Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Integrated Geological Mineralogical and Geophysical Characterisation of the Efon Alaaye Basement Terrain in Southwestern Nigeria for Slope Stability and Infrastructure Development

Hammed Adeshina Hamzat

shinnourspeak007@gmail.com

Federal University Oye Ekiti

Joshua Tunbosun Akinwamide

Federal University Oye Ekiti

Research Article

Keywords: Basement Complex, Efon Alaaye, engineering geology, slope stability, XRF, XRD, groundwater, geophysics, southwestern Nigeria

Posted Date: November 5th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11233237/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Efon Alaaye, Ekiti State in southwestern Nigeria, is located within the Precambrian Basement Complex with features of rugged topography, heterogeneous crystalline rocks with variable weathering profiles. This study combines geological mapping, structural measurements, slope assessment, natural-electric-field/electromagnetic reconnaissance survey, X-ray fluorescence (XRF) and X-ray diffraction (XRD) to define the geology of the materials and its implications for slope stability, groundwater occurrence and infrastructure development. Based on field observations granite, quartzite, schist, laterite and minor pegmatite were picked out; and the discontinuities were mainly NW-SE and NE-SW. Five slope traverses were recorded on an inclination range of 25–42°, the maximum slope inclination is 42° and this slope inclination is the greatest recon level concern due to steepness, fracturing and erosion susceptibility. The results of XRF analyses are extremely silica-rich, from 97.12 to 98.44 wt. % SiO_2, with the other major oxides present at very low levels. The diffractograms shown here indicate that quartz reflections are significant in all three samples. Reconnaissance geophysical interpretation delineates surficial material, clayey/weathered horizons, partly fractured basement and deeper basement crystalline, it can be seen that engineering behaviour is controlled by combined effects of lithology, discontinuity geometry, weathering, groundwater and slope morphology. Steep, fractured, deeply weathered and seepage prone areas should be assessed geotechnically and properly drained, and development should be avoided on these areas.Gently sloping ground with a good drainage capacity underlain by verified competent material is preferable for development, while the steep, fractured, deeply weathered and seepage prone areas require detailed geotechnical assessment and drainage control.

1. Introduction

The crystalline Basement Complex terrains pose unique problems for engineering development and for groundwater prospecting, due to the possibility of rapid changes in properties over short distances. The competent crystalline rock can be found in close proximity to the deeply weathered, fractured or clayey material, and apparently good outcrops can be weak with unfavorable orientation of joints, foliation or faulting. The characterisation of rocks is therefore more complex than it is if it is based solely on rock type, and involves the integration of lithology, weathering, structural geology, geomorphology and the groundwater conditions (Bell, 2007; Dearman, 1991; Bieniawski, 1989). The Nigerian Basement Complex is part of Pan-African mobile belt to the east of the West Africa Craton. It comprises older migmatite-gneiss complexes, metasedimentary and metavolcanic sequences related to schist belts, and granitoid intrusions that represent various stages of the crustal evolution and Pan-African tectonothermal reworking (Ajibade, 1987; Rahaman, 1988; Obaje, 2009). Gneissic, schistose, quartzitic and granitic assemblages are common in the southwest of Nigeria and the Ilesha region is a significant lithological analogue to that found around Efon Alaaye (Dada et al., 1998). Aeromagnetic surveys undertaken in the region by the authors have revealed strong NE-SW and NW-SE structural lineaments on top of an older north-south structural grain (Olasehinde et al., 1990). They are of direct engineering interest, as conditions of rock mass behaviour are influenced by the orientation, spacing, persistence, roughness and infilling of discontinuities, and by groundwater conditions (ISRM, 1978; Bieniawski, 1989). On natural

slopes and excavated slopes, persistent planes or intersecting joint sets can give rise to planar, wedge or block failures (Wyllie & Mah, 2004; Hoek et al., 2002). The occurrence of groundwater in crystalline basement terrains is also in great contrast to the majority of occurrence in fresh rock, being largely in secondary porosity of weathered and fractured rock. Local geology, overburden weathering, fractured basement and integrated geophysical interpretation have proven to be important factors in groundwater exploration in southwestern Nigeria (Ajayi & Adegoke-Anthony, 1988, Abiola et al., 2009, Bayewu et al., 2017, Oyedele, 2019). Efon Alaaye is a proper location for an integrated engineering-geological investigation. The data available in the field is for granite, quartzite, schist, laterite, pegmatite, steep terrain and structural discontinuities, seepage zones, and contrasting weathering. The present paper therefore combines the geological mapping, slope and discontinuity observations, XRF/XRD data and reconnaissance geophysical information to evaluate the geological control on slope stability, groundwater occurrence and even infrastructure development.

1.1 Aim and objectives

This study aims to establish an integrated geological and engineering interpretation of Efon Alaaye by examining its lithological and mineralogical characteristics, structural framework, subsurface conditions and slope behaviour, and by relating these findings to infrastructure planning and groundwater development.

1. Characterise the principal lithological units and their geomorphological expression.

2. Assess major- and trace-element composition and evaluate the mineralogical information supplied by XRD.

3. Describe discontinuity characteristics and their implications for rock-mass behaviour.

4. Evaluate slope geometry and identify plausible instability mechanisms.

5. Interpret the reconnaissance geophysical data in terms of weathered, fractured and competent basement domains.

6. Integrate the findings to identify implications for foundations, roads, drainage, groundwater and settlement planning, while clearly identifying uncertainties that require further verification.

2. Literature Review

2.2 Geological setting of southwestern Nigeria

Prior to the Pan-African orogeny, the Nigerian Basement Complex is polycyclic with Archean and Proterozoic components of the crust being recorded. Ajibade (1987) documented the role of the pan-African reworking during the development of western Nigeria while Rahaman (1988) compiled the main relationships between migmatite-gneiss complexes, metasedimentary sequences and granitoid

intrusions. These units are also placed in a general context of the geological characteristics of Nigeria and the resources of minerals found in the country by Obaje (2009). The Ilesha-Ife area of SW Nigeria has later intrusive and deformational events, and it contains banded and granite gneisses, schists and metasedimentary quartz rich rocks (Dada et al., 1998). The quartzite, schist and granite found at Efon Alaaye therefore, have regional consistency. The importance of structural interpretation can also be noted as NE - SW and NW - SE lineaments are recognised at the regional scale (Olasehinde et al., 1990) which gives a tectonic context to the discontinuity trends seen in the present study.

