4. DESCRIPTION OF STUDY AREA

4.1. Physiography and climate

The Limpopo Province is in the north-eastern corner of South Africa, bordering on Zimbabwe in the north and Mozambique in the east. The study area covers an area of approximately 23 500 km^2 and straddles the eastern and western parts of the Limpopo and, Luvuvhu/Letaba Water Management Areas respectively (Figure 4.1). In the Limpopo WMA portion of the study area the main surface drainages are the Sand-, Hout- and Brak Rivers. The gentle relief results in relatively slow flowing rivers which accumulate extensive alluvial deposits on their floodplains particularly along the Sand River. All of these rivers flow towards the Limpopo River in the north and eventually reach the Indian Ocean in Mozambique.

In both WMA's the runoff is highly seasonal and variable, with intermittent flow in many of the tributaries. Only a small number of river courses are perennial and most rivers sustain flow only during the wet season (December to April) or following intense rainfall events. The two main perennial rivers in the Luvuvhu/Letaba WMA portion of the study area are the Great Letaba- and Little Letaba rivers. The mountainous zone or Great Escarpment in the WMA includes the northern portion of the Drakensberg mountain range, which lies on a north-south axis (Figure 4.1). This zone is deeply incised by the major tributaries draining towards the east. The topography of the area varies from a zone of high mountains in the west through low mountains and foothills in the central parts to plains in the east. The average elevation in the central part of the study area is 400 to 800 metres above sea level, and is 1200 to 1600 metres above sea level in the Blouberg and Soutpansberg (north of Makhado) regions (Figure 4.1).

Climate

The climate varies from sub-tropical to semi-arid. The western parts have a dry, hot steppe semi-arid climate, becoming cool along the escarpment. The Luvuvhu/Letaba WMA is characterised by subtropical temperatures with a fairly high humidity. Large variations are observed for seasonal temperatures, while the eastern parts of the study area (i.e. Polokwane) experience cooler generally temperatures compared to the north-eastern parts (i.e. Giyani). Maximum temperatures are experienced in January and minimum temperatures occur on average in July (Table 4.1).

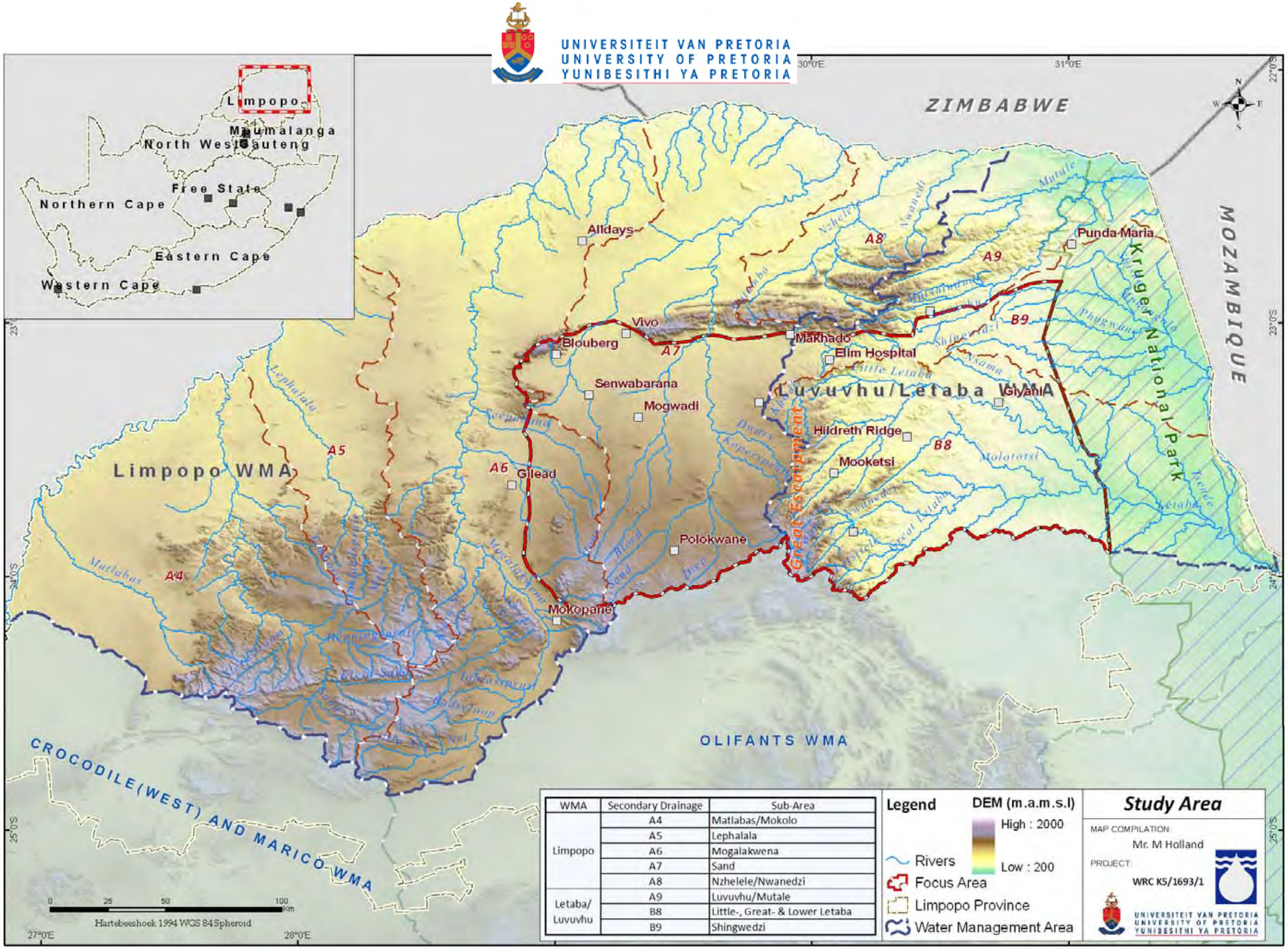


Figure 4.1. Regional surface drainage features, topography and study area.

Table 4.1. Temperature (°C) variations of selected towns and climate stations.

Station*	Summer		Winter		Annual	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*
Polokwane	16	27	8	22	25	12
Mara	17	29	8	25	27	12
Tzaneen	18	27	14	24	25	16
Modjadji	14	26	11	23	25	13
Levubu	18	28	12	25	27	15
Thoyandou	18	29	12	26	27	15
Giyani	19	31	11	27	29	15

*- South African Weather Services (SAWS).

Long term rainfall records exist for several South African Weather Services (SAWS) meteorological stations distributed throughout the area. The spatial distribution of climate stations in the study area together with the average monthly rainfall for selected stations is illustrated in Figure 4.2. and presented in Table 4.2.

Table 4.2. Rainfall data for selected stations distributed throughout the study area.

Nr*	Station*	*Start Date*	*Status*	Annual Rainfall (mm)		*Elevation (mamsl)*
				Mean	*Median*	
677099	**Chloe-Sisal**	1965	Active	365	342	1139
721562	**Dendron**	1971	Active	403	400	1040
679227	**Hans Merensky School**	1960	Active	950	911	727
721665	**Mara Police**	1947	Active	454	442	1051
766779	**Palmaryville**	1907	Active	916	887	581
677834	**Pietersburg Hospital**	1904	Active	455	450	1318
723073	**Rossbach**	1974	Active	912	867	994
724790	**Shangoni**	1972	Closed (2003)	446	397	431
722779	**Soekmekaar**	1965	Active	648	585	1135

*- South African Weathers Services.

Orographic rains occur frequently along the Great Escarpment and the mean annual rainfall varies accordingly from 1 000 mm in the central parts to only 300 mm in the west and 400 mm in the east respectively. As a result of the low rainfall over most of the study area, relatively little surface runoff is generated. The runoff is highly seasonal and variable, with intermittent flow in many of the tributaries. Only a number of major river courses are perennial and most rivers sustain flow only during the wet season (November to March) or during intense rainfall events. The spatial rainfall variability is clearly illustrated in Figure 4.2. The average potential mean annual gross evaporation (as measured by A-pan) ranges from 1 600 mm in the central mountainous region to over 2 000 mm in the western and eastern areas.

