Engineering geological mapping in Pietermaritzburg, South Africa: Constraints on development

NICK P. RICHARDS[1], G.A. BOTHA[1], P. SCHOEMAN, B.M. CLARKE, M.W. KOTA & F.N. NGCOBO

[1] *Council for Geoscience, South Africa. (e-mail: gabotha@mweb.co.za)*

Abstract: Detailed 1:10,000 scale engineering geological mapping of Pietermaritzburg covered an area of approximately 670km^2, some of which is experiencing rapid growth and development across a geologically varied area. This variation has resulted in a number of differing geological and geotechnical conditions, some of which are problematic and likely to have significant negative consequences for future developments. The mapping provided very detailed engineering geological coverage of the area and focused on delineating areas where hazardous geological or geomorphological conditions could impose environmental constraints or elevated cost implications on future infrastructure development. The use of digital elevation data has enabled the production of innovative map products that provide enhanced visualisation of the geotechnical and engineering geological data for the area.

The geological and terrain morphological diversity of the Pietermaritzburg city bowl and surrounding hilly areas results in a very complex interplay between geology, soils, slope gradient and potentially unstable transported sediments. The hummocky topography below steep escarpments is underlain by ancient landslide debris, which is potentially erodible and unstable. Much of the agricultural ground to the south of the city area is characterized by shallow soils and relatively unweathered diamictite bedrock, which hinders excavation. The carbonaceous shales that occur in the dry southern and central part of the map area weather to produce shallow soils with active clay minerals that can impact on house foundation conditions. Another negative impact of shallow rocky soils on shale and dolerite is on the high demand for expansion of cemetery sites serving the communities in the western part of Pietermaritzburg. The variation from shallow soils to deeply weathered saprolite with intervening hard corestones over short distances imposes financial constraints on the excavation and installation of septic sewage systems in high-density low cost housing developments with the result that new systems fail shortly after installation.

Résumé: La campagne de cartographie géotechnique détaillée à une échelle de 1:10 000 de Pietermaritzburg a réprésenté une superficie de 670 km^2 environ, dont il y a une partie qui est en voie d'expansion et de développement rapide à travers une région d'une variété géologique immense. Cette variation a produit un nombre de conditions géologiques et géotechniques différentes, dont il y en a qui sont problématiques et susceptibles à avoir des conséquences négatives importantes pour des développements futurs. La campagne de cartographie a fourni une couverture géotechnique très détaillée de la région et s'est concentrée sur la délimitation de zones où des conditions géologiques où géomorphologiques dangereuses risquent d'imposer des contraintes écologiques ou d'augmenter des coûts de développements d'infrastructure futures. L'usage des données numériques d'altitude a permis la réalisation de produits cartographiques novateurs, et de rehausser l'aspect visuel des données géotechniques et de la géologie de l'ingénierie de la région.

La diversité morphologique de la géologie et du bassin de la ville de Pietermaritzburg et les environs accidentés entraîne une interaction très complexe entre la géologie, les sols, le gradient de la pente, et éventuellement des sédiments instables transportés. La topographie onduleuse à l'aplomb des escarpements raides repose sur des anciens éboulis de glissements de terrain qui sont susceptibles à l'érosion et l'instabilité. Une grande partie de la zone agricole au sud de la ville se caractérise par des sols peu profonds et par un socle de diamictite assez inaltéré qui entrave les travaux d'excavation. Les schistes carbonatés se localisant dans la partie sèche sud à central de la zone cartographiée s'altèrent aboutissant à des sols peu profonds à minéralisation argilifère active qui risque d'atteindre la sûreté des fondations des maisons. Encore un impact négatif des sols rocheux peu profonds sur les schistes et la dolérite concerne la demande élevée pour l'expansion des sites de cimetières desservant les communautés dans la partie ouest de Pietermaritzburg. La variation, allant de sols peu profonds jusqu'aux saprolites profondément altérées ayant des roches noyaux intercalées sur de courtes distances, impose des contraintes financières sur les travaux d'excavation et l'implantation des réseaux d'égouts septiques dans des développements HLM à haute densité, ce qui entraîne leur défaillance très peu de temps après leur installation.

Keywords: engineering geology maps, geological hazards, mass movement, regional planning, soil erosion.

INTRODUCTION

Detailed geological mapping of the Pietermaritzburg area was originally carried out by King in 1948. The most up to date 1:50,000 scale geological map, 1:10,000 scale field sheet compilations for the map, and explanation is that of Botha & Botha (2002). Other geological investigations have focussed on lithostratigraphic mapping with very little emphasis on the geology of unconsolidated sediments or regolith that extends from the surface to bedrock. Although some geotechnical characterization has been done at a site specific level, for example for low cost housing developments, no attempt has been made to provide an overview of the geotechnical conditions at a mapping scale of

1:10,000 for the Pietermaritzburg map area. A Metropolitan Plan for the Pietermaritzburg area has been produced on the basis of 1:50,000 scale base maps (Pietermaritzburg City Engineer's Department, 1988). However, information at this scale regarding the geology, soils and topography is very generalised. The Pietermaritzburg area has not been categorised in terms of geotechnical conditions or potential geohazards. Site specific studies have been made with respect to the slope stability problems encountered in the region (Maurenbrecher and Booth, 1975), and in particular slope instability around the N3 highway in the World's View area (Maurenbrecher, 1973; Maud, 1985). The current study utilizes mapping techniques first introduced by Leith & Johnson (1998).

The Pietermaritzburg mapping area is bounded by latitudes 29°30'S and 29°45'S and longitudes 30°15'E and 30°30'E, which covers an area of approximately 670km^2 (Figure 1). Approximately 25% of the area is urbanized comprising the Pietermaritzburg Central Business District (CBD), which is surrounded by a number of industrial and suburban areas. There are many informal settlements that occur around the residential, business and industrial areas, often in areas geotechnically unsuitable for development. An established network of roads and a rail system provides easy access to most of the region. The remaining open ground comprises farms, agricultural holdings, forestry areas, recreational areas and nature reserves.

