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# Increasing effect of metamorphism on rock properties

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A R T I C L E I N F O

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A B S T R A C T

This work studied the effect of increasing degree of metamorphism on the properties of rocks. The properties investigated are the physical, mechanical and dynamic parameters. They are important inputs in the design of many mining and civil engineering techniques such as in tunnelling, slope stability and dynamic activities associated with seismicity and fragmentation. This work compared the degree of metamorphism examined through petrographic studies of the Transvaal Sequence in South Africa with the properties of the rocks. The study shows that as the effect metamorphism increases, the state of stress, compaction of grains, cementation and the brittleness of the rocks increases. In addition, increase in the metamorphic effect increases the value of the rock property. The degree of metamorphism of an outcrop is the key factor influencing its property value. Therefore the metamorphism effect of an outcrop may act as a guide to its engineering properties.



## 1. Introduction

Geological formations ranging from fluvial origin to hard rocks are subjected to various physical, chemical, mechanical and dynamic processes. These processes include intrusive hot magma flow, water ingression, chemical dissolution and recrystallization; dynamic shearing of subsurface structures associated seismicity and tectonic activities. These had been going on through the geological to the recent time. These activities affect and invariably alter the geological engineering property of the parent rock. Furthermore, as a consequence, the subsurface geological processes lead to variability in the geologic conditions and uncertainty in geotechnical parameters, the most distinctive parameters of engineering design within the same geological district and even a cross section of lithological faces. Therefore it is important for designer or engineer to bear in mind that before an excavation or construction of any civil or mining engineering opening, the behaviour of the rock in the field had been greatly influenced in terms of loading conditions (i.e. stress) and resulting deformations (i.e. strain), over the geological history of the rock.

Accordingly, knowing the geological history of the target rock or the imprint of the geology interpreted from petrographic examination of the target rock sample will do a lot of good in understanding the geological condition of the rock in terms of state of stress, lithification, compaction, cementation, porosity, straining and history of depositional environment. This will guide the designer in evaluating the engineering (physical, mechanical and dynamic) performance of an excavation. Hence this paper is undertaken to evaluate the influence of the increasing effect of metamorphism on the physical, mechanical and dynamic properties of rock using the Transvaal Supergroup depositional environment in South Africa as a case study. The study shows that the degrees of metamorphism is indicated in the petrographic imprint and are also evidence to the failure-deformation process of the rock and in addition influences the rock properties.

## 2. Geology of study area

A brief geology of the study area is described in order to provide the background for the metamorphic implication of the influence of the mafic intrusion of the Bushveld Igneous Complex into the Transvaal Supergroup in South Africa on the properties of the host rocks. The Transvaal Supergroup sediments can be typically described by three sequences of unconformity that are exposed in two geological districts. These are: the Transvaal group, where it encloses the Bushveld Complex and the Griqualand West basin at the Western Kaapvaal margin [1] that extends to the Southern Kalahari basin in South Africa. The Transvaal basin (Fig. 1) encloses the Bushveld Complex shown as BC, the Rooiberg group and outcrop of alkaline intrusions. The eastern part of the Transvaal Supergroup is underlain by sedimentary and crystalline rocks (igneous and metamorphic). The Transvaal Supergroup was intruded by ultramafic magmas sills of the Bushveld Complex emplaced to the unconformity between country rock sediments.

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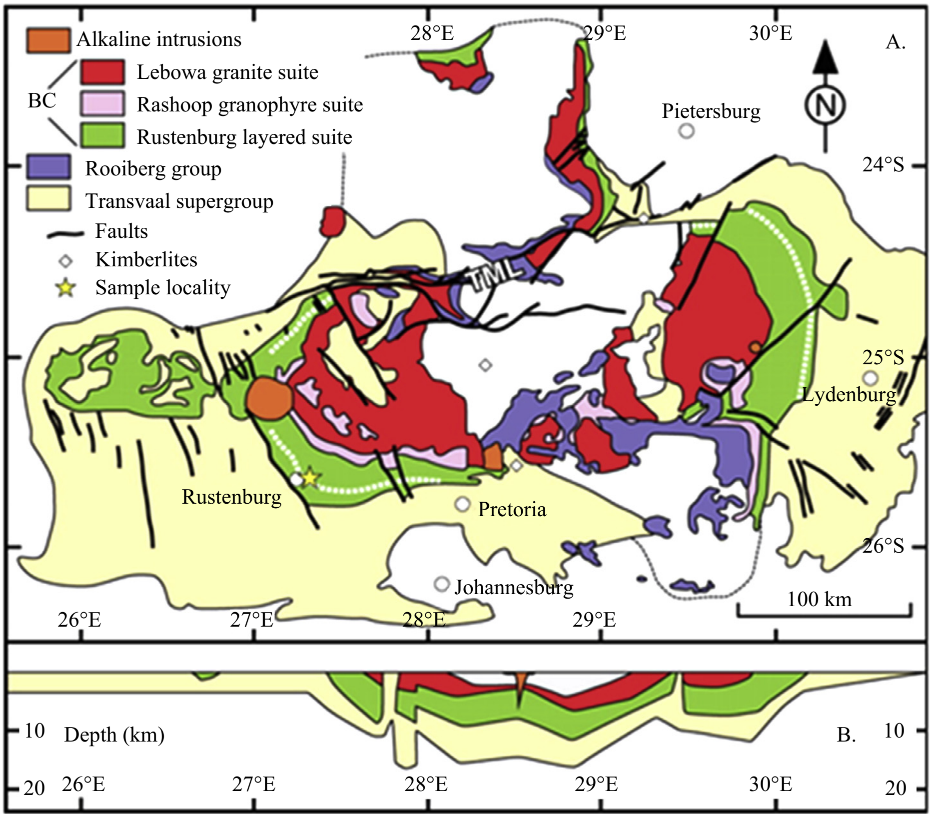