2.2 Tropical weathering, laterite and engineering behaviour

Thick profiles of humid tropical weathering of crystalline basement rocks may form, including lateritic soil, saprolite, weathered rock and increasingly fresh bedrock. They are governed by their engineering behaviour which depends on the nature of parent material, degree of weathering, alteration of minerals, moisture state and fabric. Gidigasu (1976) has shown that appearance is not a reliable indicator of the physical and mechanical properties of lateritic materials, due to significant variation in these properties with pedogenic and geological history. Engineering – Geological viewpoints: The difference between the competence of the rock mass and the strength of the intact rock is basic. Fresh granite or quartzite can be strong in hand specimen, but structurally weak due to the presence of persistent and closely-spaced or unfavorable dip joints. On the other hand, weathered schist and lateritic materials can be significantly weaker and weaker to water. As a result, the site investigation must also include a description of the weathering, groundwater, and discontinuities as well as lithology (Dearman, 1991; Bell, 2007).

2.3 Structural controls on slope stability

According to ISRM (1978), the essential parameters to describe the structure of rock masses are orientation, spacing, persistence, roughness, aperture, infilling, seepage, and number of discontinuity sets. All these variables, either directly or indirectly, enter into popular rock-mass classification and engineering assessment methods (Bieniawski, 1989). Failure along joints in a jointed rock is frequently structurally controlled. A persistent plane that dips towards and daylights in a slope may allow for planar sliding and the intersection of two sets of joints may allow for wedges that are able to slide from the face. Steep joints separating unstable blocks can result in block release and rock fall. The shear resistance can be further decreased by weathering and/or the water pressures can increase, both of which will destabilise the slope (Wyllie & Mah, 2004; Hoek et al., 2002).

2.4 Basement groundwater and geophysical investigation

Groundwater occurrence is most likely to be associated with weathered regolith, joints, faults and fractured parts of the bedrock, as the fresh crystalline basement contains very little primary pore space. The impact of local geology on the productivity of borehole has been established by Ajayi and Adegoke Anthony (1988) in the south west of Nigeria. Ado-Ekiti, Abiola et al. (2009) mapped topsoil, weathered material and partially weathered/fractured basement over resistive bedrock, demonstrating the significant variability in vertical and lateral basement terrain at Ado-Ekiti. A combination of integrated

electromagnetic, resistivity and GIS techniques can enhance groundwater targeting using both structural and weathering, topographic and drainage information. The electromagnetic reconnaissance and resistivity sounding was demonstrated by Bayewu et al. (2017) and the lineament, slope, drainage and geomorphological data around Ado-Ekiti was combined by Oyedele (2019). However, geophysical responses are not unique as many situations can yield the same signature due to clay, saturation, weathering and mineralisation. Hence, the interpretation should be matched up to geological observations, boreholes or other independent controls (Telford et al., 1990; Kearey et al., 2002; Reynolds, 2011).

2.5 XRF and XRD in geological characterisation

Geological evidence is complementary for XRF and XRD. XRF is used for bulk elemental and oxide composition, including some trace elements, while XRD is used for crystalline phase detection by utilizing diffraction properties. The former dictates the mineral assemblage that can be found and the latter gives mineral-specific evidence. The interpretation of clay-bearing materials is complicated, especially for materials which show peak overlap, preferred orientation and mixed assemblages (Brindley & Brown, 1980). Thus, the interpretation of the XRF and XRD should be consistent between themselves, and the qualitative peak identification at the higher abundance levels should not be used to achieve a precise mineral abundance where the bulk chemistry indicates otherwise. When accurate phase proportions are needed, quantitative XRD (including Rietveld refinement as appropriate) is preferred.

3. Study Area

3.1 Location and accessibility

Efon Alaaye is situated in the Southwest part of Nigeria, in the state of Ekiti. The field data used translates the study area to be at a latitude of 7°65'56.9"N, and a longitude of 4°92'13.5"E. Access to the town is possible via regional road access towards Ilesa, Aramoko and Ado-Ekiti and local field access is limited by steep slopes, rocky outcrops, seepage zones and clayey ground (Integrated Geological, Geotechnical and Geophysical Survey Report, 2026).

3.2 Regional and local geological setting

Efon Alaaye is part of the Precambrian Basement Complex of the southwestern part of Nigeria. Mapped lithologies are granite, quartzite, schist, laterite and minor pegmatite. The resistant quartzite and relatively fresh granite are correlated with high relief areas, whereas the weathered schist and lateritic are more prone to degradation and erosion. The structural fabric also influences topography, groundwater flowlines and engineering behavior of the rock mass as illustrated in Figure 2.

3.3 Topography, drainage and climate

The topsoil is undulating to hilly with ridges, valleys and rolling slopes. The reported elevations are about 500 - 600 m above sea level. Resistent high ground is created by quartzite and granite ridges and seasonal streams and seepage are in valleys. Drainage is generally dendritic, with a few areas influenced by structure. The field data sets represent a humid tropical climate with bimodal rainfall and an average of 1,200 to 1,500 mm of annual precipitation, which makes the infiltration, runoff, erosion, and seasonal changes in pore-water pressure significant factors in weathered and fractured slopes as indicated in the three geospatial maps shown in Figure 3.

4. Materials and Methods

4.1 Field materials and geological mapping

The fieldwork involved the use of a compass-clinometer, handheld Global Positioning System (GPS), geological hammer, measuring tapes, field notebook, map case, base maps, masking tape, sample bags and marker pens. Geological mapping was done on 5 traverses. Descriptions of rock types, outcrop conditions, geomorphological setting and weathering characteristics were made and representative samples collected for laboratory analysis. Where exposed, structural features such as joints, fractures, foliation and potential fault-related structures were noted. Strike and dip or discontinuity orientation, as well as spacing, persistence, roughness, infilling and seepage were measured. The rock mass description is presented in the style of well-established rock mass description practice (ISRM, 1978), in which discontinuity characteristics are recorded along with the lithology.

4.2 Slope Assessment

Five traverses were measured, with a measurement of slope angle, approximate height and orientation along each traverse. Reconnaissance interpretation was used to consider persistence of field evidence of erosion, seepage, weathering. The assessment was designed to provide an indication of potentially sensitive slopes and possible failure mechanisms and not to determine a formal factor of safety. Complete datasets of discontinuity dip/dip-direction, material strength parameters and groundwater data would be needed for detailed kinematic or limit-equilibrium analysis.

