conglomerate, forming part of the Sekokoro Formation, part of the Wolkberg Group, which in turn forms part of the Transvaal Sequence. Gneiss and schist rocks are thus the most important rocks as part of the study site. Refer to Fig. 3 for the geological mapping of the study site.

Mariepskop is a hill area or ‘koppie’ separate from the rest of the escarpment with a valley to the south-western side of Mariepskop. The topography gradually increases from south to north to a peak of 1946m a.m.s.l. (Google Earth, 2013), from where it gradually decreases further north to approximately 1250m a.m.s.l. From here, to the north-west through to the north-east, a cliff ends at an elevation of approximately 1100m a.m.s.l. to the west and 1200m a.m.s.l. to the east. A gradual decrease in topography gives way to the base level of Mariepskop at about 850m a.m.s.l. into the tributaries of the Blyde River.

2.3 Climate

According to the Department of Water Affairs (2012), the total average rainfall from 1971 to 2012 is 641.6mm, with the highest rainfall between March and May. Summer rainstorms occur occasionally. The summit of Mariepskop has an annual maximum temperature range of less than 25ºC. Higher parts of the study site, has temperatures rising to between 25ºC and 27ºC and the lower part of the study site has an annual maximum temperature of 27ºC to 29ºC. Winters are cold on the top of Mariepskop; being an average of 2.1ºC to 4ºC. However, the temperatures are moderate further north into the study site, ranging between an average of 6.1ºC and 8ºC. The maximum temperature in summer is moderate, ranging between an average of 25ºC and 29ºC. Frost does not occur regularly. Evaporation is estimated to be low in the area, with readily available moisture. The study site is therefore described as a humid area. The western part of the study site, occurring at higher altitudes, is described as sub-humid (South Africa, 2007b).

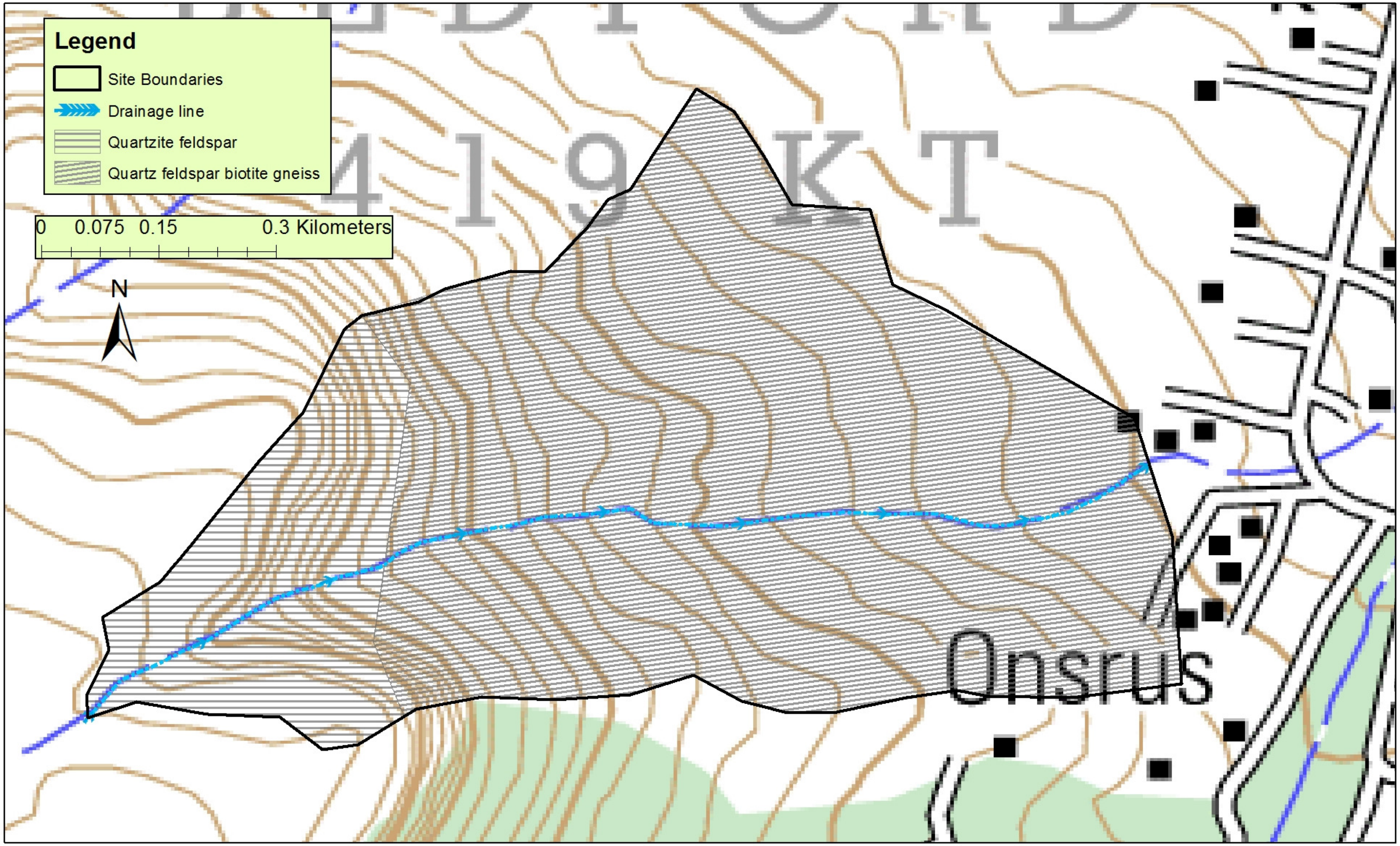

FIGURE 3: Geological map of the study site

2.4 General vegetation of the area and Mariepskop

Mariepskop is known for its diverse vegetation with over 2000 plant species (Anon, 1999). According to South African National Biodiversity Institute (South Africa, 2007a), the vegetation unit on the northern slope is Granite Lowveld with Legogote Sour Bushveld in the higher parts of the north facing aspect. These two units have tall shrubland to dense woodland vegetation characteristics. Mariepskop is divided into four different types of specific vegetation patterns. These are deciduous bush, forest, fynbos and grassland (Ferguson & Rautenbach, 2012).

2.5 Specific study site

Only a portion of Mariepskop will form part of the study site. The reasoning for the study site is twofold. First, the study site was determined to correlate with research done by Ferguson and Rautenbach (2012) on grass patterns, including location of these grass patches and the declining of the grass patches since 1938. These grass patches cover areas on the northern slope of the Mariepskop, as indicated in Fig. 2. Second, this site is divided into a northern and southern part, separated by a prominent drainage line. Thus the study site has an approximate symmetry around this drainage line. It starts within the upper parts of Mariepskop and extents into Kampersrus Agricultural Holdings. Channel length is 1412m, from where it originates to where it extent into Kampersrus. The drainage line, within the study site on Mariepskop, was dry during the site visits. Addendum 1 tabulates all measured characteristics of this drainage channel. The river channel is situated within the B603 quaternary catchment area. According to the whole river classification, modelled by Horton in 1945 (see also Petts & Foster, 1985), the drainage line is a third order stream. Fig. 4 shows the sequence of the orders and the channel within the study site. Therefore, even though there are no significant drainage lines linking into this drainage line, it is not considered a first order drainage line. The part of this site north of the drainage line, consists mostly of dense vegetation (deciduous bush) and the part south of the drainage line consists of some dense vegetation (deciduous bush), as well as large parts of the grass patches (grassland) mentioned above. It is hypothesised that the northern part will be, in terms of geology and/or geomorphology, different from the southern part, and thus creates differences in vegetation. Geological upliftment of the area has created a cliff area in the western part of the study site.

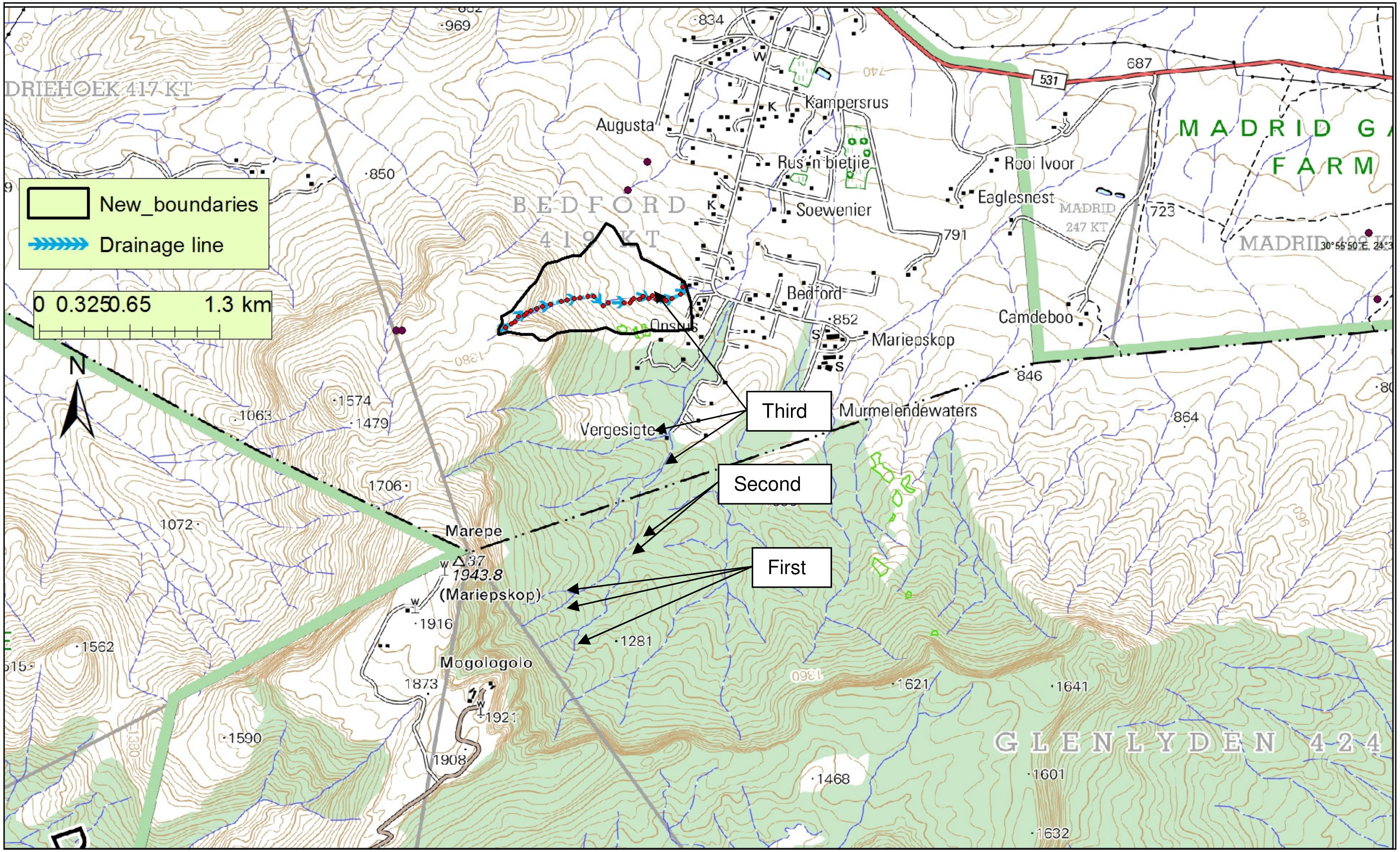

FIGURE 4: Whole river classification of the study site (adapted from Horton, 1945)

During the site visit conducted in November 2010, the northern slopes of the Mariepskop were surveyed to refine the study site boundaries. The northern boundary is also defined by a drainage line. The eastern boundary was formed to exclude the human settlement area, Kampersrus AH, to exclude as far as possible, any anthropogenic changes to the natural processes. The south-eastern part of the study site is situated within the outskirts of a lodge called Amafu Forest Lodge. This lodge and neighbouring residences are situated in the area named ‘Onsrus’ on the topographical map. The western boundary is a connection between the eastern and western boundaries on the top part of the Mariepskop's northern slope. The southern boundary is located on a convex slope, south of the drainage line. The drainage line, separating the site into two parts, joins a tributary ±8km north-east of Kampersrus AH. This tributary in turns joins Rietspruit 19.6km north-north-west of Kampersrus AH. The Rietspruit flows into the Blyde River. See Fig 2 for the study site for the boundaries.

Chapter 3: Literature review

The study site is situated on a portion of a hillslope, divided by a drainage channel and does not include low-lying areas. This area has a steep slope and is a production and transportational area. The literature review gives a brief background on processes associated with the study site, focusing on hillslope and drainage channel. Hillslopes and channels are formed by internal processes such as tectonic activities and bedrock geology, external processes such as climate and environmental or geomorphological processes such as weathering, erosion and wash processes, soil properties, and mass movement processes. These internal, external and geomorphological processes work in a feedback (Finlayson & Statham, 1980; Parsons, 1988; Roering, 2007) and could either be new or historic (Parsons, 1988). Finlayson & Statham (1980) stressed the importance of climate on geomorphological processes, as climate influences the balance between weathering and erosion.

3.1 Geological processes and regolith production

3.1.1 Bedrock geology

The Drakensberg Escarpment, a part of the Swazian Basement Complex[1] and the Transvaal Sequence, has been formed on the plate edges of a passive continental margin (Owens & Slaymaker, 2004). According to Gilchrist & Summerfield (1990), and Raab *et al.* (2006), an escarpment on a passive margin is due to uplift from material unloading as a result of denudation and isostatic flexuring, as the adjacent plateau erodes along its margins (Slaymaker, 1995). The Swazian Basement Complex was formed approximately 2900 Million years ago in the Archaeozoic eon[2] (King, 1951; McCarthy & Rubidge, 2005). It consists of thick layers granites and sediments which were highly metamorphosed and intruded by igneous rocks to form schists and gneisses. Igneous rock intrusions are greyish granite known as the “old”, “ancient” or “Achaean” granite, therefore this complex always crops out in association with granite. Schist and gneiss rocks are metamorphic rocks. Metamorphism is the structural and mineralogical changes in a rock due to two external conditions, temperature and stress, over a period of time. Metamorphism is broadly divided into two types, katamorphic or anamorphic processes. Katamorphic processes are constructive and anamorphic are destructive processes (Leith & Mead, 1915; Spry, 1969). Anamorphism includes thermal or contact metamorphism, dynamic or shock metamorphism and regional or plutonic metamorphism. Thermal metamorphism takes place at moderate to high temperatures at low to moderate pressure (Spry, 1969). According to Longwell *et al.*

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[1] Also known as the Swaziland Basement Complex

[2] A division of the Precambrian super-eon

(1969) this process occurs when a magma body is inserted into cooler strata. The area of metamorphism is usually small-scale. Metamorphic rocks that are formed due to thermal metamorphism are known as hornfels (Spry, 1969). Dynamic metamorphism occurs at a rapid rate at low temperatures with various pressures and on small-scale if compared to regional metamorphism. The group of rocks formed by dynamic metamorphism is great and differ largely depending on the conditions under which it was formed (Spry, 1969). Regional metamorphism is due to large-scale dynamic and thermal tectonic processes. This type of metamorphism differs from thermal or contact metamorphism, because the deformation in this large-scale process produces some type of foliation, lineation or banding. Schists and gneisses are both resistant to contact and dynamic metamorphism and are therefore regional metamorphic rocks (Longwell *et al.*, 1969; Spry, 1969). Schists and gneisses are usually spread over a large area and a significant part of the continental crust, exposed as orogenic belts and Precambrian cratons. These rocks are formed and spread in regional metamorphic tectonostratigraphic terrane (Longwell *et al.*, 1969; Spry, 1969; Hyndman, 1972; Passchier *et al.*, 1990).

Metamorphism must take place within a certain temperature range. This process must take place at a temperature higher than that of original deposition of the rock, which is approximately 150^{0}C. If this is not the case, rock change is due to diagenesis and not due to metamorphism. If the rock is changed at temperatures which melt the rock to a state of magma, the product classed as igneous rock and not metamorphic rock (Miyashiro, 1987). Granitic rocks have a lower melting point than other igneous rocks, thus, metamorphic rocks originating from granites are formed at lower temperatures than other metamorphic rocks. In terms of metamorphic rocks formed from granitic rocks, slates form at the lowest temperatures, phyllites at higher temperatures, schists at higher and gneisses at highest temperatures (Miyashiro, 1987). Regional metamorphism takes place at either higher pressures or slower rise in temperature. Therefore, rocks formed from regional metamorphism have usually larger grains than that of contact metamorphic rocks (Hyndman, 1972). Both schists and gneisses are coarse or medium grained, with gneiss being coarser than schist. Some quartz-feldspathic rocks re-crystallise at lower temperatures than gneisses. These rocks have characteristics of gneisses, but are not classified as gneisses (Miyashiro, 1987). During metamorphism, minerals such as quartz and feldspar migrate to different bands. If these migrations lead to the formation of parallel or nearly parallel arrangement of minerals, it is defined as foliation. Schistosity and gneissocity are two types of foliation (Whitten, 1966), leading to foliated metamorphic schist or gneiss rocks with distinct bands of light and dark coloured layers. Bands in gneisses are thicker, more prominent, coarser-grained, rough in appearance and irregular, compared to bands in schists

(Von Engeln & Caster, 1952; Longwell *et al*., 1969; Hyndman, 1972). Quartzite and feldspar-rich schist rocks, with conglomerate or tuff, were deposited in terrestrial and shallow marine environments. Schist can be mafic, whereby minerals such as chlorite dominate or feldspar-rich schist in which light-coloured minerals such as feldspar dominates. Quartz is abundant and feldspar is an important mineral in all schist rocks (Longwell *et al*., 1969). Xenolith is an igneous rock included in another rock, such as schist (Anhaeusser & Wilson, 1981). Gneiss rocks originate from impure sandstones, conglomerates, shales, slates, schist, or granite rocks. Major minerals in quartz-feldspar-biotite-gneiss are quartz, plagioclase, biotite and orthoclase feldspar[3] (Von Engeln & Caster, 1952; Hyndman, 1972; Passchier *et al.,* 1990). Textural elements of gneisses are coarse-grained quartz-feldspar leucosomes (Walraven, 1989) pegmatite[4] (Von Engeln & Caster, 1952; Longwell *et al*., 1969) and amphibolites[5] (Miyashiro, 1987).

Two factors work on a body, such as a rock or regolith, in terms of hillslope processes (Strahler, 1952; Leopold *et al.,* 1964; Farmer, 1968). Stress applied by force on a body is the first of these two factors. There are different types of stresses such as gravity[6], molecular stress within a body[7], biological stress[8], and the inter-particle stress of a body[9] (Young, 1972). Strain resulting from the stress of such a body is the second factor working on a body. Strains include a fracture along a plane[10] , laminar flow[11], and turbulent flow[12] (Young,

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[3] Orthoclase feldspar is the term for potassium-feldspar, which is present in many igneous rocks such as granite. Different from many other types of feldspar, orthoclase feldspar is not glassy and the minerals are not ordered (Barth, 1969).

[4] Pegmatite is extremely coarse-grained granite with a combination of large orthoclase feldspar crystals, similarly large mica crystals and large intergrowths of quartz. The granite grains can be larger than 10mm in size (Von Engeln & Caster, 1952; Longwell *et al*., 1969).

[5] Amphibolites are coarse-grained mafic metamorphic rocks; consisting of hornblende, orthoclase feldspar, plagioclase and quartz; originating mainly from igneous rock such as granite (Miyashiro, 1987). It differs from gneiss in colour by being darker due to the amphiboles in its structure (Longwell *et al*., 1969).

[6] This acts vertically on a body.

[7] It can be either in the form of swelling and shrinkage, wetting and drying, or as expansion due to temperature changes.

[8] It is the effect of plant roots or the movement of animals on a body.

[9] This stress differs from the molecular stress as these are forces greater than that of molecular stress (Young, 1972).

[10] Material on either side of the plane stays undeformed. Such fractures include shear fracture and tensional fracture.

[11] The strain exists throughout the body material

1972). Stresses and strains lead to two processes: weathering and surface transport[13], which are responsible for slope formation (Young, 1972).

3.1.2 Weathering of bedrock geology

Weathering is the transformation of rock minerals and weathering takes place on different depths within the lithosphere, which ranges from the surface to considerable depths in well-jointed rocks where minerals are in contact with the atmosphere, hydrosphere and biosphere. The type, degree and rate of weathering depend on the rock properties, rock temperature and rock moisture (Hall, 1999; Hall & André, 2001; Hall *et al.*, 2012). Various authors have stated that climate influences weathering through temperature and moisture. Peltier (1950) compiled a weathering graph, indicating the type of weathering occurring at different climatic regions. According to this graph, chemical weathering is strongest at high annual rainfall and high temperatures. Mechanical weathering is strongest at lower annual rainfall and lower temperatures. There is, however, a difference between air temperature and rock temperature, whereby the latter influences weathering. This temperature may change in certain depths within the material being weathered, thereby changing the type, rate and degree of weathering occurring (Hall & André, 2001). Moisture availability is important for chemical weathering to take place; however, chemical processes cannot take place without the necessary minerals present within the material being weathered (Hall *et al.*, 2012).

Parent material has a certain mineralogy and physical nature such as rock strength and rock structure, which will influence the weathering type, degree and rate (Egli *et al.*, 2008). Terzaghi (1962) concluded that the strength of unweathered rock depends on its structure's strength. Structure strength is weakened by the structural planes, also known as discontinuities within the rock. Structural planes weaken the rock depending on its nature, frequency of occurring, continuity as well as the orientation[14] (Parson, 1988). Henscher (1987) has listed different types of structural discontinuities in rock masses for igneous, sedimentary and metamorphic rocks. Discontinuities occurring within metamorphic rocks are from fractures due to tectonic joints and faults, sheeting joints, boundaries between different rock types, slaty cleavage discontinuities[15], and schistosity. Schist is rated as a strong rock, whereas gneiss is rated as a very strong rock; which can only be chipped by a geological

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[12] Deformation is irregularly distributed throughout the body (Young, 1972).

[13] This is in the form of erosion and wash processes (Young, 1972), as well as mass movement processes.

[14] Depending on the orientation of the plane, it can weaken or strengthen the rock (Parson, 1988).

[15] Slaty cleavage is a characteristic of schist and gneiss.

hammer, therefore, schist will be more prone to weathering than gneiss (Marinos & Hoek, 2000). Weathering within heterogeneous parent material will also be heterogeneous, due to the fact that different minerals within a heterogeneous rock will expand and contract at different rates (Branner, 1896; Hall, 1999; Price & Velbel, 2003).

Biological activity such as vegetation also influences chemical as well as physical weathering. Roots from vegetation and movement of animals may increase the rate of physical weathering. Lichens increase the rate of hydrolysis and ligands developed from biotic activities promote dissolution reactions, which are all chemical weathering (Parsons, 1988; Hall *et al*., 2002; Egli *et al*., 2008; Hall *et al*., 2012). To conclude, weathering is not solely dependent on climate, and may vary in the same climate, consequently; the Peltier weathering graph may not be accurate.

3.1.3 Soil formation and soil characteristics

Hillslope processes take place upon either bare bedrock or soil. As early as 1877, Gilbert divided slopes into being weathering-limited (resistance-limited or detachment-limited) or transport-limited (capacity-limited). He stated that the balance between slope forms and slope processes depends on how processes can form hillslopes in relation to how they can transport sediment. Weathering-limited slopes occur when weathered rock is removed through erosion before soil can form. A weathering-limited slope has a bare rock surface and includes cliffs. Transport-limited slopes occur if the rate of weathering is greater than the rate of material removal. A transport-limited slope will have a surface covered by weathered material such as regolith and soil. If the rate of weathering equals the rate of erosion, such a slope is in equilibrium. A slope in equilibrium will keep its form, but can be lowered as weathering and erosion takes place (Finlayson & Statham, 1980; Gerrard, 1992). A slope could change rapidly between being weathering-limited and being transport-limited (Gerrard, 1992).

Soil is the ‘unconsolidated material above unweathered parent material which has been significantly modified relative to the parent material’ (Phillips *et al.,* 2008). The soil mantle character as well as the associated mass movement phases is changed throughout by weathering. Weathering causes change in the hillslopes gradient, which then leads to the soil mantle being unstable. This mantle only becomes stable again due to weathering (Parsons, 1988). The soil mantle could also act as a buffer against weathering if it covers the geology, thereby preventing physical weathering. Moisture within the soil is an important factor for weathering (Ellis & Mellor, 1995). Additional to weathering, there are a number of independent variables that affects the formation of soil, its physical and chemical characteristics. These variables include climate or weather, parent material, surface relief or slope, drainage and the presence of vegetation (Fitzpatrick, 1980; Wild, 1993; Ellis & Mellor, 1995; Buol *et al*., 2011). A combination of these variables also influences soil formation (Gökbulak & Özcan, 2008), in particular on a heterogeneous hillslope. The extent to how much each variable influences soil formation depends on the age of the soil (Phillips *et al*., 2008). Various authors have stated that a rise of 10°C in soil temperature leads to an increase in the rate of chemical reactions with a factor of 2 (Fitzpatrick, 1980; Buol *et al*., 2011). Temperature further affects type and amount of vegetation, rate of organic material breakdown in the presence of water and change in soil colour. Temperature in soil is due to solar radiation. The soil temperature is influenced by hourly, diurnal or seasonal variations, latitude and aspects, altitude, whereby the air temperature decreases with 1°C for every 170m rise, cloudiness, humidity, winds, colour of the soil and water in soil (Ellis & Mellor, 1995; Buol *et al*., 2011). Water input into soil is from rainfall. The rainfall on the soil is affected by factors such as topography and vegetation (Buol *et al*., 2011). Climate change may lead to change in temperature and water input from rainfall; therefore it can change soil processes, weathering and mineral formation (Dahlgren *et al*., 1997; Richter *et al*., 2007).

Parent material also influences soil formation, physically as well as chemically (Gökbulak & Özcan, 2008). This is more pronounced in younger soils (Wild, 1993). Physical properties of the geology affect the rate of weathering and therefore the depth of the soil formation (Ellis & Mellor, 1995). According to Miyashiro (1987), granite-gneiss weathers slowly and the soil is poorly developed. Chemical composition of the parent material influences physical properties such as soil texture (Jacobs, 1998). Soil texture is defined as the "relatively proportions of various soil separates in a soil material" (Soil science of America, 1996), whereby these separates are clay, silt and sand (Wild, 1993). The percentage of the clay, silt and sand is measured on the basis of the mass of each and is divided into 12 textural classes (Ellis & Mellor, 1995; Buol *et al*., 2011). In terms of soil texture, the wider the range of particle sizes in a certain soil, the more poorly sorted soil (Ellis & Mellor, 1995; Buol *et al*., 2011). The contrast in soil texture leads to different soil properties such as drainage potential of soil, water holding capacity and erosional properties (Brown *et al*., 2004). Chemical properties of the soils are due to the chemical properties of the parent material. In general, soils have the following dominant chemicals present, shown from highest concentrations to lowest concentrations: O>Si>A1>Fe=Ca=C>K>Na>Mg>TI>N>S; with potassium being approximately 1.5% of the soil concentration and all other elements in concentrations or less than 0.1% (Wild, 1993). Weathered granite-gneiss produces an acid soil with low contents of base cation. Biotite produces a soil with chemicals such as K, Mg, Zn, and Mn (Gilkes, 1973; Harris *et al*., 1985;

Kretzschmar, 1997). Controlling factors influencing soil pH are the amount and type of base cations. These cations are also controlled by external factors such as rainfall, which depletes the cations, and organic matter. Soils with pH values lower than 3.5 indicate the presence of sulphates and/or pyrites, and are usually found in drained marshes and swamps. In the case of pH values being higher, but still indicating acidity, it may be due to elements such as aluminium or hydrogen ions. Higher pH values indicate the soils are fully based saturated and elements such as sodium and $CaCO_3$ are present (Fitzpatrick, 1980; Buol *et al.*, 2011). Schist weathers to produce an acid soil with aluminosilicates. Further, soil from feldspars usually has sodium, potassium and aluminium chemistry (Fitzpatrick, 1980; Wild, 1993; Buol *et al.*, 2011).

In addition to influencing organic carbon in soil, vegetation influences denudational processes within the soil. It can increase denudational processes in soil due to the weight of the roots or can counteract the effect of denudational processes due to the strength of the roots binding the soil. DeGraff (1979) discussed how the changes in vegetation can affect shallow landsliding. Vegetation hydrology due to the interception, infiltration or transpiration-evaporation of water also influences the denudational processes (Greenway, 1987; Parsons, 1988). Vegetation cover can also protect the soil from rainsplash erosion (Polyakov & Lal, 2004). Transpiration affects the sediment yield (Haigh, 1980). Moss or the formation of moss lobes changes the infiltration of the soil which may affect the micro relief, which in turns affects denudation (Marsh & Koerner, 1972; Parsons, 1988).

Surface relief or slope and drainage also influence soil formation including the physical and chemical characteristics. Hillslope position influences soil properties (Malo *et al.*, 1974; Chen, 2002). This was first suggested by Milne (1934, cited in Brown *et al.*, 2004:52). He described the soil succession down a slope as a catena, whereby these soils are dependent on the slope as well as other properties such as landscape patterns, geological interactions, drainage, solute transport and the erosional and depositional properties of the slope (Brown *et al.*, 2004; Brunner *et al.*, 2004). Soil moves downslope, therefore the soil layer on a higher slope is usually thinner, with a thicker layer in downslope areas where soil has been deposited. Other authors suggested that the degree of the slope influence depends on the slope angle, vegetation cover, soil properties and rainfall events (Fitzpatrick, 1980; Wild, 1993; Ellis & Mellor, 1995; Buol *et al.*, 2011). Soil colour is an indication of the moisture within the soils as well as chemicals and organic content (Gerrard, 1992; Ellis & Mellor, 1995; Buol *et al.*, 2011). Reddish brown soil indicates soils rich in iron oxides. These types of soils usually occur in upland and well- drained soils. Brown to yellow soils indicate an increase in the hydration of the iron oxide. These types of soils occur in middle and lower parts where drainage is slower and moisture seepage takes place downslope, therefore causing the soil to remain moist for longer periods. Grey and bluish-grey to greenish-grey coloured soils indicate a reduction of the iron oxide and occur in lowest slope where the soil is water logged. Weathered products of gneiss are also rich in iron oxides (Le Pera *et al.,* 2001). Organic material is also important for the cycling of these chemicals and other nutrients (Wild, 1993). Dark coloured soils indicate a high organic content in the soil (Ellis & Mellor, 1995). The type and quantity of organic content is related to the type of parent material (Ball, 1964; Cresser *et al*., 2007), type of soil, vegetation, climate and slope (Konen *et al*., 2002; Cresser *et al*., 2007). According to the Munsell chart, soil colour is identified based on its Hue, Value and Chroma (Munsell, 1954). These three colour identifications were explained by Moshia (2012, pers comm.):

"If we understand what determines soil colour, then we can use colour to make some inferences about history, chemistry and hydrology of the soil. In soil classification, soil colour is the first soil physical property that is used to differentiate soil horizons, because soil colour changes with soil depth and it is directly related to a variety of processes that are occurring in the soil. For example, an obvious change in colour between horizons in a soil profile is a real indication of changes in soil properties, which are the result of biological activity, water movement, and weathering. The soil colour does not affect the behaviour of the soils, but provides insights into environmental conditions, formation processes, and other influences on the soil. It is easy to identify soil colour through human eyes and use simple colour names, however, there is a fixed naming system for soil colour. The Munsell system is the international standard and divides colour into Hue, Value, and Chroma, and displays 322 standard colour chips.

E.g: from Munsell Soil Colour Chart,
7.5 YR 5/2
7.5YR is the HUE 5/s the VALUE, and
2 is the CHROMA

Hue refers to the relative purity, strength, or saturation of a colour, directly related to the dominance of the determining spectral wavelength of the light (red, yellow, green, blue, etc) and inversely related to greyness. The symbol for hue is the letter abbreviation of the colour preceded by a number from 0 to 10. With the YR (yellow red) range, the hue becomes more yellow and less red as the number increases.

Value (lightness or darkness of colour)

Value refers to the degree of light/dark of a colour in relation to a neutral gray scale. On a neutral gray scale, a value of 10 indicates pure white, and value of 0 indicates pure black. Value runs north-south (Vertical) on the Munsell page. All colour chips in a row have equal value.

Chroma (strength of colour)

Chroma is the relative purity or strength of the spectral colour and increases with decreasing greyness. Chroma runs from 0 (neutral gray) to 8 (highest strength of colour found in soils). Chroma increases to the right across the Munsell page. All colour chips in a column have equal chroma. Zero-chroma chips have no colour, they are neutral gray. Often they are simply given a hue designation N (neutral)."

3.2 Hillslope processes and formation

3.2.1 Erosion and wash processes

Numerous different distinguishes have been made between weathering, erosion and mass movement, from various authors (Hall *et al*., 2012). In 1899, Davis concluded that erosion is the slow movement of weathered material downslope and does not include landslides. Weathering and erosion are to some degree coupled; whereby weathered material is necessary for erosion and removal of material from surfaces is necessary for weathering to continue (White *et al*., 1999; Riebe *et al*., 2004). Two components, a hillslope component and a dominant fluvial component, form part of erosion (Bryan, 2000; Schlunegger, 2002). Erosional rates depend on factors such as soil, slope angle, climate, vegetation and other environmental factors (Gerrard, 1992; Bryan, 2000; Dlamini, 2011; Ghahramani *et al.,* 2011; Fu *et al*., 2012; Mullan, 2012). Erosion rate increases at steep angles, because of a reduction in the amount of water percolating into the soil (Gerrard, 1992). At certain steepness, mass movement becomes a controlling factor, and the rate of erosion is not coupled with an increase of angle anymore (Burbank *et al*., 1996; Montgomery & Brandon, 2002). Soil properties will be a dominant factor on erosion where the hillslope surface is covered by soil (Bryan, 2000). Ghahramani *et al.* (2011) argued that soil erosion is reduced in areas where vegetation is dense, such as forested areas. As a result, erosion intensities differ on different parts of a hillslope, meaning heterogeneity in hillslope erosion (Brunner *et al*., 2004).

Fluvial erosion involves the detachment of particles from the impact of raindrops, the impact from the water flow, and the impact of the particles moved by the water flow (Morgan, 2001; Dlamini, 2011; Ghahramani *et al.,* 2011). Fluvial processes are important agents of erosion through the weathering of bedrock, thereby lowering of the base level and removal of material to valleys (Schumm, 1977; Richards, 1982; Knighton, 1984; Bryan, 2000; Owens and Slaymaker, 2004). According to Ghahramani *et al.* (2011), it is difficult to differentiate between rainsplash erosion and overland flow. Rainsplash detachment is a combination of the detachment of soil particles by the kinetic energy of the raindrop and the removal of the detached particles. Raindrops can further seal the soil surface and aid in the increase of surface run-off. Effects of raindrops on the surface vary between vegetated areas and bare soil. Dense vegetation protects the soil from direct rainsplash impact, increases infiltrations, improve soil structure and increase soil strength. Therefore, the effect of rainsplash is greater on bare soils than vegetated soil (Young, 1972; Knighton, 1984; Petts & Foster, 1985; Polyakov & Lal, 2004). Climate also influences rainsplash, whereby rainsplash is more effective in rainstorms. A hillslope that is dominated by rainsplash detachment will form a convex profile (Knighton, 1984).

