

Mineralogical Characterisation and IUGS-SCMR Classification of Metasediments from Ikpeshi, Southern Nigeria: an XRD and Multivariate Statistical Approach

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ABSTRACT

Eight (8) samples (SL1–SL8) from a mapped metasedimentary outcrop at Ikpeshi, Southern Nigeria, were characterised using semi-quantitative X-ray diffraction (XRD) data and the modal-mineralogical principles of the IUGS Subcommission on the Systematics of Metamorphic Rocks (SCMR). The assemblage comprises quartz (22.8–82.6 wt. %), K-feldspar, albite, muscovite or phlogopite (up to 55.6 wt. %), and variable illite and montmorillonite. Pearson/Spearman correlation, principal component analysis (PCA), and Ward hierarchical clustering distinguish three mineralogical groups. Harker-type diagrams constructed from oxide compositions recalculated from XRD modes show inverse relationships between Al_2O_3 and K_2O and SiO_2 ($r = -0.88$ and -0.94), reflecting modal dilution by quartz rather than igneous differentiation. Following the SCMR structural criterion, six samples are classified as schists, SL5 as montmorillonite quartzite, and SL3 as orthoclase-quartz rich granofels because it falls below the 75% quartz threshold and the available mineralogical evidence does not demonstrate a schistose fabric. The classifications remain provisional because XRD values are semi-quantitative weight percentages, whereas SCMR thresholds are based on modal volume proportions, and only eight samples were examined.

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INTRODUCTION

Naming a metamorphic rock has never been as simple as naming a granite, because the same rock can carry a name based on its protolith, fabric, dominant mineral or inferred history. The International Union of Geological Sciences (IUGS) Sub commission on the Systematics of Metamorphic Rocks (SCMR) therefore published a scheme in which any rock is named from two observations: its structure, expressed by one of three root terms (schist, gneiss or granofels), and its mineral content, expressed by hyphenated prefixes ranked by increasing modal abundance (Fettes & Desmons, 2007; Schmid et al., 2007). Metamorphic rocks have no simple counterpart to the total alkali–silica diagram, so the scheme leans heavily on modal data (Schmid et al., 2007).

Powder X-ray diffraction (XRD) is a practical way to obtain such modes for fine-grained schists, where grains are too small for point counting and clays complicate thin-section work (Moore & Reynolds, 1997). It has two catches: XRD gives weight per cent whereas SCMR thresholds are in volume percent, and quantification depends on sample preparation and preferred orientation, especially for micas and clays (Hillier, 2000). A defensible classification must show that the names survive these uncertainties.

The Ikpeshi area lies in Akoko-Edo Local Government Area, where schists occur alongside marble and calc-silicate rocks (Chaanda et al., 2019) and marble and dolomite are quarried around Ikpeshi and Igarra (Taiwo & Omotehinse, 2022). Published work has concentrated on the carbonate units

(Odokuma-Alonge, 2019; Taiwo & Omotehinse, 2022), and, by limited knowledge, the siliciclastic schists have not been classified with the SCMR scheme. The objectives of this article therefore are (i) present the XRD modal mineralogy of eight samples (SL1–SL8); (ii) classify them following Fettes and Desmons (2007); (iii) explore their variability with correlation, principal component and cluster analysis; and (iv) use Harker-type diagrams (Harker, 1909) to see what controls the compositional spread.

Geological Setting and Study Area

The Nigerian basement complex forms part of the Pan-African mobile belt between the West African and Congo cratons (Caby, 1989). It is conventionally divided into a migmatite–gneiss complex, supracrustal schist belts and the Older Granites, the schist belts being largely sediment-dominated sequences infolded into the gneissic basement (Rahaman, 1988). In the Igarra district the supracrustal rocks include schist, amphibolite, calc-silicate gneiss and marble, deformed in more than one phase and later intruded by post-tectonic Pan-African granitoids (Chaanda et al., 2019).

The mapped ground near Ikpeshi covers roughly $32.3 \text{ m} \times 18.8 \text{ m}$, between $\text{N}07^\circ09'44.4''$ – $\text{N}07^\circ09'48.1''$ and $\text{E}006^\circ10'06.6''$ – $\text{E}006^\circ10'08.9''$, with low relief (Fig. 1). The geological map shows it as quartz-mica schist with a foliation reading of 58° (Fig. 2). Sample locations are code named SL1–SL8 on both maps and the XRD data set.