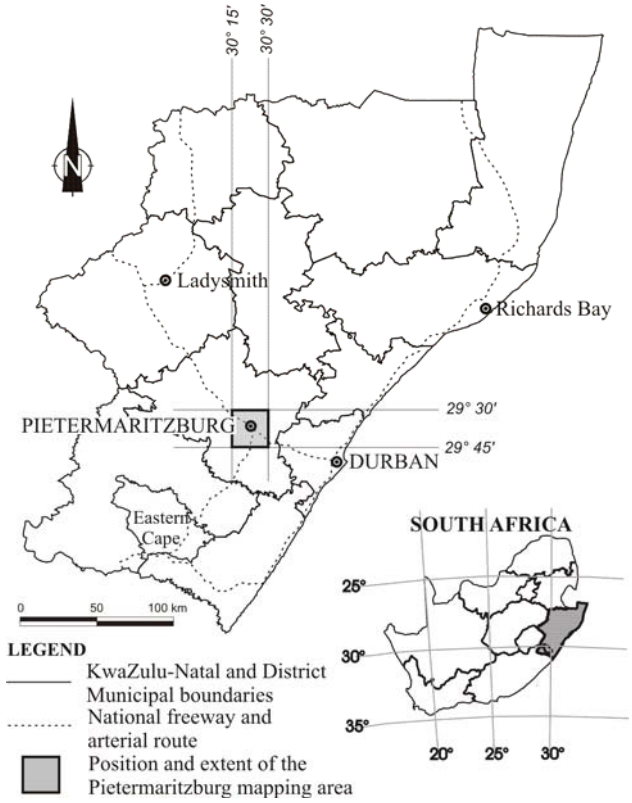

Figure 1. Locality map of KwaZulu-Natal showing the position and extent of the Pietermaritzburg mapping area

Topography is the major control on slope stability in the Pietermaritzburg area and the majority of the mapping area is classified broadly as open hills, lowlands and mountains with moderate to high relief and with predominantly concave and convex slope forms (Kruger, 1983). Elevations range from 1330m in the extreme southwest of the area to less than 500m in the Msunduze River valley to the east of Pietermaritzburg. A prominent physiographic feature, the broadly arcuate World's View escarpment, lies to the west of Pietermaritzburg. The high-lying landscape to the west of the escarpment comprises hilly, undulating topography with wide valley plains characterised by open grassland and intensive farming. The landscape to the east comprises gentle undulating topography with resistant dolerite sills defining low mesas.

The Pietermaritzburg area is diverse both in geology and terrain morphology. The Pietermaritzburg CBD area is flat lying or very gently sloping adjacent to the major rivers that pass through it. The city is surrounded by hilly areas and steeper slopes under an escarpment formed of thick sandstone units. The geological and terrain morphological diversity of the area results in a complex interplay between geology, soils, slope gradient and potentially unstable transported sediments and palaeolandslide debris.

GEOLOGY

The following is a short description of the major rock types that occur in the mapping area with a summary of their geological evolution. Most of the information was obtained from the geological commentary (Botha & Botha, 2002) that accompanies the 1:50,000 scale geological map of Pietermaritzburg (Council for Geoscience, 2002) see Figure 2.

The geology of the area comprises rocks ranging in age from Mokolian to Recent. Basement metamorphic and intrusive igneous rocks comprise part of the ~1.1Ga, Natal Metamorphic Province (NMP) and consist of an east–west striking supracrustal assemblage of interdigitating banded acid, intermediate and basic gneisses (Mapumulo Group) and intrusive biotite-bearing megacrystic granite (Oribi Gorge Granitoid Suite).

The Phanerozoic Karoo Supergroup consists of the basal Dwyka Group diamictite and sandstone overlain by the Pietermaritzburg, Vryheid and Volksrust Formations (Ecca Group). Jurassic dolerite sheets, sill and dykes intrude all of the lithostratigraphic units but are predominantly associated with the argillaceous rocks of the Ecca Group. Detailed lithostratigraphic mapping has enabled both the Dwyka Group and Vryheid Formations to be subdivided into a number of mappable units based on lithofacies associations.

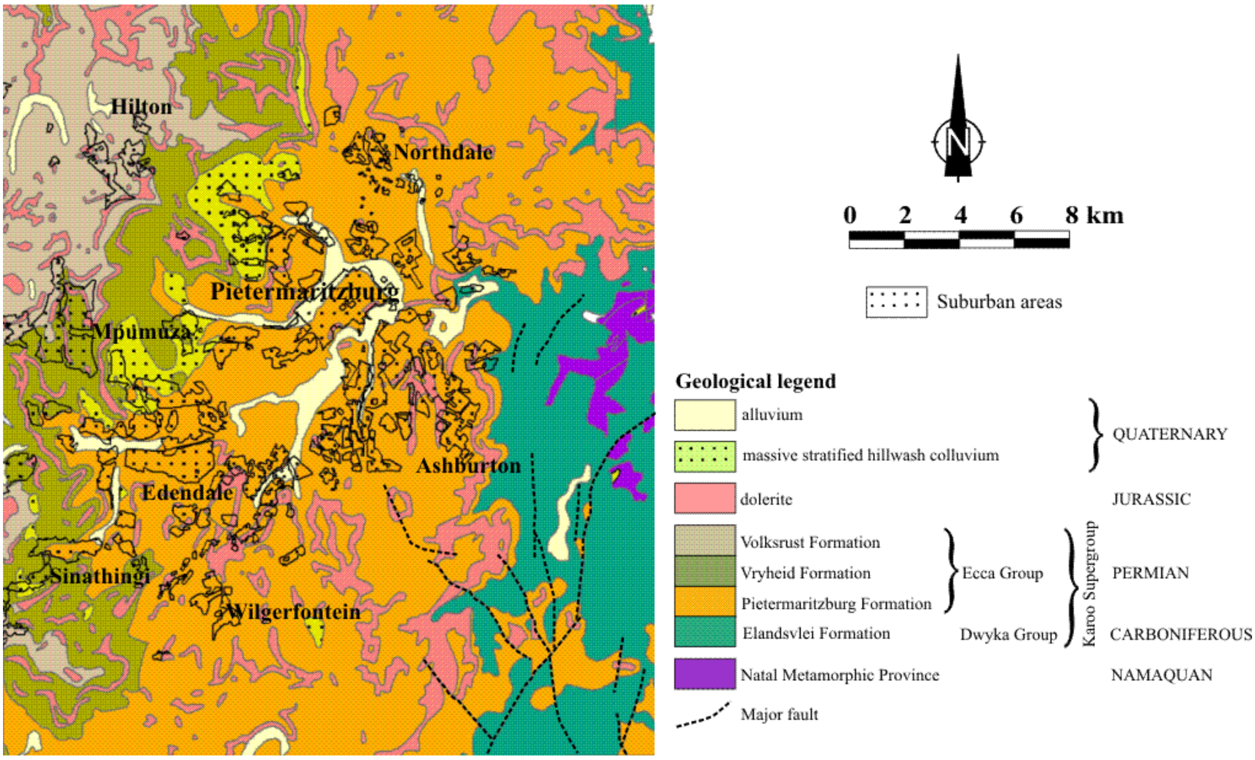

Figure 2. Simplified geological map of the Pietermaritzburg area showing the major suburban areas. Modified after the 1:50,000 geological map (Council for Geoscience, 2002)

The Dwyka Group in this region is represented by the Elansvlei Formation homogenous diamictite sequence constituting the bulk of this succession with a thin basal heterolithic sequence of argillaceous and arenaceous diamictite, sandstone, granulestone, conglomerate and siltstone. An upper, stratified lithostratigraphic unit, comprising sandy diamictite, argillaceous diamictite, siltstone and shale, is gradational upwards, marked by the disappearance of dropstones, into the massive or laminated carbonaceous shale or siltstone of the overlying Pietermaritzburg Formation (Ecca Group). The Vryheid Formation sedimentary rocks form the escarpment west of the city where the succession has been subdivided into three informal stratigraphic units, further subdivided into subunits on the basis of sedimentary lithofacies associations. These are the lower transition unit (siltstones and occasional fine-grained sandstone), several sandstone-dominated with interbedded siltstone units and the upper transition unit (interlaminated sandstone, siltstone). The Volksrust Formation underlies the undulating topography above the World's View escarpment and comprises siltstone with rare, interbedded sandstone horizons. Thick dolerite sills, which intrude the argillaceous country rock exhibit a range of mineralogical and textural characteristics.