Rainsplash creates soil erosion in the form of sheet flow[16], rill flow and gully flow (Knighton, 1984; Miura *et al.*, 2003). Rainsplash declines rapidly if overland flow increases (Kirkby & Kirkby, 1974; Knighton, 1984). Overland flow has been discussed by a number of authors using different models. Infiltration-excess overland flow is a model developed by Horton (1935, cited in Viessman & Lewis, 1996:58). This model takes instantaneously and simultaneously place over a catchment area on soil-covered slopes, whereby the rainfall intensity exceeds the infiltration capacity. Excess water will initially fill the small depressions in the microtopography of the hillslope; subsequently these depressions become rapidly overtopped (Knighton, 1984; Parsons, 1988; Viessman & Lewis, 1996). Authors have questioned the accuracy of this model. Surface areas must be uniform, with no rills present, for this model to work. Overland flow is not stable and creates rills during rainstorms. Rills create erosion activity concentrated in a certain area. In addition to the formation of rills, the surface of an area is usually covered with various sizes rocks and vegetation, creating a micro-topography and therefore disrupting uniform overland flow (Petts & Foster, 1985; Ruiz Sinoga *et al.*, 2010). In time, soil lower down on a hillslope will be finer textured. Finer textured soil has a lower infiltration capacity and hence the infiltration rate over the hillslope is not uniform, thereby preventing uniform surface infiltration-excess overland flow (Knighton, 1984; Parson, 1988).

Saturation flow is a different type of overland flow, and has been modelled by Kirkby & Chorley (1967). Unlike infiltration-excess overland flow, saturation flow occurs even if rainfall intensity is lower than infiltration capacity. Water will flow when the soil pores become full; when the surface and deeper impermeably layers become saturated (Knighton,

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[16] Overland flow not occurring within a well-defined channel

1984; Parsons, 1988). Saturation flow depends on soil characteristics such as volume, water content before during and after rainfall, and the slope gradient. Saturation flow is prone to take place on a thin soil, which is likely to be situated at a slope foot and extend to upper slopes or convex hillslopes. Saturation flow also occurs readily in soil with high initial water content. Soil with high water content usually occurs on low angled footslopes or near water, such as a drainage line. The flow depth of saturation flow decreases if the slope increases. As this type of flow occurs on lower slope angles and the distance from top of the hillslope to the foot is short, this flow has a low capacity for sediment transport (Young, 1972; Richards, 1982; Knighton, 1984; Parsons, 1988). Partial area streamflow generation is a third type of overland flow which takes place on densely vegetated soils in humid areas which have high infiltration capacities (Richards, 1982).

Erosion can create an incision and a permanent channel if the surface water flow force and frequency is high enough. Weathering and erosion of rocks lead to sediment supply, transport and depositions in the channel (Knighton, 1998; Pietersen, 2009). Material transportation in a channel can either be in the form of bedload, suspension, or solution[17] (Owens & Slaymaker, 2004). The type of transportation depends on the size of the particles versus the velocity (energy) of the particles or the stream power, and is dependent on the channel morphology. Bedload transportation is usually greatest in mountain channels which have capacity-limited streams, therefore more coarse material and the velocities are high due to the profile gradient (Knighton, 1984; Owens & Slaymaker, 2004). The type of bedload transportation is determined by the size and shape of the bedload and could be either as rolling, sliding or salutation. Suspended load includes mineral particles, organic debris and microscopic organisms from erosion. Sediments are transported in suspension during turbulent flow. The turbulent flow supports the particles against the drag force of the weight from the particles (Richards, 1982; Petts & Foster, 1985). Dissolved load originates from chemical weathering. Wash load originates from slope erosion and can settle out if the flow velocities are reduced (Richards, 1982; Knighton, 1984). Even though solution transportation has little influences on alluvial channel forms, it may be a dominant transportational control in humid climates (Richards, 1982; Knighton, 1984; Petts & Foster, 1985).

Material transportation in a channel may lead to bedrock erosion[18] or bank erosion[19]. Bank erosion depends on the bank properties in addition to erosional properties of the

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[17] As wash load or dissolved load

[18] Vertical erosion

[19] Lateral erosion

sediment transportation. Bank properties include the bank material and the size, geometry and structure of the bank. Bank material is weakened by weathering and soil moisture. Erosional properties are direct action of water, slumping and rotational slipping. The direct action of water takes place at high discharges and is effective on cohesive and non-cohesive bank material. This direct action of water could cause the removal of large boulders due to the undercutting of material around the boulders, causing gravitational failure of the heavier bank material (Knighton, 1984; Merritt *et al.,* 2003). Bedrock erosion takes place due to abrasion, or could be as a result from the removal of sand and gravel. Sand and gravel are situated in the channel bed due to bank erosion and limit abrasion due to sediment overlying bedrock, limiting its exposure to erosion (Knighton, 1984; Ahnert, 1996; Merritt *et al.*, 2003). According to Schumm (1977), young streams are highly active and erode rapidly, whereby older streams do not erode as rapidly.

3.2.2 Mass movement on hillslopes

Mass movement could be a major factor controlling certain geomorphic processes on hillslopes (Crozier, 2010); however, these processes are only a determining process if it can dictate the landform geometry and control the rate of denudation (Wolman & Gerson, 1978). In the literature, authors have classified movement processes differently since the early fifties into the present time. These classifications include that of early authors such as Sharpe (1938), Varnes (1958), Hutchinson (1968) and Carson & Kirkby (1972). The classification of Varnes (1958) included two variables, the type of movement and type of material. The classification by Carson & Kirkby (1972) was done in terms of the rate of movement of the material, the water content of this material and whether movement was a flow or heave. This classification does not include fall, such as rockfall, which can play a vital role in movement especially in cliff areas. Owens & Slaymaker (2004) classified movement processes into two different systems. The first system is a coarse-grained sediment system. This system includes certain mass movement processes such as rockfall, landslides and debris flow. This system has been classified to cluster together the movement of material between cliffs or other types of bare rock walls and the depositional process, therefore linking together high elevation parts and lower, flatter parts as well as hillslopes and channels. This first system can be further divided into a long and/or medium term movement, which will include all movement controlled by the bedrock or the surficial geology, as well as short term movement, which is controlled by either the climate of by human influences. The second system is a fine-grained sediment system which includes certain mass movement such as soil creep, erosion as well as wash / fluvial processes. Chuang & McEwen (2010) determined that there are 10 different types of mass wasting processes, shown in Fig. 5. The shear plane is the plane at which material breaks or shears. Material above this plane will stay undefromed, however the strength or resistance of this material will be lowered after the movement has taken place (Young, 1972; Finlayson & Statham, 1980).

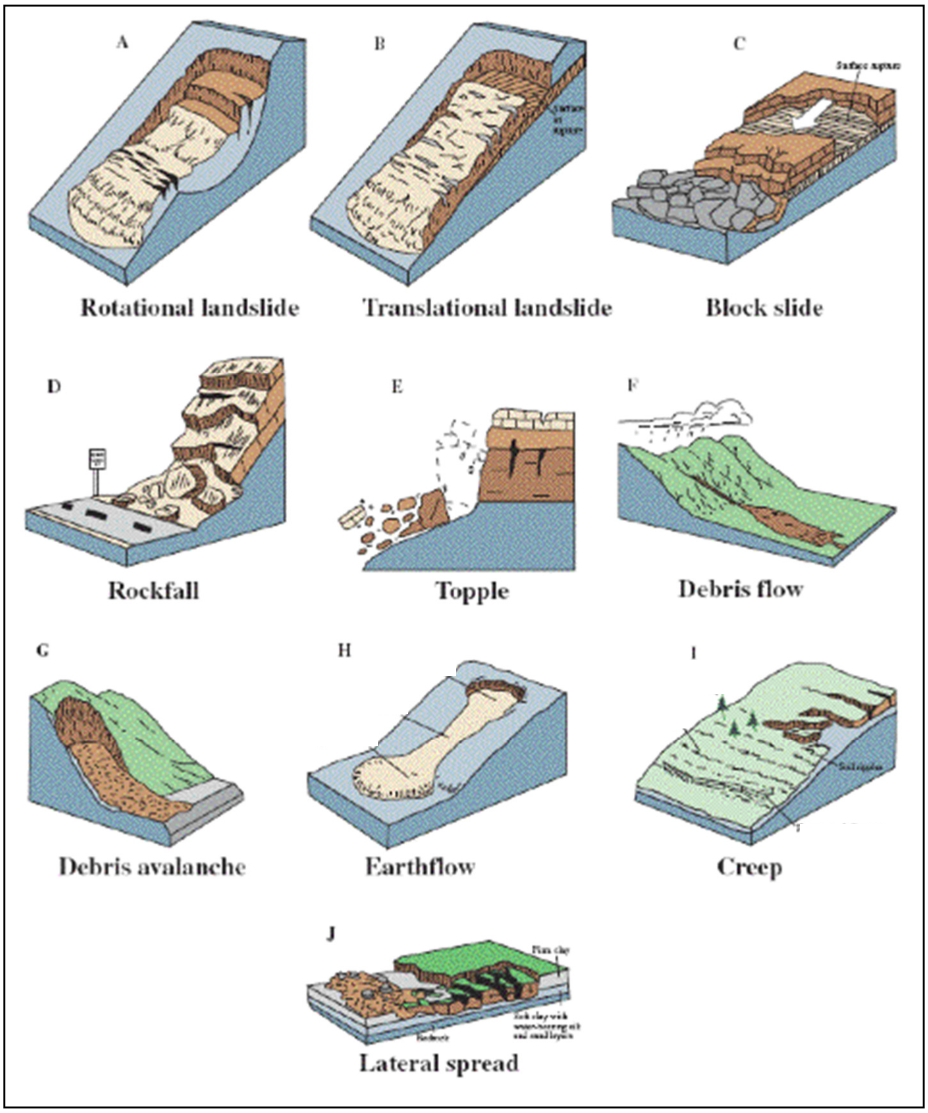

FIGURE 5: Examples of different types of mass wasting processes (taken from Chuang & McEwen, 2010).

Rockfall takes place on steep bare rocks such as rock wall and cliffs (Clark & Small, 1982), which is a weathering limited plane (Selby, 1982). Rockfall can be seen as a relative small landslide (Selby, 1982) or a translational slide with a shear plane (Finlayson & Statham, 1980). Different from a normal landslide, during rockfall, rocks fall and bounce rather than slide down a plane (Clark & Small, 1982). Rockfall is usually superficial and individual fragments (Clark & Small, 1982; Selby, 1982) on a small scale (Finlayson & Statham, 1980) and such movement may be relatively frequent (Selby, 1982). Rockfall takes place due to the properties of the rocks as well as the processes working on the rock. The parting in the rock, in the form of joints, faults and fissures, controls the strength of the rock.

A parting can be due to various reasons, such as cooling of joints in schist rocks. The partings control the strength of the rock depending on its size, spacing, continuity and lastly its stability at a certain angle (Clark & Small, 1982; Selby, 1982). The steepest angle at which a cliff is stable is the critical angle. If the cliff-form changes to have an angle above the critical angle, rockfall will occur. The critical angle depends on the joining in the rock (Young, 1972). Processes that may lead to rockfall may include internal factors such as stress release or hydrofracturing within the rock, or granular disintegration of weak rock cements. External factors include tree roots, animal movement, water-pressure (Young, 1972), undercutting by streams, underlying rock which weather faster (Selby, 1982) or change in climate (Duarte & Marquínez, 2002). Rockfall leads to the retreat of a cliff or rock wall and the accumulation of debris lower down (Young, 1972; Clark & Small, 1982). Rockfall is not common in soft rocks as these types of rocks are very prone to denudation leading to a soil and vegetation cover (Selby, 1982).

A landslide usually starts as a slip on a separate failure surface and is a movement across a relatively defined slide plane with a uniform velocity (Young, 1972; Clark & Small, 1982). It is also associated with weathering-limited slopes because the valley side becomes undercut (Owens & Slaymaker, 2004). This movement is controlled by the type of material, the steepness of the slope and is triggered, either in the long term through weathering, or in the short term through water pressure after rains. Movement takes place if gravity due to slope steepness exceeds the resisting forces within the material. The resistance within the rock consists of friction, the resistance of material to slide over another material, and cohesion, the forces which physically or chemically glue the sediment grains together (Finlayson & Statham, 1980). Brooks *et al.* (2002) describes the effects of rainfall on landslide formation. Episodic rainstorms in New Zeeland have triggered many landslide events in the form of shallow, rapid flows and slides of debris and soil. These landslides are an important process of erosion in the area (Brooks *et al.*, 2002). Most rapid flows occur when the material becomes exceptionally wet. This movement includes failures in clay such as earthflow or mudflow. A failure in granular soil is another type of rapid flow and includes debris avalanches (Young, 1972; Finlayson & Statham, 1980).

Heave differs from other mass movements as the material not only moves down a plane but also up and down. Material from this type of movement originates on a concave plane and comes to rest on a convex plan; therefore hillslopes dominated by heave usually have concave and convex plans or profiles (Parsons, 1988). Creep is the downslope movement of regolith and can be further divided into soil creep and rock creep. Soil creep is more a flow than a slide (Clark & Small, 1982) and is confined to the root zone. Soil creep movement is rapidly reduced with depth (Finlayson & Statham, 1980). The movement is basically the expansion and contraction of soils due to gravity, and the volume and speed of flow depends on the amount of clay present in the soil, which controls the inter-particle stresses of the soil (Young, 1972; Finlayson & Statham, 1980; Clark & Small, 1982). According to Young (1972), soil creep movement is caused by a number of different external factors. These factors include climatic factors such as the expansion and contraction of the soil due to temperature changes, expansion and contraction due to wetting and drying and the freezing and thawing of the soil moisture. Biological factors include the interference of plant roots and the movement of soil fauna within the soil. Physical factors are weathering which causes volume changes and then finally a temporary increase in the load on the soil from rain or animals. There are different types of soil creep. The first type is seasonal creep as defined by Terzaghi (1950)[20]. Continuous creep occurs only due to gravity and not with the aid of external factors (Young, 1972; Finlayson & Statham, 1980). Random creep takes place when soil particles are set into motion by any process (Finlayson & Statham, 1980). Rock creep, or also known talus shift, is the slow downhill movement of rocks or rock fragments (Young, 1972). The rate of denudation also depends on the plan and profile form of the landscape. Material will be deposited in a concave slope and will be eroded on a convex slope (Gerrard, 1992). The grain size of soil is reduced during weathering, making the grain more susceptible to erosion. Therefore, an increase in weathering may lead to increase in erosion. Lastly, in high rainfall areas, the vegetation cover is usually dense, reducing the creep potential (Gerrard, 1992).

A single hillslope is not formed by a single material movement process. A number of studies have been done in the past to observe which type of process dominates a hillslope. Some landforms are controlled by events with a moderate magnitude and moderate frequency. Young (1972), however, stated that a single event that is great in magnitude, such as a landslide, may dominate a hillslope form. On this same hillslopes another type of process may be great in frequency, but does not control hillslope form (Parsons, 1988). This same statement was made by Selby (1974), whereby he stated that the landform of a hillslope is controlled by activities great in magnitude. According to Selby (1974), landslides are the dominant control in a hillslope area. He stated that landslides shape the source areas and dominate the depositional areas of a hillslope, and further concluded that the evolution of a hillslope may be due to the frequency of landslides.

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[20] This creep is not a restricted definition and only excludes creep taking place over a long duration (Sharpe, 1938; Parizek & Woodruff, 1957; Young, 1972).

3.2.3 Slope profile and plan characteristics

Bedrock geology, weathering, erosion, wash processes, soil properties and mass movement lead to the slope characteristics. The shape of a hillslope can be described either by using a plan form or a profile form (Selby, 1982). A plan form views the shape of the surface such as curvature of the contours on a horizontal plane. Such a plan can be rectilinear, concave or convex. A profile form is a two dimensional shape along a vertical plane (Young, 1972; Parsons, 1988). Hillslope analysis is done by dividing a profile form into a sequence of parts named slope units (Young, 1972). A slope unit indicates the character of a certain area (Parsons, 1988). Such an area can either be straight (rectilinear), in which case such a slope unit is named a segment, or an area can be curved (curvilinear), in which case such a slope unit is named an element (Clark & Small, 1982). A segment is associated with a cliff or a free face which is weathering- limited. A cliff or free face has a minimum angle of 45º. Threshold conditions, such as rapid mass movement due to river undercutting or underlying strata retreating, may lead to the formation of a segment. In contrast to a segment, an element is transport-limited and the processes leading to the formation is slow or slower than that of a segment. There are two types of elements, convex and concave elements. A convex element only occurs where the surface slope is below failure limit. A convex element develops due to rainsplash, or, in humid areas, mainly due to soil creep. Therefore such a slope is transportational. In contrast, a concave element is a depositional slope and best developed in humid areas where the infiltration rate of soil is low and the rainfall is high. Convex slopes occur usually in the upper part of a slope (Finlayson & Statham, 1980). The angles of the slope profile are also important to consider for hillslope, as these could indicate certain controlling aspects or processes on a hillslope. Angles, such as that of a cliff, are not due to hillslope processes, but due to historic conditions such as upliftment and underlying geology. Such an angle could be lowered by denudational processes, whereby hillslope processes become a factor. Hillslopes, in certain conditions, will have a certain upper angle limit. These conditions include different geology, soil cover and vegetation cover (Young, 1972; Clark & Small, 1982).

The sequentially arranging of slope units creates the opportunity to study an area in the form of the slope profile. The first such studies to interpret geomorphology were conducted in 1875 by Tylor and in 1928 by Lake (Young, 1972). Slope profiles can either be studied as a whole or partially (Young, 1972). Different slope models have been generated to aid in the study of partial slope profiles. The first slope model was formulated by Wood (1942). This was a 4-unit model with convex unit at the top, cliff or free face, rectilinear or consistent slope and concave unit at bottom (Finlayson & Statham, 1980; Clark & Small, 1982; Parsons, 1988). King (1957) formulated a flexible 4-unit model (cited in Parsons, 1988:50). This model was also based on the fundamental principles of Wood (1942), whereby there is a convex slope or upper / summit convex, two rectilinear slopes, of which the second slope is less steep, and a concave slope (Clark & Small, 1982). He argued that this model can be used for different environmental conditions. The slope model was further modified by Dalrymple *et al.* (1968) into a 9-units slope model (cited in Clark & Small, 1982; Parsons, 1988). Where the original 4-unit model is based on geomorphic processes, the 9-unit model is based on geomorphic as well as pedogenetic processes. This 9-unit model correlates with the understanding that soil has different properties at different slope formation. Further, the soil properties influence erosional and wash processes, which in turn influences slope formation (Brooks & Richards, 1993; Brunner, 2004). Dividing a slope into smaller units also helps to incorporate hydrological investigations and slope modelling (Wood *et al.*, 1988; Flügel, 1995; Wood, 1995; Park & Van den Giesen, 2004). This 9-unit model has also been included in studies to understand slope failures (Ayalew & Yamagishi, 2004). The 9-unit model was formulated for a humid type of area where the norm is that a slope will change from convex to concave.

According to Young (1972) (Fig 6), units 1-3 of this model combined, forms the convex unit of the fundamental slope model. Unit 1 occurs only once in a slope profile, however, this unit must occur in a profile, whereby it is not necessary for all the other units to occur in a slope profile (Parson, 1988). Soils are usually uniform if this unit is broad or somewhat uniform if this unit is narrower. Pedogenetic processes and vertical water movement within the soils dominate at unit 1 and 2. Pedogenetic and geomorphological processes such as erosion and soil creep dominate at unit 3 (Hall, 1983; Gerrard, 1992). Unit 4 of the model forms the first steep rectilinear slope of the fundamental slope model. According to the slope model of King (1957, cited in Parsons, 1988:50) this slope may comprise of mass movement such as rill action or slumping. The slope angle will depend on the strength of the rock, the processes that undercut the rock and the processes that flatten the slope (Selby, 1982). Weathering is also an important process in this unit (Gerrard, 1992). Unit 5 coincides with the second rectilinear slope of the fundamental unit. The model by King (1957) comprises of debris from mass movement such as slumping (cited in Parsons, 1988:50), creep and flow (Hall, 1983) on the second rectilinear unit and weathering (Gerrard, 1992). The soil is usually heterogeneous in terms of physical and chemical composition. These soils have thinner A-horizons and may have thicker B-horizons (Hall, 1983). Units 6 to 9 coincide with the concave slope of the 4-unit model. Unit 6 is concave in profile, which is mainly the area where deposition occurs and normally has a smooth regolith cover. Pedogenetic and geomorphological processes such as mass movement dominate (Hall, 1983; Gerrard, 1992). Soils occurring on this unit are in general heterogeneous due to the mass movement and the diverse deposition. The A-horizons can be variable but tend to be thicker downslope (Hall, 1983). Units 7-9 are associated with hydraulic processes with limited down-cutting (Young, 1972; Finlayson & Statham, 1980). Subsurface water movement dominates at unit 7 and fluvial processes at units 8 and 9 (Gerrard, 1992). Soils on these units are usually heterogeneous and the A-horizons thick due to frequent deposition.

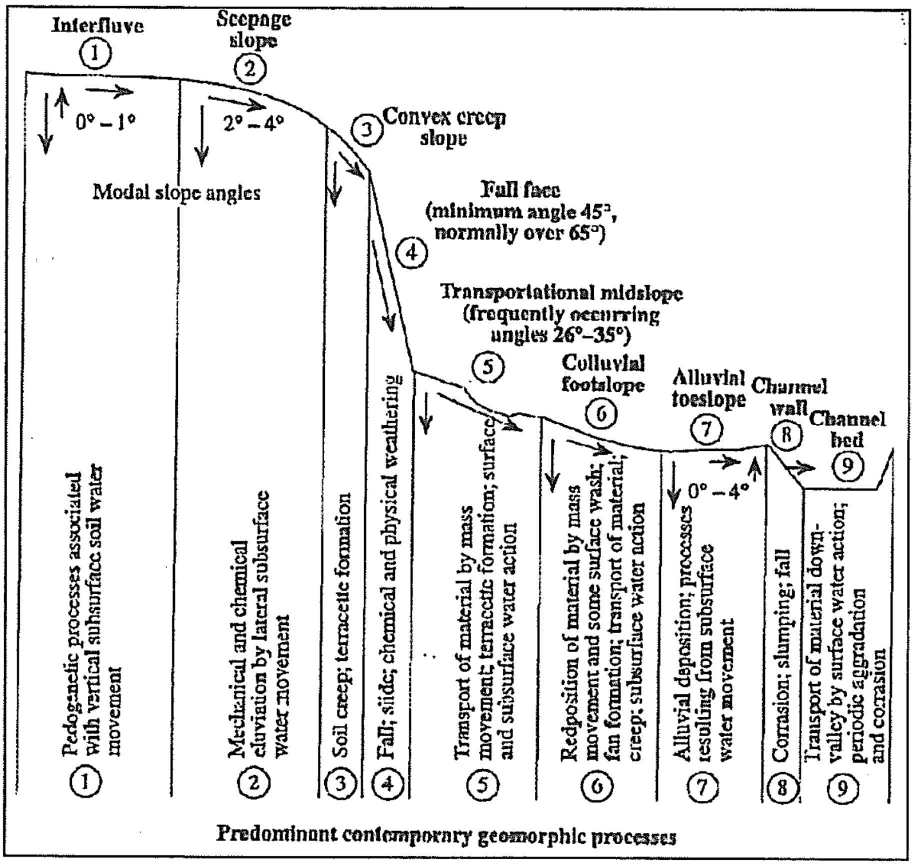

FIGURE 6: Hypothetical 9-unit landscape model (Dalrymple *et al.*, 1968 taken from Ellis & Mellor, 1995)

3.2.4 *Channel formation and longitudinal profile*

Various factors control channel formation, shape and longitudinal profile. Geology could be a direct or indirect control on the channel. This is primarily through the influence of the geological structure of the area; including historical upliftment; which in returns leads to an initial relief of the area influencing incision rate of rivers especially in mountainous areas. Other structural influences are fractures which influence channel flow, and factors such as undercut reaches and rock steps. Indirect influences are due to the lithology of the rocks, and weathering and erosional processes. Different vegetation has similar transpiration, however the interceptions, storage and evaporation differs significantly. Vegetation further influences channel formation through the binding of soil. In the case of tree roots binding soil, channels are usually wider and shallower. If grass roots bind the soil, the channels is usually narrow (Richards, 1982; Knighton, 1984). Climate also plays a role in channel formations, shape and profile. Climate and climate change could also influence erosion and deposition. Land use practices and human influences also play a role on the channel. Another control is drainage texture. The spacing of the channels also influences the channel. All the above controls are in return dependent on time as a variable. This includes the history of the channel and land form leading to the present channel (Schumm, 1977; Richards, 1982; Petts & Foster, 1985; Knighton 1987; Viessman & Lewis, 1996; Owens & Slaymaker, 2004).

Depending on the rate and degree of transportation, deposition and erosion, a channel can be either a bedrock channel or a sand channel or various forms in-between. Bedrock channel consist of a cohesive rock layer with little or none loose material. The channel is usually short lengths and in steep areas such as mountainous areas. The bedrock channel areas within the drainage channel could be associated with knick-points where there are short lengths of steep areas. Boulder-bed channels, which could also be classified under bedrock channels, include large boulders. A bedrock channel is resistance-limited due to the resistance of the bedrock. Such a channel may have some gravel accumulation in pool areas; however this gravel will be removed with the next flood event. The energy of such a stream will firstly be used to down-cut the bedrock either by the water energy or due to the gravel that is still present. All additional energy will be dissipated through turbulence or rapid water movement. This energy surplus will therefore not be used for channel formation (Ahnert, 1996). In short, for a resistant-limited stream or channel erosion is greater than deposition. Sand channels consists mostly of sand and some gravel and could be transported at lower discharges, whereby gravel channels consists mostly of gravel and some sand and could only be transported by higher discharges. A last type of channel associated with the gravel/sand channel is a silt-clay channel. The transition of bedrock channel to gravel/sand channel or from gravel/sand channel to bedrock channel can be abrupt or gradual. Spatially, these transitions could be due to change in width of channel, gradient or insertions of geology such as boulders. Temporally these transitions could be due to a change in the hydraulic regime or in the sediment load (Knighton, 1984; Howard, 1987). Energy of the water flow is used to move the material in the channel. As long as there is material available to be transported, all the energy will be used. In short, for a resistant-limited stream or channel, erosion is greater than deposition (Ahnert, 1996). Alternatively, for a transport-limited stream or channel deposition, is greater than erosion. If more energy is present than the amount of material to be transported, material will be removed, leading to bedrock channel, which is in turn then resistance-limited. This is termed the fluvial equivalent. A channel can therefore alternate between being resistance-limited or transported-limited (Ahnert, 1996). In a channel, there will usually be more bank material than bed material. Sediment yield from eroded bank material is therefore higher than the sediment yield from bed eroded material (Petts & Foster, 1985).

Smaller streams usually have stretches of slow flowing water alternated with shorter stretches of shooting flow. Slow flowing water occurs over areas where the channel floor is deeper than that of shooting flow, where the channel floor is shallower. Deeper channel floor stretches are named pools and that of the shallower channel floor stretches are riffles. If the gradient between a riffle and a pool is steep, it is rather named a step and a pool. Riffle-pool sequence can occur in straight or meandering channel and is common in low flow channels. Riffles occur in topographical higher points in the channel long profile where coarse sediment can accumulate. If riffles are flat, being less than 40mm high and length of more than 600m, it is named a dune. Pools, on the other hand, occur in topographical low point in the channel long profile where finer material accumulates (Richards, 1982; Petts & Foster, 1985; Davies, 1987; Ahnert, 1996; Lofthouse & Roberts, 2008). There are two main types of valleys, namely a flat-floored valley and a V- shaped valley (Ahnert, 1996). A V-shaped valley occurs mostly in a straight stream further down in a stream. A flat-floored valley is produced by lateral erosion into gravel type banks (sidewalls). If these banks are composed of bedrock, lateral erosion can create rock-floored valleys. A channel could either be straight, meandering or braiding. Stream braiding can be in the form of erosional braiding where the bed load is not everywhere equally resistant to erosion, which then creates braiding, in-channel braiding where the deposition of material creates braiding of the channel and lastly new channel braiding (Ahnert, 1996).

The general formation or change of a longitudinal profile arises from the bed material, the rock type, and erosional and transportational processes (Knighton, 1984; Rãdoane *et al.*, 2003). Channel geometry consists of the cross-section, plan form and the longitudinal or long profile. These three are interrelated to each other. Many studies of the longitudinal profile of a water body, such as a river, stream or a drainage line/channel, have been done during the last century. This profile is an important tool to measure fluvial geomorphology and other geomorphological characteristics (Rãdoane *et al.*, 2003; Phillips & Lutz, 2008). The longitudinal profile of a water body indicates the gradient of the channel (Ahnert, 1996). According to literature ranging from the 1900's authors such as Surrel in 1870 (cited in Lee & Henson, 1976: 191) and Gilbert in 1877 to authors such as Goldrick & Bishop in 2007 and Larue in (2008) have stated that the general or overall pattern of a longitudinal profile will be concave upwards. It is further observed in studies also ranging from the 1900's to the 2100's that the reason for this is that as the discharge of the water body increases downhill, the gradient decreases until an equilibrium is reached whereby the profile is smooth and does not change anymore. Another thought is that as the discharges increase downhill the bed load also increases (Lee & Henson, 1976; Rãdoane *et al.*, 2003; Phillips & Lutz, 2008). The general profile will appear smooth as it excludes riffles-pools sequences; however, from a closer perspective, this profile is rarely smooth (Richards, 1982; Knighton, 1984).

3.3 Channel classification

River classification is the arrangement or zoning of a river into groups and is done to understand the river system behaviour and morphology (Rowntree & Wadeson, 1999). The classification of a river system is difficult due to the fact that fluvial system boundaries, which form the river systems, are not always distinct (Naiman *et al.*, 1988; Pringle *et al.*, 1988). There are different types of river classification. Zonal classification is a longitudinal classification system. In general, this classification will have a headwater upstream, a shallow, turbulent mountain stream with a steep gradient and the main sediment producer downstream. The headwater zone will usually have a channel substrate comprising of coarse gravels, boulders and rock outcrops. The headwater will further also be a zone of high potential energy and erosional properties. The middle zone will be sediment transport. The lowland zone will be where the potential energy is low, due to factors such as excess sediment and lowered gradient, and sediment is deposited (Petts & Foster, 1985; Rowntree & Wadeson, 1999). Schumm (1977) proposed an idealised fluvial system divided into three zones. In each zone, one process is dominant. Zone 1 is the production zone which includes the sediment sources where only very little or no sediment storage takes place. The dominant process is sediment transfer. This zone depends on morphological components such as climate, lithology and land use. Zone 2 is the transfer zone and essentially in equilibrium. Zone 3 is the sink or depositional area. This model was extended by Pickup (1984). This model was divided into five zones, as shown in Fig. 7. These zones are the upper source zone with coarse and poorly sorted material added directly from adjacent slopes; the armoured reaches with well sorted material covering poorly sorted substratum; the gravel-sand transition zone with rapid fluctuations in bed material sizes and sorting; the sand or mobile zone with sorted finer material; and backwater with poorly sorted finer material. Many ecologists have adopted the zonal classification to explain biotic distribution down the longitudinal river channel. Harrison (1965, cited in Rowntree & Wadeson, 1999:12) and Nobel & Hemens (1978) produced such a classification for South African rivers. This classification has seven zones, shown in Table 1.

TABLE 1: Ecological river zonation after Harrison (1965) and Noble & Hemens (1978)

Zone	Physical characteristics	Flow characteristics	Turbidity
High altitude source zone	Source often with sponge or spring. Substream bedrock or humic turf.	Slow flow, often seepage, but may be dispersed with waterfalls.	Negligible, even during storms.
Mountain stream	Mountain torrents, waterfalls and rapids, little or no true emergent vegetation. Substream bedrock, boulders and smaller stones. Deposition negligible, stone surfaces clean.	Fast to torrential turbulent, always oxygenated.	Negligible, even during storms.
Foothill: rocky bed	Gradient moderate but still noticeable. Substrate dominated by bedrock, boulders and smaller stones, but with occasional patches of gravel and coarse sand. Some epilithic growth. Sparsely distributed emergent vegetation. May or may not be interspersed with occasional waterfalls.	Fast, but with slow flowing pools.	Generally low, turbid during floods.
Foothill: sandy bed	Stony runs alternate with sand or sediment. Marginal riverine vegetation becomes noticeable and islands may form within river channel.	Lower flow velocity, but fast in rapids and during floods.	Extremely variable, turbid at least during floods.
Midland river	Further reduction in gradient. Deposition increases. Substratum predominantly sand and finer sediments, but with occasional stony runs. Emergents can become extensive.	Generally slow.	Variable but usually turbid.
Lowland river	Substratum changing to fine silts. Flood plains and meanders can occur or channels may be braided. Islands often present. Emergents usually prominent in channel and on margins.	Flow relatively slow.	Usually turbid.
Swamp	Area of wet spongy ground with a substratum of fine clays and silts high in organic materials. Channels are braided and usually blind. Emergent macrophytes are dominant and form dense impenetrable masses.	Generally slow.	Negligible to low turbidity except during floods.

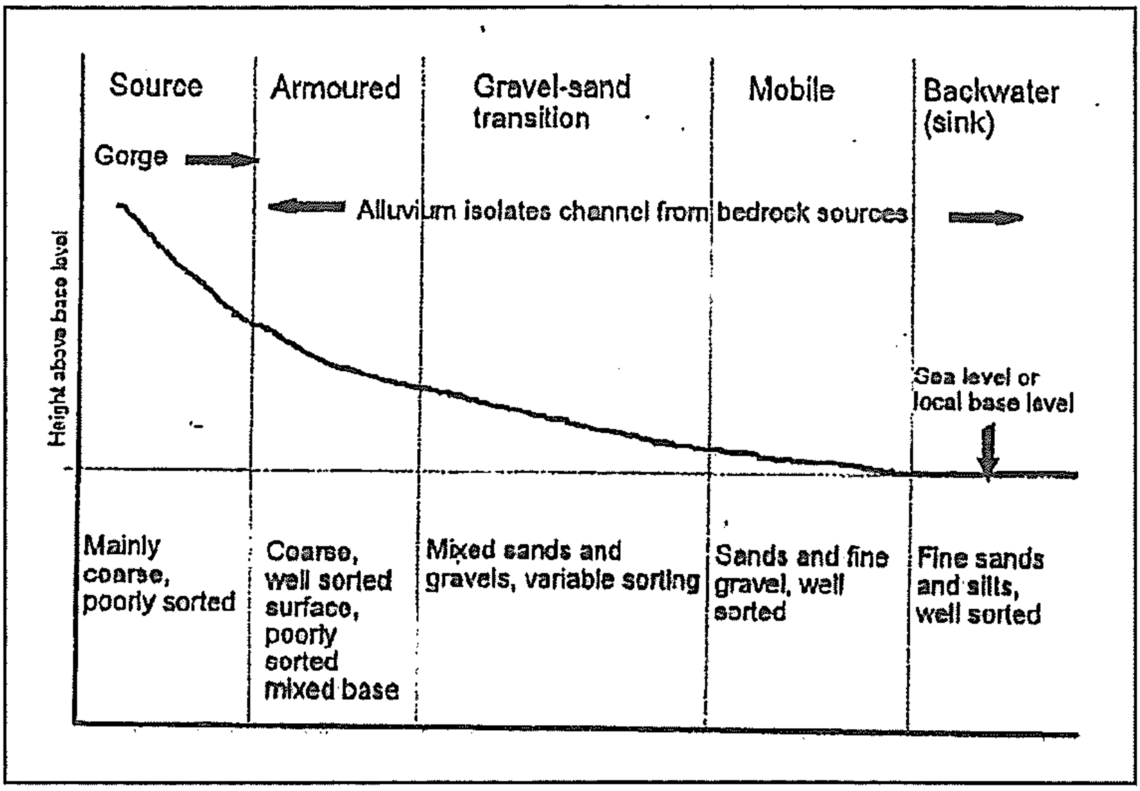

FIGURE 7: River zones characterised by particle size distribution after Pickup (1984)

An alternative model is the hierarchical classification model. The hierarchical classification is based on the physical characteristics or controls of the surrounding area of the river channel. The first controls are independent and include climate, geology and drainage evolution. The second set of controls is the catchment controls. These include impoundments and inter-basin transfers, hydrology, soils, vegetation and catchment management. The last set of controls is the channel controls such as suspended sediment, water temperature, dissolved oxygen, solute load and geomorphology. The suspended sediment is important due to its effect on the biotic system. Water temperature affects the distribution of aquatic life and dissolved oxygen, which is also a physical characteristic of the river channel. Solute loads are derived from marine or chemical weathering. The geomorphology includes channel size and gradients, as well as aspects such as riffle-pools (Rowntree & Dollar, 1996). Frissel *et al.* (1986) concluded there are two problems with a hierarchical river system classification. Firstly, the controls on different river channels will differ depending on the controlling variables of the area. Secondly, the classification will be time dependant and may be different if the classification is done in different seasons or over different years. This may be due to climate or changes in land practices.