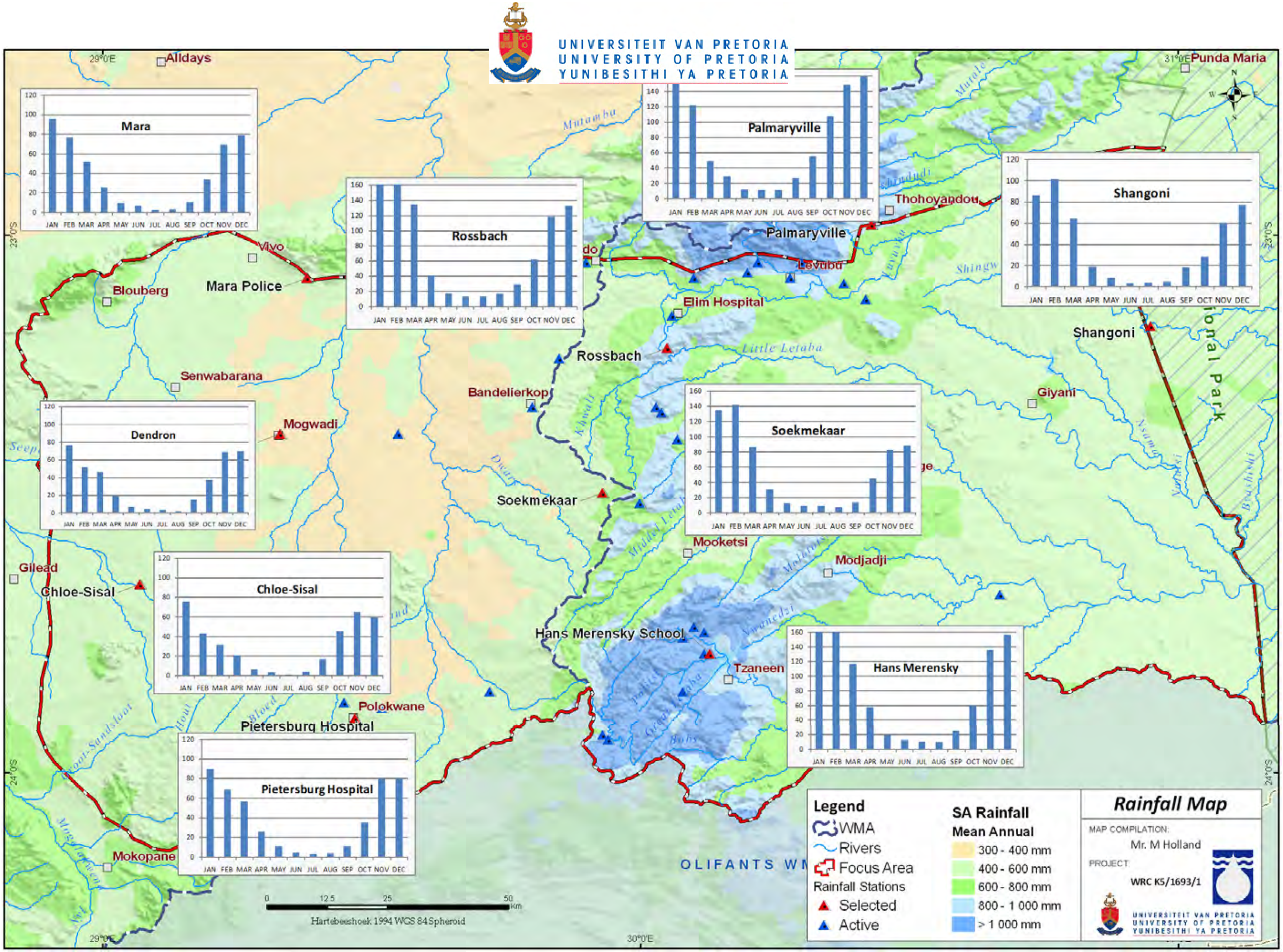


Figure 4.2. Mean annual rainfall map together with selected monthly average charts for selected stations in mm/month.

4.1.1. Geomorphology

Although the age of a land surface by itself is not an indication of the water bearing properties of the weathered zone, the factors controlling the nature and thickness of the weathered zone is partly covered by its geomorphological history. The subcontinent has been subdivided into a number of denudational land surfaces of differing age. Tectonic movements and sea level changes initiated the onset of each erosion cycle due to a new set of base levels (Partridge and Maud, 1987). King (1975) recognised the following geomorphic cycles with their approximate inception age: Gondwana (190 Ma), Post-Gondwana (135 Ma), African (100 Ma), Post-African (20 Ma), Pliocene and Quaternary (2 Ma). The erosion surfaces of southern Africa investigated by Partridge (1998) are presented in (Figure 4.3).

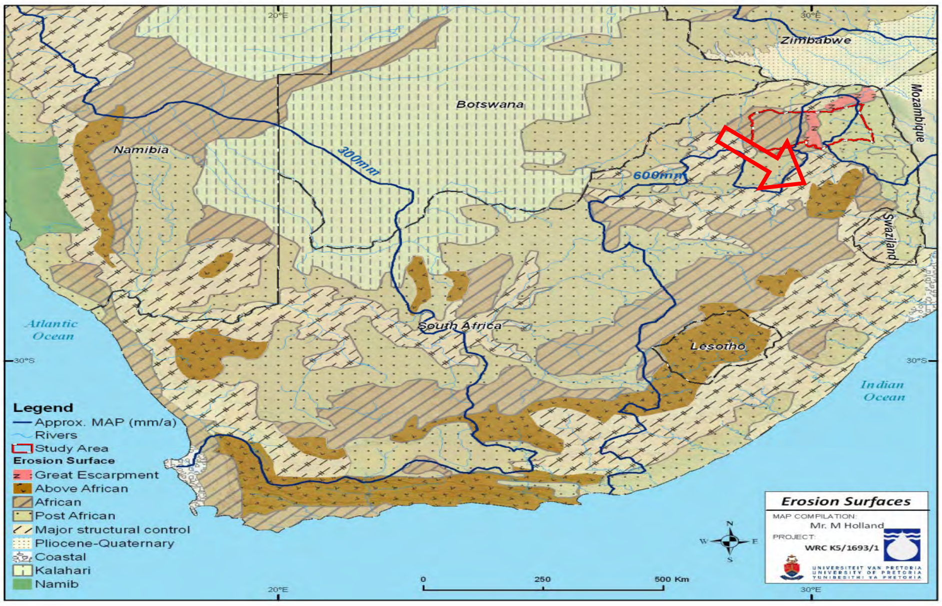


Figure 4.3. The distribution of erosion surfaces in southern Africa (adapted from Partridge, 1998; Taylor and Howard, 1999).

The geomorphic development of the subcontinent resulted in the Karoo cover being stripped and the subsequent superimposing of drainage systems onto the underlying geological formations. The study area is largely situated on the African surface in the east and the Post African surface in the west (Figure 4.3). These surfaces represent long periods of weathering and erosion. The weathering fronts associated with the different erosion surfaces would have influenced the regional groundwater levels as well as the creation of groundwater flow paths. Groundwater investigations undertaken in the 1980s and 1990s suggested that the regolith was likely to be better developed beneath the older erosion surfaces than the younger ones resulting in higher borehole yields (Jones, 1985; McFarlane et al., 1992).

Geomorphic features observed in the study area are plains, hills, inselbergs, low mountains, lowlands, foothills and valleys. The area can be divided into a number of terrain morphology units (Kruger, 1983). These geomorphic zones together with a W-E topographic profile are shown in Figure 4.4.

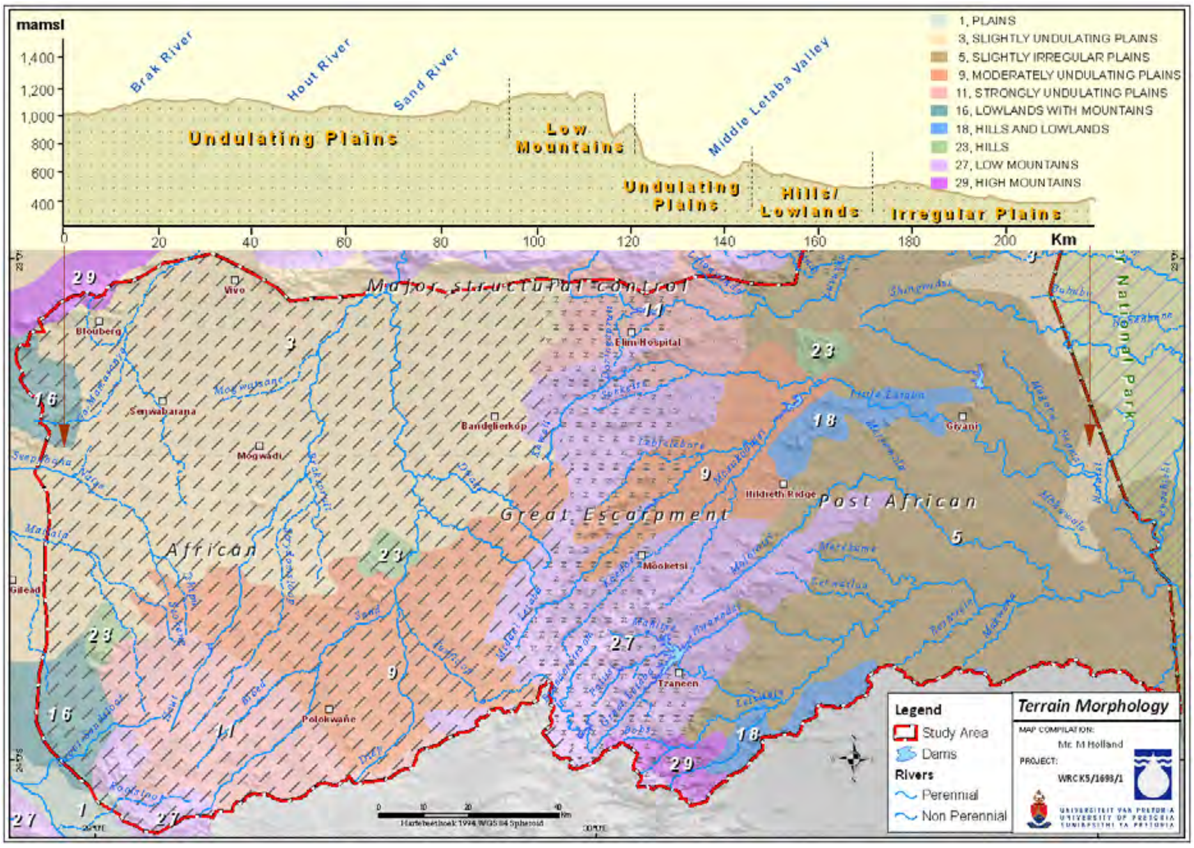


Figure 4.4. Terrain morphological zones of the study area.