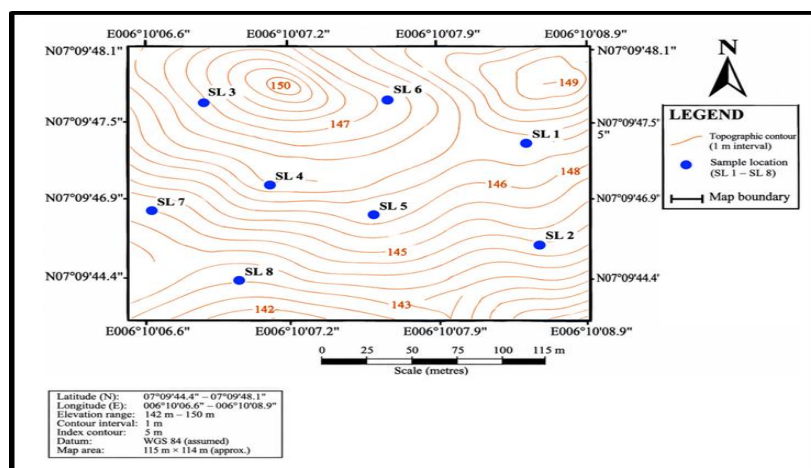


Figure 1: Topographic map of Ikpeshi Area, Edo North, Southern Nigeria (modified after Geological Survey of Nigeria (GSMN) Auchi Sheet 226, N.W. quadrant)

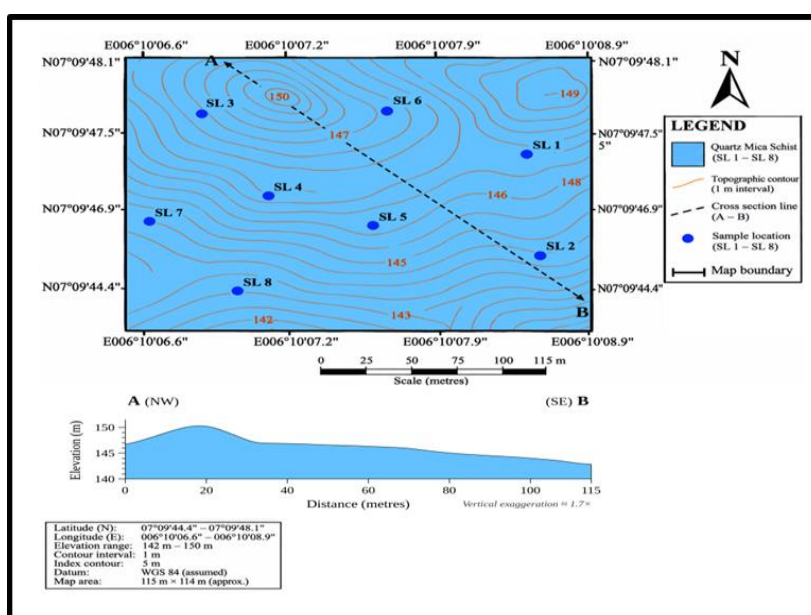


Figure 2: Geological map of the Ikpeshi schist outcrop, Edo North, Southern Nigeria (modified after Olayinka, 1992; Rahaman, 1988)

MATERIALS AND METHODS

Sampling and XRD analysis

Eight (8) representative samples (SL1–SL8) were collected from the outcrops marked in Figures 1 and 2 and analysed at the National Steel Raw Material Exploration Agency (NSRMEA), Kaduna State, using a Rigaku MiniFlex X-ray diffractometer. The powdered samples were analysed by powder XRD and the detected phases were identified from their diffraction patterns. The reported modal abundances are semi-quantitative weight percentages. Seven phases were identified: quartz, muscovite, phlogopite, orthoclase, albite, montmorillonite and illite (Table 1). The supplied laboratory information identifies the instrument model. The XRD values are consequently treated as semi-quantitative estimates rather than high-precision modal measurements. Because the individual phase totals are not exactly 100% in all samples, the values used for descriptive statistics and SCMR classification were normalized to 100%. Thus, for example, the reported quartz values of 74.0% in SL3 and 79.0% in SL5 correspond to normalized values of 73.8% and 82.6%, respectively (Table 1).

