TABLE OF CONTENTS

A1	**CASE STUDY INFORMATION**	**1**
A1.1	SWAZIAN EONOTHEM: LIMPOPO GRANULITE-GNEISS BELT	**7**
A1.1.1	CASE STUDY AREA	**7**
A1.1.2	CLIMATE AND VELD TYPES	**7**
A1.1.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**8**
A1.1.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**9**
A1.1.5	SOIL SAMPLING AND RESULTS PRESENTATION	**10**
1	***Beck 568MS***	**21**
2	***Command 588MS***	**22**
3	***Wolvedans 68MR***	**24**
4	***Zoetfontein 154MR***	**25**
A1.2	VAALIUM EONOTHEM: ROOIBERG-WARMBATHS AREA: QUARTZITE OF THE LEEUWPOORT FORMATION AND DOLOMITE OF THE MALMANI SUBGROUP	**26**
A1.2.1	CASE STUDY AREA	**26**
A1.2.2	CLIMATE AND VELD TYPES	**26**
A1.2.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**27**
A1.2.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**29**
A1.2.5	SOIL SAMPLING AND RESULTS PRESENTATION	**29**
5	***Blokdrift 512KQ***	**38**
6	***Droogekloof 471KR***	**39**
7	***Vaalfontein 491KQ***	**40**
A1.3	VAALIUM EONOTHEM: DOLOMITE OF THE MALMANI SUBGROUP IN THE PRETORIA AREA	**41**
A1.3.1	CASE STUDY AREA	**41**
A1.3.2	CLIMATE AND VELD TYPES	**41**
A1.3.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**42**
A1.3.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**43**
A1.3.5	SOIL SAMPLING AND RESULTS PRESENTATION	**44**
8	***Elandsfontein 412JR (1)***	**52**
9	***Elandsfontein 412JR (2)***	**53**
A1.4	VAALIUM EONOTHEM: ANDESITE AND GABBRO IN THE PRETORIA-BRITS AREA	**54**
A1.4.1	CASE STUDY AREA	**54**
A1.4.2	CLIMATE AND VELD TYPES	**54**
A1.4.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**56**
A1.4.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**56**
A1.4.5	SOIL SAMPLING AND RESULTS PRESENTATION	**57**
10	***Mooikloof Estate (1)***	**64**
11	***Mooikloof Estate (2)***	**65**
12	***Brits Industrial Area***	**66**
A1.5	VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE PRETORIA AREA	**67**
A1.5.1	CASE STUDY AREA	**67**
A1.5.2	CLIMATE AND VELD TYPES	**68**

A1.5.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**69**
A1.5.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**70**
A1.5.5	SOIL SAMPLING AND RESULTS PRESENTATION	**70**
13	***Kameeldrift 313JR***	**77**
14	***Kameelfontein 297JR***	**78**
15	***Skeerpoort 477JQ***	**79**
A1.6	VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE LYDENBURG AREA	**80**
A1.6.1	CASE STUDY AREA	**80**
A1.6.2	CLIMATE AND VELD TYPES	**80**
A1.6.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**82**
A1.6.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**83**
A1.6.5	SOIL SAMPLING AND RESULTS PRESENTATION	**83**
16	***Badfontein 114JT***	**94**
17	***Klipspruit 89JT***	**95**
18	***Rietfontein 88JT***	**96**
19	***Waterval 386KT***	**97**
A1.7	VAALIUM EONOTHEM: RHYOLITE OF THE ROOIBERG GROUP AND LOSKOP FORMATION IN THE VERENA-MIDDELBURG AREA	**98**
A1.7.1	CASE STUDY AREA	**98**
A1.7.2	CLIMATE AND VELD TYPES	**98**
A1.7.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**100**
A1.7.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**100**
A1.7.5	SOIL SAMPLING AND RESULTS PRESENTATION	**101**
20	***Enkeldoornoog 219JR***	**110**
21	***Kwaggasfontein 460JS***	**111**
22	***Rhenosterkop 452JR***	**112**
A1.8	VAALIUM EONOTHEM: SEDIMENTS OF THE LOSKOP FORMATION AND A DIABASE SILL IN THE BRONKHORSTSPRUIT-MIDDELBURG AREA	**113**
A1.8.1	CASE STUDY AREA	**113**
A1.8.2	CLIMATE AND VELD TYPES	**113**
A1.8.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**114**
A1.8.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**115**
A1.8.5	SOIL SAMPLING AND RESULTS PRESENTATION	**115**
23	***Klipeiland 524JR***	**124**
24	***Rietfontein 314JS***	**125**
A1.9	MOGOLIAN EONOTHEM: GRANITE OF THE NEBO GRANITE IN THE ROOIBERG-WARMBATHS AND VERENA AREAS	**126**
A1.9.1	CASE STUDY AREA	**126**
A1.9.2	CLIMATE AND VELD TYPES	**126**
A1.9.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**128**
A1.9.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**129**
A1.9.5	SOIL SAMPLING AND RESULTS PRESENTATION	**130**
25	***Droogekloof 471KR***	**145**
26	***Kareefontein 432KR***	**146**

27	***Zandfontein 476KQ***	147
28	***Klipfontein 256JS***	148
29	***Zusterstroom 447JR***	149
A1.10	MOGOLIAN EONOTHEM: THE WATERBERG GROUP IN THE WATERBERG AND MIDDELBURG AREAS	150
A1.10.1	CASE STUDY AREA	150
A1.10.2	CLIMATE AND VELD TYPES	150
A1.10.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	152
A1.10.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	155
A1.10.5	SOIL SAMPLING AND RESULTS PRESENTATION	156
30	***Hartbeesfontein 394KR***	188
31	***Pennsylvania 336LR***	190
32	***Elandsfontein 493JR***	191
33	***Leeuwfontein 492JR***	193
34	***Onspoed 500JR***	194
35	***Onverwacht 532JR***	195
36	***Trigaardspoort 451JR***	196
37	***Vlakfontein 453JR***	197
38	***Bankfontein 264JS***	199
39	***Bankplaas 239JS***	201
40	***Buffelskloof 342JS***	202
41	***Goedehoop 244JS***	203
A1.11	CARBONIFEROUS – PERMIAN EONOTHEMS: SANDSTONE AND SHALE OF THE VRYHEID FORMATION IN THE NIGEL AREA	204
A1.11.1	CASE STUDY AREA	204
A1.11.2	CLIMATE AND VELD TYPES	205
A1.11.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	206
A1.11.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	208
A1.11.5	SOIL SAMPLING AND RESULTS PRESENTATION	208
42	***Holgatfontein 326IR***	218
43	***Leeuwkraal 517IR***	219
44	***Schoongezicht 225IR***	220
A1.12	PERMIAN – TRIASSIC EONOTHEMS: ARENACEOUS AND ARGILLACEOUS ROCKS OF THE IRRIGASIE, LISBON AND CLARENS FORMATIONS OF THE KAROO SUPERGROUP IN THE MABULA-WATERBERG AREA	221
A1.12.1	CASE STUDY AREA	221
A1.12.2	CLIMATE AND VELD TYPES	221
A1.12.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	222
A1.12.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	224
A1.12.5	SOIL SAMPLING AND RESULTS PRESENTATION	224
45	***Droogesloot 476KR***	233
46	***Grootfontein 528KQ***	234
47	***Newcastle 202LQ***	235
A1.13	JURASSIC EONOTHEM: BASALT ROCK OF THE LETABA FORMATION AND DOLERITE INTRUSIONS OF THE KAROO	236

	SUPERGROUP IN THE SPRINGBOK FLATS AREA	
A1.12.1	CASE STUDY AREA	**236**
A1.12.2	CLIMATE AND VELD TYPES	**236**
A1.12.3	GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION	**238**
A1.12.4	GEOPHYSICAL AND GEOBOTANICAL INFORMATION	**238**
A1.12.5	SOIL SAMPLING AND RESULTS PRESENTATION	**239**
48	***Kalkheuvel 73JR***	**248**
49	***Langkuil 13JR***	**249**
50	***Vlakplaats 483KR***	**250**
A2	**AN OVERVIEW OF THE IDENTIFIED GEOBOTANICAL INDICATORS**	**251**
A2.1	**BIOME OVERSIGHT**	**251**
A2.2	**IDENTIFIED GEOBOTANICAL INDICATORS**	**252**
A2.2.1	***Acacia karroo* (Sweet thorn)**	**252**
A2.2.2	***Adansonia digitata* (Baobab)**	**253**
A2.2.3	***Burkea africana* (Wild seringa)**	**254**
A2.2.4	***Dichapetalum cymosum* (Poison leaf/Gifblaar)**	**255**
A2.2.5	***Celtis africana (White stinkwood)***	**256**
A2.2.6	***Clerodendrum glabrum (Tinderwood)***	**257**
A2.2.7	***Combretum erythrophyllum (River bush-willow)***	**258**
A2.2.8	***Combretum imberbe (Leadwood)***	**259**
A2.2.9	***Euclea crispa (Blue guarri)***	**260**
A2.2.10	***Ficus ingens (Red-leaved fig)***	**261**
A2.2.11	***Fingerhuthia sesleriiformis (Thimble grass)***	**262**
A2.2.12	***Rhus lancea (Karee)***	**263**
A2.2.13	***Strychnos pungens (Spine-leaved monkey orange)***	**264**
A2.2.14	***Ximenia americana & X. caffra (Blue sourplum & Sourplum)***	**265**
A2.2.15	***Zanthoxylum capense (Small knobwood)***	**266**
A2.2.16	***Ziziphus mucronata (Buffalo-thorn)***	**267**
A2.2.17	***Acacia erioloba (Camel thorn)***	**268**
A2.2.18	***Boscia albitrunca & B. foetida* subsp. *rehmanniana (Shepherd's tree & Stink shepherd's tree)***	**269**
A2.2.19	***Commiphora mollis (Velvet corkwood)***	**270**
A2.2.20	***Gardenia volkensii (Savanna gardenia)***	**271**
A2.2.21	***Lonchocarpus capassa (Apple-leaf)***	**272**
A2.2.22	***Olea europaea* subsp. *africana (Wild olive)***	**273**
A2.2.23	***Pappea capensis (Jacket-plum)***	**274**
A2.2.24	***Spirostachys africana (Tamboti)***	**275**

LIST OF FIGURES

Figure A1.1. The geology (top left), land type (top right) and aerial photograph (bottom) of Beck 568MS. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The positions of the stream and the lineament, as seen on the geological map, are indicated. The red circles indicate minor lineaments (east-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map. **22**

Figure A1.2. The geology (top left), land type (top right) and aerial photograph (bottom) of Command 588MS. The blue circles denote the positions of the boreholes (dry and yielding) and the green line the direction of the magnetic profile. The position of the calc-silicate rocky ridge is indicated. The red circles indicate minor lineaments (mainly north-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map. **23**

Figure A1.3. The geology (top left), land type (top right) and aerial photograph (bottom) of Wolvedans 68MR. The blue circle denotes the position of the borehole, the yellow line the direction of the electromagnetic profile and the orange line indicates the layout of the Schlumberger sounding. The red circles indicate minor lineaments (east-west strike). Note: The area covered by the aerial photograph is indicated by the upper purple shape in the geological map. **24**

Figure A1.4. The geology (top left, Figure A1.3), land type (top right, Figure A1.3) and aerial photograph (bottom) of Zoetfontein 154MR. The blue circles denote the position of the boreholes (existing and new) and the yellow lines the direction of the electromagnetic profiles. The area covered by the aerial photograph is indicated by the lower purple shape in the geological map. **25**

Figure A1.5. The geology (top left), land type (top right) and aerial photograph (bottom) of Blokdrift 512KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates **38**

the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Figure A1.6. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circles denote the position of the boreholes (dry and yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction at the dry borehole. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **40**

Figure A1.7. The geology (top), land type (middle) and aerial photograph (bottom) of Vaalfontein 491KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic profile direction. The red lines are interpreted lineaments. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **40**

Figure A1.8. The geology (top left), land type (top right) and aerial photograph (bottom) of Elandsfontein 412JR (1). The blue circle denotes the position of the borehole, the green lines the direction of the magnetic profiles in order to obtain the contour map and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the right purple shape in the geological map. **52**

Figure A1.9. The geology and land type can be seen in Figure A1.8. Aerial photograph of Elandsfontein 412JR (2). The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the left purple shape in the geological map. **53**

Figure A1.10. The geology (top left), land type (top right) and aerial photograph (bottom) of Mooikloof Estate (1). The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **64**

Figure A1.11. The geology and land type are pictured in Figure A1.10. The aerial photograph of Mooikloof Estate (1). **65**

The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map (shares the same area as the previous Mooikloof case study).

Figure A1.12. The geology (top left), land type (top right) and aerial photograph (bottom) of Brits Industrial Area. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the orientation of the electromagnetic traverse. The red circles indicate exfoliation ridges that are covered with vegetation (dark lines). The area covered by the aerial photograph is indicated by the purple shape in the geological map. **66**

Figure A1.13. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameeldrift 313JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the diabase intrusions around the borehole. **77**

Figure A1.14. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameelfontein 297JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the lineaments. **78**

Figure A1.15. The geology (top left), land type (top right) and aerial photograph (bottom) of Skeerpoort 477JQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates **79**

the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament (exploration target) is indicated by red circles.

Figure A1.16. The geology (top left), land type (top right) and aerial photograph (bottom) of Badfontein 114JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle). **94**

Figure A1.17. Aerial photograph of Klipspruit 89JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the brown shape in the geological map (middle rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth, compare with Figure A1.16). **95**

Figure A1.18. Aerial photograph of Rietfontein 88JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (upper rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth). **96**

Figure A1.19. The geology (top left), land type (top right) and aerial photograph (bottom) of Waterval 386KT. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The red circles points out small lineaments (general east-west strike). The borehole is sited at a lineament with a northwest-southeast strike. The area covered by the aerial photograph is indicated by the red shape in the geological map (lower rectangle). **97**

Figure A1.20. The geology (top left), land type (top right) and aerial photograph (bottom) of Enkeldoornoog 219JR. The blue **110**

circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the red shape in the geological map.

Figure A1.21. The geology (top left), land type (top right) and aerial photograph (bottom) of Kwaggasfontein 460JS. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle). Note the considerable coverage of exotic species establishment on this farm. **111**

Figure A1.22. The geology (top left), land type (top right) and aerial photograph (bottom) of Rhenosterkop 452JR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the black shape in the geological map (lower rectangle). **112**

Figure A1.23. The geology (top), land type (middle) and aerial photograph (bottom) of Klipeiland 524JR. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line is the sounding layout. The area covered by the aerial photograph is indicated by the red shape in the geological map. **124**

Figure A1.24. The geology (top), land type (middle) and aerial photograph (bottom) of Rietfontein 314JS. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the red shape in the geological map. The red circle in the aerial photograph indicates indigenous trees (serve as geobotanic indicators). **125**

Figure A1.25. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **146**

Figure A1.26. The geology (top left), land type (top right) and aerial photograph (bottom) of Kareefontein 432KR. The blue circle denotes the position of the borehole, the green line the **146**

orientation of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament is indicated by the red circles in the aerial photograph.

Figure A1.27. The geology (top left), land type (top right) and aerial photograph (bottom) of Zandfontein 476KQ. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineaments are indicated by the red circles in the aerial photograph, although the upper circles can represent the quartz vein as indicated on the geological map. **147**

Figure A1.28. The geology (top left), land type (top right) and aerial photograph (bottom) of Klipfontein 256JS. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map. **148**

Figure A1.29. The geology (top left, Figure A1.28), land type (top right, Figure A1.28) and aerial photograph of Zusterstroom 447JR. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.28). **149**

Figure A1.30. The geology (top left), land type (top right) and aerial photograph (bottom) of Hartbeesfontein 394KR. The blue circle denotes the position of the borehole and the green and yellow lines indicates the direction of the magnetic and electromagnetic profiles respectively. The area covered by the **189**

aerial photograph is indicated by the purple shape in the geological map. The red lines represent lineaments (compare with the geological map).

Figure A1.31. The geology (top), land type (middle) and aerial photograph (bottom) of Pennsylvania 336LR. The blue circle denotes the position of the borehole and the green line indicates the magnetic profile direction. Note the linear vegetated features inside the red circles (aerial photograph). The area covered by the aerial photograph is indicated by the purple shape in the geological map. **190**

Figure A1.32. The geology (top), land type (middle) and aerial photograph (bottom) of Elandsfontein 493JR. The blue circle denotes the position of the borehole and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter "E" in the geological and land type maps. Note the linear vegetated feature inside the red circle that crosses the drilled borehole. **192**

Figure A1.33. Aerial photograph of Leeuwfontein 492JR. The blue circles denotes the position of the boreholes (left = dry and right = yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter "L" in the geological and land type maps. The geology and land type are depicted in Figure A1.32. **193**

Figure A1.34. Aerial photograph of Onspoed 500JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter "O" in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the numerous lineaments in this geological setting. **194**

Figure A1.35. The geology (top left), land type (top right) and **195**

aerial photograph (bottom) of Onverwacht 532JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Figure A1.36. Aerial photograph of Trigaardspoort 451JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter "T" in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the linear streams in this geological setting that can indicate the presence of lineaments (weathered diabase). **197**

Figure A1.37. Aerial photograph of Vlakfontein 453JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the direction of the electromagnetic traverse. The area covered by the aerial photograph is indicated by the purple shape and the letter "V" in the geological and land type maps. The geology and land type are depicted in Figure A1.32. **197**

Figure A1.38. Aerial photograph of Bankfontein 264JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the lower purple shape in the geological map. Some of the lineaments are indicated by the red lines. **199**

Figure A1.39. Aerial photograph of Bankplaas 239JS. The blue circle denotes the position of the borehole, the green line **201**

the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the upper purple shape in the geological map (Figure A1.38). Some of the lineaments are indicated by the red lines. Refer to Figure A1.38 for the land type map.

Figure A1.40. Aerial photograph of Buffelskloof 342JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map (Figure A1.40). **202**

Figure A1.41. Aerial photograph of Goedehoop 244JS. The blue circles denotes the position of the boreholes (dry and yielding) and the yellow line the layout of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.40). Refer to Figure A1.40 for the land type map. **203**

Figure A1.42. The geology (top left), land type (top right) and aerial photograph (bottom) of Holgatfontein 326IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **218**

Figure A1.43. The geology (top left), land type (top right) and aerial photograph (bottom) of Leeuwkraal 517IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map. **219**

Figure A1.44. The geology (top left), land type (top right) and aerial photograph (bottom) of Schoongezicht 225IR. The blue circle denotes the position of the borehole and the green and **220**

yellow lines the direction of the (electro)-magnetic profiles. The various soundings are indicated by the orange lines. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Figure A1.45. The geology (top), land type (middle) and aerial photograph (bottom) of Droogesloot 476KR. The blue circle denotes the position of the borehole and the yellow line the direction of the electromagnetic profile. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zones. **233**

Figure A1.46. The geology (top), land type (middle) and aerial photograph (bottom) of Grootfontein 528KQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zone, note the linear vegetated pattern. **234**

Figure A1.47. The geology (top left), land type (top right) and aerial photograph (bottom) of Newcastle 202LQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red lines in the aerial photograph indicate the position of the fault, although it is not as straight linear as indicated in the geological map. **235**

Figure A1.48. The geology (top left), land type (top right) and aerial photograph (bottom) of Kalkheuvel 73JR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. Note the disturbed surface on the aerial photograph due to mining activities. No vegetation **248**

patterns are easy to recognize.

Figure A1.49. The geology (top left), land type (top right) and aerial photograph (bottom) of Langkuil 13JR. The blue circles denote the position of the boreholes (dry and yielding), the green and yellow lines the direction of the (electro)-magnetic profiles and the orange lines the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles indicate linear features that were recognized by the magnetometer. The position of the current and past river bed is indicated. **249**

Figure A1.50. The geology (top left), land type (top right) and aerial photograph (bottom) of Vlakplaats 483KR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. No vegetation patterns are easy to recognize in this cultivated landscape. **250**

Figure A2.1. Distribution of biomes across the research area and geological units (Vegter, 2001a). **251**

Figure A2.2. Distribution of *Acacia karroo* (Venter & Venter, 2005). **252**

Figure A2.3. Photographs of *Acacia karroo* (appearance, thorns, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **252**

Figure A2.4. Distribution of *Adansonia digitata* (Venter & Venter, 2005). **253**

Figure A2.5. Photographs of *Adansonia digitata* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **253**

Figure A2.6. Distribution of *Burkea africana* (Van Wyk & Van Wyk, 1997). **254**

Figure A2.7. Photographs of *Burkea africana* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986). **254**

Figure A2.8. Distribution of *Dichapetalum cymosum* (Van Wyk *et al*., 2002). **255**

Figure A2.9. Photographs of *Dichapetalum cymosum* (appearance, flowers, seeds and leaves) (Van Wyk *et al*., **255**

2002).
Figure A2.10. Distribution of *Celtis africana* (Venter & Venter, 2005). **256**
Figure A2.11. Photographs of *Celtis africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **256**
Figure A2.12. Distribution of *Clerodendrum glabrum* (Van Wyk & Van Wyk, 1997). **257**
Figure A2.13. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)). **257**
Figure A2.14. Distribution of *Combretum erythrophyllum* (Venter & Venter, 2005). **258**
Figure A2.15. Photographs of *Combretum erythrophyllum* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **258**
Figure A2.16. Distribution of *Combretum imberbe* (Venter & Venter, 2005). **259**
Figure A2.17. Photographs of *Combretum imberbe* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **259**
Figure A2.18. Distribution of *Euclea crispa* (Van Wyk & Van Wyk, 1997). **260**
Figure A2.19. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2002), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)). **260**
Figure A2.20. Distribution of *Ficus ingens* (Venter & Venter, 2005). **261**
Figure A2.21. Photographs of *Ficus ingens* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **261**
Figure A2.22. Distribution of *Fingerhuthia sesleriiformis* (Van Oudtshoorn, 1994). **262**
Figure A2.23. Photographs of *Fingerhuthia sesleriiformis* (appearance, flowers, seeds and leaves) (Van Oudtshoorn, 1994). **262**
Figure A2.24. Distribution of *Rhus lancea* (Venter & Venter, 2005). **263**
Figure A2.25. Photographs of *Rhus lancea* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **263**
Figure A2.26. Distribution of *Strychnos pungens* (Van Wyk & Van Wyk, 1997). **264**
Figure A2.27. Photographs of *Strychnos pungens* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & **264**

Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Van Wyk, 1986) and leaves (Van Wyk & Van Wyk, 1997)).

Figure A2.28. Distribution of *Ximenia caffra* (Venter & Venter, 2005). The distribution of *Ximenia americana* is similar. **265**

Figure A2.29. Photographs of *Ximenia caffra* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). The leaves of *Ximenia americana* are blue-green. **265**

Figure A2.30. Distribution of *Zanthoxylum capense* (Venter & Venter, 2005). **266**

Figure A2.31. Photographs of *Zanthoxylum capense* (appearance, flowers, seeds, thorny bark and leaves) (Venter & Venter, 2005). **266**

Figure A2.32. Distribution of *Ziziphus mucronata* (Venter & Venter, 2005). **267**

Figure A2.33. Photographs of *Ziziphus mucronata* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005). **267**

Figure A2.34. Distribution of *Acacia erioloba* (Venter & Venter, 2005). **268**

Figure A2.35. Photographs of *Acacia erioloba* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005). **268**

Figure A2.36. Distribution of *Boscia albitrunca* (Venter & Venter, 2005). The distribution of *B. foetida* subsp. *rehmanniana* is restricted to the research area. **269**

Figure A2.37. Photographs of *Boscia albitrunca* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). Note that the leaves of *B. foetida* subsp. *rehmanniana* are smaller. **269**

Figure A2.38. Distribution of *Commiphora mollis* (Steyn, 2003). **270**

Figure A2.39. Photographs of *Commiphora mollis* (appearance, flowers, seeds, bark and leaves) (Steyn, 2003). **270**

Figure A2.40. Distribution of *Gardenia volkensii* (Venter & Venter, 2005). **271**

Figure A2.41. Photographs of *Gardenia volkensii* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **271**

Figure A2.42. Distribution of *Lonchocarpus capassa* (Van Wyk & Van Wyk, 1997). **272**

Figure A2.43. Photographs of *Lonchocarpus capassa* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986). **272**

Figure A2.44. Distribution of *Olea europaea* subsp. *africana* (Venter & Venter, 2005). **273**

Figure A2.45. Photographs of *Olea europaea* subsp. *africana* **273**

(appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

Figure A2.46. Distribution of *Pappea capensis* (Venter & Venter, 2005). **274**

Figure A2.47. Photographs of *Pappea capensis* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **274**

Figure A2.48. Distribution of *Spirostachys africana* (Venter & Venter, 2005). **275**

Figure A2.49. Photographs of *Spirostachys africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). **275**

LIST OF TABLES

Table A1.1. The Pretoria geobotany example. **2**

Table A1.2. Climatic Data of the Messina & Swartwater Areas (Bonsma, 1976, Schulze, 1997 & Messina, 2002). **8**

Table A1.3a. Limpopo Granulite-Gneiss Belt: along intrusive contact. **12**

Table A1.3b. Limpopo Granulite-Gneiss Belt: no intrusive contact. **17**

Table A1.4. Climatic Data of the Rooiberg-Warmbaths Areas (Bonsma, 1976, Schulze, 1997 & Polokwane, 2003). **27**

Table A1.5a. Vaalium Eonothem: Rooiberg-Warmbaths Area: along intrusive contact. **30**

Table A1.5b. Vaalium Eonothem: Rooiberg-Warmbaths Area: no intrusive contact. **34**

Table A1.6. Climatic Data of the Bapsfontein Area (Schulze, 1997 & Johannesburg, 1999). **42**

Table A1.7a. Vaalium Eonothem: Dolomite in the Pretoria Area: along intrusive contact. **45**

Table A1.7b. Vaalium Eonothem: Dolomite in the Pretoria Area: no intrusive contact. **48**

Table A1.8. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999). **55**

Table A1.9a. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: along intrusive/weathering contact. **58**

Table A1.9b. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: absent intrusive/weathering contact. **61**

Table A1.10. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999). **69**

Table A1.11a. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: along intrusive/weathering contact. **71**

Table A1.11b. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: intrusive/weathering contact absent. **74**

Table A1.12. Climatic Data of the Lydenburg Area (Schulze, 1997, Nelspruit, 1999 & Phalaborwa, 1998). **82**

Table A1.13a. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: along intrusive/weathering **84**

contact.

Table A1.13b. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: intrusive/weathering contact absent. **89**

Table A1.14. Climatic Data of the Verena-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999). **100**

Table A1.15a. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: along intrusive/weathering contact. **102**

Table A1.15b. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: absent intrusive/weathering contact. **106**

Table A1.16. Climatic Data of the Bronkhorstspruit-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999). **114**

Table A1.17a. Vaalium Eonothem: Other geological conditions in the Bronkhorstspruit-Middelburg area: along weathered basin or intrusive contact. **116**

Table A1.17b. Vaalium Eonothem: Other geological conditions in the Bronkhorstspruit-Middelburg area: no weathered basin or intrusive contact. **120**

Table A1.18. Climatic Data of the Verena and Warmbaths Areas (Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003). **127**

Table A1.19a (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: along intrusive contact. **131**

Table A1.19b (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: intrusive contact absent. **135**

Table A1.19a (ii). Mogolian Eonothem: Nebo Granite - Verena Area: along intrusive contact. **139**

Table A1.19b (ii). Mogolian Eonothem: Nebo Granite - Verena Area: intrusive contact absent. **142**

Table A1.20. Climatic Data of the Waterberg and Bronkhorstspruit-Middelburg Areas (Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003). **152**

Table A1.21a (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: along intrusive contact. **157**

Table A1.21b (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: intrusive contact absent. **160**

Table A1.21a (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: along intrusive contact. **163**

Table A1.21b (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: intrusive contact absent. **167**

Table A1.21a (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: along intrusive contact. **171**

Table A1.21b (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: intrusive contact absent. **175**

Table A1.21a (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: along intrusive contact. **179**

Table A1.21b (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: intrusive contact absent. **183**

Table A1.22. Climatic Data of the Nigel Area (Schulze, 1997 & Johannesburg, 1999). **206**

Table A1.23 (a). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: along intrusive contact. **210**

Table A1.23 (b). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: intrusive contact absent. **214**

Table A1.24. Climatic Data of the Mabula-Waterberg Area (Schulze, 1997 & Polokwane, 2003). **222**

Table A1.25 (a). Carboniferous - Jura Eonothems: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: along fracture and/or fault contact zone. **225**

Table A1.25 (b). Carboniferous - Jura Eonothems: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: faulting or fracturing absent. **229**

Table A1.26. Climatic Data of the Springbok Flats Area around Pienaarsrivier-Settlers (Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003). **237**

Table A1.27 (a). Jurassic Eonothem: Basalt rock of the Letaba Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: along contact, weathering and/or fracture zone. **240**

Table A1.27 (b). Jurassic Eonothem: Basalt rock of the Letaba **244**

Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: contact, weathering and/or fracture zone absent.

A1. CASE STUDY INFORMATION

Additional information regarding the case studies as presented in Chapter 4 is listed in this annexure. Geological maps, land type maps and the aerial photograph of every case study are presented. On the aerial photograph the location of the borehole(s) is denoted, layout of the geophysical travers(es) and geological features like lineaments. Some additional information or background to the site might be discussed.

Of importance is the inclusion of the soil sampling tables (see Table 3.1) representing the geobotanic and non-geobotanic communities. Furthermore, some additional information about the case study area, climate and veld types, geology and hydrogeology, geophysics and geobotany is offered. The presentation of the case studies corresponds to Chapter 4.

Table A1.1. The Pretoria geobotany example.

Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magalies-berg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
Geological Formation	Swazian Granite	Malmani Subgroup	Timeball Hill Formation	Hekpoort Formation	Daspoort Formation	Silverton Formation	Magalies-berg Formation	Main Zone: Rustenburg Layered Suite	Nebo Granite	Ecca Group
Depth Sampled	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m	0.5m
Sample Co-ordinates: S.L. E.L.	 25º54.189' 28º06.119'	 25º51.622' 28º06.269'	 25º46.892' 28º12.537'	 25º45.135' 28º13.731'	 25º44.324' 28º15.522'	 25º44.865' 28º25.522'	 25º41.486' 28º11.194'	 25º38.784' 28º16.418'	 25º29.730' 28º16.567'	 25º19.595' 28º19.851'
Soil colour	Pale yellowish orange	Dusky yellowish brown	Blackish red	Dark red	Yellowish brown	Strong brown	Light brown	Dark grey	Dark yellowish orange	Moderate yellowish brown
pH	6.29	6.68	5.50	5.79	5.07	4.57	5.08	7.54	5.83	5.54
P (mg/kg)	2.5	2.6	10.1	3.1	3.0	2.6	2.6	2.7	2.6	2.7
Ca (mg/kg)	486	1090	1474	2166	127	215	150	8627	324	128
Mg (mg/kg)	145	237	468	473	44	86	71	1824	109	60
K (mg/kg)	74	151	242	270	33	80	60	204	62	24
Na (mg/kg)	16	20	29	29	20	20	17	44	18	16
Fe (mg/kg)	11.85	21.02	3.94	2.12	29.93	7.78	6.64	0.0	5.81	9.46
Mn (mg/kg)	29.61	152.08	179.77	128.35	10.12	57.71	5.65	8.63	18.13	8.47
Zn (mg/kg)	1.24	0.3	17.69	4.31	2.2	2.44	0.2	0.2	1.44	1.02

Al ($cmol_c$/kg)	0.00	0.00	0.209	0.00	0.99	0.829	0.584	0.00	0.00	0.246
Resistance (Ohm)	3000	2400	1600	1800	6200	6600	7600	400	4800	8000
C%	0.50	0.75	5.09	3.71	2.87	1.78	0.85	1.10	0.32	0.40
Total N%	0.024	0.031	0.398	0.259	0.149	0.105	0.040	0.043	0.016	0.020
Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magaliesberg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
S (mg/kg)	15.86	25.06	89.91	46.09	84.2	82.01	43.74	21.72	8.97	21.55
CEC ($cmol_c$/kg)	4.17	8.42	17.87	18.18	8.4	5.74	3.37	55.84	3.13	2.64
Clay %	22.0	26.0	22.0	42.0	10.0	30.0	22.0	52.0	12.0	12.0
Silt %	16.3	30.7	41.1	30.2	25.9	28.8	11.0	28.6	3.8	12.7
Sand %	61.7	43.3	36.9	27.8	64.1	41.2	67.0	19.4	84.2	75.3
Distinct Tree Species	Grassland	1. Acacia karroo 2. Dombeya rotundifolia 3. Rhus lancea	1. Ochna pulchra 2. Brachylaena rotundata 3. Euclea crispa 4. Vangueria infausta	1. Acacia caffra 2. Gymnosporia buxifolia 3. Rhus lancea	1. Protea caffra 2. Mundulea sericea	Grassland	1. Englerophytum magalismontanum 2. Vangueria infausta	1. Euphorbia ingens 2. Acacia karroo	1. Cussonia paniculata 2. Terminalia sericea 3. Grewia flavescens	1. Faurea saligna 2. Sclerocarya birrea 3. Rhus lancea

Average rooting depth of the indicated species (m)	1 - 2	13 - 50	2 - 7	13 - 50	3 - 7	1 - 2	4 - 8	4 - 50	2 - 8	2 - 13
Average depth of weathering (m)	1.2	2.7	0.5	3.1	0.4	0.8	0.2	3.4	1.1	1.3
Average Aquifer Yield (l/h)	2 800	7 000	3 000	6 750	3 000	3 400	3 000	6 000	2 600	3 000
Average Borehole Depth (m)	45	35	45	60	50	35	45	35	55	60
Average Depth of Water Strike (m)	31	21	32	31	37	24	37	22	43	29
Average Static Water Level (m)	16	12	19	17	16	10	16	10	21	16
Information gathered from Land Type Series Maps, Veld Type Maps and Hydrogeological Maps										
Land Type Series	Bb1a Glenrosa	Ab2a Hutton	Ib7a Rock	Ba9a Hutton	Ib3c Rock	Ba8b Mispah	Ib3a Rock	Ea3a Arcadia	Fa4b Glenrosa	Ae20b Hutton

Profile No	No data	P93	No data	P56 (diabase)	No data	P94	No data	P71 (Belfast)	P73 (Moloto)	P83
Depth Sampled	-	0.64m	-	0.51m	-	0.71m	-	0.38m	0.52m	0.6m
Gravel %	-	2	-	4	-	0	-	8	4	0
Sand %	-	44	-	40	-	39	-	22	75	63
Silt %	-	14	-	14	-	6	-	13	4	5
Parameter	Swazian Granite	Malmani Dolomite	Timeball Hill Quartzite	Hekpoort Andesite	Daspoort Quartzite	Silverton Shale	Magalies-berg Quartzite	Bushveld Complex Norite	Bushveld Complex Granite	Karoo Sandstone & Shale
Clay %	-	40	-	42	-	55	-	57	17	32
pH	-	5.9	-	6.4	-	5.4	-	7.0	4.6	5.6
P (mg/kg)	-	0.8	-	1.1	-	0.5	-	-	1.1	0.6
Ca (mg/kg)	-	580	-	2060	-	580	-	561	80	820
Mg (mg/kg)	-	144	-	1728	-	396	-	1620	36	192
K (mg/kg)	-	156	-	78	-	39	-	117	156	273
Na (mg/kg)	-	<23	-	69	-	23	-	161	<23	23
Fe (mg/kg)	-	-	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	557.3	-	90.4	-	105.1	-	1126.3	16.7	109.6
Zn (mg/kg)	-	0.33	-	0.65	-	0.21	-	0.32	0.39	0.45
Resistance (Ohm)	-	2000	-	430	-	1200	-	320	2800	900
C%	-	0.7	-	1.1	-	1.0	-	1.3	0.6	0.3
CEC ($cmol_c/kg$)	-	75	-	288	-	103	-	460	32	102

Veld Type	61 Bankenveld	61 Bankenveld	19 Sourish Mixed Bushveld	20 Sour Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	13 Other Turf Thornveld	19 Sourish Mixed Bushveld	16 Kalahari Thornveld
Hydrogeo-logical Unit	D3	B3	D2	D3	B2	D3	B3	D3	D3	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

A1.1 SWAZIAN EONOTHEM: LIMPOPO GRANULITE-GNEISS BELT

The Limpopo Granulite-Gneiss Belt is an unique geological setting in the northern parts of South Africa due to the presence of metamorphosed rocks, hotter and dryer climate with distinct vegetation species and poor aquifer conditions. Nevertheless, four sites were visited and the results are presented in Table A1.3 (a&b).

A1.1.1 CASE STUDY AREA

The Limpopo Granulite-Gneiss Belt is a lenticularly shaped, north-easterly trending belt, situated in the Limpopo Province, about 375 km long, measures about 60 km at its widest and is about 13 910 km^2 in extent. It occurs basically north of the Soutpansberg to the Limpopo River. The case study area can be sub-divided into two different areas, based on the veld types of those areas. The northern part, towards Messina, and a western part in the region of Swartwater, close to the Botswana border.

A1.1.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.2. The area is characterised by hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occuring mostly as heavy thunderstorms (Sami *et al*., 2002b). The veld types that occur (see also Table A1.3a) are Mopani veld north of the Soutpansberg in the Messina area and Arid Sweet Bushveld to Mixed Bushveld around Swartwater. Farms close to the Limpopo can be classified as part of the Arid Sweet Bushveld and those further into the interior of the country as Mixed Bushveld (Acocks, 1988). Game farming and extensive stock farming is most commonly practiced in the presented case study areas. The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Arid Sweet Bushveld: *Adansonia digitata* (baobab), *Grewia flava* (velvet raisin) and *Acacia mellifera* (black thorn).

- Mixed Bushveld: *Combretum apiculatum* (red bushwillow), *Adansonia digitata* (baobab) and *Combretum imberbe* (leadwood).
- Mopani Veld: *Colophospermum mopane* (mopane), *Combretum apiculatum* (red buswillow), *Cassia abbreviata* (sjambok pod) and *Adansonia digitata* (baobab).

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.2. Climatic Data of the Messina & Swartwater Areas (Bonsma, 1976, Schulze, 1997 & Messina, 2002).

	Quantity	
	Messina area	*Swartwater area*
Average Yearly Temperature (°C)	>20	>20
Mean Minimum Temperature (°C) in July	>8	4-6
Mean Maximum Temperature (°C) in January	>32.5	>32.5
Average Yearly Rainfall (mm)	300-400	400-600
Elevation (m)	400-800	800-1200
Evaporation (mm/year)	2250-2500	2250-2500
Frost area?	No	Almost none

A1.1.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Polymetamorphosed and highly deformed supracrustal and intrusive rocks of Swazian age and belonging to the Central Zone of the Limpopo Mobile Belt (Beit Bridge Complex) occupy the case study areas. The supracrustal rocks consist of metaquartzite, magnetite quartzite, metapelite, granulite, leucogneiss, calc-silicate rock and marble. Intrusive rocks comprise biotite gneiss, meta-anorthosite, metagabbro, serpentinite, metapyroxenite and hornblendite. The Limpopo Mobile Belt has been intruded by east-west striking granite dykes, pegmatites and by diabase and dolerite dykes, generally striking east-northeast and west-northwest (Vegter, 2001b). Although some major fault structures occur in the study area, no fault structure intersected any of the sites visited. The geology of the area is discussed at some length in Sami *et al*. (2002b).

Vegter (2001b) and Sami *et al.* (2002b) states that drilling results in these hard-rock formations are poor and those drilled by government drilling machines yield about 40% more than 360 ℓ/h. Borehole yields fall mainly in the category between 36 ℓ/h and 3600 ℓ/h. These boreholes were sited by laymen and professional earth/physical scientists and no distinct difference could be observed on borehole siting by either. Statistical analysis of drilling results in this region by Vegter (2001b) indicates that the maximum optimal strike depth ranges between 50 and 85 m below the surface and between 15 and 25 m below the water level. Higher yields do not go hand-in-hand with greater strike depth below water level.

Brittle tectonic deformation, weathering and unloading are the agents responsible for the development of openings in rocks of the Limpopo Mobile Belt. Unless faults, dykes, dyke and formational contacts are weathered and/or fractured to below water level, they do not act *ipso facto* as aquifers. Although composition and texture determine the extent to which different rock types are affected by these processes, local variability and conditions do not allow a clear-cut lithological classification in terms of water-bearing properties. The supracrustal rocks of which metaquartzite perhaps should be singled out, seem more favourable targets, than the granite gneiss (Vegter, 2001b). The rocks of the Limpopo Granulite-Gneiss Belt is a poor aquifer due to marginal to poor water quality related to nitrate levels, low recharge and extractable quantities and the extreme heterogeneity in targets (Sami *et al*., 2002b).

A1.1.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

According to Vegter (2001b), hydrogeological and geophysical siting of boreholes in the Swartwater area has shown that the probability of striking water is greatest:

- Where weathering extends to below the piezometric level (water level).
- Where the depth of weathering and of the piezometric surface does not exceed 40 m, and

- In the first 10 m below the piezometric level.

Bush (1989) advocates the application of magnetics as a primary investigation tool. This technique determines the possible presence of basic/mafic intrusions and to establish the magnetic properties of the country rocks. However, the presence of magnetite quartzite rocks prevents the application of the magnetic technique in such an area. Electromagnetic instrumentation like the Genie SE-88 was used in those cases. The Genie SE-88 must not be used in frequencies below 400 Hz as they fail to produce a significant anomaly even when large coil separations (150 m) are used (Botha *et al*., 1992). This means rather use the 3037.5/112.5 Hz frequency pair than the 337.5/112.5 Hz frequency pair. Poor conductors will yield large negative peak amplitudes at the former mentioned frequency pair. Furthermore, the Genie was found to be more cost effective (Botha *et al*., 1992), of the various electromagnetic systems evaluated, in locating good conductive fracture zones and interpreting its dip direction. This is due to data quality, absence of inter-connecting cable (benefit in bushveld), large available coil separations and survey speed. The Geonics EM-34 instrument was not used in this geological environment due to encountered instrument malfunctioning. However, this instrument is capable of operating in both low (less than 100 ohm.m) and high resistivity environments, its use as an alternative reconnaissance tool is recommended. Schlumberger soundings are less affected by lateral resistivity changes than those using the Wenner configuration, they are preferred for determining depth of weathering and fracturing across EM anomalies. Application of geophysical techniques utilised is a function of instrumentation and time available as all the case studies were derived from professional groundwater consultation work. The obtained results, together with the application of geobotany, will indicate the value of it.

A1.1.5 SOIL SAMPLING AND RESULTS PRESENTATION

Four farms were visited and the results and information gathered is presented in Table A1.3 (a&b). Where possible, two soil samples were taken at the indicated drilling spot and geobotanical indicator at depths of 0.5 m and 1.2 m. Another two soil samples were taken about 25 m away from the observed geological anomaly as indicated on the geophysical traverse. If no sample could be obtained at a depth of 1.2 m, due to the presence of unweathered rock or other obstructions, then another sample was taken in another spot at a depth of 0.5 m. The previous chapter deals with the taking of the samples, basically at the borehole or indicated drilling spot and the other one away from it and the particular soil analyses requested. It was ensured that soil sampling at the borehole was done as close as possible to any observed geobotanical indicators.

Table A1.3a. Limpopo Granulite-Gneiss Belt: along intrusive contact.

Parameter	Beck 568MS		Command 588MS		Wolvedans 68MR		Zoetfontein 154MR	
Geological Formation	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Diabase in granite-gneiss (Beit Bridge Complex)	Basic and ultrabasic rocks in granite-gneiss (Beit Bridge Complex)	Basic and ultrabasic rocks in granite-gneiss (Beit Bridge Complex)	Magnetite quartzite and diabase in granite-gneiss (Mount Dowe Group)	Magnetite quartzite and diabase in granite-gneiss (Mount Dowe Group)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	22º38.649' 29º58.235'	22º38.649' 29º58.235'	22º43.108' 29º49.706'	22º43.108' 29º49.706'	22º50.008' 28º20.441'	22º50.008' 28º20.441'	22º56.486' 28º20.558'	22º56.486' 28º20.558'
Soil colour	Black	Dark grey	Dark grey	Greyish black	Dark grey	Greyish black	Dusky yellowish brown	Dark brown
Soil texture description	clay	clay	clay	Clay	clay	clay	gravel and sandy silt	gravel and sandy silt
pH	6.64	8.27	7.44	8.16	8.96	7.31	4.67	4.92
P (mg/kg)	12.15	3.89	12.63	8.67	6.88	7.25	104.56	99.73
Ca (mg/kg)	1460	3038	1539	3397	5589	1734	1327	1180
Mg (mg/kg)	505	964	665	655	2273	758	272	239
K (mg/kg)	143	188	179	110	225	191	165	143
Na (mg/kg)	43	145	102	73	644	96	90	59
Fe (mg/kg)	122.39	94.52	142.03	38.02	24.21	143.00	270.59	472.15
Mn (mg/kg)	375.28	302.96	464.71	147.69	37.45	497.20	102.08	234.93

Zn (mg/kg)	1.03	1.27	1.55	1.23	0.51	1.84	11.83	11.84
Al ($cmol_c$/kg)	0.048	0.018	0.021	0	0.033	0.028	0.971	0.570
Resistance (Ohm)	1900	560	1800	1600	1400	1800	1600	1800
C%	1.16	0.99	1.16	0.58	0.58	1.31	7.31	5.55
Total N%	0.082	0.070	0.079	0.045	0.037	0.094	0.501	0.392
S (mg/kg)	11.78	17.27	15.30	14.01	20.31	14.27	102.44	73.70
CEC ($cmol_c$/kg)	15.058	17.536	16.105	11.556	29.786	20.450	18.657	15.877
Distinct Tree Species	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata	1. Adansonia digitata 2. Combretum imberbe 3. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Ximenia americana 4. Pappea capensis	1. Adansonia digitata 2. Combretum imberbe 3. Ximenia americana 4. Pappea capensis
Average rooting depth of the indicated species (m)	30 (estimated)	30 (estimated)	30 (estimated)	30 (estimated)	2 - 35	2 - 35	2 - 35	2 - 35
Average depth of weathering (m)	1.8	1.8	1.8	1.8	0.6	0.6	1.8	1.8

Geomor-phology	Plain	Plain	Plain with ridges	Plain with ridges	Undulating plain	Undulating plain	Plain with ridges	Plain with ridges
Geophysical instrumenta-tion used	Magnetics	Magnetics	Magnetics	Magnetics	a. Genie SE-88 b. Schlumber-ger soundings	a. Genie SE-88 b. Schlum-berger soundings	Genie SE-88	Genie SE-88
Water features present?	No	No	No	No	No	No	Small Pan, <0.01ha	Small Pan, <0.01 ha
Aquifer Yield (l/h)	650	650	500	500	770	770	650	650
Borehole Depth (m)	78	78	80	80	85	85	85	85
Depth of Water Strike (m)	58	58	46	46	52	52	37	37
Static Water Level (m)	46	46	38	38	40	40	24	24
Average Aquifer Yield (l/h)	360	360	360	360	360	360	360	360
Average Borehole Depth (m)	75	75	75	75	95	95	95	95

Average Depth of Water Strike (m)	25	25	25	25	20	20	20	20
Average Static Water Level (m)	15	15	15	15	10	10	10	10
Land Type Series	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Fc620a Glenrosa, Mispah	Fc620a Glenrosa, Mispah	Ae285b Hutton	Ae285b Hutton
Profile No	P8474	P8474	P8474	P8474	P10126	P10126	P10125	P10125
Depth Sampled	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	100 – 560 mm	100 – 560 mm	200 – 1050 mm	200 – 1050 mm
Gravel %	0.0	0.0	0.0	0.0	1.6	1.6	2.2	2.2
Sand %	33.5	33.5	33.5	33.5	57.3	57.3	73.0	73.0
Silt %	44.1	44.1	44.1	44.1	17.7	17.7	7.6	7.6
Clay %	22.4	22.4	22.4	22.4	23.4	23.4	17.2	17.2
pH (H_2O)	7.26	7.26	7.26	7.26	8.16	8.16	6.99	6.99
P (mg/kg)	2.80	2.80	2.80	2.80	2.90	2.90	1.70	1.70
Ca (mg/kg)	487	487	487	487	677	677	54	54
Mg (mg/kg)	2	2	2	2	20	20	9	9
K (mg/kg)	39	39	39	39	20	20	16	16
Na (mg/kg)	83	83	83	83	3	3	1	1
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	18.29	18.29	18.29	18.29	51.72	51.72	70.65	70.65
Zn (mg/kg)	1.03	1.03	1.03	1.03	0.21	0.21	0.12	0.12

Resistance (Ohm)	26	26	26	26	1400	1400	3000	3000
C%	0.32	0.32	0.32	0.32	2.26	2.26	0.40	0.40
CEC ($cmol_c$/kg)	19.44	19.44	19.44	19.44	19.78	19.78	4.09	4.09
Veld Type	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	14/18 Arid Sweet Bushveld/Mixed Bushveld	14/18 Arid Sweet Bushveld/Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeo-logical Unit	D2	D2	D2	D2	D2/D3	D2/D3	D2/D3	D2/D3

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Vegter (2001b). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Messina (2002). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (2003). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.3b. Limpopo Granulite-Gneiss Belt: no intrusive contact.

	Beck 568MS		Command 588MS		Wolvedans 68MR		Zoetfontein 154MR	
Geological Formation	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)	Granite-gneiss (Beit Bridge Complex)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	22º38.649' 29º58.235'	22º38.649' 29º58.235'	22º43.108' 29º49.706'	22º43.108' 29º49.706'	22º50.008' 28º20.441'	22º50.008' 28º20.441'	22º56.486' 28º20.558'	22º56.486' 28º20.558'
Soil colour	Pale yellowish orange	Dusky yellowish brown	Blackish red	Dark red	Yellowish brown		Strong brown	Light brown
pH	7.24	5.70	5.64	4.96	6.08	5.78	5.04	6.16
Soil texture description	Clay	Sandy silt	Clay	Sandy silt	Clay	Clay	Clay	Sandy silt
P (mg/kg)	3.09	2.37	3.94	2.46	5.80	12.75	5.65	2.43
Ca (mg/kg)	187	313	483	396	292	607	306	653
Mg (mg/kg)	78	146	115	138	110	174	62	290
K (mg/kg)	38	57	156	110	69	258	60	113
Na (mg/kg)	14	13	17	15	12	19	10	32
Fe (mg/kg)	48.29	67.30	56.35	83.21	59.02	215.53	46.74	90.95
Mn (mg/kg)	40.84	96.40	54.37	196.02	59.16	306.01	212.35	109.93
Zn (mg/kg)	0.65	0.38	0.69	0.77	0.78	4.10	1.38	0.46
Al ($cmol_c$/kg)	0.095	0.224	0.098	0.304	0.045	0.096	0.379	0.118

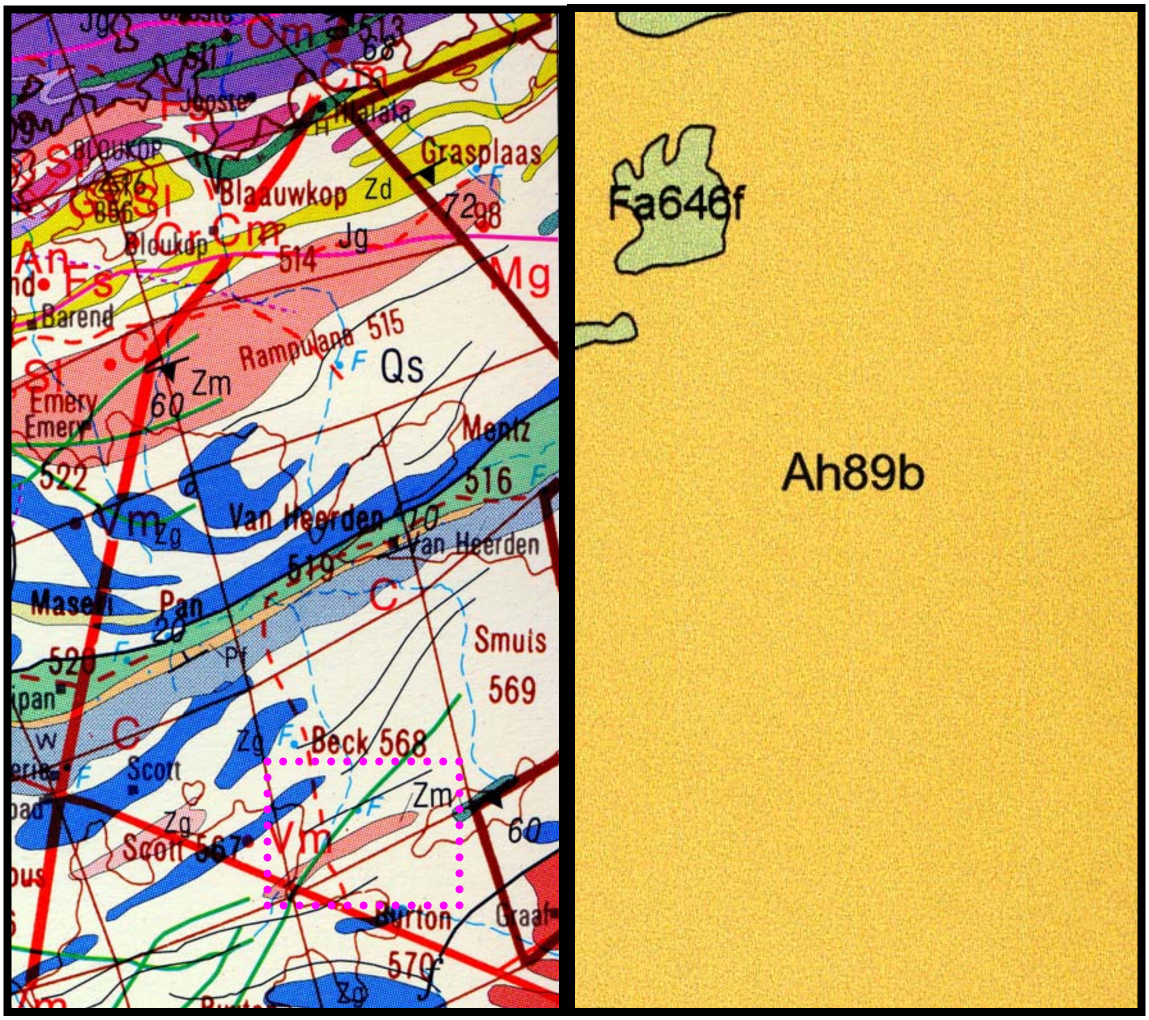
Resistance (Ohm)	6400	3400	2200	3200	3000	2000	3800	2600
C%	0.25	0.30	0.92	0.49	0.77	2.65	0.65	0.08
Total N%	0.020	0.033	0.074	0.047	0.050	0.196	0.050	0.012
S (mg/kg)	8.19	58.16	19.81	79.78	10.47	13.98	13.85	20.62
CEC ($cmol_c$/kg)	2.608	5.734	5.370	5.611	2.853	6.686	3.221	9.107
Distinct Tree Species	Colophosper-mum mopane	Colophosper-mum mopane	Colophosper-mum mopane	Colophosper-mum mopane	Combretum apiculatum	Combretum apiculatum	Combretum apiculatum	Combretum apiculatum
Average rooting depth of the indicated species (m)	5	5	5	5	4	4	4	4
Average depth of weathering (m)	1.8	1.8	1.8	1.8	0.6	0.6	1.8	1.8
Geomorphology	Plain	Plain	Plain with ridges	Plain with ridges	Undulating plain	Undulating plain	Plain with ridges	Plain with ridges
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	c. Genie SE-88 d. Schlumber-ger soundings	c. Genie SE-88 d. Schlum-berger soundings	Genie SE-88	Genie SE-88
Water features present?	No	No	No	No	No	No	Small Pan, <0.01ha	Small Pan, <0.01 ha
Aquifer Yield (l/h)	650	650	500	500	770	770	650	650
Borehole Depth (m)	78	78	80	80	85	85	85	85

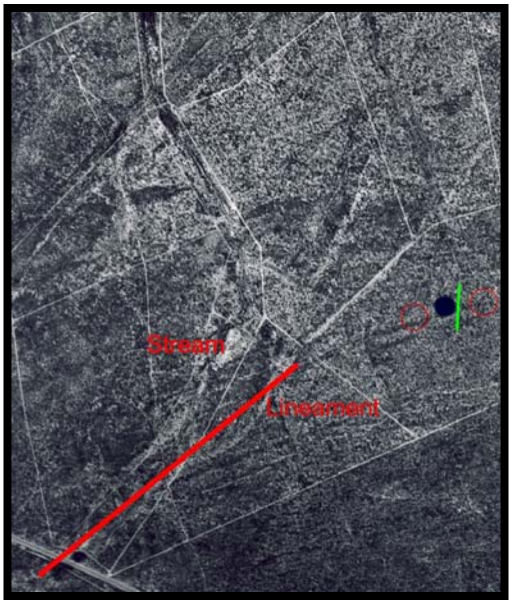
Depth of Water Strike (m)	58	58	46	46	52	52	37	37
Static Water Level (m)	46	46	38	38	40	40	24	24
Average Aquifer Yield (l/h)	360	360	360	360	360	360	360	360
Average Borehole Depth (m)	75	75	75	75	95	95	95	95
Average Depth of Water Strike (m)	25	25	25	25	20	20	20	20
Average Static Water Level (m)	15	15	15	15	10	10	10	10
Land Type Series	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Ah89b Hutton	Fc620a Glenrosa, Mispah	Fc620a Glenrosa, Mispah	Ae285b Hutton	Ae285b Hutton
Profile No	P8474	P8474	P8474	P8474	P10126	P10126	P10125	P10125
Depth Sampled	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	350 – 1200 mm	100 – 560 mm	100 – 560 mm	200 – 1050 mm	200 – 1050 mm
Gravel %	0.0	0.0	0.0	0.0	1.6	1.6	2.2	2.2
Sand %	33.5	33.5	33.5	33.5	57.3	57.3	73.0	73.0
Silt %	44.1	44.1	44.1	44.1	17.7	17.7	7.6	7.6
Clay %	22.4	22.4	22.4	22.4	23.4	23.4	17.2	17.2
pH (H_2O)	7.26	7.26	7.26	7.26	8.16	8.16	6.99	6.99
P (mg/kg)	2.80	2.80	2.80	2.80	2.90	2.90	1.70	1.70

Ca (mg/kg)	487	487	487	487	677	677	54	54
Mg (mg/kg)	2	2	2	2	20	20	9	9
K (mg/kg)	39	39	39	39	20	20	16	16
Na (mg/kg)	83	83	83	83	3	3	1	1
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	18.29	18.29	18.29	18.29	51.72	51.72	70.65	70.65
Zn (mg/kg)	1.03	1.03	1.03	1.03	0.21	0.21	0.12	0.12
Resistance (Ohm)	26	26	26	26	1400	1400	3000	3000
C%	0.32	0.32	0.32	0.32	2.26	2.26	0.40	0.40
CEC ($cmol_c$/kg)	19.44	19.44	19.44	19.44	19.78	19.78	4.09	4.09
Veld Type	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	15 Mopani Veld	14/18 Arid Sweet Bushveld/Mixed Bushveld	14/18 Arid Sweet Bushveld/Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2/D3	D2/D3	D2/D3	D2/D3

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Vegter (2001b). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Messina (2002). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (2003). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

1. Beck 568MS

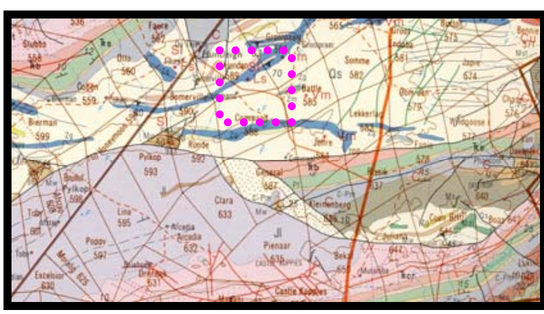

Grasplaas
Blaauwkop
Bloukop
Barend
Rampulana
515
Qs
Zm
Emery
522
Van Heerden
Mentz
516
519
Maseri
Pan
Smuts
569
Beck 568
Scott
567
Burton
570
Fa646f
Ah89b

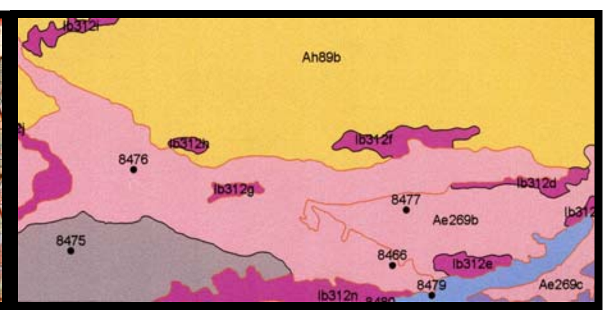


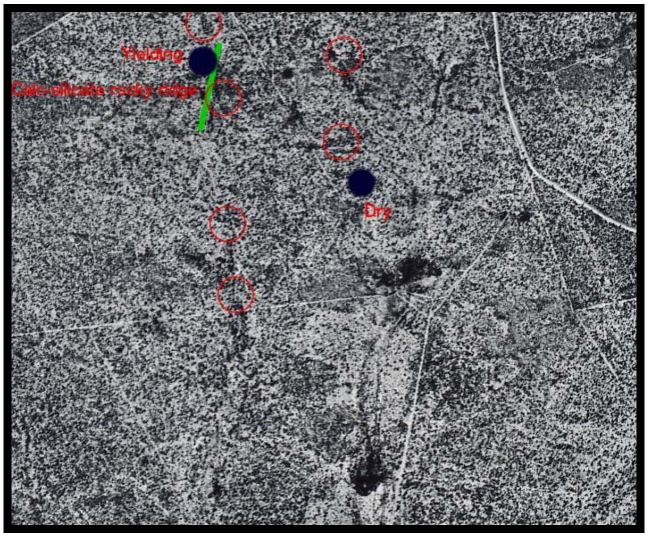
Abbreviation	Geology
Zg	Marble, calc-silicate rocks
Zm	Leucocratic quartzo-feldspathic gneiss
Qs	Sandy soil
	Diabase dyke
Abbreviation	**Soil series**
Ah89b	Hutton
Fa646f	Glenrosa

Figure A1.1. The geology (top left), land type (top right) and aerial photograph (bottom) of Beck 568MS. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The positions of the stream and the lineament, as seen on the geological map, are indicated. The red circles indicate minor lineaments (east-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

2. Command 588MS





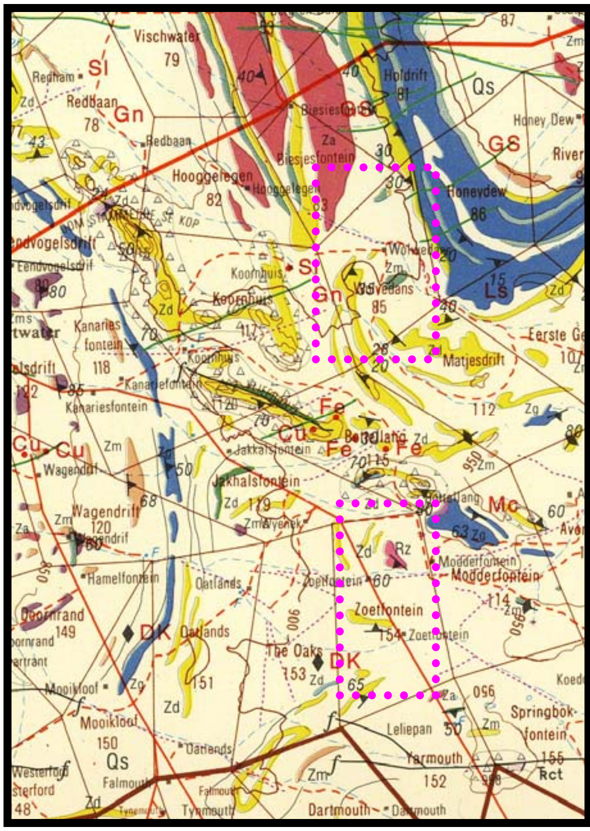


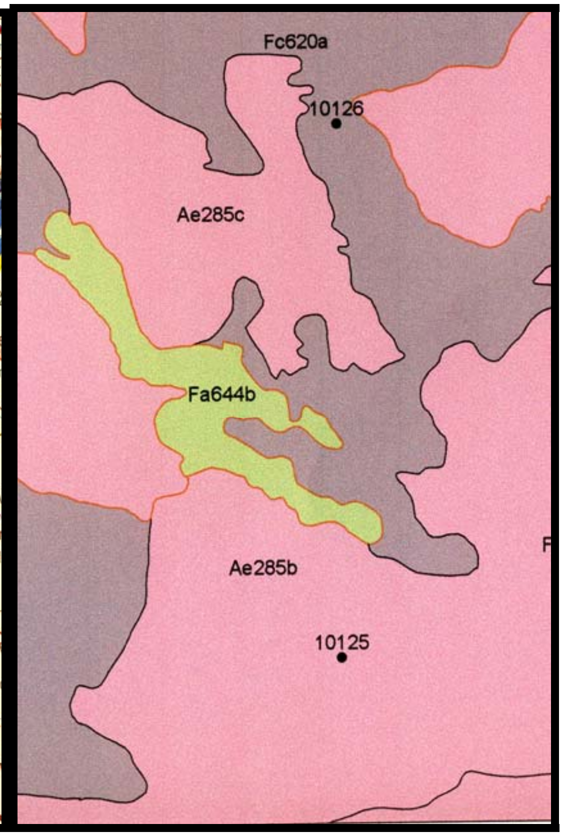
Abbreviation	Geology
Zg	Marble, calc-silicate rocks
Qs	Sandy soil
Abbreviation	**Soil series**
Ae269b	Hutton
Ah89b	Hutton
Ib312d-h	Rock

Figure A1.2. The geology (top left), land type (top right) and aerial photograph (bottom) of Command 588MS. The blue circles denote the positions of the boreholes (dry and yielding) and the green line the direction of the magnetic profile. The position of the calc-silicate rocky ridge is indicated. The red circles indicate minor lineaments (mainly north-west strike). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The farm Command is situated between the railway line and main road to Messina, from the Soutpansberg. It is southeast of the station Huntleigh.