Faulting and fracturing of bedrock in the Pietermaritzburg area is significant in terms of groundwater seepage and groundwater resource potential which impacts on development potential. The eastern half of the study area is characterised by intense faulting which is most evident in the area underlain by Dwyka Group rocks. Two dominant fault orientations, north-northeast–northeast and north-northwest–northwest are developed. Fault displacements typically vary from <1m to an estimated 30–40m on some of the larger faults. The faults are sub-vertical (80–90°) and are both eastward and westward dipping, and particularly within the diamictite, can be traced accurately for hundreds of metres due to intense silicification and/or brecciation. The fault zones passing through the Pietermaritzburg Formation are generally not as well-defined nor conspicuous as those in the diamictite.

The topography of the area is significantly influenced by resistance to weathering of the wide range of rock types in the region. Hillslope profiles that develop on granite are typically convex, steeply sloped with deeply incised rivers through the deeply weathered soil profile. Hill slopes in the Dwyka Group are also typically rounded, but slope angles increase down slope, giving many slopes a convex profile, towards dissecting gullies. Ecca Group rocks are rapidly eroded giving rise to an undulating, closely dissected landscape of subdued relief. Topographic contrast is provided by dolerite, and where present, prominent, elevated terrain forms commonly occur.

Colluvial hillslope deposits

Thick colluvial deposits of late Pleistocene to Holocene age mantle the hill slopes below escarpments and are responsible for hillslope instability and deep donga erosion. The unconsolidated colluvial deposits are predominantly confined to the steep transportational midslope and colluvial footslopes below the escarpment, which is defined by outcropping Vryheid Formation sandstone beds or dolerite. In this area the colluvium forms a thick mantle covering large areas of the hillslopes, which are underlain by the Pietermaritzburg and Vryheid Formations. The colluvium, derived by erosion of older coarse talus or landslide debris, soils and weathering profiles in bedrock, accumulates through two transportational processes, namely mass movement and slope- or sheetwash.

Thicknesses of the pedogenically-altered colluvium or slope deposits are highly variable and range from 1.5m to >16.5m. Auger drilling has revealed localised colluvial overburden depths of between 20 and 30m thick below steep slopes. The stratified deposits which incorporate interbedded buried palaeosol profiles can be correlated with the Late Pleistocene to Holocene Masotcheni Formation which is characteristic of hill slope cover over large parts of northern and central KwaZulu-Natal (Botha, 1996).

The basal deposits of the colluvium typically comprise an ill-sorted array of large dolerite boulders (0.2m to 1.5m in diameter) and shale fragments within a sandy or silty matrix, probably derived from reworking of talus or finer textured colluvial deposits upslope. The bulk of the overlying material accumulated as sheetwash deposits (Botha & Botha, 2002). The thick, clay-rich, reddish brown hillslope deposits exposed in the Sinathingi area represent dolerite-derived hill slope sediment, which has been deeply weathered in situ. Mass movement and sheetwash processes contributed crudely stratified sediment and large dolerite boulders which infill some depressions preserved within the unconsolidated colluvium.

X-ray diffraction studies have indicated that the colluvial deposits are predominantly composed of quartz, feldspar, kaolinite and illite. Smectite and interlayered illite/smectite is common in the clay fraction, with subordinate goethite, gibbsite and talc (Botha & Botha, 2002). The colluvium and palaeosols are commonly conspicuously slickensided or have a microshattered structure, indicative of soil groundmass swell/shrink due to the active nature of the clays in some of these buried soils. The presence of the hydrated aluminium oxide, gibbsite is indicative of the highly weathered nature of some of this sediment.

Alluvium

Extensive alluvial terrace deposits are associated with the confluences of the major rivers of the area. Some portions of Pietermaritzburg that lie adjacent to these rivers are founded on these alluvial deposits. The alluvium consists of interlayered dark grey-brown, brown or red-brown silty and sandy clay as well as clayey to silty sands. It varies in thickness from between 2m and 8.5m. Alluvial terraces are generally poorly developed, but in areas where they occur, deeply incised streams/rivers have exposed alluvial gravel deposits. In some exposures the alluvial boulder terraces have been weathered and ferruginisation has cemented the fine matrix.

ENGINEERING GEOLOGICAL MAPPING OBJECTIVES AND TECHNIQUES

The main objective of the engineering geological mapping was high resolution 1:10,000 scale mapping to identify and assess all potential constraints, or geohazards, that are likely to affect future land-use planning decisions or initiatives for the Pietermaritzburg city area. The compilation of the engineering geological map was a three-stage process involving the gathering and review of existing data, detailed field mapping using recent colour aerial photographs and 1:10,000 orthophoto maps, and compilation of the data on a 1:50,000 map. The underlying assumption used in the mapping was that the geotechnical properties are related to the landform type and influenced by bedrock type and the nature of the weathering products. However, regolith with similar characteristics can occur on a range of slope gradients depending on the distribution of bedrock type and weathering products preserved as in situ soils or transported sediments. The association of land forms with specific geotechnical characteristics, with variation induced by bedrock type, was characterized by analysis of representative samples from each land form which enabled the mapping of the range of engineering geological factors presented on the map sheet. Each landform was assessed in terms of six critical geotechnical factors (Table 1).

The additional sub-critical factors used during the mapping were: collapsing or settling of soil, poorly consolidated soil, permeability of soil, dispersive soil and acidic soil. These factors are regarded as sub-critical because either spatial analysis indicates that the areas affected by these factors are minimal in size, or the factor does not impose any major constraint to development in the mapping area. The mapping system is flexible in that different factors can be considered as critical or sub-critical depending on the specific geological or geomorphological terrain.

For each of the landform types and land facets, identified and compiled on 1:10,000 orthophoto maps, existing geotechnical information such as soil profile descriptions and laboratory analyses were extracted from existing geotechnical databases. During subsequent field mapping, landforms were checked, geotechnical characteristics were identified and additional soil profiles were geotechnically and pedologically described.