Frissel *et al*. (1986) further proposed a hierarchical system based on linear spatial scales. This model has been adapted by South African river systems for river management, but with some differences. Fig. 8 shows the South African river systems model. Both models are divided into six subsystems. The first subsystem for the South African model is the catchment, followed by the zone, the segment, reach, morphological unit and the hydraulic biotope. The segment reach, morphological unit and the hydraulic biotope form the channel features. Segment boundaries will be tributary junctions and/or changes in stream orders. The channel type in a segment is similar in respect of channel dimensions and bed material with local morphological variations (Rowntree & Wadeson, 1999). The reach variables such as gradient, geological heterogeneity, bank and bed material and vegetation are similar. These variables determine the flow and if the reach is a source, transfer zone or a sink. The morphological unit is similar to that of the pool-riffle level of Frissel *et al.* (1986). This morphological unit is either erosional or depositional. The hydraulic biotope occurs on a small scale of approximately 1m² an include features such as waterfall, rapid, pool, etc. (Rowntree & Wadeson, 1999).

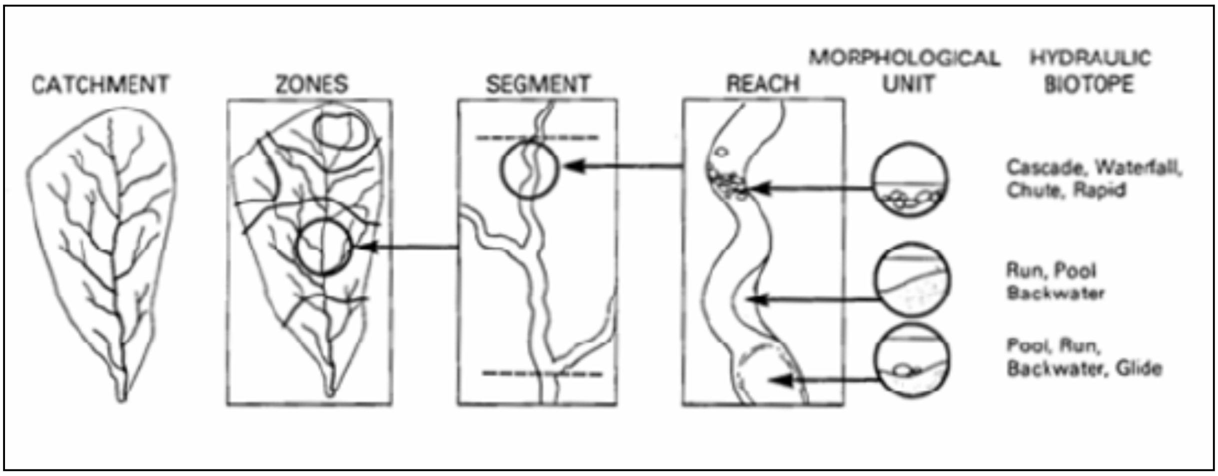

FIGURE 8: The hierarchical organisation of a South African river stream system (taken from Rowntree & Wadeson, 1999)

3.4 Geological and geomorphological mapping

The linkage between hillslope geomorphology and the different features, especially vegetation, is very complex and creates challenges in understanding these linkages (Marston, 2010). Integration of geomorphology and ecosystem ecology, in this case vegetation, may prove difficult, even though they are interacting and depended on each other. It is importance to know how abiotic and biotic processes work together in driving ecosystem changes (Zeng *et al.*, 1999). Geomorphological mapping is used to obtain data in the form of surface form, surface processes and the age of the landforms. No amalgamated geomorphological mapping model is in place (Koh, 2007). Geomorphological mapping has also not been used extensively up to date, due to difficulties such as the lacking in integrated geomorphological models (Gustavsson *et al.*, 2006). To bridge this problem, GIS is used to provide a digital input into the landscape variations (Turner *et al*., 2001; Longley *et al*., 2005; Steiniger & Weibel, 2009) and the interaction of abiotic and biotic components. The using of GIS to compile a geomorphological map is a fairly recent development. Some new developments in GIS and geomorphological mapping have taken place in the last few years, such as that of Gustavsson *et al*. (2006).

A geomorphological map is an analogue map classifying the natural landscape (Kamal & Midorikawa, 2004), whereas, a Geographic Information System is a digital geographical database (Gustavsson *et al*., 2008). GIS application is a compilation of a geomorphological map with added information, such as vegetation in this study (Gustavsson *et al*., 2008), as well as descriptive raw data to be used in multiple layers, presented in a systematic inventory (Verstappen & van Zuidam, 1968; St.-Onge, 1981). According to Gustavsson *et al*. (2006), mapping is the best source of information for explaining landforms and landscape development. Legends and scales are an important part of geomorphological maps (Gustavsson *et al*., 2008). Large-scale features and processes are easier to illustrate on these maps than small-scale features and processes. Gustavsson *et al*. (2008) presented a comprehensive legend that includes many features and processes ranging from the geology, age of rock, hydrography, morphometry (a quantitative description of shapes and landforms) and morphography (qualitative description or the configuration of the landforms), lithology consolidated rock features, structures such as dips and faults and specific features. Various features and processes are not included in this legend that may have a role in this specific study, such as erodibility mapped by Auerswald *et al.* (2009), as well as Terranova *et al*. (2009) and Nigel & Rughooputh (2010), aspect and slope by Kawabata & Bandibas (2009).

Chapter 4: Methodology

To understand the correlation of geomorphological processes on the study site, data were acquired and interpreted during site visits as well as using maps and GIS data. Maps such as the 1:50,000 topographical map (South Africa, 1997b), maps obtained from additional research (e.g. Ferguson & Rautenbach, 2012) and GIS information were used to form the baseline information for the study. Using the information from the maps, as created by Ferguson and Rautenbach (2012), the decision was made to conduct the study on the northern slope of the Mariepskop where the grass patches were located. These patches, however, cover a large area of the northern slopes of Mariepskop, which needed to be scaled down to a smaller and more manageable size for the study to be conducted. Three site visits were conducted on Mariepskop. The first site visit was conducted in November 2010, and was mostly focussed on refining the site boundaries of the study site. The study site, as described in chapter 2, was set during that site visit. During the initial site visit, various random coordinates were taken. The height reading in m a.m.s.l. of the GPS at each of these coordinates were compared against the height in m a.m.s.l. of the slope layers of the Mariepskop GIS data. This was done to examine whether the height of the contours from the GIS data coincides with the height of the GPS readings. After the initial site visit, the site boundary was defined and manually included as a polygon onto the 1:50,000 topographical map.

Channels features assessed included the stream erosional and transportational properties, the channel bed and bank properties, channel formations such as riffle-pool sequences, channel properties such as valleys, patterns including braiding, meandering or straight channels, the longitudinal channel profile and different river classifications. These features, formations, properties, and classifications were divided into different sections: section 4.1.3 and section 5.1.3 discuss the methodology and results of the channel features such as the stream erosional and transportational properties, and the channel bed and bank properties; section 4.2.3 and 5.2.3 discuss the methodology and results of the channel formations such as riffle-pool sequences, channel properties such as valleys, patterns including braiding, meandering or straight channels, and the longitudinal channel profile; section 4.3 and 5.3 discuss the channel classification. Eighteen points within the drainage channel were assessed for these different properties. These points were taken at approximate intervals of 20m. A checklist was used to indicate the drainage properties of each interval. Properties from the checklists investigated at each site were:

1. Stream lateral or vertical erosional characteristics;

2. Stream channel formation characteristics such as bedrock channel or sand/gravel channel, the presence of gravel bars, sand bars, riffles pools, valleys and levees;
3. Stream channel patterns such as braiding and meanders;
4. The longitudinal stream profile; and
5. River classification.

Due to the inaccessibility of the channel further uphill, the channel could not be observed further than these first eighteen points.

4.1 Geological processes and regolith production

4.1.1 Bedrock geology

Identification of the geology was done to assist as a basis for all other processes, formations and classifications occurring within the study site. A hard copy of the 1:250 000 Geological Series map, sheet 2430, Pilgrims Rest (South Africa, 1986) was used to obtain background information on the geology of the area. Using the lithological description on the legend of this map, and the geological description of Walraven (1989), the background geology of the area was described. Lithological units, as identified on the geological map, were taken and manually included onto the 1:50 000 topocadastral map (South Africa, 1997b) using ArcMap 10 and ArcCatalog 10. Photographs of the underlying strata and loose lying rocks that could be observed were taken during the first site visit conducted in November 2012. Photographs aid in the identification of the rocks, where after literature is used as part of the identification. During the second site visit, conducted in June 2011, weathered layers were removed from the strata and scattered rocks found on the site using a hammer (Phillips *et al.,* 2008). These strata and rocks were then photographed and GPS coordinates were taken.

Subsequent to these first two site visits, the lithological descriptions from the 1:250 000 Geological Series map, sheet 2430, Pilgrims Rest (South Africa, 1986) was compared to the rocks found on the site. Images from King (2013) were used to aid in the identification and comparison of these rocks. Many of the rocks were also identified using Google Earth (2013). These images were useful to differentiation between schist rocks and gneiss rocks. Gneiss and schist rocks have a number of features that are characteristic to the type of rock. All these features were also observed on the rocks that were studied using the background information of the geological map, information on the geological description of Walraven (1989) and again using Google Earth (2013).

4.1.2 Weathering processes

Assessment of the weathering processes was done to determine the main types of weathering occurring and whether weathering differs over the study site. The methods used by Phillips *et al.* (2008) to assess weathering were used to a large extent. Chemical and physical weathering could be observed by looking at the loose material such as soil and regolith, as well as the weathering characteristics on the larger rocks or boulders occurring on the study site. Chemical weathering could be observed, such as different colouration in the rocks and removal of certain minerals in the rocks. During the geological investigations, the interior rock colour and exterior rock colour was compared after the removal of the exterior layer using a hammer. Vegetation such as lichens growing on rock surfaces also indicates chemical weathering; which were observed during the site visit. Mechanical weathering such as cracks, foliation and abrasion could be observed on site and on the photographs. Another type of mechanical weathering, that must be included and which was also observed, was that from animals or vegetation activity. The number of animal activity in the area is not very high, however; large parts of the study site is densely vegetated by bushes and trees which have extensive root systems.

The type of material present in a landscape could also indicate the rate of weathering. It was established during the geological investigations that the two main types of rocks occurring in the study site are gneiss and schist. Schist comprises of light-coloured minerals such as feldspar and gneiss comprises of quartzo-feldspathic with biotite which is not as light-coloured. Consequently, observing the sand gravel occurring on the site, it could be deduced where weathering is dominant and which material is weathered more readily. The discontinuities within the rocks on the higher parts, such as the cliff as well as that of the loose rocks and the rock floor, where evident, were also observed to indicate if weathering has taken place or could take place.

The weathering occurring on the site and the climate conditions of the area were compared with the Peltier diagram (1950). Relevance of the Peltier diagram (1950) is discussed as part of the results. An overview of the different weathering is given in the results. These different types of weathering were then included on a map of the area.

4.1.3 Soil description

During February 2012 the last site visit was conducted with the aid of Dr. Moshia of the Soil Science Department of the University of Pretoria. Soil sampling was done at 12 points on the study site, which were surveyed using a GPS. The twelve areas used to observe the soil are shown on the map in Fig. 9.

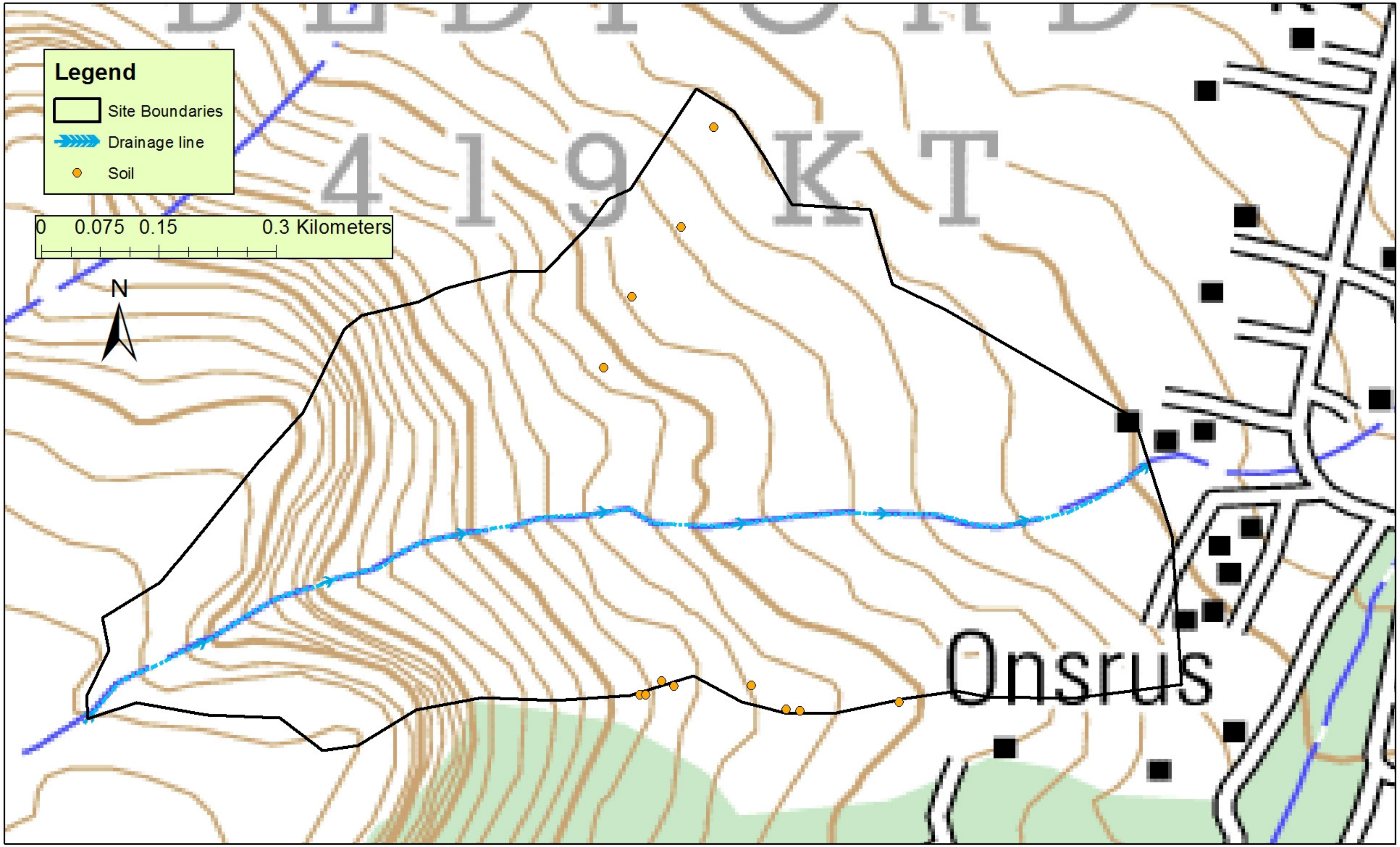

FIGURE 9: Map indicating soil sampling sites

Sampling positions were taken along a slope gradient on both sides of the drainage line. The main objective of these sampling positions was to observe different soil properties along a change in gradient in the densely vegetated area north of the drainage line and the grassed areas south of the drainage line. Similar soil profiling was done by Brown *et al.* (2004). Two profiles selected for sampling north and south of the drainage line were systematically selected along changes in soil characteristics.

Sampling was done using a shovel; removing the topsoil and subsoil layer to a typical depth of 100mm, thereby also observing the depth of both the topsoil and subsoil layer. During the sampling, a general description of the soil from the twelve sites was made and the soil was classified according to the South African system, devised by MacVicar *et al.* (1977). According to this system there are 5 topsoil diagnostic horizons and 15 subsoil diagnostic horizons. During the site visit, the soil colour was determined using the Munsell soil colour chart. According to this chart, soil colour is identified based on its Hue, Value and Chroma (Munsell, 1954).

During the sampling, 6 different soil classifications were observed, indicating similar soil sequences and classifications at some of these points. Six soil samples with a different classification were taken from site to be further analysed. Three samples were taken north and three samples south of the drainage channel to an approximate depth of 100mm. Topsoil and subsoil samples were taken at each of these 6 sites. The soil samples were taken to the Institute for Soil, Climate and Water Laboratorium, which is part of the Agricultural Research Council.

A texture analysis and percentage organic carbon analysis were done for these twelve samples. Methods used for the analysis were by means of the Bouyoucos hydrometer for the texture analysis and percent dry organic carbon: Walkley and Black method for the percentage organic carbon. The Bouyoucos hydrometer method is based on the settling time of soil particles falling through a viscous medium. The settling times of the particles are predicted using the Stokes Law (Piper, 1950; see also Gökbulak & Özcan, 2008:377). The Walkley and Black method is based on the principle that carbon is oxidized by the dichromate ion (Jackson, 1958; Gökbulak & Özcan, 2008). Additional chemical analyses done at the laboratorium were analysis of phosphorous, potassium, calcium, magnesium and sodium, resistance, pH, and total acid on the soil samples. Phosphorous was tested using P-Bray and the other chemicals were tested using ammonium acetate.

The classification of topsoil and subsoil for the 12 sites was then included in a table, as well as the soil texture and percentage organic carbon of the 6 soil samples. The soil was further defined according to the textural classes and family groupings of Buol *et al.* (2011). Chemical properties of the six soil samples were also tabled. A final table containing the soil colours, according to Munsell (1954), was also compiled. These properties, texture, percentage organic carbon, chemistry, and soil colours were compared in association with soil depth and sample location. No observations were done to indicate differences in soil due to weather or climate. This is due to the fact that the weather data for the area are general and not specific to various parts of the study site. It is envisaged that the hourly, diurnal, seasonal, latitude, cloudiness, wind and aspect will not differ between west and east; therefore these factors will not lead to changes in the soil formation.

4.2 Hillslope processes and formation

4.2.1 Erosional processes

Similar to the assessment of weathering, the types of erosion occurring and whether erosion differs over the study site were assessed. Observations of both hillslope and fluvial erosional processes took place during the site visits, as well as by studying the photographs taken on site. Hillslope erosion was surveyed by taking coordinates of all rills or gullies[21] that could be seen on the site and included on a map. Fluvial erosion was surveyed by taking the coordinates of areas where overland flow was observed (following Ghahramani *et al.,* 2011). Vegetation cover and slope gradient were also determined at areas of erosion to see whether there is a comparison between erosion, vegetation cover and slope gradient for the site (Ruiz Sinoga *et al*., 2010). Erosional properties of the drainage channel within the study site were also assessed.

Assessment of the erosional properties was based on the methodology used by Labbe *et al.* (2011). The assessment of the transportational or erosional characteristics of the channel is related to the bed and bank properties, which includes the type of bed and bank material. Bedrock channels indicate erosion has taken place, whereby channel beds with finer particles, such as sand, indicates deposition has taken place. Slumping of material or signs of undercutting or removed finer particles indicates bank erosion. Occurrence of vegetation in a channel could indicate areas of sediment deposition. This statement could be verified to observe if finer particles or even larger rocks are trapped within the vegetation or downstream due to the vegetation.

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[21] Rills and gullies assessed were based on images taken from Smith *et al.* (2011)

4.2.2 Mass movement description

Mariepskop has the characteristic appearance of large parts of the Drakensberg Mountains, whereby a cliff form the top part of the mountain and the lower area consists of accumulated material. The diagram by Chuang & McEwen (2010) (Fig. 5, page 25) illustrates the different types of mass wasting. Using this diagram, the type of mass wasting which created the geomorphological feature of the cliffs and area with accumulated material, could be identified. Vegetation was also observed for indications of mass movement such as soil creep. Areas of mass movement were compared against the slope gradients where these movements occurred. The areas of different mass movement were then plotted on a map.

4.2.3 Slope profile and plan characteristics

When choosing a profile, the area must be studied and zoned before profiling can take place (Young, 1972). Relief lines, according to the 1:50 000 topocadastral map, using ArcMap 10, were used. Finlayson & Statham (1980) argue that the slope must follow the area of steepest ground. One aspect of this study is to observe if there is a difference in the hillslope form laterally; therefore, different hillslope profiles are established over the entire study site, not only on the steepest slope area. Four profile lines, two north of the drainage line (long profile 1 and 3) and two south of the drainage line (long profile 2 and 4), were included using ArcCatalog 10 and ArcMap 10. These long profiles are included in the map in Fig. 10. Slope profile will follow the direction where the slope is perpendicular to the contour (Young, 1972; Clark & Small, 1982; Parsons, 1988); therefore, a profile line is not a rectilinear line in a hillslope. Rectilinear lines are called transect lines and are not the true slope profiles. The four profile lines included for this study were drawn perpendicular to the contours. A slope profile should begin on the top of a hillslope, where the landform has a very small slope, or has no slope (Young, 1972). All four profile lines started on the western boundary of the study site, where the area is at its highest point. Zones such as a valley should be avoided (Young, 1972; Clark & Small, 1982) when choosing a profile line, because true angle profiling is not correct over such an area. The drainage line is situated within a valley, consequently, the valley will influence the slope profiling to some extent.

Subsequent to choosing a profile line path, the different units of the slope profile must be obtained. There are different methods to measure the profile line units. One such unit is using a standard length, for example: each unit is 5m long. A second option is to use standardise units. In the second option, each distance where the profile form changes, a new units starts (Clark & Small, 1982; Parsons, 1988). The 1:50 000 topographical map includes relief lines for each 20m increase in height. Standardising the profile line units using every relief line showing a 20m increase in height is used. Thereafter, the distance of each unit must be surveyed (Clark & Small, 1982). It is advisable that the distance of a unit measured should not exceed 20m or be less than 2m in length (Young, 1972). Coordinates of the profile lines intersecting the relief lines were extrapolated onto Google Earth (2013) and the distances between these coordinates, which also indicates a decrease in 20m height, were calculated. Distances between each unit depend on a 20m decrease in height, therefore, it is probable for units to be longer than 20m or shorter than 2m, depending on the slope. The angle is then calculated (Clark & Small, 1982). The difference between the angles of two adjacent measured lengths should not exceed 2° on slopes which have an angle of less than 20°, and the difference between the angles of steep slope, slope which are more than 20° should not be more than 4°, with an exception if both units have a length of 2m (Young, 1972).

Calculated angles depend on the distance between two relief lines, which may lead to angles above the desired degrees. Slope unit angles were calculated using the formula below. Frequencies of these angles were plotted on a graph to indicate the variation of the slope angle frequency. Finally, the profile curvatures were measured. Curvature of a length on the long profile is calculated as shown in Fig. 11. Using the slope angle and curvature, an analysis of the profile form could be produced.

$$\begin{aligned}\text{Unit angle } (\theta) &= (\text{Change in unit height/change in unit length})^*\tan^{-1} \\ &= (20/\text{ change in unit length})^*\tan^{-1}\end{aligned}$$

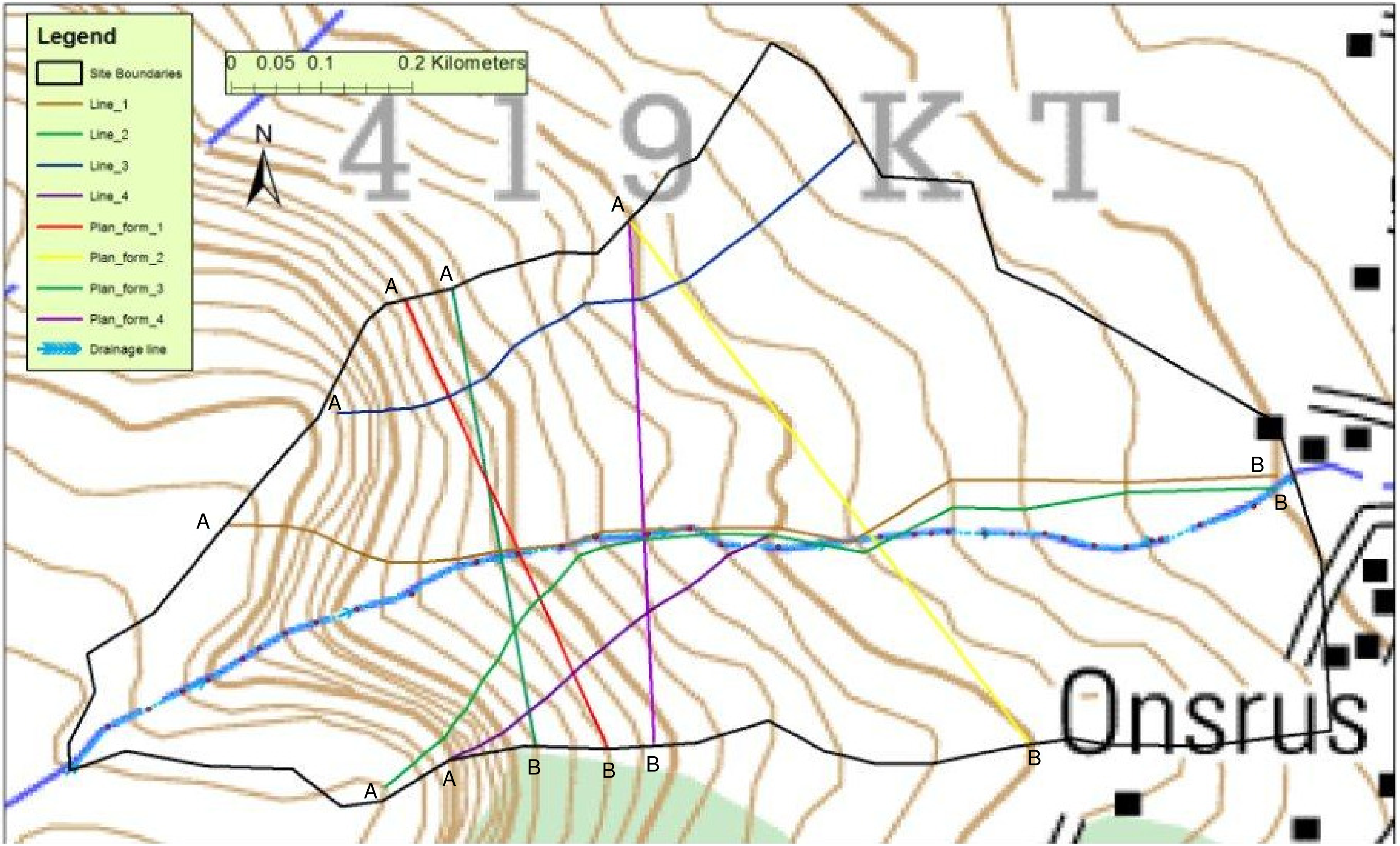

FIGURE 10: Map with the longitudinal profiles and plan forms

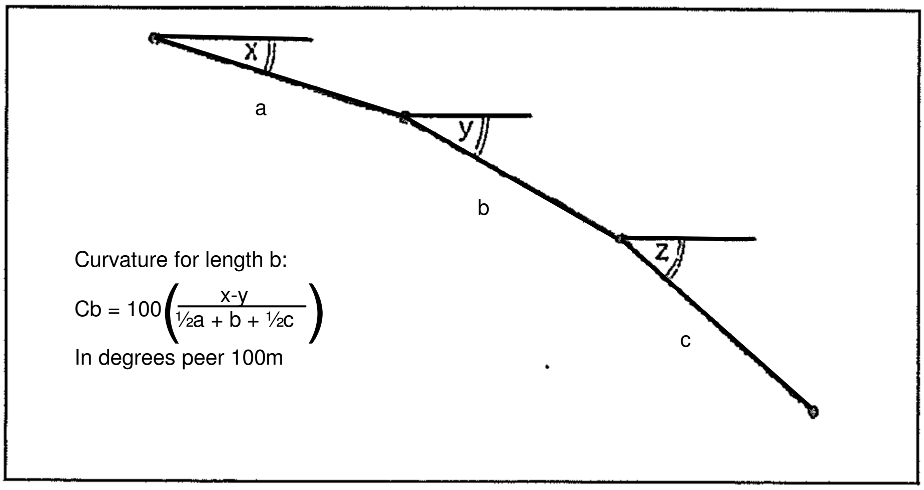

FIGURE 11: Calculation of profile curvature (taken from Clark & Small, 1982)

In contrast to profile lines, plan forms transect the area in a rectilinear line, thereby showing the difference in altitude of a certain line over and area. Plan forms differ depending how they are transacted across the study site. Different transects will indicate different features of the plan form across the site (Clark & Small, 1982; Parsons, 1988). Two different types of plan forms of the study site were measured. Four plans were drawn on the 1:50 000 topocadastral map using ArcMap10 and ArcCatalog10 (see Fig. 10). Plans 1 and 2 were included on the map, starting at a certain height at the northern boundary to the same height at the southern boundary of the study site, with plan 1 starting at 1140m a.m.s.l. on the northern boundary of the site and ending at 1140m a.m.s.l. at the southern boundary on the study site. Plan 2 starts at a height of 1000m a.m.s.l. at the northern boundary, ending at 1000m a.m.s.l. at the southern boundary. These plans will therefore show how the surface area varies from north to south, across the drainage line, from which the different angles and ultimately the contour curvature from north through to south can be observed on the study site. Plans 3 and 4 were included on the map, with plan 3 starting at 1090m a.m.s.l. on the northern boundary of the study site, and plan 4 starting at 1000m a.m.s.l. on the northern boundary of the study site, crossing the drainage line perpendicular and ending at the southern boundary of the study site. This will give an indication whether the two sides of the drainage line are similar in height across the drainage line. Similar to the slope profile lines, units will be based on a height difference of 20m, with some areas, a height difference of 10m. Slope plans will not only show an increase in height, but may also vary between different areas; therefore height differences of 10m were also used to focus on areas where the plan form changes from increasing in height and decreasing in height. Plan form angles and curvatures were calculated similar to the profile line.

Slope profile and plan angles were primarily used to layer the study site into the 9-unit slope model of Dalrymple *et al.* (1968). Areas near 1280m a.m.s.l., with slope angles which were lower than 45°, were classified as convex creep slope. Geomorphological processes were not assessed on these areas due to access constraints. All areas at high altitude, with angles between 45° and 65°, as well as any angles within such an area with angles above or below 40° and 65°, were classified as fall face slopes. According to Dalrymple *et al.* (1968), the fall face has a minimum angle of 45°, nevertheless this angle has between adjusted to ensure all angles are included into this unit and the preceding unit. Fall face slopes were also grouped together due to its geomorphological processes. Fall face units are characterised by mass movement and weathering and can be identified as a cliff face. Transportational midslope will include the area with slope angles between 26° and 39°. The angle has been adjusted as was done with the fall face unit. Similar to the fall face unit, all angles falling outside this parameter, but occurring within this unit, will also be classified as transportational midslope. Geomorphological processes that will occur on this unit are mass movement and weathering. These processes have also been considered as part of the transportational midslope. Colluvial footslopes will include the lower lying area with angles between 4° and 26°. Geomorphological processes, part of this unit, which were considered, are deposition and smooth regolith cover. Any low-lying angles less than 4° will be classified as alluvial toeslope.

4.2.4 Channel formation and longitudinal profile

To determine V-shaped and flat-floored valleys, the stream erosional properties, as well as the location within the stream, must be observed. A V- shaped valley occurs mostly in a straight stream further down in a stream. Lateral erosion of gravel banks could indicate flat-floored valleys. Bank comprising of bedrock would rather lead to rock-floored valleys. Channel patterns are observed by looking at the plan form of the channel; from resources such as the 1:50 000 topocadastral map. The identification of riffle-pool sequences was done by observing the topography of the channel, therefore the longitudinal profile of the stream (Lofthouse & Robert, 2008). Riffles are higher points in the channel long profile, but if these areas are less than 40mm high and length of more than 600m, it is named a dune. Pools are lower points, and if the gradient between the riffle and pool is steep, the sequence will be a step and pool. Therefore, before the riffle-pool sequences could be determined, the longitudinal profile of the channel must be determined. A second aspect to consider, is the bed material in the riffles and pools. Coarse sediment accumulates in a riffle and finer sediment in a pool. If riffles are flat, being less than 40mm high and length of more than 600m, it will be described as a dune. Vertical and lateral erosion of the drainage channel were plotted in a graph, which was compared to the location of the erosion on the study site (Anhert, 1996).

According to Rădoane *et al.* (2003) and Phillips & Lutz (2008), the longitudinal prolife is measured by plotting elevations along the plan form and interpolating into a linear graph. The height in m a.m.s.l. at each point was taken on the channel floor. Therefore this gradient is that of the channel floor and not of the banks of the steam. The GPS elevations in m a.m.s.l. were compared to the height of Google Earth in m a.m.s.l. There were differences in height between the actual GPS readings as taken in the field and the height from Google Earth. There may be a few reasons for this, one of which may be due to the fact that the GPS readings were taken inside the drainage channel and the Google Earth readings are given on the surface. The average difference in height for the 18 points is 18.9 (340m/18) higher reading for the Google Earth m a.m.s.l. than that of the GPS readings. Using this error, 16 points were plotted on Google Earth within the drainage channel and 19m were subtracted from the Google Earth readings. From the longitudinal profile, knick point can be identified. These are areas where the gradient of the profile makes a significant increase or decrease. The average gradient of the channel in the study site is measured as follows: Average gradient = cotan (distance/difference in height). The longitudinal profile of the drainage channel was plotted on a graph and compared to the location within the study site.

4.3 Channel classification

Zonal classification of both Schumm (1977) and Pickup (1984) were used. It was assumed that the source and armoured zones of the Pickup (1984) model coincide with zone 1 (production) of the Schumm (1977) model; the gravel-sand transition and mobile zones of the Pickup (1984) model coincide with zone 2 (transfer) of the Schumm (1977) mode; and the backwater (sink) zone zones of the Pickup (1984) model coincide with zone 3 (deposition) of the Schumm (1977) model. To conduct the hierarchical classification according to the South African model, the drainage channel, as part of the study site, had to be described as being a segment, reach, morphological unit or hydraulic biotope. Ecological river zonation of Harrison (1965, cited in Rowntree & Wadeson, 1999:12) and Noble & Hemens (1978) were used to assert the zone of the channel. Using the preceding results gathered for the drainage channel, as well as the zonation form the ecological model, the channel could be classified according to the South African hierarchical classification model. The 18 points within the drainage line that were observed during the site visits, were compared to the Ecological river zonation after Harrison (1965) and Noble & Hemens (1978) and the hierarchical organisation of a South African river stream system (taken from Rowntree & Wadeson, 1999).

4.4 Mapping of the study site

Various maps are compiled throughout this document. These maps include a topocadastral map with the grass patches included, geological map, map indicating soil sampling sites, map indicating the longitudinal profiles and plan forms, and a map indicating the 9-units slope model. These maps were all overlaid into one comprehensive map. Using this map, as well as the information regarding different geomorphological processes in the document, various associations between the different aspects of the study site could be made.