3. Wolvedans 68MR





Abbreviation	Geology
Zd	Metaquartzite, minor magnetite quartzite and massive magnetite
Zg	Marble, calc-silicate rocks
Zm	Mafic granulite
Rz	Leucocratic quartzo-feldspathic gneiss
	Diabase dyke
Qs	Sandy soil
Abbreviation	**Soil series**
Ae285b,c	Hutton
Fa644b	Mispah, Glenrosa
Fc620a	Glenrosa, Mispah

Figure A1.3. The geology (top left), land type (top right) and aerial photograph (bottom) of Wolvedans 68MR. The blue circle denotes the position of the borehole, the yellow line the direction of the electromagnetic profile and the orange line indicates the layout of the Schlumberger sounding. The red circles indicate minor lineaments (east-west strike).

Note: The area covered by the aerial photograph is indicated by the upper purple shape in the geological map.

Wolwedans is about 20 km to the northeast of Swartwater.

4. Zoetfontein 154MR

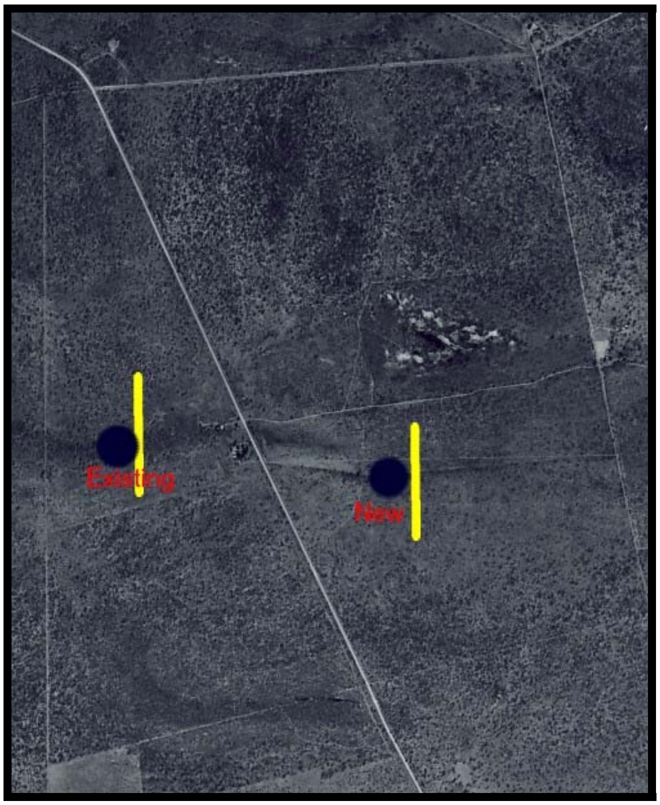


Figure A1.4. The geology (top left, Figure A1.3), land type (top right, Figure A1.3) and aerial photograph (bottom) of Zoetfontein 154MR. The blue circles denote the position of the boreholes (existing and new) and the yellow lines the direction of the electromagnetic profiles. The area covered by the aerial photograph is indicated by the lower purple shape in the geological map.

Zoetfontein is neighbouring the De Beers "The Oaks" diamond mine, approximately 20 km east of Swartwater.

A1.2 VAALIUM EONOTHEM: ROOIBERG-WARMBATHS AREA: QUARTZITE OF THE LEEUWPOORT FORMATION AND DOLOMITE OF THE MALMANI SUBGROUP

The occurrence of quartzite and dolomite in the Rooiberg-Warmbaths area is confined to small areas as the majority of the region is underlain by igneous rocks. The case studies presented are valuable as geobotanic indicators in this terrain were identified, see Table A1.5(a&b).

A1.2.1 CASE STUDY AREA

The Pretoria Group is predominantly part of the Vaalium Eonothem and outcrops are widely dispersed in the old Transvaal. Leeuwpoort Formation quartzite and shale outcrop in the Rooiberg area, with predominant faulting (north-eastern strike) and intrusive diabase dykes in a northwestern strike. Two case studies represent this geologic setting. A small band of dolomite (Malmani Subgroup) occurs in a graben between the Droogekloof and Boschpoort faults, northwest of Warmbaths. The farm Droogekloof 471KR is situated in this graben.

A1.2.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.4. The area is characterised by hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occuring mostly as heavy thunderstorms. The veld types that occur (see also Table A1.5a) are Sourish Mixed Bushveld in the lower regions and Sour Bushveld in the ridges and elevated areas (Acocks, 1988). Game farming and extensive stock farming is most commonly practiced in the presented case study areas. Irrigation practices occur in areas of high groundwater availability (more than 36 000 ℓ/h). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome:

- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea afri*cana (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.4. Climatic Data of the Rooiberg-Warmbaths Areas (Bonsma, 1976, Schulze, 1997 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18-20
Mean Minimum Temperature (°C) in July	2-4
Mean Maximum Temperature (°C) in January	27.5-30.0
Average Yearly Rainfall (mm)	500-800
Elevation (m)	800-1600
Evaporation (mm/year)	2000-2250
Frost area?	Almost none

A1.2.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Transvaal craton was stabilised 2 500 My ago, but during the Proterozoic portions of the crust became less stable resulting in subsidence and the formation of partly overlapping basins. These were developed along deep fractures, which have been repeatedly reactivated and along which lavas extruded until early Waterberg times (Mogolian eonothem) (Schutte, 1974). Deformation increased in intensity in the Rooiberg area immediately prior to or during emplacement of the Bushveld Complex granite. A north-eastern trend was superimposed, as illustrated by the Rooiberg syncline. Finally, thrustfaults developed on the limbs of the major synclines and were subsequently mineralised (Schutte, 1974).

Quartzite and shale of the Leeuwpoort Formation underlie the Rooiberg area. Rhyolite belonging to the Rooiberg Group occurs in the north of the old mining village of Rooiberg. Faulting (north-eastern strike) and diabase intrusions (northwestern strike) occur frequently in the area east of Rooiberg. The Leeuwpoort Formation is surrounded by igneous rocks, i.e. granite, granophyre and rhyolite. In the Warmbaths-Droogekloof area, a small linear dolomite outcrop of the Malmani Subgroup can be seen. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times (Mogolian eonothem) transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. The Droogekloof overthrust developed along the Zwartkloof anticline (Walraven, 1978).

Aquifers associated with the mentioned granite are:

- Basins in the granite caused by deep weathering.
- Weathered fractured zones associated with faults, dykes, shear zones or changes in lithology.
- Weathered contact zones along intrusive dykes.

Groundwater levels vary between 5 m and 30 m depending on topography and recharge.

Quartzite, dolomite and rhyolite in the area can be generalised in terms of aquifer conditions for these kinds of rock types. Dolomite aquifers consist of karst (sub-surface cavities and other solution features). Quartzite aquifers tend to be weathered contact zones with intrusive rocks and joints (Hattingh, 1996 & Meulenbeld, 1998). Rhyolite aquifers can be associated with the granite aquifers, mentioned above. Meulenbeld (1998) indicated that granite aquifers tend to yield more quantities of groundwater than rhyolite aquifers. Rhyolite, as a fine grained acid igneous rock, erodes with more difficulty than granite (medium to coarse-grained acid igneous rock). Rhyolite constitutes often hills and mountains, where granite occurs in plains.

According to the Polokwane (2003) hydrogeological map, the Leeuwpoort Formation quartzite can be classified as a meta-arenaceous fractured aquifer with a possible yield of 1800-7200 ℓ/h. The dolomite encountered in the Droogekloof graben can be grouped as a karst aquifer with a possible yield of 1800-7200 ℓ/h. However, acid igneous rocks in the area (rhyolite and granite) constitute an intergranular-fractured aquifer with a possible yield of 360-1800 ℓ/h. Detailed geohydrological information on the study area is lacking in literature. Bonsma (1976) tabled depth to the water table in this area.

A1.2.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Although no detailed geophysical studies in the area of concern are published, geophysical studies conducted on the same rock formations elsewhere can be used for reference and background information. Parts of the study area that is underlain by the Lebowa Granite Suite of the Bushveld Igneous Complex, can be referenced to the geophysical-geohydrological work of Meulenbeld (1998) & Botha *et al*. (2001).

Geophysical methods utilised depend on the expected properties of the aquifer. The presence of weathered and intrusive structures in the igneous rocks makes the utilisation of various geophysical methods preferable, like Schlumberger soundings, electromagnetic and magnetic profiles. Information on geobotany related to aquifers in the area is unknown.

A1.2.5 SOIL SAMPLING AND RESULTS PRESENTATION

Three farms were visited and the results and information gathered is outlined in Tables A1.5 (a&b). Where possible, two soil samples were taken at the indicated drilling spot and geobotanical indicator at depths of 0.5 m and 1.2 m. Another two soil samples were taken about 25 m away from the observed geological anomaly as indicated on the geophysical traverse. If no sample could be obtained at a depth of 1.2 m, due to the presence of unweathered rock or other obstructions, then another sample was taken in another spot at a depth of 0.5 m. The previous chapter deals with the taking of the samples, basically at the borehole or indicated drilling spot and the other one away from it. It was ensured that soil sampling at the borehole was done as close as possible to any observed geobotanical indicators.

Table A1.5a. Vaalium Eonothem: Rooiberg-Warmbaths Area: along intrusive contact.

Parameter	Blokdrift 512KQ		Droogekloof 471KR		Vaalfontein 491KQ	
Geological Formation	Diabase/fault structure in quartzite (Leeuwpoort Formation)	Diabase/fault structure in quartzite (Leeuwpoort Formation)	Diabase and cavities in dolomite (Malmani Subgroup)	Diabase and cavities in dolomite (Malmani Subgroup)	Diabase in quartzite (Leeuwpoort Formation)	Diabase in quartzite (Leeuwpoort Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	24º45.243' 27º45.362'	24º45.408' 27º45.604'	24º42.039' 27º33.481'	24º42.039' 27º33.481'	24º51.354' 28º07.736'	24º51.354' 28º07.736'
Soil colour	Very dark red	Strong brown	Brownish black	Dusky brown	Dusky red	Moderate reddish brown
Soil texture description	Silt	Silty clay	Sandy loam	Gravel and sand	Clayey silt	Clayey silt
pH	4.50	4.86	7.60	7.34	4.70	4.96
P (mg/kg)	9.66	7.39	2.10	2.05	21.83	15.47
Ca (mg/kg)	138	250	683	2891	115	158
Mg (mg/kg)	49	112	299	294	54	112
K (mg/kg)	41	71	159	153	23	18
Na (mg/kg)	5	61	34	15	7	19
Fe (mg/kg)	57.11	26.97	213.32	86.24	24.37	44.40
Mn (mg/kg)	17.79	172.99	1318.28	484.39	16.52	118.58
Zn (mg/kg)	0.39	0.27	0.38	0.45	0.55	0.10
Al ($cmol_c$/kg)	2.156	0.974	0.000	0.000	0.999	0.647

Resistance (Ohm)	3400	2400	4800	2000	4400	4200
C%	3.37	0.24	0.71	0.58	0.37	0.35
Total N%	0.252	0.023	0.065	0.057	0.062	0.032
S (mg/kg)	166.44	56.99	22.09	32.76	32.47	34.76
CEC ($cmol_c$/kg)	9.993	7.023	9.205	10.500	2.842	4.126
Distinct Tree Species	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense	1. Zanthoxylum capense	4. Rhus lancea 5. Acacia karroo	1. Rhus lancea 2. Acacia karroo
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	5	5	13 - 50	13 - 50
Average depth of weathering (m)	1.8	1.8	2.3	2.3	2.1	2.1
Geomorphology	Plain	Plain	Mountain slope	Mountain slope	Mountain slope with periodic stream	Mountain slope with periodic stream
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	River bed to the west (~100m)	River bed to the west (~100m)
Aquifer Yield (l/h)	60 000	60 000	100 000	100 000	1 500	1 500
Borehole Depth (m)	75	75	60	60	85	85
Depth of Water Strike (m)	70	70	50	50	45	45

Static Water Level (m)	12	12	9	9	14	14
Average Aquifer Yield (l/h)	1 900	1 900	1 400	1 400	1 900	1 900
Average Borehole Depth (m)	60	60	75	75	60	60
Average Depth of Water Strike (m)	30	30	38	38	30	30
Average Static Water Level (m)	27	27	27	27	27	27
Land Type Series	Fa4k Clovelly	Fa4k Clovelly	Ah76a Hutton	Ah76a Hutton	Bc41a Hutton	Bc41a Hutton
Profile No	P755	P755	P1377	P1377	P1405	P1405
Depth Sampled	100 – 520 mm	100 – 520 mm	280 – 1200 mm	280 – 1200 mm	200 – 1200 mm	200 – 1200 mm
Gravel %	3	3	1	1	0	0
Sand %	87	87	68	68	84	84
Silt %	4	4	12	12	3	3
Clay %	6	6	19	19	13	13
pH (H_2O)	6.0	6.0	6.4	6.4	5.2	5.2
P (mg/kg)	1.3	1.3	0.9	0.9	3.4	3.4
Ca (mg/kg)	160	160	300	300	141	141
Mg (mg/kg)	84	84	144	144	60	60
K (mg/kg)	156	156	41	41	154	154
Na (mg/kg)	23	23	11	11	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	15.4	15.4	1473.5	1473.5	36.7	36.7
Zn (mg/kg)	0.35	0.35	0.11	0.11	0.17	0.17

Resistance (Ohm)	4300	4300	2900	2900	2100	2100
C%	0.4	0.4	0.2	0.2	0.1	0.1
CEC ($cmol_c$/kg)	30	30	35	35	2.9	2.9
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeo-logical Unit	D3	D3	C3	C3	D2/D3	D2/D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average static level depth was obtained from Bonsma (1976). The average aquifer yield, average borehole depth and average water strike level were obtained from Hattingh (1996). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.5b. Vaalium Eonothem: Rooiberg-Warmbaths Area: no intrusive contact.

	Blokdrift 512KQ		Droogekloof 471KR		Vaalfontein 491KQ	
Geological Formation	Quartzite & shale (Leeuwpoort Formation) and Rhyolite (Rooiberg Group)	Quartzite & shale (Leeuwpoort Formation) and Rhyolite (Rooiberg Group)	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup)	Quartzite & shale (Leeuwpoort Formation)	Quartzite & shale (Leeuwpoort Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	 24º45.243' 27º45.362'	 24º45.408' 27º45.604'	 24º42.039' 27º33.481'	 24º42.039' 27º33.481'	 24º51.354' 28º07.736'	 24º51.354' 28º07.736'
Soil colour	Grayish red	Light brown	Brownish black	Brownish black	Moderate brown	Moderate brown
Soil texture description	Sand	Sand	Sandy loam	Sandy loam	Sand	Sand
pH	4.74	4.96	6.52	6.53	5.53	5.53
P (mg/kg)	14.53	10.97	2.64	1.54	4.45	3.92
Ca (mg/kg)	112	100	886	838	198	115
Mg (mg/kg)	36	37	363	338	80	58
K (mg/kg)	34	49	206	186	28	16
Na (mg/kg)	1	5	17	12	46	22
Fe (mg/kg)	45.42	44.24	181.98	180.50	23.78	16.77
Mn (mg/kg)	29.65	27.65	1395.76	1402.09	115.51	64.57
Zn (mg/kg)	0.50	0.59	0.43	0.46	0.52	0.82
Al ($cmol_c$/kg)	1.202	0.912	0.000	0.000	0.083	0.142

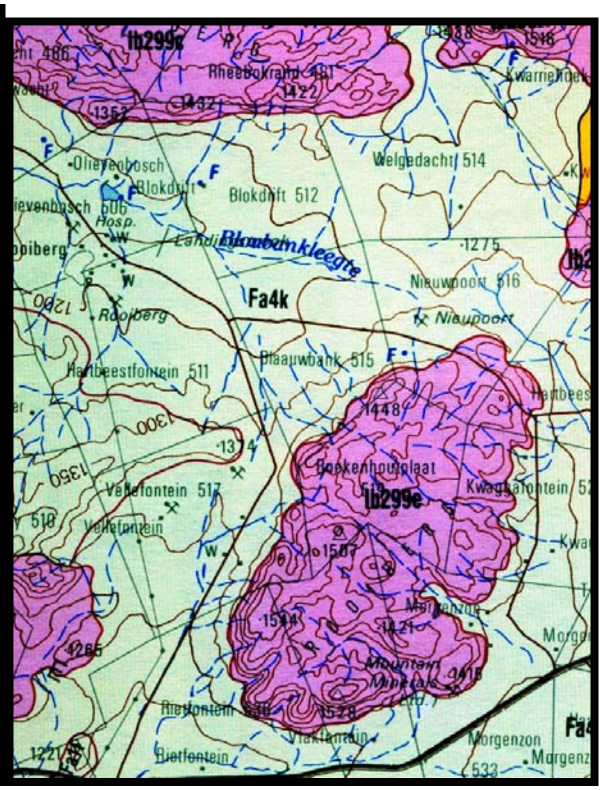
Resistance (Ohm)	4600	5600	4200	4200	20000	24000
C%	1.69	0.46	0.16	0.39	0.10	0.12
Total N%	0.106	0.028	0.034	0.048	0.010	0.014
S (mg/kg)	29.19	37.89	21.97	21.06	27.26	23.98
CEC ($cmol_c$/kg)	3.933	5.341	9.894	10.716	3.824	5.207
Distinct Tree Species	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense 2. Ficus sur 3. Acacia karroo	1. Zanthoxylum capense	1. Zanthoxylum capense	1. Rhus lancea 2. Acacia karroo	1. Rhus lancea 2. Acacia karroo
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	5	5	13 - 50	13 - 50
Average depth of weathering (m)	1.8	1.8	2.3	2.3	2.1	2.1
Geomorphology	Plain	Plain	Mountain slope	Mountain slope	Mountain slope with periodic stream	Mountain slope with periodic stream
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	River bed to the west (~100m)	River bed to the west (~100m)
Aquifer Yield (l/h)	60 000	60 000	100 000	100 000	1 500	1 500
Borehole Depth (m)	75	75	60	60	85	85

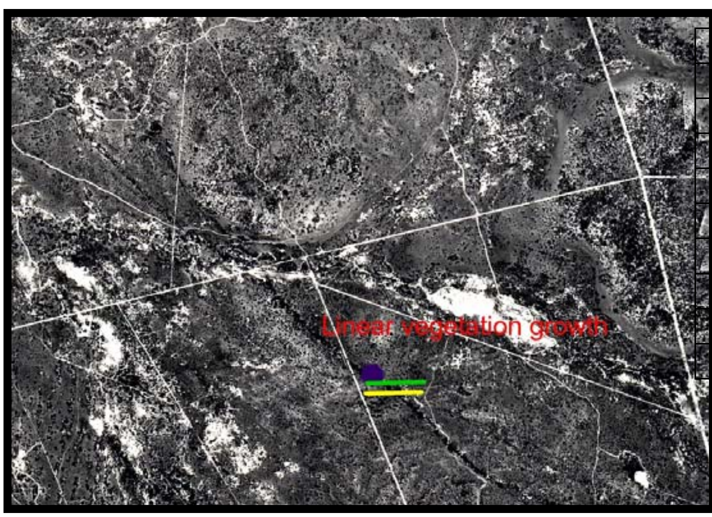
Depth of Water Strike (m)	70	70	50	50	45	45
Static Water Level (m)	12	12	9	9	14	14
Average Aquifer Yield (l/h)	1 900	1 900	1 400	1 400	1 900	1 900
Average Borehole Depth (m)	60	60	75	75	60	60
Average Depth of Water Strike (m)	30	30	38	38	30	30
Average Static Water Level (m)	27	27	27	27	27	27
Land Type Series	Fa4k Clovelly	Fa4k Clovelly	Ah76a Hutton	Ah76a Hutton	Bc41a Hutton	Bc41a Hutton
Profile No	P755	P755	P1377	P1377	P1405	P1405
Depth Sampled	100 – 520 mm	100 – 520 mm	280 – 1200 mm	280 – 1200 mm	200 – 1200 mm	200 – 1200 mm
Gravel %	3	3	1	1	0	0
Sand %	87	87	68	68	84	84
Silt %	4	4	12	12	3	3
Clay %	6	6	19	19	13	13
pH (H_2O)	6.0	6.0	6.4	6.4	5.2	5.2
P (mg/kg)	1.3	1.3	0.9	0.9	3.4	3.4
Ca (mg/kg)	160	160	300	300	141	141
Mg (mg/kg)	84	84	144	144	60	60
K (mg/kg)	156	156	41	41	154	154

Na (mg/kg)	23	23	11	11	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	15.4	15.4	1473.5	1473.5	36.7	36.7
Zn (mg/kg)	0.35	0.35	0.11	0.11	0.17	0.17
Resistance (Ohm)	4300	4300	2900	2900	2100	2100
C%	0.4	0.4	0.2	0.2	0.1	0.1
CEC ($cmol_c/kg$)	30	30	35	35	2.9	2.9
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D3	D3	C3	C3	D2/D3	D2/D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average static level depth was obtained from Bonsma (1976). The average aquifer yield, average borehole depth and average water strike level were obtained from Hattingh (1996). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

5. Blokdrift 512KQ

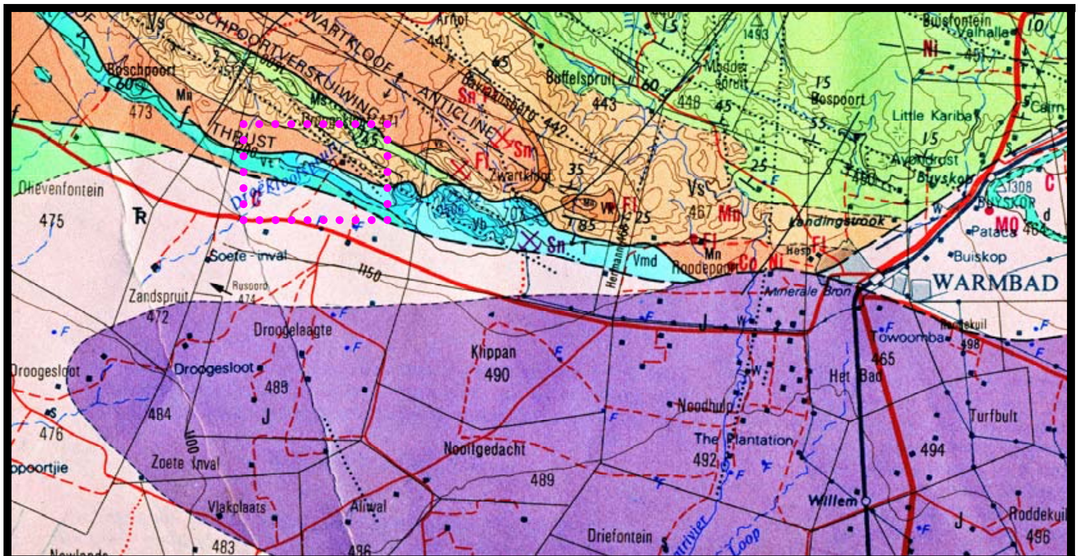


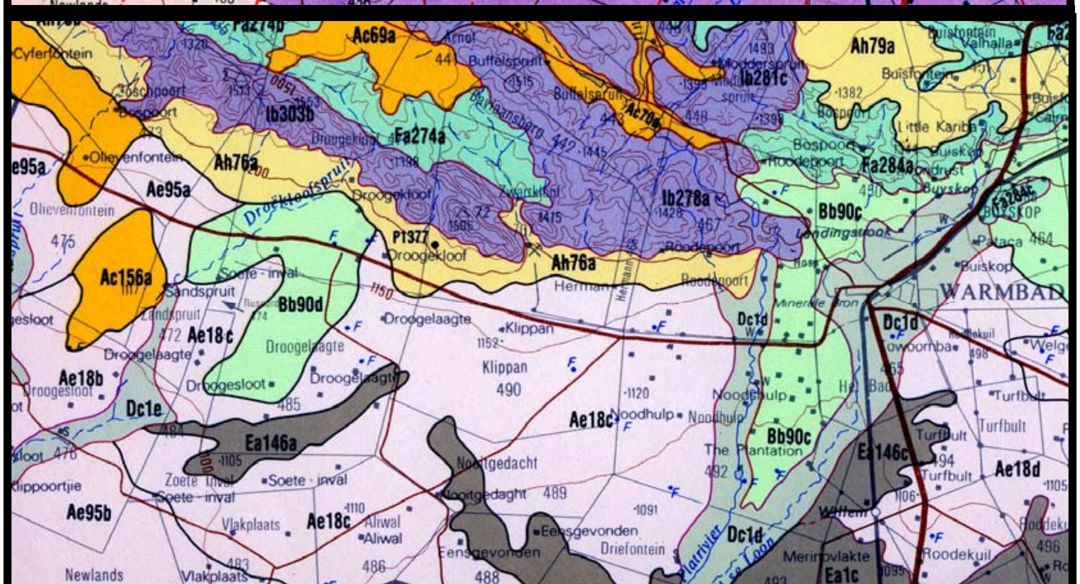


Abbreviation	Geology
T3mQ	Quartzite
T3sL	Andesite
T3sS	Shale
3Lf	Rhyolite
Lf	Rhyolite dyke
di	Diabase
Abbreviation	**Soil series**
Fa4k	Clovelly
Ib299c	Rock

Figure A1.5. The geology (top left), land type (top right) and aerial photograph (bottom) of Blokdrift 512KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

6. Droogekloof 471KR

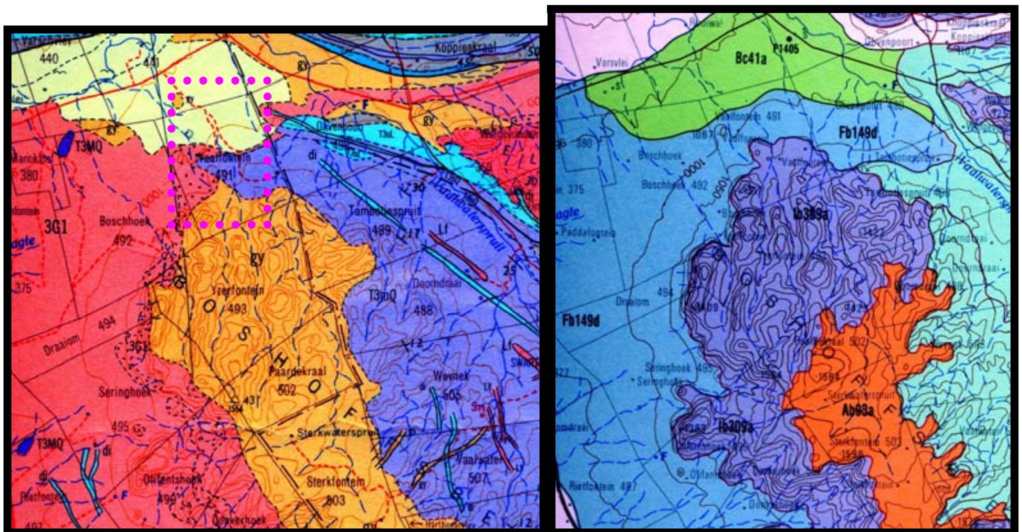


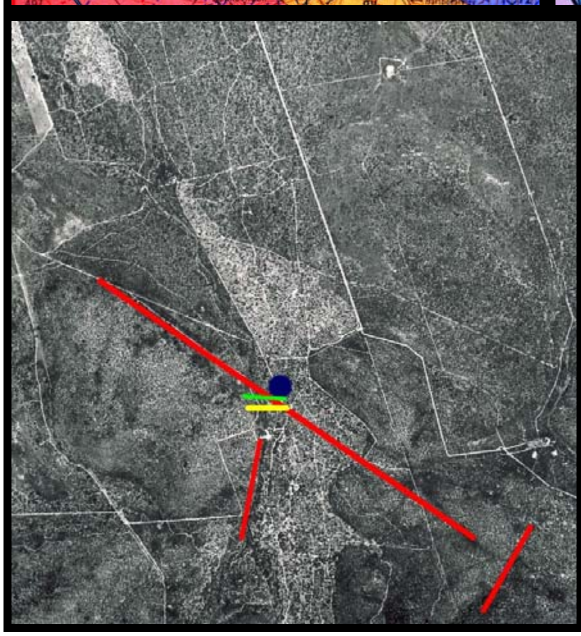


Abbreviation	Geology
Vmd	Dolomite
Vs	Rhyolite
Mn	Granite
TR	Sandstone
Abbreviation	**Soil series**
Ae95a	Hutton
Ah76a	Hutton
Bb90d	Avalon
Ib303b	Rock

Figure A1.6. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circles denote the position of the boreholes (dry and yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction at the dry borehole. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

7. Vaalfontein 491KQ





Abbreviation	**Geology**
T3mQ	Quartzite
gy	Granophyre
3G1	Granite
di	Diabase dyke
Lf	Rhyolite dyke
~~	Alluvium
Abbreviation	**Soil series**
Ab93a	Hutton
Bc41a	Hutton
Fb149d	Mispah, Glenrosa, Glencoe, Clovelly
Ib309a	Rock

Figure A1.7. The geology (top), land type (middle) and aerial photograph (bottom) of Vaalfontein 491KQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic profile direction. The red lines are interpreted lineaments. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

A1.3 VAALIUM EONOTHEM: DOLOMITE OF THE MALMANI SUBGROUP IN THE PRETORIA AREA

A band of dolomite surrounds the Pretoria Group sediments on its outer margin. In the Pretoria area, the dolomite is highly regarded for its high groundwater yield capacity. A few case studies are discussed.

A1.3.1 CASE STUDY AREA

Between the archaic granite of Halfway House and the quartzite ridges of Pretoria, a band of dolomite outcrops. This band of dolomite extends south of Pretoria and stretches towards Delmas and Bapsfontein in the southeast. This area is characterised by intensive farming practices that demand large quantities of water. Today, this huge subtraction is responsible for sinkhole forming at Bapsfontein. The dolomite defines plains with a deep soil profile, where chert stands out as hills and ridges, if quite thick, as it more resistant to the elements of weathering and erosion. Some of the dolomite and chert is intersected by intrusions of syenite, carbonatite and diabase. In general these intrusions strike from north and northwest to south and southeast. Two case studies are presented from the Bapsfontein – Kempton Park area.

A1.3.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.6. The area is characterised by cool and wet summers and cold, dry winters. The wet season lasts approximately from October to April with rainfall occuring mostly as heavy thunderstorms. The veld type that occur (see also Table A1.7a) is Bankenveld (Acocks, 1988). Intensive (crop irrigation) and extensive (cattle, maize) agricultural practices occur in this area, depending on the availability of groundwater and dolomite outcrops as the dolomite is surrounded by shale and quartzite of the Pretoria Group with extremely lower aquifer yields. The following tree species are eminent of this veld type (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Due to the winters being severely frosty, high rainfall, altitude and regular burning of the grassland, the veld is particularly sour with acid soils and is not hosting a wide variety of trees or shrubs. The Bankenveld represents the grassland biome in this region.

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.6. Climatic Data of the Bapsfontein Area (Schulze, 1997 & Johannesburg, 1999).

	Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1500-1700
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.3.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Chuniespoort Group and Malmani Subgroup south and southwest of Pretoria are composed of dolomite with interbedded quartzite and chert. Manganese oxides occur in small deposits in the Malmani Subgroup (Walraven, 1978b). Overburden of soil and shale belonging to the Dwyka Formation of the Karoo Supergroup occurs frequently in the study area and are a concern during geophysical groundwater exploration as depressions are often filled up with these and yield lower resistivities with depth, although it only represents clay and no aquifer or water filled cavity. Some dykes cross the dolomite and as for the study area these dykes consist of diabase. On the one Elandsfontein 412JR case study, quartzite of the Boshoek Formation is present and forms small ridges and scattered quartzite pebbles can be found on the lands.

Furthermore, a lineament, most probably diabase, stretches from north to south on this farm. Along this lineament is a perennial spring situated with an estimated yield of 10 800 ℓ/h. This water is gathered in a dam and utilised for irrigation purposes.

In this environment, the dolomite aquifer is classified as karst with a possible yield above 18 000 ℓ/h (Johannesburg, 1999). Aquifer targets are solution cavities (gravimetric and direct current sounding methods) and contact zones with diabase (magnetic and electromagnetic methods).

A1.3.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Most geophysical studies relating to dolomite is on the topic of sinkhole definition by means of the gravimetric method. This method is highly specialised and too expensive to use in the field for ordinary groundwater exploration methods. Therefore, it is easy to obtain geophysical reports dealing with dolomitic sinkholes and gravimetric results. Information on geophysical groundwater exploration by means of magnetic, electric and electromagnetic methods is less abundant and difficult to obtain, as these are mostly confident consultants reports. The exploration target is intrusive bodies within the dolomite or possible sinkholes.

Groundwater levels vary around 12-20 m and the level where groundwater can be struck is about around 21-34 m according to Frommurze (1937), but it was found that currently this level increased to around 40-50 m, most probably to over utilising of this pristine resource.

Diabase intrusions can be localised with the magnetic method. If the electromagnetic method is incorporated, then one is able to distinguish between different rock types on ground of their electrical conductivity. Basins of weathering along intrusions can also with ease be established. Electrical sounding's purpose is to determine resistivity changes with depth and to locate possible aquifers or weathering basins. The local hydrocensus will indicate depths of weathering, or alterations in resistivity, co-incite with the required depth to strike groundwater as indicated in Table A1.7. The occurrence of sinkholes in the area will also indicate the likelihood of the existence of other cavities that can act as aquifers.

Geobotanic indicators are not known relating to dolomite (Scott & Le Maitre, 1998) and are even worse to study on the Highveld due to the localised and rare occurrence of shrubs and trees. However, this study identified some and as a fact are not so rare where intrusions occur in the dolomite or zones of deeper weathering in the dolomite that are often covered with white stinkwood (*Celtis africana*) trees.

A1.3.5 SOIL SAMPLING AND RESULTS PRESENTATION

The same soil sampling procedure was followed as in the previous cases. Take two samples at the geobotanic/borehole site at depths of respectively 0.5 m and 1.2 m and another one some distance removed from this spot where there are neither obvious signs of conspicuous vegetation growth nor any anomalous signatures on the geophysical data. The same sampling depths applies here, see Tables A1.7a&b. Two farms were studied in close vicinity of each other. The farm Elandsfontein 412JR is situated on the road between Bapsfontein and Kempton Park, a well known dolomite and sinkhole area with numerous agricultural irrigation installations.

Table A1.7a. Vaalium Eonothem: Dolomite in the Pretoria Area: along intrusive contact.

Parameter	Elandsfontein 412JR (1)		Elandsfontein 412JR (2)	
Geological Formation	Small diabase intrusion in dolomite/cavity	Small diabase intrusion in dolomite/cavity	Diabase intrusion in dolomite	Diabase intrusion in dolomite
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º59.317’ 28º22.433’	25º59.317’ 28º22.433’	26º00.815’ 28º20.151’	26º00.815’ 28º20.151’
Soil colour	Brownish black	Brownish black	Moderate brown	Moderate brown
Soil texture description	Sandy loam	Sandy loam	Clayey silt	Clay
pH	6.73	6.53	5.54	5.16
P (mg/kg)	1.23	1.07	3.40	2.99
Ca (mg/kg)	1859	861	323	221
Mg (mg/kg)	252	329	397	496
K (mg/kg)	210	211	56	49
Na (mg/kg)	40	9	25	34
Fe (mg/kg)	136.10	188.80	59.30	183.14
Mn (mg/kg)	893.72	1381.32	434.00	1035.38
Zn (mg/kg)	0.24	0.50	0.88	2.77
Al ($cmol_c$/kg)	0	0	0.519	0.589
Resistance (Ohm)	2400	3600	4800	5200
C%	0.79	0.34	0.37	0.81
Total N%	0.071	0.046	0.060	0.035
S (mg/kg)	37.17	12.46	88.25	10.84

CEC ($cmol_c/kg$)	8.470	13.774	10.926	14.658
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	6 - 50	6 - 50
Average depth of weathering (m)	3.1	3.1	3.1	3.1
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	To the north a spring (800m)	To the north a spring (800m)
Aquifer Yield (l/h)	22 000	22 000	45 000	45 000
Borehole Depth (m)	50	50	65	65
Depth of Water Strike (m)	46	46	43	43
Static Water Level (m)	17	17	15	15
Average Aquifer Yield (l/h)	25 000	25 000	25 000	25 000
Average Borehole Depth (m)	60	60	60	60
Average Depth of Water Strike (m)	44	44	44	44
Average Static Water Level (m)	19	19	19	19

Land Type Series	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton
Profile No	P55	P55	P55	P55
Depth Sampled	830-1200mm	830-1200mm	830-1200mm	830-1200mm
Gravel %	2	2	2	2
Sand %	66	66	66	66
Silt %	8	8	8	8
Clay %	24	24	24	24
pH	5.6	5.6	5.6	5.6
P (mg/kg)	2.0	2.0	2.0	2.0
Ca (mg/kg)	92	92	92	92
Mg (mg/kg)	44	44	44	44
K (mg/kg)	414	414	414	414
Na (mg/kg)	229	229	229	229
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	2.8	2.8	2.8	2.8
Zn (mg/kg)	0.46	0.46	0.46	0.46
Resistance (Ohm)	7000	7000	7000	7000
C%	0.4	0.4	0.4	0.4
CEC ($cmol_c$/kg)	4.0	4.0	4.0	4.0
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	C5	C5	C5	C5

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and a local hydrocensus. It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.7b. Vaalium Eonothem: Dolomite in the Pretoria Area: no intrusive contact.

	Elandsfontein 412JR (1)		Elandsfontein 412JR (2)	
Geological Formation	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup)	Dolomite (Malmani Subgroup), quartzite (Boshoek Formation) and Karoo overburden	Dolomite (Malmani Subgroup), quartzite (Boshoek Formation) and Karoo overburden
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º59.317' 28º22.433'	25º59.317' 28º22.433'	26º00.815' 28º20.151'	26º00.815' 28º20.151'
Soil colour	Moderate brown	Pale reddish brown	Brownish grey	Greyish brown
Soil texture description	Sandy gravel	Sandy loam & gravel	Clay	Silty clay
pH	6.52	6.50	6.44	6.04
P (mg/kg)	2.77	1.02	2.23	1.90
Ca (mg/kg)	877	564	372	243
Mg (mg/kg)	365	416	285	193
K (mg/kg)	178	146	92	126

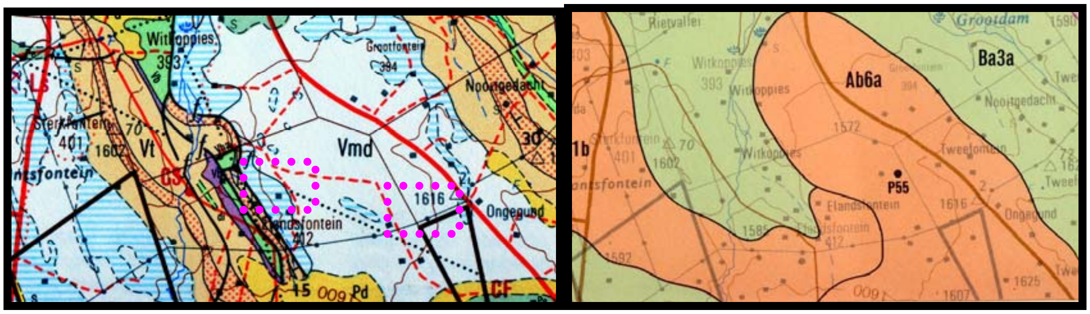
Na (mg/kg)	33	8	12	138
Fe (mg/kg)	191.77	226.96	175.95	340.05
Mn (mg/kg)	1426.25	1356.11	1203.42	1615.81
Zn (mg/kg)	0.64	1.95	0.23	0.56
Al ($cmol_c$/kg)	0	0	0	0
Resistance (Ohm)	3800	5200	2600	1600
C%	0.19	0.24	0.06	0.95
Total N%	0.037	0.033	0.117	0.022
S (mg/kg)	21.13	20.97	134.38	90.05
CEC ($cmol_c$/kg)	12.958	11.464	4.588	4.497
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana	1. Acacia karroo 2. Euclea crispa 3. Rhus lancea 4. Celtis africana
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	6 - 50	6 - 50
Average depth of weathering (m)	3.1	3.1	3.1	3.1
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	To the north a spring (800m)	To the north a spring (800m)
Aquifer Yield (l/h)	22 000	22 000	45 000	45 000
Borehole Depth (m)	50	50	65	65
Depth of Water Strike (m)	46	46	43	43
Static Water Level (m)	17	17	15	15

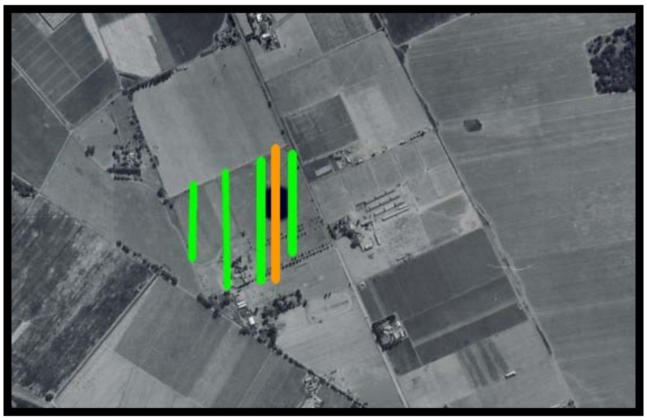
Average Aquifer Yield (l/h)	25 000	25 000	25 000	25 000
Average Borehole Depth (m)	60	60	60	60
Average Depth of Water Strike (m)	44	44	44	44
Average Static Water Level (m)	19	19	19	19
Land Type Series	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton	Ab6a Hutton
Profile No	P55	P55	P55	P55
Depth Sampled	830-1200mm	830-1200mm	830-1200mm	830-1200mm
Gravel %	2	2	2	2
Sand %	66	66	66	66
Silt %	8	8	8	8
Clay %	24	24	24	24
pH	5.6	5.6	5.6	5.6
P (mg/kg)	2.0	2.0	2.0	2.0
Ca (mg/kg)	92	92	92	92
Mg (mg/kg)	44	44	44	44
K (mg/kg)	414	414	414	414
Na (mg/kg)	229	229	229	229
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	2.8	2.8	2.8	2.8
Zn (mg/kg)	0.46	0.46	0.46	0.46
Resistance (Ohm)	7000	7000	7000	7000
C%	0.4	0.4	0.4	0.4
CEC ($cmol_c$/kg)	4.0	4.0	4.0	4.0

Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	C5	C5	C5	C5

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and a local hydrocensus. It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

8. Elandsfontein 412JR (1)





Abbreviation	Geology
Vmd	Dolomite, chert
Vt	Shale, quartzite
Vb	Quartzite
Vha	Andesite
di	Diabase
Pd	Tillite, shale
_______ƒ	Fault
Abbreviation	**Soil series**
Ab6a	Hutton
Ba3a	Hutton

Figure A1.8. The geology (top left), land type (top right) and aerial photograph (bottom) of Elandsfontein 412JR (1). The blue circle denotes the position of the borehole, the green lines the direction of the magnetic profiles in order to obtain the contour map and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the right purple shape in the geological map.

The first case study on the farm Elandsfontein 412JR is about 7 km to the west of Bapsfontein, between Pretoria and Delmas.

9. Elandsfontein 412JR (2)

Figure A1.9. The geology and land type can be seen in Figure A1.8. Aerial photograph of Elandsfontein 412JR (2). The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the left purple shape in the geological map.

The second case study on the farm Elandsfontein 412JR is situated about 12 km to the west of the town Bapsfontein.

A1.4 VAALIUM EONOTHEM: ANDESITE AND GABBRO IN THE PRETORIA-BRITS AREA

All the results are presented in Table A1.9 (a&b). The name gabbro will be used in the text as no mineralogical analyses were done on rock samples of the Brits area to distinguish between gabbro and norite. Preference is given to the name gabbro as gabbro is darker in appearance then norite, as observed from the local outcrops.

A1.4.1 CASE STUDY AREA

New residential development east of Pretoria, named Mooikloof Estates, urged the need for groundwater supply to every new household. Each residential development is on 1 ha and establishes the arena for in depth geophysical profiling on these properties with the aid of contouring the data in order to select the best drilling spot. The two smallholdings investigated were both situated on andesite (Hekpoort Formation of the Pretoria Group) and localised tree clusters and stand alone trees occur on these smallholdings prior to the commence of building activities. The terrain is extremely undulating and scattered andesite boulders are common. It is a pity that when a successful borehole is sited, often all the vegetation around it is cleared and diminishes the existence of geobotanical indicators if the site is visited afterwards. The one remaining case study is situated in Brits Industrial Area. The entire area consists of gabbro and norite of the Rustenburg Layered Suite - Bushveld Igneous Complex. The borehole was drilled for groundwater pollution monitoring and selected on the basis of geophysical data and observed geobotanical growth. This terrain is basically plain with some small ridges that may be reminisces of exfoliation weathering.

A1.4.2 CLIMATE AND VELD TYPES

Climatic data is presented in Table A1.8. The Pretoria area is characterised by cool and wet summers and cold, dry winters, but the Brits area experiences hotter, wet summers (and abundant hail) and the winters are mild and dry. The wet season lasts approximately from October to April with rainfall occuring mostly as heavy thunderstorms. The veld type that occurs (see also Table A1.9a) is Bankenveld for Pretoria and Norite Black Turf Thornveld in the Brits area (Acocks, 1988). Intensive (crop irrigation) and extensive (cattle, maize) agricultural practices occur in this area, depending on the availability of groundwater and weathering profiles in the norite, especially close to water courses. The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush)-Grassland biome.
- Norite Black Turf Thornveld: *Acacia karroo* (sweet thorn), *Rhus lancea* (karree), *Ziziphus mucronata* (buffalo-thorn)-Savanna biome.

The andesite on the Bankenveld supports various tree species, normally in tree clusters that are very conspicuous around ridges, valleys and sometimes in the open veld, unless the fact that frost occurs. Normally more frost resistant tree species protect less frost resistant tree species in such a cluster as it serves as a shield. The Brits area is less impacted by frost and hence more abundant vegetation growth occurs on the black turf, although in patches, where more species variation occurs along small ridges (about 500mm in height) that are more probably residues of exfoliation of the gabbro rock.

Geobotanical investigations on the presented case studies will indicate other occurring tree species as well and the marker tree species that can be utilised for groundwater exploration.

Table A1.8. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999).

	Pretoria Area Quantity	**Brits Area Quantity**
Average Yearly Temperature (°C)	14-16	16-18
Mean Minimum Temperature (°C) in July	0-2	2-4
Mean Maximum Temperature (°C) in January	25.0-27.5	27.5-30.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1500-1700	800-1200
Evaporation (mm/year)	2000-2250	2000-2250
Frost area?	150-175 days a year	Almost none

A1.4.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Volcanic rocks (andesite) of the Hekpoort Formation, Pretoria Group, Transvaal Sequence, occur in a east-west band through Pretoria. It stipulates a plain with a red-brown clay soil between the quartzite ridges of the Timeball Formation and Daspoort Formation. The volcanic beds of the Hekpoort Formation do not have any dip. About 10 km north of the Hekpoort Formation gabbro of the Bushveld Igneous Complex (Rustenburg Layered Suite) outcrops in a vast plain, just north of the quartzite mountains of the Magaliesberg Formation (Pretoria Group). The gabbro in the Brits area weatheres to a black turf and small variations in the local topography can be ascribed to exfoliation of weathered gabbro. Exfoliation planes act as aquifers (Hattingh, 1996).

Aquifers associated with andesite and gabbro are classified as intergranular and fractured according to the Johannesburg (1999) hydrogeological map. Yields vary from 360-5400 ℓ/h in the andesite to 1800-7200 ℓ/h obtained from boreholes drilled in gabbro. Water strike is about 31 m in andesite and 20 m in gabbro (Frommurze, 1937).

A1.4.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Published geophysical case studies of the Pretoria-Brits area are scarce. Abundant confidential geophysical reports exist of the area regarding groundwater supply and groundwater pollution studies. A couple a case studies relating to the Pretoria Group and similar lithologies are presented and discussed by Meulenbeld (1998). The nature of the Pretoria Group in this area is that numerous intrusive basic or ultra-basic bodies at various depths often intersect sedimentary rocks. Empirical implication is that groundwater can therefore be intersected at basic any point. However, geophysical siting of these boreholes is extremely important as it improves the yield of such a borehole significantly. Other case studies in the Pretoria Group, Pretoria area, will also illustrate this. The range of metamorphic, volcanic and sedimentary rocks in the Pretoria Group creates a distinctive signature of every rock type regarding conductivity/ resistivity values and eases interpretation of the geophysical data.

Information on geobotany of the Pretoria area is not elsewhere documented. The discussion in Chapter 3 can be incorporated in these case studies.

A1.4.5 SOIL SAMPLING AND RESULTS PRESENTATION

Two 1 ha small holdings in the Mooikloof Estate, east of Pretoria are presented together with a geophysical pollution borehole siting study in the Brits Industrial area. Depth of soil sampling varies between 0.5 m and 1.2 m at the geobotanic indicator and at the same corresponding depth at some distance removed from it. The soil sample results and other useful information is presented in Tables A1.9 (a&b).

Table A1.9a. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: along intrusive/weathering contact.

	Mooikloof Estate (1) Pretoria East		Mooikloof Estate (2) Pretoria East		Brits Industrial Area	
Geological Formation	Andesite (Hekpoort Formation) and fault zone	Andesite (Hekpoort Formation) and fault zone	Fractured andesite (Hekpoort Formation)	Fractured andesite (Hekpoort Formation)	Weathered basins in gabbro (Rustenburg Layered Suite)	Weathered basins in gabbro (Rustenburg Layered Suite)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	25º49.467’ 28º20.283’	25º49.467’ 28º20.283’	25º49.217’ 28º19.701’	25º49.217’ 28º19.701’	25º38.257’ 27º47.433’	25º38.257’ 27º47.433’
Soil colour	Greyish brown	Dusky yellowish brown	Dark reddish brown	Weak red	Brownish black	Black
Soil texture description	Clay	Clay	Sandy loam	Loam	Silty clay	Clay
pH	7.84	7.64	5.54	6.02	7.71	7.89
P (mg/kg)	11.26	6.50	4.62	3.19	22.85	19.46
Ca (mg/kg)	2380	3291	2330	1771	10849	10497
Mg (mg/kg)	698	617	533	460	888	1431
K (mg/kg)	108	132	244	196	540	562
Na (mg/kg)	61	25	19	36	41	37
Fe (mg/kg)	121.25	139.21	102.11	70.55	22.43	14.02
Mn (mg/kg)	289.18	355.16	425.05	372.62	141.98	107.08
Zn (mg/kg)	1.29	0.84	4.37	1.29	8.87	11.68
Al ($cmol_c$/kg)	0.060	0.037	0.00	0.00	0	0
Resistance (Ohm)	1600	1600	580	2200	310	360

C%	1.01	1.02	4.11	2.81	2.03	3.07
Total N%	0.064	0.064	0.275	0.173	0.104	0.151
S (mg/kg)	14.20	14.46	36.25	30.34	34.40	25.63
CEC ($cmol_c$/kg)	17.662	19.816	14.968	15.556	1.00	55.32
Distinct Tree Species	1. Euclea crispa	1. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Ziziphus mucronata 3. Rhus lancea	1. Clerodendrum glabrum 2. Ziziphus mucronata 3. Rhus lancea
Average rooting depth of the indicated species (m)	4	4	4 - 7	4 - 7	4 - 13	4 - 13
Average depth of weathering (m)	0.9	0.9	0.9	0.9	2.3	2.3
Geomorphology	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Plain	Plain
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	No	No	No	No
Aquifer Yield (l/h)	15000	15000	20000	20000	18000	18000
Borehole Depth (m)	60	60	65	65	45	45
Depth of Water Strike (m)	23	23	21	21	17	17

Static Water Level (m)	9	9	7	7	11	11
Average Aquifer Yield (l/h)	6750	6750	6750	6750	7520	7520
Average Borehole Depth (m)	56	56	56	56	44	44
Average Depth of Water Strike (m)	31	31	31	31	20	20
Average Static Water Level (m)	17	17	17	17	12	12
Land Type Series	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ae21 Hutton	Ae21 Hutton
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	13 Norite Black Turfveld	13 Norite Black Turfveld
Hydrogeological Unit	D2	D2	D2	D2	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.9b. Vaalium Eonothem: Andesite and Gabbro in the Pretoria-Brits Areas: absent intrusive/weathering contact.