**Fig. 1.** Transvaal Supergroup and the Bushveld Complex [2].

The Transvaal Sequence, the Bushveld Complex and the southern part of Kalahari basin (including Kanye) thought to have had an interrelated tectonic history. A similar intracontinental rift setting is claimed by many authors for Proterozoic layered intrusions, including the Bushveld Complex [3]. The Transvaal Supergroup circumscribed the outcrop of the Bushveld Complex, the Transvaal basin and the lower part of Kalahari in South Africa to the southern part of Kalahari in Botswana, the Kanye. The study area therefore, comprises of the lower southern part of the Kalahari basin in South Africa which consist of immature sandstone.

Further away to the Transvaal Supergroup, the lowermost sequences of Western Ghaap Group, is typified by quartz arenite and towards the Bushveld Complex, the Pretoria Group with meta-quartzite rock type. This work therefore studied the metamorphic effect of ultramafic and mafic magma intrusion of the Bushveld Complex, into the Transvaal Supergroup on the properties of rocks in the immediate vicinity and progressively away from the source of intrusion to the lower southern part of Kalahari basin in South Africa which appears to be relatively undisturbed.

The Kalahari basin consists of sediments cutting across six countries of South Africa, Namibia, Botswana, Zimbabwe, Zambia and Angola (Fig. 2). The lower southern part of the Kalahari basin is intersected by the south-eastern lower part of the Transvaal Sequence in South Africa, see Fig. 3. The lower part of this basin in the south-eastern part of the Transvaal Supergroup consists of Sandstones stratigraphic column of the Eden formation in South Africa. This part is unlithified sediment of ductile immature sandstone. It appears undisturbed by tectonism or any geological processes. Samples are taken here for laboratory examination.

Towards the lowermost eastern sequences of the Transvaal Supergroup of the Western Ghaap Group, Submarine landslides in addition with mild compressional forces reworked the materials into semi-lithified sediment producing a foliated quartz arenite. Metamorphism of this succession is very low (Griqualand West). The Ghaap Group is described by limited thrusting [4]. According to Vajner metamorphic grades in the Ghaap Group do not exceed the lawsonite. This made the outcrop more matured with a characteristic brittle behaviour. Samples are also taken for analysis. It is the opinion of the author that the mild compressional forces would have arisen as a result of the ultramafic intrusion of the Bushveld Complex giving the outcrop a lower metamorphic succession.

The lithified quartz arenite was compressed by east–west compressional forces, uplifting the rock above sea level. This resulted in contact metamorphic of the quartz arenite into a meta-quartzite rock in the Pretoria Group. A transverse cross-section through the contact zone shows metamorphism of the Transvaal sediments into quartzite (Fig. 4). The intrusive sill of 8 km thick overlay the sedimentary rocks. The metamorphic effect of the mafic intrusive rock resulted into compaction, stressing, deformation and straining of the host rock. The metamorphism produced fine grained, well bedded, very brittle and jointed meta-quartzite that dips at about $35^0$–$40^0$ towards the north. This leads to a rock of high metamorphic succession. Partly by tectonism and ultramafic intrusion created discontinuities and partings in the rocks leading to faulting, shearing, foliation and parting planes see Fig. 5. Samples are also taken here for analysis.

## 3. Material and methods

The samples from the study area were prepared to determine the physical and mechanical properties of the rocks following the suggested methods of ISRM [5]. Several authors claimed that petrographic analysis and mechanical strength properties of rocks are both important when deciding their suitability under various loading and engineering purposes [6–13]. The dynamic parameters were also determined according to suggested method of