A number of laboratory analyses were completed on samples from the map sheet area. The tests comprised the basic indicator tests such as the Atterberg limits (liquid limit and plasticity index) and linear shrinkage. Additional parameters that were measured included the percentage clay fraction of a sample, grading modulus, degree of potential expansiveness, and soil classification according to the revised ASTM standard on the unified classification system (Howard, 1984). The final stage of the mapping involved the interpretation of regolith profiles, geotechnical laboratory results, geological, hydrological, hydrogeological, slope and topocadastral data to compile the 1:50,000 engineering geological map.

Table 1. Listing of critical geotechnical factors mapped in the Pietermaritzburg area, with definitions, implications for development and classes of severity used

Critical Geotechnical factor and explanation (in ranking order)	Implications of factor for development	Severity class(es) of factor*
1. Inundation (flooding) Area that experiences flooding by either: (1) flood water volumes that exceed the channel carrying capacity of the channel, in which case the flood waters move out and onto the floodplain that is usually present on both sides of the channel; or (2) sheetwash where flooding is unrelated to a channel and occurs as unconfined flow.	A critical environmental factor. Floods are natural events that have to be taken into account where development encroaches on or close to stream channels. Residential development cannot be erected in areas below the 1 in 50 year flood line. Certain developments may have significant affects on the flood behaviour of the river. Factors such as changed hydrology, sediment loads and river diversions can have significant impacts to the extent that areas before development with a low risk of flooding can become high risk areas after development.	**Inu2** Area at risk from inundation
2. Slope Instability Areas where slopes in excess of 18° are a major constraint to development. Areas that are recognised palaeolandslides or areas of latent mass movement. Areas comprising unstable geological materials that could move either gradually (creep) or suddenly as a slump or a slide. Risk of movement determined by factors such as the nature of the slope, gradient of slope, role of water, type and nature of vegetation cover, seismicity and impact of human activities such as undermining of a slope.	Can be a significant cost factor for certain types of development, particularly low cost housing. Detailed slope stability analysis may be required. Steep slopes, many of which are mantled by old landslide debris or thick in-situ soils, are likely to exhibit instability problems. Many of the slope movements in Pietermaritzburg result from anthropogenic environmental changes related directly to development.	**Slo2** Unstable slopes (gradient undifferentiated) **Slo3** Slopes 12 - 18°, some constraints to development **Slo4** Slopes > 18°, major constraint to development, potentially unstable slopes **Slo5** Unstable slopes & active mass movement, evidence of palaeo- or active landslides
3. Excavatibility of Ground The ease with which ground can be dug to a depth of 1.5m. This is the depth most significant in terms of excavations for foundations and services.	A high cost factor in development when installing foundations and underground services such as water pipes and sewers. Many areas are affected by shallow (Mispah Form) soils where bedrock lies at depths of <0.5m. The use of mechanical excavation methods, or even blasting techniques are required throughout much of the area.	**Exc2** Excavatibility problems are anticipated (unspecified) **Exc3** Slight excavatibility problems (can be hand dug) **Exc4** Moderate excavatibility problems (backactor is required) **Exc5** Severe excavatibility problems (blasting and/or power tools are required)
4. Active, Expansive or Swelling Soil The amount of expansion in millimetres (expressed as total soil heave) that can be expected when the moisture in the soil changes. Moisture changes can be due to seasonal changes in rainfall or changes in the level of groundwater due to abstraction, drainage changes or river modification.	The degree to which a soil expands or contracts is a critical cost factor in foundation design especially of single storey residential buildings. Expansive clays are probably one of the most widespread problem soils in South Africa and can result in significant damage to buildings and pipelines. Many of the soils in the mapping area are of moderate to high expansive potential and show evidence of heaving. Problems are mitigated by ensuring adequate depth of founding below the active soil zone and by ensuring adequate flexibility of structures to accommodate heave movement.	**Act2** Active or expansive soil is present (amount of expected heave is unknown) **Act3** Low expansion (heave is expected to be 0 - 5mm) **Act4** Moderate expansion (heave is expected to be 5 - 30mm) **Act5** High expansion (heave is expected to be greater than 30mm)
5. Erodible Soil The extent to which a soil can be eroded by water flow and wind. The erosion feature may be local such as erosion channels, dongas, gullies and piping affects or it may be of a more regional extent.	A critical environmental factor. Certain types of development on erosion-prone soil can result in dramatic increases in sediment load entering water bodies and watercourses. This would have negative impacts on the biotic and abiotic elements of wetland and river environments. Erosion is exacerbated with development on erosion prone soils for example by storm water discharge from roads, and the use of erodible soils as fill material around culverts.	**Ero2** Erodible soil is present **Ero3** Sheet or rill erosion is the dominant process **Ero4** Active growth of deep dongas by sidewall collapse or head-cut erosion
6. Shallow Water Table A shallow water table is where the top of the permanently saturated zone occurs close to the ground surface. This definition also includes a perched water table where geological conditions results in a local zone of saturation that is far above the regional water table.	A shallow water table is liable to contamination by incorrectly sited developments such as waste sites, pit latrines and cemeteries. Knowledge of a shallow water table can be critical information when planning certain developments. Fluctuating water tables in areas of active soils is also critical in terms of development.	**Sha2** Shallow water table is present

* Severity classes based on nomenclature adopted from Leith & Johnson (1998)

An innovative two-dimensional legend was developed that best illustrates all combinations of critical and sub-critical factors for the mapping area (Leith & Johnson, 1998). There was no generalisation of the geotechnical factors during the Pietermaritzburg map compilation. Therefore, possible constraints to development with respect to all geotechnical conditions were considered. This was to ensure that the geotechnical factors would be of value to a variety of land-use and development issues for the area and not be restricted to one type of development (although the geotechnical characteristics of soils and bedrock are particularly relevant in terms of low cost housing projects). In realising that a landform type or area can exhibit several geotechnical properties, a legend was developed that informs the reader not only of the dominant geotechnical factor but also any additional geotechnical factors. This was achieved by ranking each geotechnical factor in terms of overall significance, related to land use issues and then classifying the ranked list into groups having a critical and subcritical status. Table 1 illustrates the ranking order of the critical factors.

The ranking of geotechnical factors was based on (1) the cost of remedial measures that would be required to make a site or area suitable for development, and (2) the cost of repairs where that geotechnical condition were to affect a development. The ranking is also based on the local knowledge of the person undertaking the mapping and the factors that are most significant in terms of limitations to development.

The ranking of geotechnical factors is not definitive in the sense that a quantifiable difference necessarily exists between an expansive or swelling soil and an area exhibiting slope instability. The environmental or cost risk implication of any of the geotechnical factors identified in an area must be based on the nature of any development planned in that area. The purpose of geotechnical factor ranking is to enable the identification of the highest ranked factor out of several geotechnical factors present in the same area. Further details regarding the legend compilation and explanation of the map colours and geotechnical factor combinations can be found in the commentary for the 1:50,000 scale geotechnical map for Pietermaritzburg (Richards *et al*. in press).