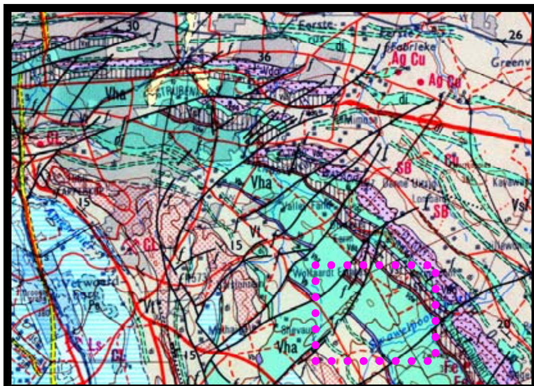
	Mooikloof Estate (1) Pretoria East		Mooikloof Estate (2) Pretoria East		Brits Industrial Area	
Geological Formation	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Andesite (Hekpoort Formation)	Gabbro (Rustenburg Layered Suite)	Gabbro (Rustenburg Layered Suite)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	 25º49.467' 28º20.283'	 25º49.467' 28º20.283'	 25º49.217' 28º19.701'	 25º49.217' 28º19.701'	 25º38.257' 27º47.433'	 25º38.257' 27º47.433'
Soil colour	Greyish brown	Dark reddish brown	Dark reddish brown	Weak red	Dark grey	Dark grey
Soil texture description	Clay	Clay	Sandy loam	Loam	Silty	Silty
pH	7.40	6.91	5.06	5.61	7.79	8.18
P (mg/kg)	15.91	7.19	3.48	3.28	19.43	17.98
Ca (mg/kg)	1696	1551	721	741	10829	7111
Mg (mg/kg)	469	388	273	324	3053	2720
K (mg/kg)	95	110	199	211	260	272
Na (mg/kg)	33	22	29	23	133	186
Fe (mg/kg)	134.02	199.07	55.34	65.80	20.29	39.11
Mn (mg/kg)	310.42	276.15	318.10	393.77	56.61	138.64
Zn (mg/kg)	1.04	1.28	0.91	2.29	0.41	2.11
Al ($cmol_c$/kg)	0.091	0.051	0.317	0.044	0	0
Resistance (Ohm)	1800	2000	2000	2200	400	440
C%	0.94	1.00	1.45	1.60	0.73	1.02

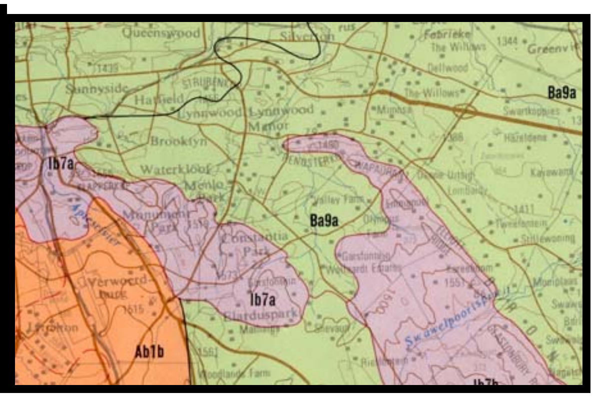
Total N%	0.062	0.066	0.095	0.100	0.042	0.065
S (mg/kg)	13.32	10.55	60.83	39.20	25.79	23.11
CEC ($cmol_c/kg$)	13.351	11.460	8.725	9.623	52.555	43.651
Distinct Tree Species	1. Euclea crispa	1. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Zanthoxylum capense 3. Euclea crispa	1. Clerodendrum glabrum 2. Rhus lancea 3. Ziziphus mucronata	1. Clerodendrum glabrum 2. Rhus lancea 3. Ziziphus mucronata
Average rooting depth of the indicated species (m)	4	4	4 - 7	4 - 7	4 - 13	4 - 13
Average depth of weathering (m)	0.9	0.9	0.9	0.9	2.3	2.3
Geomorphology	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Steep ridges and valleys	Plain	Plain
Geophysical instrumentation used	Magnetics	Magnetics	Magnetics	Magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	No	No	No	No
Aquifer Yield (l/h)	15000	15000	20000	20000	18000	18000
Borehole Depth (m)	60	60	65	65	45	45
Depth of Water Strike (m)	23	23	21	21	17	17

Static Water Level (m)	9	9	7	7	11	11
Average Aquifer Yield (l/h)	6750	6750	6750	6750	7520	7520
Average Borehole Depth (m)	56	56	56	56	44	44
Average Depth of Water Strike (m)	31	31	31	31	20	20
Average Static Water Level (m)	17	17	17	17	12	12
Land Type Series	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ib7b Mispah, Clovelly	Ea3b Arcadia	Ea3b Arcadia
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	13 Norite Black Turfveld	13 Norite Black Turfveld
Hydrogeological Unit	D2	D2	D2	D2	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

10. Mooikloof Estate (1)





Abbreviation	Geology
Vt	Shale, quartzite
Vb	Quartzite
Vha	Andesite
Vdw	Quartzite, chert
Vst	Shale
Vdq	Quartzite
Abbreviation	**Soil series**
Ba9a	Hutton
Ib7a	Rock

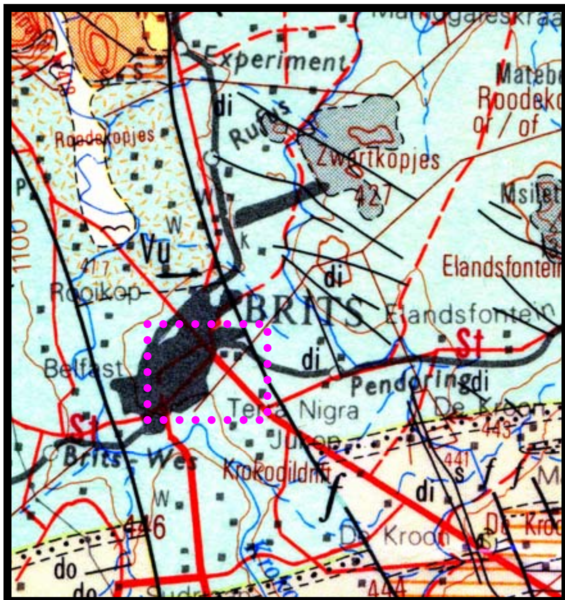
Figure A1.10. The geology (top left), land type (top right) and aerial photograph (bottom) of Mooikloof Estate (1). The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

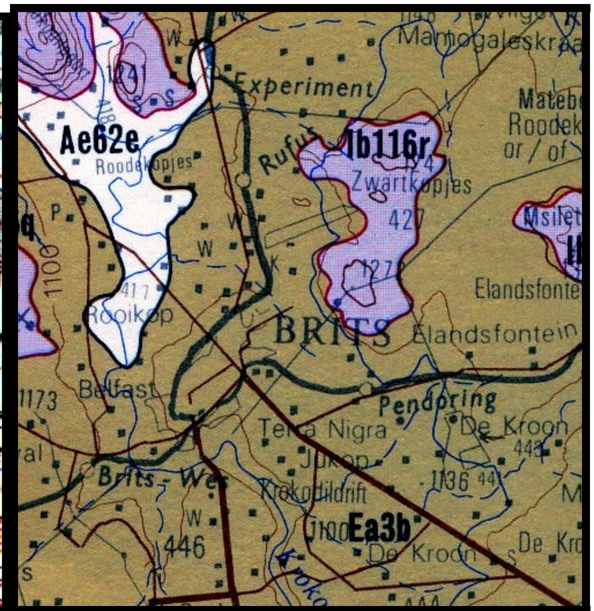
Mooikloof Estate is a new small holding development east of Pretoria and is part of the suburb Garsfontein.

11. Mooikloof Estate (2)

Figure A1.11. The geology and land type are pictured in Figure A1.10. The aerial photograph of Mooikloof Estate (1). The blue circle denotes the position of the borehole and the green lines the direction of the magnetic profiles in order to obtain the contour map. The area covered by the aerial photograph is indicated by the purple shape in the geological map (shares the same area as the previous Mooikloof case study).

12. Brits Industrial Area





Abbreviation	Geology
Vu	Ferrogabbro
di	Diabase
________ƒ	Fault
Abbreviation	**Soil series**
Ae62e	Hutton
Ea3b	Arcadia
Ib116r	Rock

Figure A1.12. The geology (top left), land type (top right) and aerial photograph (bottom) of Brits Industrial Area. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the orientation of the electromagnetic traverse. The red circles indicate exfoliation ridges that are covered with vegetation (dark lines). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

A1.5 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE PRETORIA AREA

The Pretoria Group of the Transvaal Sequence is widely distributed in the old Transvaal as outcrops occur in Thabazimbi in the west, Pretoria and Marble Hall in the centre towards Lydenburg in the eastern escarpment. The case studies relating to the Pretoria Group in the Lydenburg area will be discussed separately in this chapter as the climate and geological conditions differ from these around Pretoria. A milder climate gives rise to more abundant vegetation cover and the Pretoria Group sediments are intruded by numerous diabase intrusions in the Lydenburg area that metamorphosed shale into slate and hornfels at certain sites. This section will deal with shale and quartzite outcrops of the Pretoria Group in the region around Pretoria. All the results are presented in Table A1.11 (a&b).

A1.5.1 CASE STUDY AREA

The extent of the Pretoria Group around the city of Pretoria results in a huge population residing on the sediments and metamorphosed rocks of this group. In the outskirts of the city numerous smallholdings can be counted. Most of these smallholdings do not have access to municipal drinking water, or if they have, groundwater abstraction is required for intensive agricultural farming enterprises. As indicated in Chapter 3, Pretoria is an interesting case study on its own regarding geobotany. The shale, for instance, of the Silverton and Rayton Formations stipulate vast plains with sparse vegetation cover. These plains are structurally confined by quartzite ridges or mountains of the Magaliesberg and Daspoort Formations in the northern parts of Pretoria. Loose standing quartzite-sandstone ridges among the shale plains belong to the Rayton Formation. This kind of geological environment can be observed around the Cullinan diamond mine. Abundant diabase intrusions in the form of sills and dykes can readily be identified in the sediments of the Pretoria Group and especially among the Rayton Formation on the basis of botanic abundance. The three case studies presented stretch from the Hartebeespoortdam area west of Pretoria towards Cullinan, east of Pretoria.

A1.5.2 CLIMATE AND VELD TYPES

Due to the Bankenveld geomorphology of the Pretoria area, a vast amount of microclimates can be measured in the region. The influence of the microclimate can be observed in the diversity of botanic species in the region and on various rocks and soils. The temperature rises from north to south with a definite hotter climate just north of the Magaliesberg mountain range. The climatic conditions of Pretoria are cool, wet summers and cold, dry winters (Table A1.10). The climatic conditions confine the two biomes important to this study. The grassland biome south of the Magaliesberg and north of it transgressing into the savanna biome.

All the case studies have some kind of vegetation growth, some more luxurious than the other depending on the development of the smallholding. Therefore, it is not difficult to understand that all three case studies belong to some kind of Bushveld veld type as classified by Acocks (1988). The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997), all part of the savanna biome:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

In general the entire surface is encroached by shrubs and trees. The gaps in between are grassed. This makes it difficult to identify any geobotanic indicators or bush-clusters due to an uniform and general homogenic species occurrence. A survey of the trees in such an area will reveal if any conspicuous botanic species occur.

Table A1.10. Climatic Data of the Pretoria and Brits Areas (Schulze, 1997 & Johannesburg, 1999).

	Pretoria Area Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1500-1700
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.5.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Pretoria Group of sediments stretches east-west through the city of Pretoria with a north-east extension towards the town of Cullinan. In the Cullinan area sediments and meta-sediments of the Rayton Formation (Pretoria Group) cover mafic rocks of the Bushveld Igneous Complex. The Silverton Formation is confined by quartzite of the Daspoort and Magaliesberg Formations. The Rayton Formation occurs north of the Magaliesberg and is surrounded by the Bushveld Igneous Complex, sandstone and conglomerate of the Waterberg Group and sandstone and shale of the Karoo Supergroup. Abundant dykes and sills of diabase are to be found among the sediments of the Rayton Formation. Dykes and sills intrude shale of the Silverton Formation as well but on a lesser spatial extent. West of Pretoria the shale beds of the Silverton Formation dip about 25º north. Localised dips of the Rayton Formation can be observed, but are not mapped due to the irregular outcrops of this formation intersected with diabase intrusions.

Hydrogeological classification of the aquifers associated with the discussed lithologies, after Johannesburg (1999), are undifferentiated rock and various mixed lithologies attached to the Rayton Formation and predominantly meta-argillaceous rocks (slate and hornfels) regarding the Silverton Formation. Both formations' aquifers can yield 1800-7200 ℓ/h according to the hydrogeological mapping. Aquifers are typically associated with contact zones of intrusions (Hattingh, 1996).

A1.5.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Some geophysical case studies of the Pretoria Group of sediments are published in the guide by Hattingh (1996) and dissertation by Meulenbeld (1998). These works can be referenced to understand the depth profile of the Pretoria Group, namely its association with diabase intrusions in the sub-surface. The numerous diabase intrusions make every case study quite unique in the sense that different weathering, metamorphoses, dips and soil covers with associated vegetation originate at every site. In this kind of environment geophysical instruments like the magnetometer and electromagnetic EM34-3 apparatus will yield favourable results as the variations in magnetic intensity and conductivity of the various rocks and its weathered products will have its own distinct signature. Information on geobotanical indicators in this area is not known. However, some farmers believe that *Zizuphus mucronata* in this area can be used as a geobotanic indicator. This must be used with caution, however, as it is one of the distinct and frequent occurring tree species in the Sourish Mixed Bushveld veld type (Acocks, 1988).

A1.5.5 SOIL SAMPLING AND RESULTS PRESENTATION

In order to establish if geobotanic communities have remarkable differences in their soil make-up, soil sampling at depths of 0.5 and 1.2 m was undertaken. Another site with no distinct geobotanic cover was also sampled at the same depth intervals. These results are listed in Tables A1.11(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.11a. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: along intrusive/weathering contact.

	Kameeldrift 313JR		Kameelfontein 297JR		Skeerpoort 477JQ	
Geological Formation	Shale (Silverton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions	Quartzite (Rayton Formation) with diabase intrusions	Quartzite (Rayton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions	Shale (Silverton Formation) with diabase intrusions
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	 25º41.757' 28º00.512'	 25º41.757' 28º00.512'	 25º38.483' 28º24.857'	 25º38.483' 28º24.857'	 25º46.364' 27º46.751'	 25º46.364' 27º46.751'
Soil colour	Dark reddish brown	Moderate brown	Dark reddish brown	Dark red	Moderate brown	Greyish brown
Soil texture Description	Clay	Clay	Silt	Clayey silt	Clayey silt	Clay
pH	5.31	6.13	7.23	6.49	8.03	5.86
P (mg/kg)	2.40	2.23	3.79	3.37	1.64	1.26
Ca (mg/kg)	881	688	265	195	1256	385
Mg (mg/kg)	575	685	137	100	555	227
K (mg/kg)	52	46	55	54	89	137
Na (mg/kg)	14	39	0	19	471	13
Fe (mg/kg)	133.13	84.18	60.38	38.44	286.46	48.56
Mn (mg/kg)	586.34	305.83	314.62	138.66	128.90	67.11
Zn (mg/kg)	0.18	1.36	2.63	0.81	0.42	0.96
Al ($cmol_c$/kg)	0.243	0	0	0	0	0.255
Resistance (Ohm)	1800	2800	3120	4970	540	4400
C%	1.41	0.47	0.46	0.39	0.92	0.82

Total N%	0.087	0.038	0.024	0.023	0.062	0.067
S (mg/kg)	39.88	23.46	13.27	11.82	20.90	20.85
CEC ($cmol_c$/kg)	16.797	10.349	63.26	3.64	15.93	8.72
Distinct Tree Species	1. Acacia karroo 2. Zanthoxylum capense	1. Acacia karroo 2. Zanthoxylum capense	1. Ximenia caffra 2. Ziziphus mucronata	1. Ximenia caffra 2. Ziziphus mucronata	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	4 - 13	4 - 13	4 - 50	4 - 50
Average depth of weathering (m)	1.7	1.7	2.5	2.5	1.7	1.7
Geomorphology	Even terrain	Even terrain	Even terrian with small koppies	Even terrian with small koppies	Northern slope	Northern slope
Geophysical instrumentation used	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics
Water features present?	No	No	No	No	Skeerpoort River 500m to the north in valley	Skeerpoort River 500m to the north in valley
Aquifer Yield (l/h)	12000	12000	8000	8000	2500	2500
Borehole Depth (m)	55	55	70	70	80	80
Depth of Water Strike (m)	24	24	38	38	33	33
Static Water Level (m)	8	8	13	13	16	16

Average Aquifer Yield (l/h)	3375	3375	3000	3000	3375	3375
Average Borehole Depth (m)	35	35	45	45	35	35
Average Depth of Water Strike (m)	24	24	27	27	24	24
Average Static Water Level (m)	17	17	13	13	17	17
Land Type Series	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ae22a Hutton	Ae22a Hutton	Ba8a Mispah, Clovelly, Hutton	Ba8a Mispah, Clovelly, Hutton
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.11b. Vaalium Eonothem: Shale and Quartzite in the Pretoria Area: intrusive/weathering contact absent.

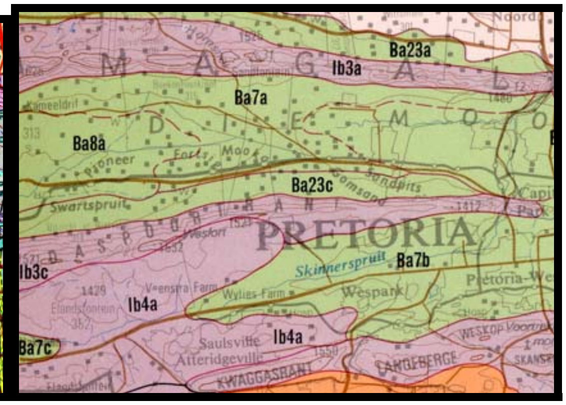
	Kameeldrift 313JR		Kameelfontein 297JR		Skeerpoort 477JQ	
Geological Formation	Shale (Silverton Formation)	Shale (Silverton Formation)	Quartzite (Rayton Formation)	Quartzite (Rayton Formation)	Shale (Silverton Formation)	Shale (Silverton Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	25º41.757' 28º00.512'	25º41.757' 28º00.512'	25º38.483' 28º24.857'	25º38.483' 28º24.857'	25º46.364' 27º46.751'	25º46.364' 27º46.751'
Soil colour	Moderate brown	Dark brown	Moderate brown	Strong brown	Clay	Clay
Soil texture description	Loam	Loam	Silty sand	Silty sand	Dark reddish brown	Dark reddish brown
pH	4.62	5.36	7.02	6.38	6.67	6.81
P (mg/kg)	4.95	2.81	4.17	4.04	1.60	1.26
Ca (mg/kg)	128	253	237	191	928	548
Mg (mg/kg)	54	72	90	104	174	104
K (mg/kg)	20	22	31	22	117	91
Na (mg/kg)	2	1	19	10	7	7
Fe (mg/kg)	23.81	41.88	13.21	9.28	47.68	30.33
Mn (mg/kg)	16.27	57.64	43.52	8.71	280.63	163.21
Zn (mg/kg)	0.54	0.17	0	0.34	0.50	0.48
Al ($cmol_c$/kg)	0.614	0.115	0	0	0	0
Resistance (Ohm)	3200	4200	5900	3300	3000	4600
C%	0.36	0.63	0.12	0.06	0.60	0.48
Total N%	0.035	0.049	0.012	0.009	0.047	0.048

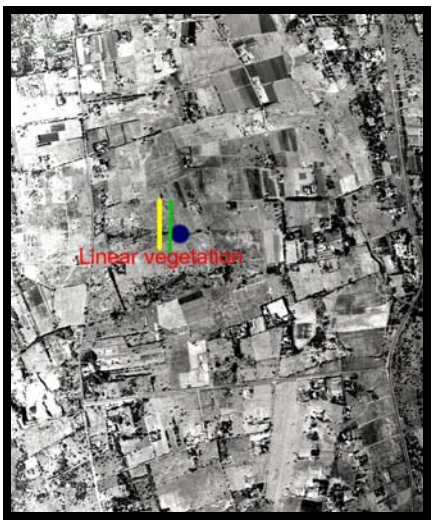
S (mg/kg)	20.08	17.93	4.01	14.59	2.98	1.75
CEC ($cmol_c$/kg)	2.421	3.126	4.66	3.13	6.79	7.31
Distinct Tree Species	1. Acacia karroo 2. Zanthoxylum capense	1. Acacia karroo 2. Zanthoxylum capense	1. Ximenia caffra 2. Ziziphus mucronata	1. Ximenia caffra 2. Ziziphus mucronata	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum	1. Rhus lancea 2. Acacia karroo 3. Clerodendrum glabrum
Average rooting depth of the indicated species (m)	5 - 50	5 - 50	4 - 13	4 - 13	4 - 50	4 - 50
Average depth of weathering (m)	1.7	1.7	2.5	2.5	1.7	1.7
Geomorphology	Even terrain	Even terrain	Even terrian with small koppies	Even terrian with small koppies	Northern slope	Northern slope
Geophysical instrumentation used	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics	Magnetics and Electromagnetics
Water features present?	No	No	No	No	Skeerpoort River 500m to the north in valley	Skeerpoort River 500m to the north in valley
Aquifer Yield (l/h)	12000	12000	8000	8000	2500	2500
Borehole Depth (m)	55	55	70	70	80	80
Depth of Water Strike (m)	24	24	38	38	33	33
Static Water Level (m)	8	8	13	13	16	16

Average Aquifer Yield (l/h)	3375	3375	3000	3000	3375	3375
Average Borehole Depth (m)	35	35	45	45	35	35
Average Depth of Water Strike (m)	24	24	27	27	24	24
Average Static Water Level (m)	17	17	13	13	17	17
Land Type Series	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ba8a Mispah, Clovelly, Hutton, Glenrosa	Ae22a Hutton	Ae22a Hutton	Ea72a Shortlands	Ea72a Shortlands
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

13. Kameeldrift 313JR

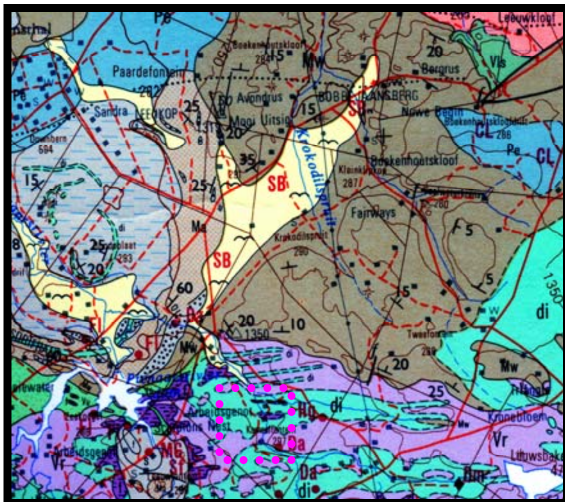


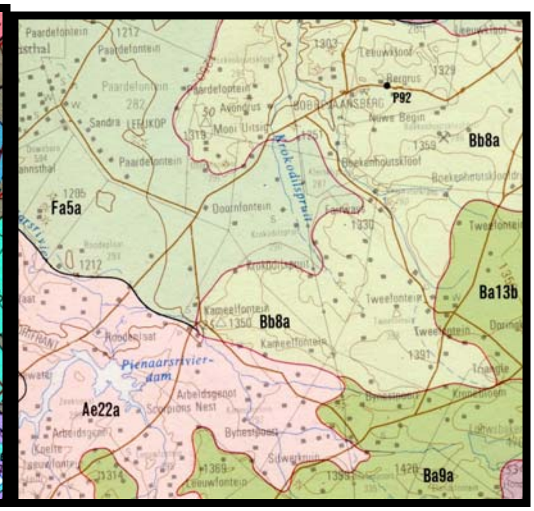


Abbreviation	Geology
Vdq	Quartzite
Vha	Andesite
Vm	Quartzite
Vsi	Shale
di	Diabase
Abbreviation	**Soil series**
Ba7a	Shortlands, Hutton
Ba8a	Hutton, Mispah, Clovelly, Glenrosa
Ba23c	Hutton
Ib3a	Rock

Figure A1.13. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameeldrift 313JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the diabase intrusions around the borehole.

14. Kameelfontein 297JR



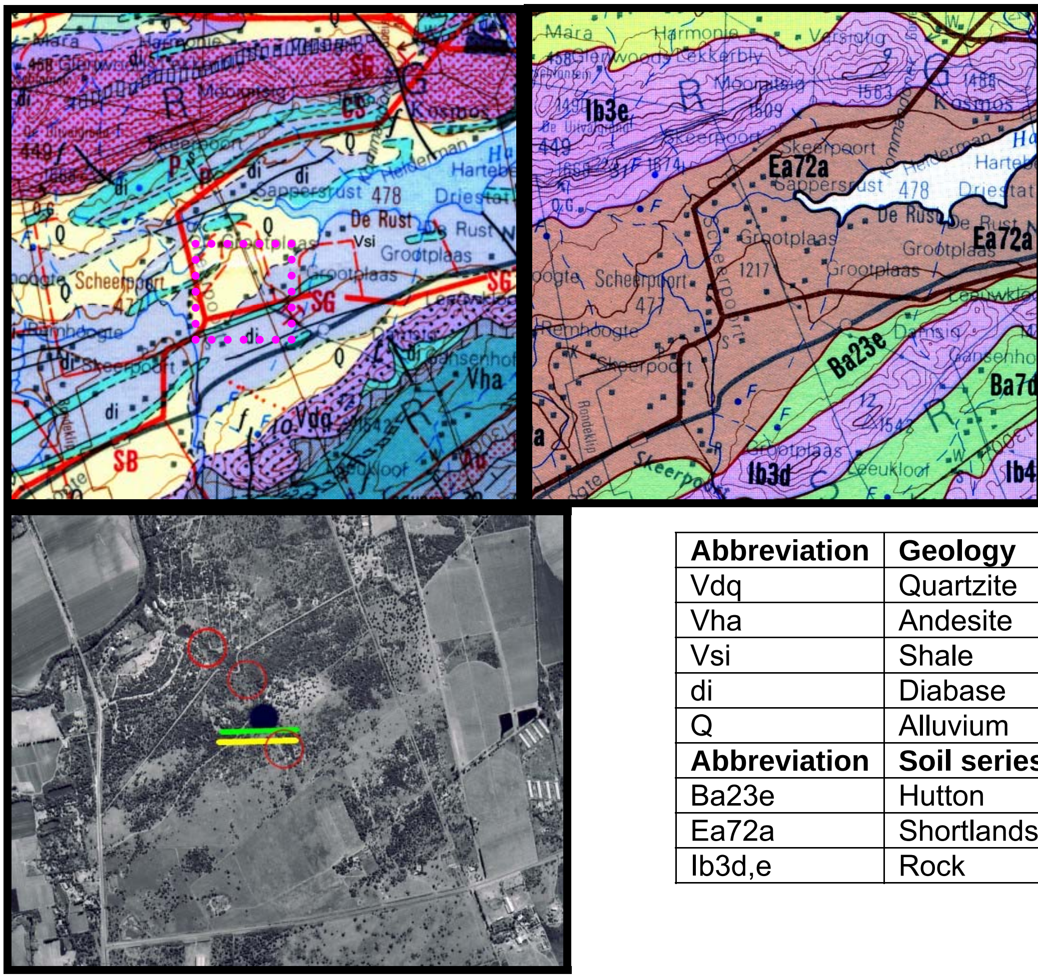


Abbreviation	Geology
Vr	Quartzite, shale, subgraywacke
Mw	Sandstone, conglomerate
f	Hybrid, fenitised rocks
di	Diabase
Abbreviation	**Soil series**
Ae22a	Hutton
Ba9a	Shortlands, Hutton
Bb8a	Mispah, Glenrosa
Fa5a	Mispah

Figure A1.14. The geology (top left), land type (top right) and aerial photograph (bottom) of Kameelfontein 297JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. Note the linear vegetation growth on the lineaments.

The area northeast of Pretoria is divided in smallholdings of about 20-30 ha in size due to its popularity as a residential dwelling just outside the city. Kameelfontein 297JR is also subdived in a couple of smallholdings. This portion of Kameelfontein was developed for agricultural purposes, namely an peach orchard was established on the farm and the existing borehole was yielding only 3 500 ℓ/h, too little groundwater supply for the existing and planned extension of the orchard, especially during times of drought stress.

15. Skeerpoort 477JQ



Abbreviation	Geology
Vdq	Quartzite
Vha	Andesite
Vsi	Shale
di	Diabase
Q	Alluvium
Abbreviation	**Soil series**
Ba23e	Hutton
Ea72a	Shortlands
Ib3d,e	Rock

Figure A1.15. The geology (top left), land type (top right) and aerial photograph (bottom) of Skeerpoort 477JQ. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic traverse direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament (exploration target) is indicated by red circles.

A1.6 VAALIUM EONOTHEM: SHALE AND QUARTZITE OF THE PRETORIA GROUP IN THE LYDENBURG AREA

The eastern escarpment of the South African Highveld constitutes outcrops of the Pretoria Group of the Transvaal Sequence. The same sequence of rocks, as described in the Pretoria case in Chapter 3, can be found from the archaic granite and gneiss in the Lowveld towards the norite and gabbro of the Bushveld Igneous Complex further inland. It appears that the Lydenburg area was subjected to intense volcanic activities that altered the composition of the lithology in this area, as slate and hornfels with numerous diabase, andesite intrusions, volcanic tuff and some extinct volcanoes are silent remains of the abrupt energy of the past millennia. One such extinct volcano is the Motlolo volcano, west of Lydenburg. The pipe of the volcano is rich in lime (Walraven, 1989).

A1.6.1 CASE STUDY AREA

The Badfontein area between Machadodorp and Lydenburg, in the Kwena basin, was investigated and represented by three case studies. The area was previously known for its thermal springs, but unfortunately the building of the Kwena dam flooded these springs. One other case study is situated between Lydenburg and Burgersfort on the Watervalsrivier Pass. All areas' primarily economic activity is in the agricultural sector, namely livestock, cultivation of land and orchards towards Burgersfort.

A1.6.2 CLIMATE AND VELD TYPES

Lydenburg is situated in the transgression zone from Highveld to Lowveld and is hence called Middelveld. The botany that occurs in this area reflects a climatic zone between the Highveld and Lowveld; abundant in *Acacia* and some other species, with some Lowveld species occurring, like *Syzygium cordatum* (water berry). It still reflects the savanna biome. The climatic conditions are represented in Table A1.12, cool and dry winters and hot, wet summers associated with violent thunderstorms. The undulating nature of the topography gives rise to numerous microclimates and veld types. The botany is indicative of warmer conditions towards the poort of the Crocodile River. The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Lowveld Sour Bushveld: *Acacia caffra* (common hook-thorn), *A. sieberiana var woodii* (paperbark thorn), *Englerophytum magalismontanum* (Transvaal milkplum), *Dombeya rotundifolia* (common wild pear), *Ficus ingens* (red-leaved fig) and *Gymnosporia senegalensis* (red spike-thorn).
- Lowveld: *Acacia nilotica subsp. kraussiana* (scented thorn), *A. nigrescens* (knob thorn), *A. tortilis subsp. heteracantha* (umbrella thorn), *Bauhinia galpinii* (pride-of-De-Kaap), *Cussonia natalensis* (rock cabbage tree), *Euclea crispa* (blue guarri), *Olea europaea subsp. africana* (wild olive), *Grewia hexamita* (giant raisin), *Strychnos madagascariensis* (black monkey orange) and *Ziziphus mucronata* (buffalo-thorn).
- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

In general the entire surface is encroached by shrubs and trees. The gaps in between are grassed. A distinct frontier between grass and trees can be observed on certain hills and towards the high quartzite cliffs of the Pretoria Group. The bushed areas generally consists of *Acacia caffra*, *Rhus chirindensis* (red currant) and *Ziziphus mucronata*. Geobotanic indicators can be identified by the appearance (height, leave colour, bark) of certain tree species in this environment compared to the remaining resident botany.

Table A1.12. Climatic Data of the Lydenburg Area (Schulze, 1997, Nelspruit, 1999 & Phalaborwa, 1998).

	Badfontein Area	**Watervalsrivier Pass Area**
Average Yearly Temperature (°C)	14-16	12-14
Mean Minimum Temperature (°C) in July	2-4	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5	22.5-25.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1200-1600	1200-2000
Evaporation (mm/year)	1750-2000	1750-2000
Frost area?	<150 days a year	<150 days a year

A1.6.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The geological map of the Badfontein area (Barberton, 1986) indicates surficial deposits, alluvium and scree with numerous outcrops and intrusions of diabase; medium-grained, current-bedded, flaggy quartzite with gritty and conglomeratic layers and occasional shale layers (Daspoort Formation); greenish, fine-grained shale and mudstone with tuff and subordinate carbonate layers, hornfels in places (Silverton Formation, Boven Member); and very fine-grained tuff, coarser grained agglomerate and basic lava (Silverton Formation, Machadodorp Member).

The farm Waterval 386KT crosses the Watervals River on a plain of surficial deposits, including alluvium and scree and greenish, fine-grained, laminated shale and subordinate mudstone with occasional limestone layers (Silverton Formation, Lydenburg Member). The entire farm is surrounded by cliffs of pure white, coarse-grained quartzite with non-continuous shaly layers belonging to the Magaliesberg Formation of the Pretoria Group, Transvaal Sequence. This area is stratigraphically younger in the sequence than the rocks in the Badfontein area.

Hydrogeological classification of the aquifers associated with the discussed lithologies, after Nelspruit (1999) and Phalaborwa (1998), are alluvium and undifferentiated rock and various mixed lithologies attached to the sedimentary rocks of the Pretoria Group in the

Badfontein and Watervalsrivier Pass areas. The intergranular and fractured aquifers in the alluvium (surficial deposits) yield on average 1800-7200 ℓ/h according to the hydrogeological mapping. Aquifers associated with the Silverton Formation and diabase intrusions contact zones can yield up to18 000 ℓ/h.

A1.6.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

This area is not referenced in any published geophysical literature. As the basic geology is the Pretoria Group, obtained geophysical results can be compared to geophysical results obtained in Pretoria Group sediments in other regions. Due to the presence of numerous diabase intrusions and alluvium beds, the application of the magnetic, electro-magnetic and direct current sounding methods are suitable.

The area increased its interest and importance by its presence of various geobotanic indicators associated with the common vegetation. The case studies will reflect on the geobotanic indicators in detail, but for reference purposes they will be mentioned hereunder:

- *Combretum erythrophyllum* (river bushwillow)
- *Ficus ingens* (red-leaved fig)
- *Zanthoxylum capense* (small knobwood)

A1.6.5 SOIL SAMPLING AND RESULTS PRESENTATION

In order to establish if geobotanic communities have remarkable differences in their soil make-up, soil sampling at depths of 0.5 and 1.2 m was undertaken. Another site with no distinct geobotanic cover was also sampled at the same depth intervals. These results are listed in Tables A1.13(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence or localisation of geobotanic communities.

Table A1.13a. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: along intrusive/weathering contact.

	Badfontein 114JT		Klipspruit 86JT		Rietfontein 88JT		Waterval 386KT	
Geological Formation	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Alluvium, Shale, Hornfels (Boven Member) with diabase intrusions	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation) with diabase intrusions	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation) with diabase intrusions
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	 25°20.017' 30°23.933'	 25°20.017' 30°23.933'	 25°17.434' 30°24.405'	 25°17.434' 30°24.405'	 25°14.051' 30°26.512'	 25°14.051' 30°26.512'	 24°57.036' 30°18.339'	 24°57.036' 30°18.339'
Soil colour	Weak red	Dusky red	Dark brown	Dusky yellowish brown	Dusky red	Dusky red	Strong brown	Strong brown
Soil texture Description	Sandy silt	Clayey silt	Clayey silt	Clay	Clay	Clay	Clay	Clay
pH	6.67	6.56	6.40	6.69	6.49	6.56	5.97	6.21
P (mg/kg)	1.54	1.37	1.54	1.49	3.54	3.08	4.70	4.45
Ca (mg/kg)	1275	1490	1795	1968	1533	1035	216	228
Mg (mg/kg)	987	949	736	921	434	412	97	117
K (mg/kg)	101	123	119	126	31	26	43	71
Na (mg/kg)	12	13	19	11	16	21	6	28

Fe (mg/kg)	95.82	131.07	155.05	154.69	123.26	81.49	40.57	57.80
Mn (mg/kg)	500.53	754.72	880.51	776.37	515.46	295.39	72.06	172.93
Zn (mg/kg)	1.65	1.99	0.98	0.81	0	0	0.45	0.18
Al ($cmol_c$/kg)	0	0	0	0	0	0	0.095	0
Resistance (Ohm)	1160	860	790	1090	1010	1290	5600	6000
C%	1.10	1.45	1.18	1.09	2.32	1.26	0.08	0.01
Total N%	0.081	0.107	0.081	0.077	0.087	0.055	0.009	0.007
S (mg/kg)	16.32	21.25	23.26	8.95	39.13	23.87	16.28	28.21
CEC ($cmol_c$/kg)	16.82	19.18	22.79	23.38	10.87	24.36	3.831	4.482
Distinct Tree Species	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Zanthoxy-lum capense Combretum erythro-phyllum Ficus ingens	Zanthoxylum capense Combretum erythro-phyllum Ficus ingens	Ficus ingens	Ficus ingens
Average rooting depth of the indicated species (m)	12	12	12	12	5 - 12	5 - 12	12	12

Average depth of weathering (m)	1.6	1.6	1.6	1.6	1.6	1.6	0.4	0.4
Geomorph-ology	Western slope to depression	Western slope to depression	Western slope to depression, with small hills	Western slope to depression, with small hills	Ridge close to stream	Ridge close to stream	Eastern ridge	Eastern ridge
Geophysical instrumen-tation used	Magnetics and Direct current soundings	Magnetics and Direct current soundings	Magnetics and Electromag netics	Magnetics and Electromag-netics	Magnetics and Electromag netics	Magnetics and Electromag-netics	Magnetics	Magnetics
Water features present?	No	No	No	No	Yes, 50m east (stream)	Yes, 50m east (stream)	Yes, 350m down (river)	Yes, 350m down (river)
Aquifer Yield (l/h)	7200	7200	8400	8400	8000	8000	5500	5500
Borehole Depth (m)	30	30	55	55	25	25	75	75
Depth of Water Strike (m)	14	14	18	18	8	8	34	34
Static Water Level (m)	9	9	12	12	5	5	31	31

Average Aquifer Yield (l/h)	4800	4800	4800	4800	4800	4800	4800	4800
Average Borehole Depth (m)	37	37	37	37	37	37	37	37
Average Depth of Water Strike (m)	17	17	17	17	17	17	17	17
Average Static Water Level (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Land Type Series	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ae107b, Fb170c Hutton, Rock	Ae107b, Fb170c Hutton, Rock
Profile No	P845	P845	P845	P845	P844	P844	P961	P961
Depth Sampled	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 620 mm	250 – 620 mm	860 – 1200 mm	860 – 1200 mm
Gravel %	4	4	4	4	0	0	1	1
Sand %	13	13	13	13	25	25	61	61
Silt %	14	14	14	14	27	27	21	21
Clay %	69	69	69	69	48	48	17	17
pH (H_2O)	7.0	7.0	7.0	7.0	6.2	6.2	9.0	9.0
P (mg/kg)	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Ca (mg/kg)	320	320	320	320	100	100	28	28

Mg (mg/kg)	224	224	224	224	52	52	283	283
K (mg/kg)	7	7	7	7	8	8	35	35
Na (mg/kg)	7	7	7	7	2	2	44	44
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	952.5	952.5	952.5	952.5	405.6	405.6	15.3	15.3
Zn (mg/kg)	0.17	0.17	0.17	0.17	0.21	0.21	0.21	0.21
Resistance (Ohm)	320	320	320	320	900	900	200	200
C%	0.7	0.7	0.7	0.7	0.6	0.6	0.2	0.2
CEC ($cmol_c$/kg)	42.0	42.0	42.0	42.0	14.2	14.2	23.8	23.8
Veld Type	9 & 10 Lowveld Sour Bushveld & Lowveld	9 & 10 Lowveld Sour Bushveld & Lowveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld
Hydrogeolo-gical Unit	A3	A3	A3/D4	A3/D4	A3/D4	A3/D4	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps originating from Acocks (1988) and hydrogeological information from DWAF: Nelspruit (1999) and Phalaborwa (1998). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1989a,b). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.13b. Vaalium Eonothem: Shale, Hornfels and Quartzite in the Lydenburg Area: intrusive/weathering contact absent.

	Badfontein 114JT		Klipspruit 86JT		Rietfontein 88JT		Waterval 386KT	
Geological Formation	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Alluvium, Shale, Hornfels (Boven Member)	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation)	Shale, Hornfels (Lydenburg Member), quartzite (Magaliesberg Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	25º20.017’ 30º23.933’	25º20.017’ 30º23.933’	25º17.434’ 30º24.405’	25º17.434’ 30º24.405’	25º14.051’ 30º26.512’	25º14.051’ 30º26.512’	24º57.036’ 30º18.339’	24º57.036’ 30º18.339’
Soil colour	Greyish brown	Moderate yellowish brown	Moderate brown	Strong brown	Dark reddish brown	Light brown	Dark yellowish orange	Light brown
Soil texture Description	Silt	Silt	Sandy silt	Silty clay	Silt	Silty clay	Sand	Sand
pH	6.84	6.86	6.47	6.98	6.49	6.84	4.95	4.88
P (mg/kg)	1.40	1.38	2.12	1.88	5.30	4.77	19.60	18.11
Ca (mg/kg)	712	471	629	593	1734	1138	107	97
Mg (mg/kg)	779	544	565	683	600	888	42	43
K (mg/kg)	46	47	100	51	200	79	12	6
Na (mg/kg)	34	51	22	79	18	11	27	41
Fe (mg/kg)	143.97	81.23	105.79	89.24	98.23	105.68	30.71	15.64
Mn (mg/kg)	657.20	393.14	616.64	457.32	455.41	674.63	132.86	25.02
Zn (mg/kg)	1.08	0.72	2.69	0.93	0.87	1.75	0.12	0.49

Al ($cmol_c/kg$)	0	0	0	0	0	0	0.601	1.021
Resistance (Ohm)	2850	2550	2040	1800	780	1260	5200	5000
C%	0.46	1.13	1.44	0.71	2.49	0.79	0.10	0.03
Total N%	0.050	0.072	0.107	0.066	0.177	0.074	0.009	0.004
S (mg/kg)	9.20	11.16	16.43	10.52	32.14	23.17	71.90	51.53
CEC ($cmol_c/kg$)	12.39	12.01	28.83	15.38	3.42	18.74	4.108	3.636
Distinct Tree Species	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Combretum erythro-phyllum	Zanthoxylum capense Combretum erythrophyllum Ficus ingens	Zanthoxylum capense Combretum erythrophyllum Ficus ingens	Ficus ingens	Ficus ingens
Average rooting depth of the indicated species (m)	12	12	12	12	5 - 12	5 - 12	12	12
Average depth of weathering (m)	1.6	1.6	1.6	1.6	1.6	1.6	0.4	0.4

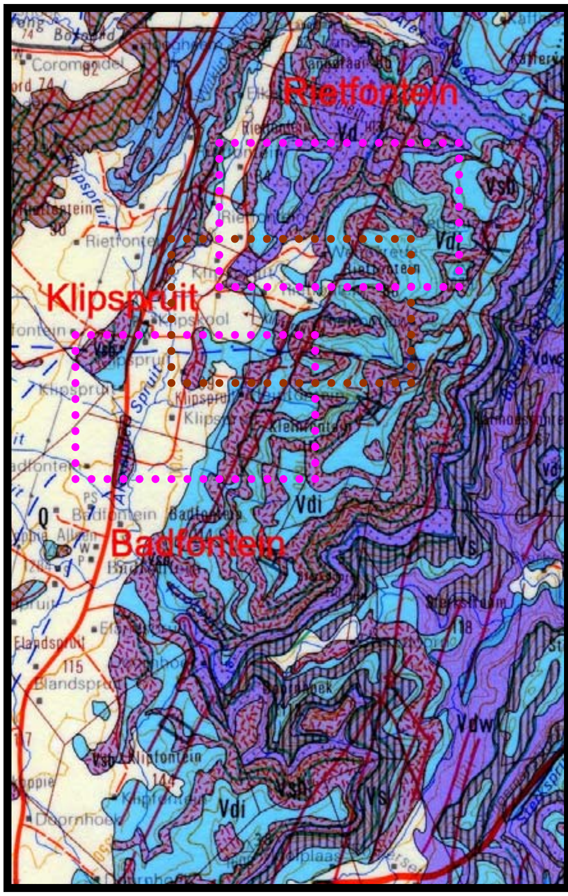
Geomorph-ology	Western slope to depression	Western slope to depression	Western slope to depression, with small hills	Western slope to depression, with small hills	Ridge close to stream	Ridge close to stream	Eastern ridge	Eastern ridge
Geophysical instrumen-tation used	Magnetics and Direct current soundings	Magnetics and Direct current soundings	Magnetics and Electro-magnetics	Magnetics and Electro-magnetics	Magnetics and Electromagnetics	Magnetics and Electro-magnetics	Magnetics	Magnetics
Water features present?	No	No	No	No	Yes, 50m east (stream)	Yes, 50m east (stream)	Yes, 350m down (river)	Yes, 350m down (river)
Aquifer Yield (l/h)	7200	7200	8400	8400	8000	8000	5500	5500
Borehole Depth (m)	30	30	55	55	25	25	75	75
Depth of Water Strike (m)	14	14	18	18	8	8	34	34
Static Water Level (m)	9	9	12	12	5	5	31	31
Average Aquifer Yield (l/h)	4800	4800	4800	4800	4800	4800	4800	4800
Average Borehole Depth (m)	37	37	37	37	37	37	37	37

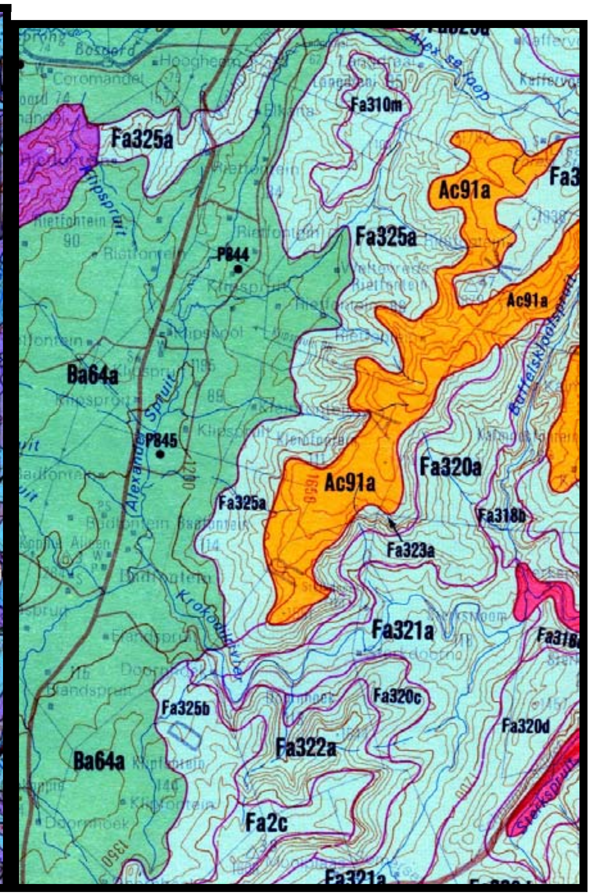
Average Depth of Water Strike (m)	17	17	17	17	17	17	17	17
Average Static Water Level (m)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Land Type Series	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ba64a Glenrosa, Hutton	Ae107b, Fb170c Hutton, Rock	Ae107b, Fb170c Hutton, Rock
Profile No	P845	P845	P845	P845	P844	P844	P961	P961
Depth Sampled	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 500 mm	250 – 620 mm	250 – 620 mm	860 – 1200 mm	860 – 1200 mm
Gravel %	4	4	4	4	0	0	1	1
Sand %	13	13	13	13	25	25	61	61
Silt %	14	14	14	14	27	27	21	21
Clay %	69	69	69	69	48	48	17	17
pH (H_2O)	7.0	7.0	7.0	7.0	6.2	6.2	9.0	9.0
P (mg/kg)	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Ca (mg/kg)	320	320	320	320	100	100	28	28
Mg (mg/kg)	224	224	224	224	52	52	283	283
K (mg/kg)	7	7	7	7	8	8	35	35
Na (mg/kg)	7	7	7	7	2	2	44	44
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	952.5	952.5	952.5	952.5	405.6	405.6	15.3	15.3
Zn (mg/kg)	0.17	0.17	0.17	0.17	0.21	0.21	0.21	0.21

Resistance (Ohm)	320	320	320	320	900	900	200	200
C%	0.7	0.7	0.7	0.7	0.6	0.6	0.2	0.2
CEC ($cmol_c/kg$)	42.0	42.0	42.0	42.0	14.2	14.2	23.8	23.8
Veld Type	9 & 10 Lowveld Sour Bushveld & Lowveld	9 & 10 Lowveld Sour Bushveld & Lowveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	9 Lowveld Sour Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld	18 & 19 Mixed Bushveld & Sourish Mixed Bushveld
Hydrogeolo-gical Unit	A3	A3	A3/D4	A3/D4	A3/D4	A3/D4	D3	D3

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the veld type maps originating from Acocks (1988) and hydrogeological information from DWAF: Nelspruit (1999) and Phalaborwa (1998). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1989a,b). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

16. Badfontein 114JT





Abbreviation	Geology
Vd	Quartzite
Vdi	Diabase
Vs	Shale, hornfels
Vsb	Shale, tuff
Q	Alluvium
	Dolerite (Lineament)
Abbreviation	**Soil series**
Ba64a	Glenrosa, Hutton
Fa325a	Rock, Mispah

Figure A1.16. The geology (top left), land type (top right) and aerial photograph (bottom) of Badfontein 114JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle).

Between the highlands of Machadodorp and Lydenburg a geological basin is situated. Locally it is known as the Kwena Basin and encloses the floodplain of the Crocodile River and Kwena dam. The Kwena dam flooded the hot, sulphur springs of the area, hence the name Badfontein referring to these hot springs that where used for recreational and therapeutic purposes in the past. These hot, sulphur springs reflect also on the abrupt, violent geological past. Remnants of this past are reflected in eroded volcanoes, tuff deposits and agglomerates, especially in the Silverton Formation, Machadodorp Member. With this kind of environment numerous diabase sills and dykes intruded the sediments of the Pretoria Group and altered/metamorphosed these rocks in rock types like hornfels and some slate (Walraven, 1989). The diabase is at times enriched in lime due to the fact that in weathered horizons of the diabase small, white lime nodules are found.

The farm is situated on the western slope of the foothills of the escarpment between Lydenburg, Sabie and Sudwala on the banks of the Kwena dam. It is notably covered with *Acacia caffra, A. karroo*, *Combretum erythrophyllum* and *Ziziphus mucronata*, forming part of the Lowveld Sour Bushveld & Lowveld veld types.

17. ***Klipspruit 89JT***

Figure A1.17. Aerial photograph of Klipspruit 89JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the brown shape in the geological map (middle rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth, compare with Figure A1.16).

The farm Klipspruit 89JT is situated a couple of kilometers north of the farm Badfontein 114JT. The boreholes that were investigated and sited on this farm and the adjacent Kleinfontein 111JT are on a higher elevation situated than the borehole at Badfontein. The Kwena dam is also a couple of kilometers southwest of these localities.

18. *Rietfontein 88JT*

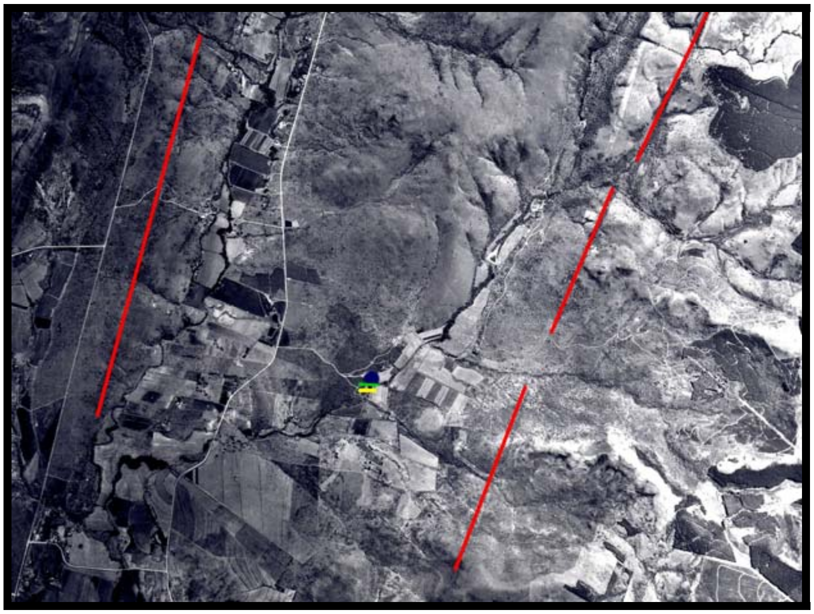
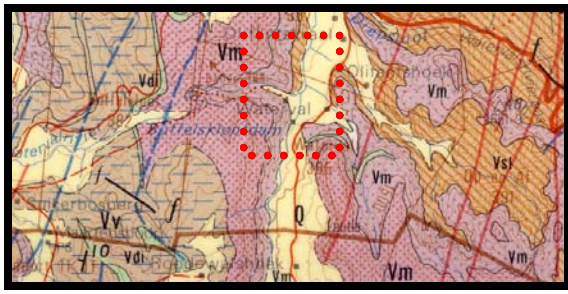
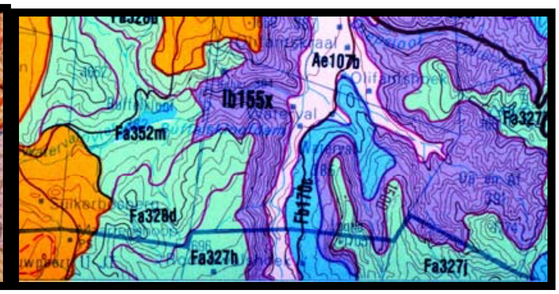


Figure A1.18. Aerial photograph of Rietfontein 88JT. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line indicates the electromagnetic travers direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map (upper rectangle). The geology and land type are depicted in Figure A1.16. Red lines indicate lineaments (suspicious linear vegetation growth).

Some three kilometers to the north of the case study mentioned under Klipspruit 89JT, the case study on the farm Rietfontein 88JT is found. These cliffs are covered by luxurious vegetation growth not seen in other areas in this region. Tree species that occur are *Acacia caffra* (common hook-thorn), *Brachylaena rotundata* (mountain silver oak), *Celtis africana* (white stinkwood), *Clausena anisata* (horsewood), *Combretum eryhrophyllum* (river bushwillow), *Ficus ingens* (red-leaved fig), some *Rhus* species, *Zanthoxylum capense* (small knobwood) and *Ziziphus mucronata* (buffalo thorn).

19. Waterval 386KT





Abbreviation	Geology
Vsl	Shale, mudstone, hornfels
Vm	Quartzite
Vv	Hornfels, carbonate layers
Vdi	Diabase
Q	Alluvium
Abbreviation	**Soil series**
Ae107b	Hutton
Fb170c	Rock
Ib155x	Rock

Figure A1.19. The geology (top left), land type (top right) and aerial photograph (bottom) of Waterval 386KT. The blue circle denotes the position of the borehole and the green line the direction of the magnetic profile. The red circles points out small lineaments (general east-west strike). The borehole is sited at a lineament with a northwest-southeast strike. The area covered by the aerial photograph is indicated by the red shape in the geological map (lower rectangle).

A1.7 VAALIUM EONOTHEM: RHYOLITE OF THE ROOIBERG GROUP AND LOSKOP FORMATION IN THE VERENA-MIDDELBURG AREA

After the deposition and formation of the Pretoria Group sediments and igneous intrusions during the Vaalium Eonothem, the development of the Rooiberg Group had its origin and thereafter the Loskop Formation. The Rooiberg Group consists of the Damwal and Selonsrivier Formations, both formations lithology is predominantly volcanic rocks, namely rhyolite. The Selonsrivier Formation is relatively homogeneous and consists of red porphyritic lava and case studies of this formation will be discussed. The Loskop Formation follows more or less concordantly on the Rooiberg Group without any trace of a major regional unconformity. The formation is separated from the overlying Waterberg sediments by a prominent regional unconformity and consists of a thick succession of finely layered siltstone, mudstone, feldspathic sandstone and shale. Volcanic rocks of early Loskop age occur in a number of places, e.g. Rhenosterkop 452JR and Honingkranz 536JR. At Rhenosterkop the rocks are pyroclastic with fragments of lava (Pretoria, 1978). Sediments of the Loskop Formation associated with diabase intrusions will be addressed in the next section.

A1.7.1 CASE STUDY AREA

Three case studies situated on rhyolite is presented. The first case, Enkeldoornoog 219JR is situated east of Kwamhlanga, between Pretoria and Marble Hall. Rhyolite of the Rooiberg Group outcrops in this area. The second case, Rhenosterkop 452JR, is a remnant of an old volcano of the Loskop Formation, and is east of the road between Bronkhorstspruit and Groblersdal, close to Verena. The last case study of the Rooiberg Group is on the farm Kwaggasfontein 460JS, south of the road from Middelburg to Belfast, in the vicinity of Arnot Power Station. Agricultural practices range from subsistence farming at Enkeldoornoog to extensive livestock farming on Rhenosterkop and land cultivation at Kwaggasfontein.

A1.7.2 CLIMATE AND VELD TYPES

The study area is situated on the South African Highveld and the transgression zone towards the Bushveld including the savanna and grassland biomes. Climatic data is indicated in Table A1.14, pointing to mild to cold, dry winters and mild to hot, wet summers. The south-eastern case study, Kwaggasfontein, is the coldest and hence sparse indigenous shrub and tree cover is observed. The farm Rhenosterkop is situated on Rhenosterkop, a prominent hill in the Bronkhorstspruit area. Due to its prominence, the wind chill factor is a restrictive factor that limits abundant and luxurious tree and shrub growth, but the narrow valleys are more luxurious inhabited by trees and shrubs as it is protected from wind. Enkeldoornoog is the warmest area of all three and a Bushveld character is eminent of the place. As mentioned earlier, the Highveld and the transgression to the Bushveld defines two veld types in this area, the Bankenveld at Kwaggasfontein (grassland biome), and Sourish Mixed Bushveld for the other two case studies (savanna biome). The following tree species are eminent of the veld types (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).

Due to the winters being severely frosty in the Bankenveld combined with high rainfall, altitude and regular burning of the grassland, the veld is particularly sour with acid soils and is not hosting a wide variety of trees or shrubs.

Table A1.14. Climatic Data of the Verena-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999).

	Enkeldoornoog	**Rhenosterkop**	**Kwaggasfontein**
Average Yearly Temperature (°C)	14-16	12-14	12-14
Mean Minimum Temperature (°C) in July	2-4	0-2	0-2
Mean Maximum Temperature (°C) in January	27.5-30.0	22.5-25.0	22.5-25.0
Average Yearly Rainfall (mm)	600-800	600-800	600-800
Elevation (m)	1200-1600	1400-1700	1600-2000
Evaporation (mm/year)	2000-2250	2000-2250	1750-2000
Frost area?	<150 days a year	<150 days a year	150-175 days a year

A1.7.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The case studies presented in this section are all on rhyolite. The formations involved are the Selonsrivier (Rooiberg Group) and Loskop Formations. In the introduction to this section an overview over the geology has been explained. Of interest is the inclusion of a pyroclastic deposit, Rhenosterkop. Intrusions of diabase create potential aquifer positions and generally increase the possibility to drill a successful borehole with a yield larger than would be obtained if drilled in an aquifer not associated with diabase, see Frommurze (1937) and Meulenbeld (1998).

Rhyolite on the Johannesburg (1999) map is indicated as acid/intermediate and extrusive rocks with associated intergranular and fractured aquifers compatible with yields ranging from 360-7200 ℓ/h.

A1.7.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The linear and limited extent together with its geographical location of the Selonsrivier and Loskop Formations makes it a non-important target for geophysical and geohydrological studies. The formations occur not in remote areas that are dependent on groundwater supply for survival. Large portions of the formation are in agricultural areas, but primarily in areas of extensive livestock farming due to the fact that rhyolite is resistant to chemical weathering and thus these areas are mountainous. Where the formations occur close to towns like Witbank, Middelburg and Kwamhlanga, all these towns are served by municipal drinking water where dependency on aquifers diminishes. In the study by Meulenbeld (1998), Rhenosterkop was included and a farm close to Kwaggasfontein, namely Luipaardsfontein. The published results will be referenced in this study as well. Another geophysical study by Botha *et al*. (2001) in this area focuses only on Nebo Granite of the Mogolian Eonothem in the Limpopo Province. As the majority of aquifers are fractured and/or associated with diabase intrusions, the magnetic and electromagnetic methods are preferred.

The study of geobotanical indicators was initiated during a visit to the old volcano at Rhenosterkop by Meulenbeld (1998) where conspicuous vegetation clusters grow on diabase intrusions. Furthermore, termitary associated with these tree clusters where found to be red in colour, whereas termitary in the grassed field where grey in colour. Geophysical profiles along the vegetation clusters and termitary indicated the presence of small diabase intrusions. Mentioned geobotanic indicators were found to be applicable in other areas, like in the Swartwater region (section 4.1).

A1.7.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling was undertaken as referenced in the previous sections at the same depths. The results are listed in Tables A1.15(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.15a. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: along intrusive/weathering contact.