The final map was created using the legends from Gustavsson *et al*. (2006). According to the legend of Gustavsson *et al*. (2006), the geology is coloured according to different epochs or periods. Rock type occurring is given a code and indicated on the map in the colour coding according to the epoch/period, in this case red. Geomorphological processes included in the legend are morphometry/morphography, lithology, hydrography and additional specific processes. Morhpometry (morphography) includes features such as slope, escarpment and undulating terrains. Lithology includes clastic types; from clay to large boulders. The drainage line of the site is a hydrographic feature. Specific processes include creep and overland flow. The drainage line will be included in the map as a blue colour. All other geomorphological processes on the map will be colour coded according to the type of process/genesis occurring. These processes are endogenic, mass movement and weathering. In addition to the inclusion of the processes as stated in Gustavsson *et al*. (2006), the units of the 9-unit slope model will also be included as well as the grassland patches.

Chapter 5: Results and observations

Results and observations are provided in four main parts. Geological processes and regolith production, part one, comprises of bedrock geology, weathering processes, and soil description results. Hillslope processes and formation, as part two, comprise of erosional processes, mass movement description, slope profile and plan form, and channel formation and longitudinal profile. Part three show results of channel classification, and part four is a summary of these results presented within a geomorphological map.

5.1 Geological processes and regolith production

5.1.1 Bedrock geology

Soil covers the largest part of the study site; however there are a few areas without a soil cover where the underlying geology was exposed. Rocks from rockfall events were also observed across the largest part of the study site, but do not show the same type of prominent banding as was seen with the underlying strata where it outcrops. Predominantly, the rocks from rockfalls are from the quartzite and feldspar-rich schist rock unit. Feldspar-rich schist does not have the characteristic foliation than that of gneiss. The scattered feldspar-rich schist rocks vary from relatively small sized, no more than 300mm in length, to large boulders of more than 2m in length, and are generally dark with some white minerals included. Various characteristics occurred within these scattered rocks. White bands, which differ from schist and gneiss banding, could be observed in the darker rocks. These white bands are quartz-feldspar leucosomes. Leucosomes can be seen in Fig. 12, which is a photograph taken of a feldspar-rich schist rock located on the southern part of the study site. Leucosomes are the small and prominent white banding within the schist rock. Large clusters of scattered rocks are bonded into one large boulder by means of a cementing material known as tuff or conglomerate. Fig. 13 is a photograph of feldspar-rich schist and tuff. Parts of the rocks are distinctly white with some dark minerals included, which are xenoliths enclosed in the feldspar-rich schist as shown in Fig. 14.

Underlying strata, which outcrops at a few sites, showed prominent banding that differs from leucosomes. Rocks from these underlying strata are termed biotite-gneiss. Fig. 15 is a photograph taken of the underlying biotite-gneiss. In the photograph a leucosome can be seen, occurring just above a piece of biotite-gneiss banding. Black and white minerals, with a coarser texture than the feldspar-rich schist, can be seen in the biotite-gneiss. Pegmatite could also be observed in the gneiss banding. No amphibolites were observed in the rocks. The geological map, indicating the location of the feldspar-rich schist and biotite-gneiss, has been updated in Fig. 16.

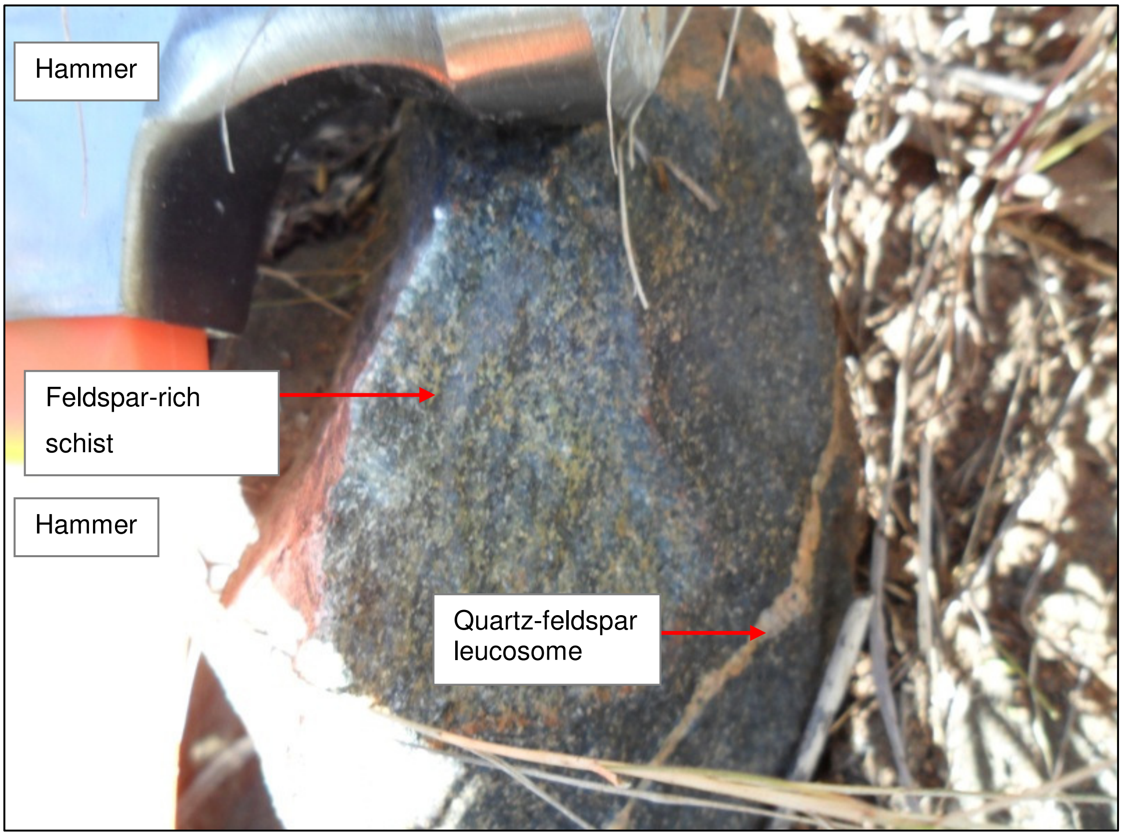

FIGURE 12: Feldspar-rich schist with an intrusive quartz-feldspar leucosome

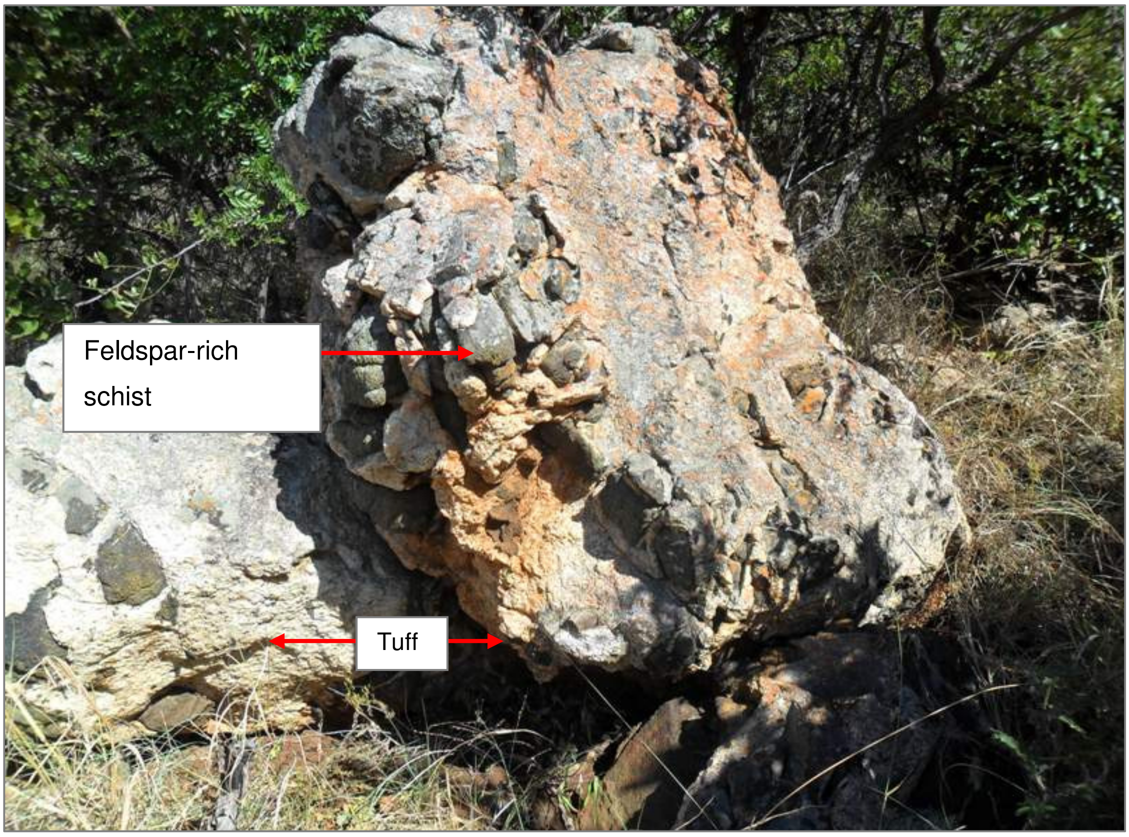

FIGURE 13: Feldspar-rich schist with associated tuff

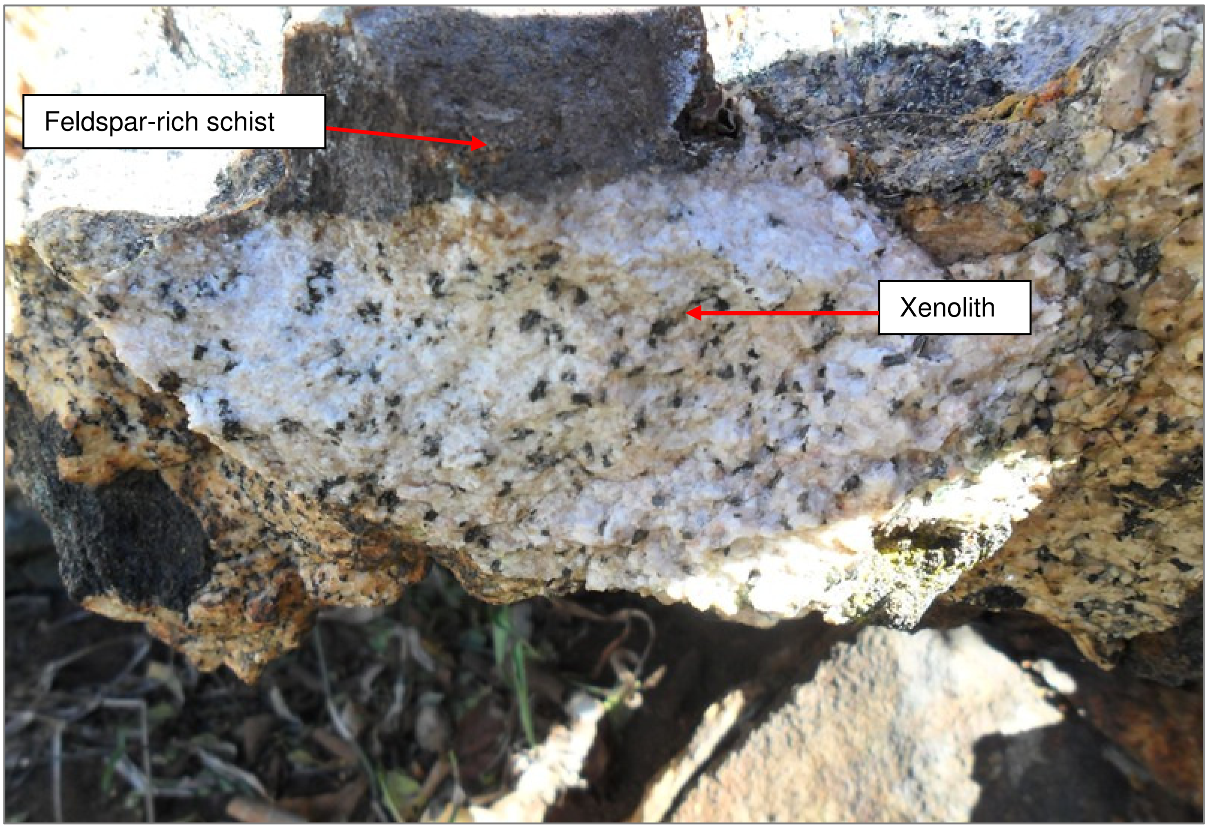

FIGURE 14: Feldspar-rich schist with mafic Xenolith

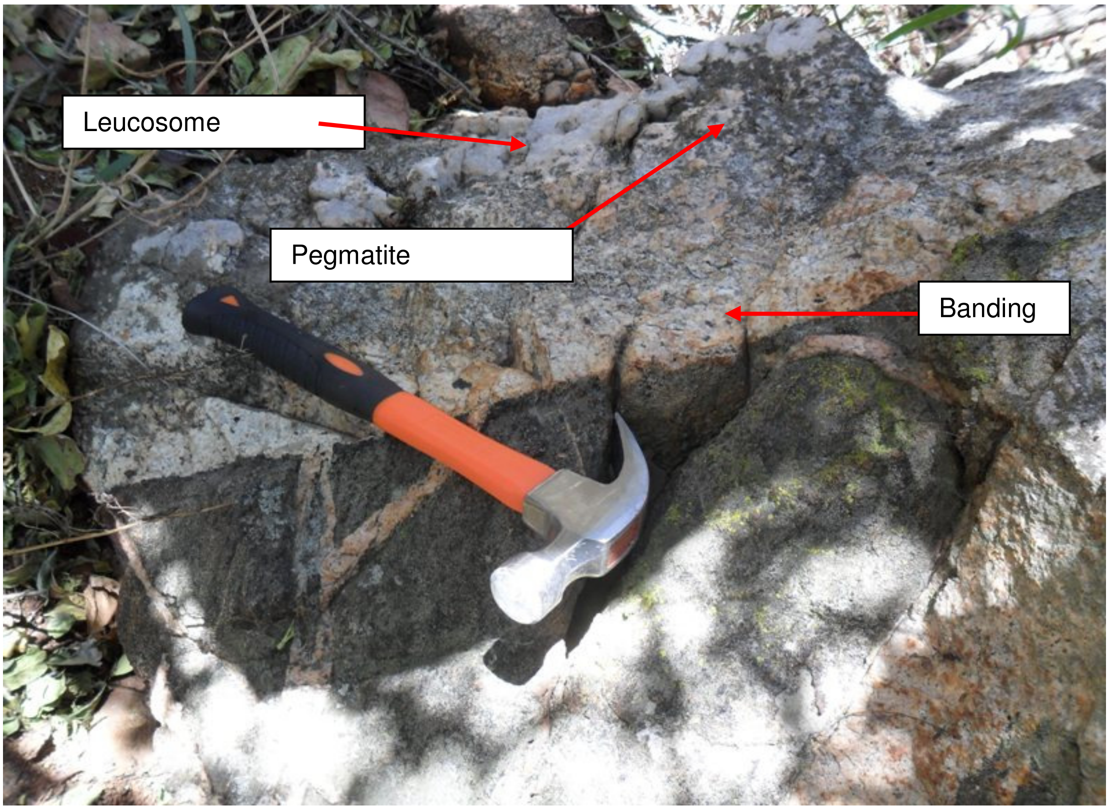

FIGURE 15: Biotite-gneiss with leucosome

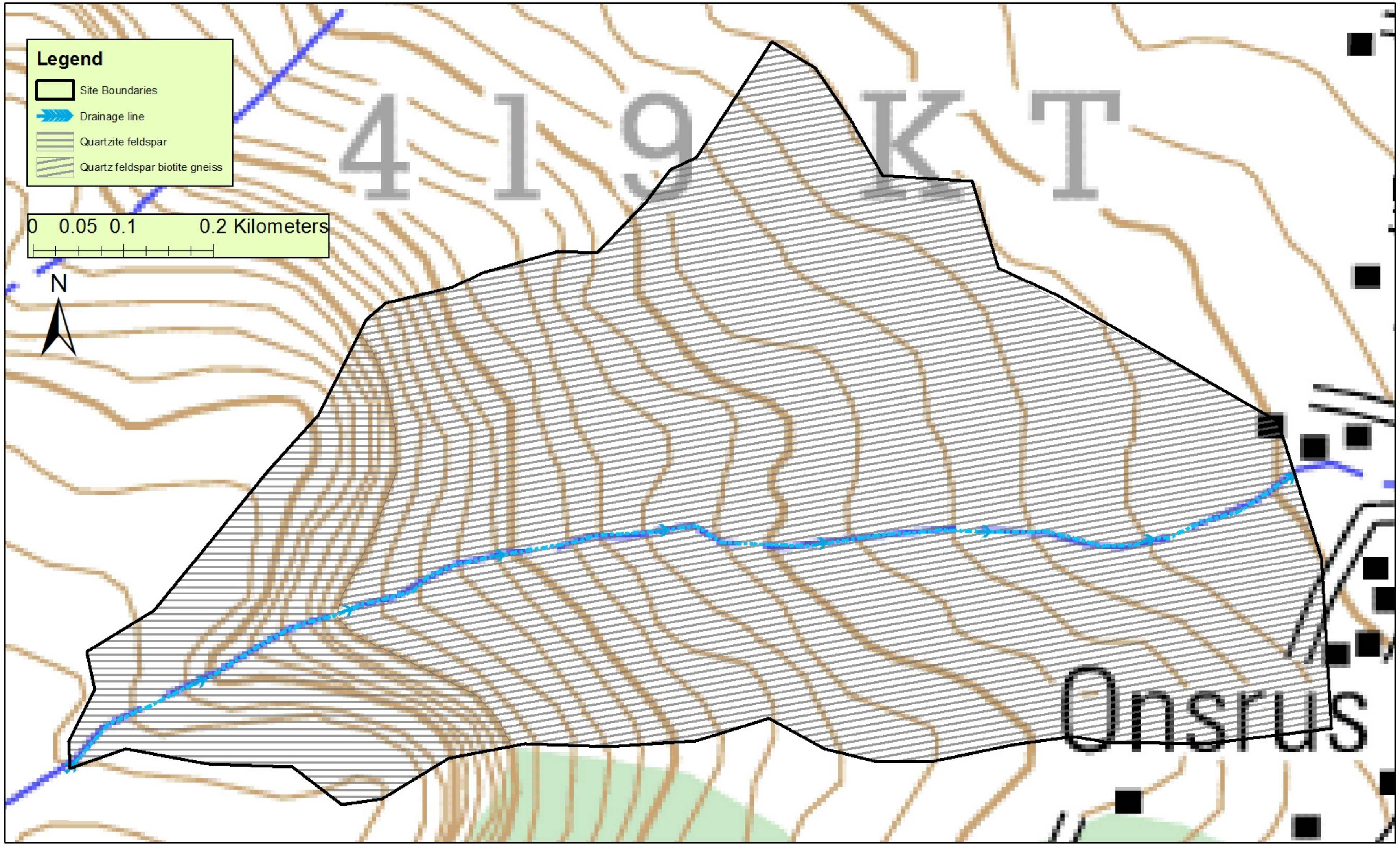

FIGURE 16: Updated geological map of the study site

5.1.2 Weathering processes

The study site can be divided into a cliff area towards the west and a general material covered area further to the east. Weathering-limited slopes will include the cliff on the western part of the study site and the drainage channel between points 12 and 15 (Fig 42 shows all weathering processes as part of the geomorphological map). The largest part of the study site is transport-limited. Weathering of the geology could be observed on the entire study site. Stains on the rocks were observed over the whole study site. Foliation on larger rocks was also observed. This foliation was mostly limited to larger rocks with a larger surface exposed to the atmosphere. Two examples of rocks showing chemical and physical weathering are given below in Fig. 17 and Fig. 18. The first of these two figures was taken in a more densely vegetated area than the second figure. Biological weathering in the form of moss was also observed on the rocks. Cracks can also be observed on the rock in Fig. 17. Roots of vegetation could also lead to physical weathering; these are not indicated in the photographs. The loose material towards the south is most probably physical weathering from the schist.

Mariepskop has an annual rainfall of 641.6mm and annual temperature between 15ºC to 21ºC. Comparing this to the Peltier graph, the area should be prone to moderate chemical weathering, but this is at best a generalisation. This varying in type of weathering shows that the weathering is not influenced by the weather of the area as described by the Peltier graph. Within the denser vegetated area, which is located on the larger part of the area, excluding the western part of the study site (cliff face), gravel type material from physical weathering was not observed. This area is mostly covered with well- formed soil or larger boulder type of rocks. The southern part of the site, where vegetation is not dense, the surface is covered with smaller grained light-coloured material, as shown in Fig. 19. As can be seen from this material, it is lightly coloured. The drainage channel is covered by various materials ranging from very fine soil material to large boulders. Discontinuities could also be observed in the cliff on top of the study site. According to these results, the vegetation cover influenced chemical weathering or physical weathering. The loose material on the northern part of the study site and drainage channel was darker with in-between light coloured pebbles. These light coloured material dominated many parts of the southern part of the study site. The light coloured material is weathered schist material. The darker material could either be due to an increase in the weathering of gneiss rock, which is less readily weathered, or due to chemical weathering being more prone. Kinetic energy from fluvial processes in the drainage channel causes additional physical and chemical weathering processes.

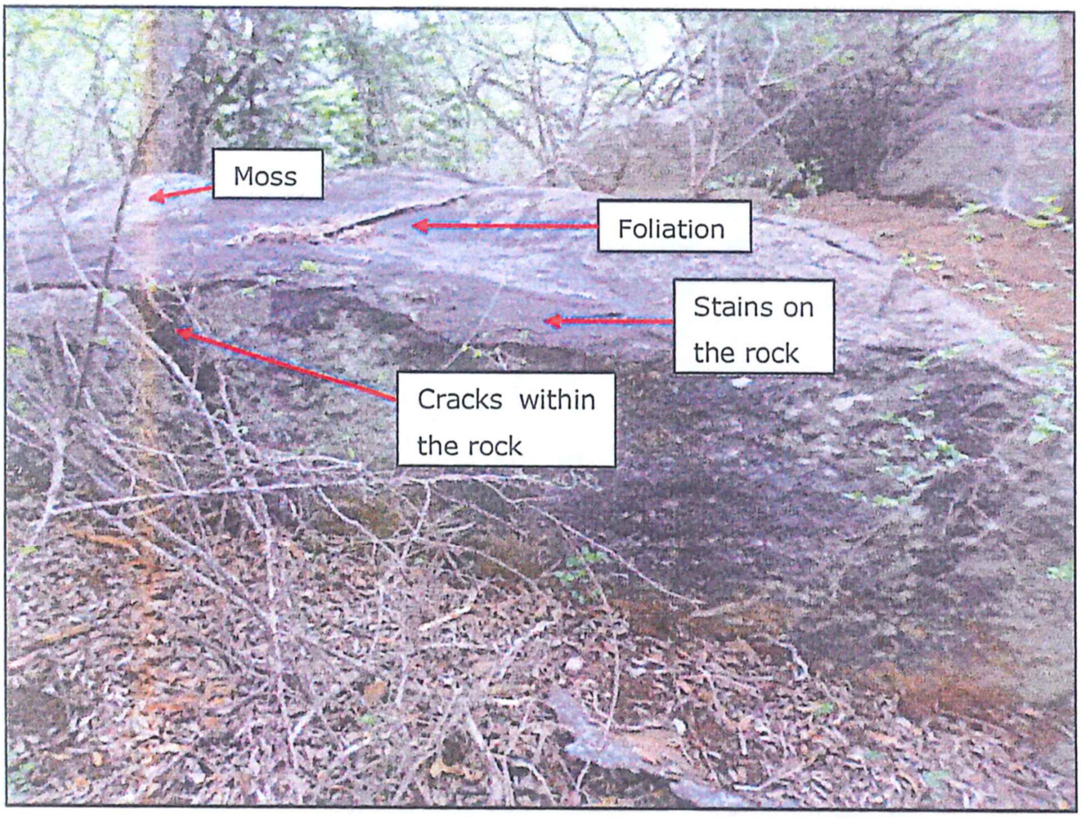

FIGURE 17: Chemical and physical weathering on a rock in densely vegetated area

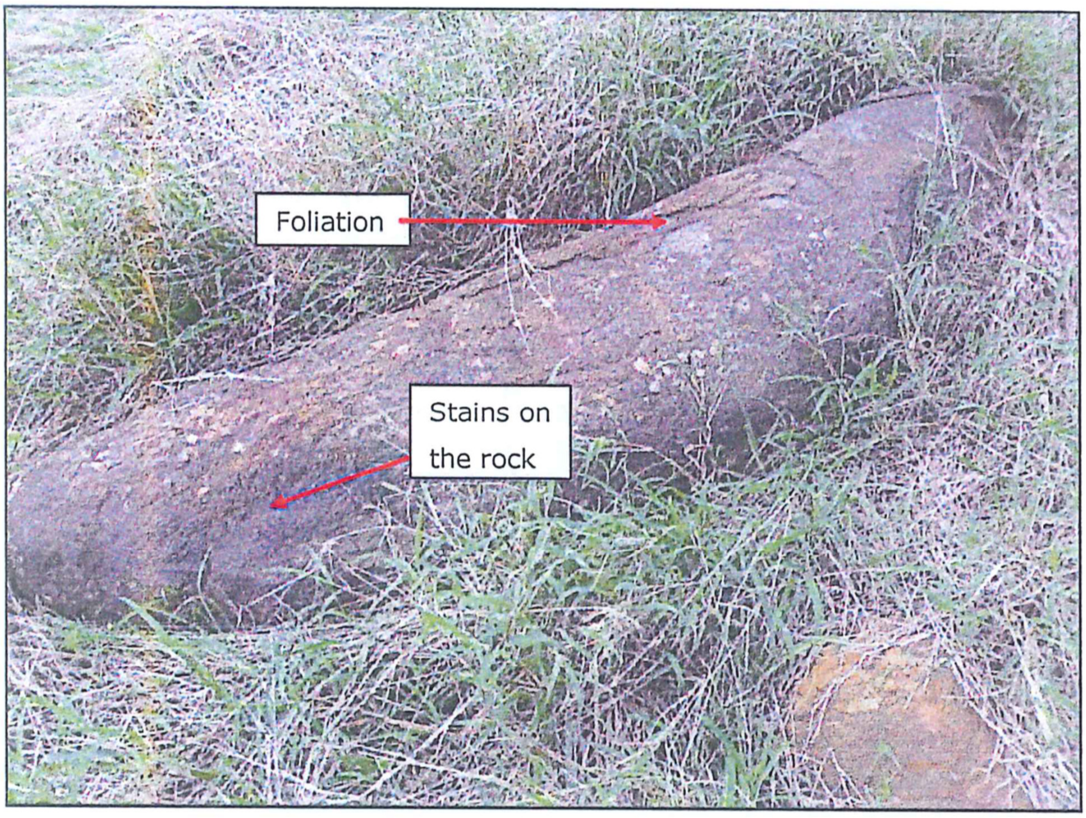

FIGURE 18: Chemical and physical weathering on a rock in grass areas which is less densely vegetated

FIGURE 19: Photograph of the grass area on the study site showing rock surface with scattered feldspathic material.

5.1.3 *Soil description*

The classification of topsoil and subsoil layers, as well as additional descriptions, is given in Table 2. Poorly developed soil, due to the weathering of granite-gneiss, was observed on the study site as an orthic A-horizon. The slow weathering could also be observed due to the lithocutanic B-horizon. The feldspathic material observed on the soil will be due to the weathering of the schist. The soil texture, as well as the percentage organic carbon, is given in Table 3. Table 4 is the classification of the samples into these classes and family groupings.

TABLE 2: Topsoil classification of topsoil and subsoil layers (see Figure 9 on page 42 for the soil sampling locations)

Site	Coordinates	Sample		Classification	Description	Soil group
1	S24°31'25.773"	1	Topsoil	Orthic A	Approximately 200mm deep A horizon; no erosion visible; many ant heaps; many small, scattered feldspar-rich schist material (pebbles) on soil surface; B horizon is cutanic; many feldspathic rocks in B horizon; therefore young soils on weathered rock.	Lithic
	E30°52'49.532"		Subsoil	Lithocutanic B		
2	S24°31'25.773"		Topsoil	Orthic A	A horizon less thick than site 1; many ant heaps; many small, scattered feldspar-rich schist material (pebbles) on soil surface; B horizon is cutanic; therefore young soils on weathered rock.	Lithic
	E30°52'49.763"		Subsoil	Lithocutanic B		
3	S24°31'25.234"		Topsoil	Orthic A	A horizon less thick than site 1; no erosion visible; many ant heaps; many small, scattered feldspar-rich schist material (pebbles) on soil surface; B horizon is cutanic; many feldspathic rocks in B horizon; therefore young soils on weathered rock.	Lithic
	E30°52'50.397"		Subsoil	Lithocutanic B		
4	S24°31'25.422".	2	Topsoil	Orthic A	Shallow A horizon; iron concentrated, apedal B horizon; B horizon is not cutanic.	Oxidic (hutton)
	E30°52'50.919"		Subsoil	Apedal B		
5	S24°31'25.396".		Topsoil	Orthic A	Very shallow A horizon; many smaller rocks (stones) in A horizon; iron concentrated, apedal B horizon; B horizon is not cutanic.	Oxidic (hutton)
	E30°52'54.145"		Subsoil	Apedal B		
6	S24°31'26.399".		Topsoil	Orthic A	Very shallow A horizon; many smaller rocks (stones) in A horizon; iron concentrated, apedal B horizon; B horizon is not cutanic.	Oxidic (hutton)
	E30°52'55.584"		Subsoil	Apedal B		
7	S24°31'26.467".		Topsoil	Orthic A	Very shallow A horizon; many smaller rocks (stones) in A horizon; iron concentrated, apedal B horizon; B horizon is not cutanic.	Oxidic (hutton)
	E30°52'56.133”		Subsoil	Apedal B		
8	S24°31'26.099"	3	Topsoil	Orthic A	Very shallow A horizon; many smaller rocks (stones) in A horizon; iron concentrated, apedal B horizon; B horizon is not cutanic.	Oxidic (hutton)
	E30°53’0.25"		Subsoil	Apedal B		
9	S24°31’12.256"	4	Topsoil	Orthic A	More rocks than on southern part of drainage line; rocks are feldspathic; A horizon is deep, B horizon mostly rocks; therefore young soils on weathered rock.	Lithic?
	E30°52'48.009"		Subsoil	Lithocutanic B		
10	S24°31'9.309"		Topsoil	Orthic A	More rocks than on southern part of drainage line; rocks are feldspathic; much more smaller rocks on soil surface; smaller drainage line going from north to south (into main	Lithic?
	E30°52'49.199"		Subsoil	Lithocutanic B		

Site	Coordinates	Sample		Classification	Description	Soil group
					drainage line); A horizon is deep; B horizon is mostly rocks; therefore young soils on weathered rock.	
11	S24°31'6.407" E30°52'51.245"	5	Topsoil	Orthic A	More rocks than on southern part of drainage line, but less than at site 9 and 10; rocks are feldspathic; much more smaller rocks on soil surface; smaller drainage line going from north to south (into main drainage line); A horizon is deep; B horizon is mostly rocks; therefore young soils on weathered rock.	Lithic
			Subsoil	Lithocutanic B		
12	S24°31'2.256" E30°52'52.564"	6	Topsoil	Orthic A	Fewer rocks than sites 9 to 11; shallow A horizon; B horizon mostly rocks and less weathered than sties 9-11; therefore very young soils on weathered rock.	Lithic
			Subsoil	Lithocutanic B		

TABLE 3: Soil texture and percentage organic carbon of the 6 soil samples

Sample nr	Topsoil/subsoil	Sand (W)	Silt (W)	Clay (W)	Org. C (/o)
1	Topsoil	68	14	18	1.55
	Subsoil	72	12	16	2.75
2	Topsoil	56	18	26	2.61
	Subsoil	70	10	20	3.14
3	Topsoil	60	12	28	2.79
	Subsoil	70	12	18	2.56
4	Topsoil	76	12	12	3.07
	Subsoil	Insufficient soil for analysis			1.35
5	Topsoil	58	14	28	3.54
	Subsoil	48	20	32	1.74
6	Topsoil	68	12	20	2.67
	Subsoil	Insufficient soil for analysis			

TABLE 4: Classification of soil samples into textural classes and family groupings

Sample nr	Topsoil/subsoil	Textural class	Soil family
1	Topsoil	Sandy loam	Coarse loamy
	Subsoil	Sandy loam	Coarse loamy
2	Topsoil	Sandy loam	Coarse loamy
	Subsoil	Sandy loam	Coarse sandy
3	Topsoil	Sandy clay loam	Fine loamy
	Subsoil	Sandy loam	Coarse sandy
4	Topsoil	Loamy sand	Sandy
	Subsoil	No data	No data
5	Topsoil	Sandy loam	Coarse loamy
	Subsoil	Sandy clay loam	Fine loamy
6	Topsoil	Sandy loam	Coarse loamy
	Subsoil	No data	No data

Using the information from Table 3, the soil was plotted onto a triangular diagram for texture class (Fig. 20 to Fig. 22) and soil family groupings (Fig. 23 to Fig. 25) on the basis of particle size (taken from Buol *et al.*, 2011). The red dots indicate topsoil and the blue dot indicate subsoil for each sample. Data from Table 3 and Table 4 can be summarised as follows: the amount of subsoil taken at samples sites 4 was too small for textural analysis and there was no subsoil sample taken at sample site 6. The reason for the subsoil at sample site 6 not being analysed, was due to the fact that there was only a shallow A-horizon and no B-horizon. B-horizon at sample site 4 was also very shallow.

