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COMPARATIVE ANALYSES OF PETROGRAPHIC AND PHYSICO-MECHANICAL PROPERTIES OF SELECTED GNEISSES FROM OKENE, SW BASEMENT COMPLEX, NIGERIA

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Abstract

In an attempt to determine the more suitable gneiss for foundation works (house, road, and dam construction), the need arises to search for geomaterials that will help to minimize the cost of executing durable engineering projects. Selected samples of gneisses' petrographic and physico-mechanical properties were examined to ascertain which type of gneiss is more suitable for engineering projects. Physico-mechanical and petrographic analyses were done on 10 representative samples, 5 each for granite gneiss and granodiorite gneiss taken randomly from different outcrops in Okene. The cores were prepared to meet the recommended heights/diameter (H/D) ratio of 2 – 2.5. The results show the mean values of minerals such as quartz (28%), orthoclase (26%), plagioclase (22%), biotite (10%) and muscovite (12%) for granite gneiss and quartz (30%), orthoclase (16%), plagioclase (31%), biotite (9%) and muscovite (7%) for granodiorite gneiss respectively. The granite gneissis is medium-coarse grained with persistent foliation and minor evidence of mineral alteration, while the granodiorite gneiss is fine-medium grained characterized by discontinuous foliation. The Uniaxial compressive strength (UCS) of granite gneiss was between 57.8 Mpa and 142.2 Mpa and is strong to very strong rock and is designated as very strong to strong rock while granodiorite gneiss with UCS between 57.6 Mpa and 88.1 Mpa and is designated as strong rock .In comparison. The mean values of water absorption capacity (WAC) of granite gneiss (0.66%) and (0.65%) for granodiorite gneiss fell within permissible limit of <1.00 %. Also the mean values of specific gravity of 3.19 and 3.30 for granite gneiss and granodiorite gneiss falls within the >2.55 recommended by. However the Correlation coefficient (R) for WAC vs UCS, reveals that granodiorite gneiss with R = 0.737 is more susceptible to a sharp decline in strength with increasing water absorption than granite gneiss with R = 0.550. The failure modes observed were the shear failure and vertical splitting and were influenced by the nature and orientation of foliation plane. Granite gneiss in the absence of large scale mineral alteration which may possibly result in its higher water absorption capacity is more suitable to be used for engineering construction, and will perform better for deep and shallow foundations compared to granodiorite gneiss.

Keywords: Granite gneiss, Granodiorite gneiss, Petrography, Physico-mechanical

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1.0 INTRODUCTION

Gneiss is a high-grade metamorphic rock formed from the metamorphism of granite or diorite (Singh & Murthy 2016).Gneisses found in the Okene region belong to Nigeria's southwestern Basement Complex and are known for their economic value and use in engineering construction (Olade, 1978; Dada,2006). The ISRM (1979) has designated these gneisses as very strong to solid rock with uniaxial compressive strength (UCS) values ranging between 100 to >250 Mpa. This suggests that they may be suitable for constructing infrastructures such as roads. More importantly, they can be used to build dams/embarkments in nearby towns and villages that are situated in the flood plains of the Rivers Niger and Benue. These areas often experience severe flooding that leads to the loss of lives and properties.

Gneisses have been considered to rank high among rocks with high usability. This is due to the fact that they play host to mineral ores and may serve as useful source of construction aggregates and as well as the its utilization in interior and exterior decoration on the basis of their aesthetic properties. However for rocks such as gneiss that is characterized by the existence of variants, there exist the need to compare and contrast the petrographic and physico-mechanical properties rather than an isolated study of single gneiss, which will not suffice in the identification and use of gneiss that is most suitable for engineering constructions.

Otokiti and Adebayo (2024) posited the significance of uniaxial compressive strength (UCS) in influencing the extent of fragmentation of rocks, as rock with high UCS tend to exhibit high resistance to crushing forces.

Improvement or the decline in rock strength properties has been opined by some authors to be attributable to the mineralogy of the rocks (Ugbe *et al.*, 2023a and Ugbe *et al.* 2023b). Feldspar and mica are considered to be characterized by the tendency to form micro-cracks up on loading, which results in a decline in rock strength (Zhou et al. 2024). In the same vein Ugbe (2020) while investigating the mineralogical physico-mechanical properties of Iyuku granite identified an improvement in the granite index properties with increase in its quartz content.

However, Hassan *et al* (2019) cautioned against the exclusive use of mineralogy in the prediction of rock strength as other factors such as grain size, frequency of micro-cracks may also influence rock properties Askaripour *et al* (2022). This position is further supported by Adekoya (2011) who studied the relationship between the petrography and uniaxial compressive strength (UCS) of selected crystal line rocks of Southwestern Basement Complex of Nigeria suggested that the UCS of rocks is more dependent on the textural and micro-structural properties than its mineral content, which may be true for anisotropic rocks characterized by significant variations in their properties, a situation that largely depends on the arrangement and orientation of flaky and elongated mineral which form bands and foliations (Li *et al.*,2021).