	Enkeldoornoog 219JR		Rhenosterkop 452JR		Kwaggasfontein 460JS	
Geological Formation	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Fractured rhyolite and diabase intrusions (Loskop Formation)	Fractured rhyolite and diabase intrusions (Loskop Formation)	Rhyolite (Selonsrivier Formation) and a diabase intrusion	Rhyolite (Selonsrivier Formation) and a diabase intrusion
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	25º24.331' 28º47.409'	25º24.331' 28º47.409'	25º36.307' 28º55.659'	25º49.217' 28º19.701'	25º53.783' 29º38.339'	25º53.783' 29º38.339'
Soil colour	Dark reddish brown	Moderate brown	Greyish orange	Pale reddish brown	Dark red	Moderate brown
Soil texture description	Loam	Clayey silt	Clay	Clay	Silty clay	Silty clay
pH	5.86	5.60	5.72	6.10	6.08	5.84
P (mg/kg)	7.98	1.94	8.52	6.79	1.02	0.73
Ca (mg/kg)	587	618	924	779	466	514
Mg (mg/kg)	230	300	80	96	405	508
K (mg/kg)	0	25	138	132	26	2
Na (mg/kg)	209	286	41	40	90	194
Fe (mg/kg)	30.88	64.27	202.22	130.67	41.36	64.04
Mn (mg/kg)	169.90	379.66	31.20	15.58	233.90	321.53
Zn (mg/kg)	47.20	1.03	1.82	3.64	0.53	0.26
Al ($cmol_c$/kg)	0	0.155	0.061	0	0	0
Resistance (Ohm)	2600	3200	670	1070	2600	2600

C%	3.02	1.60	1.91	2.94	0.46	0.83
Total N%	0.099	0.177	0.109	0.118	0.037	0.061
S (mg/kg)	39.39	27.26	106.43	54.91	102.86	46.68
CEC ($cmol_c$/kg)	6.605	8.392	10.26	8.34	7.911	10.204
Distinct Tree Species	1. Clerodendrum glabrum 2. Rhus lancea	1. Clerodendrum glabrum 2. Rhus lancea	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Acacia karroo	2. Acacia karroo
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 50	4 - 50	50	50
Average depth of weathering (m)	1.2	1.2	0.5	0.5	2.7	2.7
Geomorphology	Plain	Plain	Kop	Kop	Plain	Plain
Geophysical instrumentation used	Magnetics Electro-magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	Perennial stream, 100 m northwest	Perennial stream, 100 m northwest	Perennial stream, 400m south	Perennial stream, 400m south
Aquifer Yield (l/h)	7500	7500	2050	2050	4700	4700
Borehole Depth (m)	55	55	2	2	48	48
Depth of Water Strike (m)	17	17	2	2	21	21

Static Water Level (m)	11	11	2	2	14	14
Average Aquifer Yield (l/h)	1770	1770	1770	1770	4700	4700
Average Borehole Depth (m)	64	64	64	64	35	35
Average Depth of Water Strike (m)	44	44	44	44	24	24
Average Static Water Level (m)	16	16	16	16	8	8
Land Type Series	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	Ib37a Rock, Mispah, Clovelly	Ib37a Rock, Mispah, Clovelly	Bb14b/Ba19a Hutton, Avalon	Bb14b/Ba19a Hutton, Avalon
Profile No	No Data	No Data	No Data	No Data	P62	P62
Depth Sampled	No Data	No Data	No Data	No Data	250-500mm	250-500mm
Gravel %	No Data	No Data	No Data	No Data	6	6
Sand %	No Data	No Data	No Data	No Data	64	64
Silt %	No Data	No Data	No Data	No Data	6	6
Clay %	No Data	No Data	No Data	No Data	24	24
pH	No Data	No Data	No Data	No Data	4.7	4.7
P (mg/kg)	No Data	No Data	No Data	No Data	0.8	0.8
Ca (mg/kg)	No Data	No Data	No Data	No Data	800	800
Mg (mg/kg)	No Data	No Data	No Data	No Data	243	243

K (mg/kg)	No Data	No Data	No Data	No Data	2346	2346
Na (mg/kg)	No Data	No Data	No Data	No Data	70	70
Fe (mg/kg)	No Data	No Data	No Data	No Data	-	-
Mn (mg/kg)	No Data	No Data	No Data	No Data	132.60	132.60
Zn (mg/kg)	No Data	No Data	No Data	No Data	0.26	0.26
Resistance (Ohm)	No Data	No Data	No Data	No Data	5200	5200
C%	No Data	No Data	No Data	No Data	0.7	0.7
CEC ($cmol_c$/kg)	No Data	No Data	No Data	No Data	38	38
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.15b. Vaalium Eonothem: Rhyolite in the Verena-Middelburg Areas: absent intrusive/weathering contact.

	Enkeldoornoog 219JR		Rhenosterkop 452JR		Kwaggasfontein 460JS	
Geological Formation	Rhyolite (Selonsrivier Formation)	Rhyolite (Selonsrivier Formation)	Rhyolite (Loskop Formation)	Rhyolite (Loskop Formation)	Rhyolite (Selonsrivier Formation) and sandstone (Vryheid Formation)	Rhyolite (Selonsrivier Formation) and sandstone (Vryheid Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	0.5m
Borehole Co-ordinates: S.L. E.L.	25º24.331' 28º47.409'	25º24.331' 28º47.409'	25º36.307' 28º55.659'	25º49.217' 28º19.701'	25º53.783' 29º38.339'	25º53.783' 29º38.339'
Soil colour	Light brown	Dark yellowish orange	Weak red	Weak red	Dark brown	Dark reddish brown
Soil texture description	Sandy silt	Silt	Silt	Silt	Silt	Loam
pH	5.37	4.86	5.12	6.23	5.34	5.79
P (mg/kg)	3.82	2.77	8.75	5.63	2.35	2.02
Ca (mg/kg)	322	268	562	653	313	332
Mg (mg/kg)	95	94	77	109	96	138
K (mg/kg)	11	23	108	111	0	10
Na (mg/kg)	141	153	38	19	120	123
Fe (mg/kg)	64.21	40.38	234.13	59.95	88.89	62.02
Mn (mg/kg)	211.64	181.08	26.13	47.36	67.30	190.22
Zn (mg/kg)	1.42	0.56	1.65	1.84	0.16	0.30
Al ($cmol_c$/kg)	0.251	0.293	0.412	0	0.203	0.156
Resistance (Ohm)	2900	2300	1470	1530	4000	4300

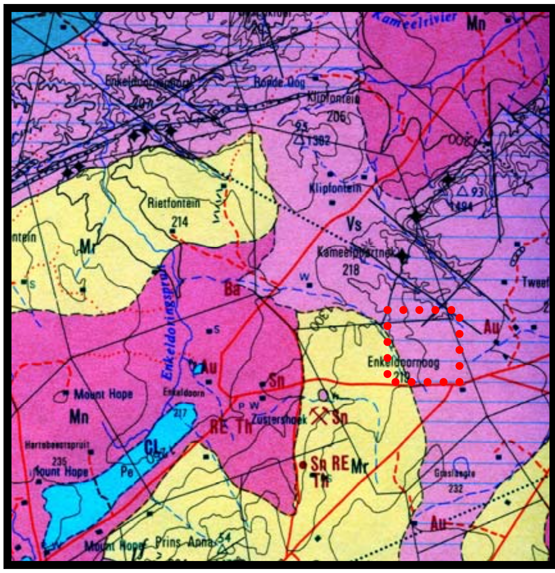
C%	1.39	0.54	2.03	1.32	1.02	0.43
Total N%	0.098	0.042	0.092	0.071	0.075	0.041
S (mg/kg)	18.33	27.83	34.06	23.01	21.07	21.73
CEC ($cmol_c$/kg)	4.384	3.750	1.20	7.15	3.779	4.468
Distinct Tree Species	1. Clerodendrum glabrum 2. Rhus lancea	1. Clerodendrum glabrum 2. Rhus lancea	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Ximenia caffra 2. Acacia karroo 3. Euclea crispa 4. Ziziphus mucronata	1. Acacia karroo	1. Acacia karroo
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 50	4 - 50	50	50
Average depth of weathering (m)	1.2	1.2	0.5	0.5	2.7	2.7
Geomorphology	Plain	Plain	Kop	Kop	Plain	Plain
Geophysical instrumentation used	Magnetics Electro-magnetics	Magnetics Electro-magnetics	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics Direct current sounding	Magnetics Electro-magnetics	Magnetics Electro-magnetics
Water features present?	No	No	Perennial stream, 100 m northwest	Perennial stream, 100 m northwest	Perennial stream, 400m south	Perennial stream, 400m south
Aquifer Yield (l/h)	7500	7500	2050	2050	4700	4700
Borehole Depth (m)	55	55	2	2	48	48
Depth of Water Strike (m)	17	17	2	2	21	21
Static Water Level (m)	11	11	2	2	14	14

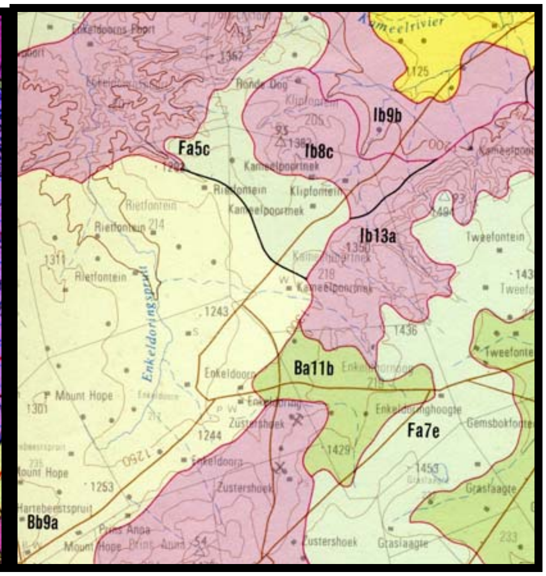
Average Aquifer Yield (l/h)	1770	1770	1770	1770	4700	4700
Average Borehole Depth (m)	64	64	64	64	35	35
Average Depth of Water Strike (m)	44	44	44	44	24	24
Average Static Water Level (m)	16	16	16	16	8	8
Land Type Series	Ba11b/Fa7e Hutton/Rock, Clovelly, Hutton, Glencoe, Mispah	Fa7e Rock, Clovelly, Hutton, Glencoe, Mispah	Ib37a Rock, Mispah, Clovelly	Ib37a Rock, Mispah, Clovelly	Bb14b/Ba19a Hutton, Avalon	Bb14b/Ba19a Hutton, Avalon
Profile No	No Data	No Data	No Data	No Data	P62	P62
Depth Sampled	No Data	No Data	No Data	No Data	250-500 mm	250-500 mm
Gravel %	No Data	No Data	No Data	No Data	6	6
Sand %	No Data	No Data	No Data	No Data	64	64
Silt %	No Data	No Data	No Data	No Data	6	6
Clay %	No Data	No Data	No Data	No Data	24	24
pH ($CaCl_2$)	No Data	No Data	No Data	No Data	4.7	4.7
P (mg/kg)	No Data	No Data	No Data	No Data	0.8	0.8
Ca (mg/kg)	No Data	No Data	No Data	No Data	800	800
Mg (mg/kg)	No Data	No Data	No Data	No Data	243	243
K (mg/kg)	No Data	No Data	No Data	No Data	2346	2346
Na (mg/kg)	No Data	No Data	No Data	No Data	70	70

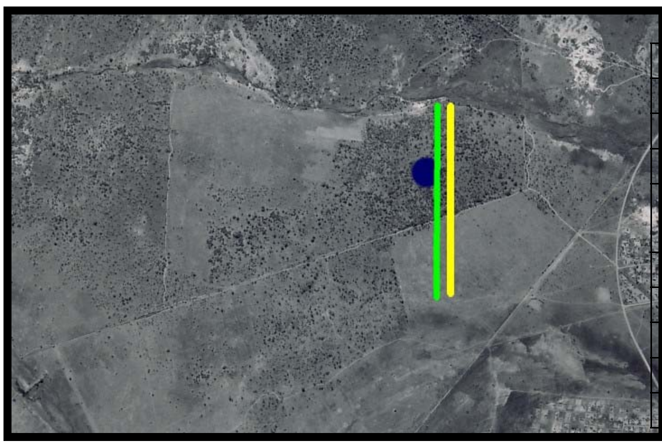
Fe (mg/kg)	No Data	No Data	No Data	No Data	-	-
Mn (mg/kg)	No Data	No Data	No Data	No Data	132.60	132.60
Zn (mg/kg)	No Data	No Data	No Data	No Data	0.26	0.26
Resistance (Ohm)	No Data	No Data	No Data	No Data	5200	5200
C%	No Data	No Data	No Data	No Data	0.7	0.7
CEC ($cmol_c$/kg)	No Data	No Data	No Data	No Data	38	38
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level was obtained from Frommurze (1937). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

20. Enkeldoornoog 219JR





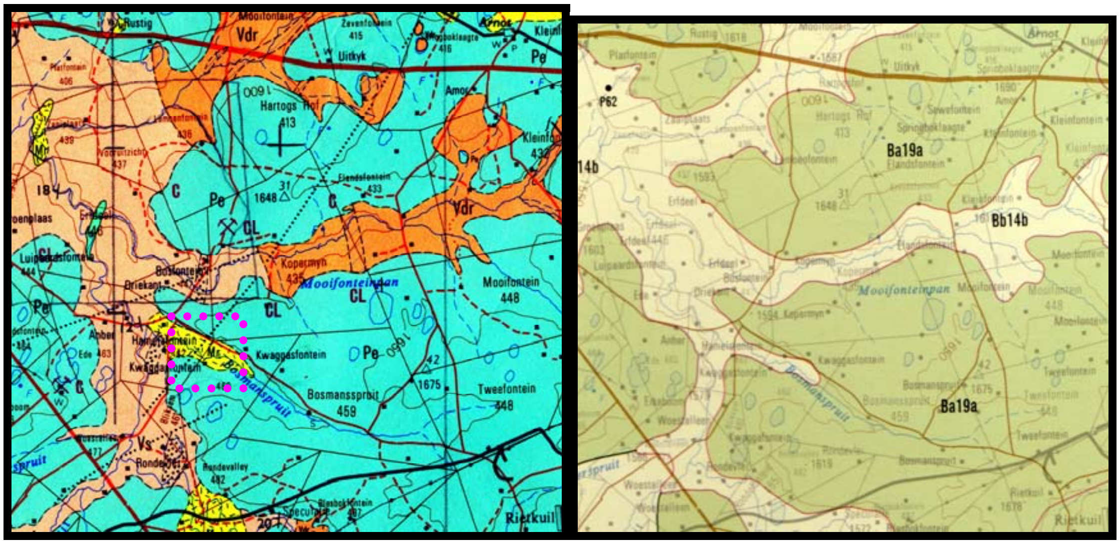


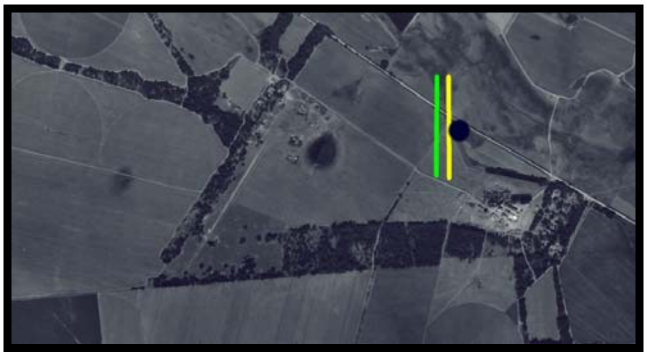
Abbreviation	Geology
Vs	Rhyolite
Mr	Granophyre
Mn	Granite
Pe	Shale, grit, sandstone
Abbreviation	**Soil series**
Ba11b	Hutton
Bb9a	Mispah, Glenrosa
Fa7e	Rock, Clovelly
Ib13a	Rock

Figure A1.20. The geology (top left), land type (top right) and aerial photograph (bottom) of Enkeldoornoog 219JR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the red shape in the geological map.

Enkeldoornoog 219JR is situated east of Kwamhlanga, the former capital of the homeland KwaNdebele.

21.Kwaggasfontein 460JS



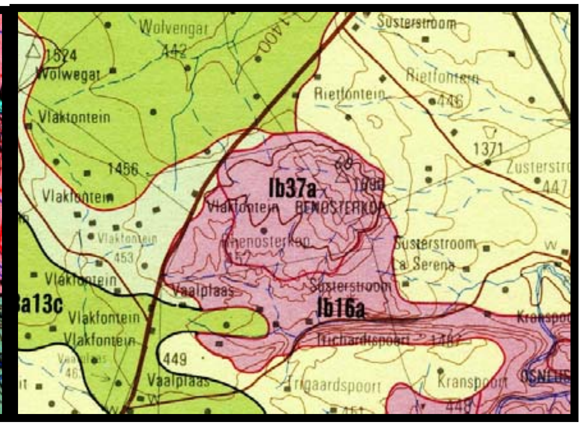


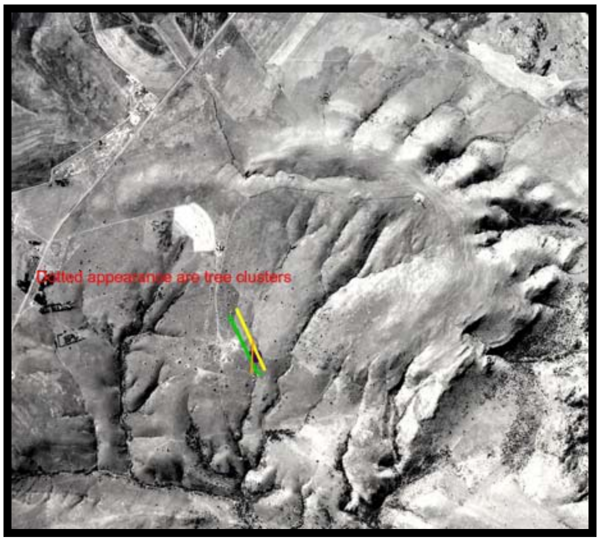
Abbreviation	Geology
Vdr	Black rhyolite
Vs	Red rhyolite
Mr	Granophyre
Pe	Shale, grit, sandstone, coal
………………	Lineament (diabase)
Abbreviation	**Soil series**
Ba19a	Avalon
Bb14b	Hutton

Figure A1.21. The geology (top left), land type (top right) and aerial photograph (bottom) of Kwaggasfontein 460JS. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map (lower rectangle). Note the considerable coverage of exotic species establishment on this farm.

The farm is situated south of the main road between Middelburg and Belfast.

22. Rhenosterkop 452JR





Abbreviation	Geology
Vls	Rhyolite
Mn	Granite
Mw	Sandstone
di	Diabase
Abbreviation	**Soil series**
Ib16a	Rock
Ib37a	Rock

Figure A1.22. The geology (top left), land type (top right) and aerial photograph (bottom) of Rhenosterkop 452JR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the black shape in the geological map (lower rectangle).

Rhenosterkop presents an unique example of geobotanic interaction with weathered rock, soil and termitary. Termitary reflects the parent rock in depth by the colour appearance of the termitary in association with tree clusters that are distinct features on the grassy hill sides of the kop. Another extict volcano to the southeast of Rhenosterkop is the kop Honingkranz on the farm Honingkranz 536JR, close to Balmoral. The geobotanic communities as presented on Rhenosterkop are also present but not so distinct and well defined.

A1.8 VAALIUM EONOTHEM: SEDIMENTS OF THE LOSKOP FORMATION AND A DIABASE SILL IN THE BRONKHORSTSPRUIT-MIDDELBURG AREA

This chapter included various lithologies from the Pretoria Group and rhyolite of the Rooiberg Group and Loskop Formation. These lithologies are representative of the Vaalium Eonothem. However, sediments of the Loskop Formation and geophysical groundwater exploration in a diabase environment have not been addressed thus far. This section represents the sediments of the Loskop Formation, associated with diabase intrusions, and a diabase environment. Due to the limited extent of the Loskop Formation and confined occurrence of outcropping diabase sills amongst rocks of the Pretoria Group, only one case of each is included. The geobotanic occurrences is relevant and of importance in the context of this study. Both case studies are located in the grassland biome.

A1.8.1 CASE STUDY AREA

A diabase outcrop south of Bronkhorstspruit is investigated together with a case study southwest of Middelburg. Both case studies are associated with farming activities.

A1.8.2 CLIMATE AND VELD TYPES

Being on the Highveld implies cold, dry winters and hot, wet summers. Thunderstorms are the deliverers of rain. Climatic data of the area is indicated in Table A1.16. The climate restricts bush establishment due to frost, fire, wind and acid soil conditions in places (sourveld), due to higher rainfall compared to localities in the Bushveld. Notwithstanding this, the Bankenveld veld type of this area hosts some shrub and tree species in surroundings protected against the mentioned elements. The following tree species are eminent of the veld type (after Acocks, 1988 and Van Wyk & Van Wyk, 1997):

- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Table A1.16. Climatic Data of the Bronkhorstspruit-Middelburg Area (Land Type Survey Staff, 1987, Schulze, 1997 & Johannesburg, 1999).

	Study Area
Average Yearly Temperature (°C)	12-14
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	22.5-25.0
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1200-1600
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days a year

A1.8.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The Loskop Formation follows more or less concordantly on the Rooiberg Group without any trace of a major regional unconformity. The Formation is separated from the overlying Waterberg sediments by a prominent regional unconformity and consists of a thick succession of finely layered siltstone, mudstone, feldspathic sandstone and shale. The deposition of the Loskop Formation is regarded as being the final sedimentary phase of the development of the Transvaal Basin, following directly on the volcanic phase of the Rooiberg Group (Pretoria, 1978). Basic rocks around Bronkhorstspruit form predominantly transgressive sills in the Pretoria Group and are locally also intrusive into Waterberg strata (section 4.10). They include diabase, granophyric quartz-norite, intermediate rocks and pseudorhyolite (Pretoria, 1978).

Sediments of the Loskop Formation are regarded as predominantly arenaceous rocks, like sandstone, on the Johannesburg (1999) map and classified as an intergranular and fractured aquifer with a yield ranging from 360-1800 ℓ/h. If associated with intrusions, the arenaceous rocks will probably be brecciated and jointed (Hattingh, 1996). Aquifers associated with diabase, or described as undifferentiated rocks and mixed lithologies on the Johannesburg (1999) map, are also categorised in the intergranular and fractured aquifer group, but with yields ranging from 1800-7200 ℓ/h.

A1.8.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The Loskop Formation and diabase environments around Bronkhorstspruit were included in the study by Meulenbeld (1998). The geophysical signatures listed under the case studies will be referenced to the mentioned work. The use of magnetics, electromagnetics and Schlumberger soundings on diabase derived soil is advocated due to differences in magnetic intensity and conductivity between sediments and intrusive rocks. Soundings indicate zones of deeper weathering, pointed out by differences in electrical conductivity of the measured dipoles (EM34-3).

Information on geobotanical indicators associated with the sediments of the Loskop Formation and diabase intrusions in the Bronkhorstspruit-Middelburg area is not available. However, geobotanical indicators as found in the same area but linked to other lithologies can be utilised for reference, especially if the basic soil chemical properties are corresponding.

A1.8.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling was undertaken as referenced in the previous sections at the same depths. The results are listed in Tables A1.17(a&b). From these results and the other case studies presented elsewhere, certain remarks can be made regarding available soil nutrients and the presence of geobotanic communities.

Table A1.17a. Vaalium Eonothem: Other geological conditions in the Bronkhorstspruit-Middelburg area: along weathered basin or intrusive contact.

Parameter	Klipeiland 524JR		Rietfontein 314JS	
Geological Formation	Weathered basin in diabase	Weathered basin in diabase	Diabase intrusion in shale, sandstone and conglomerate (Loskop Formation)	Diabase intrusion in shale, sandstone and conglomerate (Loskop Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º49.094’ 28º44.433’	25º49.094’ 28º44.433’	25º50.412’ 29º21.517’	25º50.412’ 29º21.517’
Soil colour	Dark yellowish orange	Strong brown	Moderate brown	Moderate brown
Soil texture description	Silty clay	Clay	Clay	Clay
pH	4.97	5.60	5.68	6.06
P (mg/kg)	1.54	1.30	2.37	2.34
Ca (mg/kg)	340	347	1001	724
Mg (mg/kg)	164	164	355	328
K (mg/kg)	87	83	160	109
Na (mg/kg)	29	20	13	0
Fe (mg/kg)	78.93	45.98	79.49	49.05
Mn (mg/kg)	343.15	216.87	297.75	178.90
Zn (mg/kg)	25.31	0.87	0.24	0.48
Al ($cmol_c$/kg)	0.040	0.041	0.037	0
Resistance (Ohm)	1910	3040	900	1660
C%	0.70	0.49	1.18	0.46
Total N%	0.048	0.036	0.059	0.027

S (mg/kg)	57.93	15.61	60.81	19.39
CEC ($cmol_c$/kg)	11.45	6.77	17.41	17.75
Distinct Tree Species	3. Acacia karroo 4. Euclea crispa	1. Acacia karroo 23. Euclea crispa	5. Acacia karroo 6. Rhus lancea	5. Acacia karroo 6. Rhus lancea
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50
Average depth of weathering (m)	3.2	3.2	2.6	2.6
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	No	No
Aquifer Yield (l/h)	9 000	9 000	7 500	7 500
Borehole Depth (m)	42	42	60	60
Depth of Water Strike (m)	18	18	23	23
Static Water Level (m)	11	11	10	10
Average Aquifer Yield (l/h)	4 600	4 600	5 000	5 000
Average Borehole Depth (m)	39	39	57	57
Average Depth of Water Strike (m)	27	27	24	24
Average Static Water Level (m)	13	13	8	8
Land Type Series	Ab5a Hutton	Ab5a Hutton	Ba37a Hutton	Ba37a Hutton

Profile No	P56	P56	P60	P60
Depth Sampled	1010-1200+mm	1010-1200+mm	200-450mm	200-450mm
Gravel %	1	1	1	1
Sand %	70	70	62	62
Silt %	7	7	33	33
Clay %	22	22	4	4
pH (H_2O)	6.5	6.5	4.9	4.9
P (mg/kg)	2.8	2.8	-	-
Ca (mg/kg)	13026	13026	100	100
Mg (mg/kg)	10085	10085	365	365
K (mg/kg)	391	391	1173	1173
Na (mg/kg)	690	690	115	115
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	68.0	68.0	125.0	125.0
Zn (mg/kg)	0.63	0.63	0.16	0.16
Resistance (Ohm)	590	590	9999	9999
C%	0.3	0.3	0.4	0.4
CEC ($cmol_c$/kg)	163	163	31	31
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.17b. Vaalium Eonothem: Other geological conditions in the Bronkhorstspruit-Middelburg area: no weathered basin or intrusive contact.

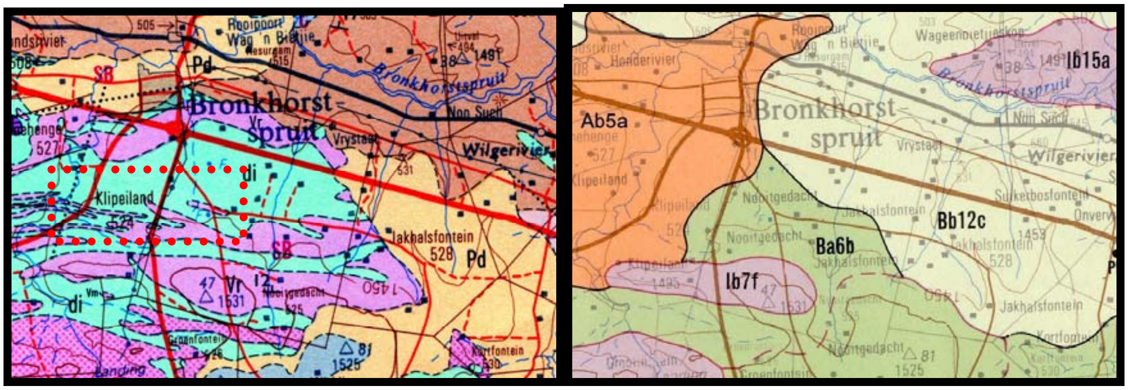
	Klipeiland 524JR		Rietfontein 314JS	
Geological Formation	Shallow weathered diabase	Shallow weathered diabase	Shale, sandstone and conglomerate (Loskop Formation)	Shale, sandstone and conglomerate (Loskop Formation)
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º49.094' 28º44.433'	25º49.094' 28º44.433'	25º50.412' 29º21.517'	25º50.412' 29º21.517'
Soil colour	Yellowish brown	Dark yellowish orange	Very dusky red	Greyish brown
Soil texture description	Clayey silt	Silt	Clayey silt	Silt
pH	6.04	5.67	7.16	7.35
P (mg/kg)	1.65	1.53	2.10	1.81
Ca (mg/kg)	289	282	2381	1375
Mg (mg/kg)	161	112	198	176
K (mg/kg)	54	87	110	83
Na (mg/kg)	5	18	35	6
Fe (mg/kg)	29.19	40.79	57.83	47.52
Mn (mg/kg)	74.72	104.89	443.12	262.06
Zn (mg/kg)	0.12	0.24	0.89	0.83
Al ($cmol_c$/kg)	0	0.062	0	0
Resistance (Ohm)	4650	3720	940	1650
C%	0.54	0.53	0.80	0.14

Total N%	0.035	0.031	0.058	0.013
S (mg/kg)	14.07	15.71	7.62	4.81
CEC ($cmol_c$/kg)	5.68	5.26	8.62	21.54
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50
Average depth of weathering (m)	3.2	3.2	2.6	2.6
Geomorphology	Plain	Plain	Undulating terrain	Undulating terrain
Geophysical instrumentation used	Magnetometer & Schlumberger soundings	Magnetometer & Schlumberger soundings	Magnetometer & Electromagnetics	Magnetometer & Electromagnetics
Water features present?	No	No	No	No
Aquifer Yield (l/h)	9 000	9 000	7 500	7 500
Borehole Depth (m)	42	42	60	60
Depth of Water Strike (m)	18	18	23	23
Static Water Level (m)	11	11	10	10
Average Aquifer Yield (l/h)	4 600	4 600	5 000	5 000
Average Borehole Depth (m)	39	39	57	57
Average Depth of Water Strike (m)	27	27	24	24
Average Static Water Level (m)	13	13	8	8
Land Type Series	Ab5a Hutton	Ab5a Hutton	Ba37a Hutton	Ba37a Hutton

Profile No	P56	P56	P60	P60
Depth Sampled	1010-1200+mm	1010-1200+mm	200-450mm	200-450mm
Gravel %	1	1	1	1
Sand %	70	70	62	62
Silt %	7	7	33	33
Clay %	22	22	4	4
pH (H_2O)	6.5	6.5	4.9	4.9
P (mg/kg)	2.8	2.8	-	-
Ca (mg/kg)	13026	13026	100	100
Mg (mg/kg)	10085	10085	365	365
K (mg/kg)	391	391	1173	1173
Na (mg/kg)	690	690	115	115
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	68.0	68.0	125.0	125.0
Zn (mg/kg)	0.63	0.63	0.16	0.16
Resistance (Ohm)	590	590	9999	9999
C%	0.3	0.3	0.4	0.4
CEC ($cmol_c$/kg)	163	163	31	31
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D3	D3	D2	D2

The average aquifer yield, average borehole depth, average water strike and average static water level were obtained from Frommurze (1937) and Meulenbeld (1998). It must be noted that the presented value is only an average for the geological formation. Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987), veld type information from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

23. Klipeiland 524JR

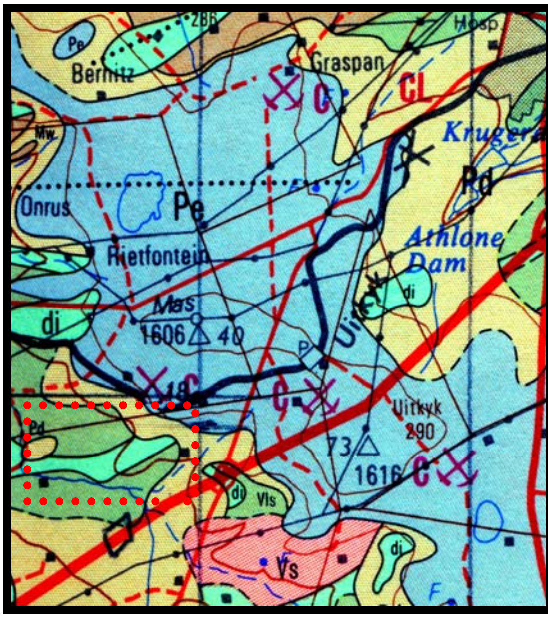


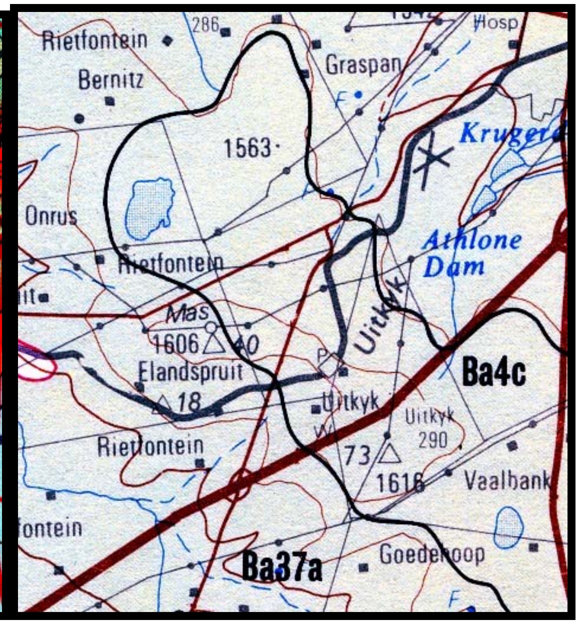
Abbreviation	Geology
Vr	Quartzite, shale, subgraywacke
di	Diabase
Pd	Shale, tillite
……………	Lineament
Abbreviation	**Soil series**
Ab5a	Hutton
Ba6b	Hutton
Bb12c	Clovelly, Glencoe, Avalon
Ib7f	Rock

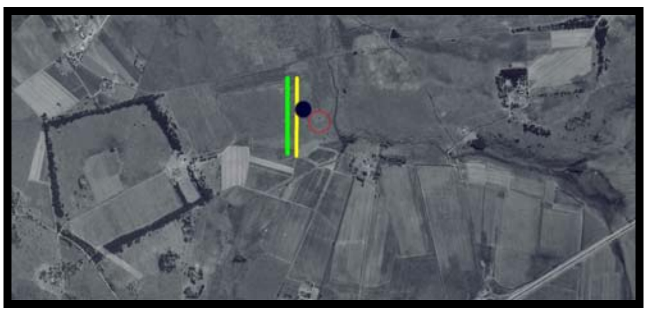
Figure A1.23. The geology (top), land type (middle) and aerial photograph (bottom) of Klipeiland 524JR. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line is the sounding layout. The area covered by the aerial photograph is indicated by the red shape in the geological map.

Klipeiland 524JR is adjoining the Taiwanese development of Bronkhorstspruit. The farm is utilised for the cultivation of crops to sustain the Taiwanese community. Need for irrigation was expressed to reduce drought risk.

24. Rietfontein 314JS







Abbreviation	Geology
Vls	Shale, sandstone, conglomerate
di	Diabase
Pd	Shale, tillite
Pe	Shale, grit, sandstone, coal
……………	Lineament
Abbreviation	**Soil series**
Ba4c	Hutton
Ba37a	Hutton

Figure A1.24. The geology (top), land type (middle) and aerial photograph (bottom) of Rietfontein 314JS. The blue circle denotes the position of the borehole, the green line is the direction of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the red shape in the geological map. The red circle in the aerial photograph indicates indigenous trees (serve as geobotanic indicators).

Southwest of Middelburg, north of the N4-freeway, the farm Rietfontein 314JS is located.

A1.9 MOGOLIAN EONOTHEM: GRANITE OF THE NEBO GRANITE IN THE ROOIBERG-WARMBATHS AND VERENA AREAS

Outcrops of rocks belonging to the Bushveld Igneous Complex are numerous in the central parts of the old Transvaal; now covering parts of the Limpopo, Mpumalanga, Gauteng and North-West Provinces. Some of these rocks were formed during the Vaalium Eonothem, and are discussed in Chapter 4. The Nebo Granite, Mogolian age, as presented in this section belongs to the Lebowa Granite Suite, part of the Bushveld Igneous Complex. The formation of the granite denotes the final stages of the Bushveld Igneous Complex. The granite in the Warmbaths area is separated from the granite in the Verena area by the Springbok Flats, mostly consisting of younger sediments and basalt, overlying the granite, belonging to the Karoo Supergroup (see Chapter 4). Due to the limited number of case studies for both areas, all the case studies will be presented together in this section with the relevant distinctions included regarding climatic and other conditions.

A1.9.1 CASE STUDY AREA

Case studies presented are situated to the northwest of Warmbaths towards the Swaershoek Mountains. This area is dominated by game ranches and extensive cattle farming. Case studies in the Verena area are situated in the Zusterstroom region, between Bronkhorstspruit and Verena. The natural vegetation of this region is altered by large scale intensive irrigation agricultural practices, where water supply is drawn from boreholes and the Wilge River.

A1.9.2 CLIMATE AND VELD TYPES

Both areas' (Warmbaths and Verena) altitude is ranging from 1200 – 1600 m, according to the Johannesburg (1999) and Polokwane (2003) maps. This altitude comparison gives rise to similar climatic conditions, see Table A1.18, with hot and humid summers and cool, dry winters. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms. The veld types that occur (see also Table A1.19a) is Mixed Bushveld in the Verena area and Sourish Mixed Bushveld in the lower regions and Sour Bushveld in the ridges and elevated areas in the Warmbaths area (Acocks, 1988). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Rhus gueinzii* (thorny karree), *Peltophorum africanum* (weeping wattle), *Pappea capensis* (jacket-plum) and *Ziziphus mucronata* (buffalo-thorn).
- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea afri*cana (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.18. Climatic Data of the Verena and Warmbaths Areas (Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity: Verena Area	**Quantity: Warmbaths Area**
Average Yearly Temperature (°C)	16-18	18-20
Mean Minimum Temperature (°C) in July	2-4	2-4
Mean Maximum Temperature (°C) in January	27.5-30.0	27.5-30.0
Average Yearly Rainfall (mm)	600-800	600-800
Elevation (m)	1200-1600	1200-1600
Evaporation (mm/year)	2000-2250	2000-2250
Frost area?	<150 days per year	Almost none

A1.9.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

(a) Warmbaths Area

The Nebo Granite (acid igneous rock) overlies basic rocks of the Bushveld Igneous Complex more or less conformably in the form of a huge sheet-like intrusion. The granite is homogeneous, but varies in grain size and ferromagnesian content, the coarser-grained varieties containing aplitic and pegmatitic sheets and lenses. The Nebo Granite consists of perthite, quartz, plagioclase, hornblende and/or biotite and accessory minerals. Hornblende is the most important mafic mineral in the lower and central parts of the granite sheet; close to the top biotite becomes progressively more important. The anorthite content of the plagioclase near the base of the sheetlike intrusion increases up to about 20%; near the top, in a leucocratic variety, the content of mafic minerals decreases from 11% to 4%. Some lineaments cross the granite in a northwestern-southeastern strike (Nylstroom, 1978).

Prominent structural structures are displayed in the Alma trough, namely the Swaershoekberge anticlinorium and the Nylstroom syncline, with accompanying anticlinal structures (Loubad and Zwartkloof anticlines). Their origin and original non-linear pattern are attributed to late-magmatic Bushveld activity during their embryonic stage. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. The Droogekloof overthrust developed along the Zwartkloof anticline. Fault and fracture structures are frequently intruded by diabase (Nylstroom, 1978).

(b) Verena Area

The Nebo Granite (1 920 $\pm$ 30 Ma) forms a huge sheet with a leucocratic facies near the top (Pretoria, 1978). Porphyritic varieties frequently occur in marginal zones and near Verena they occupy large areas. Another variety in dome-shaped bodies contains fluorite, abundant pegmatite and also porphyritic types. The Dennilton anticline plunges to the south and the Nebo Granite cuts across the limbs and core. Both structures are probably uplifted portions of the floor of the Bushveld Complex. The core of a dome-like structure in the Pretoria Group near Balmoral has been intruded by the Nebo Granite. Broad shallow synclinal brachystructures are developed mainly in Rooiberg lava near

Verena (Pretoria, 1978). Some diabase intrusions occur in stress related fractures in the granite.

As both areas discussed belong to the Nebo Granite, their hydrogeological classification according to the Johannesburg (1999) and Polokwane (2003) maps are coinciding, namely acid intrusive rocks (various granitoids) that define an intergranular and fractured aquifer. Aquifer conditions vary from weathering basins on the contact of fractures and joints and also deep aquifers associated with faults and fractures, especially in the Warmbaths area (Hattingh, 1996). Meulenbeld (1998) and Botha *et al*. (2001) identified fractured aquifers associated with dykes also. Yield from these aquifers range from 360 – 1800 ℓ/h and a depth to the water table of about 38 m in the Warmbaths area, to 1800 – 7200 ℓ/h and a water table depth of 26.5 m in the Verena area (Bonsma, 1976, Johannesburg, 1999 & Polokwane, 2003). However, higher yields are possible as will be indicated (and lower also based on the borehole siting method).

A1.9.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Published geophysical studies in this study area are restricted to a study by Meulenbeld (1998), but only cover the Verena area. A study by Botha *et al*. (2001) focuses on the Nebo Granite, but in the former homeland of Lebowa, to the northeast of the presented case studies. The latter concluded that airborne geophysical data assisted in the identifying and mapping structures of regional extent. The electromagnetic method proved to work exceptionally well in areas of weathering, faults and fractures. However, the use of airborne geophysical data is not always available and if available, or desired, only at great expense to the individual landowner. Geophysics still has to compete with laymen methods and therefore the need for geobotanic indicators. The listed case studies in this thesis will present and discuss geophysical profiles (electromagnetic and magnetic) and direct current soundings.

Geobotanical information is limited to the work of Meulenbeld (1998) that listed *Combretum erythrophyllum* (river bushwillow) on granite derived soil in the Verena (Zusterstroom) area.

A1.9.5 SOIL SAMPLING AND RESULTS PRESENTATION

As in the previous case studies, soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining sample some distance removed from it, not near such a geobotanical indicator. A total of five farms were visited, three in the Warmbaths area and two in the Verena area. The analysis of soil samples taken at these five farms are listed in Tables A1.19(a&b) i & ii.

Table A1.19a (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: along intrusive contact.

Parameter	Droogekloof 471KR		Kareefontein 432KR		Zandfontein 476KQ	
Geological Formation	Diabase/fault structure	Diabase/fault structure	Weathered diabase contact	Weathered diabase contact	Small weathered diabase dyke	Small weathered diabase dyke
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	24º50.239' 28º08.787'	24º50.239' 28º08.787'	24º42.052' 28º01.359'	24º42.052' 28º01.359'	24º40.466' 27º50.332'	24º40.466' 27º50.332'
Soil colour	Moderate reddish brown	Dark red	Strong brown	Yellowish brown	Brown	Moderate brown
Soil texture description	Sandy silt	Silty sand	Clay	Clay	Clayey silt	Clayey silt
pH	5.59	5.49	5.93	5.77	6.37	5.90
P (mg/kg)	1.52	1.14	1.48	0.88	15.81	13.72
Ca (mg/kg)	282	298	532	395	1091	453
Mg (mg/kg)	361	300	220	177	221	113
K (mg/kg)	70	69	29	27	101	68
Na (mg/kg)	38	30	18	120	230	28
Fe (mg/kg)	43.00	23.38	18.18	53.52	73.19	54.82
Mn (mg/kg)	12.30	21.68	17.98	4.90	130.74	119.95
Zn (mg/kg)	0.25	0.23	0.28	0.23	3.23	1.46
Al ($cmol_c$/kg)	1.594	1.775	0.160	0.164	0	0.119
Resistance (Ohm)	6000	5400	3400	2000	1800	2800

C%	0.14	0.15	0.19	0.06	0.44	0.70
Total N%	0.033	0.036	0.018	0.010	0.044	0.065
S (mg/kg)	7.53	17.76	1.63	4.11	15.12	11.02
CEC ($cmol_c$/kg)	9.25	10.35	10.93	7.69	8.675	5.183
Distinct Tree Species	1. Ficus ingens 2. Acacia karroo	1. Ficus ingens 2. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3.Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo
Average rooting depth of the indicated species (m)	12 - 50	12 - 50	5 - 50	5 - 50	5 - 50	5 – 50
Average depth of weathering (m)	1.4	1.4	1.9	1.9	1.7	1.7
Geomorphology	Mountainous	Mountainous	Hills and valleys	Hills and valleys	Plain and ridges	Plain and ridges
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics	Electromagnetics
Water features present?	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	No	No
Aquifer Yield (l/h)	17 000	17 000	5 500	5 500	4 250	4 250
Borehole Depth (m)	60	60	75	75	80	80
Depth of Water Strike (m)	31	31	52	52	54	54
Static Water Level (m)	16	16	19	19	27	27

Average Aquifer Yield (l/h)	1 800	1 800	1 800	1 800	1 800	1 800
Average Borehole Depth (m)	38	38	38	38	38	38
Average Depth of Water Strike (m)	43	43	43	43	43	43
Average Static Water Level (m)	21	21	21	21	21	21
Land Type Series	Fa274a Glenrosa	Fa274a Glenrosa	Ac68a Clovelly	Ac68a Clovelly	Fa4k Clovelly	Fa4k Clovelly
Profile No	P759	P759	P1366	P1366	P755	P755
Depth Sampled	800 – 1090 mm	800 – 1090 mm	300 – 1200 mm	300 – 1200 mm	100 – 520 mm	100 – 520 mm
Gravel %	2	2	1	1	3	3
Sand %	67	67	81	81	87	87
Silt %	8	8	4	4	4	4
Clay %	23	23	14	14	6	6
pH (H_2O)	7.1	7.1	5.5	5.5	6.0	6.0
P (mg/kg)	5.2	5.2	0.7	0.7	1.3	1.3
Ca (mg/kg)	2140	2140	200	200	160	160
Mg (mg/kg)	264	264	36	36	84	84
K (mg/kg)	80	80	78	78	156	156
Na (mg/kg)	23	23	22	22	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	309.9	309.9	0.7	0.7	15.4	15.4
Zn (mg/kg)	0.33	0.33	0.01	0.01	0.35	0.35
Resistance (Ohm)	480	480	6000	6000	4300	4300
C%	0.2	0.2	0.2	0.2	0.4	0.4

CEC (cmol$_c$/kg)	107	107	20	20	30	30
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average borehole depth was obtained from Bonsma (1976), while other geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.19b (i). Mogolian Eonothem: Nebo Granite - Warmbaths Area: intrusive contact absent.

	Droogekloof 471KR		Kareefontein 432KR		Zandfontein 476KQ	
Geological Formation	Granite and sandstone	Granite and sandstone	Granite	Granite	Granite	Granite
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	 24º50.239' 28º08.787'	 24º50.239' 28º08.787'	 24º42.052' 28º01.359'	 24º42.052' 28º01.359'	 24º40.466' 27º50.332'	 24º40.466' 27º50.332'
Soil colour	Moderate yellowish brown	Moderate brown	Strong brown	Moderate brown	Strong brown	Strong brown
Soil texture description	Clayey silt	Silt	Silt	Silt	Quartz sand	Quartz sand
pH	4.78	4.83	5.62	5.26	6.67	6.47
P (mg/kg)	27.92	3.86	11.78	10.17	1.94	0.85
Ca (mg/kg)	137	130	315	279	279	389
Mg (mg/kg)	50	47	93	108	66	69
K (mg/kg)	35	25	68	47	42	49
Na (mg/kg)	34	8	16	3	4	22
Fe (mg/kg)	70.76	71.90	64.79	49.88	12.56	75.72
Mn (mg/kg)	1.23	0.69	142.31	94.28	58.26	97.45
Zn (mg/kg)	0.28	0.37	0.65	1.14	0.38	0.13
Al ($cmol_c$/kg)	2.630	1.741	0.184	0.429	0	0
Resistance (Ohm)	9600	8800	5600	4400	9800	3800

C%	0.64	0.19	0.84	0.56	0.18	0.34
Total N%	0.058	0.021	0.080	0.045	0.017	0.044
S (mg/kg)	8.66	8.02	11.77	23.23	5.79	4.40
CEC ($cmol_c$/kg)	4.95	4.72	4.900	4.128	2.334	3.673
Distinct Tree Species	1. Ficus ingens 2. Acacia karroo	1. Ficus ingens 2. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo	1. Zanthoxylum capense 2. Ximenia caffra 3. Acacia karroo
Average rooting depth of the indicated species (m)	12 - 50	12 - 50	5 - 50	5 - 50	5 - 50	5 – 50
Average depth of weathering (m)	1.4	1.4	1.9	1.9	1.7	1.7
Geomorphology	Mountainous	Mountainous	Hills and valleys	Hills and valleys	Plain and ridges	Plain and ridges
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics	Electromagnetics
Water features present?	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	Yes-dry river bed	No	No
Aquifer Yield (l/h)	17 000	17 000	5 500	5 500	4 250	4 250
Borehole Depth (m)	60	60	75	75	80	80
Depth of Water Strike (m)	31	31	52	52	54	54
Static Water Level (m)	16	16	19	19	27	27

Average Aquifer Yield (l/h)	1 800	1 800	1 800	1 800	1 800	1 800
Average Borehole Depth (m)	38	38	38	38	38	38
Average Depth of Water Strike (m)	43	43	43	43	43	43
Average Static Water Level (m)	21	21	21	21	21	21
Land Type Series	Fa274a Glenrosa	Fa274a Glenrosa	Ac68a Clovelly	Ac68a Clovelly	Fa4k Clovelly	Fa4k Clovelly
Profile No	P759	P759	P1366	P1366	P755	P755
Depth Sampled	800 – 1090 mm	800 – 1090 mm	300 – 1200 mm	300 – 1200 mm	100 – 520 mm	100 – 520 mm
Gravel %	2	2	1	1	3	3
Sand %	67	67	81	81	87	87
Silt %	8	8	4	4	4	4
Clay %	23	23	14	14	6	6
pH (H_2O)	7.1	7.1	5.5	5.5	6.0	6.0
P (mg/kg)	5.2	5.2	0.7	0.7	1.3	1.3
Ca (mg/kg)	2140	2140	200	200	160	160
Mg (mg/kg)	264	264	36	36	84	84
K (mg/kg)	80	80	78	78	156	156
Na (mg/kg)	23	23	22	22	25	25
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	309.9	309.9	0.7	0.7	15.4	15.4
Zn (mg/kg)	0.33	0.33	0.01	0.01	0.35	0.35

Resistance (Ohm)	480	480	6000	6000	4300	4300
C%	0.2	0.2	0.2	0.2	0.4	0.4
CEC ($cmol_c$/kg)	107	107	20	20	30	30
Veld Type	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	20 Sour Bushveld	20 Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld	19/20 Sourish Mixed Bushveld/Sour Bushveld
Hydrogeological Unit	D2	D2	D2	D2	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Average borehole depth was obtained from Bonsma (1976), while other geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.19a (ii). Mogolian Eonothem: Nebo Granite - Verena Area: along intrusive contact.

Parameter	Klipfontein 258JS		Zusterstroom 447JR	
Geological Formation	Weathered diabase contact and deep weathering profile	Weathered diabase contact and deep weathering profile	Weathered diabase contact	Weathered diabase contact
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	 25º36.183’ 29º03.022’	 25º36.183’ 29º03.022’	 25º35.657’ 29º00.619’	 25º35.657’ 29º00.619’
Soil colour	Greyish orange	Pale red	Yellowish brown	Moderate orange pink
Soil texture description	Clayey silt	Clay	Silty clay	Clayey silt
pH	6.76	6.10	5.80	6.00
P (mg/kg)	16.27	15.42	12.88	10.28
Ca (mg/kg)	681	1452	849	1488
Mg (mg/kg)	136	288	775	1593
K (mg/kg)	49	131	39	80
Na (mg/kg)	77	533	96	72
Fe (mg/kg)	34.35	221.43	45.85	56.45
Mn (mg/kg)	50.58	857.58	52.75	65.27
Zn (mg/kg)	0.34	2.86	0.25	3.47
Al ($cmol_c$/kg)	0	0	1.080	0.894
Resistance (Ohm)	3400	1300	2600	3000
C%	0.16	0.29	0.03	0.04
Total N%	0.020	0.027	0.008	0.013
S (mg/kg)	9.01	48.11	26.29	21.40
CEC ($cmol_c$/kg)	5.503	12.107	16.624	22.096

Distinct Tree Species	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Combretum erythrophyllum 2. Acacia karroo	1. Combretum erythrophyllum 2. Acacia karroo
Average rooting depth of the indicated species (m)	12	12	12 - 50	12 - 50
Average depth of weathering (m)	0.8	0.8	0.8	0.8
Geomorphology	Plain with scattered tors	Plain with scattered tors	Plain	Plain
Geophysical instrumentation used	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes, river 400m south	Yes, river 400m south	No	No
Aquifer Yield (l/h)	55 000	55 000	18 000	18 000
Borehole Depth (m)	60	60	60	60
Depth of Water Strike (m)	18	18	15	15
Static Water Level (m)	8	8	12	12
Average Aquifer Yield (l/h)	3 750	3 750	3 750	3 750
Average Borehole Depth (m)	37	37	37	37
Average Depth of Water Strike (m)	23	23	23	23
Average Static Water Level (m)	9	9	9	9
Land Type Series	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa
Profile No	P67	P67	P67	P67
Depth Sampled	200-450mm	200-450mm	200-450mm	200-450mm

Gravel %	2	2	2	2
Sand %	62	62	62	62
Silt %	8	8	8	8
Clay %	28	28	28	28
PH (H_2O)	4.9	4.9	4.9	4.9
P (mg/kg)	1.1	1.1	1.1	1.1
Ca (mg/kg)	400	400	400	400
Mg (mg/kg)	50	50	50	50
K (mg/kg)	290	290	290	290
Na (mg/kg)	10	10	10	10
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	10.3	10.3	10.3	10.3
Zn (mg/kg)	0.65	0.65	0.65	0.65
Resistance (Ohm)	5900	5900	5900	5900
C%	0.3	0.3	0.3	0.3
CEC ($cmol_c$/kg)	15.0	15.0	15.0	15.0
Veld Type	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.19b (ii). Mogolian Eonothem: Nebo Granite - Verena Area: intrusive contact absent.

