The preliminary identification of problem soils for infrastructure projects

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ABSTRACT: During the feasibility and planning stages of infrastructure projects, the early identification of problem materials that could affect the project can save significant costs and/or redesigns later in the project. As the potentially most problematic soils are those within the top 1.0 or 1.5 m of the soil profile, a mechanism for evaluating these materials without preliminary field work and testing would be invaluable. Since 1971, the Department of Agriculture has systematically mapped the soils covering the entire land surface of South Africa, at a 1 : 250 000 scale (field scale 1:50 00). The mapping units are land types, which are defined as areas that show a marked degree of uniformity with respect to terrain form, soil type and climate. These are (coincidentally) the same criteria selected for a materials data bank for roads developed in the 1970s and must therefore be of similar use in infrastructure and particularly road engineering. As the primary aim of the soil maps was to provide information regarding the agricultural potential of the soils, comprehensive testing of various properties has also been carried out.

Analysis of the Soil Maps and their accompanying information (freely available on a local web site) indicates that they can be used to identify (in broad terms) the types of soils in any area under review, and many of the accompanying potential problems. Soils such as potentially expansive materials are identified directly, potentially dispersive soils can be identified through the exchangeable sodium ion contents provided and collapsible soils through widespread exposures of sandy and residual materials of low density. In addition, a general assessment of moist areas and those with thick or thin soils or rocky outcrops, underlying dolomitic materials, saline soils, etc, can be obtained early during any project, even before any site visit has been made. Being forearmed with such information will often lead to avoiding the threat of unnecessary land expropriation, to more efficient site investigations and more economical route alignment and to avoiding claims and delays during execution of the project.

1 INTRODUCTION

The development of any infrastructure project requires a good knowledge of the material and founding conditions at the proposed site. This information is often only obtained after the feasibility and planning, and sometimes even after the preliminary design has been done. Between 1972 and 2002 the land types of South Africa were comprehensively mapped over the whole of the country for agricultural purposes. Individual land types are based on having a "marked degree of uniformity with respect to terrain form, soil pattern and climate" (ARC-ISCW 2007a). It should be noted that the land type maps result in the same intent, although the method differs, as the requirements outlined in TRH2 (NIRR 1971, NITRR 1978). Although mapping of the land types was carried out at a scale of 1:50 000, the maps are readily available in electronic or hard copy formats at a scale of 1: 250 000 (ARC-ISCW 2007a). Each map is accompanied by a wide range of soil descriptors and properties conventionally used for agricultural purposes as well as certain selected engineering properties, e.g., Atterberg limits (Netterberg 2001). Many of the soil properties that can have a bearing on their performance as subgrade/foundation materials for development or possibly even their use in construction are available or can be roughly estimated for each land type provided.

A slightly different version of the soil maps based on broad pedological groupings (more than the land types of the ARC-ISCW) is presented by Harmse & Hattingh (1985). The soils identified on the accompanying map (1: 6 000 000 scale) can, however, be used in the same general way as those described in this paper, although less detail relating to the individual soil types is provided in the text of Harmse & Hattingh.

Although the mapping (and associated soil analyses in the case of the ARC-ISCW data) have been carried out with the purpose of indicating the potential of the soils for agricultural use, this information can prove very useful for engineering purposes. The value (and shortcomings) of this information was highlighted by Brink et al (1982). Fanourakis (1991, 1999) carried out research into the assessment of soil properties for civil engineering applications from the pedological data provided in the ARC land-type maps and profiles. Netterberg (2001) also highlighted the potential application of soil science in civil engineering. The findings and recommendations of these researchers have, however, never been extended or implemented to any extent in the civil engineering industry in South Africa.

In this paper, the application of these maps and their accompanying soil data as a preliminary indicator of the common problem soils for civil engineers is discussed. Aspects such as material thicknesses and depths and the classification, mineralogy and properties of each of the materials, the presence of problem soils (expansive, dispersive, saline, etc) and certain basic road engineering properties (e.g., soil strength) can be quickly obtained to assist in identifying optimum site planning and cost-effective field investigations. The maps are potentially useful for providing a number of other useful geotechnical properties, but these are not discussed in this paper. They have been identified separately (Paige-Green & Turner 2007).

