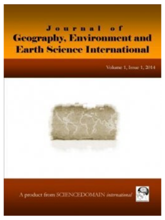

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Preliminary Structural and Petrographic Studies of Oke Ogun Rocks, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study attempts to analyze structural elements and mineralogical compositions that are present in rocks in parts of Oke Ogun and relates their occurrences to the geology of the area. The main objectives are to better understand the structural history of the rocks and the deformational episodes that pervaded them. Geological field mapping was undertaken to identify and study field occurrences and structural relationships of rock types. Strike and dip directions were measured with compass-clinometer, whereas coordinates of sampling points and locations were taken using Global Positioning System (GPS). In addition, rock samples were collected and thin sections prepared for petrographic analysis. The main lithologic units found in the area are syenite, migmatite-gneiss and porphyroblastic gneiss, mica schist, banded gneiss and biotite hornblende granite. Geologic features such as faults, joints, fractures, foliations, quartz veins, folds, and xenoliths were also observed on the outcrops. The result of petrographic studies shows that most samples have highest concentrations of plagioclase, which range from 29.4% to 26.5%, followed by quartz (24.6% to 24.4%). Few locations recorded highest concentrations of microcline ranging from 41.5% to 19.6%. Biotite values range from 17.5% to 6.7%, whereas hornblende and opaque mineral values range from 7.4% to 5.5% and from 2.0% to 0.9%, respectively. Deformation-induced

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elongations of minerals were also observed in thin sections. The resultant orientations of macro-structural veins based on structural measurements show a NE-SW and NW-SE trends, whereas joints trend N-S and E-W. These structural trends have been interpreted to be analogous to directions of tectonic events responsible for metamorphism and/or fracturing of rocks in the region.

Keywords: Field mapping; petrographic study; deformational episode; basement complex; Southwestern Nigeria.

1. INTRODUCTION

The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex, the Younger Granites, and the Sedimentary Basins [1,2]. The basement complex, which is Precambrian in age, occurs mostly in the southwestern, northern, and eastern parts of the country. In general, approximately, one half of the Nigerian land area is underlain by the Basement Complex [1]. The Basement Complex of Nigeria has been the focus of several previous work vis-à-vis tectonic histories, mineralogical compositions and, of course, mineralization and economic potentials. Examples of such work include: [2,3,4,5,6,7]; among others. The Pan-African orogeny is the last of the four tectono-thermal events to affect the Nigerian Basement Complex, and has been dated to have occurred between 500 to 600 million years ago. The Pan-African deformation was accompanied by a regional metamorphism, migmatization and extensive granitization and gneissification, which produced syntectonic granites and homogeneous granites [1,8,9,10, 11]. [12] gave evidence that within the basement complex, tectonic deformation has completely obliterated primary structures except in few places where they survived deformation. The structural and tectonic framework of the Nigerian Basement Complex has been reported as comprising NE-SW and NW-SE lineaments superimposed over a dominant N-S trend [13], and NW-SE and NE-SW pair superimposed on a N-S joint set [14,15]. [15] confirmed earlier inference of [16] through observation of presence of NW-SE aeromagnetic signatures in a regional aeromagnetic survey map that was studied.

The southwestern Basement Complex of Nigeria lies within the rest of the Precambrian rocks in Nigeria [9,16], where it has been grouped as migmatite-gneiss complex, comprising largely of metasedimentary series with associated minor igneous rock intrusions, which have been altered by metamorphic, migmatitic and granitic processes. [16] noted that some of the rocks in southwestern Basement Complex show evidence of polyphase deformation with the plutonic episode of the Pan African event being the most pervasive. This observation was corroborated by [7,10]. The Shaki potassic syenite has been described by [9] as a semi-conformable body about 180 square km in areal extent and elongated parallel to the N-S structural trend of surrounding biotite-muscovite gneiss. The contact relationship of the syenite with the surrounding rock is obscured, but is thought to be rapidly gradational. According to [12] elucidating structural fabrics, especially the fracture pattern in the Nigerian basement is a problem due to poor exposure. Also, according to [17] there are problems associated with mapping fractures, which include poor exposure and masking by surface weathering processes. Thus, such as it was the case in the present study, field mapping is required in many cases to carry out detailed geological interpretations in many areas within the basement complex. In general, a good understanding of the structural patterns in the Nigerian Basement Complex is critical to the understanding of the tectonic evolution of this part of the Pan-African terrain [2,9,16].

This study attempts to analyze geological features and structural elements present in the rocks in parts of Oke Ogun area in southwestern Nigeria. This work is aimed to carry out a detailed geological interpretation of the study area. We carried out geological field mapping with visual descriptions of outcrops and structural elements, and collection of rock samples for petrographic analyses. Information obtained from the field mapping exercise includes the geological features, mineralogical composition of rocks, nature of outcrops, texture, color and structural features. The petrographic studies enabled microscopic analyses of mineral assemblages and deformation-induced orienta-tions of the constituent minerals. Integra-tion of various information enabled a better understanding of the geology of the area, vis-à-vis nature of rocks, mineral assemblages, structural fabrics and possible tectonic and deformational episodes that pervaded the rocks in the study area.

2. THE STUDY AREA

The study area is part of Sheet 119 of southwestern Nigeria basement complex. It lies between Latitude 08°30'N and 08°42'N, and Longitude 03°20'E and 03°30'E. The study area is located in Oke Ogun area part of Oyo state, which includes Shaki, Ago Are, Tede, Irawo Ile, and Irawo Owode in Atisbo Local Government Area of the state (Fig. 1). The study area is generally accessible as availability of both tarred and un-tarred roads as well as footpaths provides good accessibility to the area. Nevertheless, in some cases during the field mapping, footpaths had to be manually cut through vegetation to access specific outcrops. The area lies within humid and sub-humid climate region with annual rainfall ranging from 700 to 1100 mm, and mean annual temperature of about 26°C. The area is drained by the upper Ogun River. Elevation ranges from 300 to 400 meters, with occasional monoliths and inselbergs jutting out dramatically from the landscape. The Oke Ogun people live in several mid-sized and large towns surrounded by farmlands and natural features. Some of the outcrops that were mapped in this study were located within the populated areas. The settlement pattern conforms to the general settlement type of a town core consisting a central market, a square and a royal palace with successsively newer structures being built around the areas.