Other index properties also studied and reported by notable authors include porosity and water absorption capacity relationship with strength properties. Strength properties are posited to decrease with increase in porosity, particularly for rocks with well developed fissures and pores (Pan et al. 2023). In addition Ayeni *et al* (2017) while comparing the physical, mechanical and geological properties of some selected granite gneiss, granite and migmatite of Supare Akoko in the Southwestern Basement Complex of Nigeria, identified the granite gneiss as the most suitable rock in terms of engineering properties. He however noticed the high susceptibility of granite gneiss to decline in its superior properties with increase in porosity.

Costa *et. al.,* (2021) opined that higher number of microscope spores will be resultant effect of high temperature on gneiss.

Zel *et. al.,* (2021) studied the anisotropic features of gneiss using X-ray and neutron tomography and established a strong correlation between the lineation and foliation fabrics in biotite gneisses and magnetic and seismic anisotropy.

Wang *et al.,* (2022) carried out a study on the impact of ground stress on the properties of gneiss and ascertained that higher ground stress will only contribute positively to its pre-peak mechanical properties.

Li and Wen (2023) opined that seepage pressure will significantly influence granite gneiss hydo-mechanical properties and deformation.

Kaushal *et. al.,* (2024) investigated alterations in Himachal gneiss due to weathering and observed a major mineralogical alteration in plagioclase feldspar which intensifies as the grade of weathering increases.

Wang *et al.,* (2024) evaluated the mechanical properties and strain localization characteristics of gneiss under-freeze thaw cycles and observed that mechanical properties decreases linearly with freeze-that cycles.

However, Bulk of the research works carried out on the gneissic rocks of the Southwestern Basement rocks of Nigeria particularly in Okene and its environs has centered majorly on their petrographic and mineralogical characteristics with the sole aim of unraveling their petrogenesis and mineral potentials, while neglecting their physico-mechanical properties that must be well understood for a sustainable civil engineering projects design and execution (Odigi, 2002; Ajigo *et. al.,* 2019; Gideon *et al.,* 2019; Adabanija *et. al.,*2020; Amigun *et. al.,*2020; Kolawole *et. al.,* 2022; Obini & Omietimi, 2020; Ominigbo, (2022); Adamu *et. al.,* 2024; OlaOlorun and Akinola, 2024).

The Okene area that play host to the Itakpe Iron ore deposit is currently in need of construction aggregates other than the severely exploited granite deposit that may not suffice for the construction of more infrastructure that may be required to support the foreseeable increase in socio-economic activities once mining activities resumes as assured by the Federal Government of Nigeria.

To annul any threat to continued infrastructural development due to dwindling granite reserve, construction engineers are bound to look out for other rocks within the Okene axis, as suitable substitute for their construction activities. On this note, the granite gneiss and granodiorite gneiss which have been established according to Emioge *et. al.,* (2023) as the dominant rock types within the gneissic group may suffice.

Thus, this study is aimed at the comparative evaluation of both gneisses in an attempt to unravel the gneissic rock with the more superior petrography and physico-mechanical properties suitable for engineering construction.

2.0 GEOGRAPHICAL LOCATION AND GEOLOGY OF OKENE

The study area is in Okene, southwestern Nigeria and lies between Latitudes 7° 30'N to 7° 35'N and Longitudes 6° 10'E to 6° 16'E (Figure 1), where the gneisses are widespread.

The migmatite-gneiss is the most common type of rock found in the study area, making up approximately 70% of the entire lithological unit. In the western part of the area, hornblende-biotite gneiss of tonalitic and granodioritic suite is the most dominant type, while in the eastern half, pink granite gneiss and migmatite are the predominant types of rock (Vachette & Umeji, 1987).