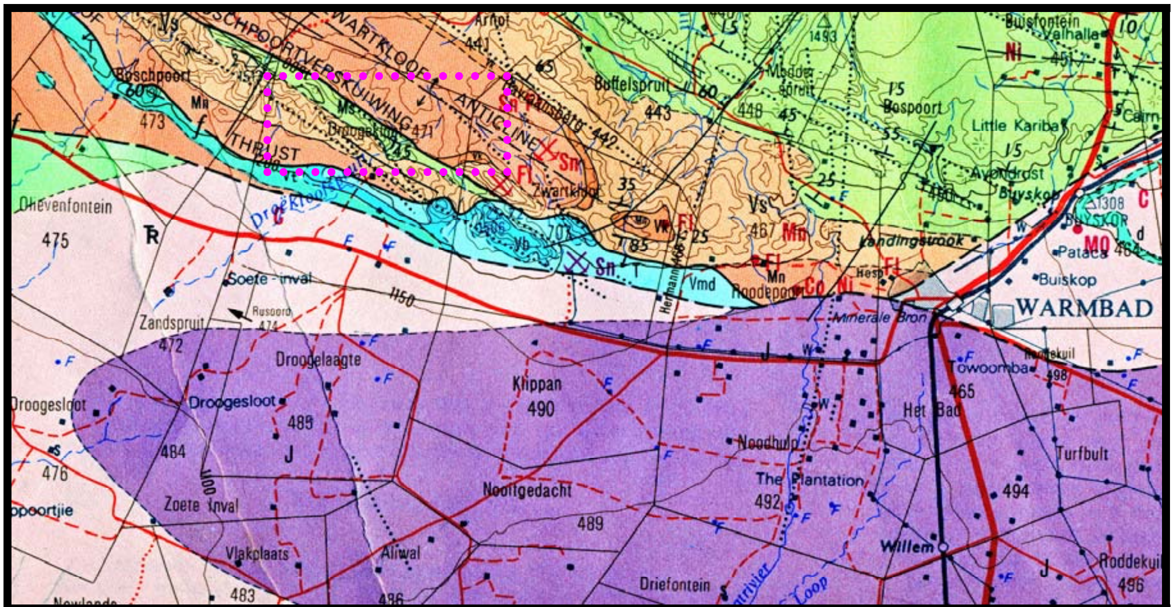
Parameter	Klipfontein 258JS		Zusterstroom 447JR	
Geological Formation	Granite	Granite	Granite	Granite
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	25º36.183’	25º36.183’	25º35.657’	25º35.657’
E.L.	29º03.022’	29º03.022’	29º00.619’	29º00.619’
Soil colour	Light brown	Dark yellowish orange	Dark yellowish orange	Moderate brown
Soil texture description	Quartz sand	Quartz clayey silt	Silty sand	Silty sand
pH	7.00	5.40	5.44	5.12
P (mg/kg)	0.92	0.88	15.08	13.13
Ca (mg/kg)	367	493	117	107
Mg (mg/kg)	159	234	47	42
K (mg/kg)	144	153	33	16
Na (mg/kg)	21	43	14	12
Fe (mg/kg)	44.73	137.99	8.02	7.98
Mn (mg/kg)	63.83	141.77	2.05	1.85
Zn (mg/kg)	0.33	0.44	0.17	0.33
Al ($cmol_c$/kg)	0	0.950	0.340	0.298
Resistance (Ohm)	7200	3000	30000	26000
C%	0.12	0.09	0.29	0.29
Total N%	0.024	0.023	0.020	0.022
S (mg/kg)	29.01	79.75	19.89	12.92
CEC ($cmol_c$/kg)	15.21	29.25	8.464	9.836

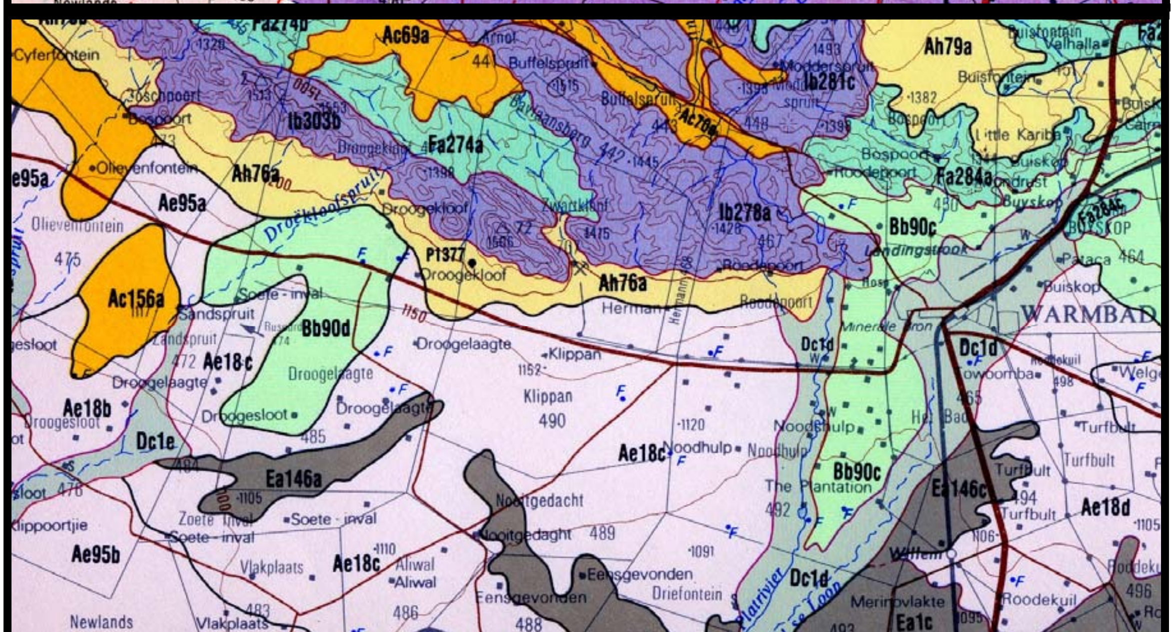
Distinct Tree Species	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Combretum erythrophyllum 2. Acacia karroo	1. Combretum erythrophyllum 2. Acacia karroo
Average rooting depth of the indicated species (m)	12	12	12 - 50	12 - 50
Average depth of weathering (m)	0.8	0.8	0.8	0.8
Geomorphology	Plain with scattered tors	Plain with scattered tors	Plain	Plain
Geophysical instrumentation used	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes, river 400m south	Yes, river 400m south	No	No
Aquifer Yield (l/h)	55 000	55 000	18 000	18 000
Borehole Depth (m)	60	60	60	60
Depth of Water Strike (m)	18	18	15	15
Static Water Level (m)	8	8	12	12
Average Aquifer Yield (l/h)	3 750	3 750	3 750	3 750
Average Borehole Depth (m)	37	37	37	37
Average Depth of Water Strike (m)	23	23	23	23
Average Static Water Level (m)	9	9	9	9
Land Type Series	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa	Bb10a Mispah, Avalon, Glenrosa
Profile No	P67	P67	P67	P67
Depth Sampled	200-450mm	200-450mm	200-450mm	200-450mm
Gravel %	2	2	2	2
Sand %	62	62	62	62

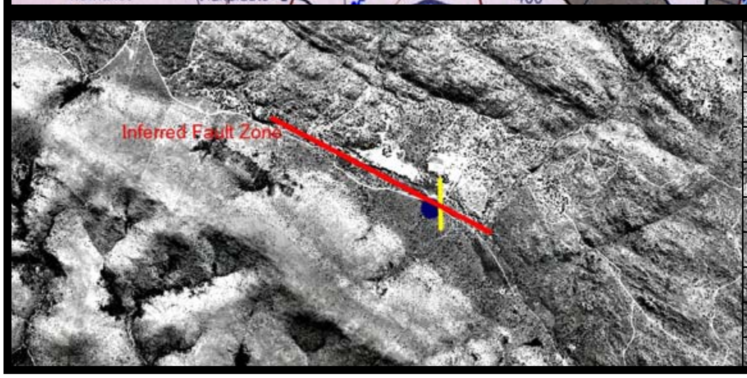
Silt %	8	8	8	8
Clay %	28	28	28	28
PH (H_2O)	4.9	4.9	4.9	4.9
P (mg/kg)	1.1	1.1	1.1	1.1
Ca (mg/kg)	400	400	400	400
Mg (mg/kg)	50	50	50	50
K (mg/kg)	290	290	290	290
Na (mg/kg)	10	10	10	10
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	10.3	10.3	10.3	10.3
Zn (mg/kg)	0.65	0.65	0.65	0.65
Resistance (Ohm)	5900	5900	5900	5900
C%	0.3	0.3	0.3	0.3
CEC ($cmol_c$/kg)	15.0	15.0	15.0	15.0
Veld Type	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

25. Droogekloof 471KR





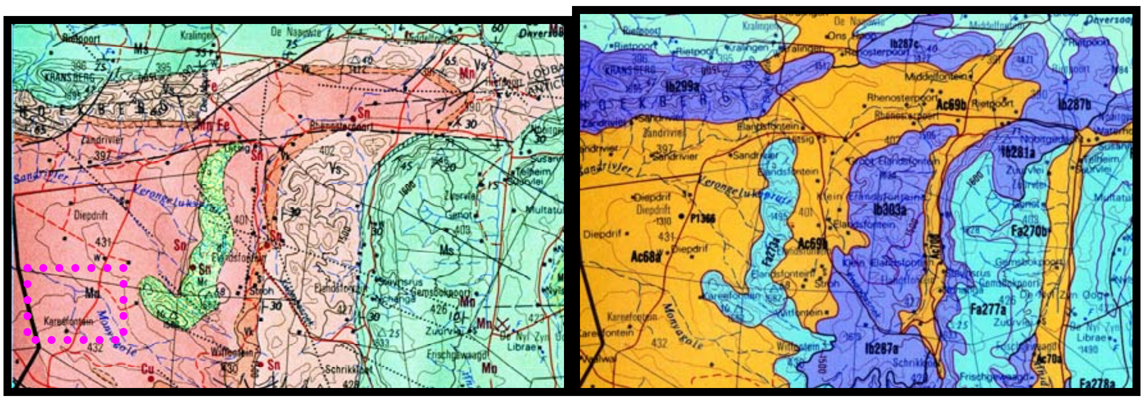


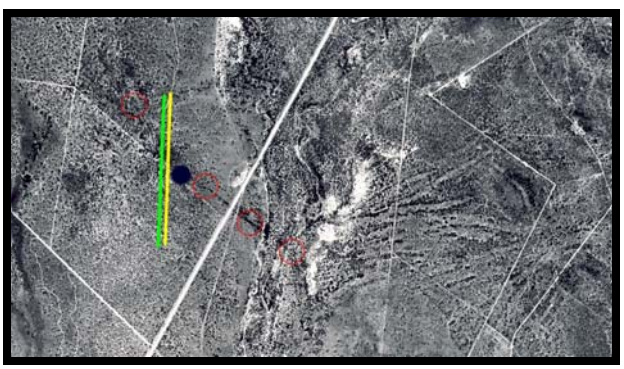
Abbreviation	Geology
Vmd	Dolomite
Vs	Rhyolite
Mn	Granite
Ms	Sandstone
Abbreviation	**Soil series**
Ac69a	Clovelly
Ah76a	Hutton
Fa274a	Glenrosa, Mispah
Ib303b	Rock

Figure A1.25. The geology (top), land type (middle) and aerial photograph (bottom) of Droogekloof 471KR. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The farm Droogekloof was previously visited (Chapter 4, case study 6), although this portion of the farm is north of the mountain range that divides the Springbok Flats from the Waterberg interior. Droogekloof is approximately 10 km to the west of Warmbaths.

26. Kareefontein 432KR

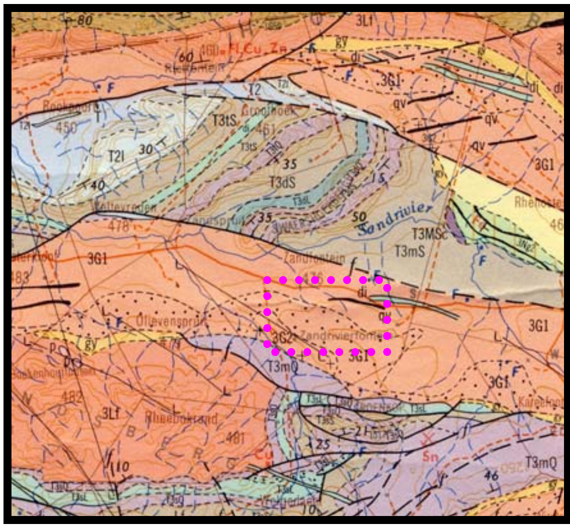


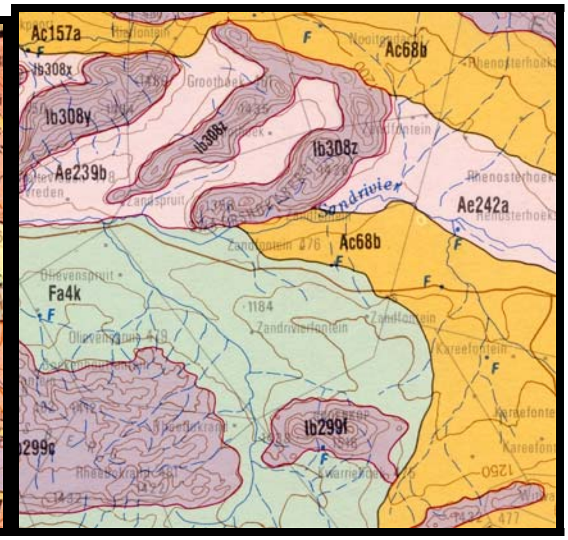


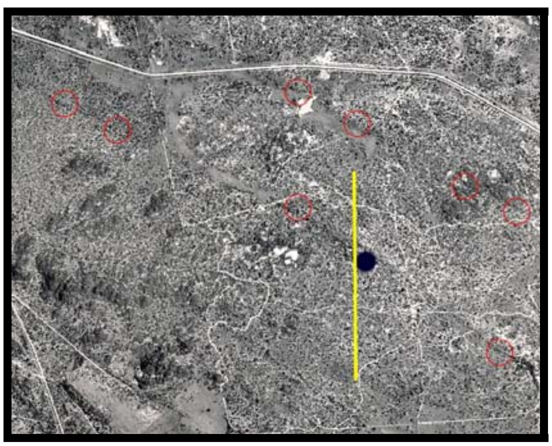
Abbreviation	Geology
Vk	Rhyolite
Mr	Granophyre
Mn	Granite
………………	Lineament
Abbreviation	**Soil series**
Ac68a	Clovelly
Fa273a	Rock

Figure A1.26. The geology (top left), land type (top right) and aerial photograph (bottom) of Kareefontein 432KR. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile and the yellow line indicates the electromagnetic profile. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineament is indicated by the red circles in the aerial photograph.

27. Zandfontein 476KQ



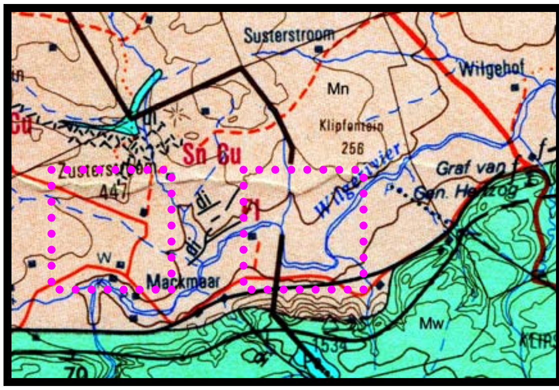


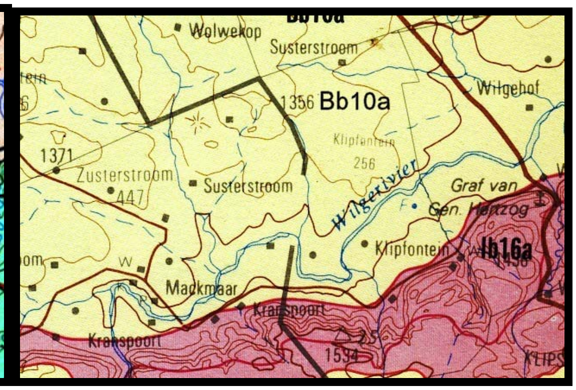


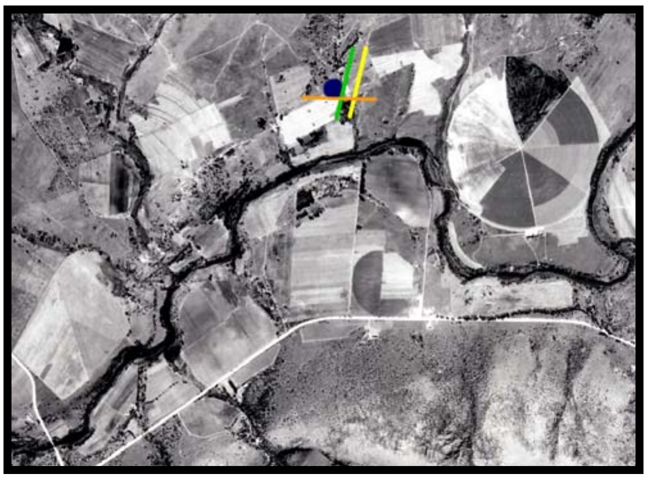
Abbreviation	Geology
T3mS	Shale, hornfels
T3mQ	Quartzite
3G1	Granite
qv	Quartz vein
di	Diabase
Abbreviation	**Soil series**
Ac68b	Clovelly
Fa4k	Clovelly
Ib308z	Rock

Figure A1.27. The geology (top left), land type (top right) and aerial photograph (bottom) of Zandfontein 476KQ. The blue circle denotes the position of the borehole and the yellow line indicates the electromagnetic profile direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The lineaments are indicated by the red circles in the aerial photograph, although the upper circles can represent the quartz vein as indicated on the geological map.

28. Klipfontein 256JS







Abbreviation	Geology
Mn	Granite
Ms	Sandstone
di	Diabase
Abbreviation	**Soil series**
Bb10a	Mispah, Glenrosa, Clovelly
Ib16a	Rock

Figure A1.28. The geology (top left), land type (top right) and aerial photograph (bottom) of Klipfontein 256JS. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map.

29. Zusterstroom 447JR

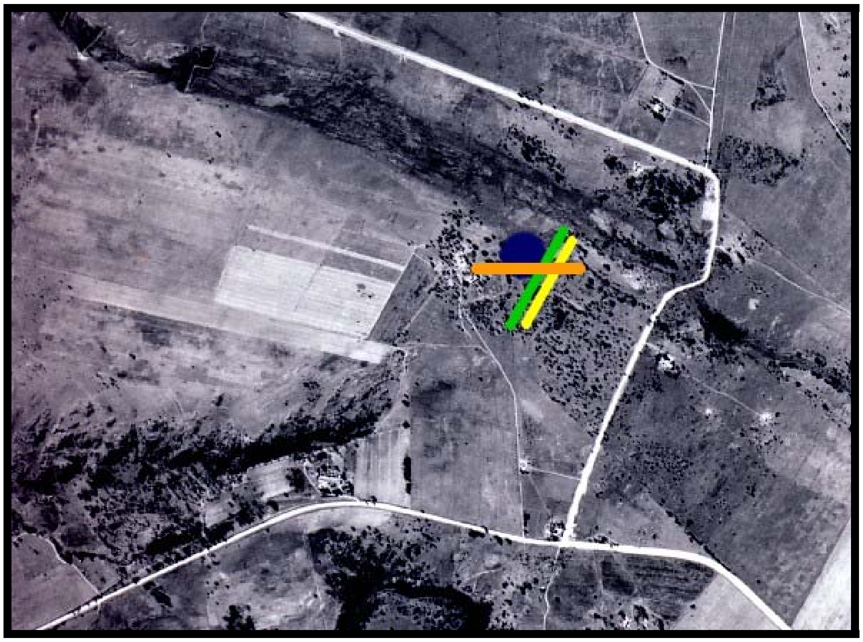


Figure A1.29. The geology (top left, Figure A1.28), land type (top right, Figure A1.28) and aerial photograph of Zusterstroom 447JR. The blue circle denotes the position of the borehole, the green line the orientation of the magnetic profile, the yellow line indicates the electromagnetic profile and the orange line the direction of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.28).

Zusterstroom 447JR is in close proximity of the case study Klipfontein 256JS, some 5 km to the west. The Wilge River is a bit further away from this farm and subsequently no irrigation practices from the river are taken place.

A1.10 MOGOLIAN EONOTHEM: THE WATERBERG GROUP IN THE WATERBERG AND MIDDELBURG AREAS

Sedimentary rocks forming part of the Waterberg Group are exposed in the vast Waterberg wilderness, around the village of Vaalwater towards the Soutpansberg in the north. A localised outcrop is prominent east of Pretoria extending till Middelburg, some 150 km east of Pretoria. The Waterberg Group is composed primarily of arenaceous rocks, implying sandstone. Sandstone does not weather easily and a resulting positive topography is experienced, not always suitable to land farming practices, depending of the soil depth. In most cases the soil is sandy in the absence of any intrusions and poor in nutrients. Extensive cattle farming, game ranching, nature reserves and wilderness areas are quite common activities encountered in the Waterberg Group. The Waterberg Group is one of the final stages of geological development in the northern parts of South Africa, as some time elapsed to the next and last major geological event that encapsulated southern Africa, namely the developing of the Karoo Supergroup (see Chapter 4).

A1.10.1 CASE STUDY AREA

A large number of case studies are presented from the Wilgerivier Formation, around the towns of Bronkhorstspruit, Witbank and Middelburg. The Waterberg Group around Alma and Baltimore in the Limpopo Province is also investigated and listed. Due to the small amount of case studies available in the latter region, they are included with the former case studies of the Wilgerivier Formation, part of the Waterberg Group.

A1.10.2 CLIMATE AND VELD TYPES

The climatic conditions vary considerably in the case study areas, becoming moist and colder towards the southeast. The altitude in the Baltimore area ranges from 800 m to 1200 meter. The Waterberg plateau and Wilgerivier Formation is on average elevated 1200 m to 1600 m above sea level, one of the reasons for the higher rainfall and isolated climatic conditions than the surrounding lower lying areas around the Waterberg plateau (see Table A1.20). Few areas are in excess of 1600 meter above sealevel. Rainfall is characteristic continental as the winters are dry and cool to cold in the southeast and hot and wet summers. The wet season lasts approximately from October to April with rainfall occurring mostly as heavy thunderstorms.

The veld types that occur (see also Table A1.21a) are Mixed Bushveld in the lower regions of the Waterberg area and Sour Bushveld in the ridges and elevated areas in the Waterberg area. Sourish Mixed Bushveld occurs in the northern localities of the Wilgerivier Formation basin and Bankenveld towards the south of the basin (Acocks, 1988). The following tree species are eminent of these veld types (after Bonsma, 1976, Acocks, 1988 and Van Wyk & Van Wyk, 1997), all veld types are part of the savanna biome, except the Bankenveld veld type which represents a transgression between the grassland and savanna biomes:

- Mixed Bushveld: *Acacia caffra* (common hook-thorn), *Burkea africana* (wild seringa), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Grewia flava* (velvet raisin) and *Mundulea sericea* (cork bush).
- Arid Sweet Bushveld: *Adansonia digitata* (baobab), *Grewia flava* (velvet raisin) and *Acacia mellifera* (black thorn).
- Sourish Mixed Bushveld: *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn) & *A. tortillis subsp. heteracantha* (umbrella thorn), *Pappea capensis* (jacket-plum), *Peltophorum africanum* (weeping wattle), *Rhus gueinzii* (thorny karree) and *Ziziphus mucronata* (buffalo-thorn).
- Sour Bushveld: *Acacia caffra* (common hook-thorn), *Combretum molle* (velvet bushwillow) & *C. apiculatum* (red bushwillow) & *C. zeyheri* (large-fruited bushwillow), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Burkea afri*cana (wild seringa), *Ochna pulchra* (peeling plane), *Olea europaea subsp. africana* (wild olive), *Ficus ingens* (red-leaved fig) and *Strychnos pungens* (spine-leaved monkey orange).
- Bankenveld: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.20. Climatic Data of the Waterberg and Bronkhorstspruit-Middelburg Areas (Bonsma, 1976, Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity: Waterberg Area	Quantity: Bronkhorstspruit-Middelburg Area
Average Yearly Temperature (°C)	16-20	14-18
Mean Minimum Temperature (°C) in July	2-6	2-4
Mean Maximum Temperature (°C) in January	27.5-32.5	25.0-27.5
Average Yearly Rainfall (mm)	400-800	600-800
Elevation (m)	800-1600	1200-1600
Evaporation (mm/year)	2250-2500	1750-2250
Frost area?	None to <150 days a year	150-175 days a year

A1.10.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

(a) Waterberg Area

The Waterberg basin around Alma and Vaalwater occupies the north-western portion of the Bushveld region and consists of two overlapping basins. In the deep basin in the south (Alma trough) beds of the Swaershoek, Alma and Sterkrivier Formation were laid down. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin. The entire succession is predominantly arenaceous, but the Aasvoëlkop and Vaalwater Formations are in part argillaceous and the Alma and Vaalwater Formations are also partly arkosic. The oldest subdivision, the lower portion of the Swaershoek Formation, is of late-Bushveld age and confined to protobasins of which the largest coincides approximately with the Nylstroom syncline. The Alma, Schilpadkop and Aasvoëlkop Formations are poorly exposed, as a rule only the conglomeratic beds are seen. The Alma Formation becomes less feldspatic to the east and the partly argillaceous Aasvoëlkop Formation grades into the arenaceous Makgabeng Formation (Nylstroom, 1978).

Prominent structural structures are displayed in the Alma trough, namely the Swaershoekberge anticlinorium and the Nylstroom syncline, with accompanying anticlinal structures (Loubad and Zwartkloof anticlines). Their origin and original non-linear pattern are attributed to late-magmatic Bushveld activity during their embryonic stage. Subsequent folding, flexing and faulting during Waterberg and post-Waterberg times transformed the embryonic structures into their present shape and locally their limbs were tilted to the vertical or over-turned. Block-faulting took place in early Waterberg times and gentle folding after deposition of the Alma Formation. To the north the succession in the late-Waterberg basin was hardly affected, with the exception of the area north of the Swaershoek Mountains, where beds of the Schilpadkop Formation are tilted to the vertical and of the Sandriviersberg Formation by 30º. Post-Waterberg tensional faults and fractures are frequently intruded by diabase dykes (Nylstroom, 1978).

In the Baltimore area, close to the Limpopo River and Botswana border, the rocks of the Waterberg Group, a mainly sedimentary succession, underlie the area where they form a conspicuous plateau intersected by narrow steep valleys. The rocks were deposited in the northern portion of the so-called late-Waterberg basin (Jansen, 1975) a large shallow intracratonic depression whose northern boundary was structurally controlled. The Mogalakwena Formation rests with a mainly conformable contact on the Makgabeng Sandstone Formation. It reaches a thickness of about 1 500 m and consists of purplish brown, coarse-grained sandstone with interbedded conglomerate and boulder conglomerate. The conglomerates occur mainly at three stratigraphic levels and form units up to 100 m thick. The well-rounded clasts may attain a diameter of 80 cm, but in general they measure between 3 and 10 cm. They consist largely of those rocks present in the Limpopo Mobile Belt (Brandl, 1986). According to Tickell (1975) the coarse arenaceous succession resembles deposition in braided streams. Palaeocurrent directions inferred from cross-bed attitudes in the sandstone indicate that most of the sediments were carried from a source lying north-east and east of the Waterberg basin.

Along the Melinda Fault the Waterberg rocks were downthrown to the south in pre-Karoo times. Vertical displacement was about 1 000 m. In post-Karoo times the fault was reactivated with a downthrow to the north. The throw was at least several hundred meters (Brandl, 1986).

(b) Bronkhorstspruit-Middelburg Area

The Waterberg Group is represented in this area by the Wilgerivier Formation. The Formation consists of a thick continuous sequence, about 2 000 m thick, of red to red-brown arenaceous sediments including quartzite, grit and sandstone (SACS, 1980 & Visser, 1989). Crossbedding occurs frequently. The Formation is separated from the underlying rocks by a prominent unconformity and it also rests with a sedimentary contact on the Nebo Granite. Its age is consequently less than 1 920 $\pm$ 30 Ma (Pretoria, 1978). This sedimentary basin is probably a protobasin of early Waterberg age and displays dips of about five degrees to the centre of the basin. The entire basin was subsequently transformed into a broad asymmetrical syncline, but around and east of Rhenosterkop (Chapter 4) the strata in the northern limb were faulted, thrust and tilted, probably also along reactivated boundary faults of the basin (Pretoria, 1978). Numerous diabase sills and dykes intrude the Formation. Inspection of borehole logs indicates that the sills can vary in thickness from less than a metre to more than 150 meters. The sills are usually weathered on the contact with the country rock. Geophysical measurements found dykes as thin as 10 m and as wide as 150 m in the study area. Although weathering of the dyke/country contact rock is the norm, exceptions do occur (Meulenbeld & Hattingh, 1999).

(c) Hydrogeological classification

Groundwater in sedimentary rocks is generally encountered in cracks, fissures, bedding planes, pore space and contact zones with intrusions (Hattingh, 1996). Sedimentary rocks of the Wilgerivier Formation are generally weak aquifers. These rocks are classified as predominantly arenaceous rocks (sandstone, feldspathic sandstone, arkose, shale and grit) and act as fractured aquifers (Johannesburg, 1999). Palaeo-weathering, deeply weathered overburden, fissures and cracks in intrusive rocks are the main aquifers found in the Wilgerivier Formation in the study area (Meulenbeld & Hattingh, 1999). Fissures, cracks, intergranular and fractured pores and rock are associated with Karoo overburden that overlies sedimentary rocks of the Wilgerivier Formation at some localities, normally the Dwyka Formation (Johannesburg, 1999). Subsequently the average yield of the arenaceous rocks is 360-1800 ℓ/h that can be increased if associated with weathered diabase contact zones to average yields between 1800-7200 ℓ/h (Meulenbeld, 1998) and with a Karoo overburden to an average yield of 360-7200 ℓ/h (Johannesburg, 1999). The average yield of the arenaceous rocks in the Waterberg area (Vaalwater-Baltimore) is around 1800-7200 ℓ/h (Polokwane, 2003).

A1.10.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Meulenbeld (1998) has studied the Wilgerivier Formation in the past in some depth and Meulenbeld & Hattingh (1999) published a paper dealing solemnly with groundwater exploration in the Wilgerivier Formation. These studies deal with applicable geophysical methods to be utilised in this formation together with some notes on geobotany and geohydrology. Some of the case studies published by Meulenbeld (1998) are included in this study with information relating to this specific research. As this section contains numerous Schlumberger depth sounding models, Meulenbeld (1998) reckons that a H-type curve is a reasonable indicator for confined aquifers. Sounding curves that are preferable to locate aquifers are KH, HA and QH, or a combination of them. Van Zijl (1987) discusses definitions and examples of sounding type curves. In the study of Meulenbeld (1998) it was noted that species like *Acacia* prefer clay soils derived from weathered diabase intrusions and hence a distinction can be made in the field based on geobotany relating to soil differences; sand soil derived from weathered sandstone and clay soil covered with *Acacia* trees derived from weathered diabase. Weathered diabase intrusions are encountered frequently in the Wilgerivier Formation and are preferable aquifers. The Waterberg Group hosts also diabase intrusions, but on a more restricted scale than found in the Wilgerivier Formation.

The following observation by Bonsma (1976) need consideration. Thorn tree roots have nodule growth on their roots, like cycads, that are responsible for nitrogen assimilation and fixation. Nitrogen, together with other macro-nutrients like carbon, sulphur, phosphorus and potassium, are important to feed *in situ* microorganisms that are associated with the nodules (for instance a blue-green alga *Anabaena* in the case of cycads) and to supply the kind of vegetation with carbohydrates, lipids, proteins and nucleic acids (Giddy, 1974 & Cloete, 2002). Occurrence of thorn trees, like in this instance, is indicative of a higher soil pH and a resultant higher availability of available calcium and phosphorus to the nodules of root systems (although the pH-P relationship is not always clear as reflected in the study's soil sample geochemical analysis, but rather a distinct relationship between CEC-Ca,Mg-values). Hence, nitrogen fixation can occur. A resultant of this is that grasses that grow in association with thorn trees obtain also a share of the available nitrogen (like fertiliser) and grow taller and appear darker/bluer in appearance than the surrounding grasses. Such grass is called sweet grass. In cases where the pH drops (sandy soil not in association with an intrusion), the calcium and phosphorus content decrease with an increase in the iron content. Nitrogen fixation is low and consequently nitrogen availability to plants and grass also. In this instance such type of grass is called sour grass (Bonsma, 1976).

In addition to the above on geobotanical information, Walker & Bothma (2005) describe the Waterberg area as follows. Most areas of the Waterberg Mountain range are underlain by sandstone, shale and quartzite. Soils derived from these sources are usually nutrient-poor, sandy or sandy-loam soils, with a poor water-holding capacity and rapid water infiltration. They vary from shallow to deep. The vegetation on such soils is usually dominated by broad-leaved trees which are generally taller than the more fine-leaved trees such as the ana tree *Faidherbia albida* and various *Acacia* species which by preference grow on the more clay soils produced from granitic (magmatic) parent rock material. These clay soils have a higher nutrient status, and water percolates slowly through it. The grazing there remains palatable and nutritious in the winter.

A1.10.5 SOIL SAMPLING AND RESULTS PRESENTATION

The soil analysis of the case studies are presented in Tables A1.21(a&b) i-iv. Soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining sample some distance removed from it, not near such a geobotanical indicator. Two farms in the Waterberg (Vaalwater-Baltimore) area were visited and ten farms in the Bronkhorstspruit-Middelburg area, representing the Wilgerivier Formation of the Waterberg Group.

Table A1.21a (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: along intrusive contact.

Parameter	Hartbeesfontein 394KR		Pennsylvania 336LR	
Geological Formation	Lineament in the Schilpadkop Formation	Lineament in the Schilpadkop Formation	Lineament in the Mogalakwena Formation	Lineament in the Mogalakwena Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:				
S.L.	24º34.687’	24º34.687’	23º15.459’	23º15.459’
E.L.	28º06.612’	28º06.612’	28º30.117’	28º30.117’
Soil colour	Dark reddish brown	Moderate reddish brown	Dark reddish brown	Dark red
Soil texture description	Clayey silt	Silty clay	Loam	Loamy sand
pH	5.50	5.06	5.70	6.24
P (mg/kg)	3.07	2.69	2.56	2.19
Ca (mg/kg)	168	111	259	282
Mg (mg/kg)	69	40	104	83
K (mg/kg)	46	31	47	31
Na (mg/kg)	4	9	8	32
Fe (mg/kg)	31.44	30.20	21.32	11.00
Mn (mg/kg)	193.71	25.68	197.53	86.34
Zn (mg/kg)	0.28	0.41	0.38	0.39
Al ($cmol_c$/kg)	0.408	0.559	0	0
Resistance (Ohm)	7000	9900	14000	16000
C%	0.15	0.31	0.21	0.06
Total N%	0.020	0.029	0.018	0.008
S (mg/kg)	23.28	12.25	22.58	7.21
CEC ($cmol_c$/kg)	4.433	3.399	3.754	2.620

Distinct Tree Species	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Combretum imberbe	1. Combretum imberbe
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	20	20
Average depth of weathering (m)	2.7	2.7	2.2	2.2
Geomorphology	Gentle northern slope towards stream	Gentle northern slope towards stream	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Magnetics	Magnetics
Water features present?	Yes, stream 700m north	Yes, stream 700m north	No	No
Aquifer Yield (l/h)	15 000	15 000	8 000	8 000
Borehole Depth (m)	64	64	70	70
Depth of Water Strike (m)	37	37	41	41
Static Water Level (m)	18	18	25	25
Average Aquifer Yield (l/h)	2 600	2 600	4 000	4 000
Average Borehole Depth (m)	56	56	43	43
Average Depth of Water Strike (m)	34	34	38	38
Average Static Water Level (m)	17	17	22	22
Land Type Series	Ac 153a Hutton	Ac 153a Hutton	Bc51a Hutton	Bc51 Hutton
Profile No	P1367	P1367	P1823	P1823
Depth Sampled	1000 – 1200 mm	1000 – 1200 mm	200 – 1000 mm	200 – 1000 mm
Gravel %	0	0	1.1	1.1
Sand %	92	92	57.6	57.6
Silt %	1	1	6.6	6.6

Clay %	7	7	34.7	34.7
pH (H_2O)	4.3	4.3	6.68	6.68
P (mg/kg)	1.8	1.8	2.40	2.40
Ca (mg/kg)	20	20	64	64
Mg (mg/kg)	9	9	38	38
K (mg/kg)	37	37	8	8
Na (mg/kg)	4	4	21	21
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	0.7	0.7	19.70	19.70
Zn (mg/kg)	0.14	0.14	0.10	0.10
Resistance (Ohm)	6200	6200	180	180
C%	0.1	0.1	0.13	0.13
CEC ($cmol_c$/kg)	12	12	8.00	8.00
Veld Type	18/20 Mixed/Sour Bushveld	18/20 Mixed/Sour Bushveld	14/18 Arid Sweet/Mixed Bushveld	14/18 Arid Sweet/Mixed Bushveld
Hydrogeological Unit	B3	B3	B3	B3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21b (i). Mogolian Eonothem: Waterberg Group – Vaalwater-Baltimore Area: intrusive contact absent.

Parameter	Hartbeesfontein 394KR		Pennsylvania 336LR	
Geological Formation	Schilpadkop Formation sandstone	Schilpadkop Formation sandstone	Sandstone of the Mogalakwena Formation and alluvium	Sandstone of the Mogalakwena Formation and alluvium
Depth Sampled	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	 24º34.687’ 28º06.612’	 24º34.687’ 28º06.612’	 23º15.459’ 28º30.117’	 23º15.459’ 28º30.117’
Soil colour	Pale reddish brown	Dark reddish brown	Light brown	Weak red
Soil texture description	Sand	Silty sand	Sand	Sand
pH	5.76	6.02	4.85	4.93
P (mg/kg)	2.44	1.94	5.24	3.74
Ca (mg/kg)	175	190	82	87
Mg (mg/kg)	71	76	31	31
K (mg/kg)	44	40	10	10
Na (mg/kg)	48	18	18	5
Fe (mg/kg)	10.37	7.95	54.53	9.30
Mn (mg/kg)	59.19	49.93	0.77	0.85
Zn (mg/kg)	0.46	0.29	0.18	0.40
Al ($cmol_c$/kg)	0	0	0.936	0.520
Resistance (Ohm)	18000	24000	18000	22000
C%	0.09	0.06	0.55	0.14
Total N%	0.013	0.009	0.023	0.020
S (mg/kg)	9.20	8.46	10.19	16.67
CEC ($cmol_c$/kg)	2.759	2.283	2.799	1.673

Distinct Tree Species	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Acacia karroo 2. Rhus lancea 3. Strychnos pungens 4. Ximenia caffra	1. Combretum imberbe	1. Combretum imberbe
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	20	20
Average depth of weathering (m)	2.7	2.7	2.2	2.2
Geomorphology	Gentle northern slope towards stream	Gentle northern slope towards stream	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Magnetics	Magnetics
Water features present?	Yes, stream 700m north	Yes, stream 700m north	No	No
Aquifer Yield (l/h)	15 000	15 000	8 000	8 000
Borehole Depth (m)	64	64	70	70
Depth of Water Strike (m)	37	37	41	41
Static Water Level (m)	18	18	25	25
Average Aquifer Yield (l/h)	2 600	2 600	4 000	4 000
Average Borehole Depth (m)	56	56	43	43
Average Depth of Water Strike (m)	34	34	38	38
Average Static Water Level (m)	17	17	22	22
Land Type Series	Ac 153a Hutton	Ac 153a Hutton	Bc51a Hutton	Bc51a Hutton
Profile No	P1367	P1367	P1823	P1823
Depth Sampled	1000 – 1200 mm	1000 – 1200 mm	200 – 1000 mm	200 – 1000 mm
Gravel %	0	0	1.1	1.1
Sand %	92	92	57.6	57.6
Silt %	1	1	6.6	6.6

Clay %	7	7	34.7	34.7
pH (H_2O)	4.3	4.3	6.68	6.68
P (mg/kg)	1.8	1.8	2.40	2.40
Ca (mg/kg)	20	20	64	64
Mg (mg/kg)	9	9	38	38
K (mg/kg)	37	37	8	8
Na (mg/kg)	4	4	21	21
Fe (mg/kg)	-	-	-	-
Mn (mg/kg)	0.7	0.7	19.70	19.70
Zn (mg/kg)	0.14	0.14	0.10	0.10
Resistance (Ohm)	6200	6200	180	180
C%	0.1	0.1	0.13	0.13
CEC ($cmol_c$/kg)	12	12	8.00	8.00
Veld Type	18/20 Mixed/Sour Bushveld	18/20 Mixed/Sour Bushveld	14/18 Arid Sweet/Mixed Bushveld	14/18 Arid Sweet/Mixed Bushveld
Hydrogeological Unit	B3	B3	B3	B3

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21a (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: along intrusive contact.

Parameter	Elandsfontein 493JR		Leeuwfontein 492JR		Onspoed 500JR	
Geological Formation	Deep weathering	Deep weathering	Weathered diabase contact	Weathered diabase contact	Weathered diabase dyke/lineament	Weathered diabase dyke/lineament
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º42.707' 28º56.652'	25º42.707' 28º56.652'	25º43.903' 28º51.929'	25º43.903' 28º51.929'	25º46.311' 28º52.134'	25º46.311' 28º52.134'
Soil colour	Dusky red	Moderate brown	Dusky red	Dark red	Dark brown	Greyish brown
Soil texture description	Clay	Silty clay	Silty clay	Silty clay	Clay	Clay
pH	6.10	6.24	5.88	6.29	6.50	6.58
P (mg/kg)	1.26	1.18	1.45	1.41	1.18	0.84
Ca (mg/kg)	1285	1200	952	1078	1940	1760
Mg (mg/kg)	381	509	448	560	727	755
K (mg/kg)	70	58	76	76	53	48
Na (mg/kg)	10	27	40	25	25	59
Fe (mg/kg)	61.18	66.11	41.59	69.36	68.97	131.49
Mn (mg/kg)	266.28	152.69	180.74	230.46	320.55	478.92
Zn (mg/kg)	0.58	0.37	0.33	0.34	0.32	0.32
Al ($cmol_c$/kg)	0	0	0.154	0.118	0	0
Resistance (Ohm)	2600	2200	2000	2800	900	2000
C%	1.57	1.46	1.14	1.00	1.20	1.98
Total N%	0.112	0.094	0.078	0.074	0.089	0.133

S (mg/kg)	10.85	14.92	31.25	10.79	12.44	15.89
CEC ($cmol_c$/kg)	12.04	13.18	14.83	15.53	19.01	13.00
Distinct Tree Species	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4.Zanthoxylum capense	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Burkea africana	1. Acacia karroo 2. Burkea africana
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	50	50	2 - 50	2 - 50
Average depth of weathering (m)	2.1	2.1	2.1	2.1	0.6	0.6
Geomorphology	Typical Bankenveld: ridges and valleys	Typical Bankenveld: ridges and valleys	Gently undulating terrain	Gently undulating terrain	Valley surrounded by cliffs	Valley surrounded by cliffs
Geophysical instrumentation used	Schlumberger depth sounding	Schlumberger depth sounding	Magnetics & Schlumberger depth soundings	Magnetics & Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings

Water features present?	No	No	No	No	Yes, Wilge River 500m north	Yes, Wilge River 500m north
Aquifer Yield (l/h)	11 000	11 000	5 000	5 000	22 500	22 500
Borehole Depth (m)	45	45	60	60	180	180
Depth of Water Strike (m)	23	23	25	25	18	18
Static Water Level (m)	4	4	7	7	5	5
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ib15a Rock, Mispah	Ib15a Rock, Mispah
Profile No	P65	P65	P65	P65	No Data	No Data
Depth Sampled	660-980mm	660-980mm	660-980mm	660-980mm	-	-
Gravel %	3	3	3	3	-	-
Sand %	26	26	26	26	-	-
Silt %	15	15	15	15	-	-
Clay %	56	56	56	56	-	-
pH (H_2O)	6.1	6.1	6.1	6.1	-	-

P (mg/kg)	0.0	0.0	0.0	0.0	-	-
Ca (mg/kg)	6950	6950	6950	6950	-	-
Mg (mg/kg)	4120	4120	4120	4120	-	-
K (mg/kg)	390	390	390	390	-	-
Na (mg/kg)	450	450	450	450	-	-
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	65.8	65.8	65.8	65.8	-	-
Zn (mg/kg)	0.35	0.35	0.35	0.35	-	-
Resistance (Ohm)	1200	1200	1200	1200	-	-
C%	0.9	0.9	0.9	0.9	-	-
CEC ($cmol_c$/kg)	109	109	109	109	-	-
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21b (ii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: intrusive contact absent.

Parameter	Elandsfontein 493JR		Leeuwfontein 492JR		Onspoed 500JR	
Geological Formation	Partially weathered sandstone	Partially weathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º42.707’ 28º56.652’	25º42.707’ 28º56.652’	25º43.903’ 28º51.929’	25º43.903’ 28º51.929’	25º46.311’ 28º52.134’	25º46.311’ 28º52.134’
Soil colour	Dusky red	Dark reddish brown	Strong brown	Moderate brown	Moderate brown	Strong brown
Soil texture description	Sand	Silty sand	Sand	Sandy silt	Sandy silt	Silty sand
pH	5.80	4.68	5.72	5.79	4.94	4.62
P (mg/kg)	1.75	0.96	3.68	1.90	2.13	0.92
Ca (mg/kg)	154	128	222	189	177	210
Mg (mg/kg)	54	49	80	68	72	95
K (mg/kg)	17	29	56	45	42	71
Na (mg/kg)	17	32	6	8	11	52
Fe (mg/kg)	8.07	45.90	30.89	21.25	21.19	25.25
Mn (mg/kg)	4.63	1.79	23.99	18.48	113.43	80.66
Zn (mg/kg)	0.47	0.34	0.78	0.47	0.40	0.50
Al ($cmol_c$/kg)	0.548	0.783	0.271	0.114	0.957	0.316
Resistance (Ohm)	20000	4200	4600	5400	3600	920

C%	0.12	0.46	0.87	0.53	0.65	0.23
Total N%	0.016	0.043	0.063	0.034	0.055	0.027
S (mg/kg)	5.78	37.96	14.51	16.15	71.71	150.19
CEC ($cmol_c$/kg)	3.38	3.60	3.06	2.62	4.20	7.53
Distinct Tree Species	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo 2. Combretum erythro-phyllum 3. Euclea crispa 4. Zanthoxylum capense	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Burkea africana	1. Acacia karroo 2. Burkea africana
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	50	50	2 - 50	2 - 50
Average depth of weathering (m)	2.1	2.1	2.1	2.1	0.6	0.6
Geomorphology	Typical Bankenveld: ridges and valleys	Typical Bankenveld: ridges and valleys	Gently undulating terrain	Gently undulating terrain	Valley surrounded by cliffs	Valley surrounded by cliffs

Geophysical instrumentation used	Schlumberger depth sounding	Schlumberger depth sounding	Magnetics & Schlumberger depth soundings	Magnetics & Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings	Magnetics, Electromagnetics and Schlumberger depth soundings
Water features present?	No	No	No	No	Yes, Wilge River 500m north	Yes, Wilge River 500m north
Aquifer Yield (l/h)	11 000	11 000	5 000	5 000	22 500	22 500
Borehole Depth (m)	45	45	60	60	180	180
Depth of Water Strike (m)	23	23	25	25	18	18
Static Water Level (m)	4	4	7	7	5	5
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe	Ib15a Rock, Mispah	Ib15a Rock, Mispah
Profile No	P65	P65	P65	P65	No Data	No Data
Depth Sampled	660-980mm	660-980mm	660-980mm	660-980mm	-	-
Gravel %	3	3	3	3	-	-

Sand %	26	26	26	26	-	-
Silt %	15	15	15	15	-	-
Clay %	56	56	56	56	-	-
pH (H_2O)	6.1	6.1	6.1	6.1	-	-
P (mg/kg)	0.0	0.0	0.0	0.0	-	-
Ca (mg/kg)	6950	6950	6950	6950	-	-
Mg (mg/kg)	4120	4120	4120	4120	-	-
K (mg/kg)	390	390	390	390	-	-
Na (mg/kg)	450	450	450	450	-	-
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	65.8	65.8	65.8	65.8	-	-
Zn (mg/kg)	0.35	0.35	0.35	0.35	-	-
Resistance (Ohm)	1200	1200	1200	1200	-	-
C%	0.9	0.9	0.9	0.9	-	-
CEC ($cmol_c$/kg)	109	109	109	109	-	-
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21a (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: along intrusive contact.

Parameter	Onverwacht 532JR		Trigaardspoort 451JR		Vlakfontein 453JR	
Geological Formation	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase dyke/lineament	Weathered diabase dyke/lineament
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º50.779' 28º53.187'	25º50.779' 28º53.187'	25º39.854' 28º55.455'	25º39.854' 28º55.455'	25º41.223' 28º52.426'	25º41.223' 28º52.426'
Soil colour	Dark reddish brown	Moderate brown	Strong brown	Dark reddish brown	Dusky red	Moderate brown
Soil texture description	Clay	Silty clay	Clay	Clay	Loam	Loam
pH	5.65	5.76	6.63	6.18	6.04	6.47
P (mg/kg)	1.11	1.07	1.45	1.14	29.32	0.89
Ca (mg/kg)	910	890	1140	1105	535	684
Mg (mg/kg)	367	406	339	313	152	216
K (mg/kg)	59	90	52	61	218	137
Na (mg/kg)	12	31	29	13	25	12
Fe (mg/kg)	48.39	51.08	88.13	99.53	79.45	88.10
Mn (mg/kg)	90.47	61.72	205.13	186.29	161.58	49.24
Zn (mg/kg)	0.42	0.35	0.29	0.36	3.63	0.44
Al ($cmol_c$/kg)	0.145	0.164	0	0	0	0
Resistance (Ohm)	2000	2600	2400	2600	2800	2600
C%	1.28	1.46	1.95	1.25	1.00	0.84

Total N%	0.088	0.096	0.125	0.088	0.068	0.080
S (mg/kg)	71.53	34.80	13.36	24.44	8.70	6.08
CEC ($cmol_c$/kg)	9.98	10.62	13.21	20.83	6.635	7.240
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Euclea crispa	1. Euclea crispa	1. Combretum erythrophyllum	1. Combretum erythrophyllum
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4	4	12	12
Average depth of weathering (m)	1.4	1.4	1.9	1.9	2.1	2.1
Geomorphology	Terraces among sandstone ridges	Terraces among sandstone ridges	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain
Geophysical instrumentation used	Magnetics & Schlumberger depth sounding	Magnetics & Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics & Electromagnetics	Magnetics & Electromagnetics
Water features present?	No	No	Yes, spring 40m north	Yes, spring 40m north	No	No
Aquifer Yield (l/h)	3 000	3 000	3 500	3 500	18 000	18 000
Borehole Depth (m)	40	40	70	70	60	60

Depth of Water Strike (m)	23	23	3, 28	3, 28	18	18
Static Water Level (m)	12	12	2	2	12	12
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Bb12c Clovelly, Glencoe, Avalon	Bb12c Clovelly, Glencoe, Avalon	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe
Profile No	P58	P58	P58	P58	P65	P65
Depth Sampled	180-560mm	180-560mm	180-560mm	180-560mm	660-980mm	660-980mm
Gravel %	0	0	0	0	3	3
Sand %	88	88	88	88	26	26
Silt %	2	2	2	2	15	15
Clay %	10	10	10	10	56	56
pH (H_2O)	5.2	5.2	5.2	5.2	6.1	6.1
P (mg/kg)	1.2	1.2	1.2	1.2	0.0	0.0
Ca (mg/kg)	400	400	400	400	6950	6950
Mg (mg/kg)	50	50	50	50	4120	4120

K (mg/kg)	775	775	775	775	390	390
Na (mg/kg)	40	40	40	40	450	450
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	7.0	7.0	7.0	7.0	65.8	65.8
Zn (mg/kg)	0.98	0.98	0.98	0.98	0.35	0.35
Resistance (Ohm)	8900	8900	8900	8900	1200	1200
C%	0.5	0.5	0.5	0.5	0.9	0.9
CEC (cmol$_c$/kg)	32	32	32	32	109	109
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2/D2	B2/D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21b (iii). Mogolian Eonothem: Waterberg Group – Bronkhorstspruit Area: intrusive contact absent.

Parameter	Onverwacht 532JR		Trigaardspoort 451JR		Vlakfontein 453JR	
Geological Formation	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone and diabase	Unweathered sandstone and diabase
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates:						
S.L.	25º50.779'	25º50.779'	25º39.854'	25º39.854'	25º41.223'	25º41.223'
E.L.	28º53.187'	28º53.187'	28º55.455'	28º55.455'	28º52.426'	28º52.426'
Soil colour	Moderate brown	Dark reddish brown	Moderate brown	Strong brown	Strong brown	Dark reddish brown
Soil texture description	Sand	Sand	Sandy silt	Silty sand	Loam	Loam
pH	5.30	4.69	4.87	5.47	5.90	5.80
P (mg/kg)	3.19	1.75	2.77	2.20	2.81	30.32
Ca (mg/kg)	223	139	139	198	382	481
Mg (mg/kg)	56	47	46	61	147	130
K (mg/kg)	70	43	28	31	53	175
Na (mg/kg)	70	5	4	16	0	20
Fe (mg/kg)	29.80	71.12	26.36	30.99	24.17	39.83
Mn (mg/kg)	33.92	6.99	58.50	182.65	17.64	93.96
Zn (mg/kg)	0.49	0.48	0.37	0.41	0.53	5.49
Al ($cmol_c$/kg)	0.449	0.634	1.064	0.381	0	0
Resistance (Ohm)	5000	6200	9200	30000	2200	1800

C%	0.37	0.28	0.89	0.52	0.64	0.64
Total N%	0.035	0.026	0.067	0.042	0.054	0.054
S (mg/kg)	8.41	17.59	23.13	24.29	12.41	8.42
CEC ($cmol_c$/kg)	3.70	2.12	5.30	3.38	3.688	4.396
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Acacia karroo 2. Euclea crispa 3. Strychnos pungens	1. Euclea crispa	1. Euclea crispa	1. Combretum erythrophyllum	1. Combretum erythrophyllum
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4	4	12	12
Average depth of weathering (m)	1.4	1.4	1.9	1.9	2.1	2.1
Geomorphology	Terraces among sandstone ridges	Terraces among sandstone ridges	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain	Gently undulating terrain
Geophysical instrumentation used	Magnetics & Schlumberger depth sounding	Magnetics & Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics & Electromagnetics	Magnetics & Electromagnetics
Water features present?	No	No	Yes, spring 40m north	Yes, spring 40m north	No	No
Aquifer Yield (l/h)	3 000	3 000	3 500	3 500	18 000	18 000

Borehole Depth (m)	40	40	70	70	60	60
Depth of Water Strike (m)	23	23	3, 28	3, 28	18	18
Static Water Level (m)	12	12	2	2	12	12
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15
Land Type Series	Bb12c Clovelly, Glencoe, Avalon	Bb12c Clovelly, Glencoe, Avalon	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Bb17b Mispah, Clovelly, Hutton, Avalon, Rock	Ba13c Hutton, Avalon, Glencoe	Ba13c Hutton, Avalon, Glencoe
Profile No	P58	P58	P58	P58	P65	P65
Depth Sampled	180-560mm	180-560mm	180-560mm	180-560mm	660-980mm	660-980mm
Gravel %	0	0	0	0	3	3
Sand %	88	88	88	88	26	26
Silt %	2	2	2	2	15	15
Clay %	10	10	10	10	56	56
pH (H_2O)	5.2	5.2	5.2	5.2	6.1	6.1
P (mg/kg)	1.2	1.2	1.2	1.2	0.0	0.0
Ca (mg/kg)	400	400	400	400	6950	6950

Mg (mg/kg)	50	50	50	50	4120	4120
K (mg/kg)	775	775	775	775	390	390
Na (mg/kg)	40	40	40	40	450	450
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	7.0	7.0	7.0	7.0	65.8	65.8
Zn (mg/kg)	0.98	0.98	0.98	0.98	0.35	0.35
Resistance (Ohm)	8900	8900	8900	8900	1200	1200
C%	0.5	0.5	0.5	0.5	0.9	0.9
CEC ($cmol_c$/kg)	32	32	32	32	109	109
Veld Type	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2/D2	B2/D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21a (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: along intrusive contact.

Parameter	Bankfontein 264JS		Bankplaas 239JS		Buffelskloof 342JS		Goedehoop 244JS	
Geological Formation	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase contact	Weathered diabase sill, ±20m below surface	Weathered diabase sill, ±20m below surface	Weathered diabase sill, close to surface	Weathered diabase sill, close to surface
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º38.893’ 29º19.297’	25º38.893’ 29º19.297’	25º31.255’ 29º20.128’	25º31.255’ 29º20.128’	25º32.207’ 29º34.194’	25º32.207’ 29º34.194’	25º35.057’ 29º29.622’	25º35.057’ 29º29.622’
Soil colour	Strong brown	Dark reddish brown	Strong brown	Moderate reddish brown	Dark reddish brown	Dusky yellowish brown	Strong brown	Moderate brown
Soil texture description	Clay	Clay	Clayey silt	Clay	Clay	Silty clay	Clay	Clay
pH	5.85	5.90	5.37	6.37	6.26	6.37	6.14	5.97
P (mg/kg)	2.24	1.79	1.56	1.37	1.58	1.38	3.19	0.96
Ca (mg/kg)	546	526	263	1066	1080	1363	323	342
Mg (mg/kg)	217	216	84	446	763	1454	245	188
K (mg/kg)	264	245	33	40	72	89	82	106
Na (mg/kg)	33	12	21	32	18	58	21	30
Fe (mg/kg)	66.23	72.92	46.62	38.94	47.41	64.95	66.61	35.77
Mn (mg/kg)	187.09	148.97	198.39	111.79	76.36	95.64	229.04	133.95
Zn (mg/kg)	0.82	0.48	0.39	0.11	0.22	0.42	0.68	0.76
Al ($cmol_c$/kg)	0.184	0.174	0.321	0	0	0	0	0.135
Resistance (Ohm)	3000	3200	2650	2020	1110	740	2900	3400

C%	1.99	2.01	0.83	1.39	1.22	1.38	0.37	0.58
Total N%	0.128	0.119	0.058	0.063	0.074	0.071	0.038	0.051
S (mg/kg)	23.24	18.99	28.41	10.15	10.15	21.45	19.33	20.54
CEC ($cmol_c$/kg)	9.16	10.31	6.36	13.02	14.99	22.54	8.03	7.69
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50	2 - 50	2 - 50	4 - 50	4 - 50
Average depth of weathering (m)	1.5	1.5	1.7	1.7	1.9	1.9	2.2	2.2
Geomorphology	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Plain	Plain	Broad valley	Broad valley
Geophysical instrumentation used	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Schlumberger depth soundings	Schlumberger depth soundings

Water features present?	No	No	No	No	No	No	Yes, stream 500m south	Yes, stream 500m south
Aquifer Yield (l/h)	3 800	3 800	3 250	3 250	3 500	3 500	2 700	2 700
Borehole Depth (m)	65	65	59	59	50	50	32	32
Depth of Water Strike (m)	10, 24	10, 24	26	26	21	21	15	15
Static Water Level (m)	8	8	14	14	8	8	6	6
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15	15	15
Land Type Series	Bb16f Clovelly, Mispah, Hutton, Rock	Bb16f Clovelly, Mispah, Hutton, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a Hutton	Ba37a Hutton
Profile No	No Data	No Data	P77	P77	P68	P68	P78	P78
Depth Sampled	-	-	650-1100mm	650-1100mm	270-740mm	270-740mm	330-690mm	330-690mm
Gravel %	-	-	1	1	1	1	0	0
Sand %	-	-	34	34	57	57	84	84

Silt %	-	-	12	12	7	7	4	4
Clay %	-	-	53	53	35	35	12	12
pH (H_2O)	-	-	6.5	6.5	6.1	6.1	5.2	5.2
P (mg/kg)	-	-	0.3	0.3	1.6	1.6	1.2	1.2
Ca (mg/kg)	-	-	10500	10500	800	800	400	400
Mg (mg/kg)	-	-	4000	4000	47	47	50	50
K (mg/kg)	-	-	380	380	390	390	15	15
Na (mg/kg)	-	-	230	230	660	660	10	10
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	-	222.5	222.5	0.4	0.4	0.4	0.4
Zn (mg/kg)	-	-	0.40	0.40	0.70	0.70	0.25	0.25
Resistance (Ohm)	-	-	1600	1600	6100	6100	6000	6000
C%	-	-	0.8	0.8	0.6	0.6	0.5	0.5
CEC ($cmol_c$/kg)	-	-	140		68	68	28	28
Veld Type	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.21b (iv). Mogolian Eonothem: Waterberg Group – Middelburg Area: intrusive contact absent.

Parameter	Bankfontein 264JS		Bankplaas 239JS		Buffelskloof 342JS		Goedehoop 244JS	
Geological Formation	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone	Unweathered sandstone
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	 25º38.893’ 29º19.297’	 25º38.893’ 29º19.297’	 25º31.255’ 29º20.128’	 25º31.255’ 29º20.128’	 25º32.207’ 29º34.194’	 25º32.207’ 29º34.194’	 25º35.057’ 29º29.622’	 25º35.057’ 29º29.622’
Soil colour	Light brown	Yellowish brown	Moderate brown	Moderate brown	Strong brown	Dark yellowish orange	Dusky red	Dark reddish brown
Soil texture description	Silt	Sandy silt	Sand	Sand	Sand	Sand	Sand	Sand
pH	4.93	4.77	5.21	4.89	5.03	5.37	4.50	5.38
P (mg/kg)	2.09	1.41	1.70	1.49	2.85	1.75	2.58	1.94
Ca (mg/kg)	144	152	136	129	126	176	171	153
Mg (mg/kg)	66	59	52	49	46	60	87	66
K (mg/kg)	87	103	18	20	13	15	18	20
Na (mg/kg)	22	12	3	0	10	26	19	29
Fe (mg/kg)	34.54	69.43	32.80	41.62	21.64	20.16	74.79	23.05
Mn (mg/kg)	22.59	233.06	113.20	144.59	2.17	1.40	13.42	23.67
Zn (mg/kg)	0.28	0.50	0.26	0.37	0.24	0.25	0.20	0.23
Al ($cmol_c$/kg)	0.858	1.471	0.501	0.620	0.651	0.237	0.685	0.412
Resistance (Ohm)	5400	7200	7200	5710	9000	18000	2000	8000
C%	0.91	0.42	0.57	0.69	0.35	0.27	1.02	0.17

Total N%	0.074	0.034	0.033	0.039	0.037	0.053	0.086	0.020
S (mg/kg)	20.39	42.01	45.09	41.57	23.65	41.52	10.81	5.85
CEC ($cmol_c$/kg)	4.17	6.50	5.10	4.40	4.95	3.52	3.68	2.62
Distinct Tree Species	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Burkea africana 3. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa
Average rooting depth of the indicated species (m)	4 - 50	4 - 50	4 - 50	4 - 50	2 - 50	2 - 50	4 - 50	4 - 50
Average depth of weathering (m)	1.5	1.5	1.7	1.7	1.9	1.9	2.2	2.2
Geomorphology	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Typical Bankenveld: sandstone ridges and terraces	Plain	Plain	Broad valley	Broad valley

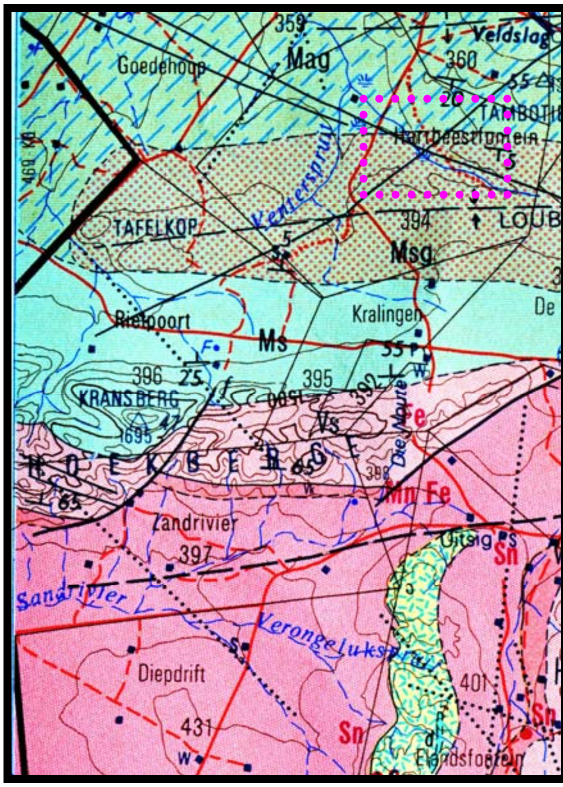
Geophysical instrumentation used	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Magnetics, Electromagnetics and Schlumberger depth sounding	Schlumberger depth soundings	Schlumberger depth soundings
Water features present?	No	No	No	No	No	No	Yes, stream 500m south	Yes, stream 500m south
Aquifer Yield (l/h)	3 800	3 800	3 250	3 250	3 500	3 500	2 700	2 700
Borehole Depth (m)	65	65	59	59	50	50	32	32
Depth of Water Strike (m)	10, 24	10, 24	26	26	21	21	15	15
Static Water Level (m)	8	8	14	14	8	8	6	6
Average Aquifer Yield (l/h)	3 000	3 000	3 000	3 000	3 000	3 000	3 000	3 000
Average Borehole Depth (m)	55	55	55	55	55	55	55	55
Average Depth of Water Strike (m)	20	20	20	20	20	20	20	20
Average Static Water Level (m)	15	15	15	15	15	15	15	15
Land Type Series	Bb16f Clovelly, Mispah, Hutton, Rock	Bb16f Clovelly, Mispah, Hutton, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba15a/Bb16f Hutton, Clovelly, Avalon, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a/Bb16g Hutton, Clovelly, Mispah, Rock	Ba37a Hutton	Ba37a Hutton

Profile No	No Data	No Data	P77	P77	P68	P68	P78	P78
Depth Sampled	-	-	650-1100mm	650-1100mm	270-740mm	270-740mm	330-690mm	330-690mm
Gravel %	-	-	1	1	1	1	0	0
Sand %	-	-	34	34	57	57	84	84
Silt %	-	-	12	12	7	7	4	4
Clay %	-	-	53	53	35	35	12	12
pH (H_2O)	-	-	6.5	6.5	6.1	6.1	5.2	5.2
P (mg/kg)	-	-	0.3	0.3	1.6	1.6	1.2	1.2
Ca (mg/kg)	-	-	10500	10500	800	800	400	400
Mg (mg/kg)	-	-	4000	4000	47	47	50	50
K (mg/kg)	-	-	380	380	390	390	15	15
Na (mg/kg)	-	-	230	230	660	660	10	10
Fe (mg/kg)	-	-	-	-	-	-	-	-
Mn (mg/kg)	-	-	222.5	222.5	0.4	0.4	0.4	0.4
Zn (mg/kg)	-	-	0.40	0.40	0.70	0.70	0.25	0.25
Resistance (Ohm)	-	-	1600	1600	6100	6100	6000	6000
C%	-	-	0.8	0.8	0.6	0.6	0.5	0.5
CEC ($cmol_c$/kg)	-	-	140		68	68	28	28
Veld Type	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61/19 Bankenveld/ Sourish Mixed Bushveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	B2	B2	B2	B2	B2	B2	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937) and Meulenbeld (1998). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

The following case studies are representative of the Waterberg Group in the Waterberg area, see also Table A1.21(a&b) i.

