FAILURE MODES AND STRENGTH ANISOTROPY OF GRANITE AND GRANODIORITE GNEISSES FROM OKENE SOUTHWESTERN BASEMENT COMPLEX OF NIGERIA

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ABSTRACT

Gneiss, as an anisotropic rock, is considered to constitute a serious challenge when encountered in underground works and thus the proper evaluation of its failure modes relative to its strength properties becomes necessary to prevent major flaws in project design and execution. In an attempt to correlate the strength properties of granite gneiss and granodiorite gneiss with their associated failure modes, a total of 20 core samples, 10 each for granite gneiss and granodiorite gneiss was obtained from Okene for uniaxial compressive strength (UCS), Brazilian tensile strength (BTS) tests and determination of failure mode. Shear failure typical of rocks with low to intermediate confining pressure was observed in granite gneiss (GRN) at UCS values between 57.8 Mpa – 142.2 Mpa. Whereas axial splitting typical of low strength rocks was observed in granodiorite gneiss (GRn) for UCS values ranging between 57.6 Mpa – 88.1 Mpa. Under tensile loading the central failure was commonly observed for both gneisses. But more unlilkely low tensile strength was observed in granodiorite gneiss regardless of the central failure mode. However higher tensile strength (4.68 Mpa – 12.45 Mpa) was observed in granite gneiss (5.06 Mpa – 7.68 Mpa).

Keywords: Granite gneiss, Granodiorite gneiss, Petrography, Physico-mechanical, shear failure, axial splitting, Okene, Southwestern Basement Complex of Nigeria

INTRODUCTION

Gniesses are one among several anisotropic rocks that exhibit varying strength and failure modes. Rock failure is one of the major problems encountered during the execution of engineering projects, errors may occur in different magnitudes depending on the extent of rock anisotropy. Engineering works associated with the construction of underground structures such as tunnels, open pit mines, dam foundations and, most importantly, evaluation of rock slopes require sufficient and accurate knowledge of the site and the physical and mechanical properties of the rocks which will be faced during the operation as well as determination of the tectonic conditions (Basu and Roychondury, 2013; Odedede and Ugbe 2016; Zargar et al, 2019; Acharya *et* al 2021). A detailed understanding on rock failure modes will immensely help to evaluate the integrity of support designs for engineering work. Bhowmick et al (2021) opined that the study of failure modes using physical models of rock samples under laboratory conditions is economical and time efficient. The crystalline rocks preserve a range of micro-flaws leading to the crack initiation, propagation and subsequent failure (Scholz 1968; Martin and Chandler 1994; Eberhardt et al. 1998; Li et al. 2003; Jaeger et al. 2007). The deformation of micro-flaws influences the behaviour of rock masses in terms of strength and failure modes (Janeiro and Einstein 2010; Du et al. 2020 and Ugbe et al., 2023b). Several researchers such as Szwedzicki (2007); Basu et al. (2009); Ugbe (2020); Ugbe et al. (2023a) have suggested a comprehensive study of the geometric arrangements of particles and micro-flaws observed in rocks. However, there exist some limitations in predicting the nature of fracture propagation as well as the mode of failure under confining pressure (Santarelli and Brown 1989). According to Santarelli and Brown (1989) posited the non-existence of numerical model that can predict the failure modes.

Basu et al. (2009) indicated that even when specimens of identical lithological composition are tested, a large range of uniaxial compressive strength (UCS) and various specimen failure modes may be observed which could be attributed to microstructural differences particularly in the form of micro-cracks, splitting along multiple extensional planes parallel to the core axis, and failure along a shear plane (sometimes with spalling at the top of the specimen). Maji (2011) indicated that the failure mode of a rock material under compression affects the resultant strength of the sample. Heap and Violay (2021) who reviewed the mechanical characteristics and failure modes of volcanic rock observed low-porosity volcanic rocks develop shear fractures at low- and high-pressures, and high-porosity volcanic rocks develop shear fractures. The granodiorite gneiss is widely distributed in the study area and may be considered to serve as useful alternative to the dwindling granite reserve. However the paucity of information bordering on their failure modes under various loading mechanism, particularly the uniaxial compressive stress constitute a serious restrain to their utilization. Thus this paper presents laboratory findings obtained from the preliminary study of the failure modes observed across core samples of granodiorite under varying compressive strength, with the aim of ascertaining the role of rock failure mode on the strength properties of some selected gneiss.