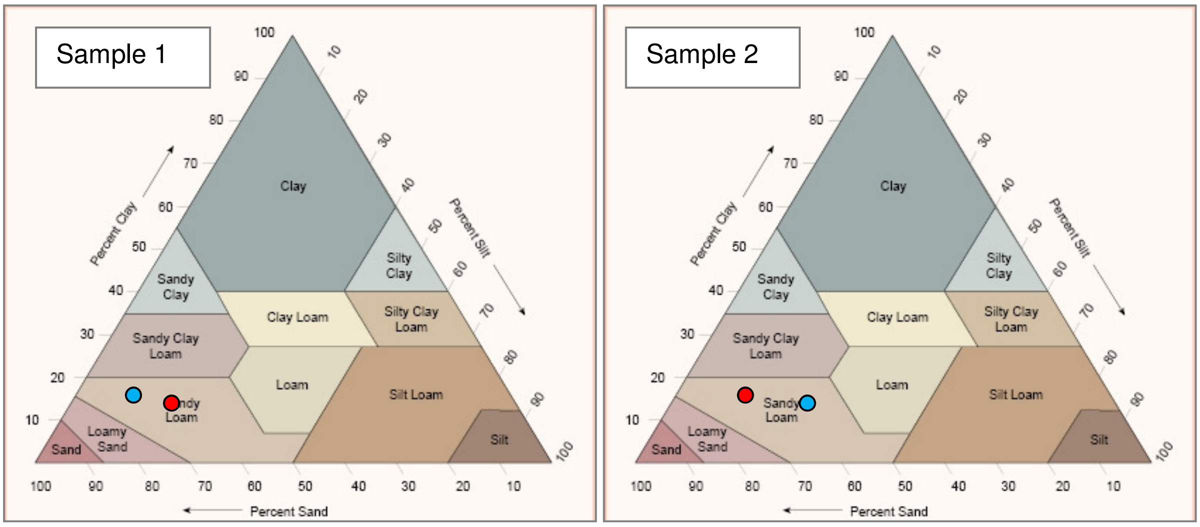

FIGURE 20: Textural classes for samples 1 and 2 (taken from Buol *et al.*, 2011)

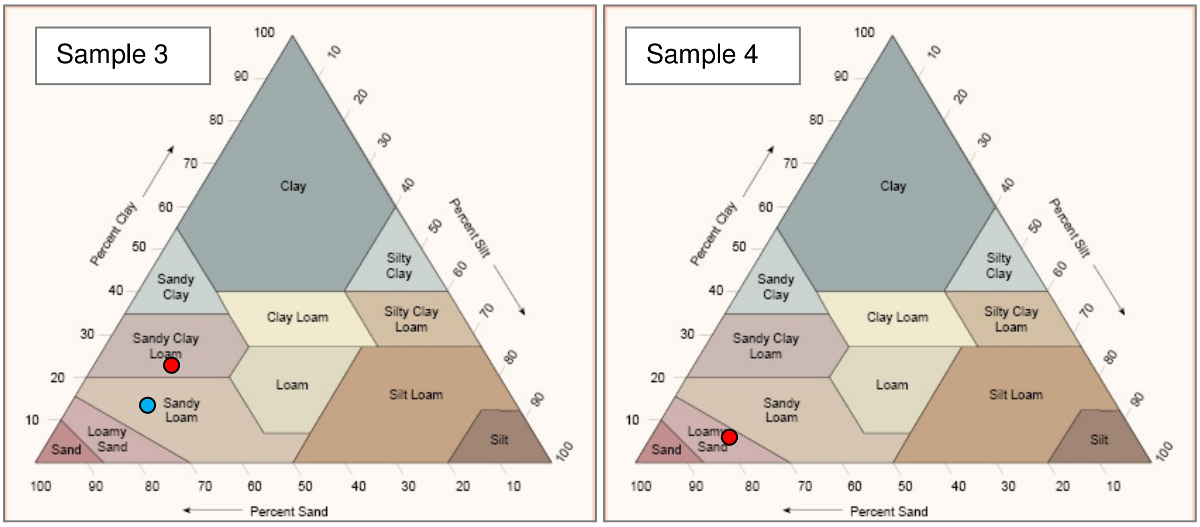

FIGURE 21: Textural classes for samples 3 and 4 (taken from Buol *et al.*, 2011)

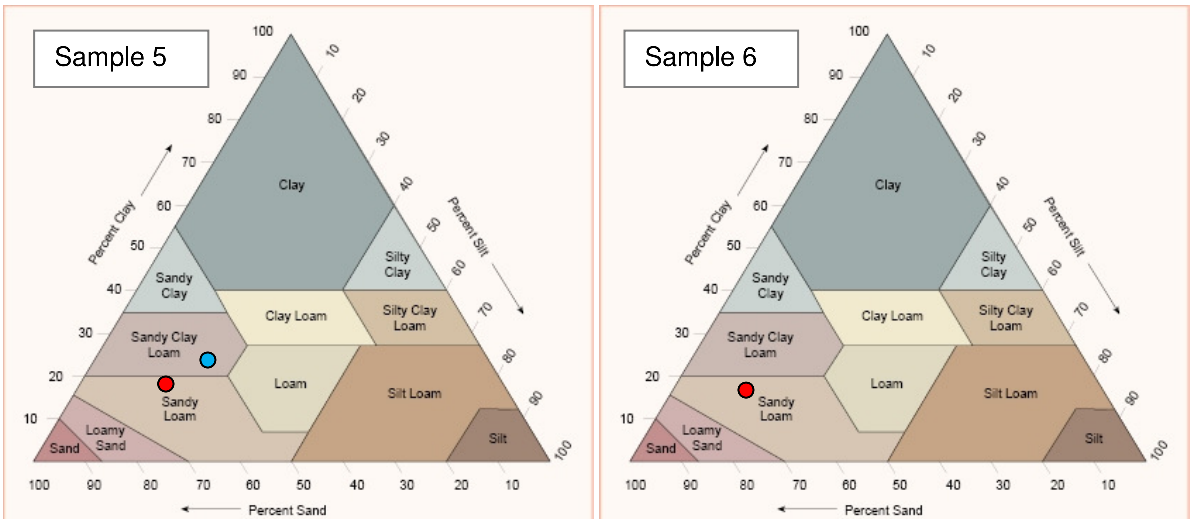

FIGURE 22: Textural classes for samples 5 and 6 (taken from Buol *et al.*, 2011)

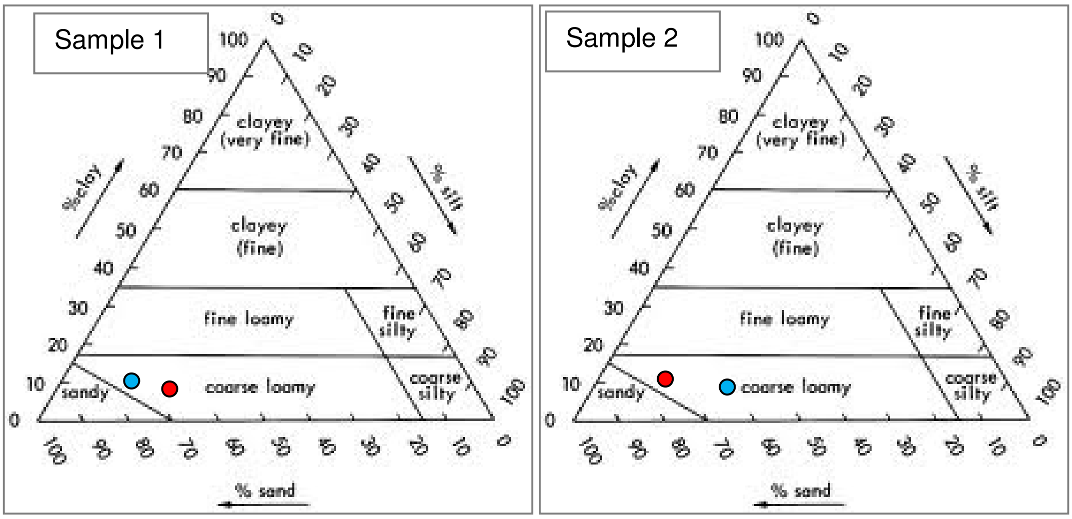

FIGURE 23: Family textural grouping for samples 1 and 2 (taken from Buol *et al.*, 2011)

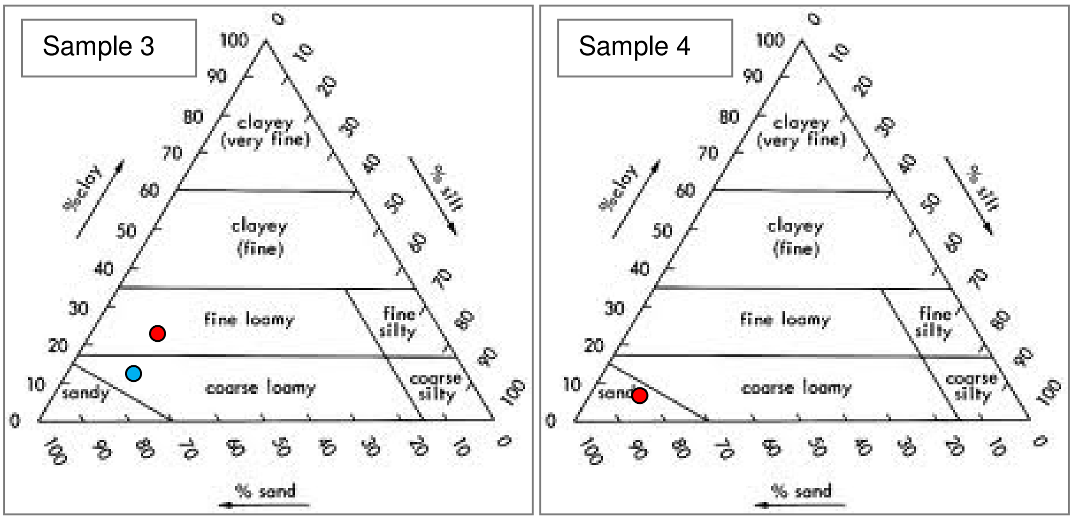

FIGURE 24: Family textural grouping for samples 3 and 4 (taken from Buol *et al.*, 2011)

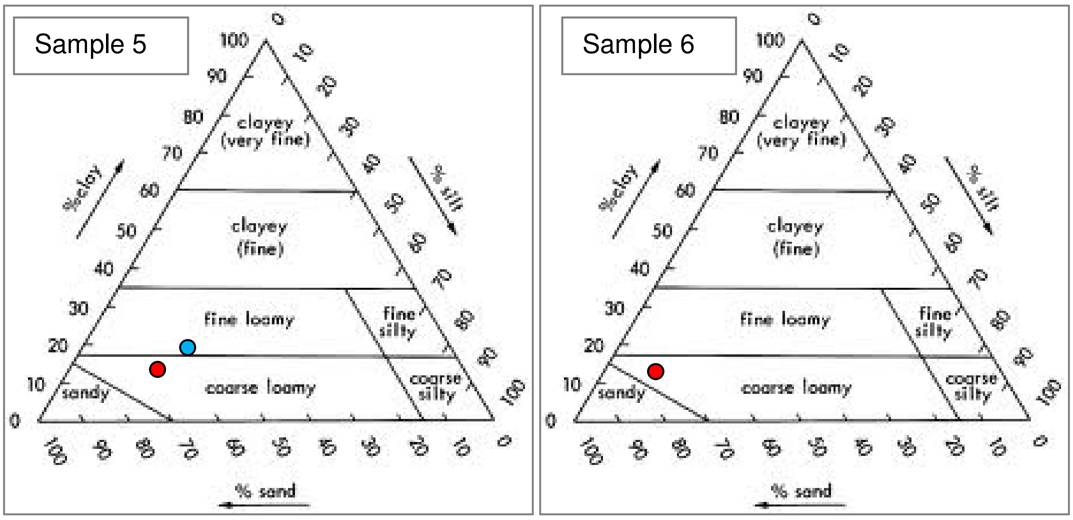

FIGURE 25: Family textural grouping for samples 5 and 6 (taken from Buol *et al.*, 2011)

The topsoil at sample site 4 has the highest percentage of sand and the lowest percentage of clay. This topsoil is also classified as the only loamy sand texture and within the sandy textural family. Seven of the ten soil samples that could be analysed, fall within the sandy loamy textural classification, which falls within the coarse loamy family grouping. The topsoil of samples site 3 and the subsoil of sample site 5 fall within the sandy clay loam textural classification and within the fine loamy classification. Most of the A-horizons are poorly sorted, as well as the B-horizon for sample 5 on the northern part of the study site. The percentage organic carbon could be analysed at eleven sites, with only no subsoil at samples site 6 to be analysed. The percentage of organic carbon is highest in the topsoil at sample site 5, with subsoil at sample site 2 and topsoil at sample site 4 also above 3%. These higher percentages are therefore occurring within the sandy loam or the loamy sand samples. Five of the remaining eight sites have organic carbon percentage above 2%. The topsoil at samples site 1, and subsoil at sample sites 4 and 5 were above 1% with the subsoil at sample site 4 being the lowest.

Chemical composition, resistance, and pH are given in Table 5. The table gives the concentrations in mg/kg; therefore 1mg is 1X10^{-6} percentage of a kg soil sample. The amount of phosphorous is the highest within the subsoil of samples site 3, being 18.67mg/kg, with the topsoil of sample site 3 and topsoil of samples site 4 being second and third highest. All other soils have a phosphorous concentration of less than 1mg/kg. The potassium concentration within the topsoil of site 5, topsoil and subsoil of site 6 are above 200mg/kg. All other soil samples have concentrations below 100mg/kg. Most of the soil samples have calcium concentrations above 1000mg/kg, with subsoil sample at site 5 being the highest. The soil samples of site 1 as well as the subsoil sample at site 4 have a calcium concentration below 1000mg/kg. Magnesium concentration is the highest within the subsoil of sample 5 and topsoil of samples site 2, being above 2000mg/kg. Soil samples at site 3 have concentrations of magnesium above 1000mg/kg. All other samples have magnesium concentrations below 1000ng/kg. The sodium concentration is the highest in the subsoil of samples 5, thereafter in the topsoil of samples site 2. The soil resistance is the highest in topsoil of sample site 1, soils of samples site 4 and subsoil of sample site 2. All soil pH measures are within the broader neutral spectrum, all being somewhat lower than 7. The lowest pH is 5.7, which is the subsoil of sample site 4. All soils on the study site have a pH of less than 7, indicating cations form the gneiss. The subsoil of sample site 1, soils at sample site 3, and topsoil of sample site 4 are also more acidic; being less than a pH of 6.

TABLE 5: Chemical properties of the six soil samples

Sample nr	Topsoil/subsoil	P	K	K	Ca	Ca	Mg	Mg	Na	Na	R	pH
		mg/kg	mg/kg	me/100g	mg/kg	me/100g	mg/kg	me/100g	mg/kg	me/100g	ohm	
1	Topsoil	0.12	27	0.0691	640	3.1936	796	6.5514	31.8	0.1383	3230	6.05
	Subsoil	0.69	69	0.1765	878	4.3812	565	4.6502	20.7	0.0900	1840	5.91
2	Topsoil	0.44	40	0.1023	2415	12.0509	2029	16.6996	46.9	0.2040	1200	6.29
	Subsoil	0.73	94	0.2404	964	4.8104	858	7.0617	17.7	0.0770	2720	6.14
3	Topsoil	4.72	98	0.2506	1364	6.8064	1185	9,7531	25.9	0.1127	1750	5.91
	Subsoil	18.67	86	0.2199.	1182	5.8982	1126	9.2675	31.9	0.1388	1820	5.77
4	Topsoil	2.8	35	0,0895	1230	6.1377	684	5.6296	17.5	0.0761	3040	5.85
	Subsoil	0.65	25	0.0639	530	2.6447	760	6.2551	19.2	0.0835	3150	5.7
5	Topsoil	0.55	395	1.0102	2126	10.6088	783	6.4444	14.2	0.0618	1400	6.39
	Subsoil	0.46	29	0.0742	3364	16.7864	2510	20.6584	76.1	0.3310	1080	6.64
6	Topsoil	0.45	209	0.5345	1334	6.6567	609	5.0123	12.2	0.0531	2180	6.35
	Subsoil	0.45	209	0.5345	1334	6.6567	609	5.0123	12.2	0.0531	2180	6.35

There is no conformity between high sodium and potassium in the soil samples; however, the schist occurring on the study site contains potassium-feldspar. Where potassium within the soil samples is high, it could indicate the increased weathered schist in the soil. The potassium levels are high at sample 6 and topsoil of sample 5 on the northern part of the study site, as well as sample 3 occurring south-east on the study site. These three samples are all located on a lower altitude than the other samples. If it is considered that the air temperature rise for every 170m fall in altitude, it could be assumed that these chemical reactions at the samples sites showing high potassium values have been higher, therefore a more readily weathering of the schist. The samples sites on the northern part of the study site could also have higher chemical reactions due to the different type of vegetation growth. The soil depth decreases on the southern part of the study site from higher to lower altitude; which is inconsistent with the statement that soil moves downslope, therefore the soil layer on a higher slope is usually thinner, with a thicker layer in downslope areas where soil has been deposited. The soil on the northern part of the study site is also the deepest on the higher altitudes. Therefore, the slope profile or plan, as well as the slope angle, may influence the soil formation.

Soil colours are given in Table 6. The following results are given using the matrix colours of Fitzpatrick (1980). All soils that are yellowish red or weak red indicate high amounts of iron oxide. These soils have a high water drainage capacity. Reddish yellow soils are common in tropical and sub-tropical area and are due to the colour of the sediments form which formed. Dark yellowish brown and brown soils have low concentrations of iron oxide and indicate soils with slower water drainage. Soils that are brown or dark brown contain ferric hydroxide and / or colloidal organic matter. These soils contain therefore organic matter and are in the early stages of weathering. Soils with weak red colours were also sandy loam soil. The percentage of organic carbon within these three samples differs from above 1%, above 2% and above 3%. The reddish yellow soil sample occurs within sandy loam soil with a low organic carbon content of 1%. Yellowish brown soil samples occur within sandy loam and sandy clay loam soils. The percentage organic carbon for these two areas are moderate compared to the other sites, above 2%. The dark yellowish brown soil samples occur within sandy loam soil with moderate percentage organic carbon compared to the other sites. The brown soil occurs within loamy sand with a relative high organic content compared to the other site, above 3%. Lastly, the dark brown soil occurs within sandy clay loam with low organic carbon compared to the other sites. Most of the soils on the northern part of the study site are dark and contains red colours. This therefore indicates these soils have high organic content as well as being well-drained soils.

The soils on the southern part of the study site are lighter and more yellowish, indicating less well-drained soils with less organic content. This lower organic content may be due to the fact the vegetation cover is grass, whereby the vegetation cover for the northern soil samples are denser. No grey of bluish soil occur on the study site.

TABLE 6: Soil colours according to Munsell (1954) of the six soil samples

Sample nr	Topsoil/subsoil	Hue	Value	Chroma	Colour
1	Topsoil	7.5 YR	6	8	Reddish yellow
	Subsoil	10 YR	5	4	Yellowish brown
2	Topsoil	10YR	4	4	Dark yellowish brown
	Subsoil	No data			
3	Topsoil	10 YR	5	8	Yellowish brown
	Subsoil	10 YR	4	6	Dark yellowish brown
4	Topsoil	7.5 YR	5	2	Brown
	Subsoil	7.5YR	5	6	Yellowish red
5	Topsoil	2.5 YR	4	2	Weak red
	Subsoil	10YR	3	3	Dark brown
6	Topsoil	2.5YR	4	2	Weak red
	Subsoil	No data			

5.2 Hillslope processes and formation

5.2.1 Erosional processes

Major gullies do not occur on site; however a number of rills varying in size were observed on the northern part of the study site. Fig. 26 is a photograph taken of the northern part of the study site showing rills. It is envisaged that the smaller rills have been created due to the scattered feldspar-rich schist rocks, vegetation, or even from human impacts. Fig. 26 indicates that the scattered feldspar-rich schist rocks create an area of concentrated water flow, which leads to the formation of the smaller rills; therefore these rills are not developed due to subsurface flows. Large rills, which were also observed on the northern part of the study site, have not been formed due to scattered rock concentrating water flow and can be an indication of subsurface flow. No gullies or rills were observed on the southern part of the study site.

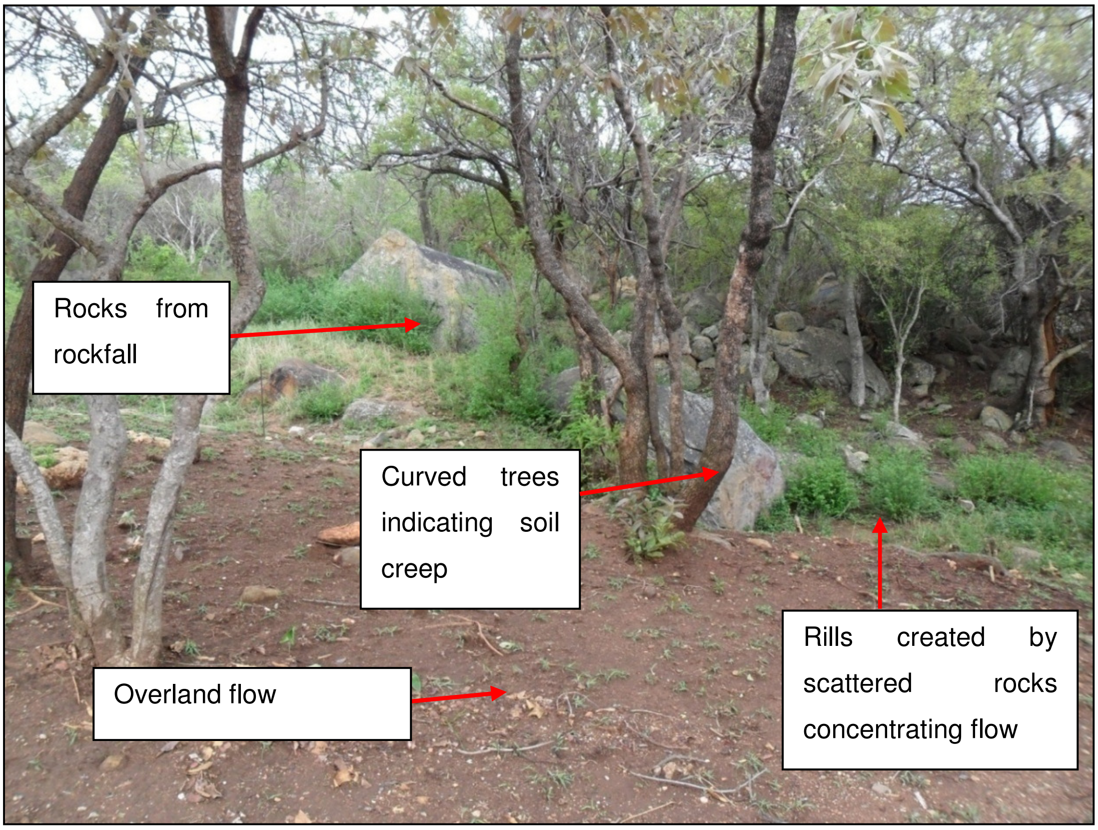

FIGURE 26: Photograph of the northern part study site located south of the drainage channel, indicating the scattered rocks from rockfall, soil creep and flow.

Fluvial erosion can occur over the entire study site in the form of rainsplash or overland flow run-off. Erosion from splash can occur in the more densely vegetated area due to large raindrops falling from leaves and branches, and from direct rainsplash in the less densely vegetated area due to a decreased vegetation cover to prevent rainsplash erosion. In the event of a storm, erosion will initially be due to rainsplash erosion and which will then be replaced by overland flow. It is therefore difficult to assess whether such erosion is from rainsplash, or from overland flow. There are a few patches on the southern part of the study site that have no soil layer (Fig. 19, page 56). A layer of feldspar-rich schist material covers gneiss bedrock on these patches. These patches occur at a height of approximately 990m a.m.s.l. to 1002m a.m.s.l. Overland flow and/or rainsplash erosion dominates these patches.

To observe deposition and/or erosion of material within the channel is not clear-cut. The absence of loose material such as gravel, soil and/or rocks in the drainage channel, may be due to either the removal of such material through erosion or, due to the lack of such material occurring in the vicinity of and in the drainage channel. When examining the surrounding areas of this drainage channel, as well as the drainage channel itself, sufficient material is present. Therefore it can be deducted that the absence of any loose material in the drainage line is not from a lack of loose material, but indicates the removal of material through erosion. Some of the loose rocks in the channel are significantly rounded, indicating rocks either being transported through fluvial processes for some distance or due to chemical weathering. Point 6 (Fig. 27) has loose rocks transported by fluvial processes. Material occurring within the channel may be as a result of excess material situated within the channel, which has not yet been eroded away. This material could also occur because erosion have taken place in an earlier stage; however material which is present within the channel at the time of the site visit may have been deposited after erosion has taken place. This material will then be removed once the channel is in flow. Material within the channel may also be windblown material or due to material from the channel banks falling into the channel. Windblown material is evident in Fig. 27, also taken at point 6.

The drainage channel occurs in an area where the vegetation is denser and not dominated by grass species. Rills, due to erosion from channelled surface water, are also associated with this area. The deposition of sediment in highly vegetated areas could be as a result of vegetation such as logs and trees; trapping the sediment. Most of the drainage channel contains some type of vegetation. This vegetation could be grass in some areas to trees in other areas. There is no clear cut correlation between vegetation density and type and deposition of transport of sediment. Smaller plants growing in the channel indicate that it is probable erosion did not take place for the time-span of the plant's growth as water flowing would have removed the plant. Large plants, such as trees, can, however, not be used as such an indicator. Open tree roots may in fact mean erosion has taken place to have removed all soil around the roots. Many different kinds of vegetation occur within the drainage channel. Fig. 28 illustrates grass growing in the drainage line at point 13, whereas Fig. 29 illustrates the roots of large trees growing in the drainage channel at point 11. This vegetation could also aid in the deposition of material.

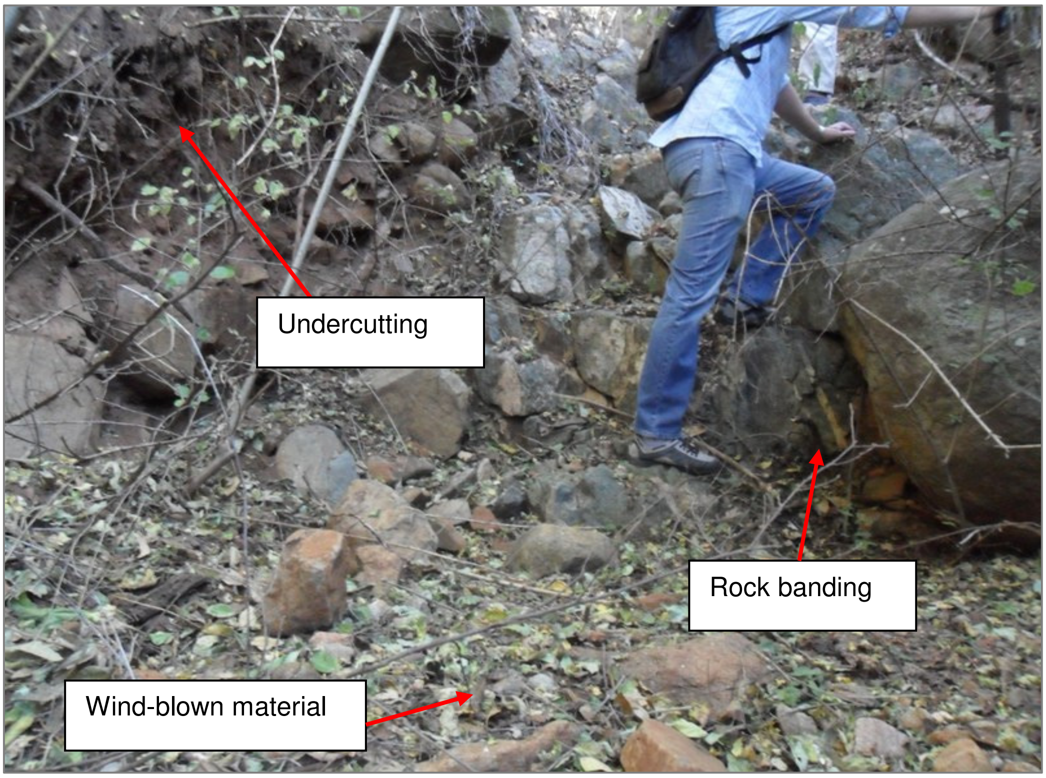

FIGURE 27: Photograph taken at point 6 in the drainage channel indicating windblown material, undercutting by erosion, and banding of gneiss rock and non-banded schist loose rocks.

FIGURE 28: Photograph taken of the drainage channel at point 13 showing grass growing and rocks which are not rounded by fluvial action (rocks are between 400mm and 500m in size).

FIGURE 29: Photograph taken of the drainage channel at point 11 showing bare roots from larger plants.

There is a general pattern whereby bedrock erosion is more prominent higher up the drainage channel, and decreases towards the lowest point of the drainage channel. This could be due to sand and gravel transported downstream, preventing bedrock abrasion from taking place. There is a trend whereby bank erosion decreases directly after a decrease in bedrock erosion going downstream. This may be due to less sediment available to aid in the erosion of the bank. Slight vertical erosion is evident on the channel floor at point 1 through to point 4. The drainage channel in this stretch has banks; but these banks are not very high. Vegetation growth is dense in this stretch and at point 2 relative large ant mounds occur. These are all indicators that deposition is overall more prominent than erosion. The channel floor of the drainage line is transport-limited from point 1 to point 4, therefore, gravel to sand channel floor. This stretch is a total of 185.32m. Some lateral erosion is also present.

From point 5 the height of the banks increase significantly to approximately 3m at point 5 and little lower (approximately 2m) at points 6 and 7. Most of the material that does occur in this stretch of the channel, is wind-blown plant material (Fig. 27). Some deposition has taken place which is not wind-blown. This is, however, very slight and the soil material is also comparatively shallow. This indicates a significant increase in the vertical erosion on this stretch of the channel floor. The floor of the channel changes then to a resistance-limited channel from point 5 to point 7, therefore an overall bedrock channel floor. This stretch is a total of 77.7m. Lateral erosion has taken place into the bedrock. Some bank erosion at point 6 in Fig. 27, due to undercutting, is evident. At point 8 and 9 more material has been deposited on the channel floor. Rocks also occur in greater abundance on the drainage line floor, which is due to transportation and not part of the channel floor bedrock. However, banks are still high, somewhat lower than the stretch from point 5 to 7, but not as low as the first stretch; therefore some vertical erosion is evident on the channel floor. This channel floor is mostly gravelly or sandy with some patches of bedrock channel floor. Lateral erosion has taken place into the bedrock.

A great amount of material has been deposited on the channel floor throughout points 10 and 11. Vegetation growth at point 11 is dense, which indicates deposition is overall more prominent than erosion. The amount of material, in the form of rocks and soil, is more than in previous stretch. The rocks that do occur on drainage line floor are due to transportation. However, some vertical erosion may have taken place before deposition due to height of banks. This channel floor is therefore a gravel or sand bed. Lateral erosion has taken place into the bedrock. For the stretch at points 12 and 13 the banks are not very high, therefore vertical erosion either slight or not evident. There are almost no rocks, but the few rocks that do occur on the drainage line floor are due to transportation. A relatively thick soil layer compared to the other drainage channel stretches occur. This channel floor is therefore a gravel or sand channel bed, as well as boulder bed channel. Lateral erosion is not evident for points 12 to 14.

Vertical erosion becomes more evident at point 14 and increase at points 15 and 16 due to an increase in the height of the banks. There are many large rocks present in the drainage channel. Soil patches occur, as well as patches where bedrock is evident. The channel bed is a mixture of sand, gravel, boulders and bedrock. Lateral erosion has taken place in the bedrock for point 15 and 16; however, many trees are situated on the banks of the channel. The stretch for points 17 and 18 has no or very slight vertical erosion. Vegetation growth is dense and soil deep in this stretch which indicates deposition is overall more prominent than erosion. This channel floor is therefore a gravel or sand bed. Lateral erosion has taken place in the bedrock. Fig. 30 is a representation of the degree of vertical and lateral erosion within the drainage channel from point 1 to 18.

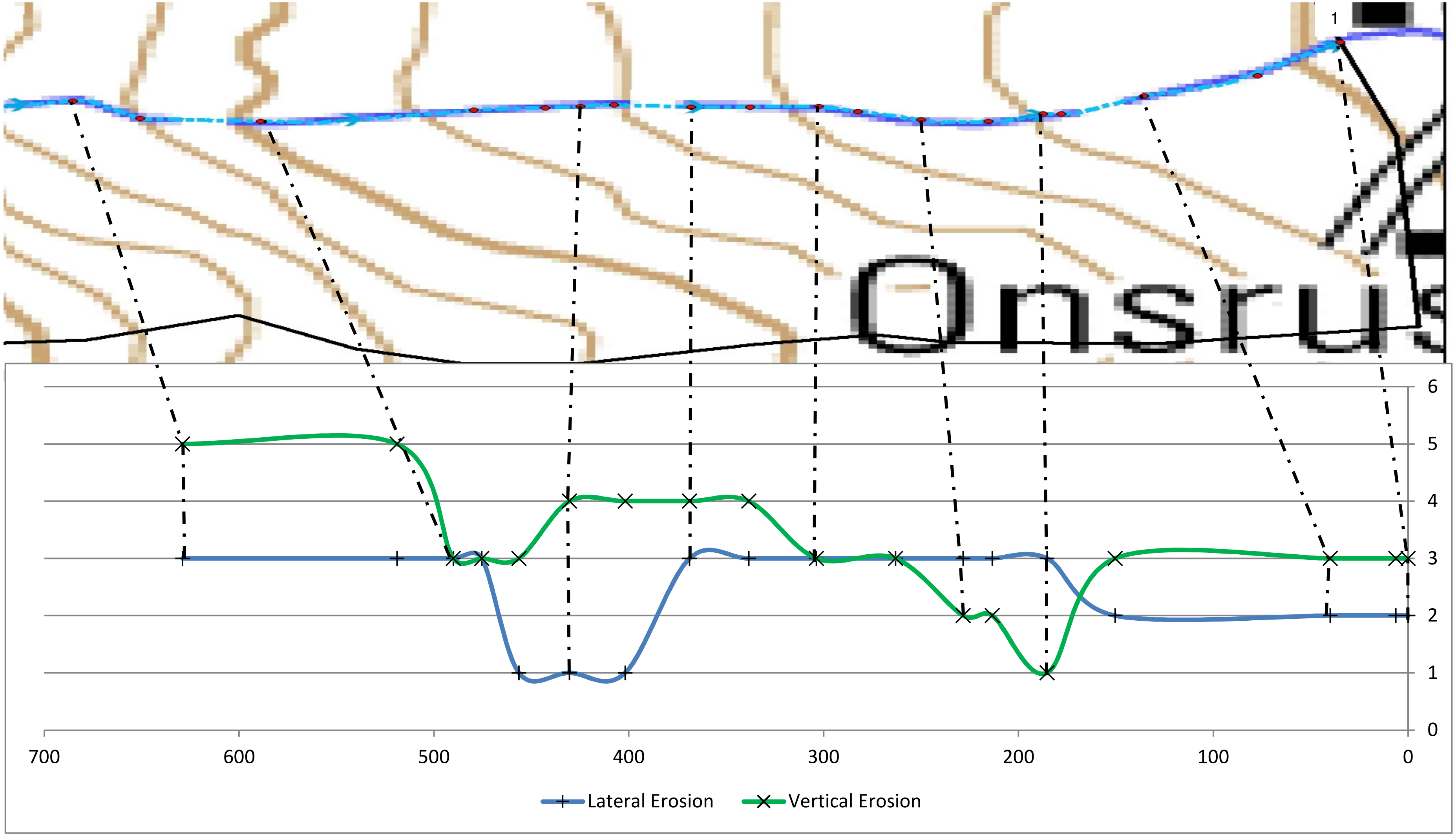

FIGURE 30: Degree of vertical and lateral erosion of the drainage channel within the study site from point 1 to 18 (0 = no erosion, 5 = high degree of erosion)

5.2.2 Mass movement description

Various schist rocks from rockfall were observed east of the cliff in the study site. Fig. 26 (page 68) is a photograph indicating rocks from rockfall occurring on the northern part (south of the drainage line) of the study site. At the scree or cliff face, there is no indication of toppling, illustrated as E in the diagram by Chuang & McEwen (2010) (Fig. 5, page 25), taking place and it is assumed that the rocks occurring on the site which are not part of the underlying geology, are due to rockfall. Even though the largest part of the study site has rocks from rockfall, there is an area on the southern part of the study site that has no such rocks (Fig. 31). A slumped area, due to slide movement, was noted east of the cliff on the southern part of the study site (Fig. 32). This area has not formed due to a block slide, illustrated as C in the diagram by Chuang & McEwen (2010) (Fig. 5, page 25), as no such block material areas can be seen downhill of the cliff; therefore this landslide is either a translational or a rotational landslide. A translational landslide occurs on a single plane whereby a rotational landslide leads to an upwards curving of the slope downhill. It is evident from Fig. 32 that an upward curving occurs, indicating that the slumping is potentially due to a rotational landslide. Old scars of debris flow can also be observed on both the northern and southern parts of the study site (Fig. 32). No rapid flow from failures in clay, such as earthflow and mudflow, were observed in the study site. Many trees, on both the northern and southern parts of the study site, are growing askew. Fig. 26 (page 68) shows curved trees on the northern part of the study site. Different tree species show this tendency; consequently, this may be an indication of soil creep taking place, but it cannot be concluded whether the soil creep is seasonal or continuous.

FIGURE 31: Photograph of the study site showing an area of no scattered rocks occurring.