In recognizing that the design and planning of future development by planners and developers takes account of financial costs and environmental implications the geotechnical factors were classified into these categories described in this paper. A geotechnical factor that has financial cost implications is one where a significant financial input is required to change either that condition or reduce its impact on the proposed development or land-use change. For example, slope instability has a high financial category because of the high costs required to install slope-stabilizing structures in relation to the development of lower cost housing units. Steeper, less stable slopes can influence the spacing of housing units and the footprint of potentially unstable fill embankments.

A geotechnical factor that has environmental implications is one whose change by proposed development and land-use modifications could have a significant impact on the condition of the environment. For example, development of an area with erodible and dispersive soils should take account of possible preventive measures to minimize soil erosion by concentrated storm water runoff. Similarly, an area with a shallow water table presents a predominantly environmental factor because of the potential for groundwater contamination.

An important part of the geotechnical mapping was to incorporate existing borehole and geotechnical test pit information. This information is contained in several databases that form part of the Council for Geoscience's GEODE database. For the Pietermaritzburg area, the database contains information for in excess of 1400 test pits and borehole locations. During the course of the field mapping a further 2880 sites were investigated at which either soil descriptions or other geotechnical information was recorded, giving a total of 4280 data points which equates to an average of 6.4/km^2.

SUMMARY OF GEOTECHNICAL CONDITIONS

Spatial analysis of the Pietermaritzburg map sheet shows that inundation, slope instability, excavatability, active, expansive or swelling soils, erodible soils, and shallow water table are the dominant geotechnical factors (Table 2).

Table 2. Spatial analysis showing the total area (km^2) and area of severity class (Table 1) for each geotechnical factor mapped on the Pietermaritzburg map sheet

Geotechnical factor	Total area km^2 and percentage of map sheet	Area km^2 and percentage of map sheet of each severity class
Inundation (flooding)	63.5 (9.5%)	Inu2 - 63.5 (9.5%)
Slope instability	204.2 (30.5%)	Slo2 - 1.4 (0.2%) Slo3 - 89.5 (13.4%) Slo4 - 60.2 (9.0%) Slo5 - 53.1 (7.9%)
Excavatability of ground	616.5 (92.0%)	Exc2 - 50.6 (7.6%) Exc3 - 91.5 (13.7%) Exc4 - 470.5 (70.2%) Exc5 - 3.9 (0.6%)
Active, expansive or swelling soil	306.2 (45.7%)	Act2 - 274.9 (41.0%) Act3 - 0.5 (<1%) Act4 - 27.6 (4.1%) Act5 - 3.2 (0.5%)
Erodible soil	240.3 (35.9%)	Ero2 - 179.9 (26.9%) Ero3 - 5.5 (0.8%) Ero4 - 54.9 (8.2%)
Shallow water table	329.5 (49.2%)	Sha2 - 329.5 (49.2%)

Lower slope positions exhibit thicker accumulations of soils which are poorly drained, contain active clay minerals and have a tendency to heave. Some new roads along streams in southern Ashburton exhibit cracking of the paved surface due to the underlying active soils. New houses are being constructed on the margin of this area which should have been declared unsuitable for development had an adequate geotechnical investigation been conducted. Large areas of low-cost housing development in areas of relatively steep slopes underlain by shale, a resultant over-utilization of the surrounding grasslands, in the southwest of the area have altered the storm water runoff pattern with the result that severe flooding affects communities along parts of the major rivers. Floodplains along the valley bottoms are commonly used for routing services, such as powerlines and pipelines although the thick, active and saturated clays and heightened flood risk impose financial risks.

The very steep, north-south rainfall gradient results in much deeper weathering in the Hilton area above the World's View escarpment and most soils are stable but the high clay content results in poor drainage conditions which impacts on the reliability of septic sewage systems.

A range of 175 samples, predominantly from unconsolidated sediments, across a variety of underlying rock types were subjected to analysis of key indicator tests and other parameters for the map sheet. The results highlight a number of geotechnical and geomorphological relationships, for example high or medium potentially expansive soils are found predominantly in bottom slope positions. There are areas (particularly in the northeast sector of the mapping area) where very thick accumulations of colluvial material occur. This material is derived from a number of bedrock types, namely the Dwyka Group, shales of the Pietermaritzburg Formation and dolerite. The weathering products of these rocks comprise high clay contents including smectite. Samples of these thick colluvial soils taken from bottom slope areas have indicated medium to high potential expansiveness. In terms of geotechnical mapping therefore, thick colluvial soil accumulations such as these are regarded as being potentially highly active and also highly erosive.

Inundation (flooding)

In recent years the province of KwaZulu-Natal has been affected by numerous flood events. The flooding of September 1987 was, in terms of loss of life and damage, probably the worst flood disaster ever experienced in South Africa (van Schalkwyk and Thomas, 1991). A large number of slope failures also occurred as a result of the heavy rains. In terms of development potential the assessment of the susceptibility of an area to flooding or inundation is an important geotechnical and environmental consideration. The assessment of flooding potential is particularly important in areas where development encroaches on surface drainage courses and large water bodies. Flooding assessment was carried out initially by aerial photography and demarcation of areas where known recent alluvial floodplain deposits occur. These potential flood areas were confirmed during the field investigation stage of the mapping during which additional observations were made to compile an overall flood potential map of the area.

Slope instability

A number of different types of landslide mechanisms have been recognised within the Pietermaritzburg area. Small translational type slides involving both rock and colluvium occur at the interface between colluvium and dipping shale beds. Small scale lateral slumping of donga sidewalls is responsible for extension of gully erosion forms. The slumps normally take the form of shallow, non-circular rotational slides resulting from the over-steepening of the sides with resultant sliding along the bedrock/colluvium interface. There is also evidence of rock falls where rock scree deposits have accumulated on slopes in places below the escarpments.

Because of the tendency of Ecca Group shales to fail along bedding and at the bedrock/soil interface, the geotechnical mapping included an analysis of bedding dip and direction and correlation with topography in the Pietermaritzburg Formation bedrock areas. A map of slopes in excess of 12° was compiled to indicate areas of potential slope instability. This map was correlated with the bedrock dips and strikes coverage of the area. Because of the very localised nature of some shale bedding attitudes (due to the intrusion of dolerite for example), where bedding dips more steeply than regional dip, and steep topography, a number of areas were identified where shale bedding dip and direction is concordant with slope dip and direction. These areas were highlighted as potential slope failure zones.

The mapping indicates areas in which slope gradients fall between 12° and 18°, where there are some limitations to development (severity class **Slo3**, Table 1). In areas where slope gradients in excess of 18° exist, there are not only more limitations to development but increases in the likelihood of slope instability (severity class **Slo4**, Table 1). The maps of areas of potential slope instability indicate broad areas that may locally suffer from slope stability problems. In terms of development, these maps define areas that would require slope stability assessment as part of a site investigation. The geotechnical map also indicates areas of latent mass movement (severity class Slo5, Table 1) where the potential for future slope instability exists due to the presence of deposits or topographic features related to colluvial hillslope deposits or palaeolandslide debris.