3. METHODOLOGY

Geological field mapping was undertaken in order to identify and study field occurrences and structural relationships of rock types that are present in the study area. The study started with a reconnaissance survey involving general familiarization with road network, settlement patterns, drainage channels and outcrop occurrences. This was followed by detailed field mapping. Before taking field measurements on

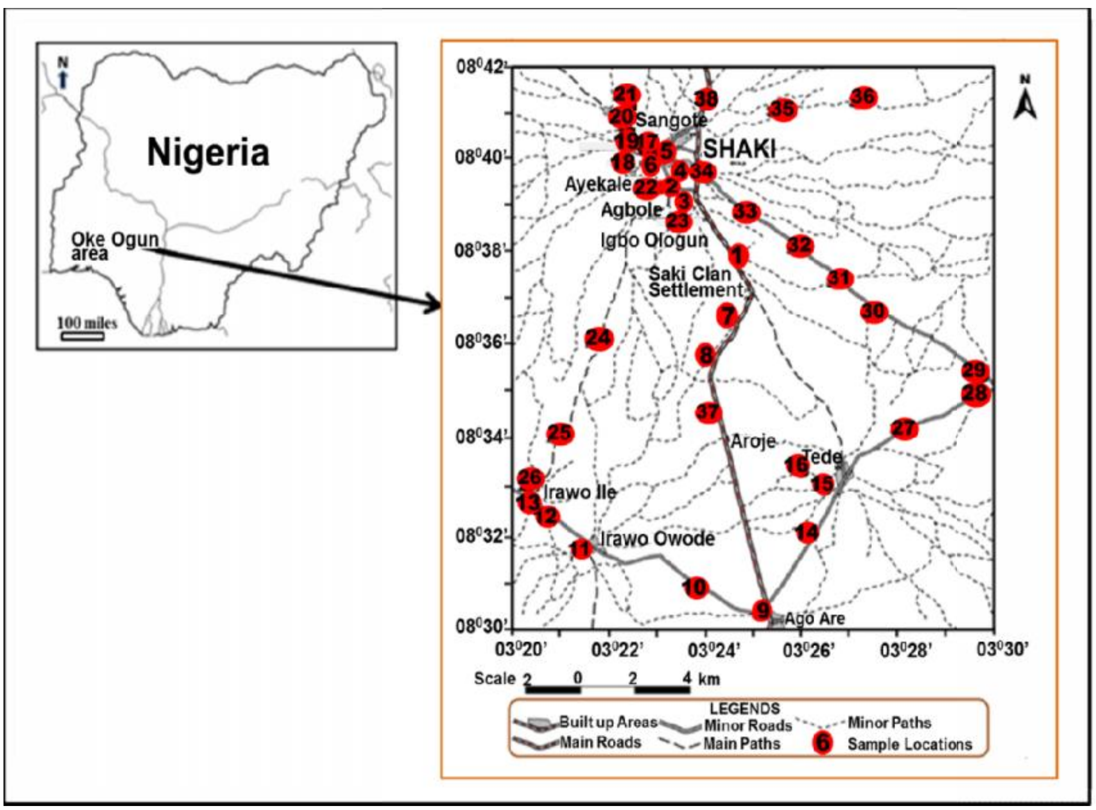


Fig. 1. Location map of the study area showing sampling locations and road network

some of the outcrops, especially those that were located in the urban areas, there were needs for discussion with villagers, community leaders, and in some cases, local government officials, to enlighten them on purpose of our field campaign. Generally, outcrops encountered were studied for their mineralogical and structural characteristics. Preliminary observation and identification of constituent minerals were carried out using magnifying lens. Strike and dip directions were taken with compass-clinometer, whereas coordinates of sampling points and locations were taken using Global Positioning System (GPS). Orientations and characteristics of structural imprints such as joints, trends and veins, were also recorded. Plots of rose diagrams were made to determine dominant structural trends and infer orientations of possible geologic events that could have led to observable rock deformation in the area. The field-measured orientation data were first grouped into classes and number of measurements within each angle class was plotted. The resultant rose diagrams consist of wedges with lengths proportional to number of data in each angle class, and spanning angles representing the classes. Thirty-eight locations were visited with visual description of rocks and observable mineralogical and structural properties carried out in situ. The sample locations are shown in Fig. 1. The nature, colour, and texture of outcrops, as well as weathering and vegetation types in each location are summarized in Appendix 1. Fresh rock samples were collected from which fifteen rock samples were prepared for petrographic studies. The samples were observed under plane polarized light (PPL) and cross polarized light (XPL) in thin sections, where mineral assemblages and micro-structural fabrics were analyzed.

4. RESULTS OF FIELD MAPPING

4.1 Lithological Descriptions

The main lithologic units which were discovered during geologic field mapping of the area include syenite, migmatite-gneiss and porphyroblastic gneiss, mica schist, banded gneiss, and biotite hornblende granite. The nature of the outcrops are relatively low-lying (occurring at relatively low elevation above the ground), undulating to massive rocks. The weathering types as observed from the study include physical, chemical and biological weathering. Vegetation of the study area ranges from thick to sparse vegetation, though vegetations have been obliterated in some areas due to urban development. The colour of the rocks ranges from leucrocratic to melanocratic. More specifically, only Sample Locations 11 and 23 from the 38 sample locations are melanocratic. The texture ranges from medium to coarse grained to medium to fine grained granitic rocks. The details of the field mapping and geological information from the sample locations are summarized in Appendix 2. Also, the geological map of the area is shown in Fig. 2, whereas photographs of major geological features as observed from some of the outcrops are shown in Figs. 3 to 10. The lithological descriptions of these rock units are discussed in detail below:

Syenite: Syenite constitutes more than 50% of rocks in the study area (Fig. 2). It is an intrusive rock, belonging to the alkali series of intermediate plutonic rocks. Alkali feldspar (such as orthoclase) is the major mineral component of syenite found in the study area, and total feldspar content in the rock was found to be greater than 65%, with quartz typically lacking. The color varies, but are typically leucrocratic with texture being phaneritic.

Migmatite Gneiss: Migmatite gneiss constitutes about 5% of the gneiss rocks in the study area. They have both phaneritic and aphanitic texture. The darker minerals are well pronounced in most places, whereas lighter minerals proportions are relatively small.

Granite Gneiss: Gneiss is a high grade metamorphic rock, meaning that it has been subjected to higher temperatures and pressures than schist. It is formed by the metamorphism of granite, or sedimentary rocks. Gneiss displays distinct foliation, representing alternating layers of light and dark minerals. However, unlike slate and schist, gneiss does not preferentially break along planes of foliation because less than 50% of the minerals formed during the metamorphism are aligned in thin layers. Because of the coarseness of the foliation, the layers are often sub-parallel, that is they do not have a constant thickness and are not discontinuous.