Classification Procedure

Names were assigned following the SCMR procedure (Fettes & Desmons, 2007; Schmid et al., 2007). The 75% threshold was first tested for a dominant mineral constituent. Constituents $\geq 5\%$ were then considered major and written as hyphenated prefixes in increasing order of modal abundance; constituents $< 5\%$ were treated as minor. The SCMR root term is a structural term: schist requires a demonstrable schistose fabric, whereas granofels is appropriate where a schistose or gneissose fabric is not established. XRD provides mineral proportions but cannot by itself demonstrate microstructural fabric. Accordingly, SL3 is assigned provisionally as orthoclase-quartz granofels because its normalized quartz content is below 75% and the available mineralogical data do not establish a schistose fabric; the assignment should be confirmed by thin-section petrography. For SL1, SL2, SL4 and SL5–SL8, the root term schist is retained because the samples were collected within the mapped quartz-mica schist body with documented field foliation, but this remains a field-scale structural assignment rather than a substitute for sample-specific petrographic verification. To assess the effect of the wt.%/vol.% mismatch, the normalized XRD weight

fractions were additionally converted to approximate volume fractions using densities of quartz (2.65), muscovite (2.83), phlogopite (2.80), orthoclase (2.56), albite (2.62), montmorillonite (2.35) and illite (2.75 g cm⁻³), based on Deer et al. (2013). The classification steps were then repeated. This conversion is approximate and does not remove uncertainty arising from preferred orientation, incomplete phase detection, solid solution and the semi-quantitative nature of the XRD data.

Statistical Analysis

Descriptive statistics were calculated from the normalised mineral proportions. Associations were examined using Pearson's *r* and Spearman's *ρ*. With *n* = 8, the approximate two-tailed 5% significance thresholds are $|r| > 0.71$ and $|\rho| > 0.74$. Because compositional proportions sum to a constant, correlation coefficients may be affected by closure (Chayes, 1960; Aitchison, 1986) and are therefore interpreted descriptively rather than as independent geochemical processes. For PCA, the mineral variables were standardised to zero mean and unit variance and the correlation matrix was analysed (Jolliffe, 2002). Hierarchical clustering used standardised mineral proportions, Euclidean distance and Ward's minimum-variance linkage (Ward, 1963). Calculations and figures were produced in Python using NumPy, SciPy and Matplotlib. Given the small sample size, PCA and clustering are used as exploratory tools for mineralogical grouping rather than as evidence for population-wide relationships.

Harker-Type Diagrams

Harker diagrams plot oxide contents against SiO₂ (Harker, 1909). No whole-rock chemical analyses accompany these samples. Approximate bulk-oxide compositions were therefore recalculated from the XRD mineral modes by summing the oxide contributions of the idealised mineral formulae: muscovite KAl₂(AlSi₃O₁₀)(OH)₂, phlogopite KMg₃(AlSi₃O₁₀)(OH)₂, orthoclase KAlSi₃O₈, albite NaAlSi₃O₈, montmorillonite Na_{0.33}Al_{1.67}Mg_{0.33}Si₄O₁₀(OH)₂ and illite K_{0.75}Al₂(Si_{3.25}Al_{0.75})O₁₀(OH)₂. The results were recalculated to 100% on a water-free basis. Iron, solid solution and unquantified phases were not included. Accordingly, these are Harker-type modal recalculation plots, not whole-rock geochemical data, and their relationships must not be interpreted as conventional igneous differentiation trends.

RESULTS AND DISCUSSION

Modal Mineralogy

Quartz is the most abundant phase in five samples (SL1, SL3, SL4, SL5, SL7) and ranges from 22.8 to 82.6 wt. % (mean 46.8 ± 21.7; Table 1). Muscovite dominates SL2, SL6 and SL8 (28.8–55.6 wt. %), whereas phlogopite is the main mica in SL1 and SL7 (30.0 and 24.0 wt. %); the two micas never occur together in significant amounts. Orthoclase is present throughout (2.1–27.0 wt. %), albite is persistent but modest (2.0–15.9 wt. %), illite is recorded in all samples but is substantial only in SL4 (22.0 wt. %), and montmorillonite occurs in four samples, reaching 10.0 wt. % in SL5.

