The use of index laboratory testing to determine the engineering behaviour of granitic saprolite

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Abstract: Large parts of South Africa are covered by granitic rocks of different ages. Due to the present day climatic variation from wet conditions along the eastern coastline to arid conditions along the western coast, varying weathering products and depths to bedrock exist. Furthermore, the mineralogical differences between these granitic rocks also influence the engineering properties of the residual soils.

A large volume of engineering geologic data exists on the properties of the weathered zone, especially in the central part of the country where geotechnical investigations for urban development are the main source of the data. The Council for Geoscience has also mapped large areas around growth nodes in the north-eastern parts of the country. The data are comprised mainly of detailed soil profile descriptions, land facet zonation and appropriate laboratory tests.

The aim is to combine this existing data (all the available profile descriptions and foundation indicator test results) in order to correlate the geotechnical properties of sites underlain by granites. In particular, a relationship is sought between basic foundation indicator test results and the petrology of the granites. Through conducting these indicator tests in representative soil horizons, and through assessing the mineralogy of the rock, certain correlations can possibly be made with other properties of the saprolite.

Finally, as a much cheaper alternative, foundation indicator testing will aid in saving both time and money for future geotechnical investigations in these granitic areas with the emphasis on low-cost housing developments.

Résumé: Les grandes parties de Sud Afrique sont en dessous des rochers granite qui ont les ages different. Dû à les variations climatic d'aujour d'hui, des conditions humide la côte est a la côte oust, les produits de désagréger et les profondeurs aux rochers existent.

Un gros volume des données d'inginerie existe pour les propriétés de la zone désagréger; particulièrement pour les parties central et de l'est du pays. Cette donnée comprend surtout des descriptions du sol, et les resultants du laboratoire.

Nous avons visons mettre en correlation entre tout les propriétés d'inginerie des emplacements au-dessous granite. En particulier un rapport a recherché entre les resultants du laboratoire et la composition mineral du rocher.

Enfin, un alternative à prix réduit comporte des testes laboratoire aiderai economiser d'argent et les temps pour les investigations du avenir.

Keywords: engineering properties, index tests, laboratory tests.

INTRODUCTION

South Africa is underlain by a variety of granitic rocks. This study compares the engineering properties of some such rock types from the Archaean to the Vaalian Erathems (older than two billion years in age).

Two distinct zones were incorporated in this study, both of which are located in the eastern, higher rainfall portion of the country. The resulting weathering in this area is inherently more chemical than physical in nature, and weathering is often characterised by distinct changes in mineralogy (or decomposition) as opposed to mere physical disintegration of the mineral grains.

Data were obtained from the Council for Geoscience's Engineering Geological mapping program, comprised of regional engineering geological mapping data, including laboratory analyses of areas covered by certain 1:50 000-scale topographical sheets. The limitations of the survey, however, are that refusal was often encountered in transported soils, and that only designated areas were covered. In many instances the indicator testing was only on the upper transported soils covering the residual granite and the only data available are then the soil profile descriptions.

AIM

The investigation aims to combine existing Atterberg limit data from two distinct granitic terrains, and from mineralogically different granites in South Africa. Based on this, it is intended to generalize residual granite properties to in the end be able to conduct Phase 1 Geotechnical Assessment with less inherent costs. The Phase 1 Geotechnical Assessment refers to the site investigation conducted after a Provincial Government has granted approval of housing subsidies and forms part of the feasibility report (National Department of Housing, 2002).

The aim is furthermore to rely on the petrology of the rock instead of excessive laboratory testing to deduce the engineering properties of granitic saprolite.

GRANITES IN SOUTH AFRICA

Two distinct granitic terrains were used as study areas in order to simplify engineering properties of granitic soils. These areas are the Gauteng Province including the Johannesburg Dome, as well as the Mpumalanga Province from White River to Bushbuckridge. These two areas are similar in that weathering is predominantly via chemical decomposition, and mineralogy of the mother rock is consequently altered. This is as opposed to the western part of South Africa where rainfall is low and the weathering is essentially via physical disintegration (Figure 1).