4.3 X-ray fluorescence analysis

The representative rock samples were first air dried and gently disaggregated to remove aggregates. The samples were pulverised in tungsten-carbide mill to obtain a homogeneous fine powder, generally passing through a 75 µm sieve. Where required the powdered samples were oven-dried and then placed in clean and labelled containers for analysis. An X-ray fluorescence spectrometer (XRF) was used to measure the concentrations of major and selected trace elements. A weighed amount of the homogenised powder was made into either a fused glass bead, as appropriate to the analytical needs and range of elements. The prepared specimen was subjected to X-ray bombardment with the primary radiation from the X-ray tube during analysis. The spectrometer was used to measure the resulting characteristic secondary X-rays that are emitted by the constituent elements. The measured intensities

were used to determine the elemental concentration based on the calibration curve of the instrument, which were determined by using certified reference materials. Analytical drift was monitored by conducting replicate analyses on some samples and using reference materials and blanks to monitor for analytical precision. The results were expressed as weight percentages (wt.%) for major oxides, and in mg/kg (ppm) for trace elements as appropriate. The most frequent elements analysed were Si, Al, Fe, Ti, Mn, Ca, Mg, Na, K and P, and expressed as oxides (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MnO, CaO, MgO, Na_2O, K_2O and P_2O_5).

4.4 X-ray diffraction analysis

X-ray diffraction (XRD) was used for mineralogical identification. Samples were first dried and then finely powdered with care to ensure a uniform sample. Special attention was given to avoid undue grinding, resulting in a broadening or a structural change of diffraction peaks. This powdered material was placed on a low background sample holder and leveled for a relatively flat and randomly oriented surface. An X-ray Diffractometer with Cu-Kα radiation source was used to analyse the prepared samples. The diffracted X-rays were recorded within a suitable 2θ angular range, typically 5–70° 2θ to identify minerals, at suitable step interval and counting time. The instrumental conditions such as tube voltage, current, scan rate and step size were kept the same for all the samples.The diffraction patterns received were processed by detection of positions and relative intensities of characteristic diffraction peaks. The mineral phases were identified by matching the diffraction pattern obtained to the standard reference patterns from an appropriate crystallographic database, e.g. the International Centre for Diffraction Data (ICDD) database. Evaluation of diagnostic reflections and known mineral chemistry was used as an aid to peak matching where necessary. The interpretation approach is similar to the one outlined by Brindley and Brown (1980).

4.5 Reconnaissance geophysical survey

The lateral and vertical changes in subsurface electrical response were explored with a PQWT-TC150 natural-electric-field/frequency-selection instrument on the study traverses. The top material, the clayey/weathered zones, the partly fractured/weathered basement and the comparatively fresh basement were broadly distinguished in the field. Natural-electric-field (NEF) and electromagnetic (NEM) responses can be non-unique, and so are herein considered as reconnaissance evidence that needs to be calibrated rather than as direct evidence of lithology or groundwater occurrence, as per Telford et al. (1990) and Kearey et al. (2002) and Reynolds (2011).

5. Results and Discussion

5.1 Lithology, geomorphology and engineering significance

These were defined as five major lithological or surficial units namely granite, quartzite, schist, laterite and pegmatite in the field. Granite is mainly coarse-grained and massive with locally developed fractures. Quartzite has high intact competence despite the locally persistent joints, and it forms ridges

that are resistant. Schist is a foliated rock and so has strong mechanical anisotropy, while laterite is a cover formed by weathering. Pegmatite is found as relatively resistant bodies that cut the granitic terrain.

Table 1. Summary of lithology, mineralogical interpretation and engineering significance.

Lithology	Field character	Mineralogical interpretation	Engineering significance
Granite	Coarse-grained, light-coloured; generally massive but locally fractured	Quartz-feldspar assemblage expected; subordinate mafic minerals	Potentially competent when fresh; fractures and weathering reduce rock-mass competence
Quartzite	Hard, resistant ridge-forming rock; persistent joints locally	Dominantly quartz	Strong intact rock, but joint-controlled planar, wedge or block failure may occur
Schist	Fine- to medium-grained, foliated; weathered zones present	Quartz- and mica-bearing metamorphic assemblage plausible	Strong anisotropy; foliation may form slip surfaces and weathering may reduce shear resistance
Laterite	Extensive cover on gentler slopes; variable thickness	Fe/Al oxides and clay minerals expected as weathering products	Potential road/fill material only after testing; exposed slopes vulnerable to runoff and erosion
Pegmatite	Minor resistant cross-cutting bodies associated with granite	Coarse quartz-feldspar with possible mica/accessory minerals	Generally strong, but contacts and blockiness can complicate excavation

These units are important for the engineering aspects because of the difference between failure of the intact material and the behaviour of the whole rock mass. The rock mass may be competent, but the presence of persistent joints can significantly affect the stability of the rock mass. In addition to foliation, schist is also affected by planes of weakness (Table 1). The observations confirm the necessity to consider the discontinuity geometry and weathering along with lithological identity (ISRM, 1978; Bieniawski, 1989; Bell, 2007).

5.2 Major and trace-element geochemistry

Silica is predominant in the chemically analysed samples. SiO_2 varies from 97.12 to 98.44 wt.%, with a reported mean of 97.743 wt.%. The concentrations of Al_2O_3, Fe_2O_3, TiO_2, CaO, P_2O_5, K_2O and MgO are relatively low and the relative variations are relatively large for the others—MnO and Na_2O. Loss on ignition ranges from 0.61 to 0.73 wt.%. The bulk chemistry therefore suggests a very quartz-rich composition although no definite lithological or industrial classification is suggested from the chemical data.

Table 2. Major-element oxide composition of Samples A-C (reported as wt.% in the source dataset).

Oxide	Sample A	Sample B	Sample C	Mean	Range
SiO_2	98.44	97.12	97.67	97.743	97.12-98.44
Al_2O_3	0.12	0.30	0.21	0.210	0.12-0.30
Fe_2O_3	0.04	0.05	0.06	0.050	0.04-0.06
TiO_2	0.05	0.03	0.02	0.033	0.02-0.05
CaO	0.03	0.02	0.03	0.027	0.02-0.03
P_2O_5	0.01	0.01	0.01	0.010	0.01-0.01
K_2O	0.02	0.03	0.03	0.027	0.02-0.03
MnO	0.01	0.33	0.31	0.217	0.01-0.33
MgO	0.02	0.03	0.03	0.027	0.02-0.03
Na_2O	0.05	0.50	0.44	0.330	0.05-0.50
LOI	0.61	0.67	0.73	0.670	0.61-0.73

The numerical ranges reported for most of the trace elements are quite small. The three samples have Zr range of 5-7 ppm, Cu range of 7.02-8.00 ppm and Mo at 2 ppm. Cautions should be exercised when drawing conclusions concerning enrichment and/or contamination from these concentrations as they cannot be evaluated without the detection limits, analytical uncertainty and certified quality control information.