DESCRIPTION OF LOCATION AND GEOLOGY OF THE STUDY AREA

The study area is located in Okene, Southwestern Basement Complex of Nigeria. It is located between Latitudes $7^{0}30$'N and $7^{0}35$'N and Longitudes $6^{0}10$'E and $6^{0}16$'E. It is also part of the Southwestern Basement Complex of Nigeria (Figure 1). .

The Okene area is underlain by Precambian Basement rocks of southwestern Nigeria (Clark 1985; Oyinloye and Ademilua 2005). The migmatite-gneiss forms the dominant lithological unit in the presence of supracrustal rocks covering about 70% of the entire lithological units that can be found in the study area.

Vachette and Umeji (1987) reported the domination of hornblende-biotite gneiss of tonalitic and granodioritic suite in the western part while pink granite gneiss and migmatite occupy the greater parts of the eastern half of the Okene area.

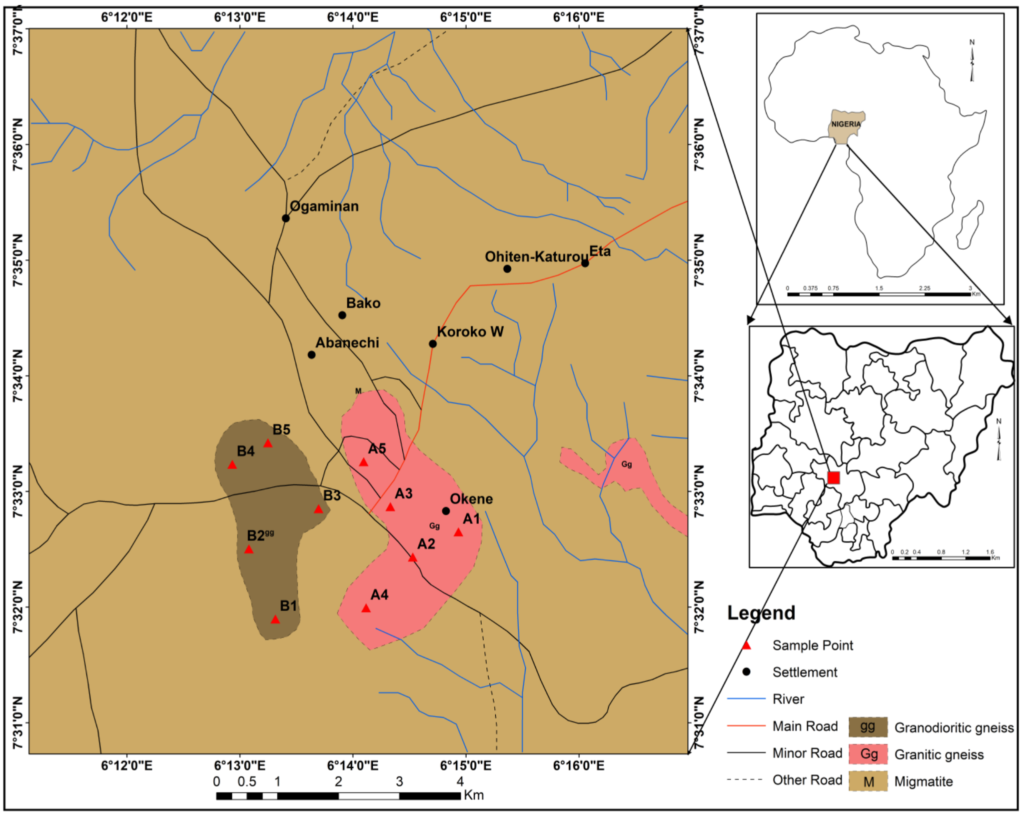

Figure 1: Geological map of the study area

METHODS

This research work involves the geological mapping and collection of core samples from Okene using diamond drilling techniques.