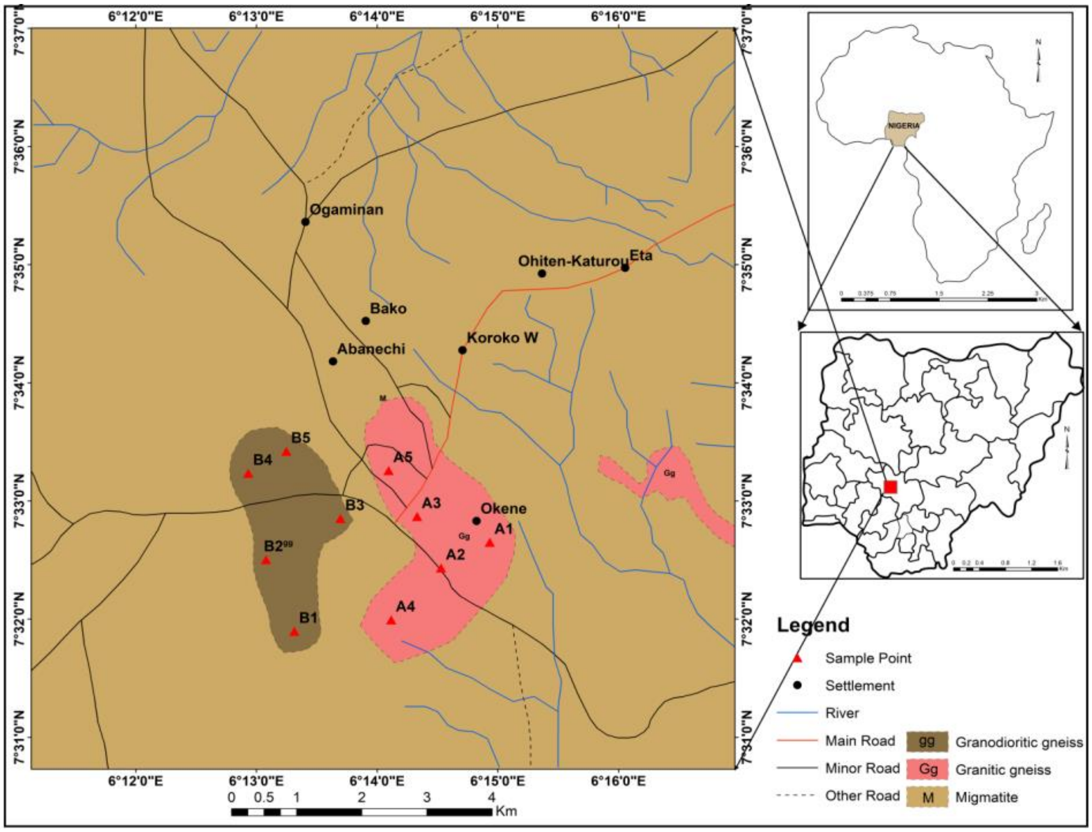

Figure 1: Geological map of the study area adapted from (Emioge *et. al.*, 2023)

3.0 MATERIALS AND METHODS

This research involves random geological mapping and collection of cores across various outcrops in the Okene area using diamond drilling, followed by visual inspection of cores before testing to enhance the reliability of the cores for petrographic and physico-mechanical evaluation. A total of 10 core samples [five (*n=5*) granite gneiss and five (*n=5*) granodiorite samples were obtained from the study area. Thin section petrography analysis was done on the representative samples of the gneisses in the Department of Geology Laboratory of the University of Lagos, Nigeria. The core samples were prepared to meet the Height-Diameter ratio (H/D) of 2 – 2.5, and then tested in a certified compression machine. From the stress-strain plot, Young modulus (ε) and deformation modulus ε_{50} were calculated. Young modulus represents the stiffness, while ε_{50} is the ratio of 50% of the peak strength of rocks to the corresponding strain ε_{50}. These values are necessary for modelling the rock and for computing deformations where the rock is assumed to be an elastic continuum. The failure modes were determined by visual inspection relative to the foliation plane. To assess the consistency of the data for various parameters examined, a statistical method that involved calculating the mean, standard deviation (SD), and coefficient of variation

(COV) was used. The recommended standard ASTM C 127, (1990) was followed to determine bulk density, specific gravity, and water absorption capacity for the rock index properties.

The statistical test using Microsoft excel was carried out to ascertain the mean, standard deviation (SD) and coefficient of variation (COV) in an attempt to determine the homogeneity of the data set for the different parameters investigated.

The rock index properties such as bulk density, specific gravity and water absorption capacity were determined in accordance to ASTM C 127 (1990) recommended standard.

4.0 RESULTS AND DISCUSSIONS

Petrography of the Gneisses

The results of the modal composition of granite gneiss and granodiorite gneiss. The petrographic study revealed the average values of minerals such as quartz (28% and 30%), orthoclase (26% and 16%), plagioclase (22% and 31%), biotite (10% and 9%), and muscovite (12% and 7%) for granite gneiss and granodiorite gneiss respectively. With regards to the quartz content, granite gneiss has a mean value of 28%, standard deviation of 1.90 %, and coefficient of variation of 6.78% as shown in Table 1. It is characterized by low heterogeneity.Granodiorite gneiss with an average quartz content of 30%, SD of 4.56%, and COV of 15.20% (Table 1) can be considered to have low mineral heterogeneity.