The plateau to the west of the escarpment can be described as an extremely old erosion surface underlain by primitive basement rocks into which several mature rivers have incised themselves. The escarpment contains a series of northeasterly trending mountain spurs, containing the upper reaches of rivers such as the Middle Letaba. Towards the east of the escarpment the ground surface drops eastwards to form a plain known as the Lowveld region.

4.2. Regional geology

Geologically, the study area covers part of the junction between the granite-greenstone terrain of the north-eastern part of the Kaapvaal Craton and the highly metamorphic rocks of the Southern Marginal zone of the Limpopo Mobile Belt (Figure 4.5). Some authors (i.e. Roering et al. 1992) have suggested that the Limpopo Mobile Belt in the northern part of South Africa is the world’s earliest example of a Himalayan-type continent-continent collisional orogeny between two large cratons (Kaapvaal- and Zimbabwe Cratons). However, according to Kramers et al., (2006) no consensus regarding the geological process, setting or timing of the Limpopo Mobile Belt have been reached. The resulting Limpopo Mobile Belt consists of three main crustal zones, namely the Northern Marginal Zone, the Central Zone and the Southern Marginal Zone, which lie parallel to one another in an ENE direction (Figure 4.5).

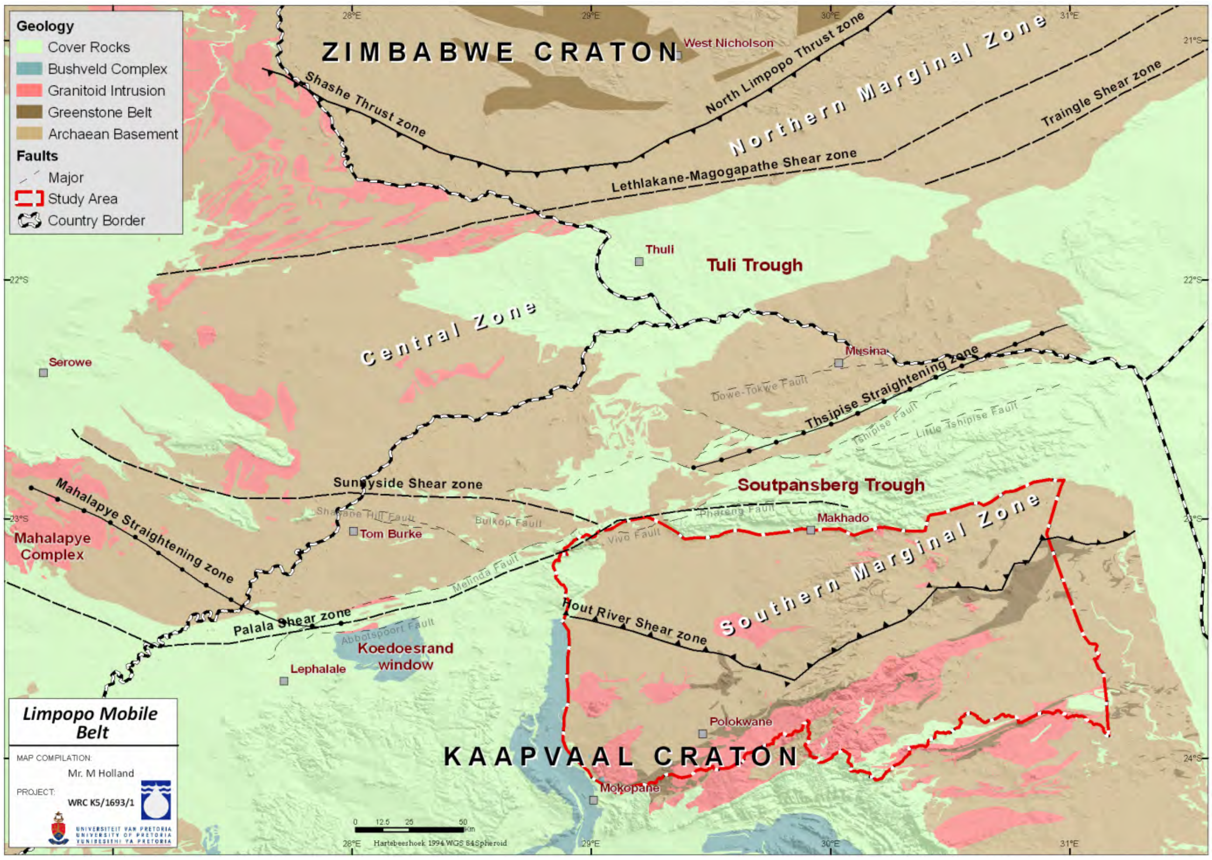


Figure 4.5. Generalised map of the Limpopo Mobile Belt showing the main features and subdivisions (adapted from Boshoff et al., 2006).

The northward dipping Hout River Shear Zone forms the boundary between the low-grade metamorphism granitoid-greenstone terrane of the Kaapvaal Craton to the south and the higher grade metamorphism rocks of the Southern Marginal Zone to the north (Figure 4.5). In general the HRSZ comprises EW striking, steeply northward-dipping thrusts and reverse faults, as well as several NE-SW striking strike-slip faults (Smit et al., 1992). The Hout River Shear Zone can be traced for over 250 km from west to east across the southern margin of the Limpopo Mobile Belt and acts as a complex thrust system developed over a width of up to 4 km in places (Anhaeusser, 1992).

4.2.1. Description of local geology

The geology of project area is dominated by Archaean basement rocks (granite, gneiss and greenstone) which outcrop in an approximately rectangular area bordered (Figure 4.6);

- to the south by younger overlying sedimentary strata and the major surface water divide,
- to the north by the Soutpansberg Group (Volcanic rocks),
- to the west by the Northern limb of the Bushveld Complex, and
- to the east by the Drakensberg basalts of the Lebombo mountains.

Archaean Gneisses

The geology of the study area is dominated by two lithostratigaphical units in the crystalline complex, namely the Goudplaats-Hout River Gneiss and Groot-Letaba Gneiss. These Palaeoarcheaen (3,600-3,200 million years) gneissic bodies range from homogenous to strongly layered, leucocratic felsic to mafic minerals (Anhaeusser, 1992). According to Robb et al. (2006) the previous subdivision of the strongly migmatised Hout River Gneiss and less well-migmatised Goudplaats Gneiss is no longer regarded as tenable. However, granitoid gneisses occurring between the Murchison (Gavelotte Group) and the Pietersburg-Giyani greenstone belts have been grouped together under the term Groot-Letaba Gneiss (Brandl and Kröner, 1993). These rocks are bounded in the southeast by the Letaba Shear Zone (Figure 4.6).

Archaean Greenstone Belts

The Rhenosterkoppies (Zandrivierspoort Formation), Pietersburg (Pietersburg Group), Giyani (Giyanii Group) and northern part of the Murchison (Gravelotte Group) Greenstone Belts occur in the study area. They are composed largely of extrusive mafic and, to lesser extents, ultramafic and felsic rock. These Greenstone Belts are infolded mainly into grey granitic gneisses which dominate the early Archaean terranes (Brandl et al., 2006). The NE-trending Pietersburg and Giyani Greenstone Belts extend parallel up to the southern part of the SMZ of the Limpopo Belt. The Murchison Greenstone Belts exists along a major ENE-WSW crustal lineament known as the "Thabazimbi-Murchison Lineament" (TML). Because of the orientation of the TML, the Greenstone Belts and the LMB, many of the geological structures recorded in the study area are parallel with this NE-SW trend.

Neoarchaean Intrusions

A number of massive, unfoliated granite intrusions occur as batholiths, plutons and stocks in the study area. These granitic intrusions form prominent topographical features that can be seen north of Polokwane. The most distinct of these plutons are Matlala Granite, Moletsi Granite, Mashashane Suite (Granites) and Matok Granite. The Matok Granite was emplaced just north of the HRSZ. The Duivelskloof leucogranite and the Turfloop Granite, which forms elongated northeast-trending batholiths, are the most voluminous granite bodies in the study area. However, the contacts with the surrounding granitoid gneisses of these large batholiths are not well defined. Various other granite intrusives occur throughout the study area including the Schiel Complex located immediately north of the northeast-orientated Kudus River Lineament (Figure 4.6).