A total of 20 core samples, ten (10) for each of the selected gneisses were prepared from reliable length of core samples obtained from different outcrops around Okene. The representative samples of two selected gneisses were prepared into thin section, which was undertaken in the Department of Geology Laboratory of the University of Lagos, Nigeria. The core samples were prepared to meet the Height to Diameter ratio (H/D) of 2 – 2.5 and thereafter tested using a certified compression machine in accordance to the ISRM (2007) suggested method and recommended standard for Uniaxial compressive strength test. The failure modes were determined by visual inspection relative to foliation plane.

RESULTS AND DISCUSSIONS

The result of the modal composition of the selected gneisses is shown in table 1a and table 1b. The modal plot (Figure 2) revealed the selected gneisses to be granite gneiss and granodiorite gneiss respectively. The thin section of the rock samples are shown in figures 3 to 6.

In terms of the quartz content, granite gneiss with mean value of 28%, standard deviation of 1.90 and a coefficient of variation of 6.78 as shown in Table 1a is considered to be characterized by low heterogeneity.

Similarly, granodiorite gneiss with average quartz content of 30%, standard deviation of 4.56 and coefficient of variation of 15.20 Table 1b can be considered to exhibit low heterogeneity in their mineralogy.

Table 1a: Average modal composition of granite gneiss from Okene southwestern Basement Complex of Nigeria

Sample code	Quartz (%)	Orthoclase (%)	Plagioclase (%)	Biotite (%)	Muscovite (%)	Horblende (%)	Opaque mineral (%)	TOTAL
A1	30	23	22	12	11	2	-	100
A2	30	25	22	10	10	1	2	100

A3	27	25	20	10	15	3	-	100
A4	25	28	25	10	10	2	-	100
A5	28	25	23	10	12	-	2	100
Mean	28	26	22	10	12	2	1	
Standard Deviation	1.90	1.48	1.67	0.894	2.45	0.63	1	
COV	6.78	5.70	7.61	8.94	24.49	31.60	1	

Table 1b: Average modal composition of granodioritic gneiss from Okene southwestern Basement Complex of Nigeria

Sample code	**Quartz (%)**	**Orthoclase (%)**	**Plagioclase (%)**	**Biotite (%)**	**Muscovite (%)**	**Horblende (%)**	**Opaque mineral (%)**	**TOTAL**
B1	25	13	35	12	10	5	-	100
B2	30	12	40	8	5	3	2	100
B3	33	13	33	10	10	1	-	100
B4	30	20	28	10	5	5	2	100
B5	30	20	21	5	6	4	4	100
Mean	30	16	31	9	7	4	2	
Standard	4.56	3.63	6.48	2.37	2.32	1.61	0.89	
COV	15.20	22.71	20.91	26.29	33.2	33.2	40.30	

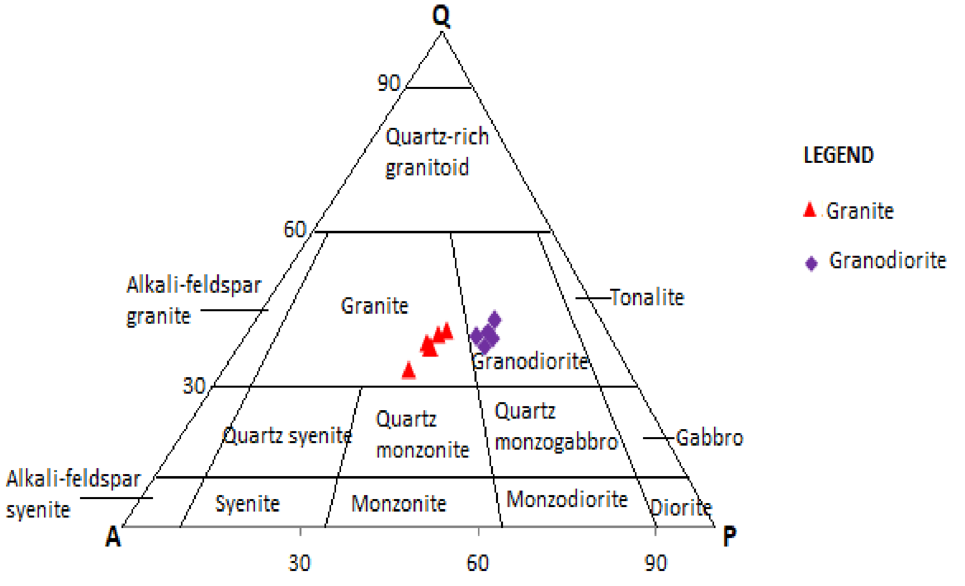

Figure 2: Modal composition of selected gneisses from Okene southwestern Basement Complex of Nigeria in IUGS-recommended Q-A-P plot diagram adapted from Streckeisen (1976)