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

Table 1: Average modal composition of gneisses from Okene, Southwestern (BC) of Nigeria (after Emioge et. al., (2023)

				Granite gneisses (n = 5)				
S/#	**Quartz**	**Orthoclase**	**Plagioclase**	**Biotite**	**Muscovite**	**Hornblende**	**Opaque mineral**	**Total**
A1	30	23	22	12	11	02	-	100
A2	30	25	22	10	10	01	02	100
A3	27	25	20	10	15	03	-	100
A4	25	28	25	10	10	02	-	100
A5	28	25	23	10	12	-	02	100
Mean	28	26	22	10	12	02	01	
S D	1.90	1.48	1.67	0.89	2.45	0.63	01	
COV	6.78	5.70	7.61	8.94	24.49	31.60	01	
				Granodiorite gneisses (n = 5)				
B1	25	13	35	12	10	05	-	100
B2	30	12	40	8	05	03	02	100
B3	33	13	33	10	10	01	-	100
B4	30	20	28	10	05	05	02	100
B5	30	20	21	05	06	04	04	100
Mean	30	16	31	09	07	04	02	
SD	4.56	3.63	6.48	2.37	2.32	1.61	0.89	
COV	15.2	22.71	20.91	26.29	33.2	33.2	40.30	

S/# = sample code; SD = Standard Deviation; COV = Coefficient of Variation

Source: Emioge et al. (2023)

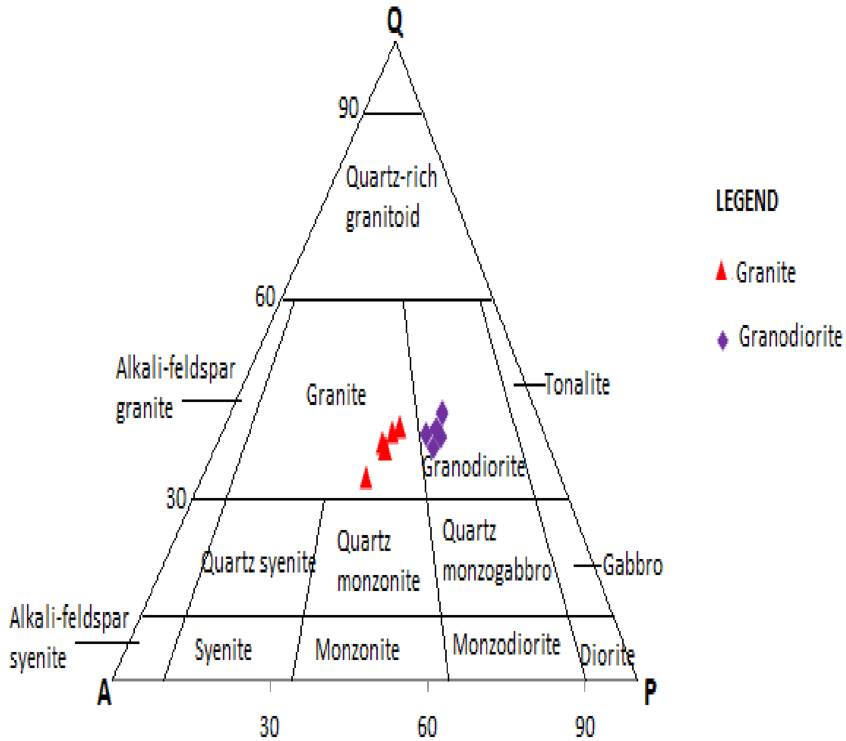

Figure 2: Modal composition of selected gneisses from Okene Southwestern (BC) of Nigeria in IUGS-recommended Q-A-P plot diagram adapted from (Emioge et. al., (2023)

The modal plot (Figure 2) was obtained using the percentage modal composition of quartz, orthoclase and plagioclase present in samples of the granite gneiss and granodiorite gneiss. While the thin sections of the rock samples are shown in Figures 3 – 6.The subhedral to angular grains was observed in figure 3 which is typical of the granite gneiss which means the granite gneiss is of low deformation and stable structure (Karca et. al., 2015).