Although the overall results should be used only as preliminary indicators for planning projects, the typical types of problems that can be expected as well as issues such as the likely availability of construction materials can be identified during the early stages of projects. This information can have a significant impact on the final project design.

2 SOUTH AFRICAN LAND TYPE MAPS

Detailed or semi-detailed soil maps would be a first choice information source in civil construction projects but, with the exception of certain metropolitan areas of the Western Cape and Gauteng Provinces (ARC-ISCW 2007b), detailed soil maps are seldom available. However, land type maps, with complete coverage of South Africa, provide a useful alternative soil information source. The fundamental mapping unit of the South African land type maps is based on a combination of the topography, climate and soil pattern. Twenty eight (28) Broad Soil Pattern Groups were chosen as the basis for the soil mapping which, when combined with the topography and climate gives the land type. Soils are classified according to Soil Classification: A Binomial System for South Africa (MacVicar et al 1977) and reported in the soil and terrain inventories as Soil Forms and Series. Modal profiles have been described representing the dominant soils of most land types and samples of each horizon taken for analysis. It should be noted that the Binomial System has subsequently been revised and Soil Forms and Families are now used (Soil Classification Working Group (SCWG) 1991). The Soil Family criteria have not yet been applied to the maps.

The maps are printed as 1° x 2° sheets at a scale of 1:250 000 with accompanying memoirs and are available from the Agricultural Research Council (ARC), Institute for Soil, Climate and Water (ISCW) in electronic or hard copy formats. They can also be accessed directly on the Department of Agriculture web-site (http://www.agis.agric.za/agis). The soil analysis test results are provided in land type memoirs (ARC-ISCW 2007a) or through the ARC-ISCW Soil Profile Information System (ARC-ISCW 2007c). Land type soil data are provided as inventories, of which there are some 7 200 comprising about 65 000 soil components. The memoirs include about 2 500 modal profiles for which comprehensive soil analysis data are available for the various horizons. Examples of a portion of a land type map and a typical extract from the accompanying Memoir are given in Appendix A.

In addition to this conventional soil property information, data related to the topography, climate and parent geology is available. Land type modal profile data (point data) has been extrapolated using spatial modelling techniques to illustrate the spatial distribution of soil property values over South Africa. Maps illustrating, for example, the distribution of soil pH, cation exchange capacity and the potential for erosion (predicted soil loss) are accessible on the AGIS (Agricultural Geo-Referenced Information System) website as the Natural Resource Atlas (AGIS NR Atlas 2007). Used in combination with land type survey data these maps and data sources provide very useful information for the road design engineer.

3 INFORMATION AVAILABLE

Essentially, the printed maps and memoirs provide the basic data. A much wider range of interpretive maps is provided on the website and the two sources of information are discussed separately below.

When using land type information, an appreciation of the underlying variability of natural materials and the scale of the published information source must be maintained. Although the mapping units are clearly differentiated on the maps significant differences in the depth and nature of the soils can occur over relatively short distances. A strong materials or engineering geological background with some experience in soil mapping, profiling and terminology is thus essential to gain maximum benefit from the use of this information in infrastructure engineering.

3.1 *Printed maps*

Besides the general topo-cadastral information provided, the maps identify the broad soil patterns in an area. Other than general properties such as the presence of vertic (swelling) or thin soils, this alone is of little use to the engineer. However, when combined with the information on the soil and terrain inventory data for the land types and the modal profile data provided in the memoirs, significant useful insight into the materials in the area can be obtained. The information in the soil and terrain data sheets is mostly spatial (area and depth) and that applicable to and useful in geotechnical engineering is summarised in Table 1.