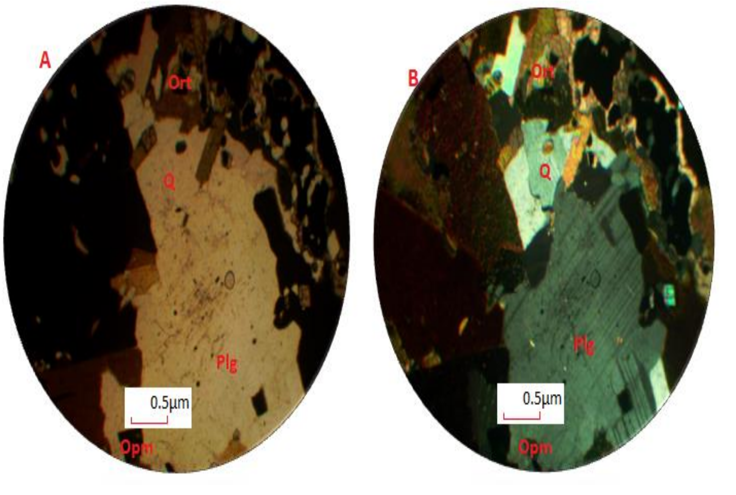

Figure 3: Photomicrograph typical of Granite Gneiss (A2) from Okene Southwestern Basement Complex of Nigeria. A = plane polarized light, B = crossed polarized light; Q = quartz, Plg = plagioclase, Ort = orthoclase, Opm = opaque mineral inclusions

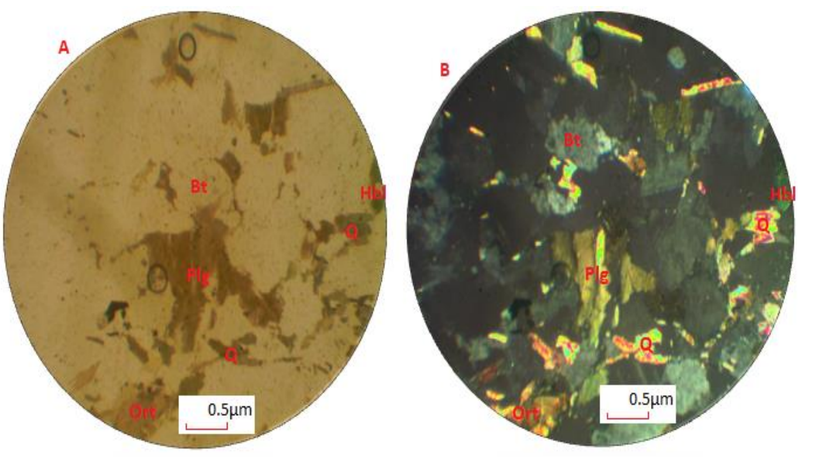

Figure 4: Photomicrograph typical of Granite Gneiss (A4) from Okene Southwestern Basement Complex of Nigeria. A = plane polarized light, B = crossed polarized light; Q =quartz, Ort = orthoclase, Bt = biotite, Plg = plagioclase, Hbl = hornblende