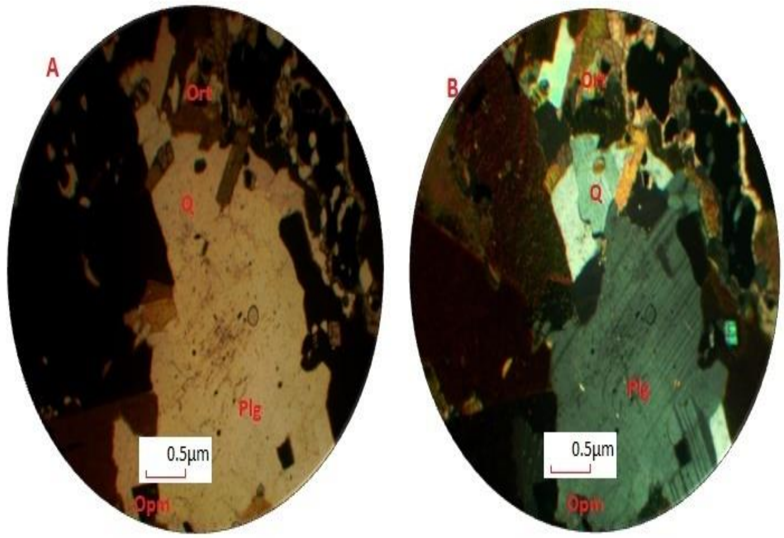

Figure 3: Photomicrographof Granite Gneisses (sample A2) A = plane polarized light, (PPL) B = crossed polarized light (XPL); Q = quartz, Plg = plagioclase, Ort = orthoclase, Opm = opaque mineral inclusions.

In Figure 4, the granodiorite gneiss exhibited subhedral crystal structures, sharp inter-grain boundaries highly visible intra-grain boundaries, highly visible intra-grain fractures particularly in feldspar but less pronounced in quartz was observed which is suggestive that the granodiorite gneiss is of low deformation, but is of high porosity which could account for a sharp decline in strength.

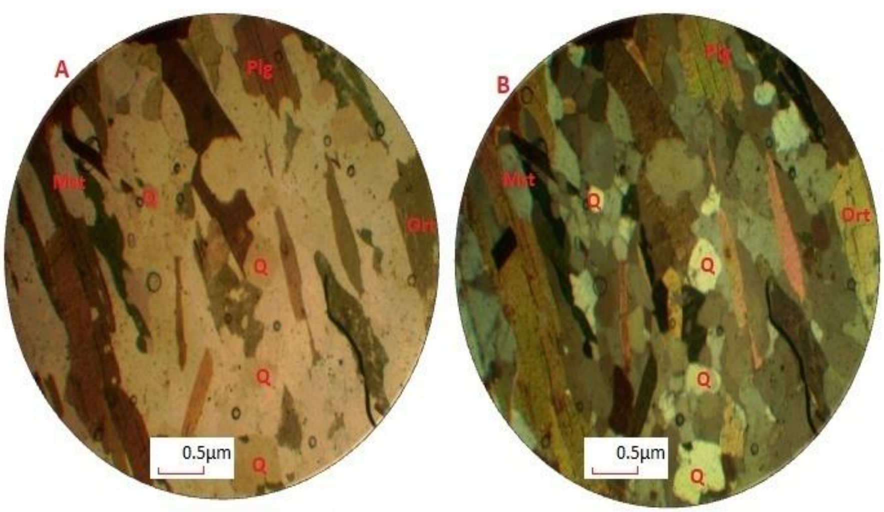

Figure 4: photomicrograph typical of granodiorite gneiss (sample B2) A = plane polarized light, (PPL) B = crossed polarized light (XPL); Q = quartz, Plg = plagioclase, Ort = orthoclase, Mst = muscovite

The physico-mechanical properties of two types of gneiss - granite gneiss and granodiorite gneiss - are presented in Tables 1c and 1d. The bulk density values ranged from 2.78g/cm3 to 3.93g/cm3 for granodiorite gneiss, while the specific gravity values ranged from 2.96 to 3.44 for granite gneiss respectively and are considered suitable, because the meet the >2.67 recommended by ISRM (1979). The higher values of specific gravity value (>2.65) reveals both the granite gneiss and granodiorite gneiss as strong rocks. Samples A1, A2, and A3, listed in Table 2, are suitable dimension stones as they all have unconfined compressive strength (UCS) values between 96 KN/m^2 and 310 KN/m^2, which is within the range recommended by (Karaca et. al., (2015). However, samples A4 and A5 are weak and not considered suitable. On the other hand, granite gneiss with UCS values ranging from 57.8 to 142.2 Mpa is considered as a solid rock according to ISRM (1979). In Table 3, the UCS values of >50Mpa for granodiorite gneiss , demonstrate it as a strong rock as stated by ISRM (1979)

The Brazilian Tensile Strength (BTS) results obtained for granite gneiss samples A1, A2, and A3 fall within the suggested range of 5-20MN/m^2, as mentioned in Winkler (1979). Therefore, these samples are deemed suitable dimension stones. However, samples A4 and A5 do not fall within this range.

The results of the BTS test conducted on granodiorite gneiss show that they fall within the range of 5 – 20MN/m^2. However, the samples A3 and A4 have a high WAC level of 1.23% and 1.4%, respectively, which indicates that they have higher porosity, and it can damage the strength of the rocks (Farmer, 1966). The water absorption capacity (WAC) results of the granodiorite gneiss samples B1 and B5 show that their WAC levels are 1.17% and 1.42%, respectively, which makes them unsuitable to be used as dimension stones.