Table 1 Information available from land type soil and terrain inventory data and its potential application to geotechnical engineering

Available (and useful) soil information	Potential application or indication
Terrain information: Slope classification and definition (slope angles, shape and lengths of terrain units, terrain unit as a percentage of the land type	Indicative of possible areas for borrow pit and quarry location
Mechanical limitations to ploughing	Excavatability, stoniness, soil thickness
Areal percentage of rock outcrop	Potential excavation problems, possible quarry materials
Soil form	Nature of the general soil properties, including surface organic matter, internal soil drainage, presence of temporary or permanent wetness, general soil mineralogy and expansiveness, soil permeability and stability to erosion, and nature and composition of underlying materials
Soil series	A more detailed expression of the properties as expressed in the soil form, but extended to additional properties including base status and cation exchange properties as possible indicators of soil stability, clay content and dominant sand grade as indicators of texture. Also indications of depth of soil, excavatability (MB), general soil properties and hardpan (plinthite) materials
Depth limiting material	Subgrade materials, location of rock or hardpan,
Clay content and soil texture	Soil type
Geology	Potential problematic material types, dolomite, shale, basic crystalline rocks, etc

It should be noted that the information provided by the maps and accompanying documents is based on the upper 1 200 – 1 500 mm of the soil profile unless hard saprolite or rock is reached before this. Although this is not necessarily deep enough for all geotechnical work, it is certainly a good indication of the likelihood of potential problems and the presence of deep soils and is highly applicable to light engineering works such as foundations for houses, light structures, roads, canals and reservoirs (Jacobs & Van Huyssteen 1996). For foundations for large structures, the normal drilling programmes will still be necessary – however, knowledge of the "surface" soil conditions can often assist in optimising the location of test pits and drilling sites.

The contents of the modal profile data are equally, if not more, useful. The information included in these profiles is summarised in Table 2. The soil profile descriptions used in pedological profiling differ from those conventionally used in soil engineering (Jennings et al 1974), although they do include moisture, colour and soil type. Descriptors for soil structure and consistency are provided but differ from conventional soil engineering definitions.

The particle size distribution results have been determined on a small 100 g sample and are thus only representative of the soil matrix. They do, however, together with the percentage retained on the 2 mm screen (where provided) and the soil description in the modal profiles indicate the general nature of the materials. Fanourakis (1991) compared the results of the soil gradings provided in the Memoirs with those from conventional geotechnical testing and concluded that the engineering grading characteristics could be estimated from the pedological grading to a significant degree of reliability. Fanourakis (1991) also attempted to estimate the plasticity characteristics from the pedological properties with mixed success. However, Atterberg limits have been determined on many of the profile samples and although not published are obtainable through the ARC-ISCW Soil Profile Information System.

Table 2. Information available from modal profile data

Profile Site Description
Soil Form and Soil Series
Water table
Occurrence of flooding
Surface rockiness/stoniness
Erosion (type and classification)
Underlying material
Weathering of underlying material
Profile Soil Description
Profile depth of layers
Profile depths, soil fractions and clay mineralogy
Soil Analyses
Organic carbon
Cation exchange capacity (CEC)
Exchangeable sodium or Exchangeable Sodium Percentage (Exchangeable Na*100/CEC)
pH
Resistance or Electrical Conductivity of Saturation Extract (EC)
Particle size distribution – Clay, Silt and Sand Contents
Soil fertility properties: Phosphate, Ca, Mg, K, CEC Soil acidity values

Soil colour can be a useful indicator of its properties Jacobs & van Huyssteen (1996). Red soils (eg, Hutton Form) are usually the result of hematite and are indicative of well-drained, highly weathered soils. Soils that have a yellow-brown colour usually contain goethite, which is indicative of higher rainfall areas with a cooler climate. Grey soils are often indicative of an excess of soil water.

3.2 *Web-based maps*

The land type maps on the website provide the basic soils information but do not have the narrative data and test results given in the memoirs in an easily accessible form. It should also be noted that these maps use the revised soil patterns, with grouping of certain patterns and thus less homogeneity of the soils within the pattern. These maps have advantages in that the scale can be altered at will such that users that do not have access to geographic information system software can make on-screen adaptations to the map scale. Various other useful layers (e.g. roads, rivers, farm boundaries, climatic data, etc) can be added or removed as required. Engineers regularly requiring the land type information should consult ARC-ISCW concerning the original information source (ARC-ISCW 2007a).