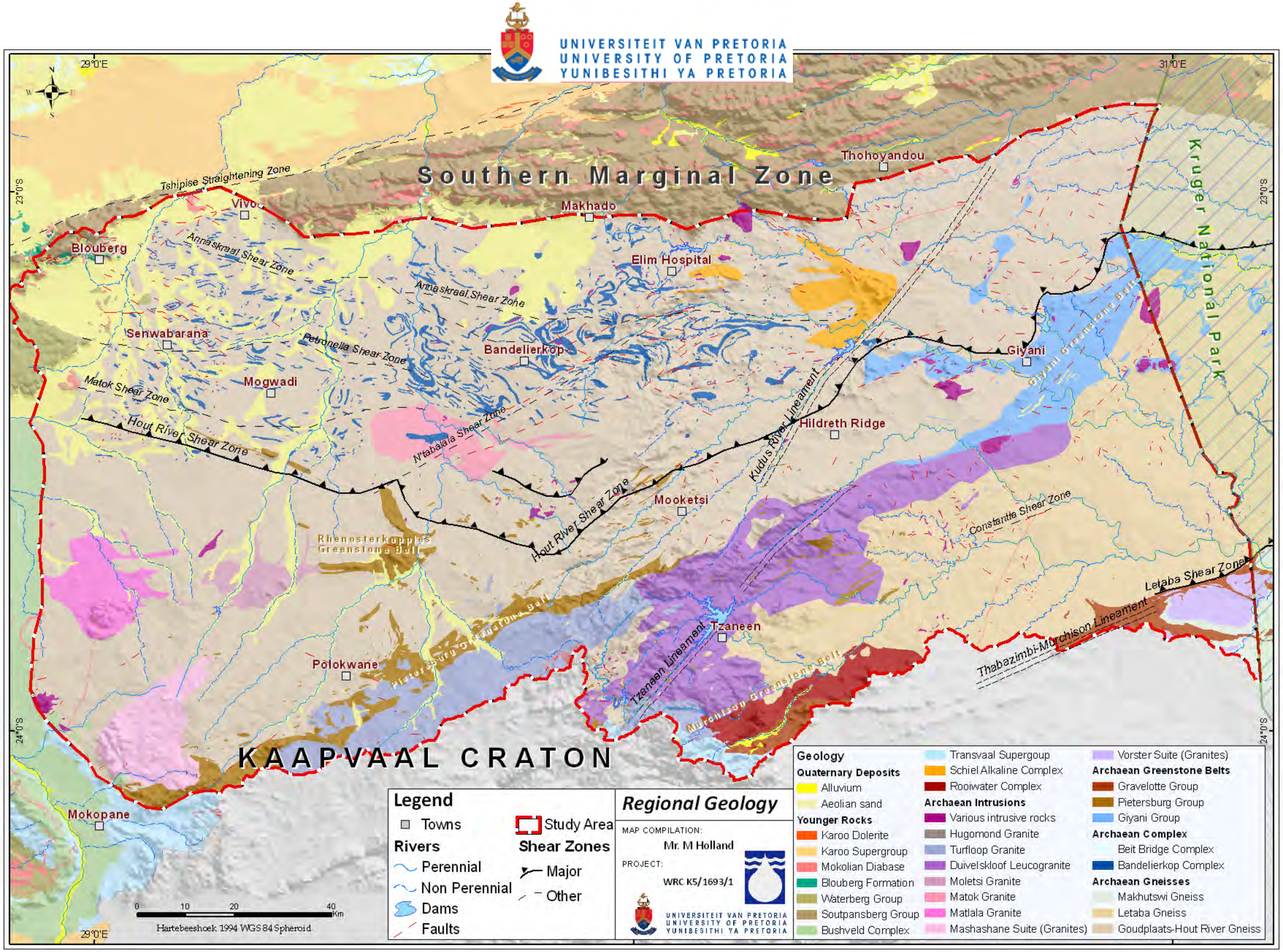


Figure 4.6. Regional geology of the study area (based on published 1:250 000 map sheets sourced from the Council for Geoscience).

Younger rocks of significance

The Soutpansberg Group emerges as a large east west trending mountain range (escarpment) from the Kruger National Park in the east to Vivo in the west, and forms the northern border of the present study area. Outliers of the volcano-sedimentary Soutpansberg rocks also outcrop further to the west (Figure 4.6). The Waterberg Group (arenites and rudites) similarly outcrops along the north-western margin of the study area and rests unconformably on the rocks of the Bushveld Complex and the Archaean gneisses. The western edge of the study area is bound by the northern limb of the Bushveld Complex. This is a large economically important layered intrusive complex, comprising the lower Rustenburg Layered Suite and Lebowa Granites Suite above, which intruded into the Archaean basement. The eastern margin of the study area is marked by the eastern edge of the Kaapvaal craton. This area is underlain by rocks of the Drakensberg Group (Karoo Supergroup) which comprise flood basalts and pyroclastic deposits. The presence of quaternary cover of soil, calcrete and ferricrete is common. These covers are generally not very thick but widespread towards the northeast of the area. Water bearing alluvial deposits is found mostly along the lower reaches of the major tributaries, but is limited in extent. Alluvial deposits are indicated on the 1:250 000 geological map sheets and are presented in Figure 4.6.

4.2.2. Geological timeline of local occurrences

The summary of crystallisation/emplacement age for granitoid intrusions and other younger rocks pertaining to the study area is based on Robb et al., (2006) and Kramers et al., (2006):

- 3 600 – 3 200 Ma Palaeoarcheaen intrusions (Goudplaats-Hout River Gneiss)
- ± 3 200 Ma Greenstone Belts (Giyani, Pietersburg, Murchison)
- 3 200 – 2 800 Ma Mesoarcheaen intrusions (Groot Letaba Gneiss; Voster Suite)
- 2 800 – 2 500 Ma Neoarcheaen intrusions (i.e. Matok- Matlala granites)
- 3 100 Ma Central Kaapvaal Craton is stable
- 2 700 Ma Limpopo Belt (First event)
- 2 700 Ma Ventersdorp-related mafic dykes.
- 2 060 Ma Intrusion of the Bushveld Complex
- 2 000 Ma Palala Shear Zone Reactivation (Second Limpopo event)
- > 1 850 Ma Deposition of Waterberg Group
- 1 850 Deposition of Soutpansberg Group
- 180 Ma Extrusion of Drakensberg Flood Basalts

4.3. Structural geology

One of the most differentiating structural features of the study area is the frequency and orientation of dyke swarms. Dyke swarms may be useful paleo-stress indicators as they record fractures that result from regional stress field operative at the time. Stettler et al. (1989) subdivided parts of the Kaapvaal Craton and the Limpopo Belt according to the prevailing aeromagnetic lineament pattern into five domains (Figure 4.7).

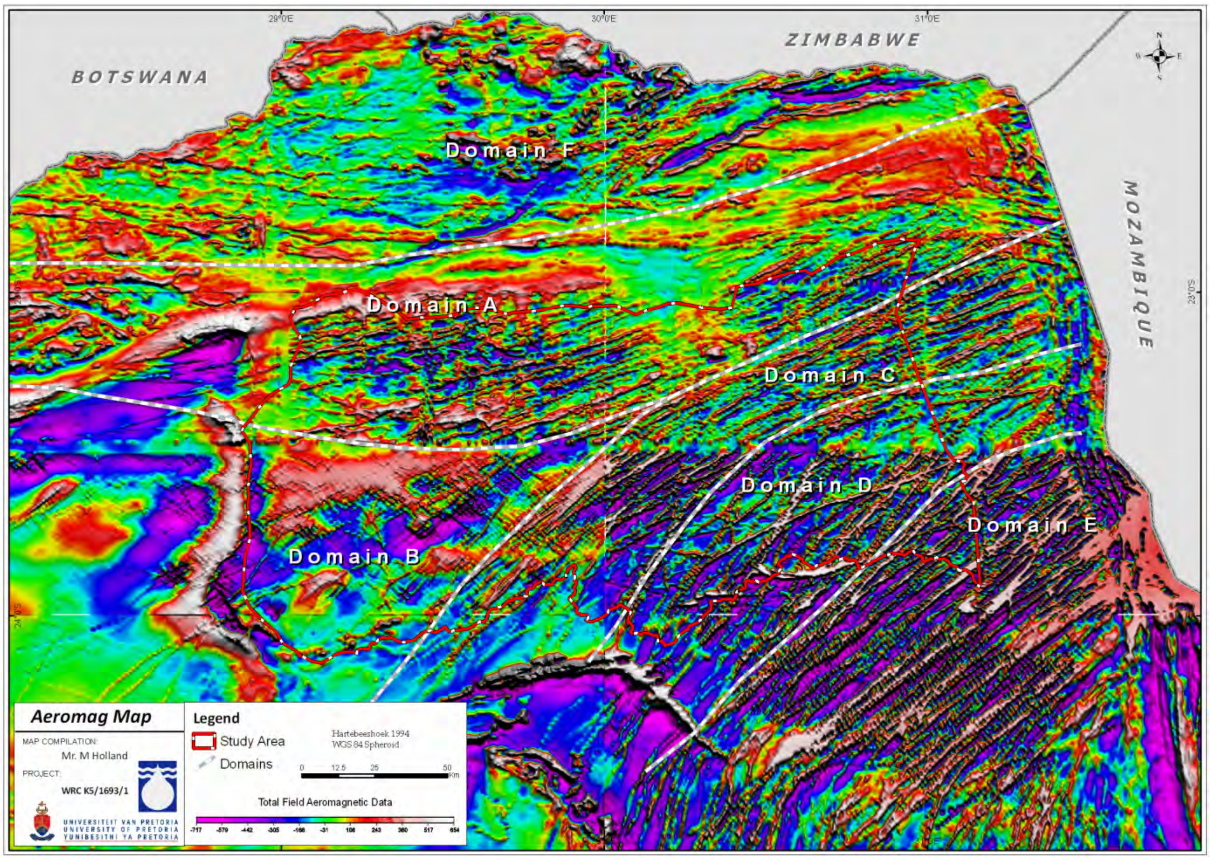


Figure 4.7. Aeromagnetic map showing tectonic domains (Adapted from Stettler et al., 1989). Data Source: Council for Geoscience (SA).

The age and orientation of the predominantly ENE to NE trending dyke swarms and associated aeromagnetic lineaments coincide with the 2 700 million years Ventersdorp rift structures, but also include similar NE trending Karoo-age dolerite dykes (Uken and Watkeys, 1997). During this period the northeastern Kaapvaal Craton underwent NW-SE extension, in contrast to the current NE-SW extensional regime (Figure 4.8). On the basis of data compiled into the World Stress Map database there is a suggestion of a horizontal principal stress direction oriented NW to NNW (Heidbach et al., 2008).