Table 2: Physico-mechanical properties of granite gneiss

S/#	Bulk density (g/cm^3)	Specific Gravity	WAC (%)	UCS (MPa)	BTS (MPa)	$Ɛ_{50}$ (GPa)
A1	3.494	3.44	0.17	142.2	12.45	13.54
A2	3.758	3.19	0.35	112.2	10.85	10.11
A3	3.262	3.21	1.23	106.5	10.70	7.13
A4	2.96	3.04	1.40	57.8	4.68	3.85
A5	2.96	3.14	0.17	80.7	5.35	4.71
Mean	3.29	3.19	0.66	99.94	8.81	7.87
SD	0.29	0.12	0.54	28.72	3.16	3.57
COV	8.81	3.76	81.81	28.74	35.86	45.36

Source: Emioge et al. (2023)

Table 3: Physico-mechanical properties of granodiorite gneiss

S/#	Bulk density (g/cm^3)	Specific Gravity	WAC (%)	UCS (MPa)	BTS (MPa)	E_{50} (GPa)
B1	2.88	3.05	1.17	57.60	6.31	4.10
B2	3.13	3.27	0.19	66.50	6.32	4.43
B3	3.93	3.42	0.17	88.10	7.68	3.72
B4	3.19	3.39	0.32	66.50	5.91	5.91
B5	2.78	3.38	1.42	57.60	5.06	5.06
Mean	3.18	3.30	0.65	67.6	6.26	4.64
SD	0.40	0.15	0.28	11.60	0.85	0.75
COV	12.58	4.54	43.08	16.50	13.58	16.16

Source: Emioge et al. (2023)

Relationship between physical, mechanical properties and quartz contents

Figure 7 and 8 represents the linear relationship between physical, mechanical properties an quartz content. A positive correlation exist between UCS vs Quartz, SG vs Quartz, BTS vs Quartz and UCS vs WAC