30. Hartbeesfontein 394KR

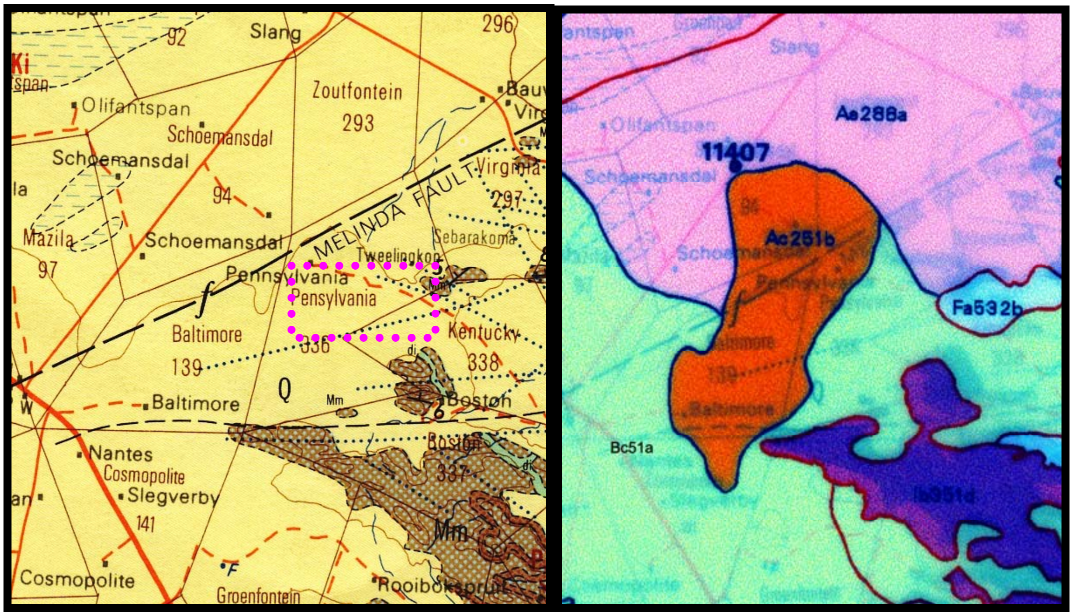


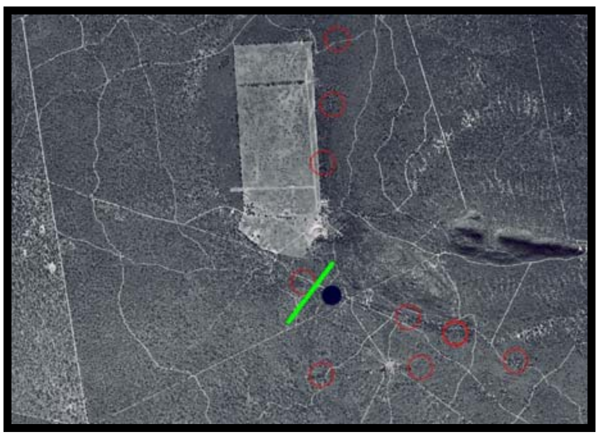
Abbreviation	Geology
Mag	Sandstone, mudstone
Ms	Sandstone
Msg	Sandstone, conglomerate
Abbreviation	**Soil series**
Ac153a	Hutton
Bb88a	Clovelly
Ib299a	Rock

Figure A1.30. The geology (top left), land type (top right) and aerial photograph (bottom) of Hartbeesfontein 394KR. The blue circle denotes the position of the borehole and the green and yellow lines indicates the direction of the magnetic and electromagnetic profiles respectively. The area covered by the aerial photograph is indicated by the purple shape in the geological map. The red lines represent lineaments (compare with the geological map).

The farm is south of Alma, about 32 km south of the village of Vaalwater. The close proximity of streams, namely tributaries of the Venter Spruit, and favourable aquifer conditions due to the presence of structural conditions in the sub-surface, contribute to the diverse agricultural enterprises in this environment. Along the stream some irrigation practices is taken place, where irrigation water is drawn from the stream, dams and boreholes. Further away from the stream, extensive cattle farming practices occur alongside game farming. The change in farming activities stresses the importance of the stream to supply water for irrigation, as the boreholes water quantity must be insufficient to satisfy the water demands of crops in this hot, dry and sandy environment. The hot, dry and sandy environment is hosting typical botanic species that one would associate with this kind of habitat setup. Botanical species like *Burkea africana* (wild seringa), *Combretum molle* (velvet bushwillow), *C. apiculatum* (red bushwillow), *C. zeyheri* (large-fruited bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Mundulea sericea* (Cork bush), *Ochna pulchra* (Peeling plane) and *Terminalia sericea* (silver cluster-leaf) are representative of this sandy environment due to their broad-leaves and the absence of thorns on the stem and/or twigs.

31. Pennsylvania 336LR



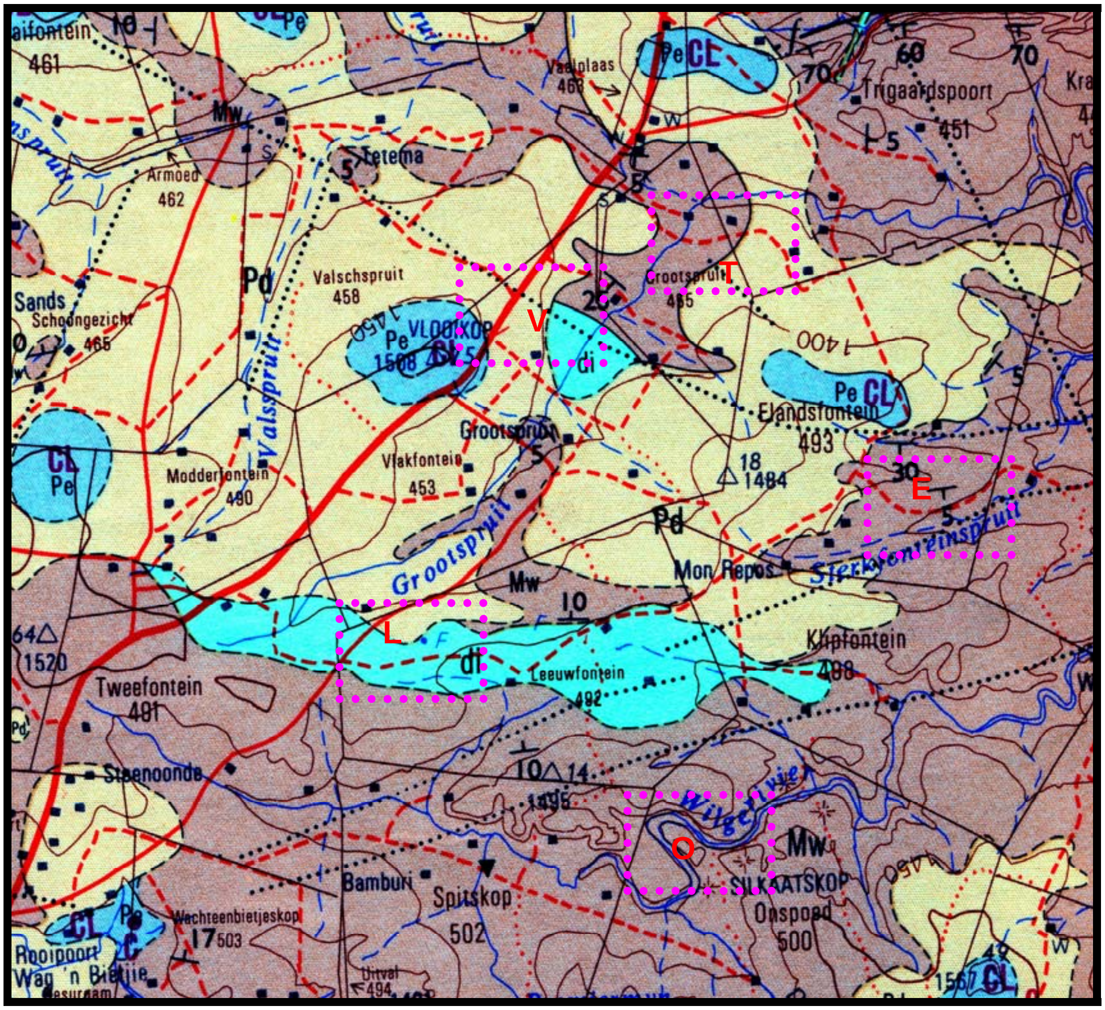


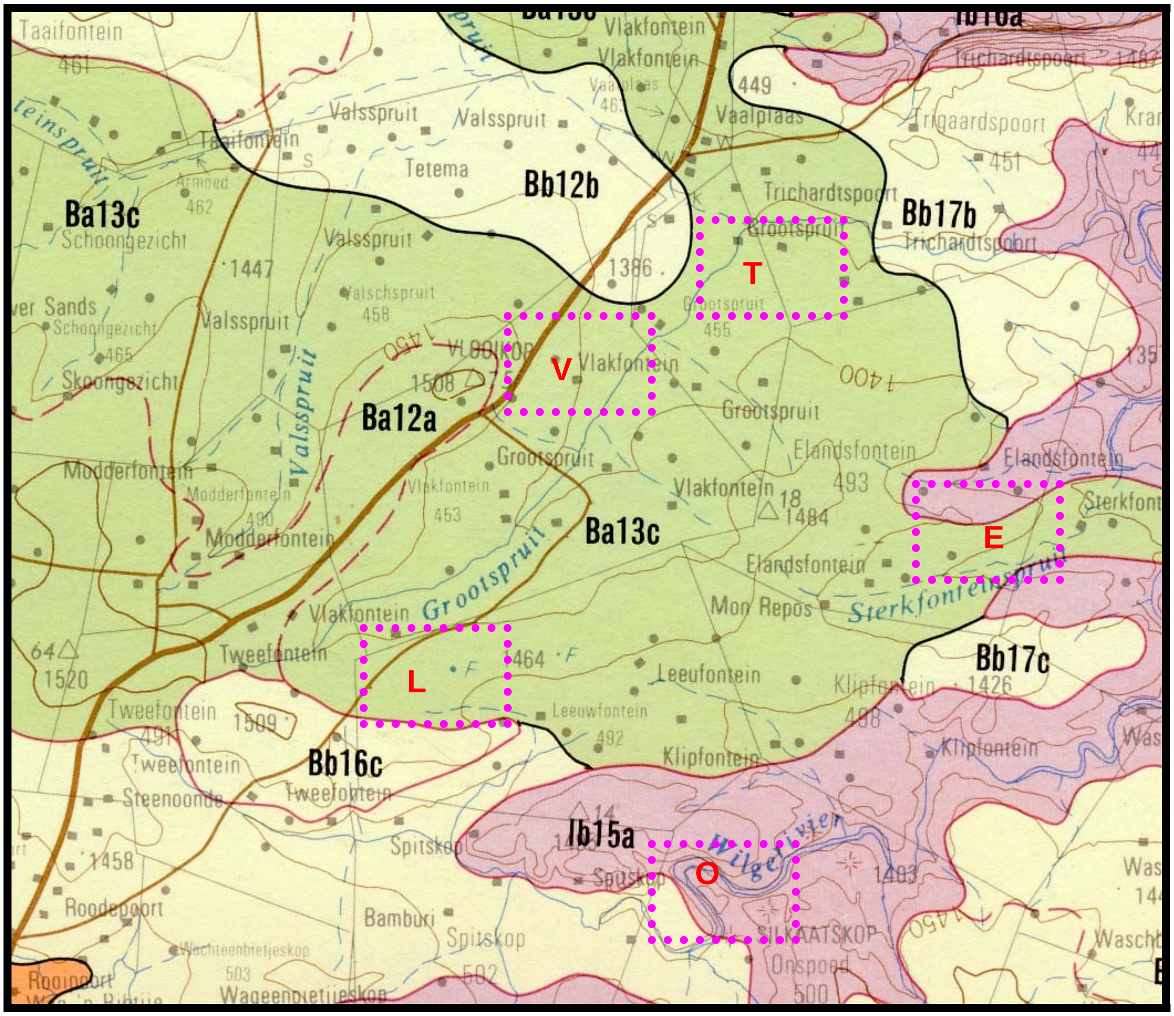
Abbreviation	Geology
Mm	Sandstone, conglomerate
Q	Alluvium
………………	Lineament
di	Diabase
Abbreviation	**Soil series**
Ac251b	Hutton, Clovelly
Ae288a	Hutton
Bc51a	Hutton
Fa532b	Mispah, Glenrosa
Ib351d	Rock

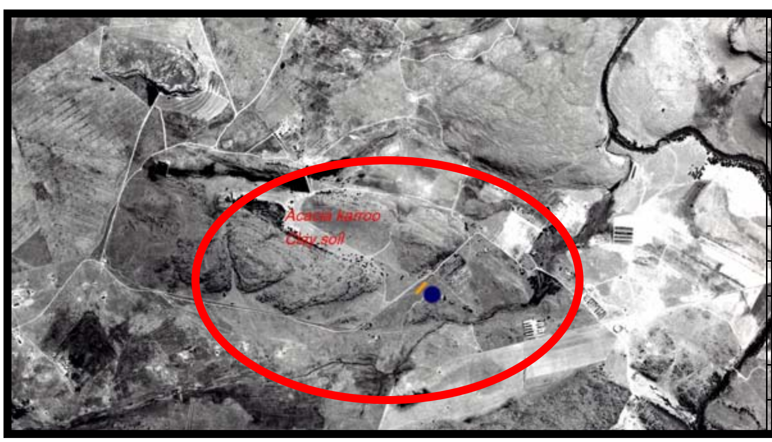
Figure A1.31. The geology (top), land type (middle) and aerial photograph (bottom) of Pennsylvania 336LR. The blue circle denotes the position of the borehole and the green line indicates the magnetic profile direction. Note the linear vegetated features inside the red circles (aerial photograph). The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The following case studies are representative of the Waterberg Group in the Bronkhorstspruit area, see also Tables A1.21(a&b) ii & iii.

32. Elandsfontein 493JR







Abbreviation	Geology
Mw	Sandstone
Pd	Shale
Pe	Shale, sandstone, coal
di	Diabase
Abbreviation	**Soil series**
Ba13c	Hutton
Bb16c	Mispah, Hutton, Glenrosa
Bb17b,c	Mispah, Clovelly
Ib15a	Rock, Mispah

Figure A1.32. The geology (top), land type (middle) and aerial photograph (bottom) of Elandsfontein 493JR. The blue circle denotes the position of the borehole and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter "E" in the geological and land type maps. Note the linear vegetated feature inside the red circle that crosses the drilled borehole.

Elandsfontein 493JR, situated about 30 km from Bronkhorstspruit in a north-eastern direction, is one of the farms that define the eZemvelo Nature Reserve of the Oppenheimer Trust. It is one of the very few nature reserves that protect the biodiversity of the Bankenveld among the rocks of the Wilgerivier Formation. The plains are covered by various grass species, where some valleys and plains consists of diabase and are covered by *Acacia* species, whereas sandstone valleys, gorges and rocky outcrops are mainly covered with broad-leaved, non-thorn bearing, shrubs and trees, very similar to these observed on the farm Hartbeesfontein (case study number 30); *Burkea africana* (wild seringa), *Combretum molle* (velvet bushwillow), *C. apiculatum* (red bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Euclea crispa* (blue guarri), *Faurea saligna* (Transvaal beech), *Mundulea sericea* (Cork bush) and *Ochna pulchra* (Peeling plane).

33. Leeuwfontein 492JR

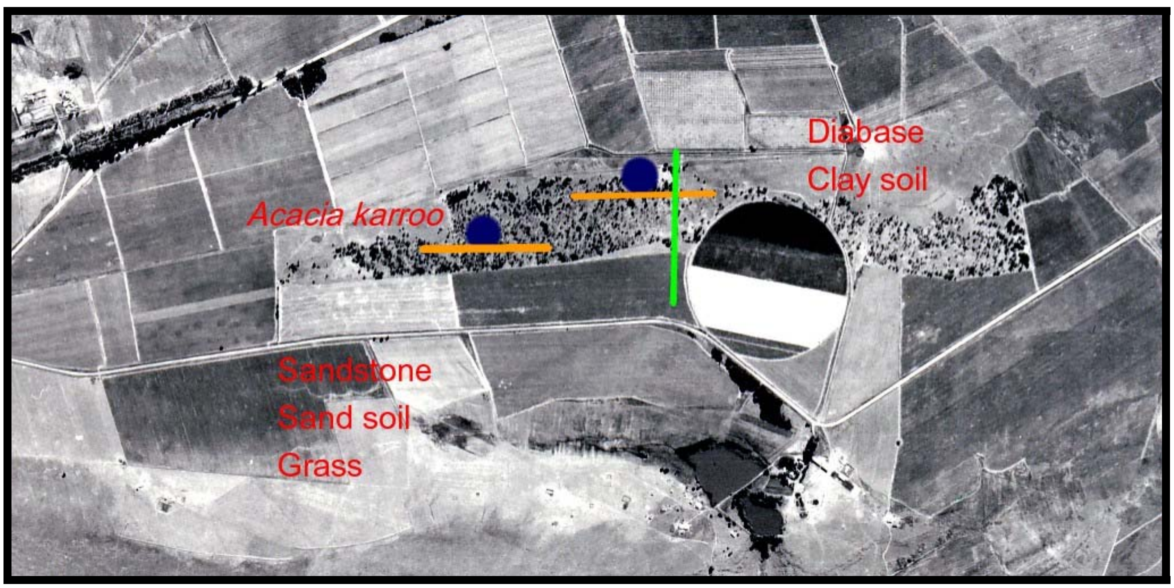


Figure A1.33. Aerial photograph of Leeuwfontein 492JR. The blue circles denotes the position of the boreholes (left = dry and right = yielding), the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “L” in the geological and land type maps. The geology and land type are depicted in Figure A1.32.

About 15 km northeast of Bronkhorstspruit, between the town and the farm Elandsfontein 493JR, the farm Leeuwfontein 492JR is situated on a plain of sandstone.

34. Onspoed 500JR

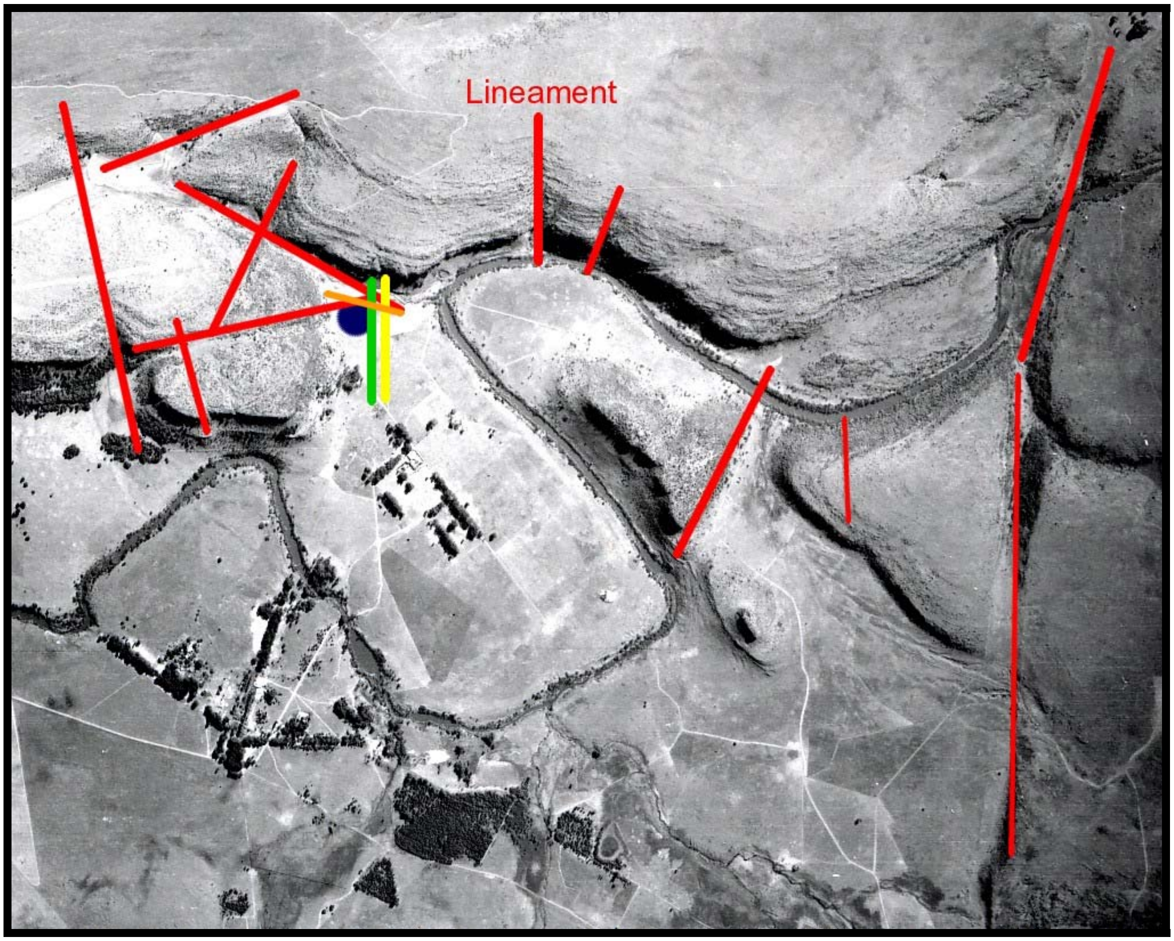
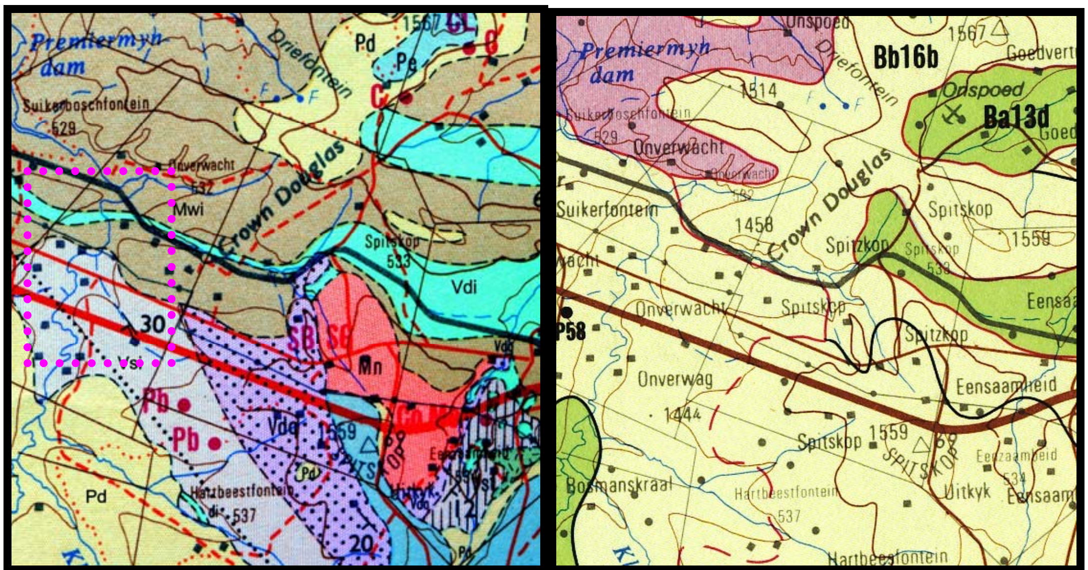
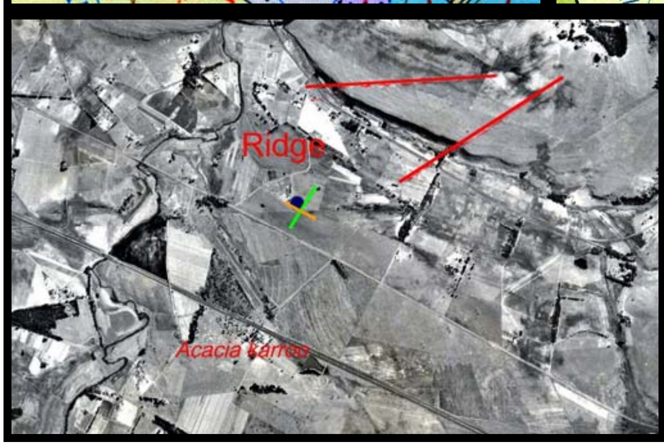


Figure A1.34. Aerial photograph of Onspoed 500JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “O” in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the numerous lineaments in this geological setting.

Nestled among the banks of the Wilge River and enclosed by high sandstone cliffs of the Wilgerivier Formation, the farm Onspoed 500JR is located. The farm has a rich history as Silkaats once occupied it (hence the name of Silkaatskop of a prominent sandstone buttress on the farm). During World War II the farm was used by British Engineering troops, as they were responsible for remaining buildings on the farm, drilling of very deep boreholes and construction of competent steel arch bridges over the Wilge River.

35. Onverwacht 532JR





Abbreviation	Geology
Vdi	Diabase
Vdq	Quartzite
Vsi	Shale, hornfels
Mn	Granite
Mwi	Sandstone
Pd	Shale
Abbreviation	**Soil series**
Ba13d	Hutton
Bb16b	Avalon, Clovelly, Glencoe

Figure A1.35. The geology (top left), land type (top right) and aerial photograph (bottom) of Onverwacht 532JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

The southern edge of the Wilgerivier Formation in contact with shale and hornfels belonging to the Silverton Formation of the Pretoria Group, cuts through the farm Onverwacht 532JR, 15 km east of Bronkhorstspruit. A clearly marked difference in vegetation is observed in this contact zone. The shale and hornfels are covered with *Acacia karroo* species in the clayey parts and furthermore grasses are luxurious. The sandstone hosts a variety shrubs belonging to the Mixed Bushveld veld type, namely *Acacia tortilis* (umbrella thorn), *Combretum molle* (velvet bushwillow), *Englerophytum magalismontanum* (Transvaal milkplum), *Ochna pulchra* (Peeling plane), *Strychnos pungens* (spine-leaved monkey orange), *Tapiphyllum parvifolium* (mountain medlar) and *Vangueria infausta* (wild medlar). However, the farm resides with the Bankenveld veld type. Most of the species are only small shrubs as the plants are exposed to cold spells like frost, wind and at times fire. Due to the numerous sandstone outcrops that define well formed ridges or terraces with intermediate linear grassed areas with little or none sandstone outcrops and sandy plains, the area is suitable for well managed extensive cattle farming in this sour habitat. These linear grassed areas are demarcated by the following species: *Acacia karroo*, *Euclea crispa* and *Strychnos pungens*. The geophysical exploration methods utilised on this farm include the magnetic method for profiling and the Schlumberger depth sounding method, with the results depicted in Figures 4.56 and 4.57.

36. Trigaardspoort 451JR

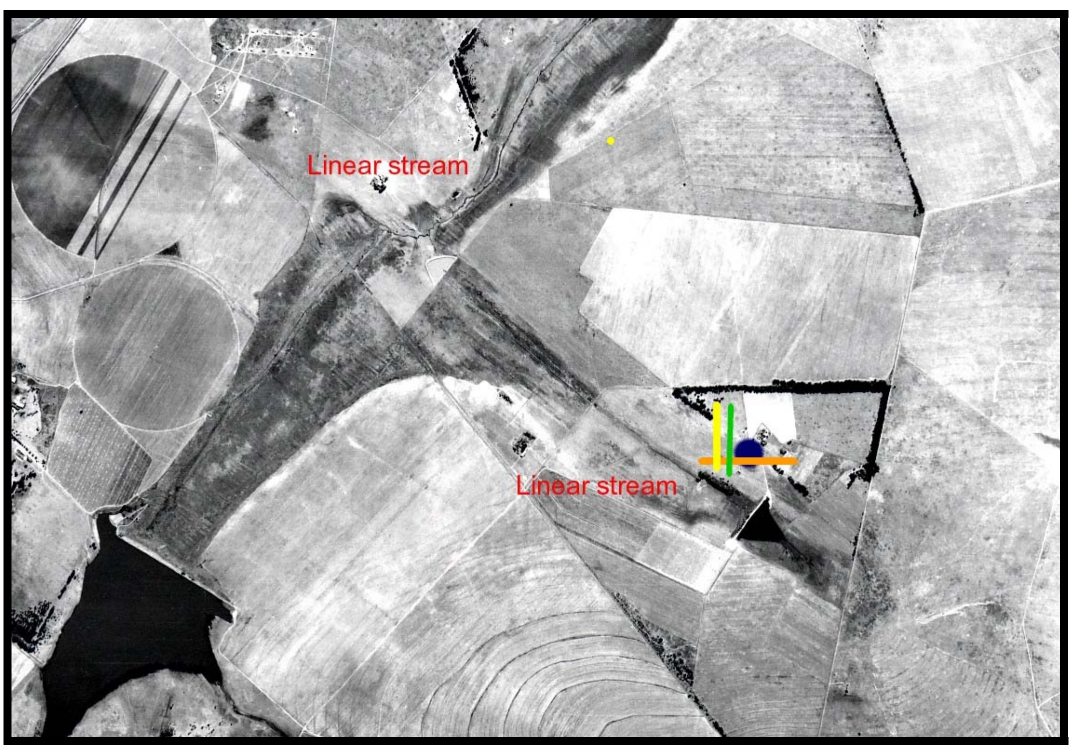


Figure A1.36. Aerial photograph of Trigaardspoort 451JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic travers and the orange line indicates the sounding direction. The area covered by the aerial photograph is indicated by the purple shape and the letter “T” in the geological and land type maps. The geology and land type are depicted in Figure A1.32. Note the linear streams in this geological setting that can indicate the presence of lineaments (weathered diabase).

The farm Trigaardspoort 451JR, approximately 20 km north of Bronkhorstspruit, marks the northern boundary of the Wilgerivier Formation in the Bronkhorstspruit district. Areas underlain by loam and clay soil structures tend to be used for cultivation agricultural practices, whereas these kinds of practices on sand soil are normally marginal productive lands. Areas underlain by the Wilgerivier Formation are mostly used for extensive cattle grazing, as is the case on this farm.

37. Vlakfontein 453JR

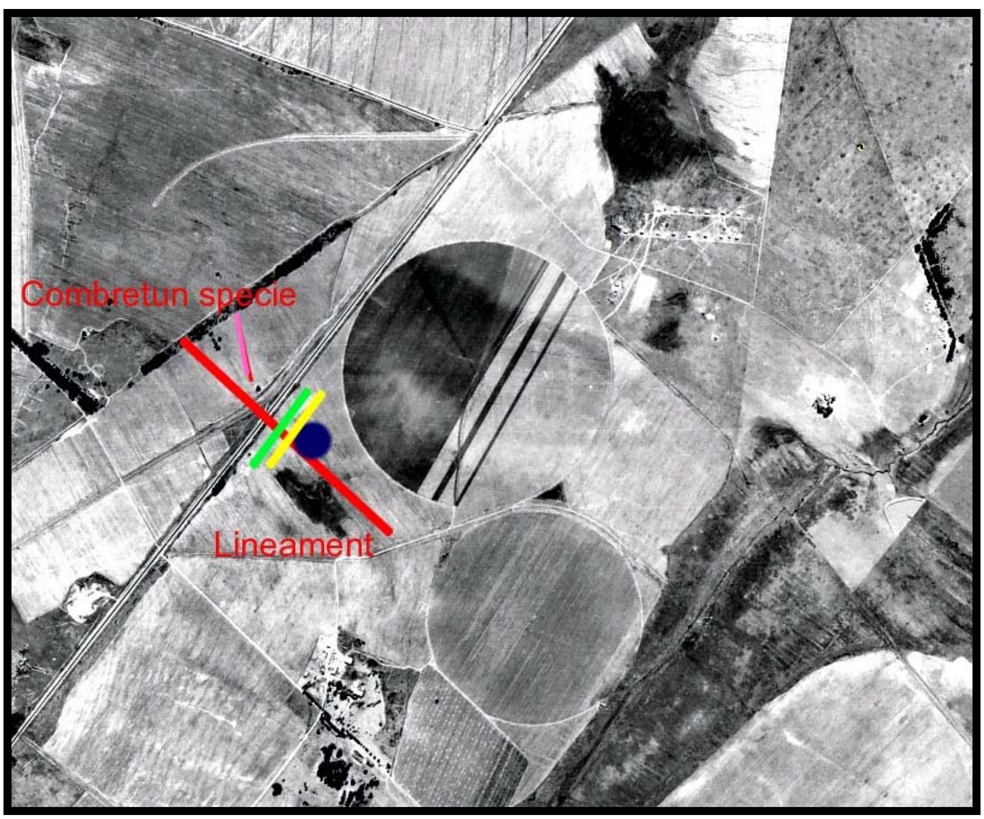
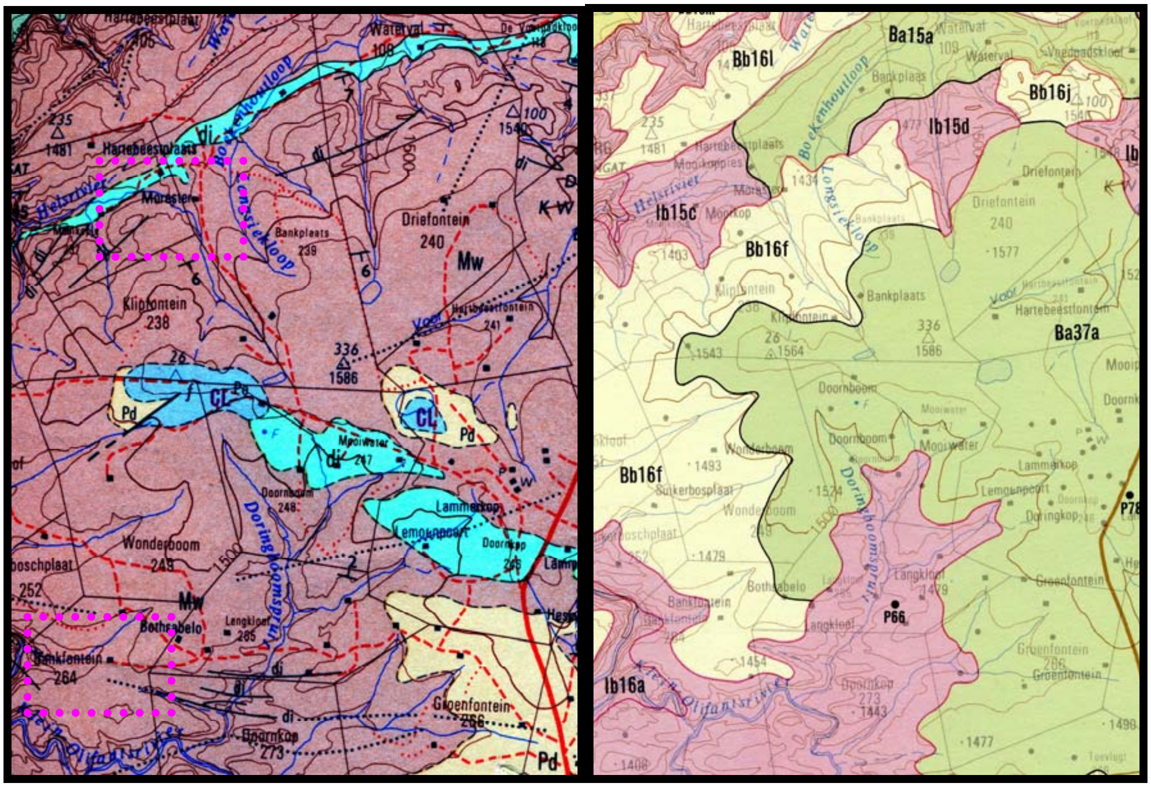


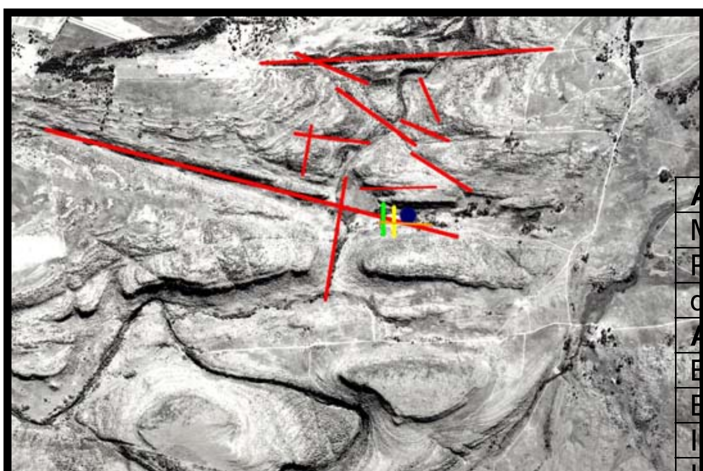
Figure A1.37. Aerial photograph of Vlakfontein 453JR. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile and the yellow line the direction of the electromagnetic traverse. The area covered by the aerial photograph is indicated by the purple shape and the letter “V” in the geological and land type maps. The geology and land type are depicted in Figure A1.32.

A prominent hill west of the farm, called Vlooikop, consists of sandstone, grit and coal of the Ecca Group, Karoo Supergroup. The coal deposit was mined in the past. The botanic diversity on Vlooikop is quite unique for this environment and surroundings as it is covered with *Heteromorpha trifoliata* (parsley tree) and *Protea caffra* (common sugarbush), the former specie only encountered on other Ecca Group outcrops in the region and the latter on sandstone ridges of the Wilgerivier Formation. Due to the variety in rocks, the farm is developed in different production units. The loamy soil of the weathered diabase is used for an orchard and maize irrigation cultivation practices. Land underlain by sandstone of the Wilgerivier Formation is used for cattle grazing and the soil derived from the Karoo sediments is utilised for dry land maize production. The water for irrigation is derived from a local dam, measuring about 50 ha in area.

The following case studies are representative of the Waterberg Group in the Middelburg area, see also Table A1.21(a&b) iv.

38. Bankfontein 264JS





Abbreviation	Geology
Mw	Sandstone
Pd	Shale
di	Diabase
Abbreviation	**Soil series**
Ba15a	Hutton
Bb16f	Mispah, Rock
Ib15c	Rock
Ib16a	Rock

Figure A1.38. Aerial photograph of Bankfontein 264JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the lower purple shape in the geological map. Some of the lineaments are indicated by the red lines.

The area surrounding the Olifants River, north of the towns Middelburg and Witbank, is characterised by sandstone terraces, ridges and cliffs. The numerous ridges gives rise to the resemblance of embankments, hence names such as Bankfontein and Bankplaas in the Bankenveld veld type. The vegetation around the Olifants River, gorges, valleys and plains at lower altitudes resemble the savanna biome, as the Bankenveld veld type transforms to the Sourish Mixed Bushveld veld type. The numerous sandstone outcrops of the Wilgerivier Formation are a hindrance for intensive agricultural practices and cultivation of land. As a result must of the area is used for extensive cattle farming, game farms, nature reserves and wilderness areas. This farm hosts the rare *Encephalartos middelburgensis* or Middelburg cycad that is declared as a national monument. The farm Bankfontein 264JS is about 20 km northwest of the town Middelburg.

Due to the various tree species that one can encounter on the farm as a transgression from the Bankenveld to the Sourish Mixed Bushveld veld type occurs, geobotanic prospecting can be done with more ease than in the Bronkhorstspruit area. Superb forests of *Protea caffra* (common sugarbush) can be found on southern slopes and hill tops on this farm. The Sourish Mixed Bushveld veld type hosts tree and shrub species including *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta subsp. robustu* (brack thorn), *Burkea afri*cana (wild seringa), *Faurea saligna* (Transvaal beech), *Ochna pulchra* (peeling plane), *Pappea capensis* (jacket-plum), *Rhus gueinzii* (thorny karree) and *Ziziphus mucronata* (buffalo-thorn).

39. Bankplaas 239JS

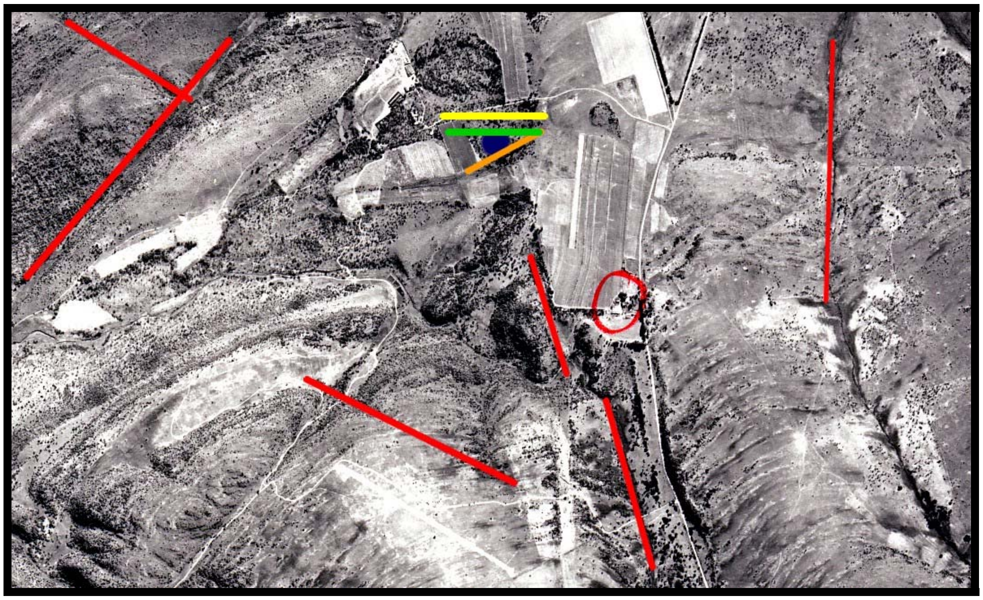
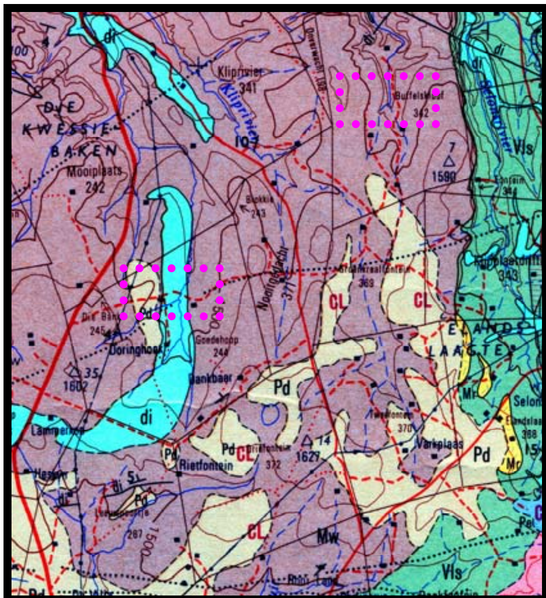
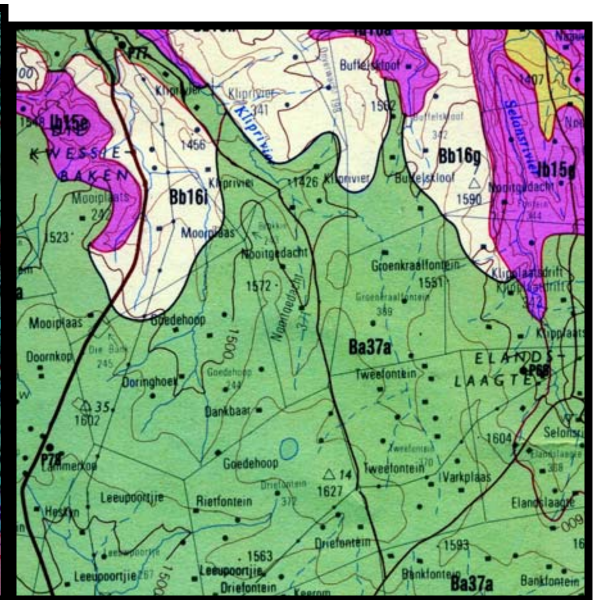


Figure A1.39. Aerial photograph of Bankplaas 239JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the upper purple shape in the geological map (Figure A1.38). Some of the lineaments are indicated by the red lines. Refer to Figure A1.38 for the land type map.

The farm Bankplaas 239JS, or locally referred to as Môrester, is located 30 km northwest of the town Middelburg, close the northern edge of the Wilgerivier Formation basin.

40. Buffelskloof 342JS





Abbreviation	Geology
Vls	Mudstone, rhyolite
Mw	Sandstone
Pd	Shale
di	Diabase
Abbreviation	**Soil series**
Ba37a	Hutton
Bb16g	Mispah, Rock
Ib15g	Rock

Figure A1.40. Aerial photograph of Buffelskloof 342JS. The blue circle denotes the position of the borehole, the green line the direction of the magnetic profile, the yellow line the direction of the electromagnetic traverse and the yellow line the lay out of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the right purple shape in the geological map (Figure A1.40).

The farm Buffelskloof 342JS is situated 30 km northeast of the town Middelburg. Temperature conditions are warmer than the area around Middelburg and subsequently Sourish Mixed Bushveld veld type trees occur on this farm and more abundantly and diverse on the neighbouring farm. Agricultural practices are divided into extensive cattle farming in areas underlain by sandstone, which is characterised by numerous sandstone outcrops and the areas underlain by diabase are used for cultivation practices.

41. Goedehoop 244JS

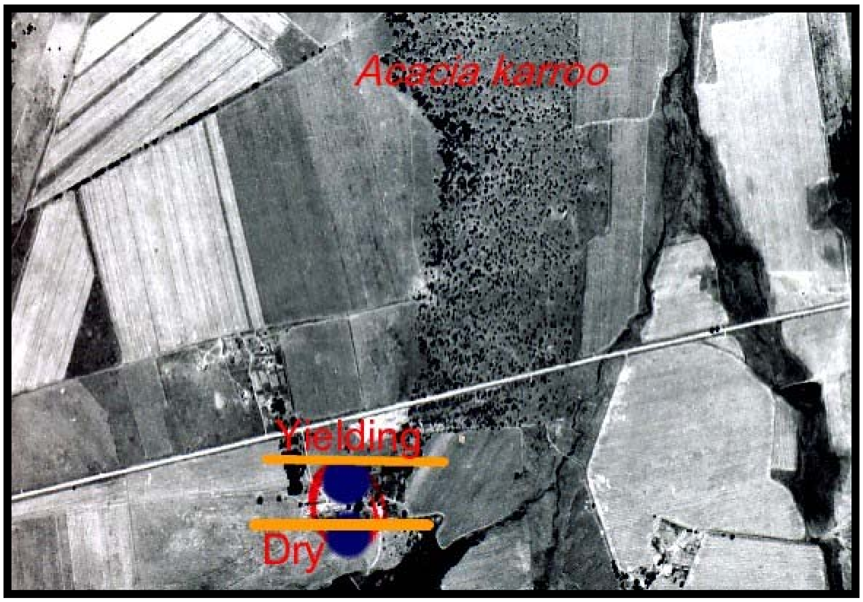


Figure A1.41. Aerial photograph of Goedehoop 244JS. The blue circles denotes the position of the boreholes (dry and yielding) and the yellow line the layout of the Schlumberger sounding. The area covered by the aerial photograph is indicated by the left purple shape in the geological map (Figure A1.40). Refer to Figure A1.40 for the land type map.

Located 22 km north of the town of Middelburg, towards Groblersdal, the farm is one of the most elevated places in the Wilgerivier Formation basin at an altitude above 1 600 meter. Mixed agricultural practices are encountered on this farm, including cattle farming and cultivation of lands.

A1.11 CARBONIFEROUS – PERMIAN EONOTHEMS: SANDSTONE AND SHALE OF THE VRYHEID FORMATION IN THE NIGEL AREA

Vast geological activity came to an end in Southern Africa during the formation of the Karoo Supergroup, which stretches from the Carboniferous Eonothem till the Jurassic Eonothem. This period lasted from 345 Ma to 150 Ma. The Karoo Supergroup covers almost to two-thirds of the South African geological landscape and is prominent in the Freestate and Karoo (Rust & Eriksson, 1996). The Karoo Supergroup consists of sedimentary arenaceous and argillaceous rocks that are frequently intruded by mafic intrusions, like dolerite, and capped by extrusive basalt formations. Some isolated patches of the Karoo Supergroup are located in the northern parts of South Africa as well. This chapter deals with geobotanic indicators associated with the Karoo Supergroup among its various lithological units, namely aquifers associated with the (i) Vryheid (sandstone and shale) Formation, (ii) Irrigasie, Lisbon and Clarens (sandstone, siltstone and shale) Formations and lastly (iii) Letaba (basalt) Formation.

The Vryheid Formation (Ecca Group-Permian Eonothem) and some older outcrops of the Carboniferous – Permian aged Dwyka Formation are exposed on the southern Highveld in the area around Nigel and further to the southeast. The area to the east is recognised for its coal mining activities, although gold mining activities occur around Nigel and towards the west – the Witwatersrand Gold Fields.

A1.11.1 CASE STUDY AREA

Three case studies are discussed in this section. The case studies are situated around Nigel and its zone of influence of activities, like towards Delmas and Greylingstad. Most parts of the area are utilised for the cultivation of crops, although wetland areas and shallow soils are utilised for cattle grazing practices. Situated on the Highveld, most of the plains are covered by indigenous grass species and indigenous shrubs and trees only occurring among some isolated rock outcrops or in areas where rocks belonging to other formations and with different lithologies are exposed. No major drainage features are associated with the presented case studies.

A1.11.2 CLIMATE AND VELD TYPES

The Highveld areas of the northern parts of South Africa are elevated 1200 – 2000 m above sea level, with higher altitudes around Nigel and stretching eastwards. The higher altitude areas are situated on a broad dolerite sill and form the watershed between rivers flowing towards the Atlantic and Indian Oceans. The larger tributaries are permanent, but their flow is very small during winter and spring. Due to the high altitude, winters are dry and cold (continental climate) and summers are wet and warm. Thunderstorms are responsible for bringing rain to these parts of the interior. Climatic information is indicated in Table A1.22. The open grass plains and cold spells during winter time, are the drivers behind the treeless landscape of the Highveld, combined with regular burning through veld fires (controlled and uncontrolled). Consequently the following veld types and trees are evident of this area and grassland biome (Acocks, 1988, Van Oudtshoorn, 1994 & Van Wyk & Van Wyk, 1997):

- Bankenveld on the farm Schoongezicht 225 IR: *Acacia caffra* (common hook-thorn), *Celtis africana* (white stinkwood) and *Protea caffra* (common sugarbush).
- *Cymbopogon-Themeda* veld on the farm Holgatfontein 326 IR: tree and shrub less veld type, dominant grass species include *Cymbopogon plurinodis* (narrow-leaved Turpentine Grass) and *Themeda triandra* (Rooigras).
- *Themeda* veld or Turf Highveld and Bankenveld to Turf Highveld Transition on the farm Leeuwkraal 517 IR: dominated by the grass specie *Themeda triandra* (Rooigras) and general absence of indigenous tree and shrub species.

Geobotanical investigations on the included case studies will indicate other occurring tree species as well and the marker tree species (geobotanic indicators) that can be utilised for groundwater exploration.

Table A1.22. Climatic Data of the Nigel Area (Schulze, 1997 & Johannesburg, 1999).

	Quantity
Average Yearly Temperature (°C)	14-16
Mean Minimum Temperature (°C) in July	0-2
Mean Maximum Temperature (°C) in January	25.0-27.5
Average Yearly Rainfall (mm)	600-800
Elevation (m)	1200-2000
Evaporation (mm/year)	2000-2250
Frost area?	150-175 days per year

A1.11.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Generally speaking, the entire study area is covered with rocks belonging to the Vryheid Formation of the Ecca Group, Karoo Supergroup. The Vryheid Formation consists of sandstone, shale and coal beds (East Rand, 1986). The rocks belonging to the Vryheid Formation display not any structural deformation on a large scale and are basically horisontal in layering. Vegter & Ellis (1968) made a detailed study of aquifer conditions and borehole siting in this area, and their findings and views are expressed hereunder.

The Karoo Supergroup which is represented by the two lowermost formations, the Dwyka Formation and the Ecca Group, rests unconformably and more or less horizontally on rocks of the Transvaal Sequence, Ventersdorp Supergroup, Witwatersrand Supergroup and Archaean granite and schist. The basal beds of the Karoo Supergroup, which are nowhere exposed, consist, according to boreholes, of tillite, sandstone, siltstone and shale of the Dwyka Formation. These beds reach a thickness of 30 m in places and are absent in others.

The Lower Ecca Group Stage is either absent or very poorly developed, in which case it consists of sandy and black shale. The Middle Ecca Group Stage is 150 to 250 m thick and comprises mostly sandstone and grit which alternate with sandy and micaceous shale and carry several coal seams. Outliers of the Upper Ecca Group Stage, which consists of blue to dark-grey, black and yellowish shales are formed around Standerton

(Volksrust Formation) where the greatest thickness penetrated in prospecting boreholes for coal is 45 meters.

Dykes and sills of dolerite and olivine dolerite have intruded the Ecca Group. Metamorphism of the country-rock by these intrusions is limited to recrystallisation of sandstone and conversion of shale to hornfels close to the intrusive contact. Microscopic examination of samples of weathered dolerite and olivine dolerite showed that the order of alteration of minerals is olivine, which changes to chlorite; and lastly feldspar (Vegter & Ellis, 1968). Spheroidal and columnar weathering of dolerite has been observed. Dykes, intensely jointed parallel and perpendicular to their contacts, weather to small oblong pieces of dolerite.

Porosities of 7 to 12.8% can be assigned to weathered sandstone beds, whereas the porosity of unweathered sandstone and shale of the Ecca Group is in the order of 2% that can increase to 12% in the case of fractures and large bedding planes (Vegter & Ellis, 1968). The permeability of fracture-free Ecca Group sedimentary rocks is too low for them to yield meaningful supplies of water in boreholes. Dolerite is neither porous nor permeable unless fractured and weathered. In the formation of aquifers, tectonic movements, intrusion of dolerite and processes of weathering have all played a part. Water-yielding structures are the following:

- Weathered and fractured sedimentary rocks not associated with dolerite intrusions.
- Indurated and jointed sedimentary rocks alongside dykes.
- Narrow weathered and fractured dolerite dykes.
- Basins of weathering in dolerite sills and highly jointed sedimentary rocks enclosed by dolerite.
- Weathered and fractured upper contact-zones of dolerite sills.
- Weathered and fractured lower contact-zones of dolerite sills.

According to the Johannesburg (1999) hydrogeological map and corresponding to the work of Vegter & Ellis (1968), the yield of aquifers in the area vary from 360 – 1800 ℓ/h to 1800 – 7200 ℓ/h, depending on the existing geological conditions. Aquifers are classified as intergranular and fractured in a predominantly arenaceous rock environment in association with ultramafic/mafic extrusive rock (andesite) and ultramafic/mafic intrusive rocks (dolerite).

A1.11.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The work of Vegter & Ellis (1968) present and discuss a number of direct current resistivity soundings and magnetometer profiles in the study area. Successful boreholes' (average yield up to 7200 ℓ/h) aquifer resistivity is between 50 – 185 Ω.m. and corresponds favourably with the results presented by Meulenbeld (1998), where the modelled aquifer resistivity value is below 100 Ω.m. and boreholes are not deeper than 85 m on average. Other geophysical work is available as confidential reports issued to mines in the area and these sources won't be referenced. From the geophysical work available, published and unpublished, it is clear that the magnetic method is of superior value due to the numerous dolerite intrusions in the area. Electromagnetic profiling is an aid to establish weathered contact zones along an intrusion. The utilisation of the electromagnetic method over areas of weathered, clayey sedimentary material is not advocated as the clay restricts signal penetration to deeper layers as it is a conductor and erroneous interpretations can be made. Schlumberger depth soundings can be a valuable tool in the presence of weathering basins and lateral sedimentary layers intruded or not by dolerite.

Geobotanical indicators of the area listed by Meulenbeld (1998) include only two species, one tree and one grass specie; *Acacia karroo* (sweet thorn) and *Fingerhuthia sesleriiformis* (thimble grass). Kent and Enslin (1965) and Vegter and Ellis (1968) point out the relevance of the specie *Fingerhuthia sesleriiformis* as a geobotanic indicator. Due to the climatic conditions of the area, regular burning of veld and gently undulating nature of the tufted grassy plains of the area, trees and shrubs do not occur frequently compared to the previous case studies. The included case studies will, although, include some tree and shrub species that occur as a result of changes in geology.

A1.11.5 SOIL SAMPLING AND RESULTS PRESENTATION

Soil sampling compares to the already included and mentioned case studies. Soil samples were analysed for available cations and nutrients in addition to pH, resistance and a few other parameters. Soil samples were taken at depths of 0.5 and 1.2 m respectively at the site of the borehole and geobotanical indicator and the remaining sample some distance removed from it, not near such a geobotanical indicator. This section deals with three case studies, Table A1.23(a&b).

Table A1.23 (a). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: along intrusive contact.