Table 3. Trace-element composition of Samples A-C (ppm).

Element	Sample A	Sample B	Sample C	Mean	Range
Ba	0.23	0.72	0.91	0.620	0.23-0.91
Zr	6	5	7	6.000	5-7
Cu	8.00	7.02	8.00	7.673	7.02-8.00
Sn	3	3	4	3.333	3-4
Cr	4	5	5	4.667	4-5
Th	5	6	7	6.000	5-7
Sr	0.01	0.02	0.01	0.013	0.01-0.02
Co	5	4	5	4.667	4-5
Zn	6	8	8	7.333	6-8
U	4	3	3	3.333	3-4
Mo	2	2	2	2.000	2-2
Sb	0.90	0.80	0.73	0.810	0.73-0.90
Ni	5	4	5	4.667	4-5

5.3 Mineralogical characteristics and XRF-XRD consistency

The XRD patterns of all three are characterized by intense reflections from quartz. The qualitative interpretation also recognizes the presence of feldspar, kaolinite and mica group phases in some samples. The description of Sample B as kaolinite-dominated, however, is not immediately consistent with the bulk chemistry reported for it: SiO_2 is 97.12 wt.% while Al_2O_3 is only 0.30 wt.%. The aluminium contribution would be expected to be high as kaolinite is an aluminium-bearing aluminosilicate, but a dominant kaolinite assemblage would not be expected to be accompanied by a corresponding high aluminium contribution.

Based on the available evidence, the analysed materials appear to be predominantly quartz-rich, while the identification of the subsidiary phases should be regarded as tentative until the original XRD files and sample identities have been independently verified. Before making any conclusions about exact mineral proportions or the industrial potential of the kaolin, quantitative XRD analysis using Rietveld refinement should be carried out. This cautious approach is appropriate for mixed mineral and clay-bearing samples, where accurate phase identification and quantification are important (Brindley & Brown, 1980).

5.4 Structural geology and rock-mass character

Field observations indicate that the joints generally occur along NW–SE and NE–SW orientations. Persistent joints were commonly observed in the quartzite, whereas the schist exposures were characterised by smoother discontinuity surfaces. The schist generally showed closely spaced

discontinuities, while the granite and quartzite exhibited relatively wider spacing. The orientations observed in the field are broadly consistent with the regional structural trends reported for the Nigerian Basement Complex by Olasehinde et al. (1990).

Table 4. Structural geology and engineering interpretation of the mapped rock masses.

Parameter	Field observation	Engineering interpretation
Joint spacing	<0.5 m in some schist; >2 m in parts of granite/quartzite	Close spacing produces smaller blocks and lower rock-mass competence; wider spacing favours larger blocks
Orientation	Mainly NW-SE and NE-SW	Failure potential depends on relationship between discontinuity orientation and slope or excavation face
Persistence	Persistent joints reported in quartzite	Long discontinuities may create continuous release surfaces
Roughness	Rougher in granite/pegmatite; smoother in schist	Rough surfaces increase interlock; smooth surfaces generally reduce shear resistance
Infilling	Clay/weathered material in schist/lateritic zones; quartz filling locally in granite	Clay infilling can reduce shear strength and increase water sensitivity

Schist is a rock type that must be considered a special case because the direction of foliation may cause a preferential shearing surface to be exposed on a slope or excavation. Persistent joints in quartzite are also significant; when quartzite is strong and intact, it can create potentially unstable blocks if the joints are favourable in orientation. However, a formal rock-mass classification would require quantitative RQD, discontinuity-condition ratings, and groundwater information, as well as intact-rock strength data (Bieniawski, 1989).

5.5 Slope-stability assessment

There are distinct differences in slope geometry for the five traverses. Traverse 3 records the maximum inclination measured, 42°, which is described as fractured and erosion prone and should, therefore, be given special attention on a reconnaissance basis. Traverses 2 and 5 also warrant additional evaluation due to the presence of relatively steep or high profiles in association with drainage and structural controls.

Table 5. Summary of slope measurements and reconnaissance interpretation.

Traverse	Angle	Height	Direction	Reconnaissance interpretation
1	25°	12 m	NE	Gentle to moderate; comparatively low observed erosion risk
2	38°	20 m	SE	Moderately steep; rainfall- and discontinuity-related instability possible
3	42°	18 m	SW	Steep, fractured and erosion-prone; highest reconnaissance concern
4	30°	15 m	NW	Moderate; reported stable under dry conditions
5	35°	22 m	E	Tall slope; drainage and discontinuity controls important

Potential instability modes are planar sliding (when persistent joints and/or foliation daylight towards the slope face), wedge failure (when a pair of discontinuity sets intersect), block release and/or rock fall in jointed granite and quartzite. In weathered schist, laterite and clay-rich rocks, shallow translational and/or rotational movements can also take place. Water can exacerbate these processes by increasing pore-water pressure, weakening of clay-rich infill and increased surface erosion (Wyllie & Mah, 2004; Hoek et al., 2002). This measured slope angle is not proof that a slope failure will happen. Before any large-scale excavation, a stereographic analysis of prior discontinuity dip and dip-direction measurements should be done in relation to proposed excavation faces for each discontinuity. In addition to the above, quantitative analysis would also demand a representative shear strength and groundwater parameters for soil-like and highly weathered materials.

5.6 Subsurface geophysical interpretation

There are four general sub-surficial domains revealed by the reconnaissance geophysical profiles: near surface material, clayey or weathered zones, partly fractured/weathered basement and relatively fresh basement. This conceptual sequence is supportive of the weathering profiles in the basement of other parts of the southwest region of Nigeria (Abiola et al., 2009; Bayewu et al., 2017).

Table 6. Summary of the reported geophysical traverse interpretations and engineering implications.