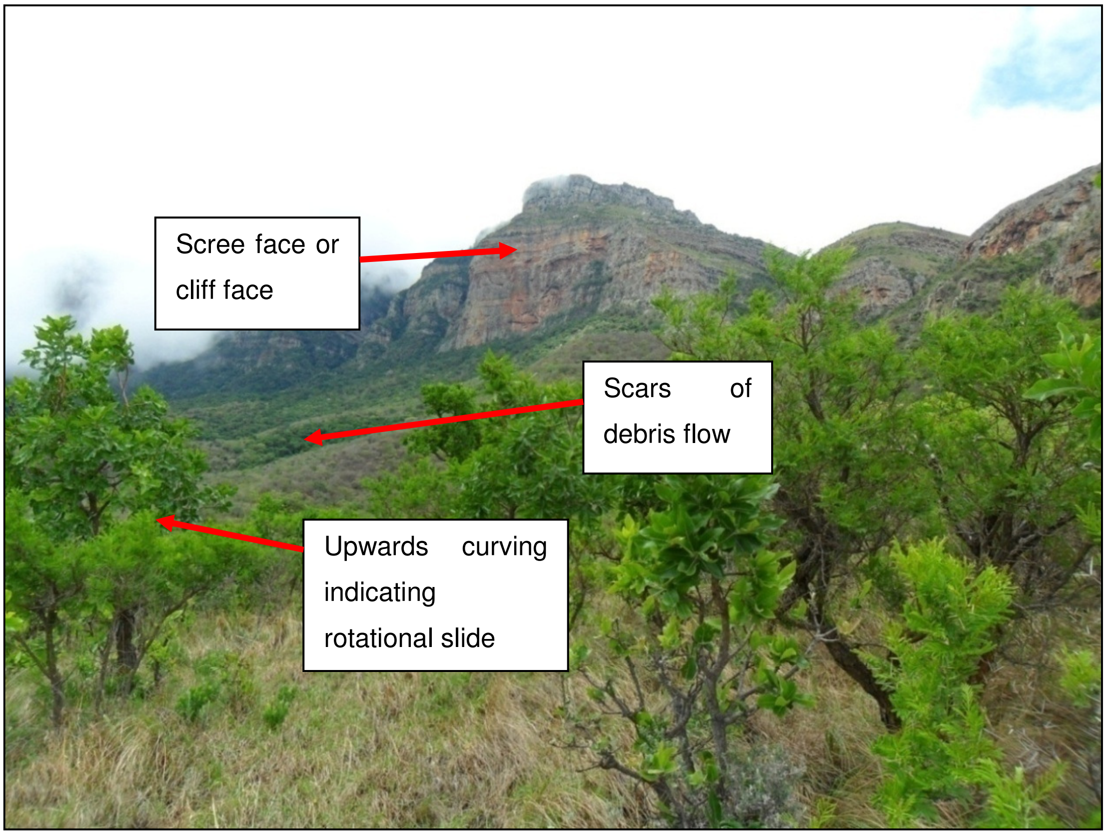

FIGURE 32: Photograph of the study site indicating the scree or cliff face, the rotational landslide as well as the scars of the debris flow.

In the drainage channel, some of the loose rock material is from mass movement such as rock fall. Loose rocks from rockfall are not rounded such as rocks being transported by fluvial processes. Loose rocks between points 1 to 4 are not very rounded, indicating the possibility of a rockfall. Points 5 and 6 have loose rocks from rockfall, as well as some transported by fluvial processes. The channel from point 7 to 18 again lacks the presence of rocks transported by fluvial processes. The rocks observed in Fig. 28 (page 70) (photograph of point 13) are not rounded and were most probably transported into the drainage channel from rockfall. Mass movement processes occurring on the study site are, thus, from rockfall, rotational landslide, debris flow and soil creep. Mass movement is distributed over both the northern and southern parts of the study site, with the exception of rockfall which is not occurring on certain areas of the southern part of the study site.

5.2.3 Slope profile and plan characteristics

The cliff face of the study site is a segment and associated with rapid mass movements such as landslides and rockfall, with the remaining part of the study site an element with concave and convex curvatures. Distances between the contours for the four longitudinal profiles, as well as the degree of angles and curvatures of the site, are given in the Table 7. Angles highlighted blue correspond with the convex creep slope unit; angles highlighted in red (pink) correspond with fall face slope; areas highlighted in orange correspond with transportational midslope unit; and angles highlighted in yellow correspond with colluvial footslope unit. Curvatures highlighted in purple are positive and curvatures highlighted in green are negative curvatures. Fig. 33 provides a schematic representation of the long profiles. ‘A’ and ‘B’ on the figure, correspond with ‘A’ and ‘B’ on the map in Fig. 10 (page 45). Long profile 1, 2 and 4 have, in general, a similar profile gradient. Distances from a gradient of 900m a.m.s.l. to a gradient of 1260m a.m.s.l. are 1009.9m for long profile 1952.29m for long profile 2, and 908.52m for long profile 4. These three profiles have similar gradients from 900m a.m.s.l. to 1000m a.m.s.l. Gradients change somewhat from this height, with each profile ending at the same height, with roughly similar distances from starting point. The point marked ‘X’ on Fig. 33 is the highest point where these three profile lines intersect the drainage line. Long profile 3 has a steeper gradient, reaching the convex creep slope unit over a shorter distance. Distance from 900m a.m.s.l. to 1260m a.m.s.l. is 608.48, approximately 300m shorter distance than the other three profiles. Long profile 3 does not cross the drainage line.

Profile angles and angle trend lines are plotted against the long profiles in Fig. 34, and the frequencies of angles are plotted in Fig. 35. According to the Table 7, as well as Fig. 34 and 35, all four long profiles show a general increase in degree of angles with an increase in height, with angles generally between 10° and 40°. Profile line 1 and profile line 2 have very similar trend in increase in degree of angles, profile line 3 starts with a higher degree of angle; but the trend in degree of angle increase is similar to profile line 1 and 2, and profile line 4 has the highest increase in degree of angles. According to the graph in Fig. 34, profile line 1 has a variety of angles between 10° and 45°, profile line 2 has mostly angles between 20° and 25°, with second highest amount between 35° and 40°, profile line 3 has the highest number of angle between 40° and 45°, and secondly 15° to 25°, and profile line 4 has mostly angles between 20° and 30°, with the higher area (above 1240m a.m.s.l.) between 60° and 65°. A negative curvature indicates convex slope and a positive curvature indicates a concave slope. In general the four profile lines have a negative curvature; therefore concave profiles (see Fig. 36), with concavity for all four profiles high at heights above 1160m a.m.s.l. Profile lines 1, 2, and 4 have alternating convex and concave curvatures between 1040m a.m.s.l. and 1140m a.m.s.l., with high increase in concavity at 1160m a.m.s.l. Profile line 3 shows a trend of high concavity at 1020m a.m.s.l., alternated by high convexity at 1060m a.m.s.l., and alternated by high concavity at 1100m a.m.s.l. The concavity decreases at 1140m a.m.s.l. (still higher than for the other three profile lines) and then a very high increase in concavity.

TABLE 7: Long profiles of the study site (long profile 1 and 3 are located on northern part, and long profile 2 and 4 are located on southern part of study site)

Long profile 1				Long profile 2				Long profile 3				Long profile 4			
Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)
900	0	N/A	N/A	900	0	N/A	N/A	900	0	N/A	N/A	900	N/A	N/A	N/A
920	152.03	7.56	N/A	920	150.12	7.55	N/A	920	0	N/A	N/A	920	0	N/A	N/A
940	255.35	10.96	-4.12	940	256.49	10.65	-4.67	940	68.39	16.30	N/A	940	255.03	4.48	N/A
960	328.83	15.23	0.84	960	327.6	15.71	-0.30	960	134.18	16.91	2.93	960	326.13	15.71	-3.51
980	451.06	9.29	0.48	980	428.55	11.21	2.36	980	229.91	11.80	-3.78	980	429.21	10.98	2.12
1000	528.84	14.42	-6.07	1000	526.04	11.59	-6.84	1000	280.23	21.68	-8.27	1000	522.27	12.13	-9.32
1020	591.72	17.64	-0.94	1020	579.18	20.62	-3.37	1020	336.5	19.57	-25.84	1020	571.07	22.29	-9.04
1040	663.4	15.59	-8.25	1040	650.66	15.63	-4.23	1040	361.55	38.60	-34.88	1040	623.06	21.04	-2.38
1060	705.11	25.62	-13.89	1060	694.42	24.56	-29.08	1060	386.16	39.10	15.13	1060	667.38	24.29	-22.16
1080	743.4	27.580	6.40	1080	721.71	36.24	-0.25	1080	423.89	27.93	18.18	1080	694.53	36.38	-3.66
1100	797.76	20.20	-20.61	1100	765.11	24.74	0.34	1100	464.82	26.04	-21.61	1100	734.38	26.65	11.14
1120	820.05	41.90	-9.46	1120	792.62	36.02	-13.26	1120	488.88	39.74	-41.72	1120	756.64	29.93	-10.39
1140	860.05	26.57	15.03	1140	822.46	33.83	18.41	1140	509.15	44.62	1.14	1140	788.07	32.47	-11.24
1160	892.38	31.74	-10.96	1160	872.38	21.83	-9.26	1160	533.62	39.26	-21.98	1160	814.93	36.67	4.34
1180	922.9	33.23	-6.79	1180	896.89	39.21	-70.54	1180	548.66	53.06	-7.69	1180	849.73	29.89	-10.79
1200	951.04	35.40	-24.68	1200	914.19	49.14	-27.13	1200	570.89	41.98	-28.23	1200	872.18	41.7	-83.48
1220	972.06	43.58	-55.65	1220	932.51	47.51	-92.46	1220	582.11	60.71	-95.82	1220	885.71	55.92	-63.35
1240	985.76	55.59	11.16	1240	939.75	70.10	-29.05	1240	591.63	64.55	N/A	1240	898.56	57.28	-36.19
1260	1009.9	39.64	N/A	1260	952.29	57.91	N/A	1260	608.48	49.89	N/A	1260	908.52	63.53	N/A
1280	1018.54	66.64	N/A	1280	991.56	26.99	N/A	1280	N/A	N/A	N/A	1280	917.81	65.09	N/A

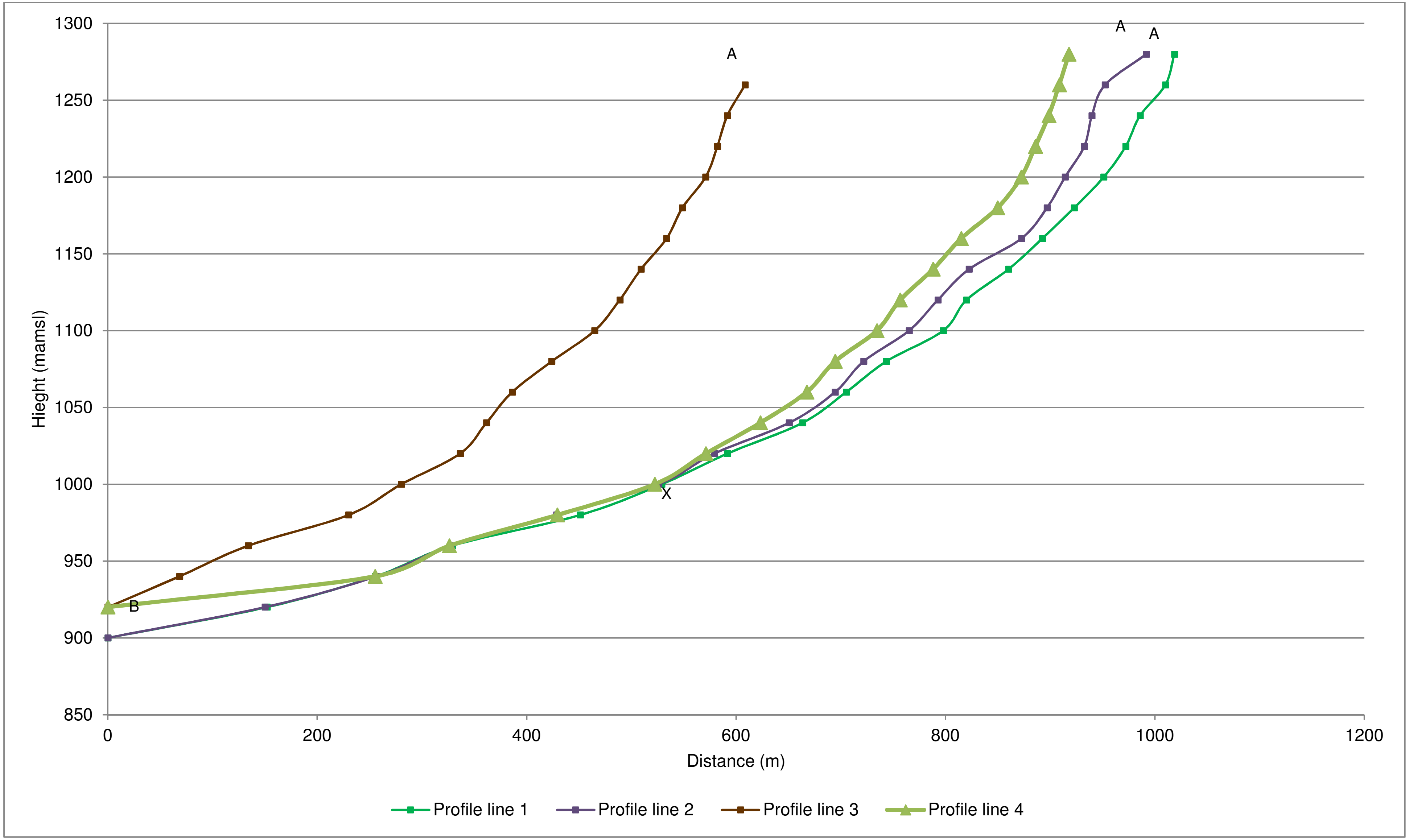

FIGURE 33: Schematic representation of the longitudinal profiles

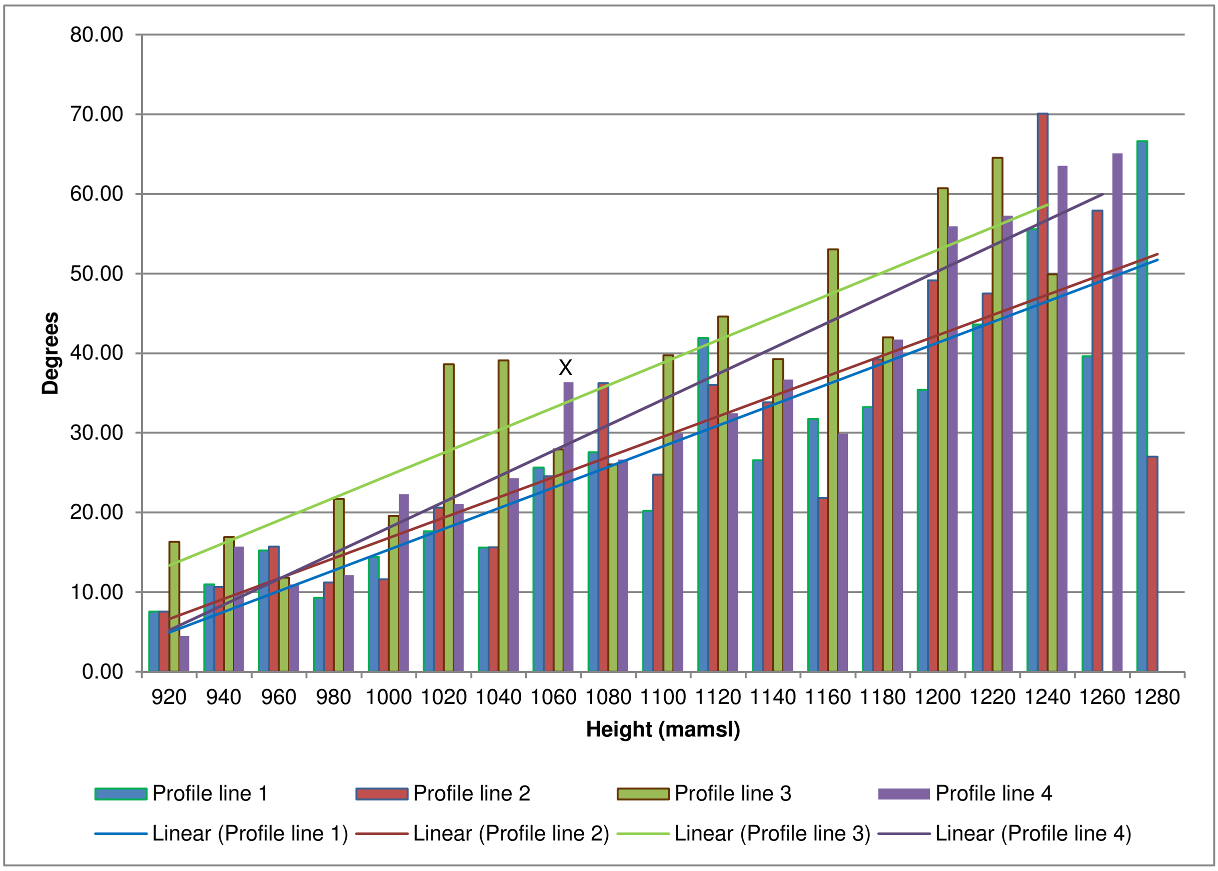

FIGURE 34: Degrees of angles on profile lines

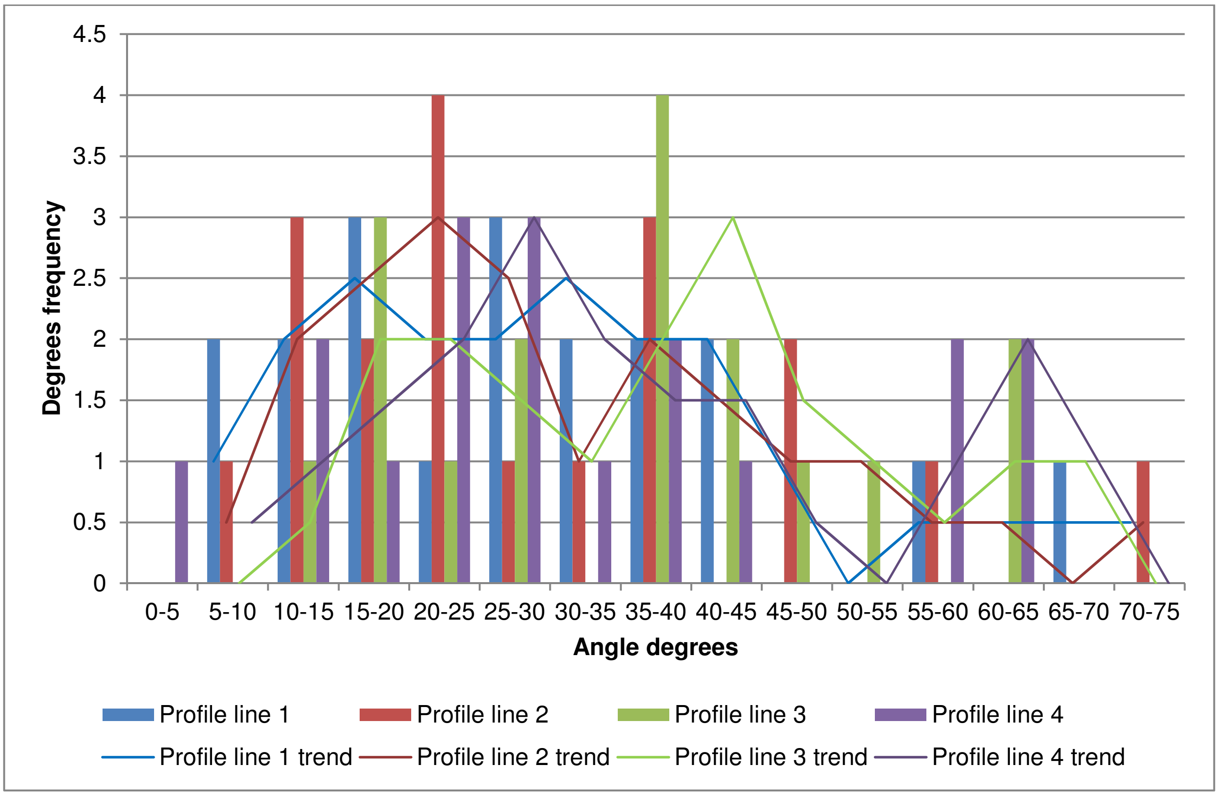

FIGURE 35: Angle frequency of the longitudinal profiles

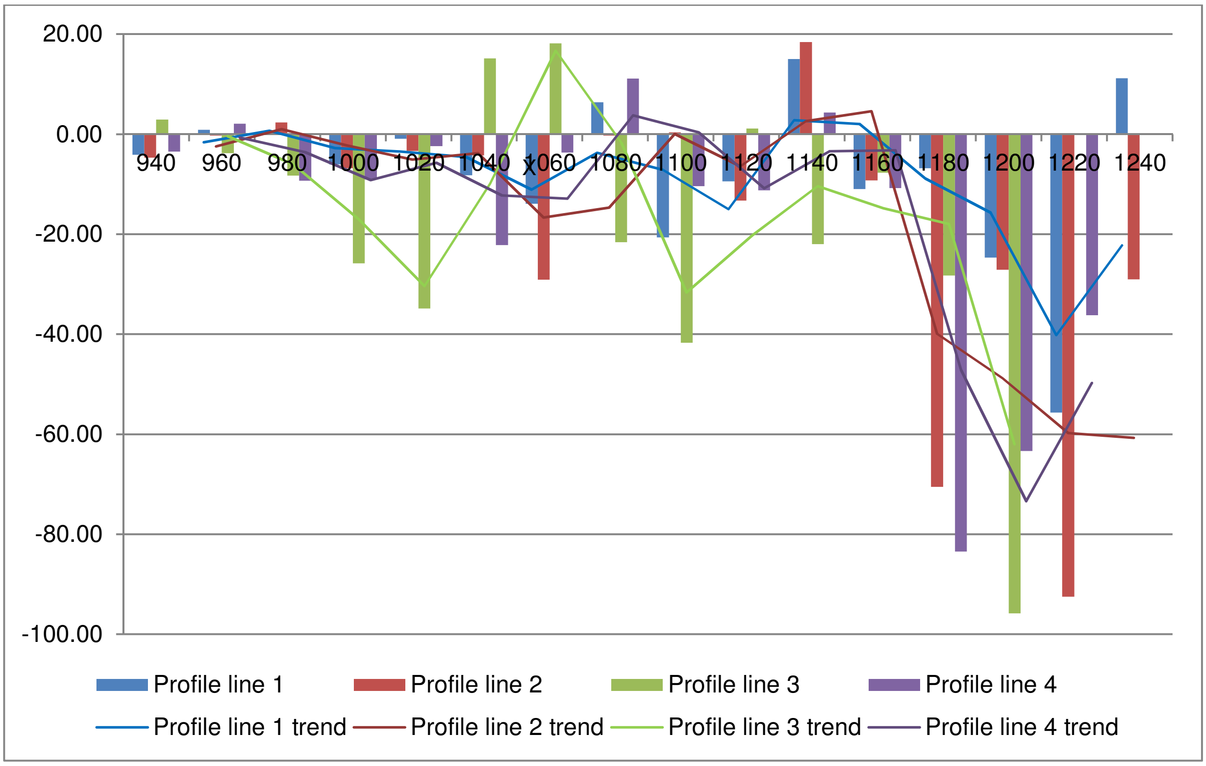

FIGURE 36: Curvature on profile line

Distances between the contours for the plan from 1 to plan form 4, as well as the angles and curvatures of the site, are given in the Table 8. Fig. 37 is a schematic representation of plan forms 1 and 2, with plan 1 starting and ending at 1140m a.m.s.l. and plan form 2 starting and ending at 1000m a.m.s.l. Fig. 38 indicates the graph for plan form 3 starting at 1090m a.m.s.l., perpendicular across the drainage line, ending at 1180m a.m.s.l.; and plan form 4 starting at 1000m a.m.s.l., perpendicular across the drainage line and ending at 1090m a.m.s.l. Curvatures highlighted in purple are positive and curvatures highlighted in green are negative curvatures. Plan forms 1 and 2 do not have similar gradients. The gradients for each plan form across the drainage line are also different. Distance of plan form 1 between point ‘A’ and the drainage line is 302.99m and the distance between the drainage line and point ‘B’ is 231.89m, giving as total of 534.88m. Distance of plan form 2 between point ‘A’ and the drainage line is 431.56m and the distance between the drainage line and point ‘B’ is 274.50m, a total of 706.06m.

TABLE 8: Plan forms of the study site

Plan 1				Plan 2				Plan 3				Plan 4			
Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)	Height (m a.m.s.l.)	Distance (m)	Angle (°)	Curvature (°/100m)
1140	0	N/A	N/A	1000	0	N/A	N/A	1090	0	N/A	N/A	1000	0	N/A	N/A
1140	124.72	0	N/A	982	78.989	-12.84	N/A	1100	61.483	9.24	N/A	1001	87.123	0.66	N/A
1145	157.333	8.72	25.22207	983	167.699	0.65	-17.64	1120	126.588	8.73	0.511247	1020	141.452	19.28	-13.42
1140	174.968	-15.83	31.60755	1000	253.004	11.27	-12.04	1130	192.819	8.59	16.24141	1040	208.577	16.59	6.77
1120	232.61	-19.14	10.42031	1002	267.032	8.11	31.13	1120	249.532	-10	22.6551	1050	257.337	11.59	25.53
1100	275.978	-24.76	-26.945	1000	277.54	-10.78	13.82	1110	300.52	-11.1	-61.2334	1040	319.963	-9.07	12.60
1098	302.996	-4.23	-54.8137	980	384.158	-10.62	-4.60	1120	315.655	33.45	-29.4865	1040	346.988	0	-24.17
1100	316.262	8.57	-21.1495	976	431.555	-4.82	-8.73	1140	376.313	18.25	12.20198	1060	414.33	16.54	-18.61
1120	384.324	16.38	-2.89252	980	489.103	3.98	-5.13	1160	438.936	17.71	N/A	1080	464.528	21.72	14.50
1130	429.83	12.39	N/A	1000	661.03	6.64	N/A	1180	511.02	15.51	N/A	1080	530.28	0	N/A
1140	534.88	5.44	N/A	1000	706.05	0	N/A				N/A	1090	576.68	12.16	N/A

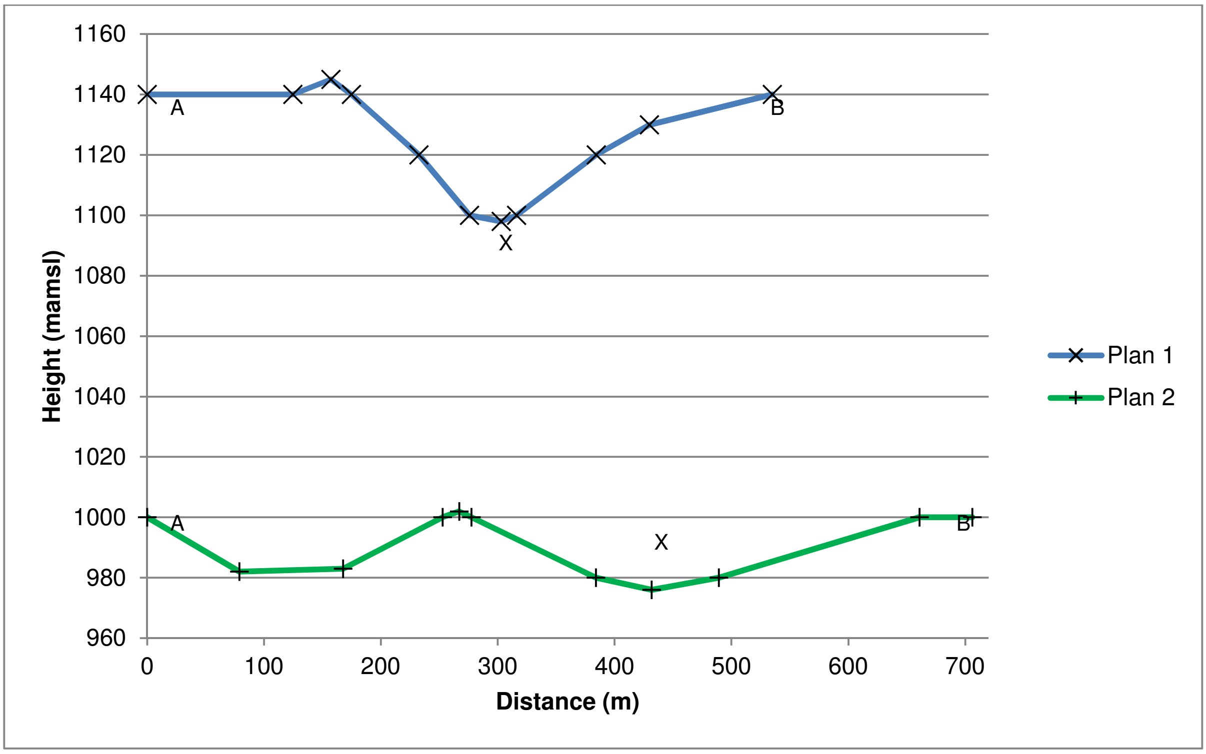

FIGURE 37: Schematic representation of the plan forms 1 and 2

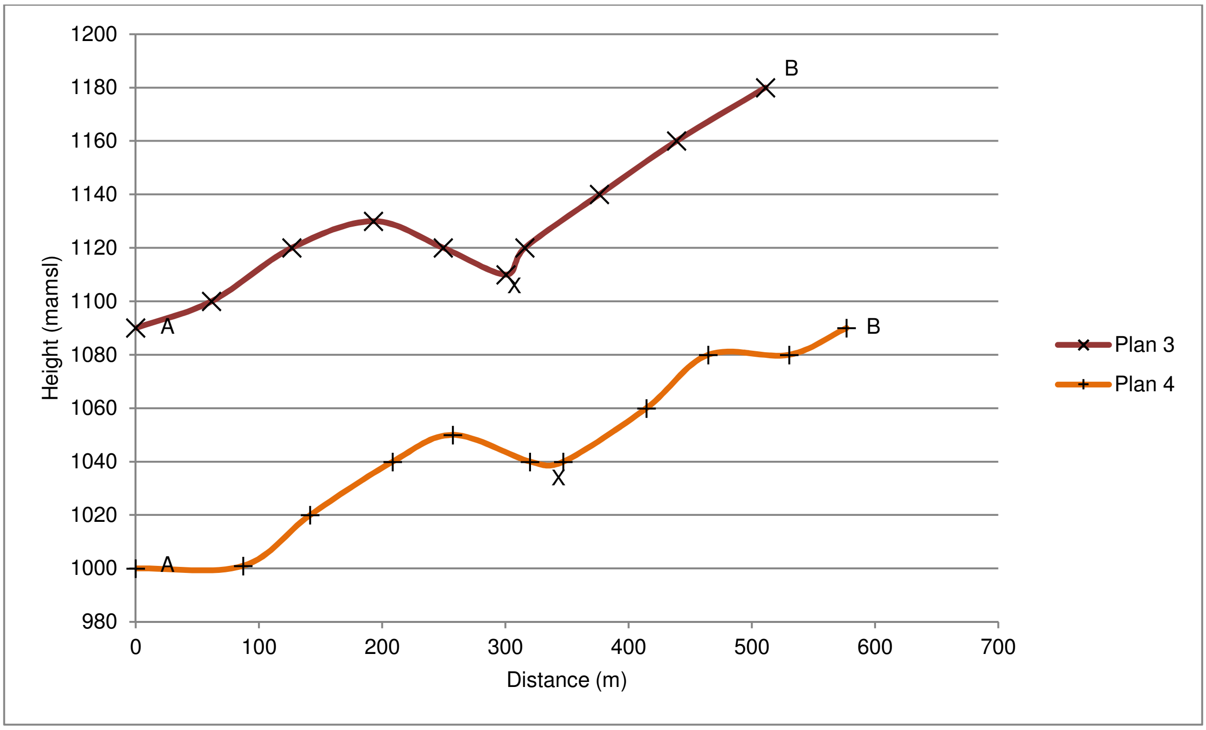

FIGURE 38: Schematic representation of the plan forms 3 and 4

Height for both plan 3 and 4 is lower on the northern part of the drainage line than on the southern part. Height difference for plan form 3 is 90m from point ‘A’ to point ‘B’; and height difference for plan form 4 is also 90m from point ‘A’ to point ‘B’. Distance between point ‘A’ of plan form 3 and the drainage line is 90.024 more than the distance between point ‘B’ and the drainage line, meaning the height difference between point ‘A’ of plan form 3 and the drainage line is 20m, with the height difference between point ‘B’ and the drainage being 70m. Distance between point ‘A’ of plan form 4 and the drainage line is 117.29m more than the distance between point ‘B’ and the drainage line, and the height difference between point ‘A’ of plan form 3 and the drainage line is 40m, with the height difference between point ‘B’ and the drainage being 50m. Distance between point ‘A’ and the drainage line for plan 1 is 302.99m and the distance between the drainage line and point ‘B’ is 231.89m. Distance between point ‘A’ and the drainage line for plan 2 is 431.56m and the distance between the drainage line and point ‘B’ is 274.50m. The area north of the drainage line shows a large amount of concavity than the area south of the drainage line.

Only four of the nine units for the 9-unit model were identified in the study site. . These units are as follow:

1. Unit 3, convex slope;
2. Unit 4, fall face;
3. Unit 5, transportational midslope, and
4. Unit 6, colluvial footslope.

Unit 1 will occur on the slope, but falls outside of the study site boundaries. Unit 3, a convex slope, occurs above the cliff face within the study site. This area is divided into two parts by the drainage channel and is dominated by pedogenetic as well as geomorphological processes. Fall face occurs just above the cliff, to the foot of the cliff where the slope angle is less than 40°. Mass movement, as part of this unit, includes landslide and rockfall. Weathering is also prominent on the cliff face. Slumping was observed just beneath the cliff face, showing the start of unit 5, the transportational midslope. The transportational midslope area is much smaller on the northern part of the study site compared to the southern part, and may be due to various geomorphological reasons as discussed above, as well as the difference in vegetation. Unit 6 comprises the lower part of the study site, the colluvial footslope, which is a larger area for the northern part of the study site compared to the southern part. Note the difference in the placement of unit 5 and 6 in the northern and southern part of the study site. A larger part of the southern part is associated with unit 5 than the northern part. The soil covered area with larger rocks can be associated with the transportational midslope, the less soil-covered area towards the south can be associated with the colluvial footslope and the cliff with the fall face unit as described above. These units on the study site are shown in Fig 40.