Porphyroblastic Gneiss: This rock was found at Irawo Ile and Irawo Owode (Fig. 2) where they occurred as small body with presence of augen gneiss. The augen gneiss occurred as an eye-like structure on the outcrops. More detail characteristics of the augen structure was also observed under the magnifying glass and this was included in naming of the rock as porphyroblastic (augen) gneiss. Originally, augen gneiss is believed to contain relatively large feldspar clasts floating in a finer-grained matrix.

Pegmatite: Pegmatite is an intrusive igneous body of highly variable grain size that often includes coarse crystal growth. A pegmatite may be segregation within an associated plutonic rock or a dyke-like vein that intrudes the surrounding country rock. Pegmatites are coarse grained and light in colour due to the larger percentage of feldspar in the outcrops that were located at Ogboro road. They were also found as intrusions cutting across the host rocks and as large veins at sampling locations in Shaki (Fig. 6).

Mica Schist: Schist is a crystalline metamorphic rock, mostly composed of more than 50% tabular and elongated minerals with grain size coarse enough to be visible to the unaided eye. Schists have a foliated or platy structure (schistosity) and are distinguished from other foliated rocks (such as slates and gneisses) by the size of their mineral crystals. Mica schist contains quartz and mica (biotite or muscovite) as main minerals. Mica schist was found as small intrusion body in the outcrops that were mapped along Igbo Ologun and along Irawo Ile road. It was leucocratic and the texture was medium to coarse grained.

Banded Gneiss: This is a metamorphic rock which was dominantly found around Igbo Ologun Irawo road. The outcrops were low lying along the stream channels in the area. The rock bodies have experienced weathering. There were also portions of banded gneiss and migmatite gneiss in Oke Galili. The intensity of metamorphism of the outcrops was interpreted to have led to observable mineralogical alteration of the mafic and felsic minerals in the rocks. Also, the texture of the outcrops was medium grained.

Biotite Hornblende Granite: Observable mineralogical contents of the rock outcrops and rock samples include: Quartz; biotite; hornblende; microcline and plagioclase feldspars. The naming of the rocks as biotite-hornblende granite gneiss was determined from both the outcrops and rock samples in which biotite and hornblende were the dominant minerals, though biotite contents were found to be significantly greater than that of hornblende.

4.2 Structural Features

Several structural features were observed on the various outcrops in the study area during the field mapping. These include: faults, joints, fractures, foliations, quartz veins, folds, xenoliths, and tension gashes. Details of the field observation are summarized in Appendix 2.

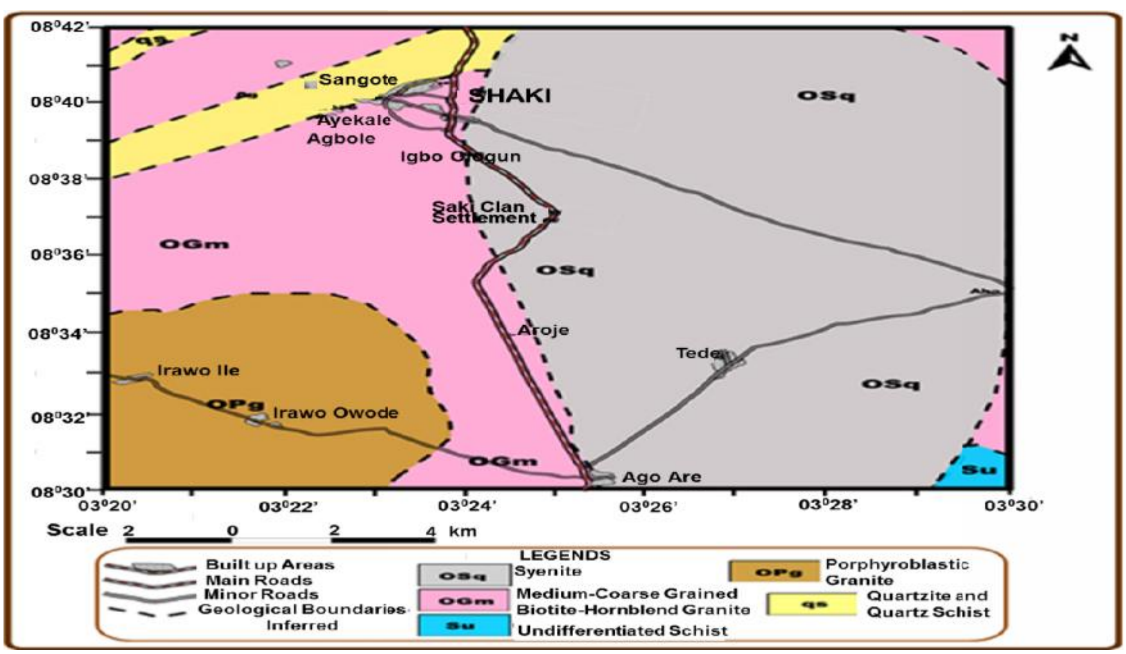


Fig. 2. Geological map of the study area showing lithological units and inferred geological boundaries

Faults: Fault is a fracture along which there has been a displacement of the sides relatively to one another. Most of the faults encountered in the study area are normal faults, where the hanging wall has relatively moved down compared to the foot wall (Fig. 5).

Joints: Jointing in the area was generally a localized feature with multi-directional trends suggesting several phases of deformation. On most of the outcrops, the joints were observed parallel to each other indicating their cogenetic relationship (common origin). Consequently, they were interpreted to be of the same deformational episodes. Cross joints were also observed on some of the outcrops, where they showed dendritic-like patterns (Appendix 2).

Fractures: These are openings or cracks in the rock body from which there are no observable displacements. These were found on almost all the outcrop in the study area (Appendix 2).

Foliations: Foliations are continuous or discontinuous layer structures in metamorphic rocks formed by segregation of different minerals or by alternation of bands of different textures. These were found on few of the outcrops in the study area (Appendix 2).

Assymmetrical Folds: This type of fold was observed on the granite-gneiss around Oge. The fold contained folded quartzo-feldspartic material embedded in host rock and forming a lineation of quartz minerals. The folds were mostly assymmetric (that is they were of unequal limbs) and they showed NW-SE and E-W axial trends (Fig. 7).