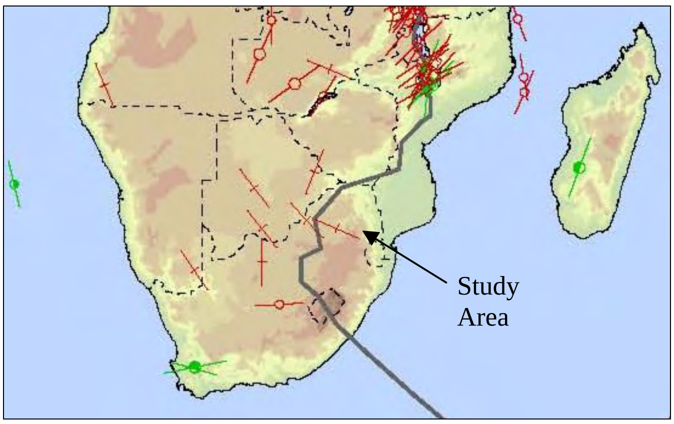


Figure 4.8. Neo-tectonic stress map of southern Africa (Zoback, 1992). Long axes indicate the orientation of crustal shortening.

According to Bird et al. (2006) southern Africa is not in a state of horizontal compression. Instead, it is generally in a state of horizontal extension which may be a result of the unbroken lithosphere's resistance to relative rotation between the Somalia Plate and the Africa Plate. More specific to the study area, Bird et al. (2006) highlighted that the ENE-WSW trending Tshipise-Bosbokpoort fault system described by Brandl (1995), is inconsistent with the strain rate field model because it is almost orthogonal to computed horizontal principal stress direction. It is evident that in regions with multiple deformation events and structural inheritance, all, none or some of the geological structures may be related to the current stress regime. This is clearly evident from field observations obtained by Petzer (2009) where normal faults and open joints were also formed in the NW-SE direction (Figure 4.9). Therefore structures inherited from the Precambrian are presumably open under the current neo-tectonic stress regime. These joints show a very poor correlation with the predominant NE trending dyke pattern; the main azimuths of the outcrop joints being oblique or even perpendicular to the main dyke azimuths (Figure 4.10).

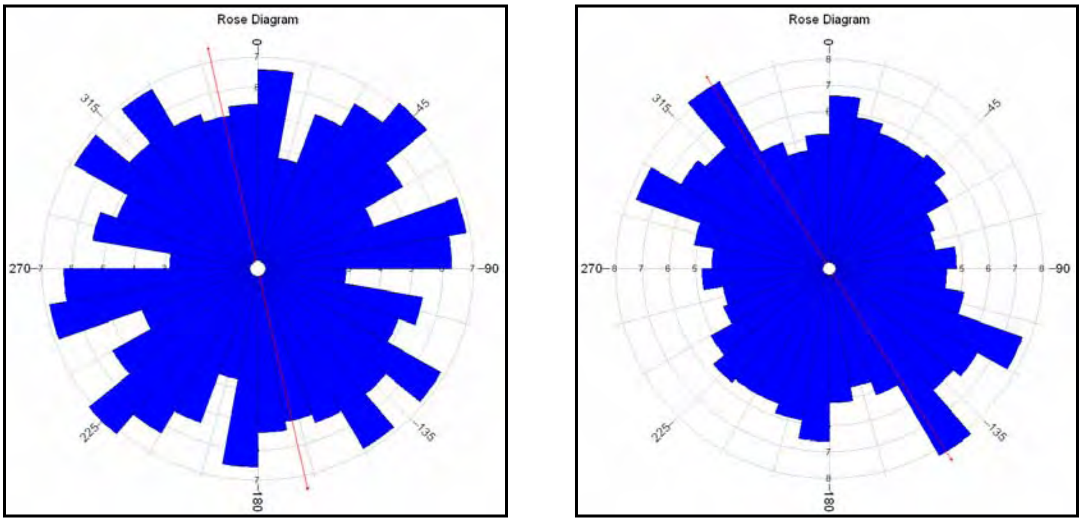
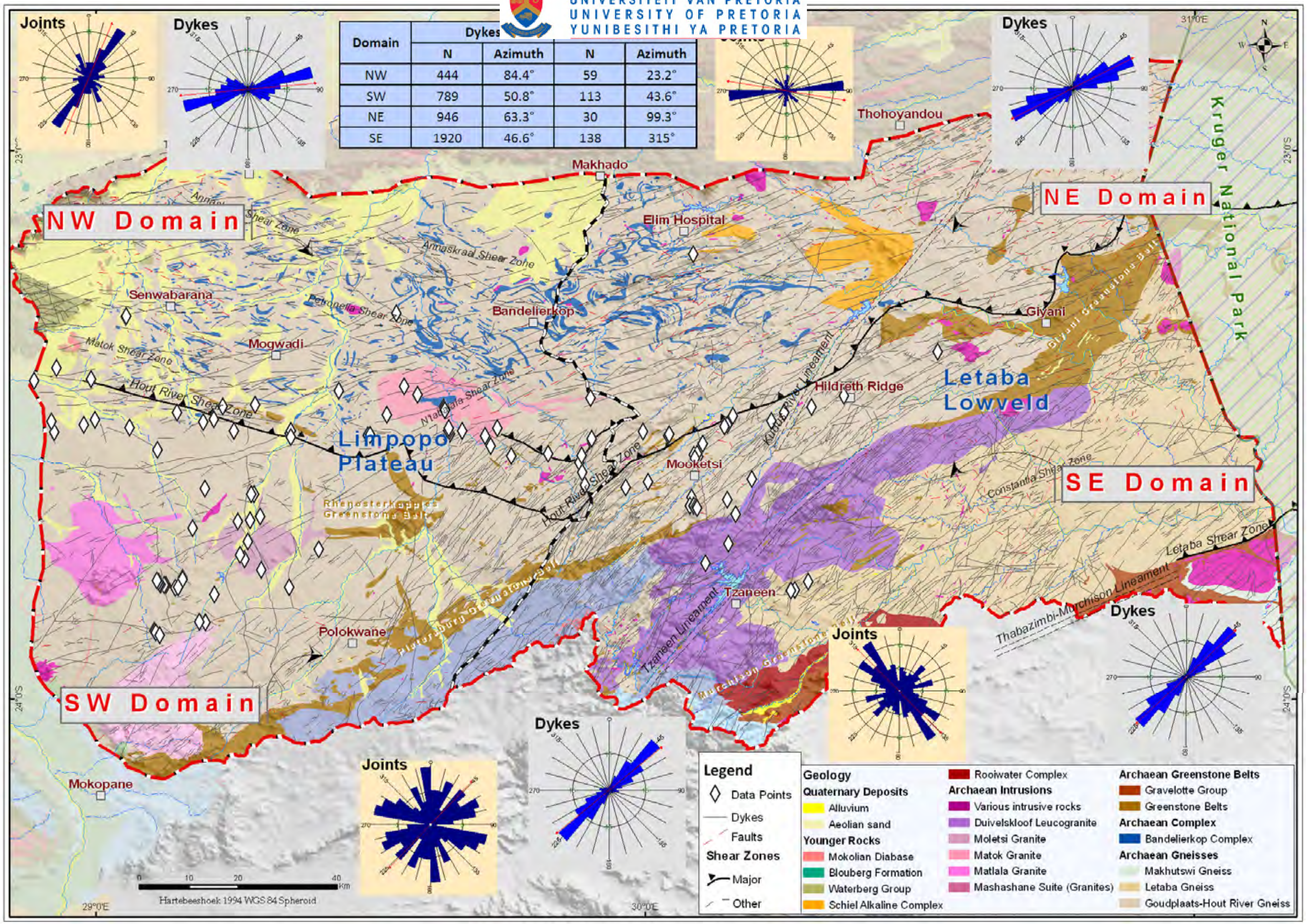


Figure 4.9. Rose diagram derived from the strikes of all joint planes (left) and faults (right).

Whereas some of these joints could have formed due to dilatation (i.e. pressure release as a result of erosion or plutonism), it is believed that many of these joints are actually tectonically induced, suggesting that the study area was at one stage subjected to compression. Such a regime would favor the formation of open joints in the NE-SW direction, but at the same time closing many brittle structures that might have been favourable groundwater conduits in the geological past. Joints striking NE-SW were probably reactivated during successive tectonic events (for example the NNE-SSW extension during later Karoo times) and lie parallel to one of two preferred lineament orientations (NE-SW and NNE-SSW), as identified by the dolerite dykes in the study area. The study area shown in Figure 4.10 can clearly be subdivided into four structural domains on the basis of aeromagnetic lineament strike direction and frequency. Most of the magnetic anomalies in the studied area are caused by linear features, inferred as dykes.



Domain	Dykes			
	N	Azimuth	N	Azimuth
NW	444	84.4°	59	23.2°
SW	789	50.8°	113	43.6°
NE	946	63.3°	30	99.3°
SE	1920	46.6°	138	315°

Figure 4.10. Identified structural domains based on the orientation of regional dykes (Aeromagnetic and published dykes).