The hummocky topography around the World's View to Otto's Bluff escarpments and the Mpumuza area is underlain by ancient landslide debris which is potentially erodible and unstable (Figure 3). There are many instability features associated with the colluvial hill slope deposits. Donga erosion has reached an advanced stage in many areas and head-cut, donga extension has incised colluvial hollows concealed beneath the land surface. A noticeable feature of many of the colluvium-mantled slopes beneath the Vryheid Formation escarpments in the north and northwest portions of the mapping area is the hummocky surface topography and micro-relief. As equilibrium conditions within hill slopes change as a result of incision by gullies, climatic change or human disturbance, mass wasting adjustments occur in the form of creep movements, debris slides and slumps.

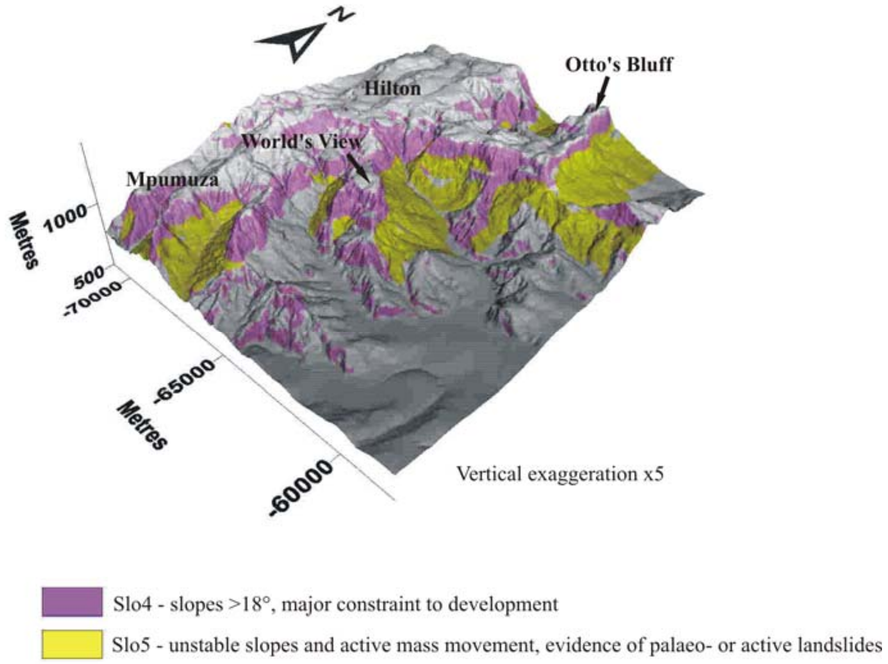

Figure 3. Digital elevation model (DEM) of the northwest portion of the Pietermaritzburg area showing areas mapped as Slo4 and Slo5.

The most documented historical geohazard problem in the Pietermaritzburg area is the zone of slope instability around Rickivy and Athlone below the Worlds View escarpment. Mass movement in the area started with the failure of the Rickivy fill material during construction in 1957 when a catastrophic failure occurred in a borrow pit, the event is referred to as The Montrose slip (Maurenbrecher, 1973). Then in 1969 the fill material began to fail and early in 1970 movement began to accelerate. In 1971 the natural slope to the east of the fill failed. According to Maurenbrecher & Booth (1975), aerial photography indicates the presence of six large landslides (from 300m to 900m wide), across the pediment below the World's View escarpment, extending from the Hilton area to Athlone through which the centre line of the N3 highway passes. These are classified as multiple regressive slides or argillaceous rock landslide on predetermined surfaces. The Rickivy failure was due to existing geological slip planes in the subsoil, propagated further by the superimposition of fill material and high rainfall events. These areas of ancient landslide debris continue to cause slope instability problems as evidenced by the continual remedial work being carried out on the N3 highway and other signs of instability such as road subsidence and embankment failure. Other large compound slide failures were identified during the course of the mapping presenting similar characteristics to those below World's View. These paleolandslide areas pose significant constraints to future development.

Excavatibility of ground

Conditions of ground excavatability are of importance to future development in the Pietermaritzburg area is excavation conditions. As much as 525km^2 or approximately 78% of the map sheet pose severe excavation problems to the extent that mechanical excavation methods such as ripping and/or blasting techniques are required.

All rocks encountered in the mapped area, from the Natal Metamorphic Province (NMP) granitoids upwards through the stratigraphic column to the siltstones of the Permian Volksrust Formation, the intrusive, post-Karoo dolerites, and unconsolidated colluvial deposits pose excavation issues. However, the severity is generally highly variable and in most cases is even locally variable at a given locality. For example, extensive dolerite outcrops in the Hilton area are not uniformly weathered and comprise dolerite corestones up to 1.5 m in diameter set in a matrix of moderately clay-rich, red apedal to pedocutanic soil. In these cases, corestones are usually dominant and as such, the excavation severity classes are high.

Much of the Pietermaritzburg area is characterised by shallow lithosols ranging in thickness from 0.1m to 0.4m. This type of profile is characteristic of areas underlain by the Dwyka and Ecca Group rocks and commonly occurs along hillcrests and in midslope areas, but is rarely encountered in the wide bottom slope areas. Areas that comprise the shallow lithosols are expected to exhibit severe excavatability problems similar to those areas of outcrop and would require the use of mechanical excavation or even blasting techniques in extreme cases, where the bedrock is relatively fresh. Much of the northeast portion of the mapping area is characterised by lithosols generally less than 0.4m thick. The thin soil mantle occurs on hillcrests and mid-slope areas underlain by Pietermaritzburg Formation bedrock. The fine-grained rocks in this area are only slightly weathered which pose difficulties for foundation or service excavations.

At some localities nodular ferricrete was frequently observed in areas underlain by rocks of the Dwyka and Ecca Groups. Here, bleached subsoil horizons show evidence of periodic lateral migration of water where infiltration is impeded by an impervious horizon or bedrock. The ferricrete occurs in different forms including discrete pebble-sized nodules, which may or may not be cemented. A hard plinthic horizon, also known as hardpan ferricrete, is formed where the nodular accumulation is cemented. Generally, the ferricretes occur at shallow depths (<1.5m) and therefore where they occur they impact severely on the excavatibility of ground particularly in areas of hardpan ferrcrete.

In the cemeteries found in the southwest portion of the mapping area, difficulty in excavating graves to the minimum required depth results in many burials at less than 1.5m below ground in poorly drained shale. The variation from shallow soils to deeply weathered saprolite with intervening hard corestones over short distances imposes financial constraints on the mechanical excavation and installation of septic sewage systems in high-density low cost housing developments in the Sinathingi and Edendale extensions. The variable, rocky or active soil conditions commonly result in failure of the new systems shortly after installation.