The website does contain a number of small-scale derived maps published as the Natural Resources Atlas (ARC-ISCW 2004) indicating potentially problematic materials. Although derived for agricultural purposes the following maps can provide a general indication of the possible local problem conditions:

- Soil susceptible to water erosion
- Soil susceptible to wind erosion
- Potential shifting sands
- Potential for soil regeneration if badly eroded
- Soils with textural contrast
- Soils with poor or impeded drainage
- Swelling clays
- Saline and sodic soils

A typical example of the map provided for swelling clays is shown in Figure 1.

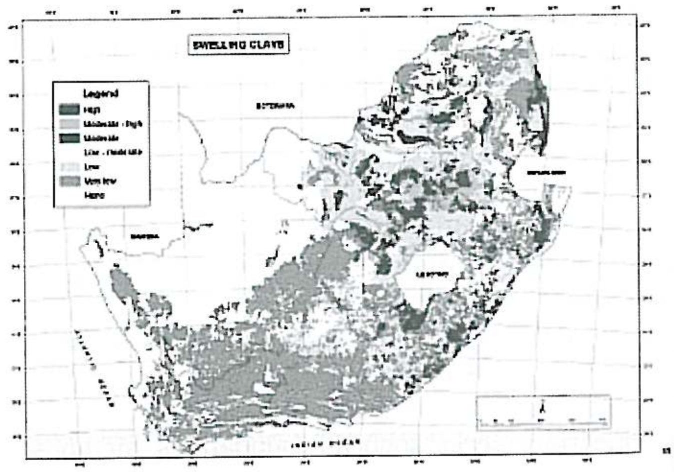

Figure 1: Example of swelling clay map provided on AGIS web-site

4 USE OF THE MAPS

In order to obtain maximum benefit from the maps they should be used in a systematic and structured way, in conjunction with other conventional information. The proposed site or route should initially be plotted on the map and its relation to the topography, surface water and the broad soil patterns established.

Particular note should be made of problems in these regards that could be avoided by realigning the route.

Once the route alignment is confirmed as being the optimum, closer inspection of the broad soil patterns should be made. The fewer the soils being traversed, the more likely that the material will be reasonably consistent and less preliminary field inspection and subgrade centre-line survey will be required. A more detailed assessment of the soil types which the road will traverse can then be made. The soil types alone will provide useful information.

Reference to the Memoirs can then provide detailed information on the local geology, terrain, materials and their properties in terms of the following problem soils:

4.1 *Expansive soils*

Vertic soils are currently defined by having a Plasticity Index (PI) > 32 (SCWG 1991). The lower limit for very high heave identified by van der Merwe (1964, 1975) was a weighted PI of 32%. Thus for fine materials with 100% passing the 0.425 mm sieve, the limit is the same. For materials containing increasing quantities of material coarser than 0.425 mm, the weighted PI will decrease correspondingly. Any material identified on the land type map as a Vertic soil should however, be considered as likely to have expansive properties. These land types include soils of the Rensburg and Arcadia Forms and should be noted early in the project (feasibility and/or planning stage), with the potential for looking at relocation or realignment of the facility where possible.

Soils with a Melanic A horizon are defined as those, which among other attributes, have a Plasticity Index of less than 32%. There is thus a good chance that those soils in the higher range (particularly if the majority of the material is finer than 0.425 mm) could also be sufficiently expansive to give problems and soils classifying as such should also be assessed in more detail.

Other soil forms, however, not defined by their Vertic or Melanic topsoil horizons but by subsoil horizons with high clay contents, high base exchange status' and which contain smectite clays also need to be assessed for their expansive properties. This information can be obtained from the Profile Descriptions and layers containing these types of soil warrant detailed investigation at the design stage.

4.2 *Dispersive soils*

Dispersive soils can lead to catastrophic failures of earth embankment dams as well as severe distress of road embankments. These soils contain clays that are high in sodium such that the individual particles repel each other to a stronger degree than the van der Waals forces of the particles to attract each other. Thus soils with high exchangeable sodium contents are normally considered to indicate potentially dispersive soils. Although there is still considerable debate regarding the positive identification of dispersive soils the use of the Exchangeable Sodium Percentage (ESP = Na+/Cation Exchange Capacity*100) can certainly give a first indication of potential dispersive problems. It is suggested that the presence of an ESP greater than 10% should be regarded as a warning (Elges 1985) and additional testing should be carried out on such soils. Gerber & Harmse (1987) indicate that the limit changes with the clay mineralogy, indicated by the Cation Exchange Capacity (CEC) but that all soils tested with ESP values higher than 15% were highly dispersive.