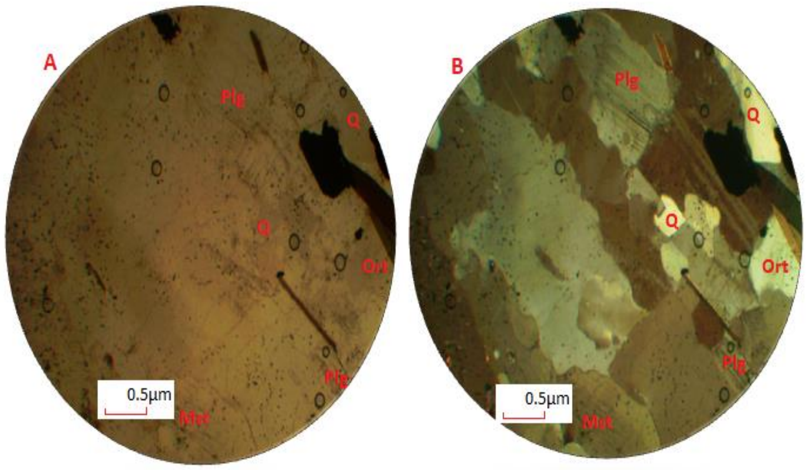

Figure 5: Photomicrograph typical of granodiorite gneiss (B2) from Okene Southwestern Basement Complex of Nigeria. A = plane polarized light, B = crossed polarized light; Q = quartz, Plg = plagioclase, Ort = orthoclase, Mst = muscovite

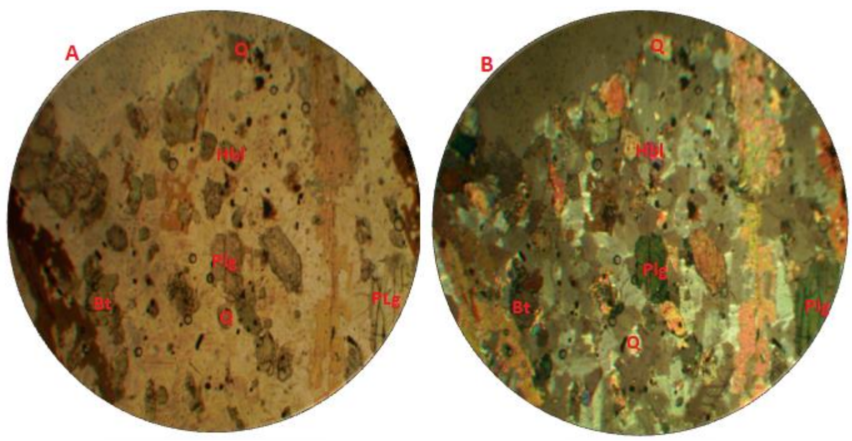

Figure 6: Photomicrograph typical of granodiorite gneiss (B5) from Okene Southwestern Basement Complex of Nigeria. A = plane polarized light, B = cross polarized light; Q = quartz, Bt = biotite, Plg = plagioclase, Hbl = hornblende

FAILURE MODE OF GRANITE GNEISS UNDER COMPRESSION

Generally, across the samples A1 – A5 the UCS values which ranged from 57.8 Mpa – 142.2 Mpa which classifies the granite gneiss according ISRM (1978) as strong to very strong rock. Similarly, shear failure along plane observed in the granite gneiss (Figure 7) has been designated for rocks that fail under intermediate confining pressure (Basu *et al*, 2013).

Figure 7: Illustration of shear failure in granite gneiss from Okene Southwestern Basement Complex of Nigeria

FAILURE MODE OF GRANITE GNEISS UNDER BRAZILIAN TENSILE STRESS

The failure mode observed under Brazilian tensile stress is predominantly the central-failure modes (Figure 8), which is largely attributable to the inability of pre-existing micro-cracks to exploit foliation in the course of their propagation (Basu *et al* 2013). The delay or inability in the exploitation existing foliation usually results in the delayed released of stored strain energy, thus, resulting in high strength of granite gneiss under tensile loading.