Traverse	Reported subsurface pattern	Interpretation	Engineering implication
1	High anomaly ~25-60 m; low anomaly ~10-40 m; gradients ~30-50 m	Competent/altered material at depth; shallow weak/weathered or clay-rich horizons	Critical structures should not rely on shallow weak zones without direct confirmation
2	Competent layers ~30-60 m; fresh basement ~70-150 m	Increasing competence with depth	Any deep-foundation interpretation requires verification
3	Low values ~15-40 m; intermediate ~40-90 m; high values ~90-150 m	Shallow weak/saturated or clayey zone with deeper weathered then fresh basement	Stations in shallow low-value zone require drainage and ground assessment
4	Weak ~1-15 m; partly fractured ~10-40 m; strong ~40-80 m	Strong depth-dependent competence contrast	Foundation depth must be confirmed by direct investigation
5	Strong ~25-30 m; weak ~10-40 m; transition ~30-50 m; deeper hard zone	Alternating competent and weak horizons	Abrupt lateral changes may contribute to differential settlement

One of the significant restrictions is that of differences in the reported depths of competent material. Several tens of metres and, in some places, 90-150 m, is the depth of strong or fresh basement, while a different conclusion in the source dataset assigns competent depth of 1.3-10.5 m. Do not make any amalgamation or averaging of these estimates. There is no resolution to this discrepancy, unless the original profiles are checked and re-processed using borehole, trial pit, conventional resistivity or rock coring, to determine the frequency to depth conversion or to independently process the profiles.

5.7 Groundwater implications

The results of the structural and geophysical work place weathered and fractured zones as the major areas to investigate for groundwater. This is in line with the findings from previous studies conducted in the southwest Nigeria, which linked basement groundwater with weathered regolith and fractured bedrock (Ajayi & Adegoke-Anthony, 1988; Abiola et al., 2009; Bayewu et al., 2017). Oyedele (2019) also showed the potentials of using lineaments, geomorphology, drainage and slope data in groundwater assessment around Ado-Ekiti. A low or conductive geophysical response cannot however be used as evidence for the presence of groundwater as the clay rich weathering may yield a similar response. The overall criteria of borehole targeting should therefore be considered to include structure and weathering thickness, topography, drainage considerations and geophysical evidence that has been calibrated, followed by borehole logs and yield testing.

5.8 Implications for infrastructure and settlement planning

The composite set shows that the suitability of the area for engineering use is significantly different in different parts. Where fracturing is limited, and the orientations of the discontinuities are favourable,

relatively fresh granite and quartzite may form competent foundation materials. Weathered schist, clayey horizons and laterites, on the contrary, can have reduced bearing capacity and moisture sensitivity. Rapid changes from competent rock to highly weathered rock also provide a potential for differential settlement.

- The project-specific geotechnical data should be used to design the foundations, not through assumptions of depth or bearing capacity.
- Roads should be oriented through quartzite and granite with consideration of the discontinuity geometry and lateritic materials should be tested for compaction, CBR and durability prior to use.
- For steep slopes and seepage areas positive surface and subsurface drainage is required and stabilisation (if necessary) should be engineered.
- Settlement expansion should be sited on well drained, well built-up slopes with underlying stable material with a preference, but seeps and deep ridges also in the valley bottom, will be subject to extra controls.

6. Conclusion

Efon Alaaye is a complex terrain of diverse Basement Complex rocks including granite, quartzite, schist, laterite and pegmatite, with varied weathering profiles, landforms and engineering responses. Rock-mass performance cannot be determined from intact-rock strength alone due to NW-SE and NE-SW discontinuities, and persistent quartzite joints and schistose foliation. The measured inclinations of 25° to 42° indicate that some areas will need to be planned with an awareness of structural processes and surface processes. Traverse 3 (42°) is fractured and erosion prone and should be investigated in detail, and Traverses 2 and 5 should be investigated for drainage and discontinuity conditions.

The three samples analysed are all > 97 wt.% SiO_2 and the provided XRD patterns are strongly dominated by the quartz reflections. The reconnaissance geophysical interpretation suggests that the subsurface is complex and is composed of weathered and clayey horizons, fractured basement and deeper competent crystalline rock with depth estimates that remain to be calibrated. The results are all consistent with a site-specific, geology-based development strategy for Efon Alaaye, where the lithology, structure, weathering and groundwater are all taken into account.

Declarations

Funding Declaration

This Research received no Specific grant from any funding agency in the Public, Commercial or Not-for profit sectors.

Authors' Contribution

Hamzat H.A, Conceptualization, Methodology, Investigation, Data Collection, Analysis and Manuscript Preparation.

Joshua T.A, Supervision, Validation, Review and Editing of the Manuscript.

Both Authors Read and Approved the Manuscript.

Ethics, Approval and Consent to Participate

Not Aplicable, This study did not involve Human Perticipant, Human Data or Animals.

Consent to Publish

Not Applicable.

Data Availability

All Data generated or analysed during this study are included in this Published article and Its supplimentary information files)

References

1. Abiola, O., Enikanselu, P. A., & Oladapo, M. I. (2009). Groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, southwestern Nigeria. International Journal of Physical Sciences, 4(3), 120-132. https://doi.org/10.5897/IJPS.9000285
2. Ajayi, O., & Adegoke-Anthony, C. W. (1988). Groundwater prospects in the Basement Complex rocks of southwestern Nigeria. Journal of African Earth Sciences (and the Middle East), 7(1), 227-235. https://doi.org/10.1016/0899-5362(88)90070-X
3. Ajibade, A. C. (1987). Proterozoic crustal development in the Pan-African regime of Nigeria. In A. Kroner (Ed.), Proterozoic lithospheric evolution (Geodynamics Series, Vol. 17, pp. 259-271). American Geophysical Union. https://doi.org/10.1029/GD017p0259
4. Bayewu, O. O., Oloruntola, M. O., Mosuro, G. O., Laniyan, T. A., Ariyo, S. O., & Fatoba, J. O. (2017). Geophysical evaluation of groundwater potential in part of southwestern Basement Complex terrain of Nigeria. Applied Water Science, 7, 4615-4632. https://doi.org/10.1007/s13201-017-0623-4
5. Bell, F. G. (2007). Engineering geology (2nd ed.). Butterworth-Heinemann.
6. Bieniawski, Z. T. (1989). Engineering rock mass classifications: A complete manual forengineers and geologists in mining, civil, and petroleum engineering. Wiley.
7. Brindley, G. W., & Brown, G. (Eds.). (1980). Crystal structures of clay minerals and their X-ray identification. Mineralogical Society.
8. Dada, S. S., Briqueu, L., & Harnois, L. (1998). Geology, geochemistry and origin of the banded and granite gneisses in the Basement Complex of the Ilesha area, southwestern Nigeria. Journal of

African Earth Sciences, 26(4), 633-641. https://doi.org/10.1016/S0899-5362(98)00037-2