Interpretation of magnetic lineaments was conducted by the Council for Geoscience (South Africa) based on regional airborne magnetic data with a 1 km line spacing. The predominant ENE dyke swarm trend appear to be cut by NW trending dykes, suggesting that the latter intruded last. These trends cut across earlier ENE trending crustal features such as the Greenstone belts, suggesting that the crust became mechanically homogenous at the time of the dyke events (Stettler et al., 1998). The Limpopo north-western and south-western domains are predominantly characterized by the gneissic rocks of the Goudplaats-Hout River Group with a much lower frequency of dykes and lineaments compared to the Letaba northeastern and south-eastern domains (Figure 4.10). Dykes in the NW and SW domain have a mean strike direction of 85° and 51° respectively. The two eastern structural domains show a high degree of preferred orientation and are characterized by the highest dyke intensity. Dyke trends in the NE domain are predominantly ENE (63°) and cut obliquely across the greenstone belts. Dykes in the SE domain have a strike direction of 47° and are almost parallel to the large elongated leucogranite batholith. The Hout River Shear Zone can be regarded as the margin between the northern and southern domains. These regions correspond closely to the domains identified by Stettler et al. (1989) and provide a tectonic and morphostructural framework to describe hydrogeologic parameters on a regional scale.

4.4. Hydrogeological description

To determine the variability of basement aquifers in the Limpopo Province, it was deemed necessary to split the area based on the topography, surface drainages and geological domains as set out in previous sections. The western portion of the area is referred to as the Limpopo Plateau and the eastern portion as the Letaba Lowveld (Figure 4.11).

Limpopo Plateau

The region is characterized by a number of batholiths, forming distinct inselbergs interpreted as residual hills that became exhumed in successive stages of stripping of weathering cover of the African erosion surface. The thickness of the regolith in the Limpopo Plateau generally extends to between 15 and 50 metres below surface. Below the weathered zone is a zone of fracturing, which according to geohydrological studies done by Dziembowski (1976) and Jolly (1986) in the Dendron/Mogwadi area may extend to depths greater than 120 m. This area is known for its high yielding boreholes which far exceed the typical expectations of crystalline aquifers with blow yields of more than 40 ℓ/s often recorded. As a result the area supports a number of large scale irrigation schemes. Towards the south west of Makhado, electrical resistivity depth soundings collected by Timmerman et al. (1983) indicate weathering depths of between 20 and 40 m. Borehole siting, drilling and pumping tests around Polokwane by Du Toit (1986) showed weathering depths of between 9 and 36 m. Du Toit (1986) concluded that although there is some correlation between yield and weathering depth, higher yields (> 3 ℓ/s) are more often associated with the fractured fissure layer irrespective of the thickness of the overlying weathered layer. The only substantial deposits of alluvium occur along the major surface drainage courses (i.e. Sand- and Hout Rivers). Orpen (1986) estimated the thickness of alluvium deposits along the Sand River to be not more than 8 to 15 m. Nel (2000) suggested that in the absence of a continuous impermeable clay (colmation) layer, the alluvial and weather-fractured aquifers are in hydraulic continuity. The alluvial deposits typically consist of red or sandy clay (calcified in places) which overlies sand, gravel and pebbles. A survey conducted by Vegter (2003a) on the Polokwane/Pietersburg Plateau groundwater region found that 52% of boreholes drilled were successful (yield > 0.1 ℓ/s).

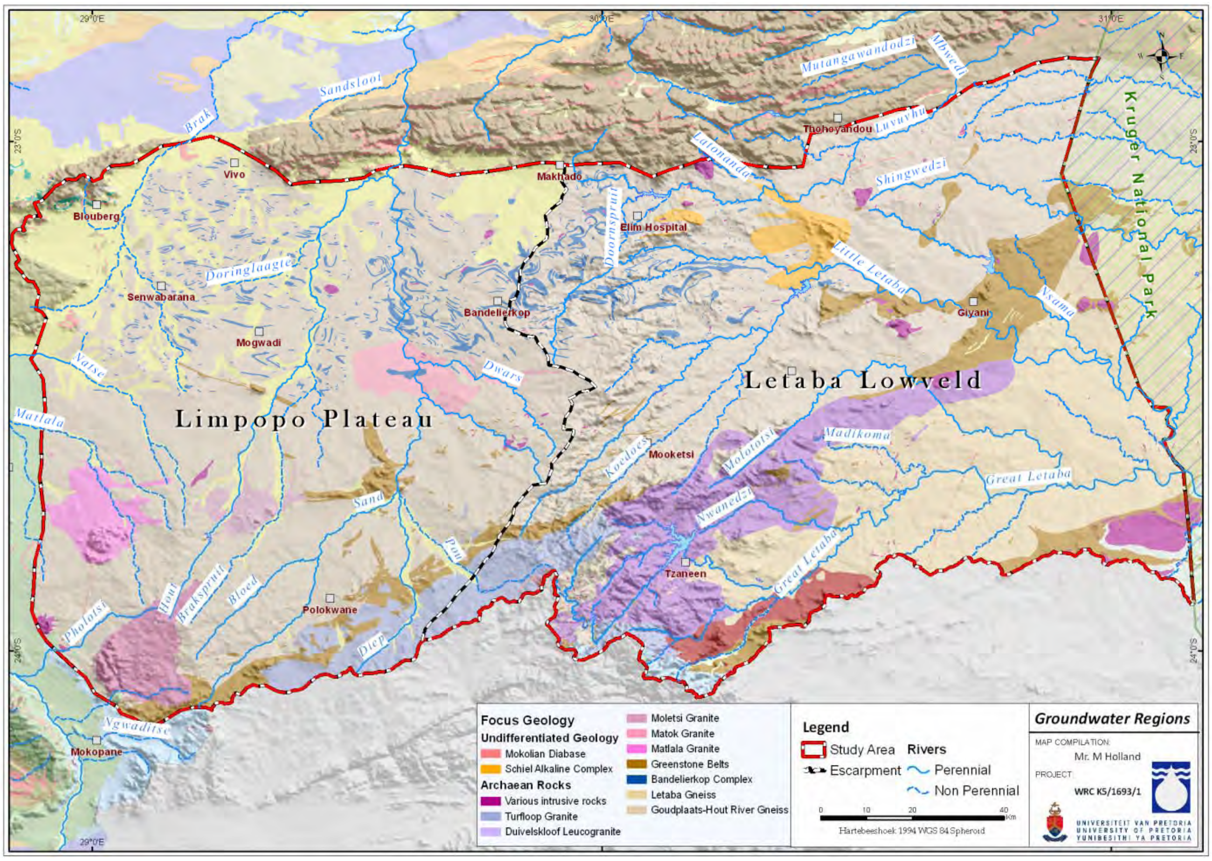


Figure 4.11. Delineation of the Limpopo Plateau and Letaba Lowveld regions.

Letaba Lowveld

Along the great escarpment the Letaba Lowveld is characterised by mountainous terrain, incised valleys, high rainfall and dense vegetation. A number of perennial springs occur in this area. The gneisses in the Mooketsi area are well weathered but regolith thickness rarely exceeds 30 m. The leucogranites underlying the higher lying areas including the footwalls east of the escarpment have a thin or absent weathered layer (i.e. the Tzaneen and Mooketsi areas) (Figure 4.11). According to Bush (1988) weathering depths rarely exceed 30 m. These elongated intrusive granitoids occur as bouldery hills with little soil cover, and are considered to be least prone to chemical weathering due to the exposure of the bare rock surface. It is expected that the weathering depth in the younger leucogranites is less than in the surrounding gneisses. Alluvial deposits occur along the major drainage courses (i.e. Molototsi-, Groot Letaba- and Klein Letaba Rivers). A survey conducted by Vegter (2003b) on the Lowveld groundwater region found that the success rate of boreholes is slightly lower compared to the Polokwane/Pietersburg Plateau groundwater region, with 49% of boreholes yielding more than 0.1 ℓ/.

4.4.1. Aquifer systems

A conceptual illustration of the aquifer systems typically found in the study area is provided in Figure 4.12. The aquifers systems developed in the Limpopo Plateau and Letaba Lowveld are:

1) Composite aquifers; comprising of a variable thickness of regolith overlying bedrock, the upper part of which is frequently fractured.
2) Deeper fractured aquifers; composed mainly of crystalline material (i.e. igneous and metamorphic rocks) characterised by an intact and relatively unweathered matrix with a complex arrangement of interconnected fracture systems.
3) Alluvial aquifers; alluvial material overlies or replaces the weathered overburden and creates a distinct intergranular aquifer type. These elongated aquifers follow rivers (so-called valley trains), sand rivers or drainage lines with limited width and depth, which typically vary according to the topography and climate.

4.4.2. Borehole data analysis

Compared with the Letaba Lowveld, the Limpopo Plateau is generally characterized by deeper boreholes due to deeper water strikes, water levels and weathering depths (Table 4.3). The depth of weathering is based on the driller's description of the formation where rock type is weathered and represents the in-situ weathered material only. The relatively thin weathering depth (generally less than 20 m) along with water strikes below the weathered zone suggest that yields are mainly derived from water bearing fractures struck at depth.

Table 4.3. Summary of borehole characteristics in the study area.

m.b.g.l*	Limpopo Plateau				Letaba Lowveld			
	N	*Min*	*Mean*	*Max*	*N*	*Min*	*Mean*	*Max*
BH Depth	2 066	7	70	250	2 813	8	63	182
Water Level	1 563	0.6	17	83	2 177	0.5	14.8	73
Water Strike	202	1	36	87	646	1	28	80
Weathering	481	1	22	63	750	3	18	82

*- meters below ground level.

The Limpopo Plateau with elevations generally higher than 1 000 mamsl is largely situated on the African erosion surface while the lower lying plains of the Letaba Lowveld with elevations below 800 mamsl are associated with the post-African surface as described by Partridge and Maud (1987). Studies conducted by the British Geological Survey in the early 1990s on crystalline aquifers throughout Africa revealed that the regolith was generally thicker beneath the oldest and uppermost erosion surface, the African surface, compared with the post-African erosion surface so offering greater storage and possibly a more productive resource potential (McFarlane et al. 1992).