The determination of the cations in the Saturation Extract of the soils has been carried out for soils with resistances of the saturated paste of less than 460 ohms. From these, the Sodium Adsorption Ratio (SAR) calculated as SAR = Na/v[0.5(Ca+Mg)] can be calculated and materials with values of greater than 2 (Bell & Walker 2000) should be investigated further for potential dispersivity. Unfortunately, only few of the samples have had their saturation extracts tested.

The results required to determine ESP and SAR (when available) are provided in the soil profile data and need to be calculated for each material. However a cursory inspection of the sodium and resistivity results (high values of sodium and low values of resistivity are immediately recognisable compared with the typical values of most materials) will usually indicate whether the data needs to be processed further.

Should any dispersive soil problems be suspected, it is recommended that the battery of tests (CEC versus ESP, crumb test, SAR, pinhole test and Total Dissolved Solids versus percentage sodium) be determined as suggested by Bell & Walker (2000) and the potential dispersivity of the material rated accordingly.

4.3 *Collapsible soil*

Soils with high single sized fine sand contents, silty sands or clayey silts (eg, deep Regic soils, some residual granites, arkoses and "dirty" sandstones and various other residual or transported materials) indicate potentially collapsible materials. Fine silty or sandy soils with high feldspar and/or kaolin contents in drier areas may also be potentially collapsible.

It is noted (SCWG 1991) that certain soils in the E horizon are prone to having a high dry strength but fail under load when wet. These are thought to resemble "fragipan" soils of other classification systems, a descriptive term implying their collapsibility.

Netterberg (2001) has recorded that most of the highly weathered ferralitic (clay fraction SiO_2/Al_2O_3 molecular ratio < 1.3) and fersialitic (clay fraction SiO_2/Al_2O_3 molecular ratio 1.3 to 2.3) soils are likely to have collapsible grain structures. These would include the widespread dystrophic to mesotrophic, fine sand and silt textured Hutton and Clovelly soils. They are readily recognised by their uniform red or yellow-brown colours respectively and weak or apedal structure.

4.4 Saline soils

The presence of saline soils under roads and structures can result in significant problems. These materials have a high soluble salt content of which sodium often comprises only a modest proportion but can result in the crystallisation of soluble salts in the top of base courses in roads leading to loosening of the compacted base course and beneath road surfacings leading to blistering and cracking of the bituminous seals. The materials discussed in this section are predominantly chlorides and hydrogen carbonates, with the soluble acid sulphates being discussed separately in the following section. The latter are generally more common in soluble slat problems in southern Africa, although a number of chloride problems have been reported (Roads Department, 2001).

Salts can originate from the in situ natural soils beneath the structures as well as from introduced material or saline construction water. This discussion only refers to the former situation.

The soil profile information provides an indication of the electrical resistance of many of the soils. In the conventional road engineering context (and application to other infrastructure developments), the identification of possible soluble salt problems is based on the pH and conductivity of the materials. The pH and the electrical resistance (which is the inverse of the conductivity) are provided in the soil profile data (ARC-ISCW 2007c). Although the techniques and the fractions tested in conventional pedological and engineering investigations differ, which could result in some differences in the results, a general assessment of any potential problems with respect to saline soils can be obtained. As a first indication, where the electrical resistance is less than 460 ? and the pH is greater than 7.0, the materials should be investigated further for their likelihood of presenting soluble salt problems. The limit is loosely based on that for pavement layers (selected subgrade to base) proposed by Netterberg (1979), but is probably equally useful for in situ subgrade materials (Roads Department 2001), especially for thin pavement structures.