Table 1: Semi-quantitative XRD Mineralogy of Samples SL1–SL8 (wt. %) and Summary Statistics of the Normalised Data

Mineral	SL1	SL2	SL3	SL4	SL5	SL6	SL7	SL8	Mean ± SD	Range
Quartz (SiO ₂)	37.0	25.0	74.0	52.0	79.0	23.0	45.0	36.0	46.8 ± 21.7	22.8–82.6
Muscovite	–	55.0	1.0	2.0	–	29.0	–	43.0	16.3 ± 22.8	0–55.6
Phlogopite	30.0	–	–	–	–	–	24.0	–	6.8 ± 12.6	0–30.0
Orthoclase	27.0	4.0	21.0	20.0	2.0	26.0	22.0	17.4	17.4 ± 9.4	2.1–27.0
Albite	4.0	10.0	4.0	4.0	4.0	16.0	2.0	2.3	5.8 ± 4.8	2.0–15.9
Montmorillonite	–	–	–	–	9.6	6.7	0.03	0.7	2.2 ± 3.9	0–10.0
Illite	2.0	5.0	0.3	22.0	1.0	0.1	7.0	1.0	4.8 ± 7.4	0.1–22.0
Total	100.0	99.0	100.3	100.0	95.6	100.8	100.0	100.4		

Note. Individual phase values are the reported semi-quantitative XRD abundances. Because sample totals are not exactly 100% in all cases, the mean, SD, range and SCMR classification were calculated from values normalized to 100%. Consequently, SL3 changes from 74.0% reported quartz to 73.8% normalized quartz, while SL5 changes from 79.0% to 82.6%. Dashes indicate phases not detected

IUGS SCMR Classification

Using the IUGS-SCMR classification scheme, only SL5 passes the 75% test, with a normalized quartz content of 82.6 wt.% (81.5 vol.%), and is therefore classified as a quartzite; its normalized montmorillonite content of 10.0 wt.% exceeds the 5% limit for a major constituent, giving montmorillonite quartzite (Table 2, Fig. 3a). SL3 has a reported quartz value of 74.0 wt.%, which normalizes to 73.8 wt.% (73.3 vol.%) because its unnormalized phase total is 100.3%; it therefore falls just below the 75% quartz threshold. On the available mineralogical evidence, SL3 is provisionally classified as orthoclase-quartz granofels rather than being described

ambiguously as either granofels or gneiss. Thin-section examination is required to confirm the structural root term. The remaining six samples are classified as schists on the basis of their occurrence within the mapped schistose outcrop; this field-scale assignment should likewise be checked against sample-specific petrographic fabric. Conversion from wt. % to approximate vol. % does not change the major/minor assignments or the reported names. The only close reordering occurs in SL7, where orthoclase and phlogopite differ by less than 0.1 vol. %. SL2 contains illite at 5.0 wt. %, exactly at the major/minor boundary.

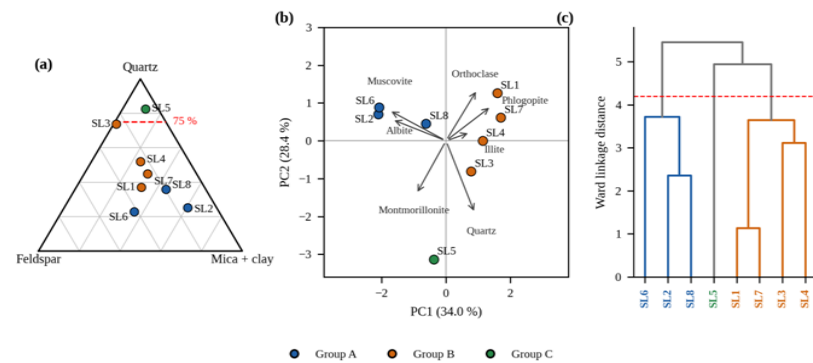


Figure 3: (a) Quartz-feldspar-mica-plus-clay ternary diagram (feldspar = orthoclase + albite); the dashed line marks 75 % quartz. (b) Principal component biplot of standardised data. (c) Ward dendrogram; the dashed line marks the cut defining groups A–C