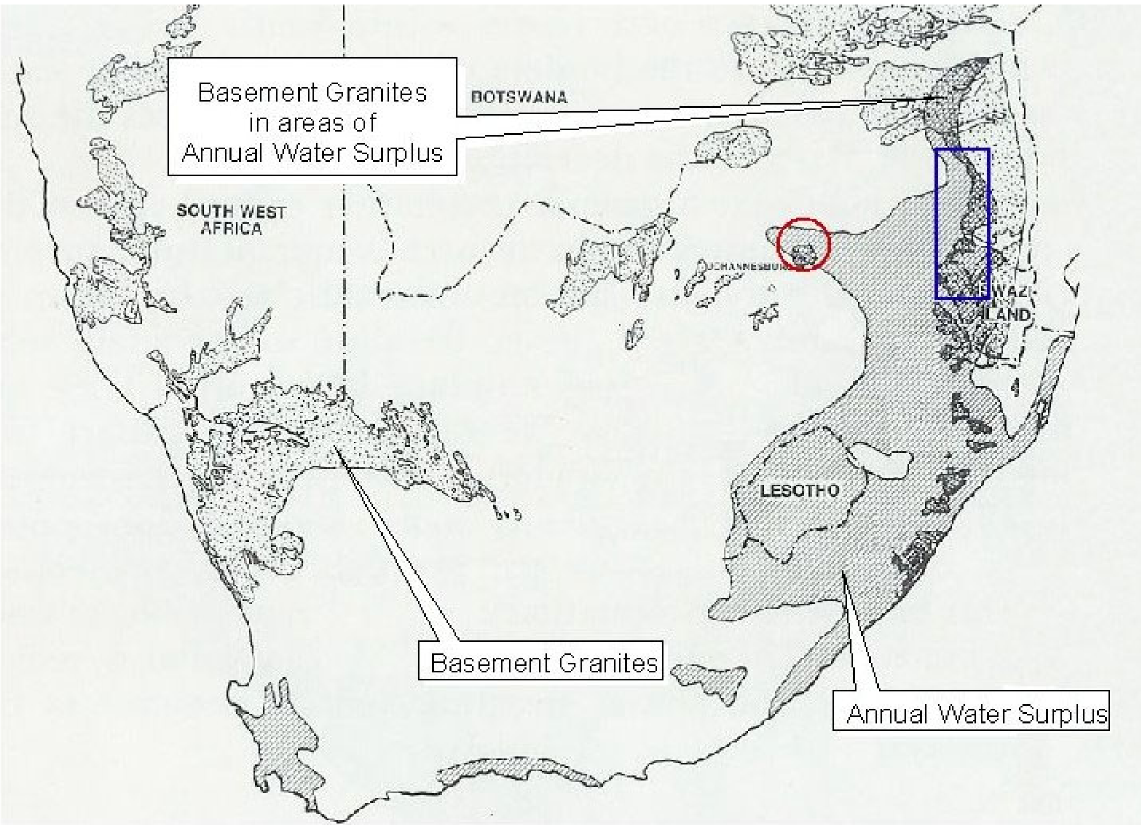

Figure 1. Mpumalanga (blue rectangle) and Johannesburg (red circle) areas (FROM: Brink, 1979).

The stratigraphy of the granites of interest is depicted in Table 1.

Table 1. Stratigraphy of relevant granite suites (SACS, 1980).

Suite	Lithology	Age	Study area
Cunning Moor (*)	Tonalite	Vaalian	Mpumalanga
Hebron	Granodiorite	Swazian	Mpumalanga
Upper Nelspruit (*)	Biotite Migmatite and Gneiss with mafic xenoliths	Swazian	Mpumalanga
Middle Nelspruit (*)	Porphyrytic Biotite Granite	Swazian	Mpumalanga
Lower Nelspruit (*)	Porphyrytic Biotite Granite	Swazian	Mpumalanga
Halfway House	Granite-gneiss	Swazian	Gauteng
(*) Name not yet approved by South African Commission of Stratigraphy (SACS).			

According to Hall (1996), granites can vary in a number of ways. For the granites incorporated in this study area, this is extremely relevant as these variations directly influence the properties of the weathering product. With relevance to the geotechnical character is the following:

- Colour, viz. that tonalites and granodiorites contain more mafic minerals than leucogranites;
- Mineralogy relating to the secondary and accessory mineral content, including micas and magnetite-series minerals.

Furthermore, metamorphism of igneous granite rocks can also alter the mineralogy of the parent rock.

For the sake of this investigation, ‘granite’ entails any intrusive or hypabasal felsic igneous rock composed of essentially quartz and feldspar (orthoclase / kfs and plagioclase / plag), or the metamorphic equivalents thereof. The definition therefore includes the rock types as indicated in Table 2.

Table 2. Generalization of granite composition (After: Snyman, 1996; Hall, 1996; Calvert, 2003).

Rock type	kfs / plag	mc / amf / px	Origin
Alkali-granite	kfs >> plag	mc and/or amf > px	Igneous
Granite	kfs >= plag	mc and/or amf > px	Igneous
Granophyre	kfs >= plag	mc and/or amf > px	Hypabasal
Granodiorite	kfs < plag	amf > mc / px	Igneous
Tonalite	kfs << plag	amf > mc / px	Igneous
Gneiss	equivalent of the above		Metamorphic
Migmatite	country rock invaded by granitic material		Metamorphic
KEY:		*mc: Mica*	
kfs: Orthoclase		*amp: Amphibole*	
plag: Plagioclase		*px: Pyroxene*	

Quartz-poor intrusive rocks such as diorite and syenite (< 20% quartz) have been excluded, together with all extrusive equivalents.