Quartz or Quartzo-Feldspartic Veins: These are formed as a result of recrystallization of silicate grains in rock crevices or joints. The grains are believed to form from mineral-riched hydrothermal fluid, where the latter later solidified. The solidified materials in the veins consist mostly quartz and feldspar. Some of these veins were found in the study area to be discordant to foliation planes. These structures were mapped on almost all the outcrop visited in the study area (Fig. 8).

Tension Gashes: Tension gashes are linear openings which are formed as a result of tensional forces developed during deformation. They were filled by minerals usually quartz and feldspar fillings.

Xenoliths: Xenoliths are rock fragments within an intrusive igneous body that are unrelated to the igneous body itself. Xenoliths represent pieces of older rocks incorporated into the magma while it was still fluid. Also, it could also be as a result of partial digestion or incomplete digestion of a country rock. Xenoliths were mapped on migmatite outcrops at Isale Oro in Shaki. They have fine texture compared to the surrounding bodies.

Fig. 3. Cross veins on an outcrop

Fig. 4. Solution hollo

Fig. 5. An example of faults

Fig. 6. A pegmatite rock

Fig. 7. An assymmetrical fold

Fig. 8. A quartzo-feldspartic vein

Fig. 9. An augen gneiss

Fig.10. A fracture on an outcrop

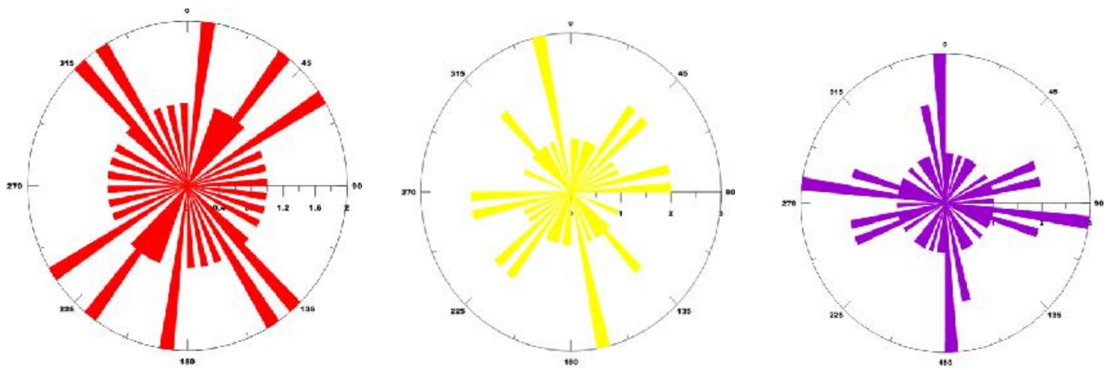
4.2.1 Rose diagrams

Plots of rose diagrams were made to determine structural trends and infer orientations of possible geologic events that could have led to observable rock deformation in the area. Fig. 11 shows plots of strike directions for some of the structural features that were measured during the field study. As shown in Fig. 11, the structural features trend in different directions, though dominant trending directions are very well interpretable. For the pegmatitic veins, the dominant structural trends are approximately NE-SW and NW-SE directions (Fig. 11a), whereas the most dominant trending direction for the quartz veins is approximately NE-SW and more specifically NNE-SSW (Fig. 11b). For the measured strike directions for the joints, the dominantly trending directions are approximately N-S and E-W (Fig. 11c)

4.3 Results of Petrographic Analyses

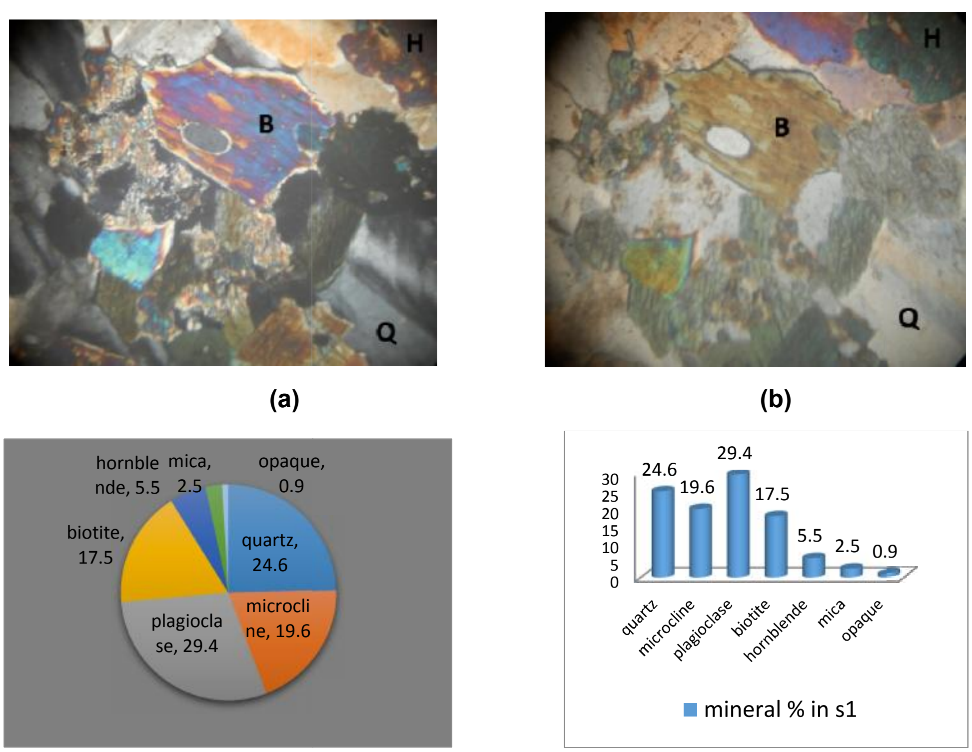
Examples of photomicrographs and associated statistical analyses from petrographic studies are shown in Figs. 12 to 14. The rocks were observed under plane polarized (PPL) and cross polarized light (XPL), where percentage compositions were visually estimated. Some of the constituent minerals as identified in thin sections are also indicated. The average modal analysis of the analyzed rock samples as observed in thin sections are summarized in Table 1. From Fig. 12, estimated mineral assemblages in the sample range from plagioclase with the highest concentration of 29.4%, followed by quartz 24.6%, microcline 19.6%, biotite 17.5%, hornblende 5.5%, mica 2.5%, and opaque minerals 0.9%. Fig. 13 shows that, for Sample 2, the estimated mineral assemblages range from microcline with the highest percent concentration of 41.5%, followed by plagioclase 26.5%, quartz 24.4%, biotite 6.7%, and opaque minerals 0.9%, with absence of hornblende and mica. For the representative Sample 3 (Fig. 14), the mineral assemblages range from plagioclase with the highest percent concentration of 31.8%, followed by quartz 22.7%, microcline 22.6%, biotite 14.7%, hornblende 7.4% and mica 0.85%, with absence of opaque minerals. Generally, as shown in Table 1, predominant minerals are quartz, microcline, plagioclase and biotite, which have relatively higher concentrations in the analyzed samples in thin sections, whereas hornblende, mica and opaque minerals have relatively low concentrations.