Table 2: Classification of SL1–SL8 following the SCMR Scheme (Fettes & Desmons, 2007; Schmid et al., 2007)

Sample	Qtz–Fsp–Mica+clay (wt. %)	SCMR name (major constituents ≥ 5 wt. %)	Minor constituents (< 5 wt. %)	Group
SL1	37–31–32	Orthoclase-phlogopite-quartz schist	Illite, albite	B
SL2	25–14–61	Illite-albite-quartz-muscovite schist	Orthoclase	A
SL3	74–25–1	Orthoclase-quartz granofels (provisional)	Illite, muscovite, albite	B
SL4	52–24–24	Orthoclase-illite-quartz schist	Muscovite, albite	B
SL5	83–6–11	Montmorillonite quartzite	Illite, orthoclase, albite	C
SL6	23–42–36	Montmorillonite-albite-quartz-orthoclase-muscovite schist	Illite	A
SL7	45–24–31	Illite-orthoclase-phlogopite-quartz schist	Montmorillonite, albite	B
SL8	36–20–45	Orthoclase-quartz-muscovite schist	Montmorillonite, illite, albite	A

Qtz = quartz; Fsp = orthoclase + albite. Minor constituents are listed in increasing abundance. Group refers to the cluster analysis (Fig. 3c). Mica plus illite total only 1.3 wt.%, so a schistosity is unlikely to be well developed.

Statistical Analyses

No correlation between individual minerals reaches the 5% significance level; the strongest individual relationships are quartz–muscovite ($r = -0.67$, $p = 0.07$), phlogopite–orthoclase ($p = 0.65$, $p = 0.08$) and muscovite–phlogopite ($p = -0.64$, $p = 0.09$). When micas and clay minerals are pooled, quartz decreases as the phyllosilicate fraction increases (Pearson $r = -0.87$, $p = 0.005$; Spearman $\rho = -0.90$, $p = 0.002$). This relationship is interpreted cautiously because the data are compositional. The first three principal components explain 34.0%, 28.4% and 17.4% of the variance,

respectively, accounting for 79.8% cumulatively. PC1 contrasts muscovite and albite with phlogopite, orthoclase and quartz; PC2 is dominated by quartz and montmorillonite against orthoclase. Ward clustering produces three groups: Group A (SL2, SL6, SL8), characterised by relatively high muscovite and albite; Group B (SL1, SL3, SL4, SL7), characterised by quartz and orthoclase with phlogopite or illite in different samples; and Group C (SL5), an isolated quartz-rich sample. These groupings are descriptive and exploratory given the small sample size.

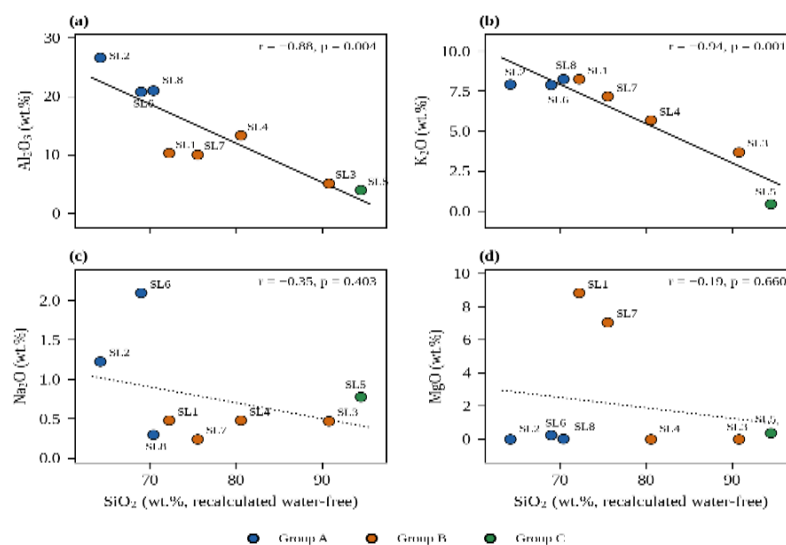


Figure 4: Harker-type diagrams of (a) Al_2O_3 , (b) K_2O , (c) Na_2O and (d) MgO against SiO_2 , using oxides recalculated from XRD modes (water-free). Lines are least-squares fits, solid where $p < 0.05$ and dotted otherwise