9. Dearman, W. R. (1991). Engineering geological mapping. Butterworth-Heinemann.
10. Gidigasu, M. D. (1976). Laterite soil engineering: Pedogenesis and engineering principles. Elsevier Scientific Publishing Company.
11. Hoek, E., Carranza-Torres, C., & Corkum, B. (2002). Hoek-Brown failure criterion - 2002 edition. In Proceedings of the Fifth North American Rock Mechanics Symposium (pp.267–273). University of Toronto.
12. Integrated Geological, Geotechnical and Geophysical Survey Report. (2026). Integrated geological, geotechnical and geophysical approach for subsurface characterisation in Efon Alaaye, Ekiti State, Nigeria [Unpublished field report].
13. International Society for Rock Mechanics (ISRM). (1978). Suggested methods for the quantitative description of discontinuities in rock masses. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 15(6), 319-368. https://doi.org/10.1016/0148-9062(78)91472-9
14. Kearey, P., Brooks, M., & Hill, I. (2002). An introduction to geophysical exploration (3rd ed.). Blackwell Science.
15. Obaje,N. G. (2009). Geology and mineral resources of Nigeria. Springer. https://doi.org/10.1007/978-3-540-92685-6
16. Olasehinde, P. I., Pal, P. C., & Annor, A. E. (1990). Aeromagnetic anomalies and structural lineaments in the Nigerian Basement Complex. Journal of African Earth Sciences (and the Middle East), 11(3-4), 351-355. https://doi.org/10.1016/0899-5362(90)90014-6
17. Oyedele, A. A. (2019). Use of remote sensing and GIS techniques for groundwater exploration in the Basement Complex terrain of Ado-Ekiti, SW Nigeria. Applied Water Science, 9, 51. https://doi.org/10.1007/s13201-019-0917-9
18. Rahaman, M. A. (1988). Recent advances in the study of the Basement Complex of Nigeria. In P. O. Oluyide, W. C. Mbonu, A. E. Ogezi, I. G. Egbuniwe, A. C. Ajibade, & A. C. Umeji (Eds.), Precambrian geology of Nigeria (pp. 11-43). Geological Survey of Nigeria.
19. Reynolds, J. M. (2011). An introduction to applied and environmental geophysics (2nd ed.). Wiley-Blackwell.
20. Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). Applied geophysics (2nd ed.). Cambridge University Press.
21. Wyllie, D. C., & Mah, C. W. (2004). Rock slope engineering: Civil and mining (4th ed.). Spon Press.

f clay minerals and their X-ray identification. Mineralogical Society; 1980.

Dada SS, Briqueu L, Harnois L. Geology, geochemistry and origin of the banded and granite gneisses in the Basement Complex of the Ilesha area, southwestern Nigeria. J Afr Earth Sc. 1998;26(4):633–41. https://doi.org/10.1016/S0899-5362(98)00037-2.

Dearman WR. Engineering geological mapping. Butterworth-Heinemann; 1991.

Gidigasu MD. Laterite soil engineering: Pedogenesis and engineering principles. Elsevier Scientific Publishing Company; 1976.

Hoek E, Carranza-Torres C, Corkum B. (2002). Hoek-Brown failure criterion – 2002 edition. In Proceedings of the Fifth North American Rock Mechanics Symposium (pp.267–273). University of Toronto.

Integrated Geological, Geotechnical and Geophysical Survey Report. (2026). Integrated geological, geotechnical and geophysical approach for subsurface characterisation in Efon Alaaye, Ekiti State, Nigeria [Unpublished field report].

International Society for Rock Mechanics (ISRM). Suggested methods for the quantitative description of discontinuities in rock masses. Int J Rock Mech Min Sci Geomech Abstracts. 1978;15(6):319–68. https://doi.org/10.1016/0148-9062(78)91472-9.

Kearey P, Brooks M, Hill I. An introduction to geophysical exploration. 3rd ed. Blackwell Science; 2002.

Obaje NG. (2009). Geology and mineral resources of Nigeria. Springer. https://doi.org/10.1007/978-3-540-92685-6

Olasehinde PI, Pal PC, Annor AE. Aeromagnetic anomalies and structural lineaments in the Nigerian Basement Complex. J Afr Earth Sci (and Middle East). 1990;11(3–4):351–5. https://doi.org/10.1016/0899-5362(90)90014-6.

Oyedele AA. Use of remote sensing and GIS techniques for groundwater exploration in the Basement Complex terrain of Ado-Ekiti, SW Nigeria. Appl Water Sci. 2019;9:51. https://doi.org/10.1007/s13201-019-0917-9.

Rahaman MA. Recent advances in the study of the Basement Complex of Nigeria. In: Oluyide PO, Mbonu WC, Ogezi AE, Egbuniwe IG, Ajibade AC, Umeji AC, editors. Precambrian geology of Nigeria. Geological Survey of Nigeria; 1988. pp. 11–43.

Reynolds JM. An introduction to applied and environmental geophysics. 2nd ed. Wiley-Blackwell; 2011.

Telford WM, Geldart LP, Sheriff RE. Applied geophysics. 2nd ed. Cambridge University Press; 1990.

Wyllie DC, Mah CW. Rock slope engineering: Civil and mining. 4th ed. Spon; 2004.

Figures

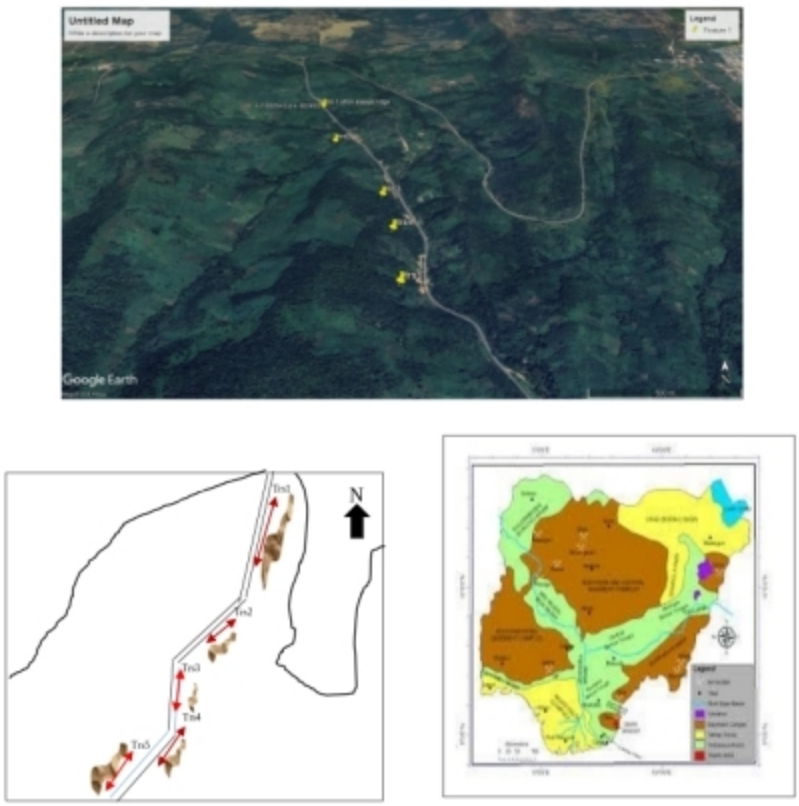


Figure 1

Digitised location and traverse map of the Efon Alaaye study area. Source: field survey dataset (2026).