Beyond mineralogical compositions, the structural orientations of the minerals are very well noticeable in thin sections, which could be attributed to strain-induced elongation of minerals as a result of deformational processes that have impacted the rocks. This is analogous to preferred orientations of macro-structural features as analyzed using the rose diagrams (Fig. 11). In Fig. 12 (a and b), it could be observed that biotite and quartz are preferentially elongated relative to other minerals in thin sections. Also, in Fig. 13 (a and b), whereas microcline shows lateral orientations; biotite exhibits a cross-cutting relationship relative to microcline and other constituent minerals. Similar cross-cutting orientations are observed for plagioclase and microcline in Fig. 14 (a and b).



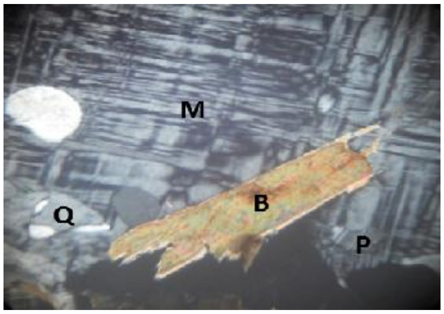
(a) **(b)** **(c)**

Fig. 11. Rose diagrams showing plotted trending directions for some of the measured structural elements from the field study (a) Pegmatitic veins (b) Quartz veins (c) Joints

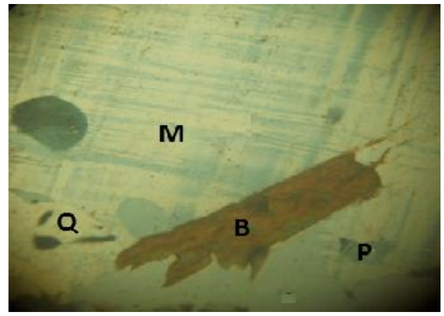


(a) **(b)** **(c)** **(d)**

Fig. 12. Results of photomicrograph studies under plane polarized light (PPL) and cross polarized light (XPL) for Sample 1: (a) Thin section under PPL (b) Thin section under XPL (c) Percentage mineralogical composition - pie chart (d) Percentage mineral composition – bar chart. Note: B = biotite, and Q = quartz



a.



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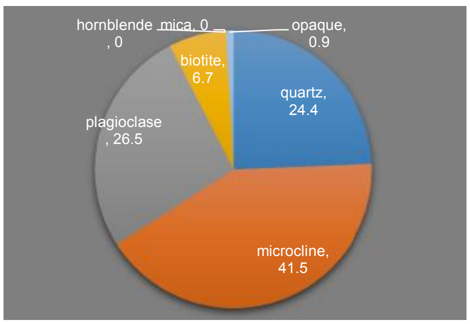

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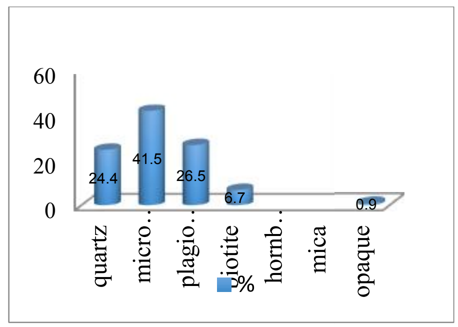


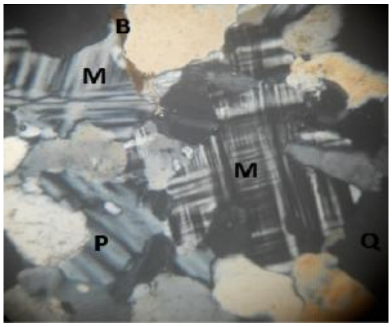
(d)

Fig. 13. Results of photomicrograph studies under plane polarized light (PPL) and cross polarized light (XPL) for Sample 2: (a) Thin section under PPL (b) Thin section under XPL (c) Percentage mineralogical composition - pie chart (d) Percentage mineral composition – bar chart. Note: B = biotite, Q = quartz, M = muscovite and P = plagioclase

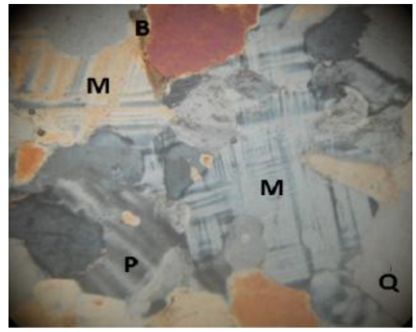
5. DISCUSSION

A good understanding of the lithological distributions and structural patterns in the Nigerian Basement Complex is critical to the understanding of the tectonic evolution of this part of Pan-African terrain. The field mapping as well as petrographic analysis has helped to better understand the geology of the study area. The field study reveals that most of the outcrops are massive with colour ranging from leucrocratic to melanocratic. The texture ranges from medium to coarse grained and medium to fine grained granitic rocks. The outcrops are relatively low-lying, undulating to massive rocks, and highly weathered in many cases, where physical, chemical, and biological weathering, were observed. According to [12,17], the problem associated with mapping structural fabrics, especially the fracture patterns in the Nigerian Basement Complex, includes poor exposure and masking by surface weathering processes. However, significant numbers of fresh and un-weathered outcrops with mappable structural features were encountered during the field survey and formed the bases for the present analyses, inferences and interpretations.