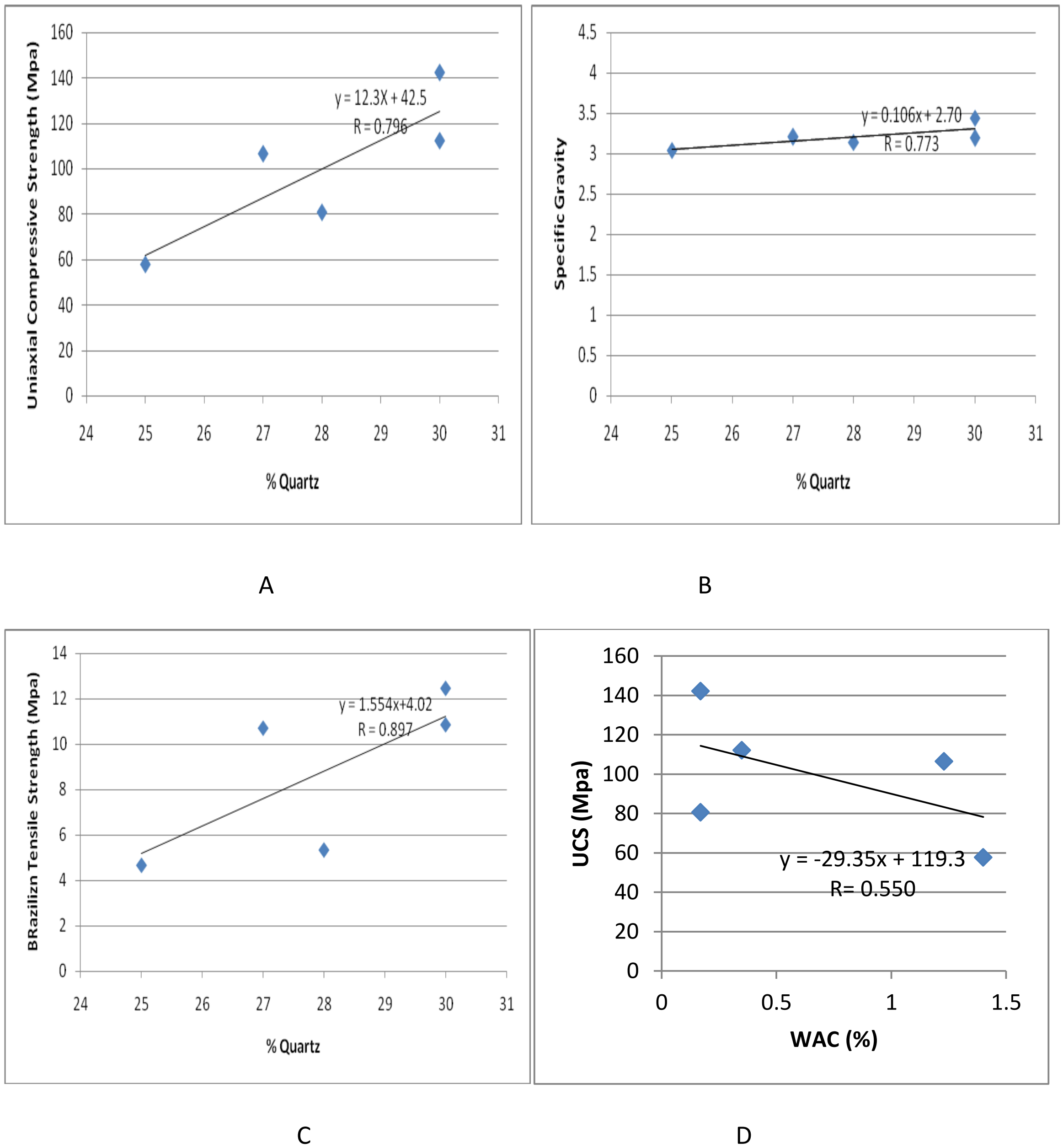

Figure 7: Regression analyses for granite gneiss: (A) UCS vs Quartz; (B) SG vs Quartz; (C) BTS vs Quartz; (D) ***UCS VS WAC***

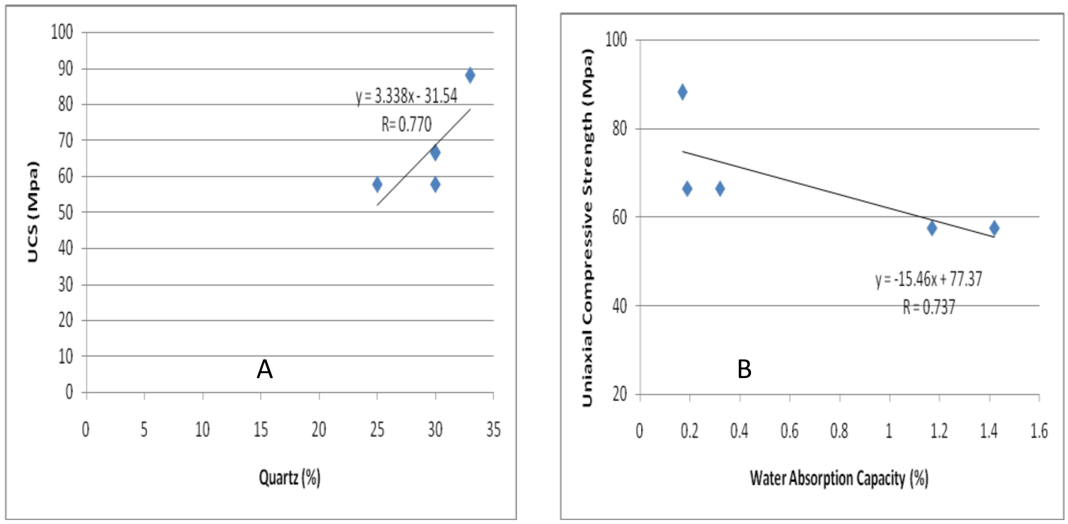

Figure 8: **Regression analyses for (A) UCS vs Quartz; (B) UCS *vs* WAC (Granodiorite gneiss)**

Failure Modes and Mechanism of granite gneiss and granodiorite gneiss from Okene, Southwestern (BC), Nigeria

Figure 9 shows that in granite gneiss, the failure mode observed was ductile-shear failure. This can be attributed to the low angle of foliation relative to the loading direction, as well as the persistent nature of alternating quartzo-feldspat

hic bands alternating with biotite-dominated bands. On the other hand, in Figure 10, vertical splitting was the failure mode observed in granodiorite gneiss. This can be primarily attributed to the high angle of foliation relative to the loading direction and the vertical propagation of micro-cracks originating from the biotite bands through the thin band of quartzo-feldspathic minerals. These observations are similar to those made by Ugbe et al., (2023a), who noticed that cracks in rocks under uniaxial compressive stress is first propagated in biotite and lastly in quartz.