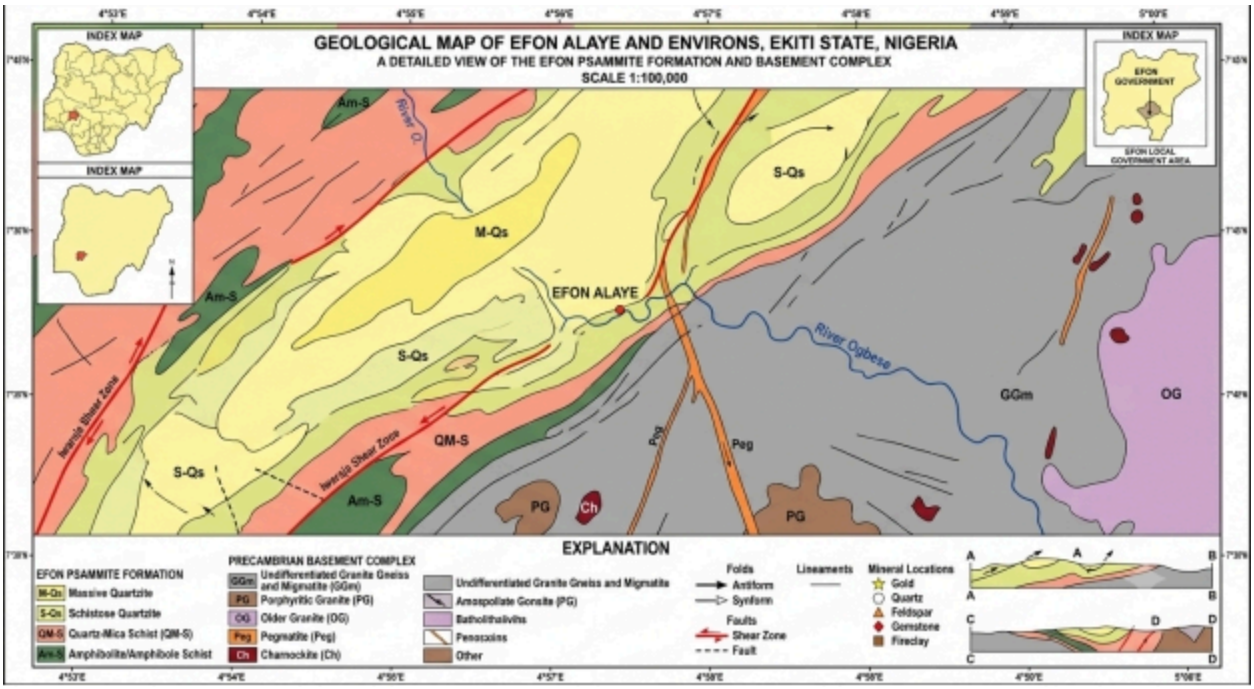


Figure 2

Geological map of Efon Alaaye and environs showing the regional lithological framework. Source: field survey dataset (2026).

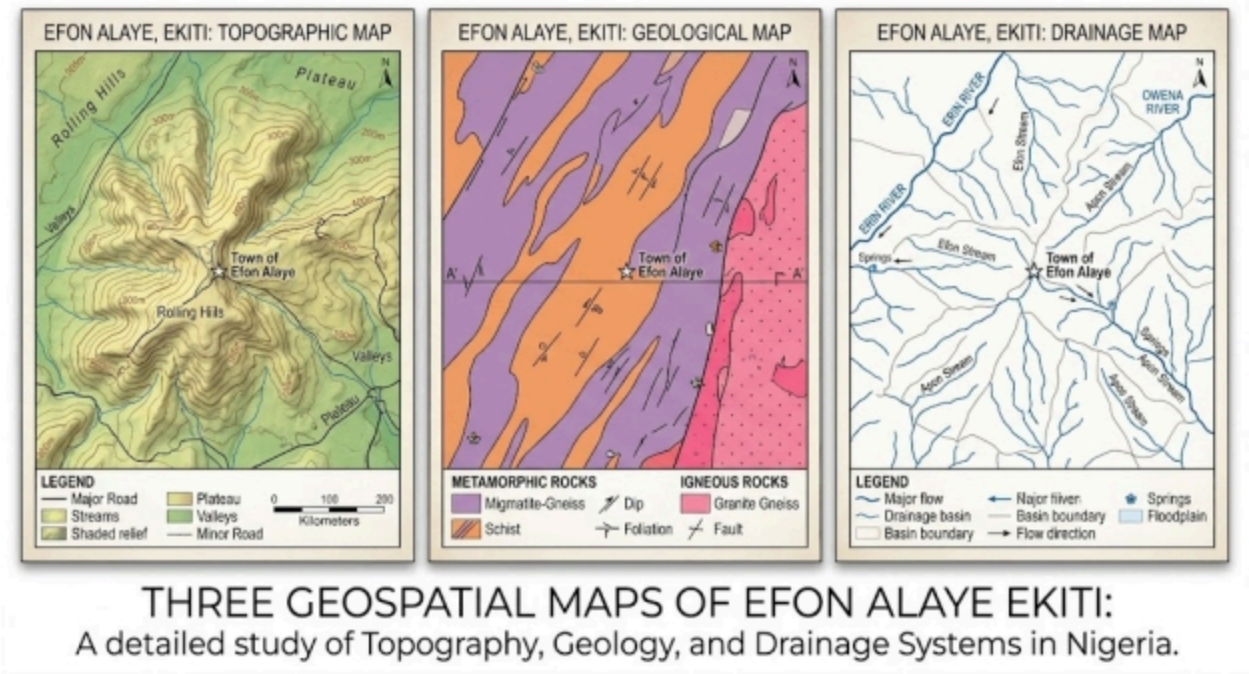


Figure 3

Topographic, geological and drainage maps of Efon Alaaye. Source: field survey dataset (2026).