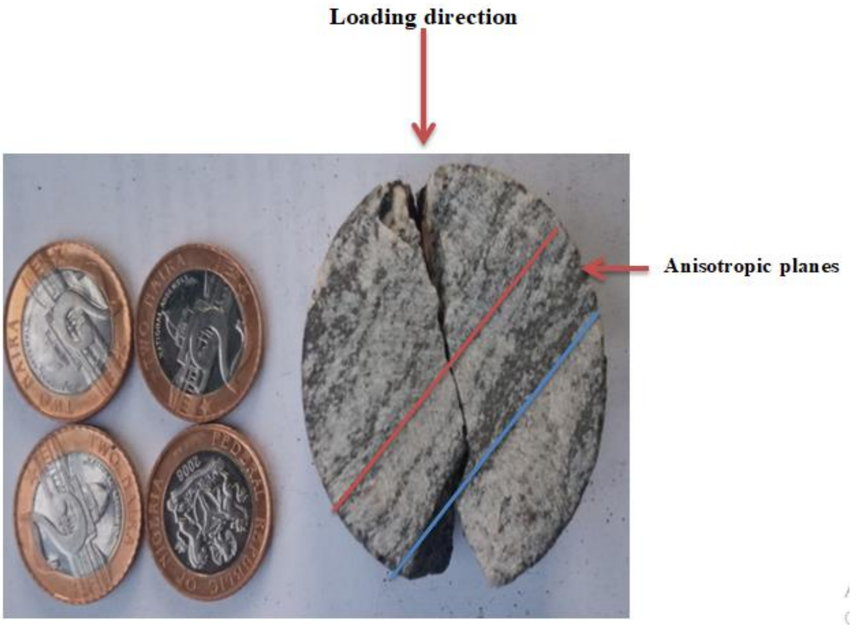

Figure 8: Illustration of central mode failure in of granite gneiss under tensile stress from Okene Southwestern Basement Complex of Nigeria

FAILURE MODE OF GRANODIORITE GNEISS UNDER COMPRESSION

The failure mode of Granodiorite gneiss observed at UCS values between 57.6Mpa – 88.1Mpa is majorly axial splitting, (Figure 9) which on the basis of strength has been categorized to be associated with rocks that fail at low confining pressure. (Basu *et al* 2013).

Figure 9: Illustration of failure mode of granodiorite gneiss under compression from Okene Southwestern Basement Complex of Nigeria

FAILURE MODE OF GRANODIORITE GNEISS UNDER BRAZILIAN TENSILE STRESS

The failure modes observed in granodiorite gneiss under tensile stress is the central mode (Figure 10), which is similar to that which has been observed in granite gneiss. However unlike what was observed in granite gneiss the BTS values of granodiorite at central failure mode is very low (5.07Gpa – 7.68). The low values of BTS may be largely related to the presence of weak minerals.

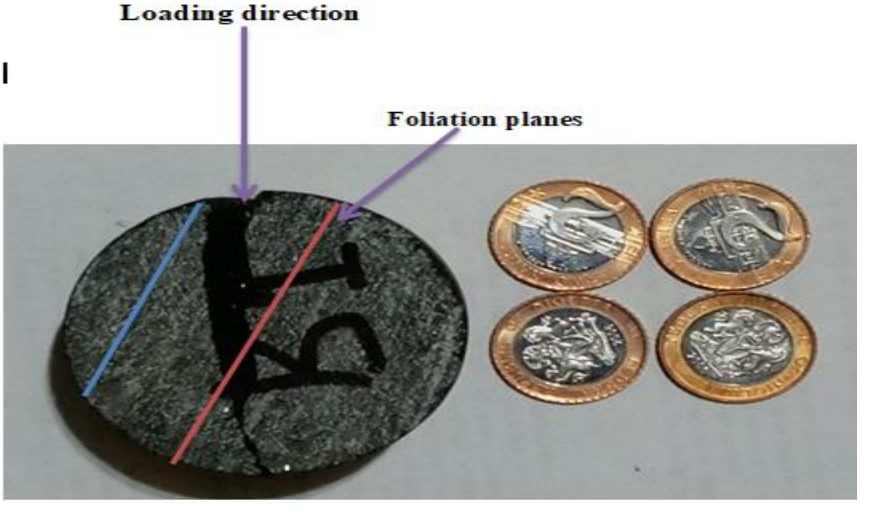

Figure 10: Illustration of central mode failure of granodiorite gneiss under tensile stress

CONCLUSION

The two selected gneisses have been identified according to IUGS-recommended Q-A-P plot diagram as granite gneiss and granodiorite gneiss. Two types of failure were observed for each of the gneisses, shear failure for granite and axial splitting for granite gneiss and granodiorite gneiss respectively. The granite gneiss exhibit higher strength when compared to granodiorite gneiss as can be deduced from it failure under compression and tensile stress.

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