The major rock types in the area namely syenite, migmatite-gneiss and porphyroblastic gneiss, mica schist, banded gneiss and biotite hornblende gneiss, are all typical Basement Complex rocks with mineralogical and structural characteristics indicative of polycyclic metamorphism as reported by previous authors [1,2,17,18]. The mineral assemblages show complex mixture of both leucocratic and melanocratic minerals, with abundant foliation and lineation, which suggest that the rocks have been subjected to several metamorphic and deformational events [1,5,6]. As stated by [1], the Nigerian Basement Complex was partly a result of at least four major orogenic cycles of deformation, metamorphism, and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan African cycles (600 Ma), and occupies reactivated region, which resulted from plate collision between the passive continental margin of the West African craton and the active



(a)



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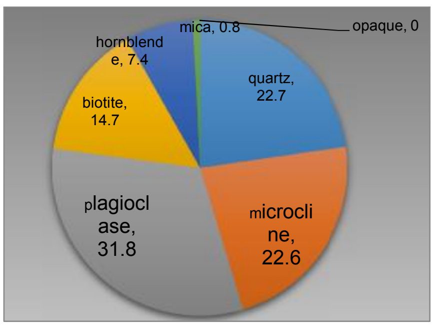

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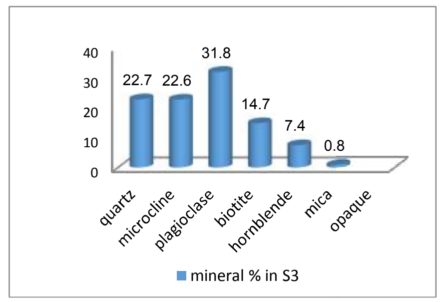

(d)

Fig. 14. Results of photomicrograph studies under plane polarized light (PPL) and cross polarized light (XPL) for Sample 3: (a) Thin section under PPL (b) Thin section under XPL (c) Percentage mineralogical composition - pie chart (d) Percentage mineral composition – bar chart. Note: where B = biotite, Q = quartz, M = muscovite and P = plagioclase)

Table 1. Average modal analyses of the rock samples in thin section

Sample no	Quartz	Microcline	Plagioclase	Biotite	Hornblende	Mica	Opaque
S1	24.6	19.6	29.4	17.5	5.5	2.5	0.9
S2	24.4	41.5	26.5	6.7	--	--	0.9
S3	22.7	22.6	31.8	14.7	7.4	0.8	--
S4	24.3	17.4	31.1	20.6	4.3	1.3	1.0
S5	20.4	21.3	30.5	15.3	10.7	--	1.8
S6	33.5	23.6	33.6	8.4	--	--	0.9
S7	22.3	22.4	29.9	18.9	4.3	1.2	1.0
S8	22.2	29.1	27.4	12.5	5.1	2.9	0.8
S9	25.4	35.0	22.6	12.2	3.1	1.1	0.6
S10	23.2	21.1	23.7	8.6	2.4	21.0	--
S11	23.1	20.1	40.3	12.5	2.1	1.1	0.8
S12	23.6	35.2	29.2	9.9	--	2.1	--
S13	29.4	19.3	28.2	13.7	8.6	--	0.8
S14	24.2	23.1	36.3	8.7	2.5	3.2	2.0
S15	21.8	23.2	40.5	10.4	3.3	--	0.8

Pharusian continental margin. Thus, the observed metamorphic and structural features are complex effects and interrelationships of these events. Tying structural patterns to particular episodes of deformation has been difficult in nearly all the basement exposures in Nigeria [1,10]. Nevertheless, cogenetic relationships as were observed for some of the joints shows that some joint sets could have resulted from similar or same tectonic events in the area.

Structural elements in the study area include those formed due to ductile deformation (such as foliations and folds) and brittle deformation (such as joints, fracture and faults). These deformation processes are also related to preferred orientations of minerals in rocks in the study area. According to [19] a good analysis of orientations of minerals could be used to interpret deformation history and structures in rocks [19]. For example, if the ductile and brittle deformations in rock are pervasive, some of the minerals, especially the uniaxial ones like quartz and biotite, would show elongation [19]. These mineral orientations may be visible in rock exposures (Figs. 3 to 10) as well as at microscopic scales (Figs. 12 to 14). Thus, elongation of minerals as observed from petrographic study (Figs. 12 to 14), could be attributed to deformation that is related to structures such as microfolding in some of the outcrops [19]. For the analyses of field-measured orientation data for the macro-structural features using the rose diagram, the observed various dominant trending directions are attributable to multiphase deformational episodes in the area. According to [10,12], the structural and tectonic framework of the Nigerian Basement Complex comprise of NE-SW and NW-SE lineaments superimposed over a dominant N-S trend. Also, based on analyses of various structural trends in some parts of basement complex of Nigeria, [16] concluded, among others, that an overprinting by a set of NE-SW fracture trend could have been cut obliquely by an E-W sinistral shearing. Thus, the result of the present study is in line with previous work. The dominant orientation of veins in the study area, based on structural measurements and analyses using rose diagram, have been found to be in the NE-SW and NW-SE directions, whereas the strike of the joints trends predominantly N-S and E-W. These multiple structural orientations, consistent with previous studies, are interpreted to be analogous to the directions of tectonic events responsible for the metamorphism and/or fracturing of basement rocks in the region.

6. CONCLUSION

The present petrographic and structural studies have helped to better understand the geology of the study area. The major rock types in the area are typical Basement Complex rocks with mineralogical and structural characteristics indicative of polyphase deformation and polycyclic metamorphism. The structural features are measured to be trending in different directions, but the dominant structural trends are NE-SW and NW-SE for the veins, and approximately N-S and E-W directions for the joints. The structural trends have been interpreted to be analogous to the directions of tectonic events responsible for the metamorphism and/or fracturing of rocks in the region. Beyond better understanding of geology and tectonic history of the study area, the results of this study have important economic implications as elucidating mineralogical and structural features is useful in mineral and water exploration programs. Also, although not the focus of this study, the pegmatite of the study area could be a host for precious rocks and gemstones such as tourmaline, aquamarine, and quartz, which could be source materials for jewelries and ornaments. In addition, extensive occurrence of laterites as observed during the field study shows that they can be exploited as good sub-base materials for engineering construction. Finally, study of joints and fracture patterns, which if complimented with geophysical investigations, can unravel the mystery behind minor tremors being experienced in recent times in Shaki and its environments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Obaje NG. Geology and mineral resources of Nigeria. Lecture Notes in Earth Sciences. Springer, New York (NY); 2009.
2. Oyawoye MO. The geology of the basement complex. J. Nigeria Mining, Geology and Metallurgy. 1964;1:87-102.
3. Megwara VI, Egesi N. Petrology and structural geology of Lankpeshi area of igarra schist belt, Southwestern Nigeria. J. Geography, Environment and Earth Science. 2017;11(2):1-15.
4. Abudulawal L, Amidu SA, Apanpa KA, Adeagbo OA, Akinbiyi OA. Geophysical investigation of subsurface water of erunmu and its environs, Southwestern Nigeria using electrical resistivity method. J. Appl. Sc. 2015;15:741-751.
DOI: 10.3923/jas.
5. Abudulawal L, Amidu SA, Adeagbo OA, Adejumo SA. Overburden thickness and potential tonnage estimate of Olode Gbayo