Parameter	Holgatfontein 326IR		Leeuwkraal 517IR		Schoongezicht 225IR	
Geological Formation	Dolerite intrusion among Vryheid Formation rocks	Dolerite intrusion among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Buried diabase (Vaalium age) under the Vryheid Formation	Buried diabase (Vaalium age) under the Vryheid Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	26º24.058’ 28º32.271’	26º24.058’ 28º32.271’	26º37.438’ 28º44.250’	26º37.438’ 28º44.250’	26º05.639’ 28º48.343’	26º05.639’ 28º48.343’
Soil colour	Greyish red	Dark grey	Dark grey	Blackish red	Moderate brown	Dark yellowish orange
Soil texture description	Clay	Clay	Clay	Clay	Silty clay	Silty clay
pH	6.39	6.79	6.47	6.56	5.62	5.73
P (mg/kg)	8.33	2.62	3.24	1.86	0.96	0.48
Ca (mg/kg)	2166	1980	1442	1844	1320	2302
Mg (mg/kg)	774	697	521	669	835	1368
K (mg/kg)	186	151	166	97	89	136
Na (mg/kg)	62	47	17	20	37	62
Fe (mg/kg)	223.36	329.13	112.46	123.76	104.27	177.63
Mn (mg/kg)	288.22	246.87	285.07	253.21	248.65	407.54
Zn (mg/kg)	2.33	1.11	1.40	1.29	0.41	1.41
Al ($cmol_c$/kg)	0	0	0.095	0.086	0.086	0.198
Resistance (Ohm)	1400	2000	1400	1600	1600	1600

C%	1.28	1.12	1.48	1.34	0.42	0.23
Total N%	0.069	0.068	0.088	0.079	0.040	0.029
S (mg/kg)	8.46	6.70	12.04	16.70	144.78	66.16
CEC ($cmol_c$/kg)	20.94	18.15	14.510	18.248	28.691	28.430
Distinct Tree Species	Acacia karroo	Acacia karroo	1.Acacia karroo 2.Euclea crispa	1. Acacia karroo 2. Euclea crispa	Acacia karroo *(Fingerhuthia sesleriiformis)*	Acacia karroo *(Fingerhuthia sesleriiformis)*
Average rooting depth of the indicated species (m)	50	50	4 - 50	4 - 50	2 - 50	2 – 50
Average depth of weathering (m)	2.2	2.2	1.8	1.8	2.5	2.5
Geomorphology	Plain with a hill	Plain with a hill	Plain and hills	Plain and hills	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes-small stream and wetland	Yes-small stream and wetland	No	No	Yes-wetland	Yes-wetland
Aquifer Yield (l/h)	7 000	7 000	6 800	6 800	9 000	9 000
Borehole Depth (m)	60	60	65	65	90	90
Depth of Water Strike (m)	26	26	23	23	65	65
Static Water Level (m)	6	6	11	11	9	9

Average Aquifer Yield (l/h)	2 400	2 400	2 400	2 400	2 400	2 400
Average Borehole Depth (m)	52	52	52	52	52	52
Average Depth of Water Strike (m)	29	29	29	29	29	29
Average Static Water Level (m)	11	11	11	11	11	11
Land Type Series	Bb19a Avalon	Bb19a Avalon	Ea20b Arcadia	Ea20b Arcadia	Ba5f Hutton	Ba5f Hutton
Profile No	P136	P136	P124	P124	P154	P154
Depth Sampled	640 – 1200 mm	640 – 1200 mm	760 – 100 mm	760 – 100 mm	600 – 1050 mm	600 – 1050 mm
Gravel %	2	2	1	1	0	0
Sand %	55	55	51	51	52	52
Silt %	6	6	11	11	4	4
Clay %	37	37	37	37	44	44
pH (H_2O)	8.8	8.8	5.5	5.5	6.3	6.3
P (mg/kg)	0.3	0.3	0.3	0.3	0.8	0.8
Ca (mg/kg)	1180	1180	1495	1495	920	920
Mg (mg/kg)	864	864	996	996	504	504
K (mg/kg)	78	78	39	39	156	156
Na (mg/kg)	621	621	69	69	207	207
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	175.2	175.2	218.93	218.93	133.3	133.3
Zn (mg/kg)	0.00	0.00	0.63	0.63	0.00	0.00
Resistance (Ohm)	360	360	5300	5300	360	360
C%	0.1	0.1	0.3	0.3	0.2	0.2

CEC ($cmol_c$/kg)	179	179	51	51	122	122
Veld Type	48 *Cymbopogon-Themeda* veld	48 *Cymbopogon-Themeda* veld	52/55 *Themeda* veld or Turf Highveld and Bankenveld	52/55 *Themeda* veld or Turf Highveld and Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D2	D2	D2/D3	D2/D3	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937), Vegter & Ellis (1968) and Meulenbeld (1998). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1985). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.23 (b). Carboniferous - Jura Eonothems: Vryheid Formation - Nigel Area: intrusive contact absent.

Parameter	Holgatfontein 326IR		Leeuwkraal 517IR		Schoongezicht 225IR	
Geological Formation	Dolerite intrusion among Vryheid Formation rocks	Dolerite intrusion among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Basalt/Dolerite intrusions among Vryheid Formation rocks	Buried diabase (Vaalium age) under the Vryheid Formation	Buried diabase (Vaalium age) under the Vryheid Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	26º24.058’ 28º32.271’	26º24.058’ 28º32.271’	26º37.438’ 28º44.250’	26º37.438’ 28º44.250’	26º05.639’ 28º48.343’	26º05.639’ 28º48.343’
Soil colour	Weak red	Greyish brown	Light brown	Light brown with laterite inclusions	Light brown	Dark red
Soil texture description	Sandy silt	Sandy silt	Silty sand	Silty sand	Silty sand	Clay
pH	5.19	5.10	4.54	4.93	6.27	5.01
P (mg/kg)	2.43	2.39	6.45	2.97	3.69	2.36
Ca (mg/kg)	647	667	148	187	200	472
Mg (mg/kg)	233	259	52	62	69	292
K (mg/kg)	138	192	95	79	63	29
Na (mg/kg)	58	30	11	13	10	29
Fe (mg/kg)	225.18	190.25	28.47	24.06	14.80	62.18
Mn (mg/kg)	141.76	173.77	7.77	13.65	44.91	204.81
Zn (mg/kg)	1.51	1.55	0.56	0.44	0.77	0.34

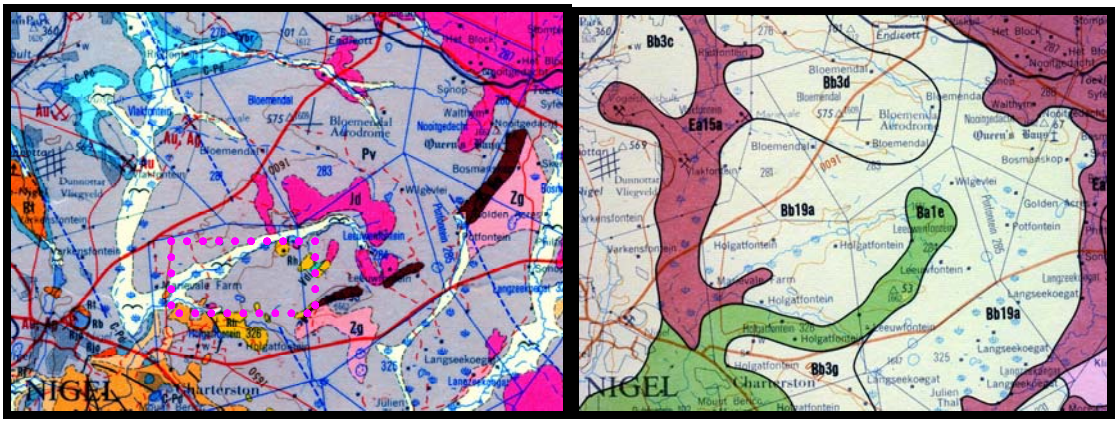
Al ($cmol_c$/kg)	0.347	0.400	1.106	0.715	0.100	0.409
Resistance (Ohm)	2000	2400	3000	3600	5200	2390
C%	2.52	2.66	0.62	0.63	0.42	0.27
Total N%	0.176	0.181	0.049	0.049	0.027	0.018
S (mg/kg)	54.36	43.47	88.36	78.29	22.95	9.23
CEC ($cmol_c$/kg)	9.52	10.56	8.928	7.861	5.452	19.19
Distinct Tree Species	1. Acacia karroo	1. Acacia karroo	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo 2. Euclea crispa	1. Acacia karroo *(Fingerhuthia sesleriiformis)*	1. Acacia karroo *(Fingerhuthia sesleriiformis)*
Average rooting depth of the indicated species (m)	50	50	4 - 50	4 - 50	2 - 50	2 – 50
Average depth of weathering (m)	2.2	2.2	1.8	1.8	2.5	2.5
Geomorphology	Plain with a hill	Plain with a hill	Plain and hills	Plain and hills	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics & Schlumberger soundings	Electromagnetics, Magnetics & Schlumberger soundings
Water features present?	Yes-small stream and wetland	Yes-small stream and wetland	No	No	Yes-wetland	Yes-wetland
Aquifer Yield (l/h)	7 000	7 000	6 800	6 800	9 000	9 000
Borehole Depth (m)	60	60	65	65	90	90
Depth of Water Strike (m)	26	26	23	23	65	65

Static Water Level (m)	6	6	11	11	9	9
Average Aquifer Yield (l/h)	2 400	2 400	2 400	2 400	2 400	2 400
Average Borehole Depth (m)	52	52	52	52	52	52
Average Depth of Water Strike (m)	29	29	29	29	29	29
Average Static Water Level (m)	11	11	11	11	11	11
Land Type Series	Bb19a Avalon	Bb19a Avalon	Ea20b Arcadia	Ea20b Arcadia	Ba5f Hutton	Ba5f Hutton
Profile No	P136	P136	P124	P124	P154	P154
Depth Sampled	640 – 1200 mm	640 – 1200 mm	760 – 100 mm	760 – 100 mm	600 – 1050 mm	600 – 1050 mm
Gravel %	2	2	1	1	0	0
Sand %	55	55	51	51	52	52
Silt %	6	6	11	11	4	4
Clay %	37	37	37	37	44	44
pH (H_2O)	8.8	8.8	5.5	5.5	6.3	6.3
P (mg/kg)	0.3	0.3	0.3	0.3	0.8	0.8
Ca (mg/kg)	1180	1180	1495	1495	920	920
Mg (mg/kg)	864	864	996	996	504	504
K (mg/kg)	78	78	39	39	156	156
Na (mg/kg)	621	621	69	69	207	207
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	175.2	175.2	218.93	218.93	133.3	133.3

Zn (mg/kg)	0.00	0.00	0.63	0.63	0.00	0.00
Resistance (Ohm)	360	360	5300	5300	360	360
C%	0.1	0.1	0.3	0.3	0.2	0.2
CEC (cmol$_c$/kg)	179	179	51	51	122	122
Land Type Series	No Data	No Data	No Data	No Data	No Data	No Data
Profile No	No Data	No Data	No Data	No Data	No Data	No Data
Veld Type	48 *Cymbopogon-Themeda* veld	48 *Cymbopogon-Themeda* veld	52/55 *Themeda* veld or Turf Highveld and Bankenveld	52/55 *Themeda* veld or Turf Highveld and Bankenveld	61 Bankenveld	61 Bankenveld
Hydrogeological Unit	D2	D2	D2/D3	D2/D3	D2	D2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937), Vegter & Ellis (1968) and Meulenbeld (1998). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1985). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

42. Holgatfontein 326IR

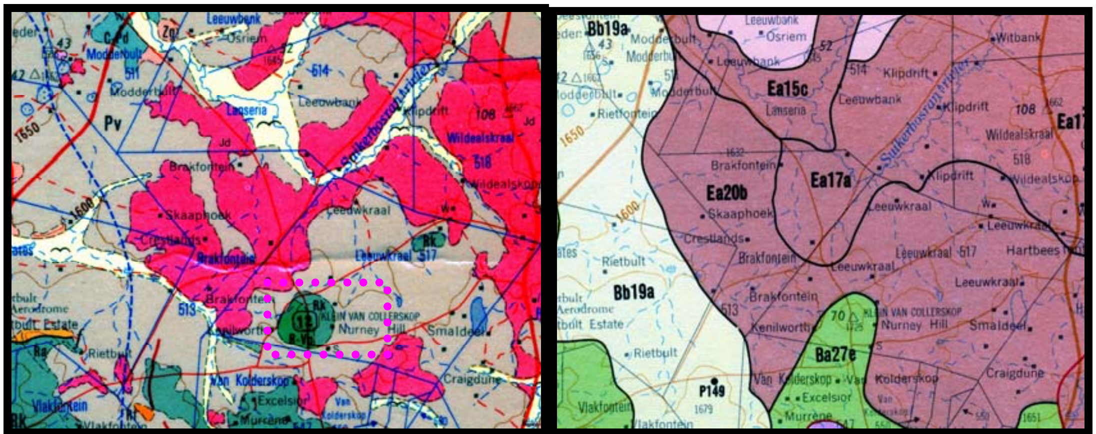


Abbreviation	Geology
Zg	Granite, gneiss
Rh (yellow)	Shale, quartzite, ironstone
Ro (brown)	Quartzite
Vdi	Diabase
Pv	Sandstone, shale, coal
Jd & -------	Dolerite
Abbreviation	**Soil series**
Ba1e	Hutton
Bb3g	Avalon
Bb19a	Avalon
Ea15a	Rensburg

Figure A1.42. The geology (top left), land type (top right) and aerial photograph (bottom) of Holgatfontein 326IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

About 12km northeast of Nigel, the farm Holgatfontein 326IR is located. To the northwest of the farm gold mining is taking please on an outcrop of the Malmani Subgroup (Chuniespoort Group, Transvaal Sequence). The gold mine is discharging underground water in the Blesbok Spruit and creates an artificial wetland. The impact of the gold mining activities on the Karoo aquifers on this farm is considered to be insignificant as the Karoo overburden does not outcrop at the mining area and therefore the aquifer’s boundaries are confined to the sedimentary rocks of the Karoo Supergroup. Note that the weathered dolerite in the upper part of the land type map defines Rensburg soil series. Where the Rensburg soil series occur in the southwestern parts of the land type map, this is due to the presence of dolerite, although not mapped as such on the geological map, but rather covered by alluvium. Geophysical profiles indicate the presence of dolerite under the alluvium at Holgatfontein 326IR.

43. Leeuwkraal 517IR

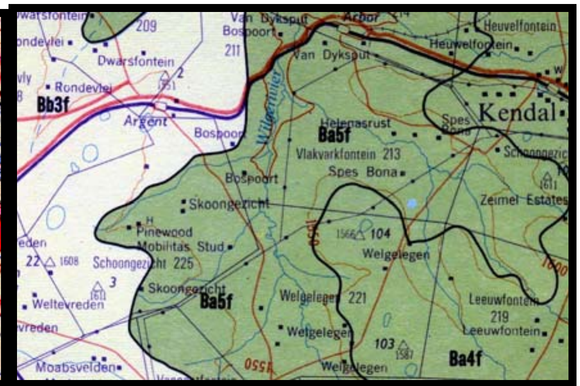


Abbreviation	Geology
Rk	Basaltic lava, agglomerate, tuff
R-Vh	Breccia, conglomerate, greywacke, shale
Pv	Sandstone, shale, coal
Jd	Dolerite
Abbreviation	**Soil series**
Ba27e	Rock
Bb19a	Avalon
Ea17a	Arcadia
Ea20b	Arcadia

Figure A1.43. The geology (top left), land type (top right) and aerial photograph (bottom) of Leeuwkraal 517IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Leeuwkraal 517IR, about 18 km northeast of Balfour, agricultural practices include maize production and extensive beef cattle farming practices.

44. Schoongezicht 225IR



Abbreviation	Geology
Vh	Andesite
Vt	Quartzite (magnetic)
Vdi	Diabase
Pv	Sandstone, shale, coal
Abbreviation	**Soil series**
Ba5f	Hutton
Bb3f	Avalon

Figure A1.44. The geology (top left), land type (top right) and aerial photograph (bottom) of Schoongezicht 225IR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The various soundings are indicated by the orange lines. The area covered by the aerial photograph is indicated by the purple shape in the geological map.

Being part of the Bankenveld veld type, the farm does not pose the characteristic Bankenveld topography as found in the Wilgerivier Formation area, north of Bronkhorstspruit and Middelburg (Chapter 4), where terraces and ridges are common and hosting a variety of trees and shrubs. The farm Schoongezicht 225IR poses rather a flat, plain topography with some small rock outcrops and local depressions are saturated with water. Most of the natural veld is damaged by agricultural practices for crop production, although some areas are still in its natural condition due to the presence of some rock outcrops.

A1.12 PERMIAN – TRIASSIC EONOTHEMS: ARENACEOUS AND ARGILLACEOUS ROCKS OF THE IRRIGASIE, LISBON AND CLARENS FORMATIONS OF THE KAROO SUPERGROUP IN THE MABULA-WATERBERG AREA

Outcrops of the Karoo Supergroup occur in isolated parts in different regions of the northern parts of South Africa. This section deals with arenaceous and argillaceous rocks (sandstone, grit, siltstone, mudstone and shale) of the Irrigasie, Lisbon and Clarens Formations of the Karoo Supergroup in the area around Mabula and the Waterberg Mountains in the vicinity of Ellisras. These formations were deposited during the Permian-Triassic Eonothems. One feature of the rocks belonging to these formations is that intrusive bodies are rare and structural faulting or fracturing might be more of a norm.

A1.12.1 CASE STUDY AREA

The area southwest of Mabula, between Warmbaths and Thabazimbi, is a flat Bushveld country with occasional hills. Due to the flat terrain, no major drainage structures cross this area. The loamy soils are beneficial for agricultural crop production activities, but groundwater quantity is a concern in certain areas. Numerous farms are used for extensive beef cattle framing and game farming purposes, mainly due to the Bushveld character of the area. The Mabula area hosts two case studies. The remaining case study is located to the north of the Waterberg plateau, east of Ellisras in the Limpopo province.

A1.12.2 CLIMATE AND VELD TYPES

In areas where Bushveld vegetation grows (savanna biome), the climate is mild and even warm to sustain vegetation, as cold spells and winds are destructive powers regarding tree growth and development. The elevation of the area is also lower than the Highveld, as the area is situated 800 – 1200 m above sea level. Winter months are mostly dry and cool, and the summer months are warm and wet with most rainfall occurring as thunderstorms, characteristic of the continental climatic conditions. The rainfall is, however, less than on the Highveld (Table A1.24). Veld types associated within this kind of climatic conditions are (Acocks, 1988 & Van Wyk & Van Wyk, 1997):

- Mixed Bushveld (Waterberg area): *Acacia caffra* (common hook-thorn), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Lannea discolor* (live-long) and *Sclerocarya birrea* subsp. *caffra* (marula).
- Sourish Mixed Bushveld (Mabula area): *Acacia caffra* (common hook-thorn), *A. karroo* (sweet thorn), *A. robusta* subsp. *robustu* (brack thorn) & *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Pappea capensis* (jacket-plum), *Peltophorum africanum* (weeping wattle), *Rhus gueinzii* (thorny karree), *Sclerocarya birrea* subsp. *caffra* (marula) and *Ziziphus mucronata* (buffalo-thorn).

The above-mentioned tree species are frequently found in the veld and their use as geobotanical indicators must only be done with extreme caution trough frequency of occurrence and circumcise mapping.

Table A1.24. Climatic Data of the Mabula-Waterberg Area (Schulze, 1997 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18 – 20
Mean Minimum Temperature (°C) in July	2 - 4
Mean Maximum Temperature (°C) in January	30.0 – 32.5
Average Yearly Rainfall (mm)	400 – 600
Elevation (m)	800 – 1200
Evaporation (mm/year)	2250 – 2500
Frost area?	No frost

A1.12.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

Three different geological formations occur in the presented case study area. The area around Mabula is covered with rocks from the Permian-Triassic Irrigasie Formation (sandstone, grit, mudstone, siltstone, marl, shale and sporadic sand layers) and Triassic Clarens Formation (fine-grained red to cream sandstone) according to the Nylstroom (1978) geological map. In the Mabula area a large post-Karoo fault-system with a downthrow up to 300 m to the south bounds the basin (Nylstroom, 1978). This fault zone runs parallel with the main road from Warmbaths to Thabazimbi and is therefore a difficult groundwater exploration target as it is outside the farm boundaries. Most outcrops are arenaceous rocks, as well in the Waterberg area, where the farm Newcastle 202LQ is positioned. The Lisbon and Clarens Formations (Triassic Eonothem) of the Karoo Sequence occur on this farm, where a localised east-west trending fault separates the two formations. The Lisbon Formation has a constant thickness of 100 to 110 m. The formation comprises a succession of dominantly red massive mudstone with siltstone, and minor silty sandstone and medium- to coarse-grained sandstone with pebble washes. The succession is characterised by cyclically repeated units (five to ten meters thick) consisting of thin sandstone at the base, grading into siltstone or mudstone. The basal contacts of individual units are generally sharp. The Clarens Formation attains a maximum thickness of 130 m. Unlike most of the other formations, rocks of the Clarens Formation form prominent hills or ridges in parts of the Ellisras area. In general, however, most of the area underlain by the Clarens Formation is characterised by fine-grained, light-coloured sand. The formation is composed almost entirely of sandstone which is generally massive, well sorted and fine grained. Medium- to coarse-grained units and thin pebbly horizons are locally developed. The contact between the Clarens Formation and the underlying Lisbon Formation is gradational. The rock is mostly cream coloured or off-white, with a light pink colour occurring locally. The sandstone consists almost entirely of quartz grains which are well rounded. Locally some feldspar grains may be present, and some calcareous concretions occur in its lower part (Brandl, 1996).

Aquifers that can be expected in this geological setting are mostly aquifers due to the existence of two-dimensional weathering, like joints, fractures and fault zones (Hattingh, 1996). Bedding planes as present in arenaceous rocks might also act as an aquifer. The hydrogeological map of Polokwane (2003) classifies the aquifers in the Mabula geological setting as intergranular and fractured in an arenaceous and argillaceous rock environment with a yield of 1800 – 7200 ℓ/h. The Lisbon and Clarens Formations north of the Waterberg are classified as predominantly argillaceous rock that hosts fractured aquifers with a yield of 360 – 1800 ℓ/h.

A1.12.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

Information on geophysical studies, relating to the magnetic, electromagnetic and Schlumberger methods, of this area is scarce. A publication by the CSIR (Van Zijl, 1978) presenting results of the Settlers basalt area to the east of the case studies indicate the thickness of the Karoo sediments (predominantly the Clarens Formation) to be around 300 meters. Schlumberger sounding curves obtained (a total of 26) by the study of Van Zijl (1978) are of the four-layered KH-shape, indicating a resistive overburden and conductor in depth. The apparent resistivity of the sediments is between 12-33 Ω.m. and the apparent resistivity of the pre-Karoo floor rocks in excess of 5000 Ω.m., although no Schlumberger depth soundings are presented in this section as the exploration targets were fracture and fault zones that require geophysical profiling techniques for proper definition of the structures, and the dense vegetation limited ordinary usage and accuracy of sounding methods.

To obtain the significance of geobotanical indicators around this area in literature is a fruitless exercise. Geobotanical indicators as listed under the previous case studies will be included. Furthermore, a source of information is local farmers that can provide information once the concept of geobotanical indicators and the presence of termitaria are discussed with them. Although briefly included in the case studies as the locality was never drilled regarding groundwater supply, the area northwest of Marble Hall is situated on Karoo sediments and according to local farmers the tree specie *Boscia foetida* subsp. *rehmanniana* (stink shepherd’s tree) is associated with linear termitaria. The linear pattern can be possibly linked to intrusive linear structures in the sub-surface, but has to be confirmed with further research. The species *Boscia albitrunca* (shepherd’s tree) and *B. foetida* subsp. *rehmanniana* are sometimes encountered in the study area, but it was not regarded as a geobotanical indicator in the Mabula-Waterberg area thus far.

A1.12.5 SOIL SAMPLING AND RESULTS PRESENTATION

To establish the importance and linkage of soil nutrients, weathered intrusive rocks, aquifers and botanic species, soil samples were taken at depths of 0.5 m and 1.2 meters. The soil chemical analytic results of the three case studies are presented in Table A1.25 (a&b), with the discussion of the case studies thereafter.

Table A1.25 (a). Carboniferous - Jura Eonothems: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: along fracture and/or fault contact zone.

Parameter	Droogesloot 476KR		Grootfontein 528KQ		Newcastle 202LQ	
Geological Formation	Fracture among Clarens Formation rocks	Fracture among Clarens Formation rocks	Fracture among Irrigasie Formation rocks	Fracture among Irrigasie Formation rocks	Fault zone along Lisbon and Clarens Formations	Fault zone along Lisbon and Clarens Formations
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	24º54.177' 28º01.823'	24º54.177' 28º01.823'	24º51.354' 27º58.931'	24º51.354' 27º58.931'	23º28.514' 27º53.036'	23º28.514' 27º53.036'
Soil colour	Strong brown	Yellowish brown	Olive brown	Moderate brown	Moderate brown	Dark yellowish orange
Soil texture description	Silt	Loam	Sand	Sand	Loam	Sand
pH	8.23	8.60	7.96	8.29	7.91	7.46
P (mg/kg)	5.89	4.37	12.61	11.98	1.41	1.30
Ca (mg/kg)	5243	4390	5189	6747	2688	3475
Mg (mg/kg)	201	129	616	879	400	490
K (mg/kg)	323	138	162	225	113	256
Na (mg/kg)	29	27	35	59	35	16
Fe (mg/kg)	2.35	2.68	11.77	11.07	69.36	44.47
Mn (mg/kg)	36.08	36.44	47.60	42.50	224.29	176.14
Zn (mg/kg)	0.52	0.33	0.31	0.55	0.53	0.84
Al ($cmol_c/kg$)	0	0	0	0	0	0
Resistance (Ohm)	2000	2400	2400	2000	2000	800

C%	0.24	0.13	0.14	0.25	0.16	0.48
Total N%	0.035	0.023	0.077	0.021	0.014	0.044
S (mg/kg)	6.94	5.42	8.38	9.57	5.34	5.77
CEC ($cmol_c$/kg)	10.39	12.00	20.141	23.116	21.44	16.45
Distinct Tree Species	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Combretum imberbe 2. Ficus ingens	1. Combretum imberbe 2. Ficus ingens
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 13	4 - 13	12 - 20	12 - 20
Average depth of weathering (m)	2.8	2.8	2.8	2.8	3.0	3.0
Geomorphology	Plain	Plain	Plain with a hill	Plain with a hill	Plain	Plain
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics
Water features present?	Yes-small stream “Karee Spruit”	Yes-small stream “Karee Spruit”	Yes-small stream “Riet Spruit”	Yes-small stream “Riet Spruit”	No	No
Aquifer Yield (l/h)	6 000	6 000	5 000	5 000	4 500	4 500
Borehole Depth (m)	75	75	65	65	70	70
Depth of Water Strike (m)	33	33	30	30	36	36
Static Water Level (m)	17	17	14	14	20	20
Average Aquifer Yield (l/h)	3 300	3 300	3 300	3 300	2 300	2 300
Average Borehole Depth (m)	60	60	60	60	69	69

Average Depth of Water Strike (m)	37	37	37	37	44	44
Average Static Water Level (m)	23	23	23	23	26	26
Land Type Series	Ae18b Hutton	Ae18b Hutton	Ae95c Hutton	Ae95c Hutton	Ah85a Hutton	Ah85a Hutton
Profile No	P1379	P1379	P1379	P1379	P1447	P1447
Depth Sampled	300 – 700 mm	300 – 700 mm	300 – 700 mm	300 – 700 mm	450 – 800 mm	450 – 800 mm
Gravel %	1	1	1	1	1	1
Sand %	48	48	48	48	51	51
Silt %	7	7	7	7	9	9
Clay %	44	44	44	44	39	39
pH (H_2O)	6.5	6.5	6.5	6.5	7.3	7.3
P (mg/kg)	2.8	2.8	2.8	2.8	1.6	1.6
Ca (mg/kg)	780	780	780	780	2910	2910
Mg (mg/kg)	360	360	360	360	520	520
K (mg/kg)	78	78	78	78	250	250
Na (mg/kg)	23	23	23	23	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	250.5	250.5	250.5	250.5	211.5	211.5
Zn (mg/kg)	0.31	0.31	0.31	0.31	0.62	0.62
Resistance (Ohm)	1600	1600	1600	1600	1000	1000
C%	0.5	0.5	0.5	0.5	0.4	0.4
CEC ($cmol_c$/kg)	72	72	72	72	63	63

Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs are from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.25 (b). Carboniferous - Jura Eonothems: Irrigasie, Lisbon & Clarens Formations – Mabula-Waterberg Area: faulting or fracturing absent.

Parameter	Droogesloot 476KR		Grootfontein 528KQ		Newcastle 202LQ	
Geological Formation	Competent Clarens Formation rocks	Competent Clarens Formation rocks	Competent Irrigasie Formation rocks	Competent Irrigasie Formation rocks	Competent Lisbon and Clarens Formations	Competent Lisbon and Clarens Formations
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	24º54.177' 28º01.823'	24º54.177' 28º01.823'	24º51.354' 27º58.931'	24º51.354' 27º58.931'	23º28.514' 27º53.036'	23º28.514' 27º53.036'
Soil colour	Strong brown	Strong brown	Dark reddish brown	Brown	Brown	Dark brown
Soil texture description	Silt	Silt	Loam	Silty clay	Sand	Silty clay
pH	8.47	8.41	8.51	8.57	7.62	8.10
P (mg/kg)	4.67	3.68	16.66	13.15	6.08	0.99
Ca (mg/kg)	5749	5364	5328	7043	2785	3992
Mg (mg/kg)	211	212	684	586	543	558
K (mg/kg)	208	282	232	214	92	107
Na (mg/kg)	22	20	83	101	26	27
Fe (mg/kg)	3.91	1.06	18.96	8.77	45.53	51.07
Mn (mg/kg)	25.37	34.70	131.49	31.17	93.31	202.25
Zn (mg/kg)	0.40	0.45	0.59	0.22	0.38	0.53
Al ($cmol_c$/kg)	0	0	0	0	0	0

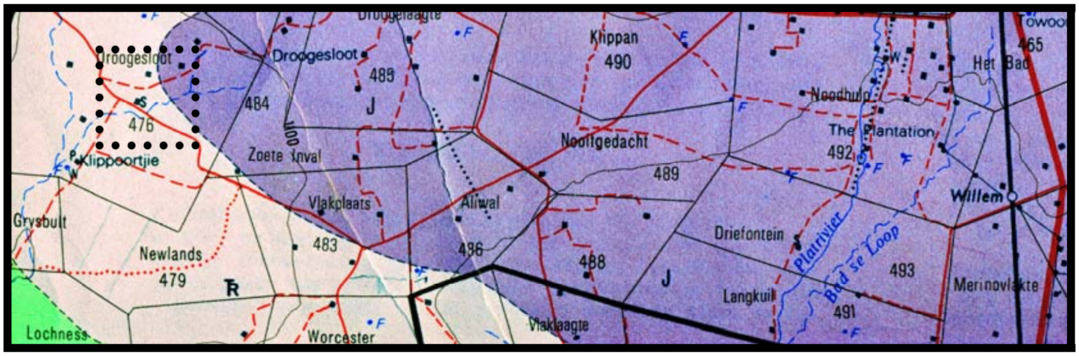
Resistance (Ohm)	1800	1800	1800	3000	2400	780
C%	0.16	0.20	0.20	0.75	0.07	0.24
Total N%	0.027	0.029	0.018	0.059	0.007	0.023
S (mg/kg)	5.76	6.59	10.15	12.43	4.13	6.14
CEC ($cmol_c$/kg)	5.53	8.61	22.931	15.885	20.05	11.51
Distinct Tree Species	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Rhus lancea 2. Strychnos pungens	1. Combretum imberbe 2. Ficus ingens	1. Combretum imberbe 2. Ficus ingens
Average rooting depth of the indicated species (m)	4 - 13	4 - 13	4 - 13	4 - 13	12 - 20	12 - 20
Average depth of weathering (m)	2.8	2.8	2.8	2.8	3.0	3.0
Geomorphology	Plain	Plain	Plain with a hill	Plain with a hill	Plain	Plain
Geophysical instrumentation used	Electromagnetics	Electromagnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics & Magnetics
Water features present?	Yes-small stream "Karee Spruit"	Yes-small stream "Karee Spruit"	Yes-small stream "Riet Spruit"	Yes-small stream "Riet Spruit"	No	No
Aquifer Yield (l/h)	6 000	6 000	5 000	5 000	4 500	4 500
Borehole Depth (m)	75	75	65	65	70	70
Depth of Water Strike (m)	33	33	30	30	36	36
Static Water Level (m)	17	17	14	14	20	20

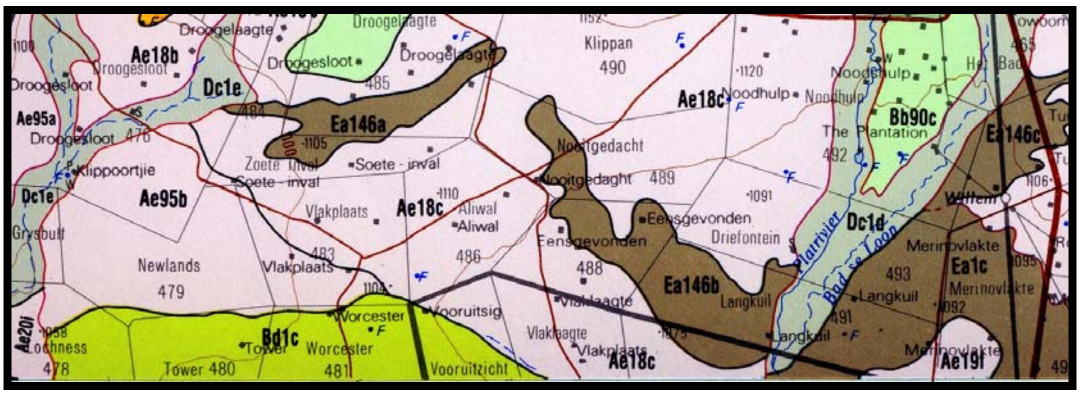
Average Aquifer Yield (l/h)	3 300	3 300	3 300	3 300	2 300	2 300
Average Borehole Depth (m)	60	60	60	60	69	69
Average Depth of Water Strike (m)	37	37	37	37	44	44
Average Static Water Level (m)	23	23	23	23	26	26
Land Type Series	Ae18b Hutton	Ae18b Hutton	Ae95c Hutton	Ae95c Hutton	Ah85a Hutton	Ah85a Hutton
Profile No	P1379	P1379	P1379	P1379	P1447	P1447
Depth Sampled	300 – 700 mm	300 – 700 mm	300 – 700 mm	300 – 700 mm	450 – 800 mm	450 – 800 mm
Gravel %	1	1	1	1	1	1
Sand %	48	48	48	48	51	51
Silt %	7	7	7	7	9	9
Clay %	44	44	44	44	39	39
pH (H_2O)	6.5	6.5	6.5	6.5	7.3	7.3
P (mg/kg)	2.8	2.8	2.8	2.8	1.6	1.6
Ca (mg/kg)	780	780	780	780	2910	2910
Mg (mg/kg)	360	360	360	360	520	520
K (mg/kg)	78	78	78	78	250	250
Na (mg/kg)	23	23	23	23	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	250.5	250.5	250.5	250.5	211.5	211.5
Zn (mg/kg)	0.31	0.31	0.31	0.31	0.62	0.62
Resistance (Ohm)	1600	1600	1600	1600	1000	1000

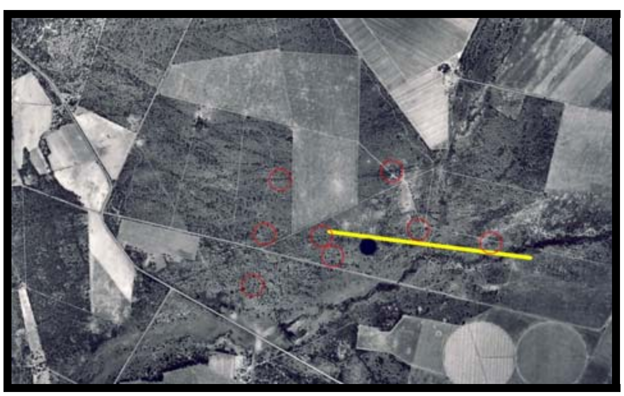
C%	0.5	0.5	0.5	0.5	0.4	0.4
CEC ($cmol_c$/kg)	72	72	72	72	63	63
Veld Type	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	19 Sourish Mixed Bushveld	18 Mixed Bushveld	18 Mixed Bushveld
Hydrogeological Unit	D3	D3	D3	D3	B2	B2

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs are from Land Type Survey Staff (1988, 2005). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

45. Droogesloot 476KR



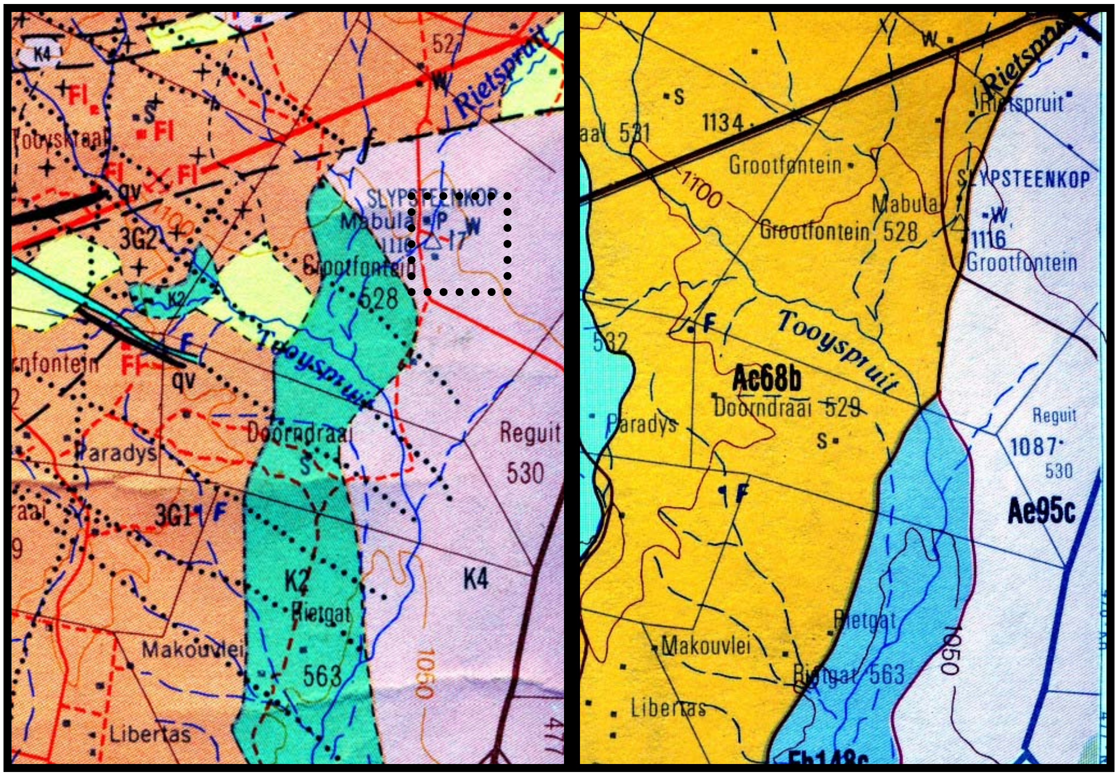


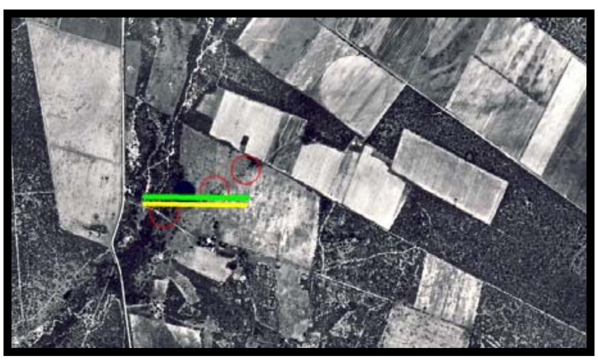


Abbreviation	Geology
Tr	Sandstone
J	Basalt, sandstone
Abbreviation	**Soil series**
Ae18b,c	Hutton
Ae95a,b	Hutton
Bd1c	Clovelly
Dc1e	Valsrivier, Sterkspruit
Ea146a	Arcadia

Figure A1.45. The geology (top), land type (middle) and aerial photograph (bottom) of Droogesloot 476KR. The blue circle denotes the position of the borehole and the yellow line the direction of the electromagnetic profile. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zones.

46. Grootfontein 528KQ



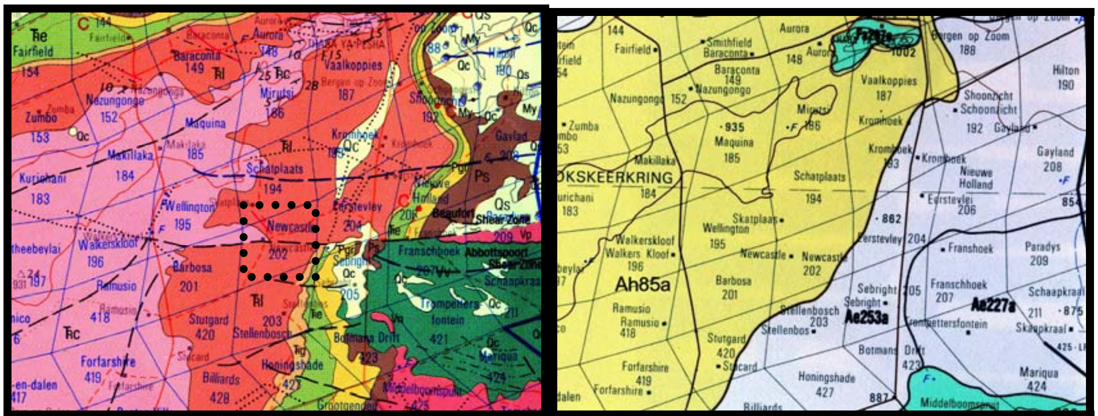


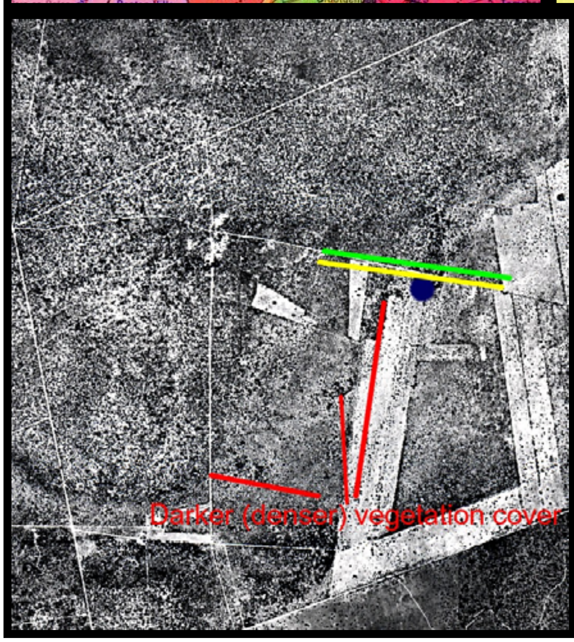
Abbreviation	Geology
3G1	Granite
3G2	Granite
………………	Lineament
K2	Shale, sandstone and grit
K4	Sandstone, marl and shale
---------*f*	Concealed fault
Abbreviation	**Soil series**
Ac68b	Clovelly
Ae95c	Hutton

Figure A1.46. The geology (top), land type (middle) and aerial photograph (bottom) of Grootfontein 528KQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles in the aerial photograph indicate the position of the fracture zone, note the linear vegetated pattern.

About 7 km west of the previous case study (Droogesloot 476KR) the farm Grootfontein 528KQ borders the small village of Mabula. Mabula is about 25 km west of Warmbaths.

47. Newcastle 202LQ





Abbreviation	Geology
Trc	Sandstone
Tre	Shale
Trg	Sandstone, conglomerate
Trl	Mudstone, siltstone
------	Fault
Abbreviation	**Soil series**
Ae253a	Hutton, Shortlands
Ah85a	Hutton, Clovelly

Figure A1.47. The geology (top left), land type (top right) and aerial photograph (bottom) of Newcastle 202LQ. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red lines in the aerial photograph indicate the position of the fault, although it is not as straight linear as indicated in the geological map.

A1.13 JURASSIC EONOTHEM: BASALT ROCK OF THE LETABA FORMATION AND DOLERITE INTRUSIONS OF THE KAROO SUPERGROUP IN THE SPRINGBOK FLATS AREA

The last deposition sequence of the Karoo Supergroup is concluded with the formation of basalt on top of the arenaceous and argillaceous rocks of the Karoo Supergroup. The extrusive basalt was feeded from the magma chamber of the earth through intrusive dolerite bodies, like sills and dykes. These dolerite bodies are nowadays exposed through weathering and erosion processes. Most of the basalt has weathered over time, but outcrops are still evident on the Drakensberg of the interior and isolated patches in the northern parts of South Africa, like in the Springbok Flats area around the town of Settlers.

A1.13.1 CASE STUDY AREA

Basalt and dolerite outcrops in the area around Pienaarsrivier, about 50 km north of Pretoria, are incorporated in the study. A total of three case studies represent this area. The terrain is extremely plain with no major drainage structures, but is densely covered by shrubs and small trees. However, due to the water bearing properties of the basalt aquifers and productive soil, large areas of bush has been cleared to make way for intensive (irrigation) agricultural practices. Other areas are still utilised for extensive beef cattle farming and game lodges.

A1.13.2 CLIMATE AND VELD TYPES

The area covered with basalt and dolerite outcrops is situated at a lower elevation (800-1200 masl) compared to the plains of the Highveld in the south. Consequently a warmer and dryer climate is encountered (see Table A1.26). The basalt plains are extremely flat and therefore no significant microclimates are present that are commonly found on the slopes of mountains or in gorges and host different botanic species. The flat terrain permits radiation and as a result mild frost happens during winter time. However, the basalt plains are luxuriously covered with shrub and tree vegetation, indicating a climate different to that found on the southern Highveld plateau. The luxurious vegetation indicates that the veld types indicative of the basalt and dolerite environment are part of the savanna biome. Veld types associated within this kind of climatic conditions are (Acocks, 1988 & Van Wyk & Van Wyk, 1997):

- Kalahari Thornveld (sand & dolerite): *Acacia erioloba* (camel thorn), *A. luederitzii* (false umbrella thorn), *A. mellifera* (black thorn), *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Boscia albitrunca* (shepherd's tree), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Mundulea sericea* (cork bush), *Peltophorum africanum* (weeping wattle), *Tarchonanthus camphoratus* (wild camphor bush) and *Ziziphus mucronata* (buffalo-thorn).
- Springbok Flats Turf Thornveld (basalt): *Acacia nilotica* subsp. *kraussiana* (scented thorn), *A. tortillis* subsp. *heteracantha* (umbrella thorn), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin) and *Ziziphus mucronata* (buffalo-thorn).
- Mixed Bushveld (dolerite): *Acacia caffra* (common hook-thorn), *Combretum apiculatum* (red bushwillow), *C. imberbe* (leadwood), *Dichrostachys cinerea* (sickle bush), *Grewia flava* (velvet raisin), *Lannea discolor* (live-long) and *Sclerocarya birrea* subsp. *caffra* (marula).

The above-mentioned tree species are frequently found in the veld and their use as geobotanical indicators must only be done with extreme caution trough frequency of occurrence and circumcise mapping.

Table A1.26. Climatic Data of the Springbok Flats Area around Pienaarsrivier-Settlers (Schulze, 1997, Johannesburg, 1999 & Polokwane, 2003).

	Quantity
Average Yearly Temperature (°C)	18 -20
Mean Minimum Temperature (°C) in July	2 - 4
Mean Maximum Temperature (°C) in January	27.5 – 30.0
Average Yearly Rainfall (mm)	400 – 600
Elevation (m)	800 – 1200
Evaporation (mm/year)	2000 – 2250
Frost area?	<150 days a year

A1.13.3 GEOLOGY AND HYDROGEOLOGICAL CLASSIFICATION

The geology of the case study area is relatively simple compared to other geological terrain as presented. Horizontal layered basalt (Letaba Formation, Karoo Supergroup) and dolerite (Karoo Supergroup) of a thickness of about 200 to 300 m (Van Zijl, 1978) covers sedimentary rock of the Karoo Supergroup. No structural phenomena are encountered in the mentioned mafic and ultramafic rocks.

According to Hattingh (1996), Johannesburg (1999) and Polokwane (2003), the intergranular and fractured aquifers associated with the basalt and dolerite rocks are mainly created through joints. The basalt aquifers' yield is above 18 000 ℓ/h. The dolerite outcrop around Pienaarsrivier is surrounded by argillaceous rock belonging to the Irrigasie Formation (see section 4.12) with a possible yield of 1800 – 7200 ℓ/h (Johannesburg, 1999).

A1.13.4 GEOPHYSICAL AND GEOBOTANICAL INFORMATION

The publication by Van Zijl (1978) is a source of vital geophysical information regarding this area. Schlumberger sounding curves obtained (a total of 26) by the study of Van Zijl (1978) are of the four-layered KH-shape, indicating a resistive overburden and conductor in depth. The apparent resistivity of the weathered basalt is between 10-200 Ω.m., the unweathered basalt between 510-1330 Ω.m. and the apparent resistivity of the pre-Karoo floor rocks in excess of 5000 Ω.m., although no Schlumberger depth soundings are presented in this section as the exploration targets were fracture and fault zones that require geophysical profiling techniques for proper definition of the structures and dense vegetation restricted proper, time-efficient conducting of soundings.

Information on geobotanical indicators for groundwater are not known in this case study area, although certain geobotanical species occur in this geological environment that also occur in other geological environments previously included and act as a reconnaissance tool.

A1.13.5 SOIL SAMPLING AND RESULTS PRESENTATION

To establish the importance and linkage of soil nutrients, weathered intrusive rocks, aquifers and botanic species, soil samples were taken at depths of 0.5 m and 1.2 meters. The soil chemical analytic results of the three case studies are presented in Table A1.27(a&b), with the discussion of the case studies thereafter.

Table A1.27 (a). Jurassic Eonothem: Basalt rock of the Letaba Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: along contact, weathering and/or fracture zone.

Parameter	Kalkheuvel 73 JR		Langkuil 13 JR		Vlakplaats 483 KR	
Geological Formation	Contact zone between dolerite and Irrigasie Formation	Contact zone between dolerite and Irrigasie Formation	Palaeo-channel in weathered basalt	Palaeo-channel in weathered basalt	Fracture zone in Letaba Formation	Fracture zone in Letaba Formation
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	 25º11.077' 28º20.609'	 25º11.077' 28º20.609'	 25º00.411' 28º14.258'	 25º00.411' 28º14.258'	 24º57.967' 28º07.129'	 24º57.967' 28º07.129'
Soil colour	Moderate brown	Strong brown	Moderate brown	Dark brown	Moderate brown	Dusky red
Soil texture description	Silt	Silty sand	Sandy silt	Loam	Loam	Loam
pH	7.78	8.13	6.79	7.16	7.24	7.04
P (mg/kg)	8.79	8.07	1.71	0.99	1.22	0.84
Ca (mg/kg)	4362	3805	5758	5739	2993	2786
Mg (mg/kg)	470	444	2061	2014	858	817
K (mg/kg)	468	486	155	153	132	100
Na (mg/kg)	31	30	72	104	41	27
Fe (mg/kg)	4.81	8.80	63.53	70.63	64.07	86.99
Mn (mg/kg)	77.46	105.74	531.08	405.50	100.86	191.05
Zn (mg/kg)	1.16	1.06	0.31	0.33	0.33	0.41
Al ($cmol_c$/kg)	0	0	0	0	0	0

Resistance (Ohm)	1600	1800	1700	2200	2800	2400
C%	1.02	0.92	0.01	0.01	0.04	0.08
Total N%	0.097	0.090	0.005	0.008	0.005	0.011
S (mg/kg)	7.67	7.88	4.48	4.33	3.88	4.56
CEC ($cmol_c$/kg)	9.27	14.94	46.47	40.22	18.39	36.82
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	12	12	4 - 50	4 - 50
Average depth of weathering (m)	2.4	2.4	1.9	1.9	2.5	2.5
Geomorphology	Plain	Plain	Plain	Plain	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger sounding	Electromagnetics, Magnetics and Schlumberger sounding
Water features present?	No	No	Yes-small stream “Plat River” 700 m east	Yes-small stream “Plat River” 700 m east	No	No
Aquifer Yield (l/h)	5 500	5 500	8 000	8 000	15 400	15 400
Borehole Depth (m)	60	60	35	35	60	60

Depth of Water Strike (m)	24	24	17	17	22	22
Static Water Level (m)	15	15	8	8	11	11
Average Aquifer Yield (l/h)	5 500	5 500	5 500	5 500	5 500	5 500
Average Borehole Depth (m)	41	41	41	41	41	41
Average Depth of Water Strike (m)	28	28	28	28	28	28
Average Static Water Level (m)	17	17	17	17	17	17
Land Type Series	Ae20b Hutton	Ae20b Hutton	Ea1a Arcadia	Ea1a Arcadia	Ae18c Hutton	Ae18c Hutton
Profile No	P89	P89	P84	P84	P89	P89
Depth Sampled	760 – 1200 mm	760 – 1200 mm	800 – 1000 mm	800 – 1000 mm	760 – 1200 mm	760 – 1200 mm
Gravel %	1	1	6	6	1	1
Sand %	70	70	17	17	70	70
Silt %	4	4	23	23	4	4
Clay %	25	25	54	54	25	25
pH (H_2O)	7.4	7.4	8.3	8.3	7.4	7.4
P (mg/kg)	1.7	1.7	0.3	0.3	1.7	1.7
Ca (mg/kg)	1000	1000	8717	8717	1000	1000
Mg (mg/kg)	192	192	1749	1749	192	192
K (mg/kg)	195	195	156	156	195	195
Na (mg/kg)	23	23	460	460	23	23

Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	83.1	83.1	395.0	395.0	83.1	83.1
Zn (mg/kg)	0.50	0.50	0.49	0.49	0.50	0.50
Resistance (Ohm)	960	960	270	270	960	960
C%	0.2	0.2	0.6	0.6	0.2	0.2
CEC ($cmol_c/kg$)	67	67	610	610	67	67
Veld Type	16/18 Kalahari Thornveld/ Mixed Bushveld	16/18 Kalahari Thornveld/ Mixed Bushveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld
Hydrogeological Unit	D3	D3	D5	D5	B5	B5

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999) & Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoir is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

Table A1.27 (b). Jurassic Eonothem: Basalt rock of the Letaba Formation and dolerite intrusions of the Karoo Supergroup in the Springbok Flats Area: contact, weathering and/or fracture zone absent.

Parameter	Kalkheuvel 73 JR		Langkuil 13 JR		Vlakplaats 483 KR	
Geological Formation	Unweathered dolerite	Unweathered dolerite	Unweathered basalt	Unweathered basalt	Unweathered basalt	Unweathered basalt
Depth Sampled	0.5m	1.2m	0.5m	1.2m	0.5m	1.2m
Borehole Co-ordinates: S.L. E.L.	25º11.077’ 28º20.609’	25º11.077’ 28º20.609’	25º00.411’ 28º14.258’	25º00.411’ 28º14.258’	24º57.967’ 28º07.129’	24º57.967’ 28º07.129’
Soil colour	Moderate reddish brown	Very dark red	Light brown	Strong brown	Dark brown	Dusky yellowish brown
Soil texture description	Clayey silt	Clay	Silty clay	Silty clay	Silty clay	Silty clay
pH	6.79	7.52	7.52	7.11	6.98	6.70
P (mg/kg)	8.10	14.87	1.67	1.11	1.22	0.88
Ca (mg/kg)	1741	2452	3738	1530	4493	1542
Mg (mg/kg)	321	357	1294	367	1511	349
K (mg/kg)	433	470	104	129	155	116
Na (mg/kg)	9	23	35	20	61	46
Fe (mg/kg)	29.55	31.77	70.87	115.17	64.56	136.35
Mn (mg/kg)	226.23	242.79	227.03	228.00	300.13	283.67
Zn (mg/kg)	0.86	2.02	0.33	1.08	0.53	0.85
Al ($cmol_c$/kg)	0	0	0	0	0	0
Resistance (Ohm)	1600	440	2000	2400	1800	2200

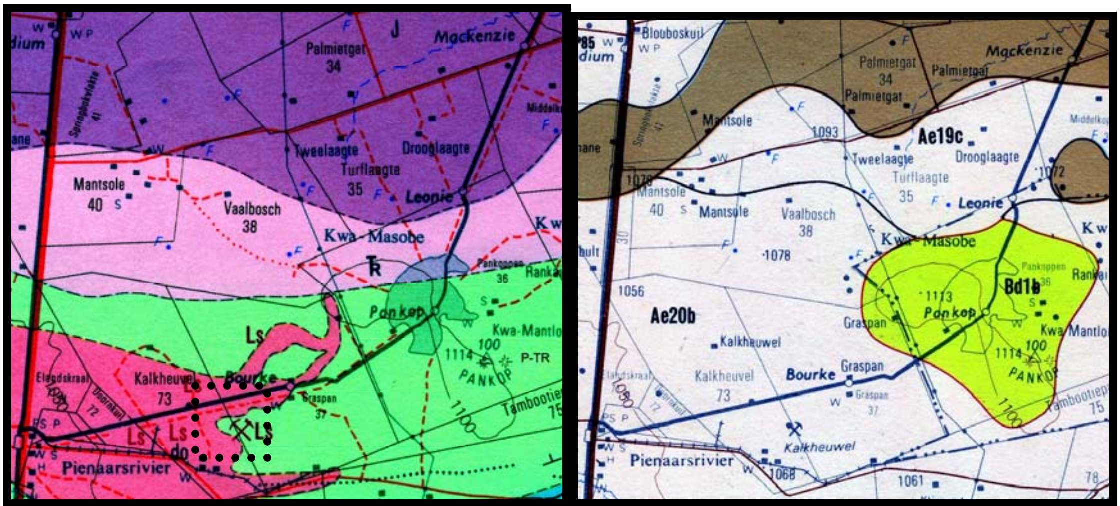
C%	0.96	1.38	0.03	0.23	0.11	0.44
Total N%	0.099	0.127	0.001	0.022	0.016	0.033
S (mg/kg)	16.99	12.69	3.84	5.19	6.67	6.30
CEC ($cmol_c$/kg)	9.828	7.52	16.86	13.78	9.14	31.40
Distinct Tree Species	1. Acacia karroo 2. Rhus lancea	1. Acacia karroo 2. Rhus lancea	1. Combretum erythrophyllum	1. Combretum erythrophyllum	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense	1. Acacia karroo 2. Ximenia caffra 3. Zanthoxylum capense
Average rooting depth of the indicated species (m)	13 - 50	13 - 50	12	12	4 - 50	4 - 50
Average depth of weathering (m)	2.4	2.4	1.9	1.9	2.5	2.5
Geomorphology	Plain	Plain	Plain	Plain	Plain	Plain
Geophysical instrumentation used	Electromagnetics & Magnetics	Electromagnetics & Magnetics	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger soundings	Electromagnetics, Magnetics and Schlumberger sounding	Electromagnetics, Magnetics and Schlumberger sounding
Water features present?	No	No	Yes-small stream “Plat River” 700 m east	Yes-small stream “Plat River” 700 m east	No	No
Aquifer Yield (l/h)	5 500	5 500	8 000	8 000	15 400	15 400
Borehole Depth (m)	60	60	35	35	60	60
Depth of Water Strike (m)	24	24	17	17	22	22

Static Water Level (m)	15	15	8	8	11	11
Average Aquifer Yield (l/h)	5 500	5 500	5 500	5 500	5 500	5 500
Average Borehole Depth (m)	41	41	41	41	41	41
Average Depth of Water Strike (m)	28	28	28	28	28	28
Average Static Water Level (m)	17	17	17	17	17	17
Land Type Series	Ae20b Hutton	Ae20b Hutton	Ea1a Arcadia	Ea1a Arcadia	Ae18c Hutton	Ae18c Hutton
Profile No	P89	P89	P84	P84	P89	P89
Depth Sampled	760 – 1200 mm	760 – 1200 mm	800 – 1000 mm	800 – 1000 mm	760 – 1200 mm	760 – 1200 mm
Gravel %	1	1	6	6	1	1
Sand %	70	70	17	17	70	70
Silt %	4	4	23	23	4	4
Clay %	25	25	54	54	25	25
pH (H_2O)	7.4	7.4	8.3	8.3	7.4	7.4
P (mg/kg)	1.7	1.7	0.3	0.3	1.7	1.7
Ca (mg/kg)	1000	1000	5758	5739	1000	1000
Mg (mg/kg)	192	192	2061	2014	192	192
K (mg/kg)	195	195	155	153	195	195
Na (mg/kg)	23	23	72	104	23	23
Fe (mg/kg)	-	-	-	-	-	-
Mn (mg/kg)	83.1	83.1	395.0	395.0	83.1	83.1

Zn (mg/kg)	0.50	0.50	0.49	0.49	0.50	0.50
Resistance (Ohm)	960	960	270	270	960	960
C%	0.2	0.2	0.6	0.6	0.2	0.2
CEC ($cmol_c$/kg)	67	67	610	610	67	67
Veld Type	16/18 Kalahari Thornveld/ Mixed Bushveld	16/18 Kalahari Thornveld/ Mixed Bushveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld	12 Springbok Flats Turf Thornveld
Hydrogeological Unit	D3	D3	D5	D5	B5	B5

Information obtained from the veld type maps from Acocks (1988) and hydrogeological information from DWAF: Johannesburg (1999) & Polokwane (2003). Soil colour was identified and classified in the veld according to the Corstor Colour Gauge that lists 168 different soil colours. Geohydrological parameters were derived from Frommurze (1937). Information obtained from the land type maps and accompanying memoirs is from Land Type Survey Staff (1987). Average weathering depth is extracted from the indicated Land Type Survey Staff and average rooting depth of the geobotanical indicators is referenced from Canadell *et al*. (1996).