4.5 Acid sulphate containing materials

Natural soils containing acid sulphates are of limited extent in South Africa, and are probably located in peat lands that on drainage produce deleterious acidity as well as in semi-arid to arid areas prone to high evaporation (Roads Department 2001). Unconsolidated rock derived materials may contain sulphides or weatherable sulphate minerals that are potential sources of acidity or hydrated sulphate minerals with negative impacts on stabilized layers and concrete structures and the potential for soluble salt damage to road structures. Similarly, acid waters derived from certain sulphide containing materials can attack chemically stabilized soils and concrete structures. Initial recognition of the soils is probably through the wet lowland positions with high organic matter, while that for the unconsolidated rock derived materials is via their mineralogy. There is no reference made in the land type memoirs to any of the anions, particularly sulphates, which can cause damage to concrete or soluble salt problems. However, it is recommended that for materials with a resistivity of less than 700 ? , qualitative testing for sulphate should at least be carried out, followed by determination of the acid soluble sulphate content if the qualitative test proves positive. The limits described by Netterberg (1979) can probably be applied to cement and lime stabilized layers to prevent acid damage to the stabilization products.

4.6 Compressible soils

Soils with poor or impeded drainage indicate potentially compressible materials, subject to significant settlement under road and/or traffic loading. When more than 40% of any land type consists of soils classified as Champagne (Ch), Rensburg (Rg), Willowbrook (Wo), Katspruit (Ka), Kroonstad (Kd), Estcourt (Es), Longlands (Lo), Wasbank (Wa), Cartref (Cf) or Lamotte (Lt) the potential for wetland compressible soils should be noted.

These materials require extreme care during construction of embankments over them as their shear strengths are low and they have a high potential for settlement, which, depending on their thickness, can require carefully designed countermeasures.

4.7 Dolomitic soils

Soils developed on dolomite have unique problems that are best identified from standard geological maps. Development on dolomite requires special investigations, carried out by specialists in dolomitic terrain investigations. Infrastructure development on dolomite will usually have identified the potential problem and need for expert investigation early in the project and the need for soil maps is thus redundant in most cases.

4.8 *Soils prone to liquefaction*

Soils with high silt contents or high clay sized components (< 0.002 mm) but which are predominantly quartz with minimal clay minerals can indicate materials potentially prone to liquefaction. These materials lose shear strength rapidly as a result of vibration, which causes a temporary increase in pore water pressure. Although South Africa is not a particularly earthquake prone area, the possibility of liquefaction adjacent to mine and heavy industrial areas cannot be excluded.

4.9 *General*

Information regarding a range of other potential problems and material properties can also be gleaned from the soil maps. These include:

- Presence of high water table
- Presence of organic material (interfere with stabilization)
- Depth to bedrock and/or excessive large stones
- Excavatability
- Potential material sources

A detailed and knowledgeable examination of the properties provided with the land type maps should provide a lot of useful information regarding the depths and qualities of the soils/materials and should be used as often as possible. It should, however, be noted that the information on the maps and accompanying data is of a fairly general nature (considering the inherent variability of geological materials) and should be used as a preliminary indicator, not replacing a proper engineering geological investigation and laboratory testing. It can, however, be beneficially used to optimise the field investigation and minimise the field and laboratory testing.

5 CONCLUSIONS

Information currently available on the land type and soil maps for South Africa can be invaluable for the identification of problem subgrade soils and for the preliminary route location of new roads and other infrastructure (eg, pipelines, railways, etc). This cost effective information source offers potential throughout the project planning cycle and is currently underutilized by engineering geologists and engineers. It must however, be accompanied by sound engineering geological experience, examination and practice in order to achieve the optimum benefits.