GRANITIC SOILS IN SOUTH AFRICA

The soils underlying the granites in the Mpumalanga region can pedologically be classified as ferrallitic. These soils are highly weathered and contain friable kaolinite and sesquioxides (Brink, 1979; Van der Watt & Van Rooyen, 1995). This has as result the common ferruginization of residual granite, often into a hardpan ferricrete horizon.

These soils furthermore underlay the area where Basement Complex Granites fall within the areas with annual water surplus (Brink, 1979; Figure 1). These conditions often have as result perched water tables, and promote the formation of pedocretes.

DATA

Table 3 summarizes the laboratory results on some residual granite soils from the above mentioned areas. Only Atterberg limits and clay fractions were available at the time of the study, and consequently only this data was used.

Table 3. Atterberg limits of some residual granites (Council for Geoscience, 2003, 2004a, 2004b & 2005).

n	LL	PI	GM	FM	LS	Clay	Lithology
KIEPERSOL							
1	48.22	7.07	No data	1.75	1.64	16.63	GRANITE, MIGMATITE, GNEISS
1	19	4	No data	2.08	1.21	13.85	
WHITE RIVER							
12	44.2	14.0	No data	No data	8.4	No data	GRANITE, MIGMATITE, GNEISS
18	34.0	8.1	No data	No data	4.3	No data	
BUSHBUCKRIDGE							
1	22.16	12.16	1.16	1.98	1.21	25.39	GRANITE , GRANODIORITE, TONALITE, MIGMATITE
1	23.23	13.23	1.29	1.93	1.21	23.47	
1	20.06	10.06	1.30	1.97	1.64	23.68	
1	20.34	10.34	1.28	1.94	1.64	23.89	
1	17.18	7.18	1.27	2.17	1.21	23.66	
1	48.03	17.03	1.38	2.08	3.21	30.06	
1	52.99	17.69	0.93	1.44	3.21	38.88	
JOHANNESBURG DOME							
44	28.2	10.8	No data	No data	6.1	4.4	GRANITE-GNEISS
KEY							
n	*Number of samples represented by dataset.*						
LL	*Liquid Limit (%).*						
PI	*Plasticity Index (%).*						
GM	*Grading Moduls.*						
FM	*Fineness Modulus.*						
LS	*Linear Shrinkage (%).*						
Clay	*Clay fraction (% passing 0.002mm).*						
Lithology	*The dominant feldspar is noted in brackets.*						

INTERPRETATION

Based on the results depicted in Table 2, the following conclusions can be made:

- Despite the Halfway House granite (in the Johannesburg Dome) exhibiting a significantly smaller clay fraction than the Mpumalanga granites, the laboratory analyses still classify it as moderately plastic (PI 5 –

10). This can possibly be ascribed to high fine silt fractions in these samples. There could also be contamination from concentrated mafic minerals in the gneissic banding which is evident in some areas of this granite area.

- The Bushbuckridge, White River and Kiepersol areas with plagioclase-rich granites have the highest plasticity indices from all the samples. This can be ascribed to the position of plagioclase in Bowen's reaction series and the supposed earlier decomposition of plagioclase minerals compared to orthoclase. Due to the sodium in the plagioclase, the residual granite soils may also be dispersive, and some expansive clays may form.
- The Bushbuckridge soils can (due to the high clay content) form soft clays or sensitive soils due to the high rainfall in this area.
- The less clayey soils in these areas are renowned for leaching out of clay minerals and the subsequent anticipated collapse settlement due to a collapsible grain structure (Brink, 1979). The areas where collapse settlement is common occurs mainly where the sites are underlain by gap-graded soils (i.e. soils composed essentially of sand and clay with lesser silt). These areas are also related to the geomorphic history of the subcontinent and occur where extensive periods of leaching took place (Brink,1979).

Generalizing on South African granites, one has to consider the influence of clay content (as noted above). Depending on the feldspar present in the bedrock, the site soils can be either dispersive, or soft clays can form. The soils can furthermore be collapsible when clays are leached. This will obviously be the case in the more humid eastern part of southern Africa where the feldspars are decomposed.

CONCLUSIONS

Based on grading and petrology alone, a preliminary geotechnical assessment of a site underlain by granite can be conducted. Geotechnical constraints are evident from only indicator testing rather than also conducting more expensive collapse potential or double oedometer testing.

Through mapping of the bedrock geology and description of the soil profiles with the emphasis on soil texture and structure, such preliminary geotechnical zonations can be made with reasonable accuracy in granitic terrain.

Where orthoclase (alkali granite, granite) is the predominant feldspar, kaolin clay and quartz sand forms through weathering. These soils are often readily leached and exhibit such collapsible grain structure. Erodibility in these areas is also often a concern as the profiles loose stability with the leaching of the finer fractions. This is not only a concern for residential development of an area, but is also a safety threat to these communities.

In the more plagic granites (tonalite, granodiorite) it was found that soft, dispersive clays are the major anticipated geotechnical constraints. Depending on the quartz fraction and geomorphic history of the area, these soils may also be collapsible.

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