pegmatite deposits, Southwestern Nigeria, using electrical resistivity method. J. Geography, Environment and Earth Science International. 2017;10(2):1-12.
6. Okunlola OA, Ogedengbe O. Investment potential of gemstone occurrences in southwestern Nigeria. In: Eluze AA, editor. Prospect for Investment in Mineral Resources of Southwestern Nigeria. Nigerian Mining and Geosciences Society; 1990.
7. Odeyemi IB. Late-Proterozoic metaconglomerates in the schist belt of Nigeria: Origin and tectonostratigraphic significance. J. Technoscience. 1977;3:56-60.
8. Grant NK. Structural distinction between a metasedimentary cover and an underlying basement in the 600 m.y. old Pan African domain of Northwestern Nigeria, West Africa. Geological Society of American Bulletin, 1878;89:50-58.
9. Oyawoye MO. The Basement complex of Nigeria. In Dessauvagie TFJ, Whiteman A.J. (eds) African Geology. Ibadan University Press; 1972.
10. Rahaman MA. Review of the basement geology of South-western Nigeria. In: Kogbe CA, editor. Geology of Nigeria, 2nd ed. Lagos: Elizabethan Publishers; 1976.
11. Oluyide PO. Structural trends in the Nigerian basement complex, In: Oluyide PO, Nwajide CS, Oni AO. (ed.) The Geology of the Ilorin Area. Nigerian Geological Survey Bulletin. 1988;42:84.
12. Olasehinde PI. Elucidating fracture patterns of the Nigerian Basement Complex using electrical resistivity methods. Z. Angew. Geowiss. 1989;8:109-120.
13. Olasehinde PI, Pal PC, Annor AE. Aeromagnetic anomalies and structural lineaments in the Nigerian Basement Complex. J. Afr. Earth Sci. 1990;11:3 and 1990;4:351-355.
14. Annor AE, Olasehinde PI, Pal PC. Basement fracture patterns in the control of water channels – An example from central Nigeria. J. Min. Geol. 1990;26(1):5-12.
15. Annor AE, Freeth SJ. Thermotectonic evolution of the basement complex around Okene, Nigeria, with special reference to deformation mechanism. Precamb. Res. 1985;28:269-281.
16. Rahaman MA, Recent advances in the study of the basement complex of Nigeria. Precamb. Geology of Nigeria, Geol. Surv. Nig. Publ. 1988;11-43.
17. Goki NG, Amadi AN, Olasehinde PI, Dada SS, Ikpokonte EA. Adekeye JID. Appraising the structural geology of Kakuri Sheet 144: Implications for the tectonic evolution of the basement complex. J. Engineering and Technology Research. 2011;3(2):26-36.
Available:http://www.academicjournals.org/JETR.
18. Ball E. An example of very consistent brittle deformation over a wide intra-continental area, the late Pan African fracture system of the Taureg and Nigerian shield. Tectonophysics. 1980;61:363-379.
19. Gokhale NW. Theory of structural Geology. CBS Publishers. Daryaganj, New Delhi; 2001.

APPENDICES

Appendix 1. Nature, colour, and texture of outcrops, as well as weathering and vegetation types in the study area

S/N	Sample location	Nature	Colour	Texture	Weathering	Vegetation
1	L1	Low lying & undulating	Mesocratic	Medium-fine	Physical, Biological, and Chemical	Thick vegetation
2	L2	Low lying & Undulating	Mesocratic	Medium-coarse grained	Chemical and physical	No vegetation
3	L3	Massive	Mesocratic	Medium-coarse grained	Physical, Biological, and Chemical	Sparse vegetation
4	L4	Low lying	Mesocratic	Medium-coarse grained	Physical and Biological	
5	L5	Low lying	Mesocratic	Medium-coarse grained	Physical and Biological	No vegetation
6	L6	Massive	Mesocratic	Coarse grained	Physical, Biological, and Chemical	Sparse vegetation
7	L7	Sprawling	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
8	L8	Massive	Mesocratic	Medium-Fine grained	Physical, Biological, and Chemical	Thick vegetation
9	L9	Low lying	Leucrocratic	Medium-fine grained	Physical, Biological, and Chemical	No vegetation
10	L10	Low lying	Leucrocratic	Medium-fine grained	Physical, Biological, and Chemical	Sparse vegetation
11	L11	Low lying	Melanocratic	Medium-fine grained	Physical and Chemical	No vegetation
12	L12	Low lying			Physical, Biological, and Chemical	Sparse vegetation
13	L13	Low lying & undulating	Leucrocratic	Medium-coarse	Physical and Biological	No vegetation
14	L14	Low lying	Mesocratic	Medium-fine	Physical, Biological, and Chemical	Sparse Vegetation
15	L15	Massive	Mesocratic	Medium-fine	Physical, Biological, and Chemical	Sparse vegetation
16	L16	Massive	Leucrocratic	Coarse grained	Physical, Biological, and Chemical	Sparse vegetation
17	L17	Massive	Mesocratic	Medium-coarse	Physical, Biological, and Chemical	Sparse vegetation
18	L18	Massive	Mesocratic		Chemical &physical	
19	L19	Massive	Mafic	Medium-coarse	Physical, Biological, and Chemical	Sparse vegetation
20	L20	Massive	Mesocratic	Medium – coarse	Physical, Biological, and Chemical	Sparse vegetation

21	L21	Massive	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
22	L22	Massive	Mesocratic	Medium-coarse grained	Physical, Biological, and Chemical	Sparse vegetation
23	L23	Massive	Melanocratic	Medium-fine grained	Physical, Biological, and Chemical	Thick vegetation
24	L24	Low lying	Leucrocratic	Fine grained	Physical, Biological, and Chemical	Thick vegetation
25	L25	Low lying	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
26	L26	Massive	Leucrocratic	Coarse grained	Physical, Biological, and Chemical	Sparse vegetation
27	L27	Low lying	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
28	L28	Low lying	Leucrocratic	Medium-fine	Physical and chemical	No vegetation
29	L29	Low lying	Leucrocratic	Medium-fine	Physical and Chemical	No vegetation
30	L30	Low lying & undulating	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
31	L31	Low lying	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick Vegetation
32	L32	Low lying	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
33	L33	Low lying& undulating	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Sparse vegetation
34	L34	Low lying	Melanocratic	Medium-fine	Physical and chemical	No vegetation
35	L35	Low lying	Leucrocratic	Coarse	Physical, Biological, and Chemical	Sparsely vegetation
36	L36	Low lying	Leucrocratic	Coarse	Physical, Biological, and Chemical	Sparse vegetation
37	L37	Massive	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation
38	L38	Massive	Leucrocratic	Medium-coarse	Physical, Biological, and Chemical	Thick vegetation