6 ACKNOWLEDGEMENTS

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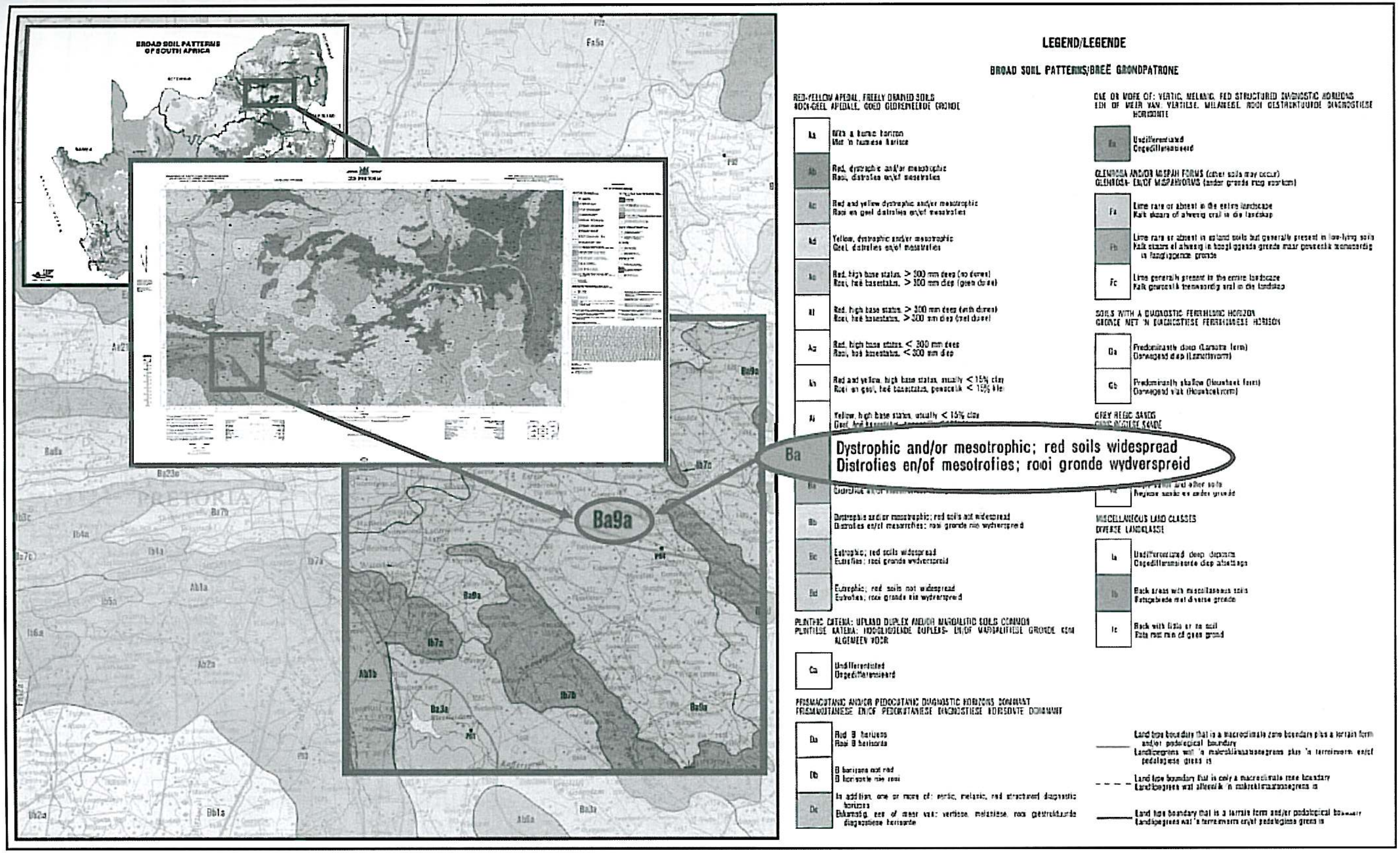
APPENDIX A 1: Overview example of the 1 : 250 000 Land Type Map 2528 Pretoria (1° x 2° size). The Land Type Ba9 and its legend description are highlighted, while background location is visible. A Broad Soil Pattern map is inset.



APPENDIX A 2: Overview example of the technical Land Type Inventory Ba9 (Ba = Plinthic Catena: Dystrophic and Mesotrophic soils; red soils widespread) listing terrain units, soil series, selected soil properties and a Modal Profile Number for associated laboratory analyses.