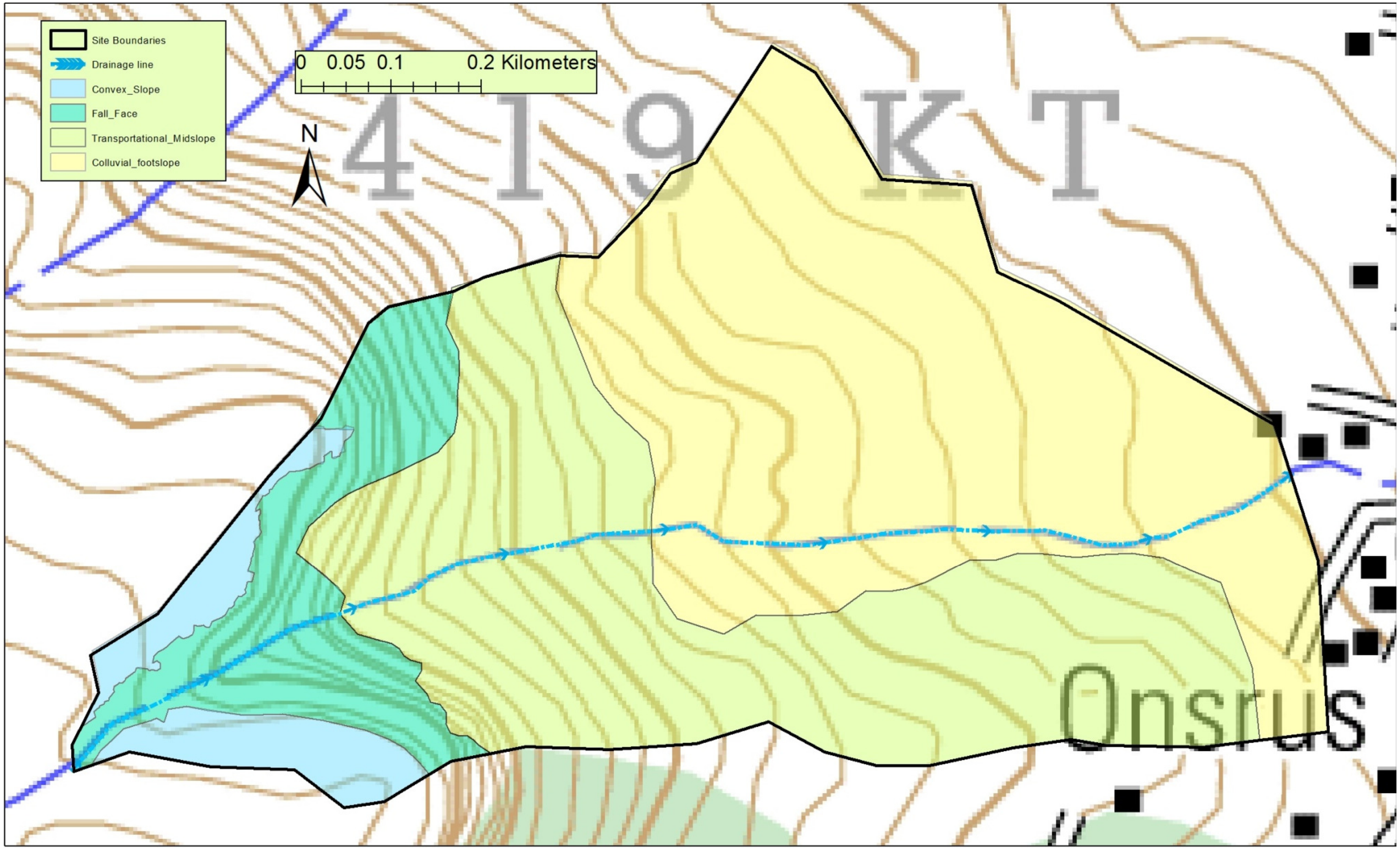

FIGURE 39: Map indicating 9-unit slope model (adapted from Dalrymple *et al.*, 1968 taken from Ellis & Mellor, 1995)

5.2.4 Channel formation and longitudinal profile

Removal of all the material will leave the channel bare, with only a bedrock floor remaining. Bedrock, however, differs from loose rock material. The greatest part of the drainage channel is located within feldspar-biotite gneiss geological unit; although the highest part of the drainage channel and above the start of the drainage channel is quartzite and feldspar-rich schist. Large parts of the area are scattered with schist, which could also lead to sediment within the drainage channel. Bedrock can thus be distinguished by the banding occurring within the gneiss. This banding will not occur within the schist. Bedrock showing the gneiss banding, as well as rocks being transported, showing no banding, is indicated in Fig. 27 (page 70): a photograph taken at point 6 in the drainage channel. Loose rocks may be located in the channel due to either stream transportation, slumping of material from bank erosion, or due to mass movement such as rock fall or rock slide. Fig. 28 (page 70) is a photo of the drainage line taken at point 13. It is evident that these rocks are loose and do not form part of the bedrock. There is also a large amount of bedload deposition within the drainage channel meaning, the bedload, as well as solution transportation, will influence the channel form. The mineral particles that will be in suspension or in dissolved load will be from the schist rocks, as well as from the gneiss rocks.

Soil is much deeper at the stretch for points 1 to 3 than the other stretches, creating a flat-floored valley. At point 4 the soil becomes less deep and the flat-floored valley is not evident. On the eastern bank of point 5, lateral erosion into bedrock has formed a rock-floored valley, but the western bank is mostly soil and not rock, therefore a rock-floored valley is not evident. In the stretch at points 6 and 7 on both banks, lateral erosion into bedrock has formed a rock-floored valley. The channel in the stretch for points 5 to 7 is very narrow and forms a V-shape. On both banks at points 12 and 13, lateral erosion into bedrock has formed a rock-floored valley, and the channel is very narrow and forms a V-shape. On the eastern bank at point 14, lateral erosion into bedrock has formed a rock-floored valley. The western bank is mostly soil and not rock, therefore a rock-floored valley is not evident. The channel at this point is very narrow and forms a V- shape. Soil at point 17 and 18 is much deeper than other points, creating a flat-floored valley. The stretch in the drainage channel from point 8 to point 18 is again transport-limited, a total of 365.97m in distance.

No river meandering takes place within the drainage line in the study site. At point 2, the channel splits, forming an island between two drainage lines with an island of deposited material, and these lines join at point 4, indicating braiding within the channel. The two channel lines are very close in distance, therefore not indicated as different lines in this study. The height of the drainage channel increases from 897mams1 at point 1 to

991mams1 at point 18, therefore an increase of 94m. These points are contained within Table 10 in Addendum 1. The distance between point 1 and point 18 is 628.99m. The average gradient from point 1 to point 18 is as follows:

Average gradient = cotan (distance/difference in height)
- cotan(581.5m/94m)
= cotan (6.69)
= 9.18°

Therefore, the stretch in the drainage channel from point 1 to point 18 has an average gradient of 9.18°. Considering the additional 16 points added to Google Earth (2013), the distance from point 1 to point 34 is 1 273.65m. The difference in height between point 1 and point 34 is 462m. The average gradient for the drainage channel within the study site is as follows:

Average gradient = cotan (distance/difference in height)
- cotan (1 273.65m /462m)
= cotan (3.06)
= 19.93°

Average gradient for the drainage channel within the study site is 19.93°. Fig. 40 shows the longitudinal profile of the drainage channel from point 1, the lowest point, to point 34, which is the highest point in the study site. Table 10 (page 120) shows the angle and curvature. Gradient for the channel from point 1 to 18 varies greatly, whereby the gradient at point 1 starts moderately compared to the rest of the channel, changing to moderate-high at point 3. The gradient is zero at point 4, with a moderate increase at point 5. And then the gradient decreases to low gradient at point 6, with sudden high gradient at point 7, and again low gradient at point 8. Gradient is then high at point 9 with a negative gradient at point 10 and a sudden high gradient at point 11. The gradient remains high at point 12, with zero gradient at point 13 and low gradient at points 14 and 15. Gradient is very high at point 16 and then zero at point 17, and then a high gradient at point 18. The channel has a more consistent gradient from point 18 to 34. The general profile of the drainage channel is concave upwards, changing to convex on the most upper part. The profile is not smooth; however, the drainage channel within the study site is only a small part of the entire drainage channel. Knick-points can be observed at points 7, 9, 11, 16, where there was an increase in height, and also knick-points at points 8, 10, 12 and 16, where there is a sudden decrease in height. On site, there is a rock wall on the western side of the drainage line at point 5, 10 and 15.

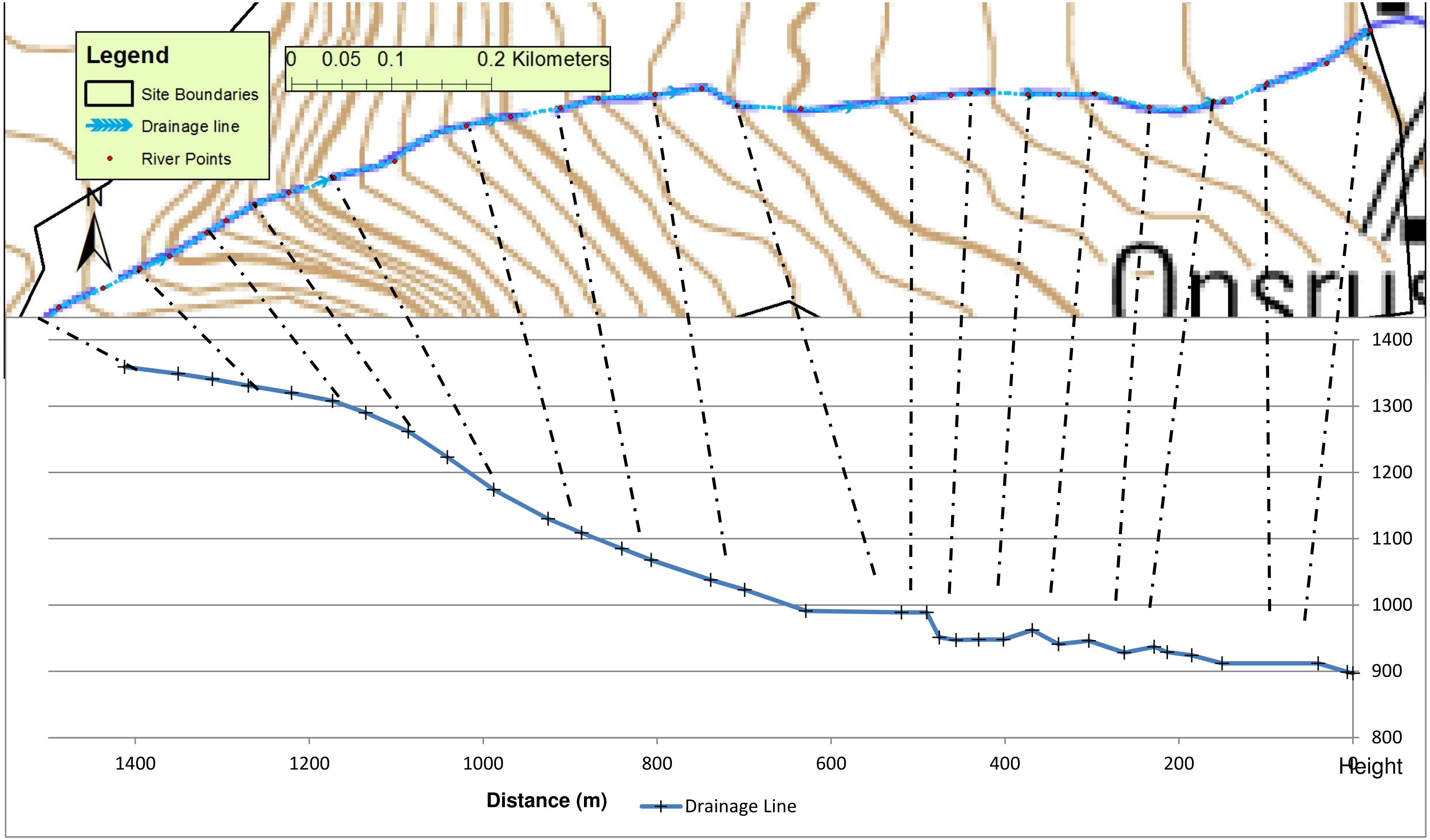

FIGURE 40: Longitudinal profile of the drainage channel within the study site

Pools and riffles could not be observed using water flow. Where the channel creates a steep downward slope against the normal downward south-west to north-east slope, within the stream flow path, it can be considered as an area where a riffle and pool converge. If this slope is more than 45°, it is considered to be where a step and a pool converge. At point 3, there is a slight decrease in gradient to point 4, indicating the formation of a shallow pool 4. At point 8 a pool area is located with a steep wall from point 7 to 8; therefore this area is rather a step and pool than a riffle and a pool. Another pool has formed at point 10 of the drainage channel. Fig. 41 is a photograph taken at point 10 looking north towards point 9, indicating the change in slope which forms a pool. The points 12 to 15 are a pool with a large step at point 15, with a very steep wall from point 15 to point 16.

FIGURE 41: Photograph taken at point 10 in the drainage line indicating pool formation (drainage channel was dry during site visit)

5.3 *Channel classification*

The channel within the study site, as well as the surrounding channels and streams, are all part of the production zone, according to Schumm (1977) river zonation, even though classified as third order according to the whole river classification. As indicated in the results, this area produces sediment and has many bedrock channel areas, as well as erosional properties. A description of the drainage channel is given in Table 10, attached as Addendum 1. According to Pickup (1984), the source zone has mainly coarse and poorly sorted material, with the armoured zone being coarse, well sorted surface and poorly sorted mixed base. The channel from point 4 to point 18 has mostly poorly sorted coarse materials on the channel bed. It is assumed that the channel bed from point 18 upwards to point 34 will have the same characteristics, or even more poorly sorted and coarser. The channel from point 3 to point 1 is somewhat better sorted and has some mixed sand and gravel, consequently, the stretch between point 4 and point 34 is well based within the source or armoured zones, therefore being the production zone of the river system. Points 1 to 3 may still be within the armoured zone, but show signs of the gravel-sand transition zone, therefore the transportation zone of the river system. If this classification is considered, the transition of the drainage line from the source or armoured zone, which is also the production zone, towards the gravel-sand transition or the transfer zone could be observed. Therefore, the lower part of the drainage channel will not be a mountain stream, but a transition to lower-lying stream.

Considering the ecological zonation of Harrison (1965, see also Rowntree & Wadeson, 1999:12) and Noble & Hemens (1978), points 1 to 3 of the channel will fall within the midland river or the foothill: sandy bed zone. According to this classification, the midland river zone has a reduction in gradient and the channel bed is predominantly sand and finer sediments with occasional stony runs. The foothill: sandy bed is characterised by stony runs alternated with sandy sediment and marginal riverine vegetation. This stretch has abundant vegetation, however, this could be due to the fact that the study site is densely vegetated. Increase in finer substratum could possibly be due to sediment load from outside the channel, therefore it would be appropriate to assume that this stretch is rather a foothill: sandy bed zone than a midlands river zone. The stretch from point 4 to point 18 consists of a moderate gradient channel with a dominant bedrock channel bed, as well as boulders and large rocks, with patches of gravel and sand. This area could be described as a foothill: rocky bed. The stretch between point 18 and point 34 has a sudden increase in gradient. Even though this area could not be observed on site, it is assumed that this area will also have a bedrock channel floor and is covered in dense vegetation due to the nature of the area, and this stretch is then classified as mountain stream.

The river channel within the study site shows similarities in the type of bed material. Bed material sizes differs greatly, as point 1 to 3 is mostly gravelly and sandy, becoming more rocky with boulders, upwards to point 34; however, the type of material it originated from is similar, namely that of the underlying geology. The valley form of the channel as described previously, varies throughout the channel; however, these differences are much localised and would be insignificant on a broad scale such as that of a complete river system. This statement is also true for the channel dimensions. The upper part of the channel within the study site excludes the originating point or source of the drainage line with approximately

20m. Downstream, the study site excludes the drainage line approximately 1km from the first tributary junction. This junction is located within Kampersrus AH. As a result, this channel forms the largest part of a segment zone, as described by Rowntree & Wadeson (1999). This river classification further divides the upper part into a mountain stream (higher up) and the rocky bed foothill, with the lower part being the sandy bed foothill; thus another transition comes into the drainage channel.

Seven basic types of morphological units occur within the drainage channel from point 1 to 18. The first morphological unit is observed at points 1, 2, 3, 17 and 18. Hydraulic biotopes associated with this unit are flat-floored valley, material deposition, and mostly dense vegetation on the channel floor. Some minor differences occur within this unit. Point 2 and 3 show signs of in-channel braiding, which is due to the deposition. Points 3 and 4 have higher banks, even though the deposition is high. The second morphological unit is observed at point 2. Hydraulic biotopes associated with this point are also flat-floored valley with high deposition, and dense vegetation on the channel floor; however, this area is also a shallow pool with high banks. Even though points 3 and 4 also have high banks, these areas are not shallow pools. The third morphological unit is observed at points 12, 13 and 14. Hydraulic biotopes associated with this unit include a rock-floored valley, creating a V-shaped valley, with dominant transportational and erosional processes. Vegetation on the channel floor is limited, but still dense on the banks.

The fourth morphological unit is observed at points 5 and 7. Hydraulic biotopes are similar to that of the previous morphological unit, with the exception that these areas are predominantly riffles within the channel. The fifth morphological unit includes points 8, 9, 10 and 15. Hydraulic biotopes within this unit five are a pool area (channel dry during site visit), with dominant deposition occurring, dense vegetation on the channel floor and signs of flat-floored valley. The sixth morphological unit is observed at point 11. This point is also a riffle; however, deposition is dominant and not transportational and erosional processes. The last morphological unit is observed at points 6 and 16. This unit is similar to that of point 11, with the exception that this point creates a step instead of a riffle. The riffle is due to the steep bank on the eastern side of point 6 and 16. Points 1, 2 and 3, which is the lowest stretch, therefore the sand foothill or beginning of the transfer zone has a similar morphological unit, which is a flat-floored valley, material deposition, and mostly dense vegetation on the channel floor. The rest of the morphological units are spread in no obvious pattern between points 4 and 18.

5.4 Geological and geomorphological mapping

Geological and associated processes, hillslope processes and drainage channel are captured in an integrated geomorphological map (Fig. 42). Feldspar-schist occurs in the convex slope, and fall face of the 9-unit slope models. Gneiss occurs within the transportational midslope and the colluvial footslope. Physical weathering dominates the southern part, therefore mostly sand and gravel areas occur. Physical and chemical weathering occurs on the northern part, leading to various types of material form weathering. Rill erosion occurs mostly around the drainage channel and overland flow erosion occurs in the southern part of the study area. Large rocks (boulders) dominate the northern part from rockfall. Soil creep occurs over the entire study site, with slumping occurring downhill from the cliff face on the southern part of the study site. Geomorphological processes and features and hillslope form, interact with each other, and these processes interact with the local vegetation (Marston, 2010). These interactions are discussed below and are followed by an integrated geomorphological map with the grassland patches (See Fig. 43, page 102).

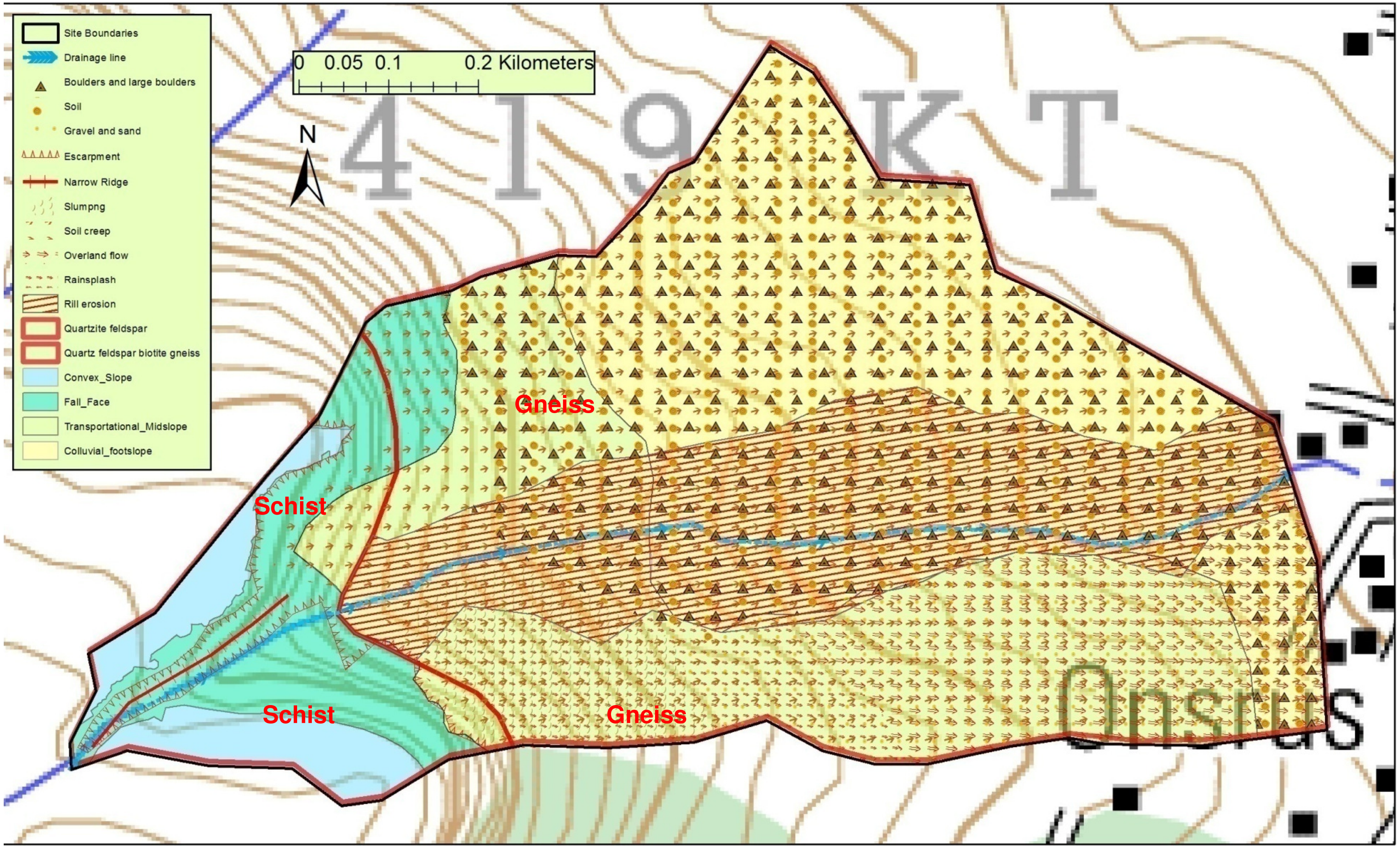

FIGURE 42: Integrated geomorphological map of the study site

Chapter 6: Discussion

The discussion has two main sections which align with the aim of this thesis. Part one is focused on the interrelationships between all the different geological, hillslope and channel classification results observed on the study site and the differences in the geomorphological processes north and south of the drainage line. Part two is focused on the correlation of the grassland patches as studied by Ferguson & Rautenbach (2012) and the aforementioned geomorphological processes on the study site. This second part of the chapter is done to determine what interrelationships there are between the geomorphological processes and the vegetation and which of these geomorphological processes may be a determinant factor in the grassland patches occurring on the southern part of the study site.

6.1 Interrelationships between the different geomorphological processes

Geomorphological processes on the northern part and southern part of the drainage line are summarised in Table 9.

TABLE 9: Summary of geomorphological and hillslope processes

Description	Northern part	Drainage channel	Southern part
Geology	Higher parts (west) are feldspar-rich schist	Higher parts (west) are feldspar-rich schist	Higher parts (west) are feldspar-rich schist
	Lower parts (east) biotite gneiss	Lower parts (east) biotite gneiss	Lower parts (east) biotite gneiss
Weathering	Cliff face is weathering-limited; remaining area is transport-limited.	Cliff face from point 18 upwards, and area between points 12 and 15 are weathering-limited, remaining area is transport-limited.	Cliff face and parts of area downhill are weathering-limited; remaining area is transport-limited.
	Combination of chemical and physical weathering	Combination of chemical and physical weathering; also weathering from fluvial processes	Mostly physical weathering
Erosion	Number of rill of various sizes occurring	Fluvial erosion – bedrock and bank erosion: Points 1-4: deposition, points 5-7: bedrock and bank erosion, points 8-9: little bedrock erosion, points 10-14: deposition, points 15-18: little bedrock erosion	Overland flow and rainsplash dominating certain areas

Description	Northern part	Drainage channel	Southern part
Soil	Deeper topsoil than southern part	Deeper soil at points 1-4, and points 17 & 18	More shallow topsoil than northern part
	Topsoil sequence from high to low: loamy sands, sandy loams, sandy clay loams		Topsoil sequence from high to low: sandy loams, sandy clay loams
	Mostly well-drained soils		Mostly not well-drained soils
	Lower parts (samples 5 & 6) high K		Lower parts (sample 3) high K
	Lower parts (samples 5 & 6) high Ca		Lower parts (sample 3) high Ca
	Mg vary over area		Mg vary over area
	Lower parts (samples 5 & 6) high Na		Lower parts (sample 3) high Na
	Higher parts (sample 4) high resistance		Higher parts (sample 1) high resistance
	pH vary over area		pH vary over area
Mass movement	Rockfall dominant factor with many scattered rocks	Rockfall dominant with many scattered rocks	Rockfall not dominant, there are some scattered rocks, but none on grass areas
	Soil creep		Slumping, soil creep and/or debris flow dominant
Valleys	Two valleys, one creates the drainage channel	Flat-floored valley at points 1-3, and points 17 & 18, rock-floored valley at points 5-7, 12 & 13 and eastern wall of point 14. V shaped valley at points 5-7, 12-14	None
Long profile	Long profile tend to slope towards either the drainage line or towards the north into an lower lying area	Variable gradient	All long profiles slope towards drainage line, no perpendicular sloping from top of profile over the entire southern part
		Pool at points 3-4, 7-8, 9	Slope steeper above

Description	Northern part	Drainage channel	Southern part
			drainage line interception
	Only few convex areas, degree of convexity much smaller than concavities	Steps (riffles) at points 12-15	Even less convex areas than northern part, also much smaller than concavities
Plan form: plan 1 and 2	Concavity in plan forms for both higher and lower plans	Plan form 1 more concave over drainage line than plan form 2	No concavity for both higher and lower plans
Plan from 3 and 4	Northern part lower	Plan form 3 more concave over drainage line, with steep wall on southern wall, than plan form 4	Southern part higher

Biotite gneiss occurs on the largest part of the study site with feldspar-rich schist occurring only on the highest part of the study site. The underlying bedrock, the biotite-gneiss will form the basis of the largest part of the study site and drainage channel on which the majority of processes take place, with the feldspar-rich schist occurring as material transported by mass movement in the lower parts of the study site. Different geomorphological units can be distinguished on the study site and drainage channel. The drainage channel does not divide the study site into these two geomorphological units, but is located within the northern geomorphological units. These two sites are divided at the boundary between the increased erosion to the north and the increased erosion and the overland flow to the south (see Fig. 42, page 90).

Hall (1999), Hall & André (2001), and Hall *et al.* (2012) stated that the type, rate and degree of weathering depend on the rock properties, temperature and moisture. The type of weathering will differ between feldspar-rich schist and biotite gneiss. Parent material has a certain mineralogy and physical nature such as rock strength and rock structure, which will influence the weathering type, degree and rate (Egli *et al.*, 2008). The type of weathering differs between north and south of the study site. However, it is the same rock on both sides; consequently, the difference in weathering is not due to the parent material. Weathering type should then possibly be either due to rock temperature, rock moisture, or discontinuities in rock that may have occurred from mass movement. Mass movement on northern part is dominated by rockfall and soil creep (see diagram by Chuang & McEwen, 2010 and fig 42, page 90). Mass movement on southern part is dominated by slumping and/or debris flow, with scattered rocks more towards the drainage channel, further north. Clarke & Burbank (2010) argued that bedrock does not only influence geomorphological processes, but processes such as valley incisions can cause changes in bedrock including landslides, slumping and/or debris flow. Mass movement in the drainage channel is dominated by rockfall. The rockfall may lead to loss of rock structure from the impact caused by rockfall. Discontinuities in rocks on northern part and in the drainage channel may be a factor for different weathering occurring. Rock moisture and temperature were not measured; however, the northern part and the drainage channel are more densely vegetated by larger types of vegetation than the southern parts. Areas in the southern part that has denser vegetation are still not as dense as on northern part or drainage channel. These different types of vegetation density will probably have different microclimates in terms of both moisture and temperature. Consequently, it is possible that the type of mass movement and type and density of vegetation may all be contributing factor to the different type of weathering. The northern part of the study site and the drainage channel, are dominated by chemical and physical weathering, the southern part is dominated by physical weathering.

As with the type of weathering, the rate of weathering will be affected by rock properties, temperature and moisture. Rock properties will be from discontinuities as well as mass movement; more feldspar-rich schist rocks occur on the northern part and drainage channel due to rockfall. An area where soil is deeper will be characteristic of an area in which the rate of weathering exceeds the rate of erosion. Whereby less soil will mean rate of weathering either decreases or the rate of erosion increases. Rate of weathering in this case will therefore probably also be higher on the northern part of the study site where the soil or sediment accumulation is deeper, with a deeper A horizon. Phillips *et, al.* (2008) stated that increased soil depths are an indication of rock weathering. Soil deposition in the drainage channel is also high. The northern part of the study site has more dense vegetation than the southern part. This could be and affecting factor for the different soil formation form west to east. The biological activities of this dense vegetation, such as root activities, could also influence weathering rates. Soil transported by erosion or soil creep will move downhill, therefore deeper soil levels downhill of an area (Brown *et al.*, 2004; Brunner *et al.,* 2004). Soil depth decreases on the southern part of the study site from higher to lower altitude. Soil on the northern part of the study site is the deepest on the higher altitudes. Soil depth at northern and southern side is inconsistent to the statement that soil moves downslope, therefore the soil layer on a higher slope is usually thinner, with a thicker layer in downslope areas where soil has been deposited. Slope profile or plan as well as the slope angle may have an influence on the soil formation.

Physical weathering of biotite-gneiss is slowly and soil is poorly developed, schist weathers more readily (Marinos & Hoek, 2000). This indicates that areas with high weathering rates will occur where feldspar-rich schist is more prominently weathered than biotite-gneiss. Oxidic soils occur at sites 4-8, which are located on the southern part at the lower altitudes (taken from by MacVicar *et al.* in 1977). Iron oxides accumulated in oxidic soils through the weathering of the parent material. Biotite-gneiss contains a high amount of iron oxides, which will lead to these oxidic soils. Dominant minerals other than Fe in biotite-gneiss are K, Mg, Al, Zn, and Mn; Ca is high within pegmatite; with dominant minerals in feldspar-rich schist being Na, K, Ca, and Al with minor amounts of P. Higher Mg levels will indicate weathering of biotite-gneiss (see Gilkes, 1973; Fitzpatrick, 1980; Harris *et al.*, 1985; Wild, 1993; Kretzschmar, 1997; Buol *et al.*, 2011). High levels of Mg were recorded in the oxidic soils, which correlate with the higher Fe levels, meaning weathered biotite-gneiss. A very high Mg level was recorded in the B-horizon of site 11, which is not an oxidic soil. The highest Na level occurred in the B-horizon at site 11; however, levels vary over the study site. K levels range from low to very high. This may be due to the weathering of both feldspar-rich schist and biotite-gneiss. K levels are highest at sites 11 and 12. The soil sites on the northern part are at lower altitudes than the soil sites on southern part, with site 9 on same altitude as site 8. If it is considered that the air temperature rise for every 170m fall in altitude, it could be assumed that these chemical reactions at the samples sites showing high K levels have been have been higher, therefore a more readily weathering of the schist (Ellis & Mellor, 1995; Buol *et al.*, 2011). The samples sites on the northern part of the study site could also have higher chemical reactions due to the different type of vegetation growth (Parsons, 1988; Hall *et al.*, 2002; Egli *et al.*, 2008; Hall *et al.*, 2012). Ca levels could also be due to either feldspar-rich schist or biotite gneiss. In general, P levels are low in the soil. P levels on the southern part, in soil increases downhill. It also increases in the southern part from A-horizon to B-horizon. P release into soil is most rapid when soils are warm and moist but well drained. Phosphate can potentially be lost through soil erosion and to a lesser extent to water running over or through the soil. The tendency of minerals in the soil is an increase in P, K, Ca and Mg levels at lower altitudes. Both gneiss and schist produce acidic soils. All soils, except for B-horizon at site 11 are slightly acidic with a pH of 6. The B-horizon soil at site 11 is neutral with a pH of 7. To summarise, soils show characteristics of both biotite-gneiss and feldspar-rich schist, with chemical properties of feldspar-rich schist dominating the soils, except at sites 4-8 where biotite-gneiss dominates. Sites 4-8 have a shallow to very shallow A-horizon with and apedal B-horizon. Soil on these sites are the product of slower weathering of biotite gneiss, compared to the other sites which are products of more readily weathering of feldspar-rich schist. Soil properties of the drainage channel were not analysed.

Erosion differs in the study site, whereby rill erosion dominates the northern part, fluvial erosion dominates the drainage channel, and the southern part has patches dominated by overland flow erosion as depicted in Fig 42 (page 90). Large vegetation in the northern part can cause concentration of water, which cause rill erosion. Rainsplash erosion will occur over the entire southern part, and will dominate the higher area of the southern part of the study site where there are no rills, and the topsoil is deeper with a coarser texture. Convex slopes are not dominating the slope profile or slope plan of the southern part, contradicting the statement by Knighton (1984) that a hillslope that is dominated by rainsplash detachment will form a convex profile. Rainsplash erosion is not dominant factors affecting the hillslope of the study site. Overland flow will be the predominant type of fluvial erosion on the patches with feldspathic material and no topsoil. Low-lying areas are usually due to overland flow because of the finer material. Soil with high water content usually occurs on low angled footslopes or near water such as a drainage channel. The flow depth of overland flow decreases if the slope increases. High profile gradients cause transport-limited streams and bedload transport being the dominant factor (Knighton, 1984; Owens & Slaymaker, 2004). Most of the drainage channel is transport-limited, fluvial erosion within the drainage channel will probably be dominated by bedload transportation. The pool area at points 12 to 15 has the lowest gradient, which may be the reason why this area is weathering-limited.

According to various authors, erosion rates depend on factors such as soil, slope angle, climate, vegetation and other environmental factors (Gerrard, 1992; Bryan, 2000; Dlamini, 2011; Ghahramani *et al.,* 2011; Fu *et al*., 2012; Mullan, 2012), and will differ over a hillslope (Brunner *et al*., 2004). Soil properties will be a dominant factor on erosion (Bryan, 2000). Climate over the study site will be similar, but rainstorms during summer months will cause higher rainsplash erosion on the southern site of the study site. Considering the statement by Ghahramani *et al.* (2011), dense vegetation in the northern parts of the study site protects the surface from rainsplash (see also Young, 1972; Knighton, 1984; Petts & Foster, 1985; Polyakov & Lal, 2004). Splash from the leaves of the dense vegetation may cause erosion, but the erosion for this splash will be less than the erosion from rainsplash. Deeper soil and more deposition on the northern side show that, as argued by Ghahramani *et al.* (2011), even though rill erosion occurs, erosional processes are decreased by the dense vegetation. Young (1972), Knighton (1984); Petts & Foster (1985); and Polyakov &

Lal, (2004) further argue that the dense vegetation improve soil strength and structure. Soil strength was not assesses, and may be a dominant factor, but the strength is not because of organic content – the average organic content on the southern part of the study site is higher the organic content on the northern part. Soil structure was also not assessed but could also be a contributing factor. Soil texture will influence soil structure. There is no trend whereby the general soil texture on the northern part differ from the general soil texture on the southern part, therefore soil structure may be a factor, but not due to soil texture. Dense vegetation on the northern part of the study site could possibly increase soil strength and structure. Steeper profile angles occur on the southern part of the study site (see Fig. 34 and Fig. 35 on page 77). Gerrard (1992) states, steeper angles will increase erosional rates because of a reduction in the amount of water. Steeper angles could thus also be a contributing factor for higher erosional rates on the southern part than on the northern part of the study site. Erosional rates are thus higher on the southern part due to the vegetation density, rainsplash from rainstorms and steeper angles. According to Young (1972), Richards (1982), Knighton (1984) and Parsons (1988), the area of overland flow will have a low capacity for sediment transport, thus rainsplash erosion will, except for fluvial erosion, most likely have the highest rate of sediment transport.

Soil depth decreases downhill at both the northern part and the southern part. Soil depth varies within the drainage channel, with deep soil at points 17-18 and points 1-4. Points 17-18 correlate in height with the deeper soil samples for the northern and southern parts. Deeper soil at points 1-4 of the drainage channel is consistent with the statement made by Brown *et al.* (2004) and Brunner *et al*. (2004); the shallower soil on the southern and northern parts are inconsistent with this statement. Soil texture shows a decrease downhill for the northern and the southern part of the study site, indicating transport of material does take place downhill; erosion is not the dominant factor affecting the hillslope of the study site. Burbank *et al*. (1996) and Montgomery & Brandon (2002) argues that mass movement will be the dominant process above a certain steepness. They do not expand on the steepness, but it is probable that due to the high angles of the study site, mass movement can be the dominant process taking place. Soil depth within the drainage channel is not only an indication of weathering and erosion but could be due to deposition as a result from change in longitudinal profile of the drainage channel. Pools at points 3-4, 7-8 could influence the deposition of material being transported by erosion. Points 1-3 are described as a foothill: sandy bed zone (Noble & Hemens, 1978). The pool at point 3 may also be a contributing factor for the braiding within the channel taking place at point 2.