Active, expansive or swelling soils

Expansive soils have been described as the most widespread problem soils in South Africa (Williams *et al.*, 1985). Much of the damage related to expansive soils is not due to a lack of appropriate engineering solutions but to the non-recognition of expansive soils and expected magnitude of expansion early in land use and project planning. In the Pietermaritzburg area the expansive types of soil are often structured, black, dark grey, red or mottled yellow/grey showing evidence of heave comprising slickensides and structural shattering of the soil profile.

Active or expansive soils are widespread throughout the mapped area, although they vary in the degree of expansivity. All soils associated with argillaceous rocks i.e. the Dwyka Group diamictite, Pietemaritzburg Formation shale and shale/mudrock of the Vryheid Formation are potentially expansive. There are numerous examples of clay-rich soils in the area that display typical characteristics of active or expansive soils and it cannot be assumed that active soils are uncommon. It was important during the course of the mapping to identify the environments in which active, expansive, or swelling soils exist. Active soils may exist where clays overlie shale, particularly in areas of Pietermaritzburg Formation bedrock. Soils are generally less than 1.5 m thick on most slopes, probably deeper in valley bottoms, and are likely to be expansive. Wherever these areas exist the soils have been designated as potentially expansive unless subsequent testing proves otherwise. The most widespread potentially expansive soils occur in areas of Pietermaritzburg Formation bedrock where colluvial and residual clays often display expansive characteristics.

Problems also exist on deeper residual soils of the Dwyka Group, particularly those overlying argillaceous or clay-rich facies close to the basal and upper parts of the Dwyka Group succession. Dolerite may decompose to residual soils containing smectite group minerals, particularly in the bottomland topographic sites. These are generally very dark or black in colour. Colour is therefore one of the most critical factors to consider when dealing with residual dolerite. Dark coloured, residual dolerite soils with characteristic blocky soil structure or shattering, are likely to be very expansive and therefore problematic with respect to ground bearing conditions. The red profiles in well-drained situations also contain smectite clays but good drainage generally produces improved stability.

In some areas evidence of activity was noted where structured subsoils, such as in weakly structured and slightly pedocutanic B horizons in dolerite-derived soils, indicated low expansiveness. In more extreme cases, where strongly structured subsoils and topsoils are developed and there is evidence of slickensides on soil peds, the soil severity class indicates a moderate to high expansiveness where heave is expected to be more than 5mm. Soils with high expansiveness are largely restricted to poorly drained valley bottom areas. The strongly structured subsoils tend to be associated predominantly with shale bedrock, although they also occur in dolerite and Dwyka Group bedrock areas.

Dominant dark reddish-brown, moderately structured clay soils have formed within deeply weathered dolerite-derived colluvium and have been preferentially eroded to form dongas. The deepest erosion occurs in colluvium-infilled bedrock depressions where the in situ weathering of dolerite-derived colluvium has formed moderately active, erodible clay soils. Closer to areas underlain by dolerite the thin surficial soil is commonly very dark reddish-brown or very dark grey topsoil with a very well-developed, fine blocky structure. This is indicative of a highly active smectitic clay component, which facilitates rapid erosion by runoff. Where housing has been developed on slopes steeper than 12^{o}, the cut embankment extends to a depth beneath the highly active clay into less expansive saprolite horizons and so few situations exist where structural damage has occurred as a result of soil activity. However, use of the very dark reddish-brown soil material and dark grey gleyed clays from bottomland areas or donga sidewalls for use in typical stick lattice-work and mud or block hut construction results in unstable homes. Inadequate protection from driving rain and thin painted "plaster" layers results in collapse of walls or even collapse of the whole structure which can be attributed to the activity of the smectite component of the clay.

Erodible soil

The thick colluvial deposits found on slopes underlain by shale and dolerite bedrock in areas southwest of Pietermaritzburg, including Edendale and Sinathingi are particularly erodible where rapid donga expansion and headward cutting is compounded by sidewall failure (Figure 4). Lateral growth of the dongas is limited by the rising bedrock sidewalls, which define the palaeo-bedrock hollows which were infilled by erodible colluvium. Although the cohesive, reddish-brown soil formed within dolerite-derived colluvium commonly has a moderate blocky structure and is not particularly erodible, loss of material through sidewall failure results in movement of material. Where active soils are present in areas that surround a donga, the likelihood of donga advance is increased due to the higher erosive potential in the structured soils. By contrast, grey stratified colluvium exposed in some dongas is potentially dispersive as well as highly erodible. Over much of the Edendale area donga erosion is triggered by storm water discharge from roads. Erosion is often exacerbated with the introduction of piped culverts. Erosion of structured soils and fill material around culverts is locally common in the Edendale area.

Figure 4. Deep donga incision (up to 18m deep) of colluvial slopes in the Sinathingi area and close proximity of informal houses to collapsing donga sidewalls.

Slopes underlain by dolerite and shale in areas to the south of Pietermaritzburg are similar to those in adjacent areas. The occurrence of colluvium-infilled bedrock depressions on steep slopes is more widespread in these valleys than areas to the east. The structured reddish-brown and black clays formed within dolerite weathering profiles and the clay-rich soils formed in colluvium are commonly erodible. Two ages of colluvial infill have been recognized in this area. Older reddish-brown clay and gravel deposits are draped with stratified, grey hillwash colluvium and gravel beds. The surface soil development in these sediments has the characteristic prismatic soil structure associated with sodium saturated clays which impart high erodibility due to dispersive characteristics. On most slopes donga erosion has incised thick, homogenous *in situ* weathering profiles through dolerite or deeply weathered colluvium, which has a large component derived from weathered dolerite. In some areas donga expansion is occurring as dendritic dongas expanding upslope from the sides of existing deep dongas.

Soil Piping

This phenomena has been observed in the thick colluvial deposits that blanket the footslopes to the east of World's View. Peculiar, sharp sided, roughly circular depressions generally <3m in diameter and 1 to 2m deep, have formed in the dolerite and Vryheid Formation derived colluvium. These depressions commonly provide refuge to small trees and bushes. The origin of these depressions is enigmatic; similar features (pseudokarst sinkholes) have been reported by Brink (1981) in sandy soils associated with sandstones of the Natal Group. It is believed that they might be a surface manifestation of subterranean soil piping, the depressions marking points of collapse of the underground pipes. These features, which are not particularly widespread, are nevertheless of major significance as they may significantly reduce the bearing capacity of the soil in which they are present.

Shallow water table

A shallow water table implies a potential for groundwater contamination through inappropriate development, and also presents additional geotechnical constraints such as the variable effect on the bearing capacity of soils and the seasonal variation of shrink and swell in active and expansive soils.