Appendix 2. Sample locations with summary of observed structural features and mineralogy

S/N	Location	Coordinate	Lithology	Features	Mineralogy
1	L1	N08º37'999'' E003º24'243''	Granitic	Fracture, joint	Biotite, quartz, felspar
2	L2	N08º39'400'' E003º23'244''	Granitic	Quartzofeldspatic vein, fracture, cross joint.	Biotite, quartz, feldspar,
3	L3	N08º39'544'' E003º23'651''	Granitic	Quartzofeldspartic vein, solution Hallo,fracture, joint, fault.	Biotite, quartz, Feldspar
4	L4	N08º40'067'' E003º23'195''	Pegmatite	Quartz vein,	Feldspar, quartz

5	L5	N08°40’147’’ E003°23’007’’	Granitic	Vein, fracture, joint	Biotite, quartz, Feldspar, muscovite
6	L6	N08°39’896’’ E003°22’978’’	Granitic	Cross Vein, Joint, solution Hallo, fault, Foliation	Biotite, quartz, Feldspar, muscovite
7	L7	N08°36’803’’ E003°24’663’’	Syenite	Joint, Fracture.	Muscivite, biotite, feldspar, quartz.
8	L8	N08°35’864’’ E003°24’123’’	Syenite	Vein, Joint, fracture.	Quartz,Feldspar, Biotite,
9	L9	N08°30’219’’ E003°25’113’’	Syenite	Cross joint, Solution Hallo, fault	Muscivite, biotite, feldspar, quartz.
10	L10	N08°30’511’’ E003°23’521’’	Syenite	Joint, fracture, cross vein, fault	Quartz, Feldspar, Biotite
11	L11	N08°31’777’’ E003°21’534’’	Augen gneiss	Fracture	Quartz, Feldspar
12	L12	N08°32’433’’ E003°30’743’’	Regolith	Quartz vein	Feldspar, Quartz
13	L13	N08°32’482’’ E003°20’249’’	Granitic	Fracture, fault, Vein, Solution Hallo, Fold	Quartz, Feldspar, Biotite, muscovite
14	L14	N08°32’031’’	Granite gneiss	Solution Hallo, Joint, Fracture	Quartz, Feldspar, Biotite, muscovite
15	L15	N08°33’246’’ E003°26’563’’	Pegmatite	Joint, Quartzofeldspartic Vein,	Quartz, Feldspar, Muscovite
16	L16	N08°33’409’’	Syenite	Solution Hallo, Joint, fracture,	Quartz, Feldspar, Biotite, muscovite
17	L17	N08°40’126’’ E003°22’473	Granitic	Quartzofeldspartic vein, fracture, fault,	Quartz, Biotite, Feldspar, muscovite
18	L18	N08°40’565’’ E003°22’445’’	Granitic	Joint, fracture, Solution Hallo	Quartz, feldspar, biotite, muscovite
19	L19	N08°40’604’’ E003°22’407’’	Biotite-hornblend Gneiss	Cross joint,	Hornblend, Biotite, Quartz, Feldspar
20	L20	N08°40’918’’ E003°22’343’’	Granite Gneiss	Cross Quartzofeldspartic vein, Solution Hallo, fracture, joint, fault	Quartz, biotite, Feldspar, muscovite
21	L21	N08^{0}41’140’’ E003°22’438’’	Granitic		
22	L22	N08°39’416’’ E003°23’121’’	Granitic rock	Fault, Fracture, Vein, joint	Quartz, Biotite, Feldspar, muscovite
23	L23	N08°38’743’’ E003°23’539’’	Granitic rock	Quartzofeldspartic vein, fracture	Quartz, Biotite, Feldspar, muscovite
24	L24	N08°36’133’’ E003°21’736’’	Banded Gneiss	Fracture	Quartz, Biotite, Feldspar, muscovite
25	L25	N08°34’114’’ E003°20’914’’	Muscovite schist	Solution Hallo,	Muscovite, Quartz, Feldspar

26	L26	N08°33'094" E003°20'314"	Granitic rock	Joint, fracture	Quartz, Feldspar, Biotite, Muscovite
27	L27	N08°34'317" E003°28'144"	Syenite	Fracture, cross joint, exfoliation	Quartz, Feldspar, Biotite
28	L28	N08°35'117" E003°29'861"	Syenite	Solution Hallo, joint, fracture	Quartz, Biotite, Feldspar,
29	L29	N08°35'407 E003°29'895"	Syenite	Vein, Fracture, Joint, Fault, Solution Hallo, exfoliation	Quartz, Biotite, Feldspar
30	L30	N08°36'792" E003°27'591"	Syenite	Solution Hallo, cross vein, fracture, joint	Quartz, Feldspar, Biotite
31	L31	N08°39'411" E003°26'799"	Syenite	Joint, Fracture	Quartz, Biotite, Feldspar,
32	L32	N08°38'111" E003°25'964	Syenite	Fracture, Vein, joint	Quartz, Biotite, Feldspar,
33	L33	N08°38'881" E003°24'820"	Granitic rock	Quartzofeldspartic vein, joint,fracture	Quartz, Biotite, Feldspar, muscovite
34	L34	N08°39'849" E003°23'971"	Migmatite	Quartzofeldspartic vein, fold	Quartz , Feldspar, Muscovite
35	L35	N08°41'240" E003°27'275"	Pegmatite		Feldspar, Quartz
36	L36	N08°41'162" E003°27'839"	Granitic rock	Solution Hallo, vein	Quartz, Biotite, Feldspar, muscovite
37	L37	N08°34'611" E003°24'185"	Granite gneiss	Quartzofeldspartic vein, fracture	Muscivite, biotite, feldspar, quartz.
38	L38	N08°41'036 E003°25'528"	Granitic rock	Vein, Fracture, Fault, Joint	Muscivite, biotite, feldspar, quartz.

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