LAND TYPE / *LANDTIPE*: Ba9 ← Land Type Number

CLIMATE ZONE / *KLIMAATSONE*: 26S ← Climate Zone

Area / *Oppervlakte*: 45310 ha

Estimated area unavailable for agriculture / *Beraamde oppervlakte onbeskikbaar vir landbou*: 500 ha

Occurrence (maps) and areas / *Voorkoms (kaarte) en oppervlakte*: 2528 Pretoria (45310 ha)

Inventory by / *Inventaris deur*: J L Schoeman

Modal Profiles / *Modale profiele*: P94 ↑ Modal Profile

Contact the ARC-ISCW for English description of the soil type

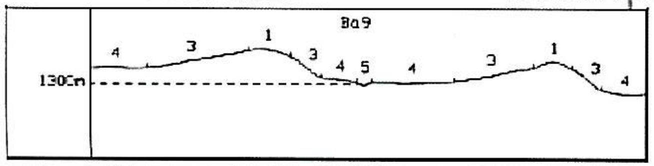
Terrain unit / *Terreineenheid*	1	3	4	5
% of land type / *% van landtipe*	15	50	30	5
Area / *Oppervlakte (ha)*	6796	22655	13593	2266
Slope / *Helling (%)*	3 - 8	4 - 15	2 - 6	0 - 1
Slope length / *Hellingslengte (m)*	100 - 300	200 - 500	100 - 400	50 - 150
Slope shape / *Hellingsvorm*	Y	Y-X	X	X
MB0, MB1 (ha)	0	10195	12234	2266
MB2 - MB4 (ha)	6797	12460	1359	0

Soil series or land classes / *Grondseries of landklasse*	Depth / *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	Total / *Totaal* ha	%	Clay content % / *Klei-inhoud %* A	E	B21	Hor	Texture / *Tekstuur* Class / *Klas*	Depth limiting material / *Diepte-beperkende materiaal*
Soil-rock complex / Grond-rotskompleks:																		
Rock/Rots		4	3398	50	4531	20					7929	17.5						
Mispah Ms10, Trevanian Gs17, Southwold Cv26	100-400	3	2718	40	4531	20					7250	16.0	15-25			A	meSaLm-SaClLm	R,so,lc
Msinga Hu26, Hutton Hu16	500-1200+	0			4531	20	1359	10			5890	13.0	20-30		20-35	B	fi/meSaClLm	so,hp
Mispah Ms10, Klipfontein Ms11, Trevanian Gs17, Williamson Gs16	150-400	3	680	10	3398	15	1359	10			5437	12.0	15-30			A	meSaLm-SaClLm	R,lc,hp
Doveton Hu27, Vimy Hu28, Argent Sd11, Richmond Sd12	450-1200+	1			1133	5	3398	25			4531	10.0	30-45		35-60	B	fiSaCl-ClLm-Cl	so
Longlands Lo21, Albany Lo22, Wasbank Wa21, Warrick Wa22	600-1200+	0					2719	20	227	10	2945	6.5	10-20	10-20		A	LmmeSa-SaLm	sp,hp
Southwold Cv26	300-750	0			2266	10	680	5			2945	6.5	20-30		20-35	B	fi/meSaClLm	so,R
Katspruit Ka10, Emfuleni Wo10, Willowbrook Wo11	350-750	0					1359	10	1360	60	2719	6.0	30-50			A	fi/meSaClLm-Cl	gc
Avalon Av26, Glencoe Gc26	450-900	0			1133	5	1359	10			2492	5.5	20-30		20-30	B	fi/meSaClLm	sp
Jozini Oa36, Dundee Du10	>900	0					1359	10	680	30	2039	4.5	20-30		20-35	A	fi/meSaClLm	gs
Swartland Sw31	750-1200+	1			1133	5					1133	2.5	20-35		35-50	A	fi/meSaClLm	so

← List of Soil Series ← Soil Depth — Total Occurence % — Clay Content % — ← Depth Limiting Material

Terrain type / *Terreintipe*: B3

Terrain form sketch / *Terreinvormskets*



Geology Description

For an explanation of this table consult LAND TYPE INVENTORY (table of contents)

Ter verduideliking van hierdie tabel kyk LANDTIPE - INVENTARIS (inhoudsopgawe)

Geology: Shale, quartzite, hornfels and chert of the Pretoria Group; diabase; andesite of the Hekpoort Formation (Transvaal Sequence).

Geologie: Skalie, kwartsiet, horingfels en chert van die Groep Pretoria; diabaas; andesiet van die Formasie Hekpoort (Opeenvolging Transvaal).