Rockfall occurrence could be influenced by the type of rock. The cliff face on both the northern and southern parts of the study site is from the same feldspar-rich schist rock group. Rock type is therefore not a contributing factor for rockfall occurrence. External factors such as tree roots, animal movement and underlying rock will also not be controlling factors for rockfall. The cliff face is relatively at the same height, meaning increase in altitude; therefore change in climate is also not a controlling factor. Change in aspect may influence rockfall, however, the cliff face on both sides, is situated to the north-east. Undercutting of rock due to the drainage channel may be a dominant factor influencing the increased occurrence of rockfall in the northern part of the study site. According to the slope profile, except for profile line 3 which deflects away from the site, the surface area slope towards the drainage channel at a height of approximately 1040m a.m.s.l. and 1060m a.m.s.l. Rocks form rockfall will rather move towards the drainage area or the area between long profile 1 and long profile 3, and not in the southern parts of the study site below approximately 1060m a.m.s.l. Many rocks from rockfall were observed within the drainage channel. Referring to the plan forms, the entire site shows an evident decrease in height from the southern part to the northern part (see Fig 38, page 80). The area just north of point 'B' on plan form 4 is convex. Rocks from rockfall do occur in this area.

Landslide movements such as slumping and debris flow are controlled by the type of material, the steepness of the slope. Geologically, the type of material is similar north and south of the drainage channel. According to Fig. 33 (page 76) the long profiles on the southern part (long profile 2 and 4) have a steeper gradient, above the drainage channel than long profile 1. The area also slopes from the southern part towards the drainage channel. Steeper slopes both west to east and south to north may be an indication of the slumping and /or debris flow occurring on the higher altitudes of the southern part. Soil creep occurs due to factors such as climate changes, soil physical changes, vegetation, animals or rain. Climate will not be a contributing factor for differences in soil creep over the study site. Soil temperature changes, expansion and contraction, and soil moisture content were not assessed. Clay percentage is higher in the northern soil samples; however, soil samples were not taken at areas of highest soil creep occurrence. Wild animals[22] roaming the area will not be restricted to either the northern or southern part. Roots from larger vegetation on the northern part may be a controlling factor for soil creep occurring.

Geomorphological processes were not assessed on unit 3 (convex slope), however the surface geology is feldspar-rich schist. Two valleys in the northern part - of which one is

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[22] Antelope were observed on site during the second site visit.

the drainage channel - originate in this unit (Fig 42, page 90). Feldspar-rich schist dominates unit 4 (fall face), and the lower part of is the boundary between feldspar-rich schist to biotite-gneiss. Weathering, rockfall and slumping dominates the fall face unit. The drainage channel divides the cliff into two parts, whereby the start of the southern cliff face is more than 60m higher than the start of the northern cliff face. Height difference at the base of the cliffs is 30m, with the base of the southern cliff face higher than the base of the northern cliff face. According to Table 7 (page 75) slope angle for profile 1 (northern part) at the cliff face is 66.64° and the slope angle for profile 2 (southern part) at the cliff face has an angle of 57.91°. Slope angle of the drainage line in unit 4 is 23°. Majority of the convex slopes occur within this unit, with the exception of the drainage channel, which is named a mountain stream (Noble & Hemens, 1978).

The starting point of the slumping or debris flow is the boundary between unit 4 and unit 5 (transportational midslope) (Fig 42, page 90). Bedrock geology is biotite-gneiss, with feldspar-rich schist rocks occurring form rockfall. Chemical and physical weathering takes place, but this unit is dominated by transportational processes and is mostly a transport-limited slope. Rill erosion, rainsplash erosion and overland flow run-off occur in this unit. One area within the drainage channel –point 12 to 15 – is weathering limited. Flat-floored valleys occur at points 1-3, and points 17 & 18, rock-floored valley at points 5-7, 12 & 13 and eastern wall of point 14. V shaped valley occur at points 5-7, and 12-14. Slumping continues from unit 4, with rockfall and soil creep also controlling processes. A-horizons are mostly thin and show heterogeneity in terms of texture and chemistry (as stated by Hall in 1983).

The boundaries of the unit 5 and unit 6 (colluvial footslope) were adjusted according to profile angle, plan form angles and dominant geomorphological processes (Fig 42, page 90). Long profile 3 has the highest slope angle, followed by long profile 4, long profile 2 and long profile 1. Long profiles 1, 2 intersect the drainage line at a height of approximately 1,060mamls and long profile 4 intersects the drainage line at a height of approximately 1010m a.m.s.l. Long profile 3 decreases north and away of the study area. Profiles 1 and 4 of the southern part have higher slope angles than long profile 1. Drainage channel profile has an average angle of 11°. Only a few small convex slopes occur within this unit, with the exception of the drainage channel with many convex and concave slopes. Convex plan forms dominate the northern part of this unit, with concave plan forms dominating the area south of the drainage channel and convex plan forms dominating the southern boundary of the study site. According to the channel classification, the drainage channel within unit 5 is a production zone (Schumm, 1977), which is similar to deposition. It is also named a foothill rocky bed. Bedrock geology at unit 6 is also is biotite-gneiss, and mostly covered by deposited material. Weathering will still take place, but natural erosional and mass movement processes decline in this unit. Decrease in soil depth contradicts the statement by Brown *et al.* (2004) and Brunner *et al*. (2004). This part of the drainage channel is characterised as a transportational zone (Schumm, 1977). Human activities including farm houses, Kampersrus AH and roads may create human-induced transportational processes, leading to the decrease in soil depth. Slope angles in unit 6 are low, with a few, small convex slopes.

6.2 Geomorphological processes on grassland patches

Grassland patches occur on lower parts of southern boundary, with changes between 1938, 1954, 1986, and 2008 (Ferguson & Rautenbach, 2012). Table 10 provides a summary of processes occurring within these different grassland patches over these 5 timeframes. See Fig 43 (page 103) for the grassland patches and geomorphological processes.

TABLE 10: Geomorphological and hillslope processes in grassland patches

Description	1938	1954	1971	1986	2008
Geology	Biotite gneiss	Biotite gneiss	Biotite gneiss	Biotite gneiss	Biotite gneiss
Weathering	Mostly physical weathering	Mostly physical weathering	Mostly physical weathering	Mostly physical weathering	Mostly physical weathering
	Area is transport-limited; part of middle area is weathering-limited	Area is transport-limited; part of upper area is weathering-limited	Area is transport-limited; part of middle area is weathering-limited	Area is transport-limited	Area is transport-limited
Erosion	Rainsplash and overland flow	Rainsplash, overland flow, and rill erosion	Rainsplash, overland flow, and rill erosion	Patch 1 – rainsplash, patch 2 – overland flow	Patch 1 – rainsplash, patch 2 & 3 – overland flow
Soil	Oxidic soils	Oxidic soils	Oxidic soils	Oxidic soils	Oxidic soils
	Shallow A-horizon	Shallow A-horizon	Shallow A-horizon	Shallow A-horizon	Shallow A-horizon
Mass movement	Soil creep	Soil creep, rockfall where area extends	Soil creep, rockfall where area extends	Soil creep	Soil creep

Description	1938	1954	1971	1986	2008
		into rill erosion	into rill erosion, slumping		
Valleys	None	Area extending into rill erosion, south of valley (drainage channel)	None	None	None
Long profile	Concave dominates	Concave dominates	Concave dominates, with convex on upper parts	Concave dominates	Concave dominates
Plan forms	Convex dominates, with concave on upper parts	Convex dominates	Convex dominates, with concave on upper parts	Convex dominates	Convex dominates
Slope units	Units 5 & 6	Units 5 & 6	Units 5 & 6	Units 5 & 6	Units 5 & 6

Geology is biotite gneiss over the entire grassland patches as well as areas with denser vegetation. Weathering is mostly physical from feldspar-rich geology, which may be from the slumping of the feldspar-rich schist. Microclimate of the grassland patches will also influence weathering differently than densely vegetated areas. Rate of weathering is in general lower in the grassland patches than denser vegetative areas. Soils occurring in areas of grass patches are oxidic soils with a shallow to very shallow A-horizon. Oxidic soils are from biotite gneiss and have a higher drainage capacity than lithic soils. High concentrations of minerals such as Fe, Ca, Mg, Na, and P occur in these soils. Fe and Na are high within biotite gneiss, Ca in both biotite gneiss and feldspar-rich schist, and Na in feldspar-rich schist. P levels are very high at samples site 3 compared to the other sites. The area surrounding this samples site is the area where grassland patches were observed throughout including 2008. P levels indicate warm soil and good drainage. It is not known why these levels are high at sample site 3. Overland flow, and in particular rainsplash, dominates erosional processes. Erosional rates are higher in the grassland patch area, due to rainsplash (from rainstorms and sparser vegetation), weaker soil and soil structure, and steeper slope profile angles. Mass movement is mostly in the form of soil creep with slumping (from steeper slope angles) and rockfall being less dominant processes. No valleys occur within the grassland patches, but the area has mostly concave long profile and convex plan form. Slope units are both transportational and colluvial footslope, therefore the area is characteristic of both transportation and deposition.

Geomorphological processes described above, dominating the southern part of the study site, are responsible for the grassland patches occurring, and it could also be argued that geomorphological processes, which only dominate the northern part of the study site, will not support the occurrence of grassland vegetation.

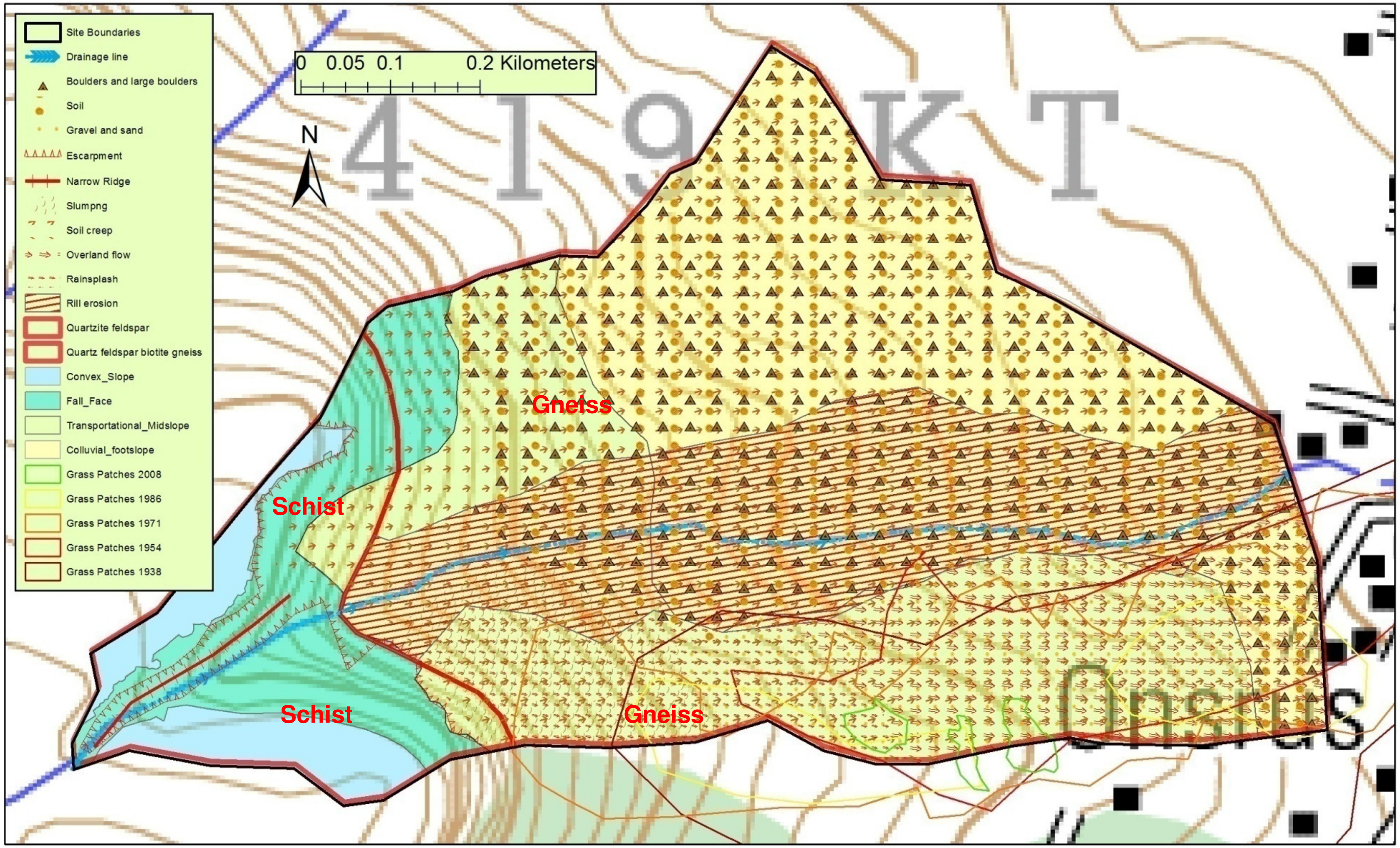

FIGURE 43: Geomorphological map with grassland patches

Chapter 7: Conclusion

Various studies assess the interactions between different geomorphological processes on a hillslope and interactions with the local vegetation (see Marston, 2010, for examples). Hillslopes are heterogeneous (Hopp & McDonnell, 2009), thus different geomorphological processes can be observed on a hillslope. Mariepskop is similar in this regard, showing heterogeneous processes both laterally and vertically over the study area. Lateral and vertical variations also occur within the vegetation of the study area both inside the study area, with a decrease in vegetation density from north to south and change in vegetation patterns from west to east on the southern slope. A number of geomorphological processes interactions were prominent, with certain processes dominating the various vegetation occurrences.

Literature shows that bedrock characteristics influence the hillslope through erosion (Clarke & Burbank, 2010), weathering (Aristizábal *et al.*, 2005) and the fluvial properties of the hillslope (Gabrielli *et al.*, 2012). Geomorphological processes on the northern and southern part of the study site are influenced by the underlying geology but, the difference in geomorphological processes on the northern and southern parts are not due to underlying geology because the same bedrock geology occurs on both parts. Crozier (2010) stated that mass movement could be a prominent factor controlling certain geomorphic processes. Coarse-grained mass movements are mostly prominent on the higher altitudes of both the northern and southern part. Mass movement in the form of slumping/debris flow is a dominant process on the southern part because of the steeper slope angle. This movement takes place below the cliff face as described by Owens & Slaymaker (2004) and may be the cause for the convexity within the slope profile as well as the convexities occurring in the plan form on the southern part of the study site. Rockfall occurs mostly on the northern part of the study site. Clark & Small (1982) argues that rockfall takes place on steep rock banks such as cliff areas. The cliff face on the northern part is not noticeably steeper than the cliff face on the southern part, and the increased rockfall is due to undercutting of the cliff by the drainage line and could also be due the convex plan form on the southern part, deflecting rocks form the area. Soil creep is a fine-grained mass movement and occurs mostly on the lower altitudes of both the northern and southern part of the study site.

Weathering is a dominant process on the northern part. Discontinuities within the rocks from rockfall will increase physical and chemical weathering on the northern part (also stated by Parsons, 1988). Rocks from rockfall are feldspar-rich schist and is not as strong as biotite gneiss (Marinos & Hoek, 2000), resulting in higher degree of weathering on rocks from rockfall. Dense vegetation on the northern part also increase weathering due to microclimates and the physical action of the roots. The importance of erosion on a hillslope is discussed by Cochrane & Flanagan (2001), and Saadat *et al.* (2008). Erosional processes are also dominant on the southern part whereas rainsplash and overland flow dominate. This erosion is affected by various factors and in particular by the convexity of the topography and steeper slope angles and could also be influenced to a large degree by the sparser vegetation. Rill erosion occurs predominantly on the northern part of the study site which is as a result of dense vegetation. According to Greenway (1987) and Schmidt *et al.* (2001) dense vegetation will inhibit rill erosion, but, as stated by Petts & Foster (1985) and Ruiz Sinoga *et al.* (2010), the combination of vegetation and rocks from rockfall, create microtopographies, which increase the possibility for rill erosion to occur. Topographical incisions such as a drainage channel lead to fluvial erosion taking place. Fluvial erosion will also influence the drainage channel topography (Knighton, 1998; Pietersen, 2009). Soil characteristics are influenced by various factors including erosion or deposition (Hancock *et al.*, 2010). Deposition is a product of weathered material on a slope that has a concave slope profile and plan form. Soil is deeper on the northern part due to weathering being dominant process, and the concavity of the topography. Soil will be shallow within the rills caused by erosion while erosional processes on the southern part result in shallower soil profiles.

The interactions between vegetation and geomorphology, as well as the change in vegetation (diversity) and different geomorphological processes on a heterogeneous hillslope, have been studied by various geomorphologists such as Gessler *et al.* (1995), Hancock *et al.* (2010) and Marston (2010). Brubaker *et al.* (1993) and Phillips *et al.* (2008) further state that different geomorphological processes on a heterogeneous hillslope lead to different soil formations, which in turn influence vegetation. The change in soil depth between the northern part and the southern part could be a prominent factor for different vegetation. Grassland patches on the southern part may therefore be due to a number of factors, including slumping from mass movement, rainsplash, soil creep, and the convexity of the plan form interacting to create shallower soil, and in particular a shallow A-horizon, which in turn affect vegetation growth. Lower rates of weathering, and the fact that weathering is mostly physical, on the southern part will also lead to shallower soil, and A-horizon, than on the northern part with higher rate of weathering and chemical weathering being important. Geomorphological processes, such as overland flow, are influenced by the grassland vegetation, therefore an interaction between the hillslope geomorphological processes and the grassland patches. Oxidic soils occur on parts of the southern part of the study area. These oxidic soils are products from the biotite gneiss, which outcrops on the southern part and are also a factor contributing to the grassland patches on the southern part.

The study by Ferguson & Rautenbach (2012) regarding drivers of long-term vegetation change at Mariepskop describes both the spatial location of these grassland patches as well as the change in size and distribution from 1938 to 2008. The study site used for this thesis only includes a small portion of the grassland patches. Various grassland patches are located south-south-east of the study site (see Fig. 44). The geomorphological factors contributing to the grassland patches in the study site will then probably also be a contributing factor to grassland patches in the other areas. Different vegetation and vegetation densities in the additional areas will also influence the geomorphological processes, as discussed for the study site. Underlying geomorphological processes differ slightly from 1938 to 2008 (see Fig 43, page 103). Grassland patches were located on both transport-limited and weathering-limited slopes from 1938 to 1971. These patches also shifted from 1938 in an area dominated by soil creep, concave profile, and concave plan form towards the drainage channel in 1954, with rockfall being prominent, and a change to a convex plan form; towards the west, away from the drainage line, where slumping dominates and profile is also mostly convex. Present locality of the grassland patches has similar geomorphological processes from 1986, but the size of these patches has decreased to small, scattered patches. Unchanged from 1938 to 2008, are the occurrence of oxidic soil, with shallow A-horizon on underlying biotite-gneiss bedrock, in an area dominated by rainsplash and overland flow run-off erosion, as well as soil creep, on a concave long profile and a convex plan form. Grassland patches on other parts of the Mariepskop northern slope will probably have similar changes over the years 1938 to 2008, with similar geomorphological processes unaltered throughout this period.

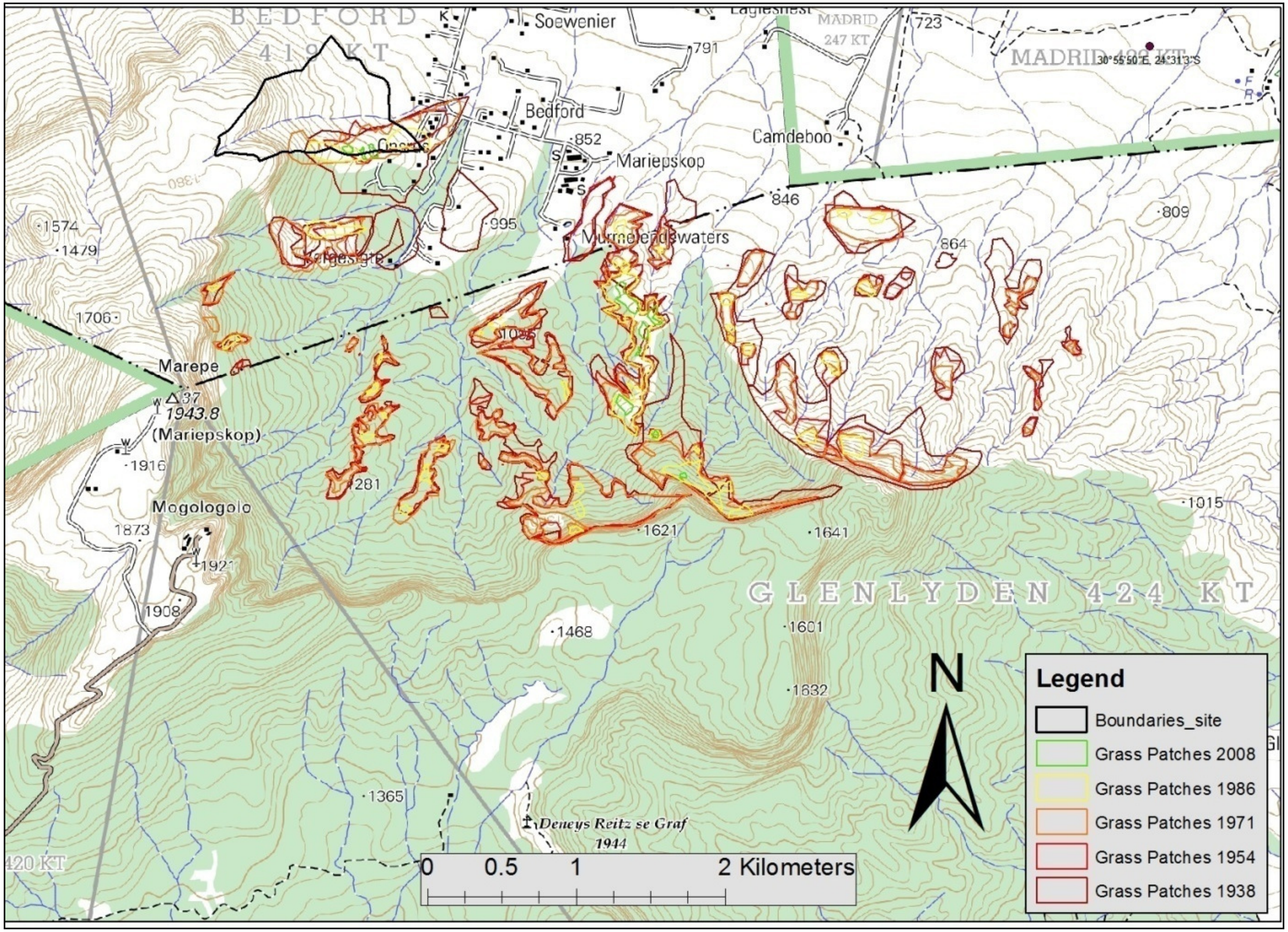

FIGURE 44: 1:50 000 Topocadastral Map indicating general area with grass patterns of Mariepskop (Adapted from: Ferguson & Rautenbach, 2010)

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Addendum 1

Refer to Table 10 for a summary of these points' coordinates, height in m a.m.s.l., distance and description of the drainage channel at point.

TABLE 11: Summary of drainage channel

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
1	24°31'15.6"S; 30°53'09.6"E	897 (900)	N/A	N/A	N/A	Transportational/erosional properties: No or very slight vertical erosion has taken place in the channel floor; The rocks that do occur on drainage channel floor are due to non-fluvial transportation and are not part of the bedrock floor; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Flat-floored valley Long profile and pool-riffle sequence: None

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Other description: Vegetation is dense with many smaller plants inside the channel and small to larger plants on the banks.
2	24^{0}31'18.3"S; 30^{0}53'07.1"E	899	2	6.35	17.482	Transportational/erosional properties: No or very slight vertical erosion has taken place in the channel floor; The rocks that do occur on drainage channel floor are due to non-fluvial transportation and are not part of the bedrock floor; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Flat-floored valley Long profile and pool-riffle sequence: Moderate gradient compared to channel. Other description: Vegetation within the channel is reduced

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						significantly; Some in-channel braiding does occur.
3	24°31'18.54"S; 30°55'52.16"E	912	13	33.6	21.152	Transportational/erosional properties: Much material has been deposited on the channel floor; Banks height increased, therefore more vertical erosion than point 1 and 2; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Flat-floored valley Long profile and pool-riffle sequence: Gradient increases from point 1; Moderate to high gradient Other description:

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Some in-channel braiding does occur; Many trees are situated on the banks of the channel.
4	24°31'18.8"S; 30°53'05.7"E	912	0	110.47	0.000	Transportational/erosional properties: Much material has been deposited on the channel floor; Banks height similar to point 3, therefore more vertical erosion than point 1 and 2; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; Rocks on 'banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: None Lone profile and pool-riffle sequence: Gradient zero, therefore no increase in height. Other description:

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Some in-channel braiding does occur; Many trees are situated on the banks of the channel.
5	24^{0}31'18.3"S; 30^{0}53'05.3"E	924	12	34.9	18.975	Transportations /erosional properties: Vertical erosion is evident; The rocks that do occur on drainage channel floor are due to fluvial transportation; No lateral erosion is evident; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Rock-floored valley on eastern side; V-shaped valley Long profile and pool-riffle sequence: Increase of gradient, still moderate compared to channel Other description: Vegetation on channel floor is scarce, with dense vegetation on banks.

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
6	24^{0}31'18.4"S; 30^{0}53'04.4"E	929	5	28.1	10.089	Transportational/erosional properties: Much material has been deposited on the channel floor; Banks not very high, therefore vertical erosion either slight or is not evident; Almost no rocks, but the limited amount rocks that do occur on drainage channel floor are due to fluvial transportation; No lateral erosion is evident; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Rock-floored valley on both sides; V-shaped valley. Long profile and pool-riffle sequence: Gradient decreases, low compared to channel Rock wall on western side Other description: Vegetation on channel floor is scarce, with

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						dense vegetation on banks; High amount of dry leaves on channel floor.
7	24°31'18.4"S; 30°53'03.4"E	937	8	15.01	28.057	Transportational/erosional properties: Much material has been deposited on the channel floor; Banks not very high, therefore vertical erosion either slight or is not evident; Almost no rocks, but the limited amount rocks that do occur on drainage channel floor are due to non-fluvial transportation; No lateral erosion is evident; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: Rock-floored valley on both sides; V-shaped valley. Long profile and pool-riffle sequence: Sudden increase in gradient, high gradient; Longitudinal profile shows a riffle.

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Other description: Vegetation on channel floor is scarce, with dense vegetation on banks.
8	$24^o31'17.7"S$; $30^o53'02.5"E$	928	9	34.59	-14.584	Transportational/erosional properties: Much material has been deposited on the channel floor; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; However some vertical erosion may have taken place before deposition due to height of banks; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: None Long profile and pool-riffle sequence: Decrease in gradient, low compared to channel; Rock wall on the western side of the drainage channel indicates knick-point;

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						According to longitudinal graph, area indicates pool. Other description: Vegetation is dense with many roots of trees and bushes.
9	24°31'18.2"S 30°53'01.6"E	946	18	40.69	23.863	Transportational/erosional properties: Much material has been deposited on the channel floor, more than with previous point; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; However some vertical erosion may have taken place before deposition due to height of banks; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: None Long profile and pool-riffle sequence:

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Increase in gradient, high gradient; Rock wall on the western side of the drainage channel indicates knick-point; Vegetation mostly on banks.
10	24^{0}31'17.7"S; 30^{0}53'00.5"E	941	-5	34.67	-8.206	Transportational/erosional properties: Material has been deposited on the channel floor; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; However some vertical erosion may have taken place before deposition due to height of banks; Rocks on banks not due to transportation thus lateral erosion has taken place; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: None Long profile and pool-riffle sequence: A low negative gradient

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Other description: Some vegetation, mostly in the form of roots on channel floor, with dense vegetation on banks.
11	24⁰31'18.5"S; 30⁰52'59.4"E	962	21	30.38	34.654	Transportational/erosional properties: Material has been deposited on the channel floor; The rocks that do occur on drainage channel floor are due to non-fluvial transportation; However some vertical erosion may have taken place before deposition due to height of banks; Rocks on banks not due to transportation thus lateral erosion has taken place; Large rock wall on the western side of the drainage channel; Deposition > erosion therefore transport limited on drainage channel floor. Valley description: None Long profile and pool-riffle sequence: Increase in gradient, high gradient;

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Drainage channel starts getting very deep; Step in a pool area with a steep wall to south; However when looking at the drainage channel profile this point is at a peak going down to south. Other description: Some vegetation on channel floor, with dense vegetation on banks.
12	$24^0$31'18.4"S; $30^0$52'58.2"E	948	-14	33.1	-22.926	Transportational/erosional properties: Vertical erosion has taken place as the channel is deep with banks more than 2m high; Most of the material that does occur in the channel is wind-blown plant material; Lateral erosion has taken place into the bedrock; Deposition < erosion therefore resistance-limited on drainage channel floor; Valley description: On both banks, lateral erosion into bedrock has formed rock-floored valley;

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						The channel is very narrow and forms a V-shape. Long profile and pool-riffle sequence: High negative gradient Other description: Some vegetation on channel floor, with dense vegetation on banks.
13	24⁰31'18.7"S; 30⁰52'57.8"E	948	0	28.58	0.000	Transportational/erosional properties: Vertical erosion has taken place as the channel is deep with banks more than 2m high; Most of the material that does occur in the channel is wind-blown plant material; However some deposition has taken place which is not wind-blown; Some of the loose rocks in the channel are mostly significantly rounded indicating rocks being transported for some distance; Some of the loose rock material not due to water transportation but due to rock fall / slide. Lateral erosion has taken place into the bedrock

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Deposition < erosion therefore resistance-limited on drainage channel floor; Valley description: On both banks, lateral erosion into bedrock has formed rock-floored valley; The channel is very narrow and forms a V-shape. Long profile and pool-riffle sequence: Gradient zero, therefore no increase in height. Other description: Increase in small vegetation on channel floor; Not many large plants on channel floor.
14	24^{0}31'19.4"S, 30^{0}52'57.2"E	947	-1	25.92	-2.209	Transportational/erosional properties: Vertical erosion has taken place as the channel is deep with banks more than 3m high; Most of the material that does occur in the channel is wind-blown plant material; However some deposition has taken place which is not windblown. This is however very

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						slight; Some of the loose rocks in the channel are mostly significantly rounded indicating rocks being transported for some distance; Some of the loose rock material not due to water transportation but due to rock fall / slide; Lateral erosion has taken place into the bedrock Deposition < erosion therefore resistance-limited on drainage channel floor; Valley description: On eastern bank, lateral erosion into bedrock has formed rock-floored valley; The western bank is mostly soil and not rock, therefore rock-floored valley not evident; The channel is very narrow and forms a V-shape; Long profile and pool-riffle sequence: A low negative gradient; Rock wall on the western side of the drainage channel indicates knick-point.

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Other description: Some vegetation on channel floor, with dense vegetation on banks.
15	$24^0$31'19.2"S; $30^0$52'56.0"E	951	4	19.05	11.858	Transportational/erosional properties: Vertical erosion is evident, however banks are low therefore it is very slight; Lateral erosion is present, however not very significantly; Deposition > erosion therefore transport limited on drainage channel floor; Vegetation density reduced. Valley description: Soil not deep and flat-floored valley not evident; Long profile and pool-riffle sequence: Increase in gradient, but still low gradient Other description: Vegetation scarce on channel floor, with dense vegetation on banks.

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
16	24^{0}31'19.5"S; 30^{0}52'52.2"E	989	38	14.61	68.970	Transportational/erosional properties: Vertical erosion is evident, however banks are low therefore it is very slight; Lateral erosion is present, however not very significantly; Deposition > erosion therefore transport limited on drainage channel floor; Channel bed and bank description: Soil much deeper than other points creating a flat-floored valley; Valley description: None Long profile and pool-riffle sequence: Very high increase in gradient Other description: Vegetation growth is dense (slightly less than point 1 and 2), many small plants and one large tree.

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
17	24^{0}31'20.0"S; 30^{0}52'51.2"E	989	0	28.93	0.000	Transportational/erosional properties: Vertical erosion is evident, however banks are low therefore it is very slight; Lateral erosion is present, however not very significantly; Deposition > erosion therefore transport limited on drainage channel floor; Valley description: Soil much deeper than other points creating a flat-floored valley. Long profile and pool-riffle sequence: Gradient zero, therefore no increase in height. Other description: Vegetation growth is dense many large bushes and trees; Many termite mounds present.
18	24^{0}31'19.8"S; 30^{0}52'51.2"E	991	2	110.04	1.041	Transportational/erosional properties: Vertical erosion is evident, however banks are low therefore it is very slight;

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Lateral erosion is present, however not very significantly; Deposition > erosion therefore transport limited on drainage channel floor; Valley description: Soil much deeper than other points creating a flat-floored valley; Long profile and pool-riffle sequence: Very low gradient, almost no gradient Other description: Vegetation growth is dense, many large bushes and trees.
19	24°31'19.8"S; 30°52'51.2"E	1023	32	70.50	24.413	Long profile and pool-riffle sequence: Increase in gradient, high gradient
20	24°31'19.8"S; 30°52'51.2"E	1038	15	38.93	21.072	Long profile and pool-riffle sequence: Decrease in gradient; Gradient moderate to high
21	24°31'19.8"S; 30°52'51.2"E	1068	30	68.25	23.728	Long profile and pool-riffle sequence: Increase in gradient;

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
						Gradient high
22	$24^0$31'19.8"S; $30^0$52'51.2"E	1085	17	33.88	26.646	Long profile and pool-riffle sequence: Slight decrease in gradient
23	$24^0$31'19.8"S; $30^0$52'51.2"E	1109	24	46.39	27.355	Long profile and pool-riffle sequence: Increase in gradient; Gradient high
24	$24^0$31'19.8"S; $30^0$52'51.2"E	1130	21	38.55	28.579	Long profile and pool-riffle sequence: Gradient similar to point 23; Gradient high
25	$24^0$31'19.8"S; $30^0$52'51.2"E	1174	44	62.39	35.193	Long profile and pool-riffle sequence: Increase in gradient; High gradient
26	$24^0$31'19.8"S; $30^0$52'51.2"E	1223	49	53.30	42.593	Long profile and pool-riffle sequence: More increase in gradient
27	$24^0$31'19.8"S; $30^0$52'51.2"E	1262	39	44.87	40.996	Long profile and pool-riffle sequence: More increase in gradient
28	$24^0$31'19.8"S; $30^0$52'51.2"E	1290	28	48.87	29.810	Long profile and pool-riffle sequence: Decrease in gradient; Gradient still high
29	$24^0$31'19.8"S; $30^0$52'51.2"E	1308	18	38.39	25.121	Long profile and pool-riffle sequence: Decrease in gradient; Gradient still high

Point	Coordinates	Height (m a.m.s.l.)	Height difference from previous point (m)	Distance from previous point (m)	Gradient from previous point (degrees)	Description
30	24°31'19.8"S; 30°52'51.2"E	1320	12	47.03	14.314	Long profile and pool-riffle sequence: Increase in gradient
31	24°31'19.8"S; 30°52'51.2"E	1331	11	49.73	12.473	Long profile and pool-riffle sequence: Decrease in gradient; Moderate gradient
32	24°31'19.8"S; 30°52'51.2"E	1341	10	41.39	13.583	Long profile and pool-riffle sequence: Decrease in gradient; Moderate gradient
33	24°31'19.8"S; 30°52'51.2"E	1349	8	39.27	11.515	Long profile and pool-riffle sequence: Slight decrease in gradient; Moderate gradient
34	24°31'19.8"S; 30°52'51.2"E	1359	10	61.64	9.215	Long profile and pool-riffle sequence: Slight decrease in gradient; Moderate gradient