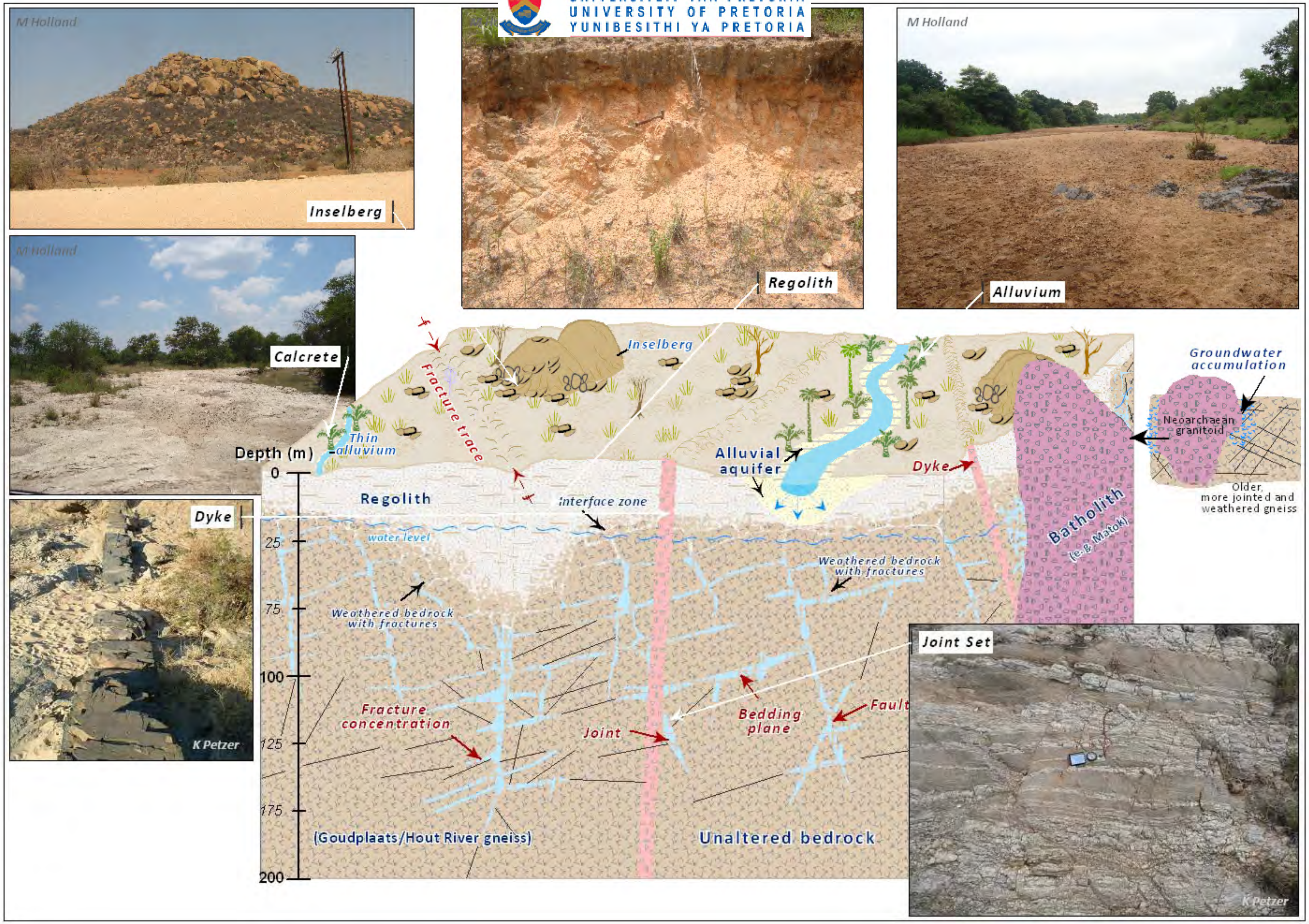


Figure 4.12. Generalised section of the aquifer systems found in the area of investigation, including photo's of observed geological features.

The borehole depths follow a normal distribution (Figure 4.13) for both regions with 60% of boreholes drilled to depths between 50 and 80 m, indicating the tendency to drill to fixed depths regardless of the hydrogeological conditions encountered. However, boreholes drilled in the Limpopo Plateau are generally deeper than in the Letaba Lowveld (Table 4.3.), with 42% of boreholes exceeding 60 m depth in the Limpopo Lowveld in comparison to 34% in the Letaba Lowveld.

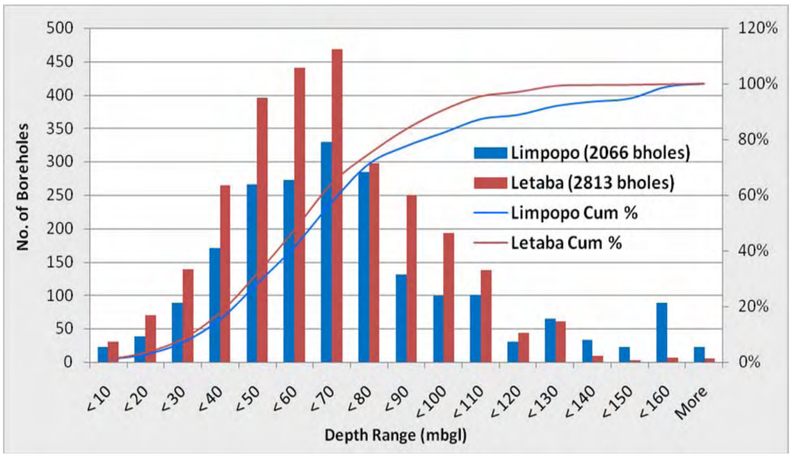


Figure 4.13. Distribution of borehole depths in the Limpopo Plateau and Letaba Lowveld.

Recorded groundwater depths follow approximately a log-normal distribution (Figure 4.14), with modes (highest frequency) between 5 and 10 m.b.g.l for both study areas and 90% of groundwater levels below 30 m.b.g.l The arithmetic mean depth to groundwater (Table 4.3) is slightly higher for the Limpopo Plateau (17 m.b.g.l) in comparison to the Letaba Lowveld (15 m.b.g.l).

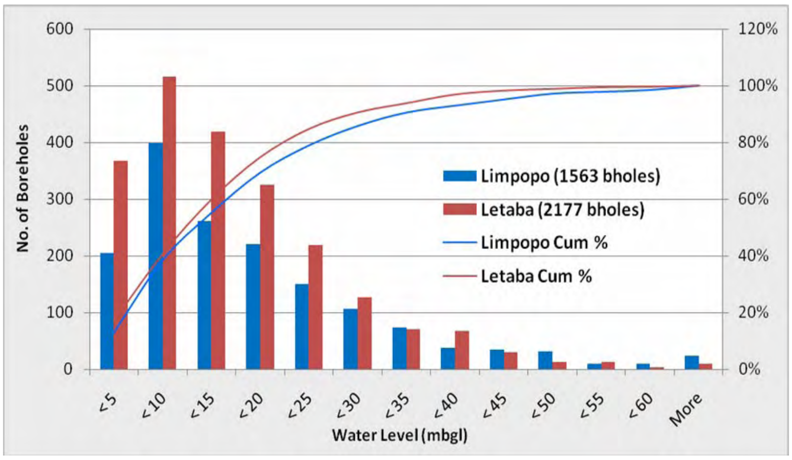


Figure 4.14. Distribution of groundwater levels in the Limpopo Plateau and Letaba Lowveld.

Fewer than 1 000 borehole database entries for both study areas contain information on water strike depths, but their frequency distribution (Figure 4.15) is markedly similar to the borehole depth distribution (Figure 4.13), suggesting that drilling is stopped once a sufficient water strike is encountered. 60% of boreholes encountered water before a depth of 40 m in the Limpopo Plateau and before 30 m in the Letaba Lowveld. This might explain the generally shallower drilling depths in the Letaba Lowveld, with a potentially higher risk of borehole failure during droughts.

202 boreholes (25 %) in the Limpopo Plateau encountered water beyond a depth of 50 m, compared to a mere 8% in the Letaba Lowveld region, suggesting a deeper base of weathering and fracturing in the Limpopo Plateau.

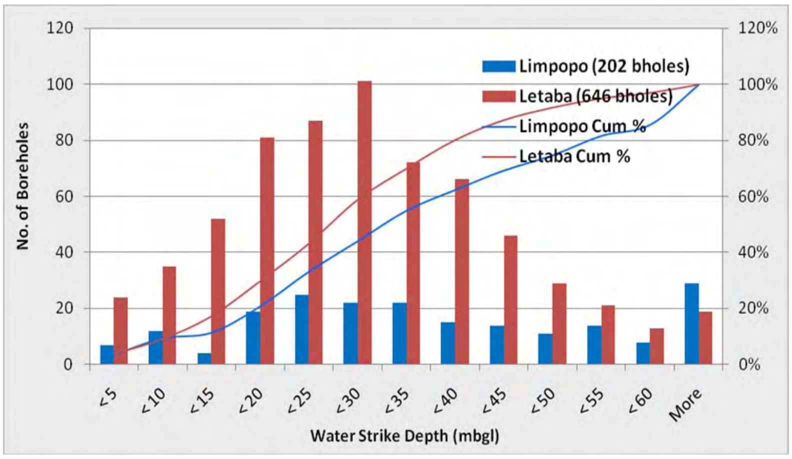


Figure 4.15. Distribution of depth of first water strikes in the Limpopo Plateau and Letaba Lowveld.