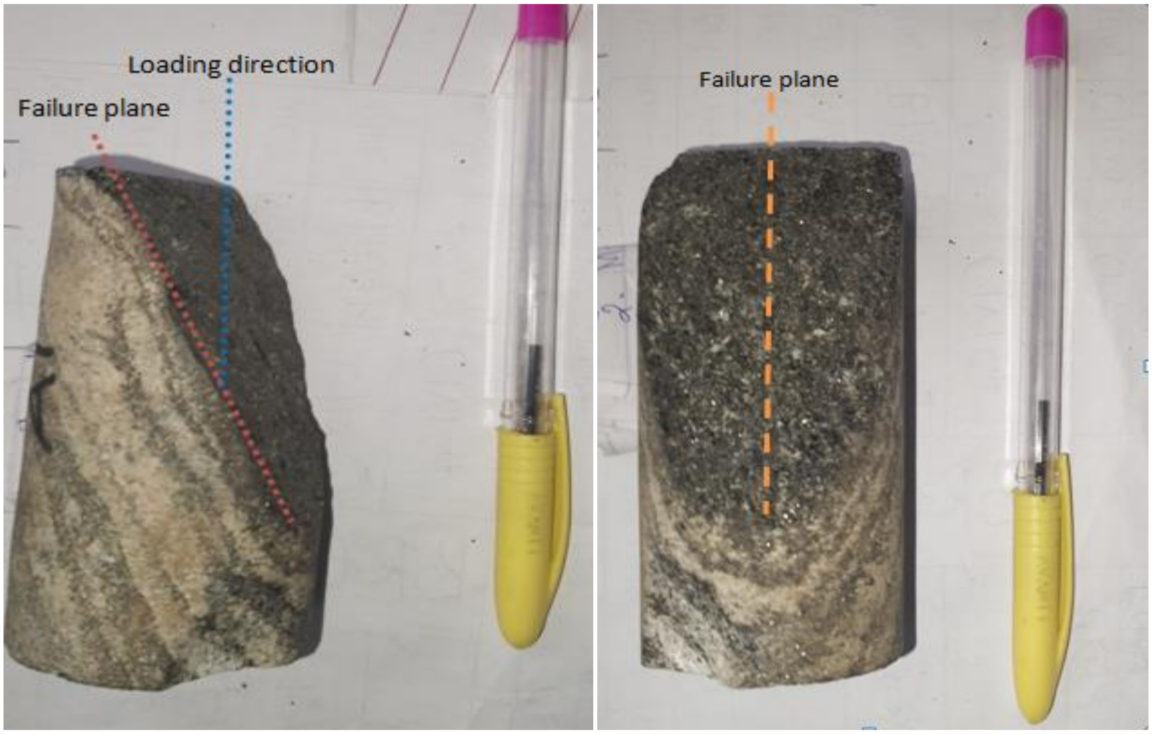

Figure 9**:** Ductile-shear failure along foliation plane of weakness in granite gneiss

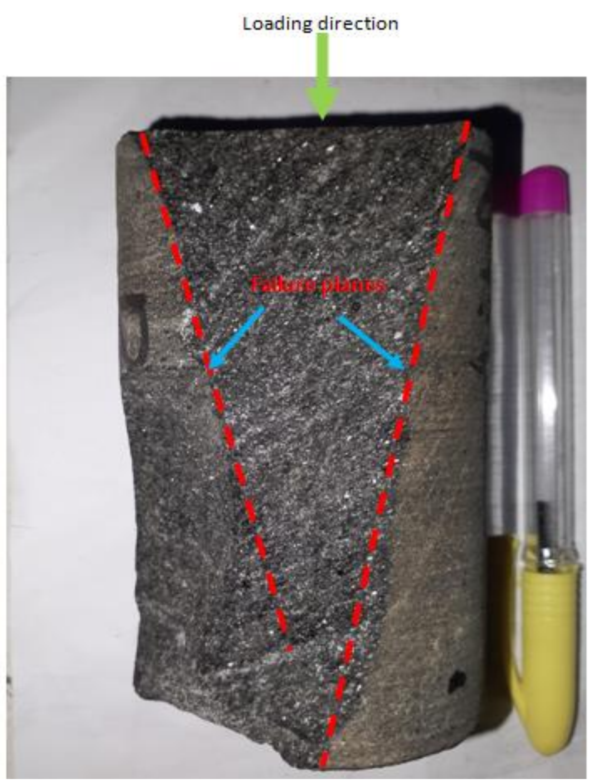

Figure 10: Vertical splitting failure in granodiorite gneiss

5.0 CONCLUSIONS

After assessing the impact of petrography on the physico-mechanical properties and failure modes of selected gneisses, the following conclusions were drawn:

The two types of gneisses identified according to the IUGS QAP diagram are granite gneiss and granodiorite gneiss.The granite gneiss is characterized by a more superior petrographic and physico-mechanical properties when compared to granodiorite gneiss in a situation where mineral alteration do not assume a dominant feature within its rock mass. The granite gneiss is considered to highly suitable for both deep and shallow foundation involving shallow water table when compared to granodiorite gneiss in the event that mineral alteration which may result in possible increase in water absorption capacity and hence decline strength does not assume a dominant feature within the rock mass.

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