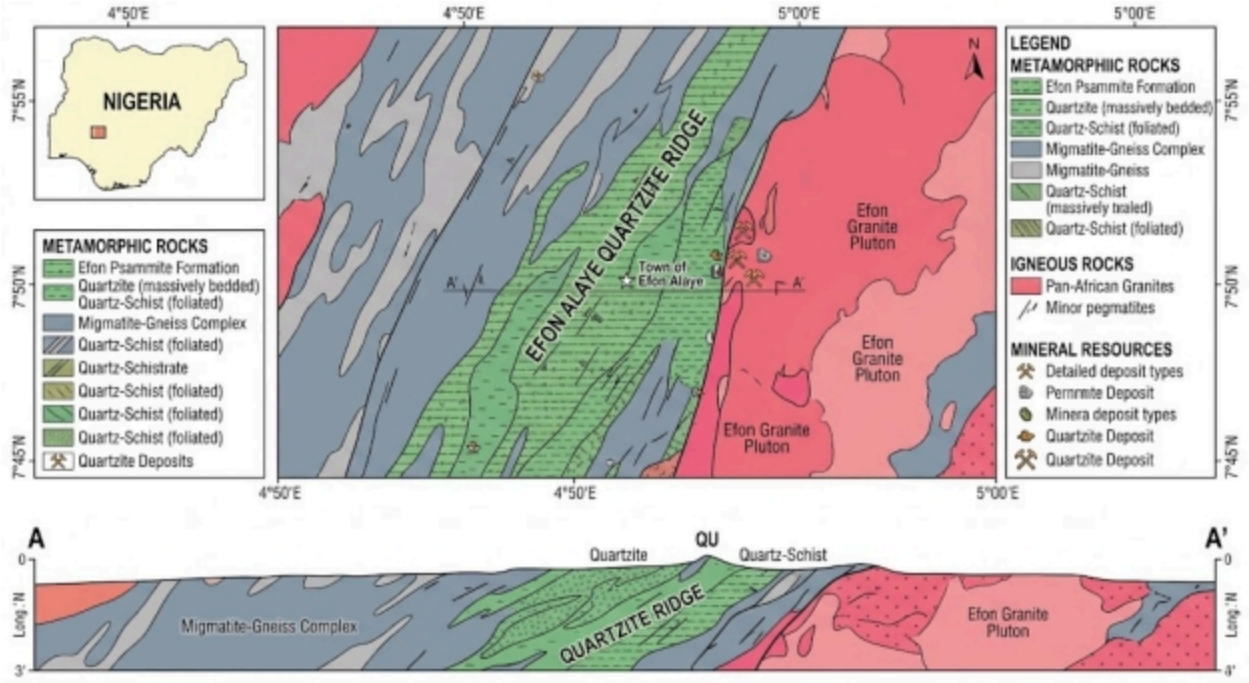


Figure 4

Detailed geological map and interpretive cross-section of the Efon Alaaye area. Source: field survey dataset (2026).

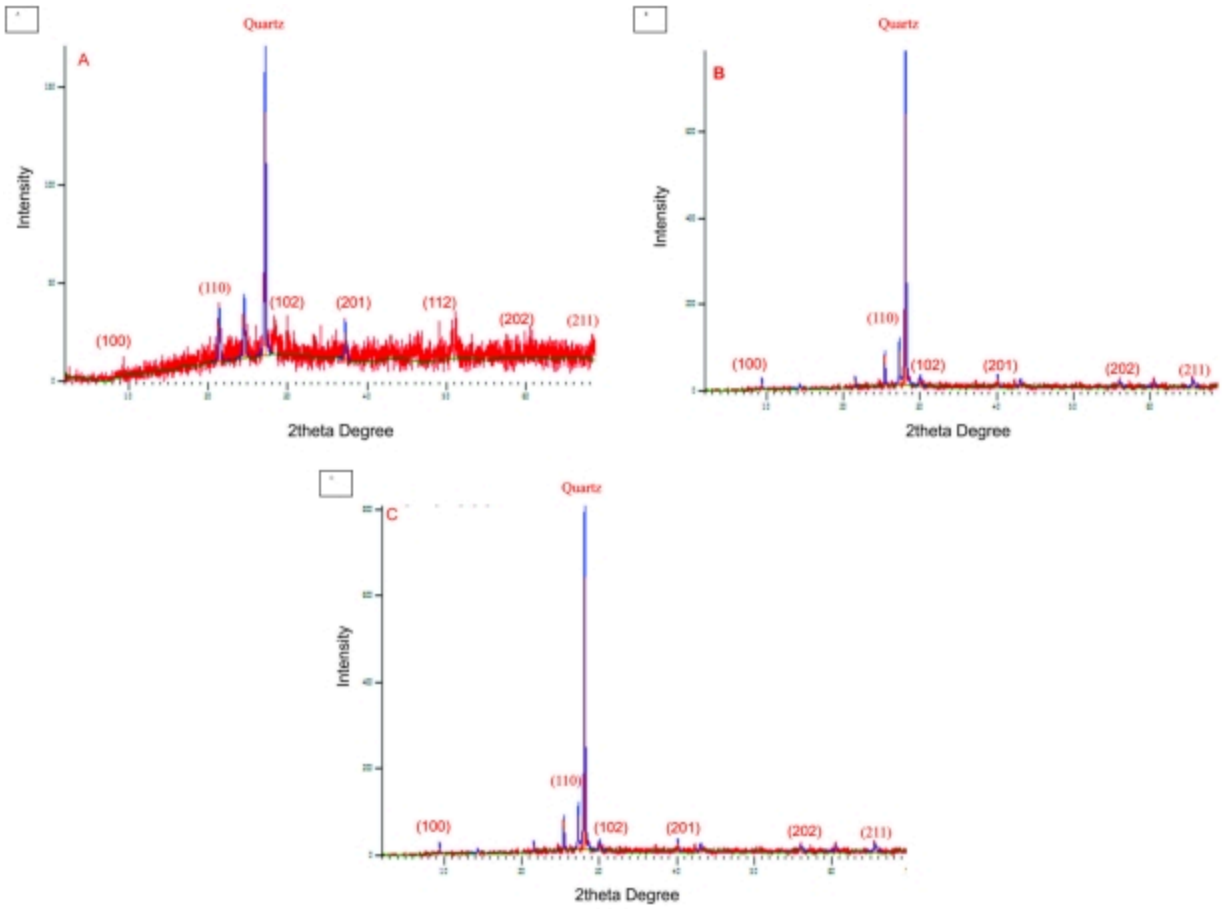


Figure 5

Supplied XRD diffractograms for Samples A-C. Strong quartz reflections are evident in all three patterns.