Figure 4.16 depicts the depth of weathering and/or fracturing based on over 1 200 geological logs for the regions. In most cases it is difficult to distinguish the depths of weathering from fracturing from the geological logs. A combined dataset was therefore produced and can be regarded as a proxy for the depth to fresh bedrock. The average depth of weathering / fracturing is 45 m in the Limpopo Plateau compared to the shallower 36 m in the Letaba Lowveld (see Table 4.3). The depth of weathering / fracturing exceeds 60 m for 23% of boreholes in the Limpopo Plateau and only for approximately 10% of boreholes in the Letaba Lowveld. In summary, boreholes drilled in the Limpopo Plateau are generally deeper, show deeper- water strikes, water levels and depths of weathering compared to the Letaba Lowveld.

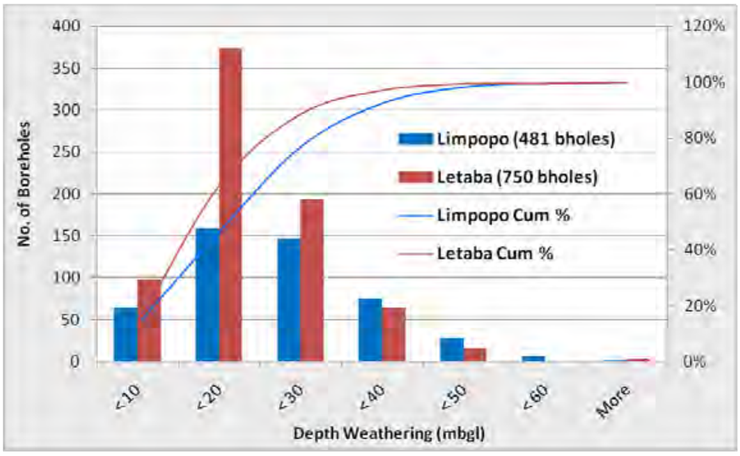


Figure 4.16. Distribution of depths of weathering plus fracturing in the Limpopo Plateau and Letaba Lowveld.

4.4.3. Success rate and yields

The yield data obtained from the GRIP dataset were examined in terms of the drilling success rate achieved (Figure 4.17). Any borehole equipped with a pump even if no yield data were recorded was regarded as successful. In 30% of the cases no yield or equipment status were recorded and in 9% of the cases dry drills (boreholes) were noted. 61% of boreholes can be regarded as successful with yields greater than 0.1 ℓ/s. This value is considerably higher than Vegter's (2003a; 2003b) success rate of 49 and 52% for the Letaba and Limpopo groundwater regions respectively, which was based on data from the National Groundwater Database prior to the Limpopo GRIP programme. The increased drilling success rate may be attributed to the success of the programme in terms of groundwater development for rural communities.

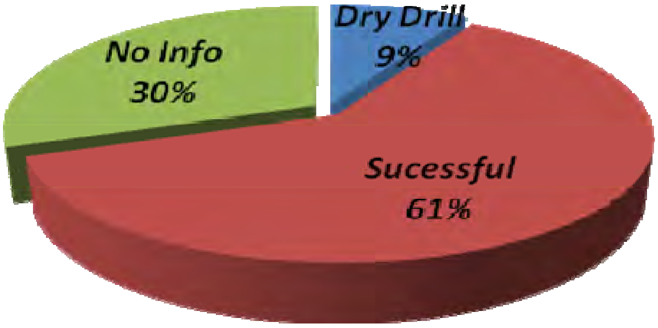


Figure 4.17. Success rate for boreholes contained the GRIP dataset for the study area.

The frequency distribution of airlift yields (for boreholes with airlift yield data) shows distinct differences between the two regions (Figure 4.18). While the total number of dry boreholes is higher in the Letaba Lowveld than in the Limpopo Plateau, they constitute only 25% of all boreholes in comparison to 35 % in the Limpopo Plateau. 30% of boreholes in the Limpopo Plateau and 39 % of boreholes in the Letaba Lowveld had an airlift yield between 0.1 and 3 ℓ/s, while 35% of boreholes drilled in the Limpopo Plateau and 36% in the Letaba Lowveld yielded more than 3 ℓ/s. Clark (1985) suggested that yields above 1 ℓ/s are considered good yields from basement aquifers. Therefore the borehole yields obtained from the Limpopo basement rocks are generally good considering the high percentage of borehole exceeding 1 ℓ/s (Figure 4.18).

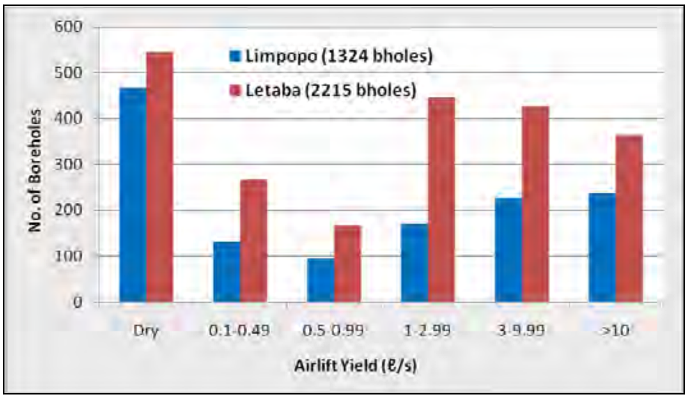
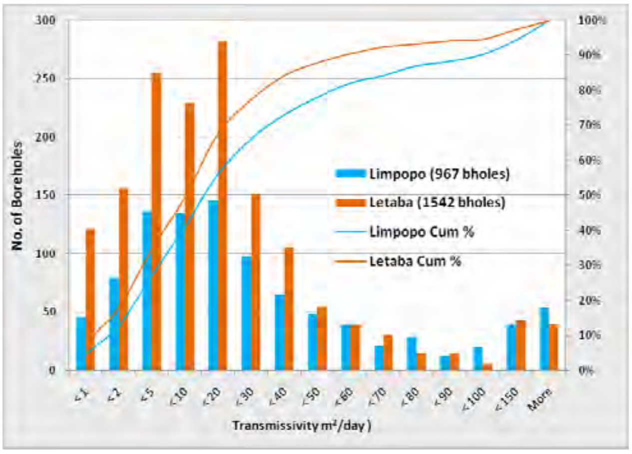


Figure 4.18. Distribution of borehole airlift yield in the Limpopo Plateau and Letaba Lowveld.

4.4.4. Transmissivity and recommended borehole yields

Transmissivity estimates obtained from the GRIP dataset analysed with the (FC method) was generally based on a late time fit of the time-drawdown curve using i.e. Cooper-Jacob or Theis methods, or by estimating the effective transmissivity values from the average maximum derivatives (representing T-late). Borehole yields are based on the recommended abstraction rates for a 24 hrs pumping cycle. The distributions of transmissivities and borehole yields for the Limpopo Plateau and the Letaba Lowveld are positively skewed and follow lognormal distributions (Figure 4.19).



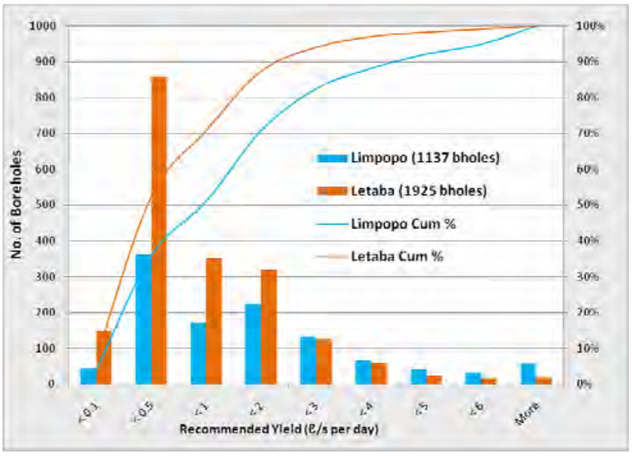


Figure 4.19. Frequency histograms and cumulative distribution of transmissivities [m^2/day] and recommended yield (ℓ/s per day) for the Limpopo Plateau and the Letaba Lowveld.

Lognormal distributions are frequently reported in regional studies of fractured rock aquifers (i.e. Hoeksema and Kitanidis, 1985; Razack and Lasm, 2006). Seventy percent of derived transmissivities lie between 4 m^2/d and 40 m^2/d; however, several boreholes with significantly high yields, especially in the Limpopo Plateau, "push" the arithmetic mean for this area to 38 m^2/d (Table 4.4). A significant correlation between transmissivity and the recommended yield with a determination coefficient (R^2) of 73 % was found.

Table 4.4. Statistical summary of transmissivities and recommended yields.

Parameter	Transmissivity m^2/d			Rec. Yield ℓ/s per day		
	Study area	*Limpopo Plateau*	*Letaba Lowveld*	***Study area***	*Limpopo Plateau*	*Letaba Lowveld*
Nr. Of BH's	**2 509**	967	1 542	**3 062**	1 137	1 925
Arithmic Mean	**29.6**	38	24.5	**1.0**	1.4	0.8
Median	**11**	15	10	**0.5**	0.8	0.4
Harmonic Mean	**3**	2.9	3.1	**0.1**	0.17	0.20
Standard Error	**1.1**	2.2	1.2	**0.02**	0.05	0.02
Standard Deviation	**56.4**	67.9	47.1	**1.38**	1.76	1.06