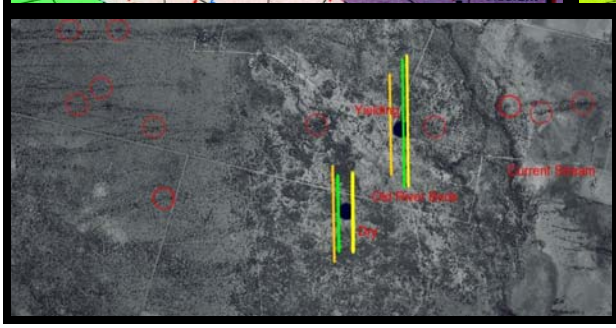
48. Kalkheuvel 73JR



Abbreviation	Geology
P-TR	Siltstone, sandstone, marl, mudstone, shale
TR	Sandstone
J	Basalt, sandstone
do	Dolerite
Abbreviation	**Soil series**
Ae19c	Hutton
Ae20b	Hutton
Bd1b	Clovelly

Figure A1.48. The geology (top left), land type (top right) and aerial photograph (bottom) of Kalkheuvel 73JR. The blue circle denotes the position of the borehole and the green and yellow lines the direction of the (electro)-magnetic profiles. The area covered by the aerial photograph is indicated by the black shape in the geological map. Note the disturbed surface on the aerial photograph due to mining activities. No vegetation patterns are easy to recognize.

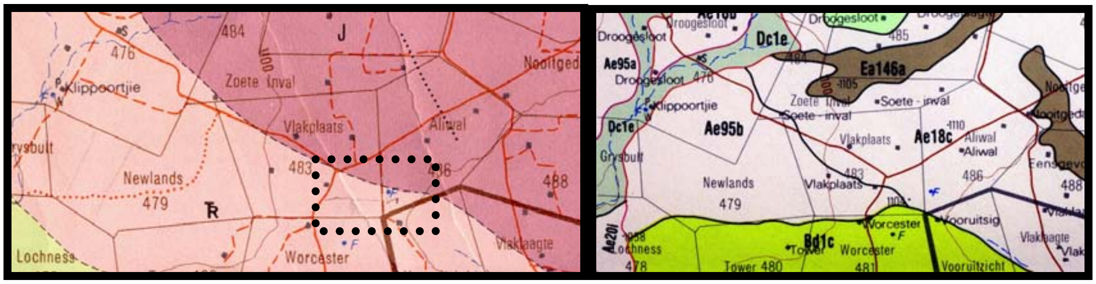
49. Langkuil 13JR

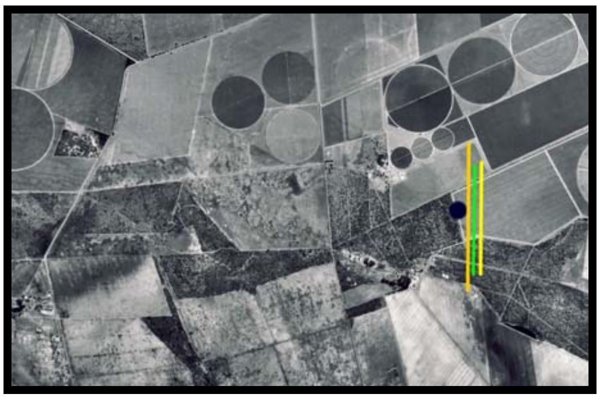


Abbreviation	**Geology**
TR	Sandstone
J	Basalt, sandstone
Abbreviation	**Soil series**
Ae18a	Hutton
Ae19a,b	Hutton
Ea1a	Arcadia

Figure A1.49. The geology (top left), land type (top right) and aerial photograph (bottom) of Langkuil 13JR. The blue circles denote the position of the boreholes (dry and yielding), the green and yellow lines the direction of the (electro)-magnetic profiles and the orange lines the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. The red circles indicate linear features that were recognized by the magnetometer. The position of the current and past river bed is indicated.

50. Vlakplaats 483KR





Abbreviation	Geology
Tr	Sandstone
J	Basalt, sandstone
………………	Lineament
Abbreviation	**Soil series**
Ae18c	Hutton
Ae95b	Hutton
Bd1c	Clovelly
Ea146a	Arcadia

Figure A1.50. The geology (top left), land type (top right) and aerial photograph (bottom) of Vlakplaats 483KR. The blue circle denotes the position of the borehole, the green and yellow lines the direction of the (electro)-magnetic profiles and the orange line the direction of the sounding electrodes. The area covered by the aerial photograph is indicated by the black shape in the geological map. No vegetation patterns are easy to recognize in this cultivated landscape.

ANNEXURE 2: AN OVERVIEW OF THE IDENTIFIED GEOBOTANICAL INDICATORS

This section presents a brief description of the locality, biome and Photographs of the identified geobotanical indicators. The geobotanical indicators that are listed are those that are tabled in Table 5.1, both the recognized (A2.2.1-16) and warrants more study geobotanical indicators (A2.2.17-24). Only the biomes relevant to the research area are mentioned.

A2.1 BIOME OVERSIGHT

The area of the study area is represented in Figure A2.1. This figure indicates the different biomes and the overlap of the different geological units as indicated in Chapter 3. Compare this figure with Figure 3.4.

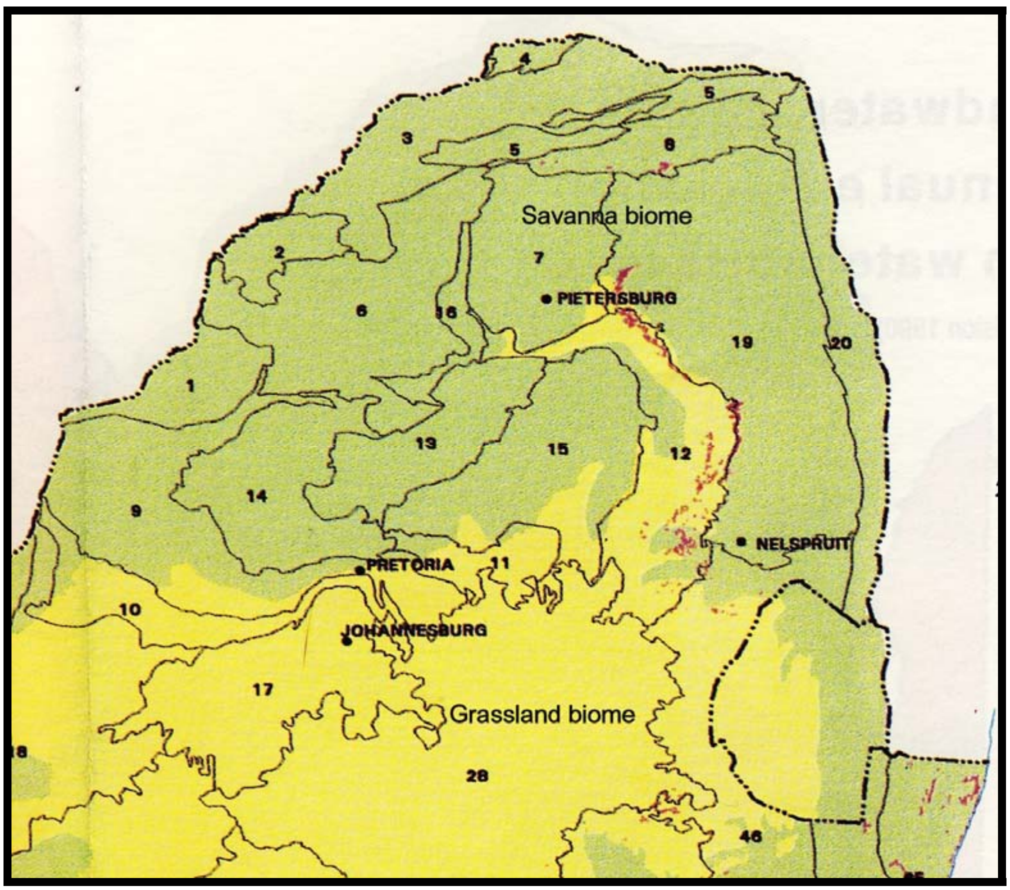


Figure A2.1. Distribution of biomes across the research area and geological units (Vegter, 2001a).

A2.2 IDENTIFIED GEOBOTANICAL INDICATORS

A2.2.1 *Acacia karroo* (Sweet thorn)

Distribution: Grassland and Savanna biomes.

Description: Shrub to medium-sized deciduous tree, variable in shape but typically with a somewhat rounded crown. Spines slender, white, often more prominent on young trees (Van Wyk & Van Wyk, 1997).

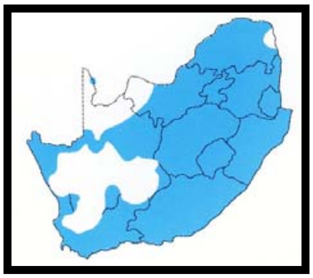


Figure A2.2. Distribution of *Acacia karroo* (Venter & Venter, 2005).

Figure A2.3. Photographs of *Acacia karroo* (appearance, thorns, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.2 *Adansonia digitata* (Baobab)

Distribution: Savanna biome.

Description: Grotesque, comparatively short, deciduous tree with hugely swollen trunk; occurring at low altitudes in hot dry bushveld (Van Wyk & Van Wyk, 1997).

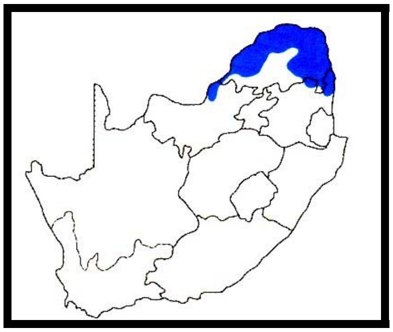


Figure A2.4. Distribution of *Adansonia digitata* (Venter & Venter, 2005).

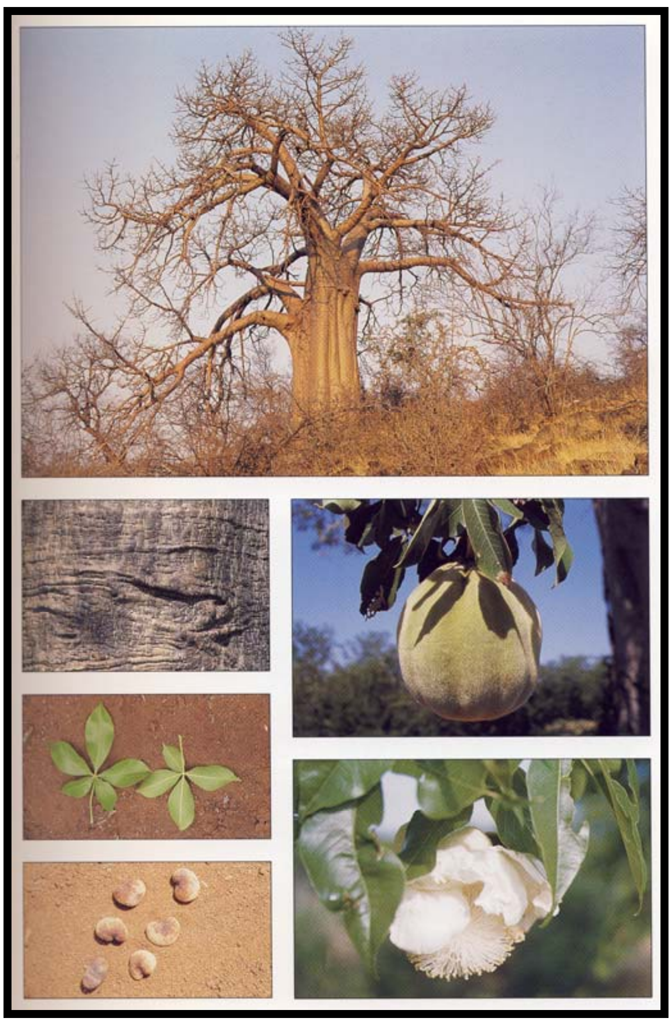


Figure A2.5. Photographs of *Adansonia digitata* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.3 *Burkea africana* (Wild seringa)

Distribution: Grassland and Savanna biomes.

Description: Medium-sized deciduous tree with a somewhat flattened and spreading crown; occurring often on deep sandy soil (Van Wyk & Van Wyk, 1997).

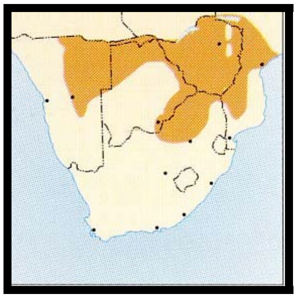


Figure A2.6. Distribution of *Burkea africana* (Van Wyk & Van Wyk, 1997).

Figure A2.7. Photographs of *Burkea africana* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986).

A2.2.4 *Dichapetalum cymosum* (Poison leaf/Gifblaar)

Found very often in association with *Burkea Africana*.

Distribution: Grassland and Savanna biomes.

Description: An enormous woody plant that grows underground except for the numerous branch tips that emerges above the ground. The species is easily recognized by the alternate (deciduous) leaves (not opposite) and the same bright green colour of the upper and lower leaf surfaces (Van Wyk *et al*., 2002).

Figure A2.8. Distribution of *Dichapetalum cymosum* (Van Wyk *et al*., 2002).

Figure A2.9. Photographs of *Dichapetalum cymosum* (appearance, flowers, seeds and leaves) (Van Wyk *et al*., 2002).

A2.2.5 *Celtis africana (White stinkwood)*

Distribution: Grassland and Savanna biomes.

Description: Medium to large deciduous tree; occurring often on dolomite (Van Wyk & Van Wyk, 1997).

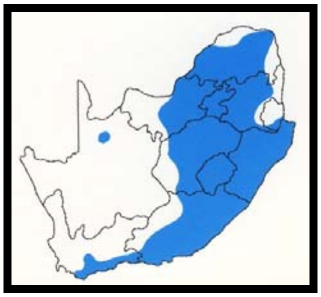


Figure A2.10. Distribution of *Celtis africana* (Venter & Venter, 2005).

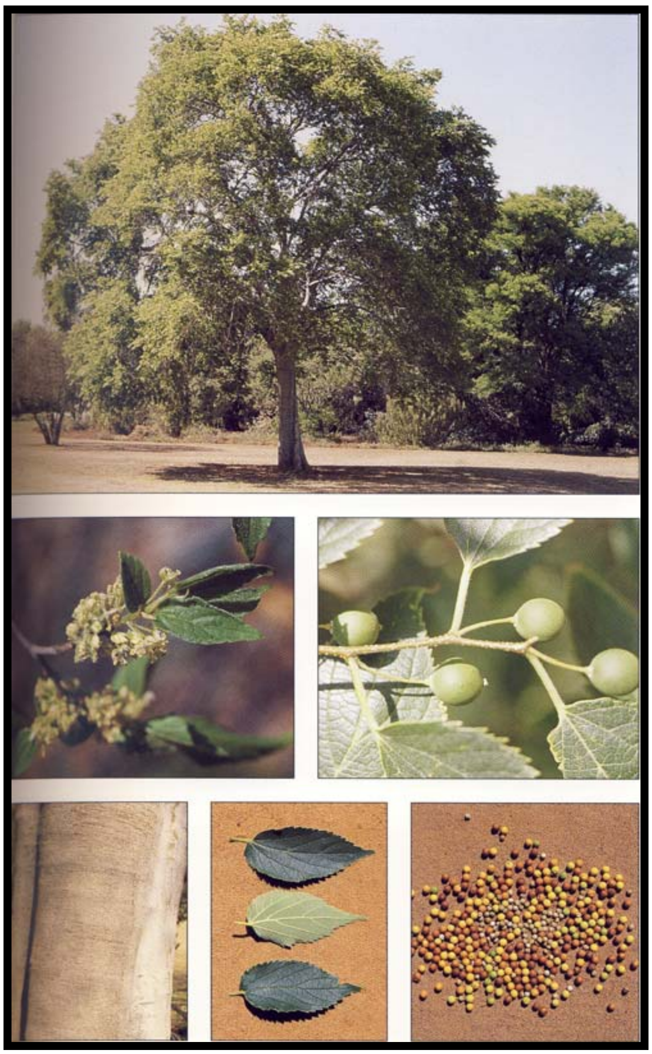


Figure A2.11. Photographs of *Celtis africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.6 *Clerodendrum glabrum (Tinderwood)*

Distribution: Grassland and Savanna biomes.

Description: Shrub or small to medium-sized deciduous tree, crown often drooping (Van Wyk & Van Wyk, 1997).

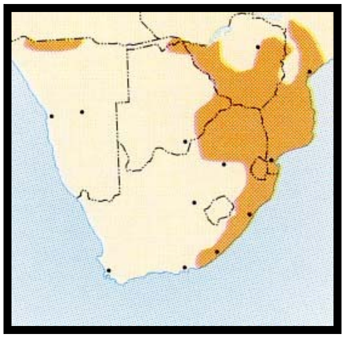


Figure A2.12. Distribution of *Clerodendrum glabrum* (Van Wyk & Van Wyk, 1997).

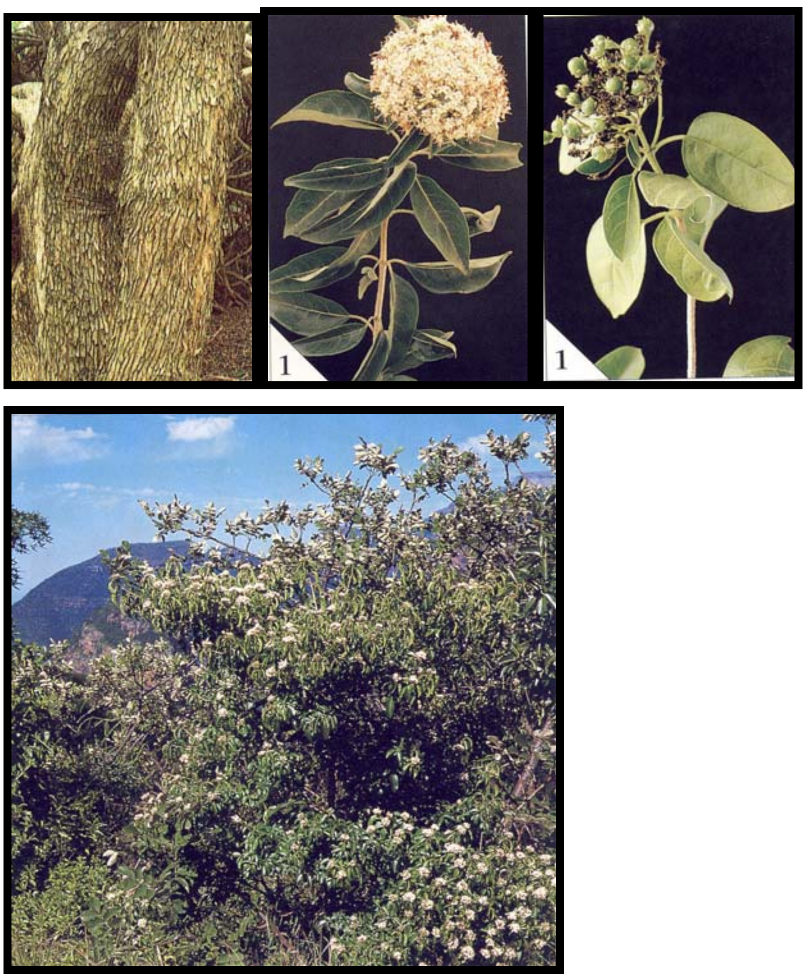


Figure A2.13. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.7 *Combretum erythrophyllum (River bush-willow)*

Distribution: Grassland and Savanna biomes.

Description: Small to large deciduous tree, with reddish autumn and sometimes whitish spring colours; occurring mainly along the banks of rivers (Van Wyk & Van Wyk, 1997).

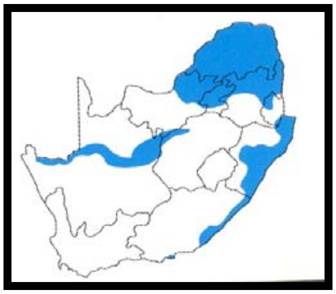


Figure A2.14. Distribution of *Combretum erythrophyllum* (Venter & Venter, 2005).

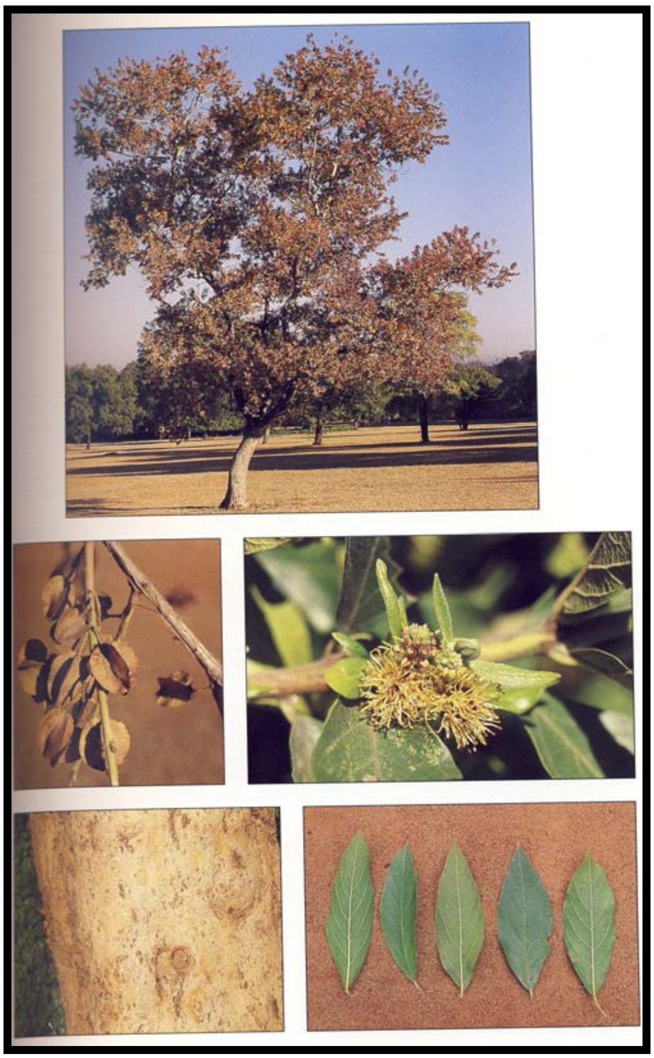


Figure A2.15. Photographs of *Combretum erythrophyllum* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.8 *Combretum imberbe (Leadwood)*

Distribution: Savanna biome.

Description: Medium to large semi-deciduous tree with a grayish appearance; occurring in bushveld, often on alluvial soils along rivers or dry watercourses (Van Wyk & Van Wyk, 1997).

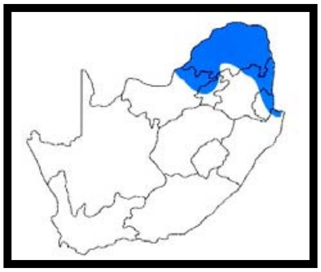


Figure A2.16. Distribution of *Combretum imberbe* (Venter & Venter, 2005).

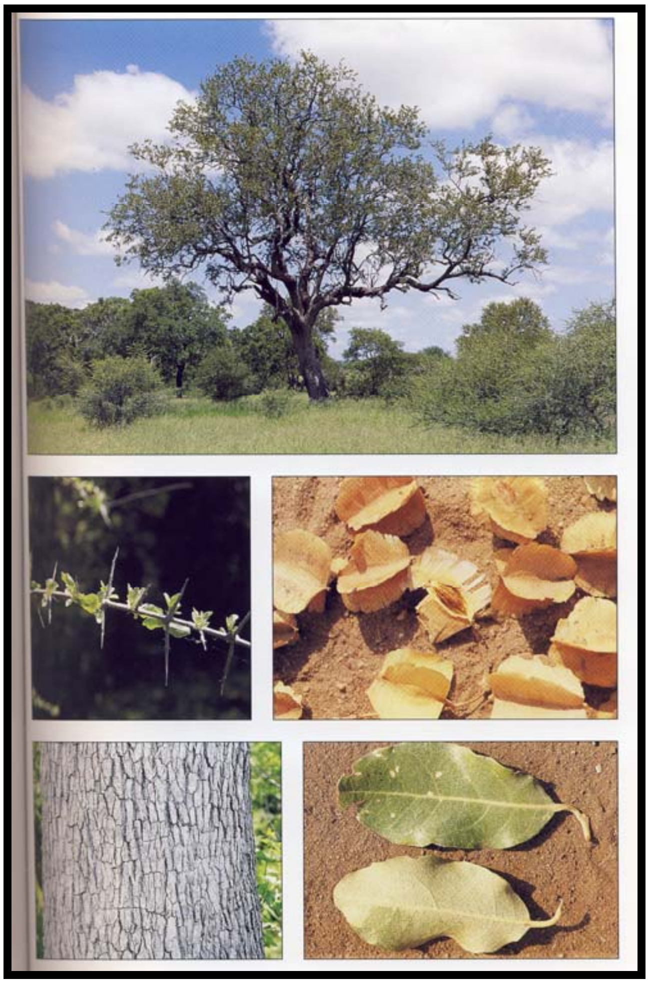


Figure A2.17. Photographs of *Combretum imberbe* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.9 *Euclea crispa (Blue guarri)*

Distribution: Grassland and Savanna biomes.

Description: Much-branched evergreen shrub or small tree, usually with a dense, grey-green crown; occurring in bushveld, forest margins and sheltered places in grassland, often in rocky places (Van Wyk & Van Wyk, 1997).

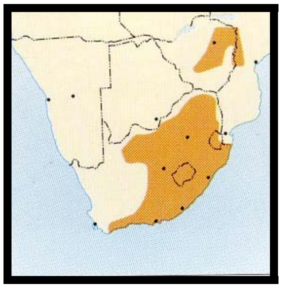


Figure A2.18. Distribution of *Euclea crispa* (Van Wyk & Van Wyk, 1997).

Figure A2.19. Photographs of *Clerodendrum glabrum* (appearance (Grant and Thomas, 2002), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Pooley, 1997) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.10 *Ficus ingens (Red-leaved fig)*

Distribution: Grassland and Savanna biomes.

Description: Dwarf spreading shrub or small to medium-sized deciduous tree, often acting as a rock-splitter; occurring in bushveld or frost-protected sites in grassland, usually on rocky hills (Van Wyk & Van Wyk, 1997).

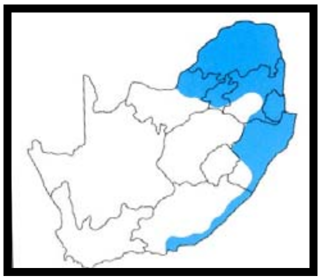


Figure A2.20. Distribution of *Ficus ingens* (Venter & Venter, 2005).

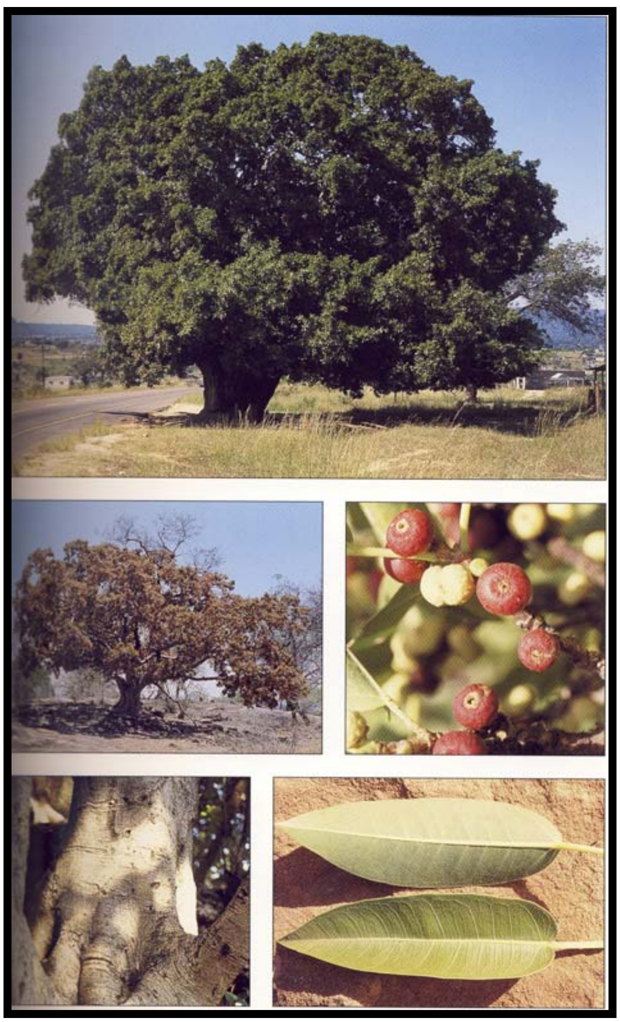


Figure A2.21. Photographs of *Ficus ingens* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.11 *Fingerhuthia sesleriiformis (Thimble grass)*

Distribution: Grassland and Savanna biomes.

Description: A perennial tuft-grass with unbranched stalks to 0.9 m long; occurring on calc-containing rock outcrops, disturbed areas and in well-drained sand and gravel soils (Van Oudtshoorn, 1994).

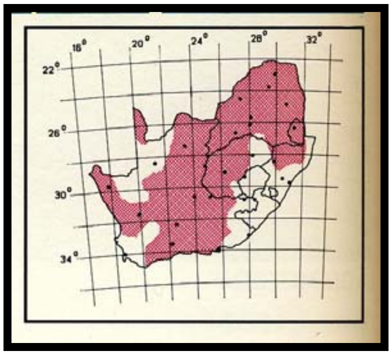


Figure A2.22. Distribution of *Fingerhuthia sesleriiformis* (Van Oudtshoorn, 1994).

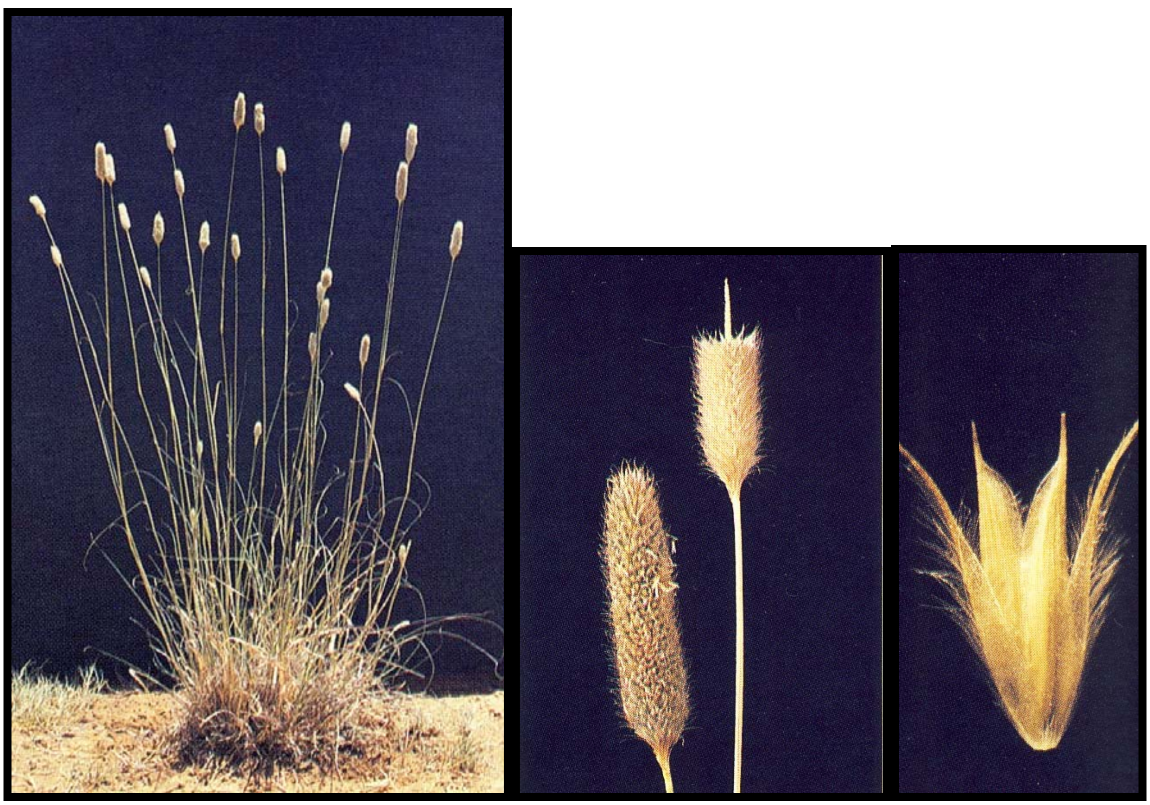


Figure A2.23. Photographs of *Fingerhuthia sesleriiformis* (appearance, flowers, seeds and leaves) (Van Oudtshoorn, 1994).

A2.2.12 *Rhus lancea (Karee)*

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree; occurring in a wide range of habitats, often on calcareous substrates (Van Wyk & Van Wyk, 1997).

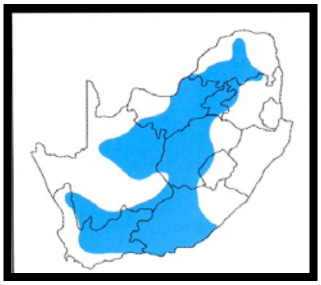


Figure A2.24. Distribution of *Rhus lancea* (Venter & Venter, 2005).

Figure A2.25. Photographs of *Rhus lancea* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.13 *Strychnos pungens (Spine-leaved monkey orange)*

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree; occurring in a wide range of habitats, often on calcareous substrates (Van Wyk & Van Wyk, 1997).

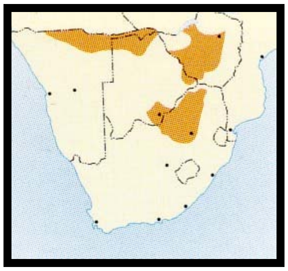


Figure A2.26. Distribution of *Strychnos pungens* (Van Wyk & Van Wyk, 1997).

Figure A2.27. Photographs of *Strychnos pungens* (appearance (Grant and Thomas, 2000), seeds (Van Wyk & Van Wyk, 1997), flowers (Van Wyk & Van Wyk, 1997), bark (Van Wyk, 1986) and leaves (Van Wyk & Van Wyk, 1997)).

A2.2.14 *Ximenia americana & X. caffra (Blue sourplum & Sourplum)*

Distribution: Mainly in the Savanna biome.

Description: *Ximenia americana*: Much-branched shrub or small deciduous tree with a blue-green appearance; occurring in bushveld, often in hot, low altitude areas.

Ximenia caffra: Sparsely branched shrub or small deciduous tree with dark green leaves (Van Wyk & Van Wyk, 1997).

Figure A2.28. Distribution of *Ximenia caffra* (Venter & Venter, 2005). The distribution of *Ximenia americana* is similar.

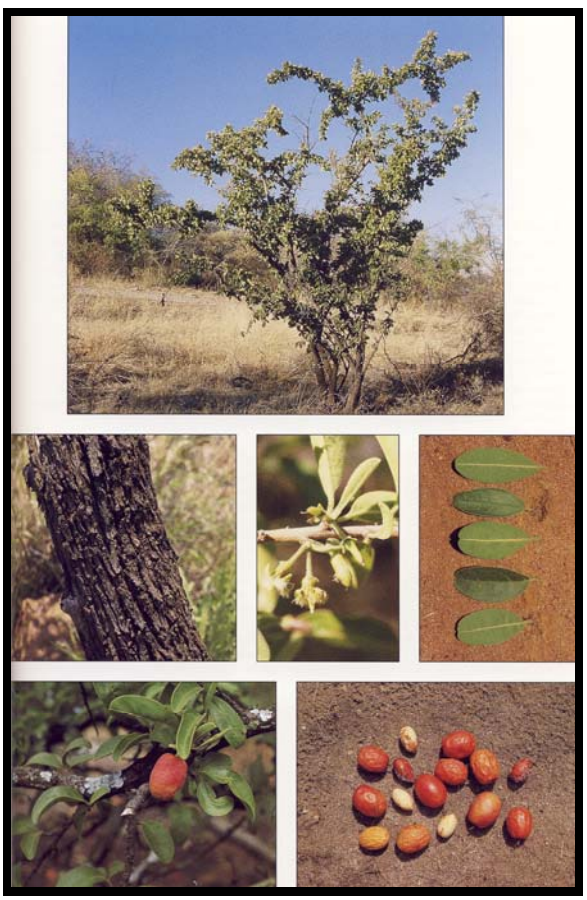


Figure A2.29. Photographs of *Ximenia caffra* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). The leaves of *Ximenia americana* are blue-green.

A2.2.15 *Zanthoxylum capense (Small knobwood)*

Distribution: Grassland and Savanna biomes.

Description: Shrub or small deciduous tree armed with prickles; occurring in grassland, bushveld and along forest margins, usually associated with bush clumps and rocky places (Van Wyk & Van Wyk, 1997).

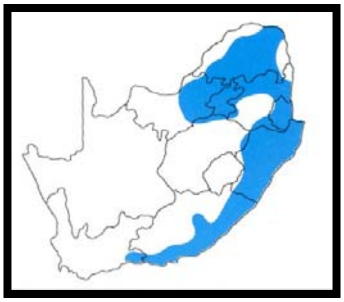


Figure A2.30. Distribution of *Zanthoxylum capense* (Venter & Venter, 2005).

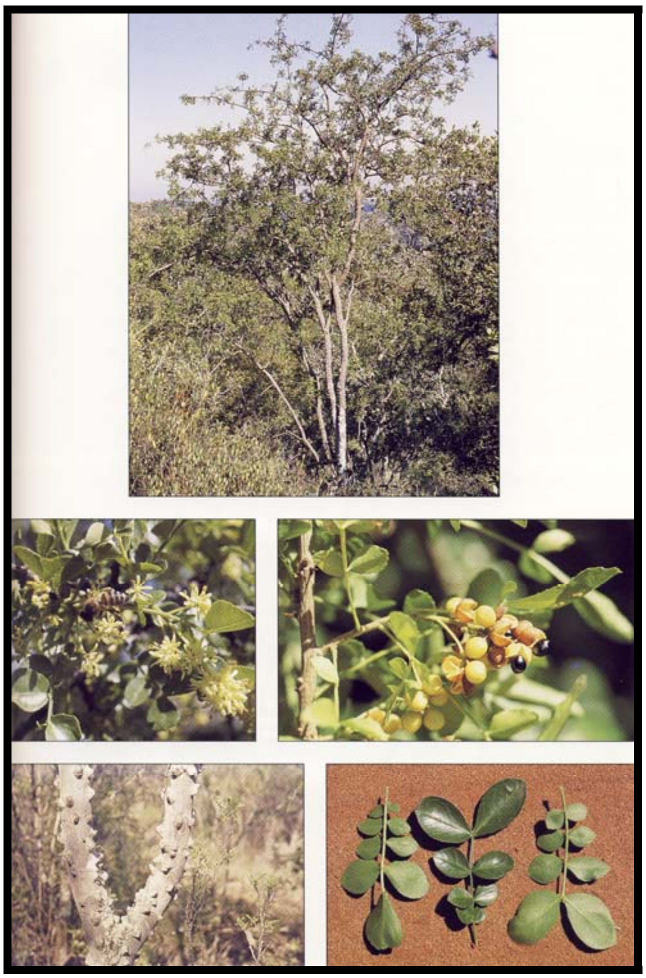


Figure A2.31. Photographs of *Zanthoxylum capense* (appearance, flowers, seeds, thorny bark and leaves) (Venter & Venter, 2005).

A2.2.16 *Ziziphus mucronata (Buffalo-thorn)*

Distribution: Grassland and Savanna biomes.

Description: Shrub or small to medium-sized deciduous tree; occurring in a wide variety of habitats (Van Wyk & Van Wyk, 1997).

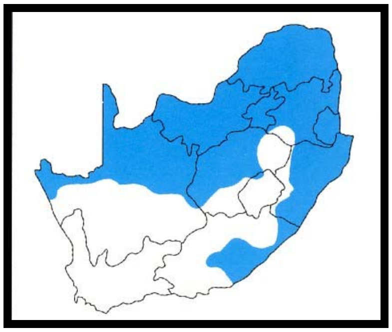


Figure A2.32. Distribution of *Ziziphus mucronata* (Venter & Venter, 2005).

Figure A2.33. Photographs of *Ziziphus mucronata* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005).

A2.2.17 *Acacia erioloba (Camel thorn)*

Distribution: Grassland and Savanna biomes.

Description: Medium to large tree with a rounded or umbrella-shaped crown; main branches often somewhat contorted in old trees; occurring in bushveld and grassland, usually on deep sandy soils or along watercourses in arid areas (Van Wyk & Van Wyk, 1997).

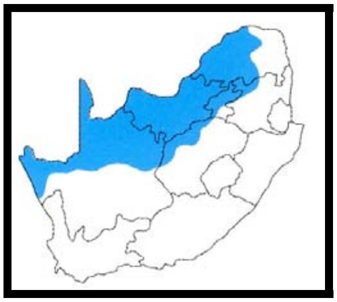


Figure A2.34. Distribution of *Acacia erioloba* (Venter & Venter, 2005).

Figure A2.35. Photographs of *Acacia erioloba* (appearance, flowers, seeds, thorns, bark and leaves) (Venter & Venter, 2005).

A2.2.18 *Boscia albitrunca* & *B. foetida* subsp. *rehmanniana (Shepherd's tree & Stink shepherd's tree)*

Distribution: Mainly in the Savanna biome.

Description: *Boscia albitrunca*: Small tree with a rounded, much-branched crown and rigid branchlets; occurring in semi-desert areas and bushveld, often on termitaria.

B. foetida subsp. *rehmanniana*: Small tree with a single stem, usually starting to branch at least 1 m above the ground; occurring in dry bushveld (restricted to the research area). Leaves are smaller than these of *Boscia albitrunca* (Van Wyk & Van Wyk, 1997).

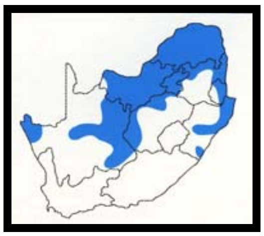


Figure A2.36. Distribution of *Boscia albitrunca* (Venter & Venter, 2005). The distribution of *B. foetida* subsp. *rehmanniana* is restricted to the research area.

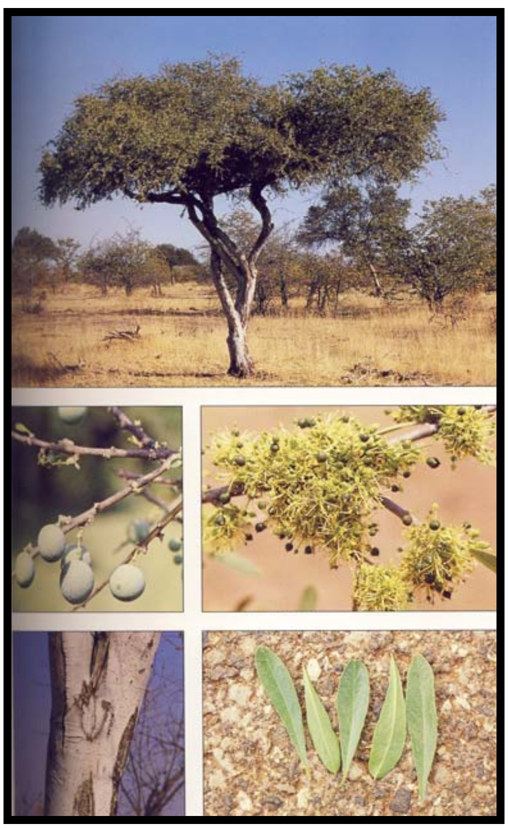


Figure A2.37. Photographs of *Boscia albitrunca* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005). Note that the leaves of *B. foetida* subsp. *rehmanniana* are smaller.

A2.2.19 *Commiphora mollis (Velvet corkwood)*

Distribution: Savanna biome.

Description: Small to medium-sized, deciduous tree; occurring in hot, dry bushveld, often on rocky outcrops (Van Wyk & Van Wyk, 1997).

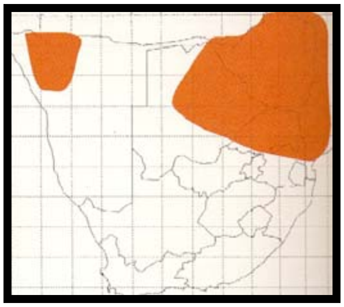


Figure A2.38. Distribution of *Commiphora mollis* (Steyn, 2003).

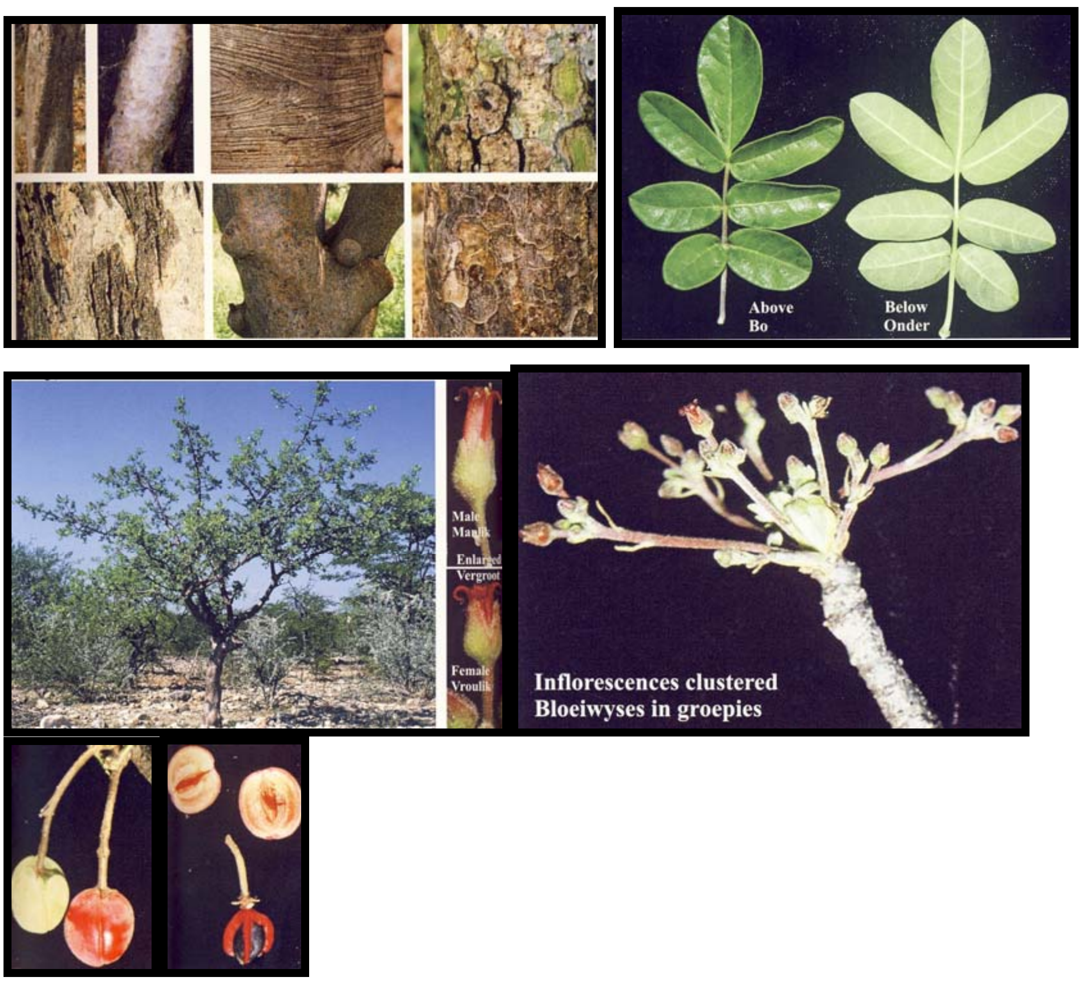


Figure A2.39. Photographs of *Commiphora mollis* (appearance, flowers, seeds, bark and leaves) (Steyn, 2003).

A2.2.20 *Gardenia volkensii (Savanna gardenia)*

Distribution: Savanna biome.

Description: Shrub or small tree, with short, rigid branches; occurring in bushveld (Van Wyk & Van Wyk, 1997).

Figure A2.40. Distribution of *Gardenia volkensii* (Venter & Venter, 2005).

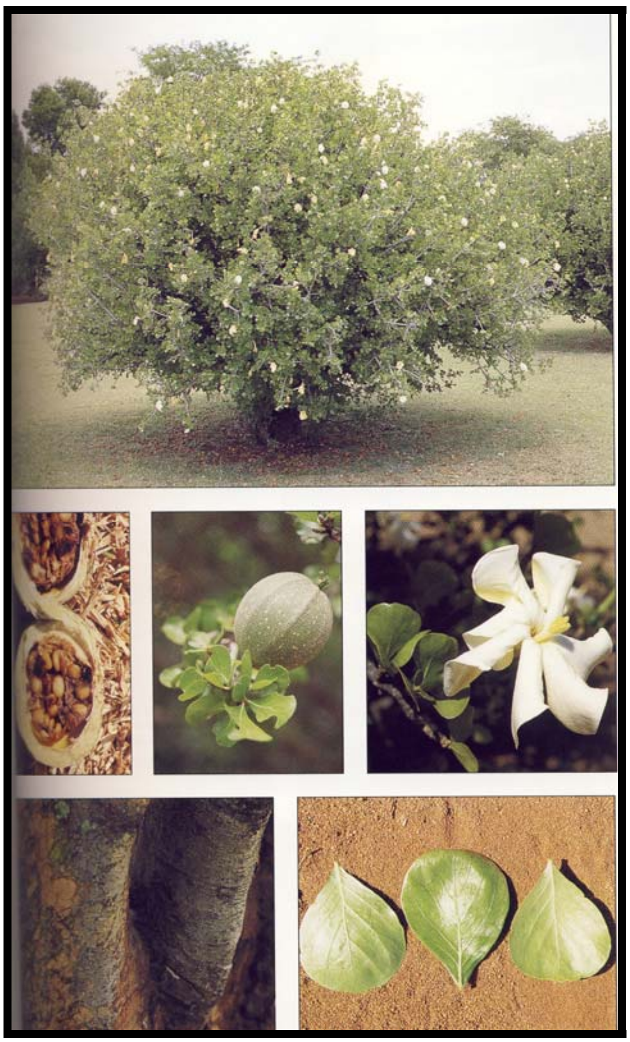


Figure A2.41. Photographs of *Gardenia volkensii* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.21 *Lonchocarpus capassa (Apple-leaf)*

Distribution: Savanna biome.

Description: Small to medium-sized deciduous or semi-deciduous tree with a rather sparse crown; occurring in bushveld and woodland, often at low altitude along rivers (Van Wyk & Van Wyk, 1997).

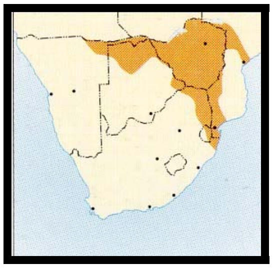


Figure A2.42. Distribution of *Lonchocarpus capassa* (Van Wyk & Van Wyk, 1997).

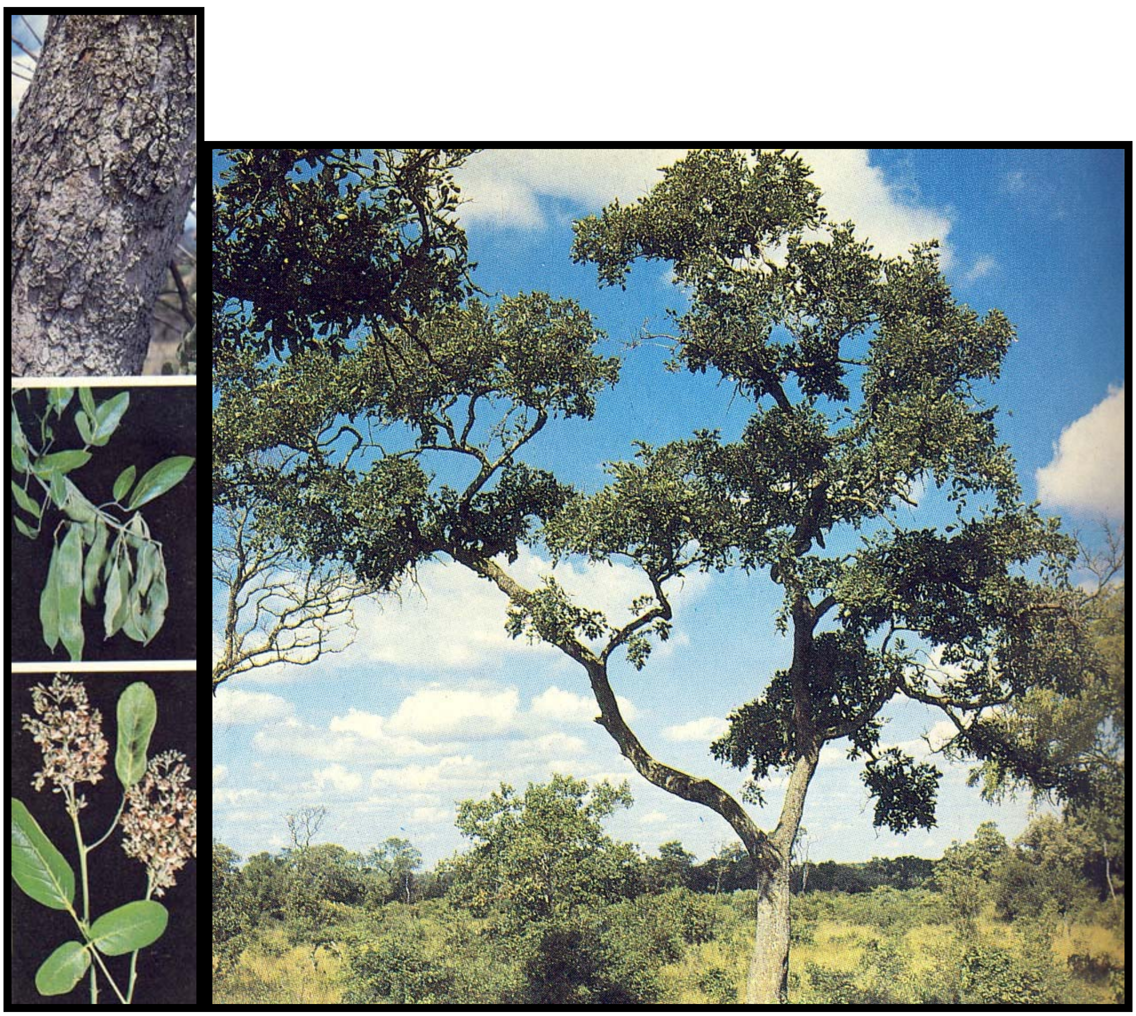


Figure A2.43. Photographs of *Lonchocarpus capassa* (appearance, flowers, seeds, bark and leaves) (Van Wyk, 1986).

A2.2.22 *Olea europaea* subsp. *africana (Wild olive)*

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized evergreen tree with a dense rounded crown and grayish green foliage; occurring in a wide range of habitats, usually on rocky hillsides or on stream banks (Van Wyk & Van Wyk, 1997).

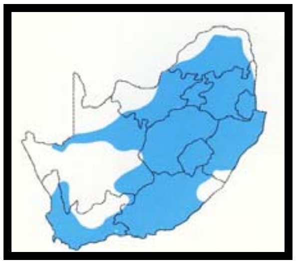


Figure A2.44. Distribution of *Olea europaea* subsp. *africana* (Venter & Venter, 2005).

Figure A2.45. Photographs of *Olea europaea* subsp. *africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.23 *Pappea capensis (Jacket-plum)*

Distribution: Grassland and Savanna biomes.

Description: Small to medium-sized deciduous tree with a spreading, often intricately branched crown; occurring in bushveld and wooded grassland (Van Wyk & Van Wyk, 1997).

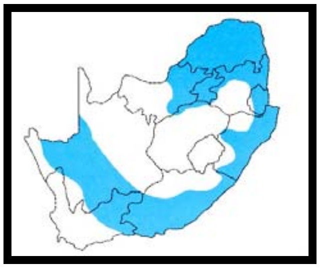


Figure A2.46. Distribution of *Pappea capensis* (Venter & Venter, 2005).

Figure A2.47. Photographs of *Pappea capensis* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).

A2.2.24 *Spirostachys africana (Tamboti)*

Distribution: Savanna biome.

Description: Medium-sized deciduous tree with a rounded crown and yellow or reddish autumn colours; latex milky; occurring in low-altitude bushveld, often on heavy soils along rivers and streams (Van Wyk & Van Wyk, 1997).

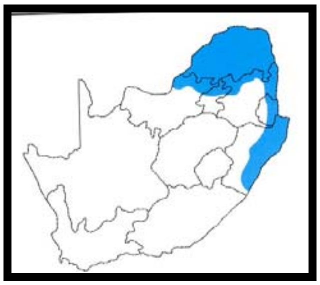


Figure A2.48. Distribution of *Spirostachys africana* (Venter & Venter, 2005).

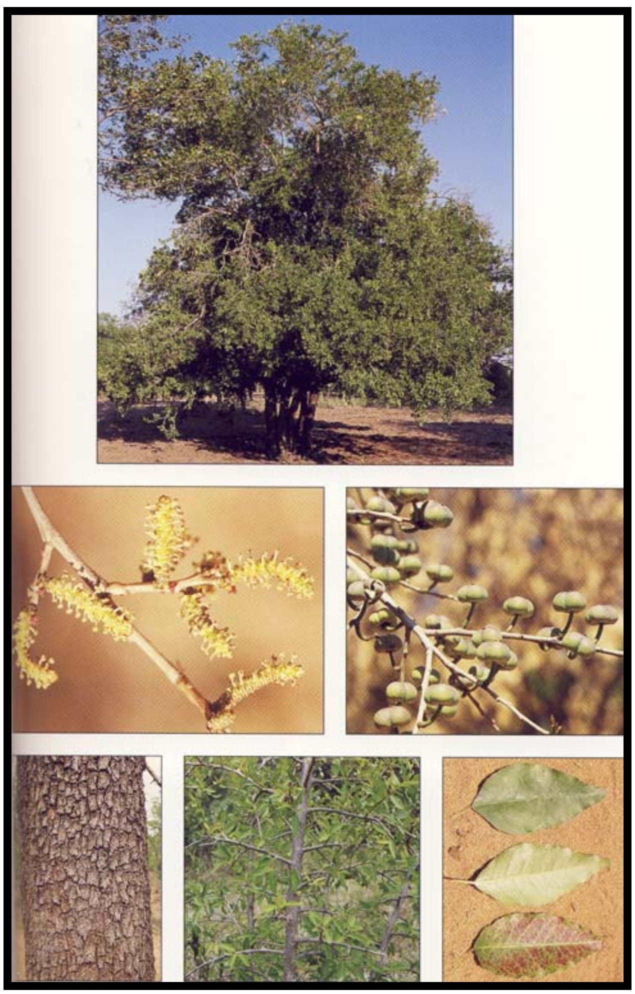


Figure A2.49. Photographs of *Spirostachys africana* (appearance, flowers, seeds, bark and leaves) (Venter & Venter, 2005).