A shallow water table is associated with surface drainage features such as rivers, streams, wetlands, pans and dams, together with the flood plains and low-lying areas associated with them. Shallow water tables (temporary or permanent) are indicated by gleyed, mottled subsoil horizons. All of the perennial rivers and streams in the mapping area, together with their respective flood plains, show evidence for shallow water tables. Numerous wetlands also occur, especially in the low-lying areas on the southeast of the mapping area.

Seepage is very common throughout the mapping area, but is very localised, being dependant on factors such as joint patterns, bedding and presence of dolerite sills for example. Where dolerite is exposed at surface, there are numerous occurrences of associated seepage.

Most of the areas of permanent wetness are characterised by profiles containing either an olive grey gleyed subsoil (G-) horizon, with reddish brown mottling due to localized oxidation (where the soil is almost permanently saturated) or a soft plinthic horizon characterised by mottling of grey soils (where a fluctuating water table exists). Shallow or fluctuating water tables in the vicinity of streams throughout the area are often indicated by the presence of mottled extremely clay-rich G horizons. Away from the low-lying stream valleys and flood plains. Perched water was encountered in areas of higher elevation.

Spring discharges are also common on many steep slopes where lateral flow of soil water seeps at the bedrock/soil interface, as observed in the Ashburton area. Another point of spring seepage, found throughout the mapping area, occurs along the contact between dolerite sills and shales in many of the tributary valleys. Spring seepage is common from the shales at the head of most tributary catchments and results in perennial flow from most dongas in the Edendale area.

Seepage is also common from landslide debris and shallow depressions within hummocky topography are often filled with water. Spring seepage and the shallow water table in the hummocky landslide debris topography on the slopes to the west of Edendale, is a potentially destabilizing attribute which could be enhanced by development.

CONCLUSIONS

The engineering geological mapping of the Pietermaritzburg area has revealed that inundation (flooding), slope instability, excavatibility, active, expansive or swelling soils, erodible soils and shallow water table are the most critical constraints to development. Many informal and formal houses established close to rivers throughout the area have been built within the 1 in 50 year floodline and are therefore at risk from flooding events. Development in areas of ancient landslide debris has resulted in subsequent structural problems due to ongoing movement in these areas. As much as 78% of the mapping area exhibits severe excavatibility conditions to the extent that mechanical, or even drilling and blasting, methods are required for foundation and service excavations. The large extent of fine-grained argillaceous bedrock types and dolerite results in colluvial and residual soils that exhibit moderate to high active or expansive characteristics, and this may increase development costs. The problems due to active soils are mitigated by ensuring adequate depth of founding below the active soil zone or by introducing appropriate structures. The thickness and structure of the colluvial soils that mantle many of the slopes to the west and southwest of the Pietermaritzburg CBD has resulted in deep donga (erosion channel) incision. Erosion has continued to the extent that the foundations of many of the houses constructed in these areas are under threat by progressive donga sidewall collapse. A shallow water table has important environmental implications for land-use planning. In particular the contamination of groundwater due to the inappropriate siting of cemeteries, waste disposal sites and sanitation related projects represent potential hazards to groundwater quality. All of the geotechnical factors have been produced in a GIS format, which enables efficient visualization of the mapping data.

Acknowledgements: Completion of the engineering and geotechnical mapping was assisted by the Msunduzi Municipality Pietermaritzburg, the KwaZulu-Natal Nature Conservation Service for access to the Queen Elizabeth Nature Reserve, and the many farmers and landowners in the Pietermaritzburg mapping area who gave permission for the Council for Geoscience to enter, examine and sample on their respective properties. The soil analysis data was originally collected and compiled by R.C.N. Botha. The author wishes to express his thanks to Brendan Clarke for his comments regarding the content and layout of this paper.

Corresponding author: Dr G.A. Botha, Council for Geoscience, South Africa, PO Box 900, Pietermaritzburg, KwaZulu-Natal, 3200, South Africa. Tel: +27 33 345 6265. Email: gabotha@mweb.co.za.

REFERENCES

BOTHA, G.A. 1996. The geology and palaeopedology of Late Quaternary colluvial deposits in northern KwaZulu-Natal, South Africa. Memoir 83 of the Geological Survey of South Africa, Council for Geoscience, Pretoria.

BOTHA, R.C.N. and BOTHA, G.A. 2002. Geology of the Pietermaritzburg area. Explanation, Sheet 2930 CB Pietermaritzburg, Scale 1:50 000. Council for Geoscience, South Africa.

BRINK, A.B.A. 1981. Engineering geology of Southern Africa: Volume 2. Rocks of 2 000 to 300 million years in age. Building Publications, Pretoria.

COUNCIL FOR GEOSCIENCE. 2002. 2930 CB Pietermaritzburg 1:50 000. Geological Map Series.

HOWARD, A.K. 1984. The revised ASTM Standard on the Unified Soil Classification System. Geotechnical Testing Journal, **7**, 216–222.

KING, L.E. 1948. The geology of Pietermaritzburg and environments. Union of South Africa, Department of mines, Geological Survey.

KRUGER, G.P. 1983. Terrain morphological map of Southern Africa 1: 2 500 000. Department of Agriculture, Pretoria.

LEITH, T. and JOHNSON, S.B. 1998. Regional engineering geological mapping investigation of a portion of map sheet 2628AD, orthophoto's 2628AD 21, 22, 23 and 24. Report, Council for Geoscience, 1998-0264.

MAUD, R.R. 1985. Instability of road embankment on N3 freeway, Rickivy, Pietermaritzburg **in** Engineering geology of Southern Africa: Volume 4. Post-Gondwana deposits (Brink, A.B.A., editor). Building Publications, Pretoria, 165–166.

MAURENBRECHER, P.M. 1973. Instability of a road embankment at Rickivy, Pietermaritzburg. The Civil Engineer in South Africa, **15**, 218–224.

MAURENBRECHER, P.M. and BOOTH, A.R. 1975. Some slope stability problems in soils derived from the Ecca Shales of Natal, South Africa. Engineering Geology, **9**, 99–121.

PIETERMARITZBURG CITY ENGINEERS DEPARTMENT. 1988. A metropolitan plan for the Pietermaritzburg area, Volume 1, physical conditions. City Engineers Department, Pietermaritzburg.

RICHARDS, N.P., BOTHA, G.A., SCHOEMAN, P., CLARKE, B.M., KOTA, M.W. & NGCOBO, F.N. (In press). Explanation of the engineering geological and geotechnical conditions for the 1:50 000 scale map sheet 2930 CB Pietermaritzburg. Council for Geoscience, South Africa.

VAN SCHALKWYK, A., and THOMAS, M.A. 1991. Slope failures associated with the floods of September 1987 and February 1988 in Natal and Kwa-Zulu, Republic of South Africa. Geotechnics in the African Environment. Proceedings of the tenth regional conference for Africa on soil mechanics and foundation engineering, 57–61.

WILLIAMS, A.A.B., PIDGEON, J.T. and DAY, P.W. 1985. Expansive soils. The Civil Engineer in South Africa, **27**, 367–377.