Harker-Type Diagrams

Recalculated SiO_2 ranges from 64.3 to 94.5 wt. % (water-free), so every sample has a chemistry the SCMR would call acid ($\text{SiO}_2 > 63$ wt. %; Schmid et al., 2007). Al_2O_3 (3.9–26.6 wt. %) and K_2O (0.5–8.3 wt. %) fall as SiO_2 rises ($r = -0.88$, $p = 0.004$; $r = -0.94$, $p = 0.001$; Fig. 4a, b), whereas Na_2O (0.2–2.1 wt. %) and MgO (0–8.8 wt. %) show no significant trend ($r = -0.35$, $p = 0.40$; $r = -0.19$, $p = 0.66$; Fig. 4c, d). MgO is high only in the phlogopite-bearing SL1 (8.8 wt. %) and SL7 (7.1 wt. %); all other samples contain 0.4 wt. % or less.

Discussion

Reading the Names

Three features stand out. First, K-bearing phases dominate: orthoclase and at least one K-rich mica or illite occur in every sample, while albite never exceeds 16 wt. %. Second, the two micas are effectively exclusive, with muscovite in SL2, SL6 and SL8 and phlogopite in SL1 and SL7. Third, the quartz-rich end is distinct. SL5 is a quartzite, whereas SL3 falls about one percentage point below the 75% quartz threshold and contains only about 1.3 wt. % combined mica plus illite. On the mineralogical evidence available here, SL3 is therefore classified as orthoclase-quartz rich granofels because a schistose fabric cannot be demonstrated from XRD mineral modes alone. Thin-section petrography is required to determine whether a gneissose fabric is present; consequently, the granofels classification remains provisional.

Clay Minerals and the Choice of Prefixes

Strict use of the ≥ 5 % rule puts illite or montmorillonite into the names of SL2, SL4, SL5, SL6 and SL7. In the humid tropical setting of southern Nigeria these phases may record weathering or low-temperature alteration rather than peak metamorphism (Velde & Meunier, 2008), and the SCMR allows small amounts of retrograde minerals to be left out of the main name (Schmid et al., 2007). Omitting the clays would shorten SL2, SL6 and SL7 to albite-quartz-muscovite schist, albite-quartz-orthoclase-muscovite schist and orthoclase-phlogopite-quartz schist, and SL5 to a plain quartzite. SL4 is different, because illite is its only significant platy phase and supports its schistose fabric. Table 2 therefore reports the strict names until thin sections settle the origin of the clays.

What Controls the Compositional Spread

The correlation, PCA and Harker-type results are mutually consistent at the level of mineralogical variation. The most pronounced relationship is the inverse association between quartz and the mica-plus-clay fraction, while Al_2O_3 and K_2O decrease as SiO_2 increases because quartz dilutes the minerals hosting these oxides. These trends arise directly from the modal recalculation because each oxide value is a weighted sum of mineral proportions. They should therefore not be interpreted as conventional magmatic differentiation trends. Instead, they describe a continuum from quartz-rich to phyllosilicate-rich compositions. The absence of abundant Ca-bearing phases and the generally low Na_2O are consistent with the mineral assemblage observed, although XRD mineralogy alone cannot uniquely distinguish a siliciclastic protolith from a felsic igneous precursor. The relatively high MgO in SL1 and SL7 is attributable to phlogopite in the modal recalculation. Any proposed carbonate-related Mg contribution remains a hypothesis requiring independent petrographic and geochemical testing.

Limitations

Eight samples from one small outcrop describe local mineralogical variation but do not justify regional generalisation and correlations at $n = 8$ are fragile and affected by closure (Chayes, 1960; Aitchison, 1986). The XRD analyser's scan range, step size, mineral identification/database, quantitative refinement method are not available. The semi-quantitative XRD approach is subject to uncertainty associated with preferred orientation, incomplete phase detection and the treatment of solid solutions, with phyllosilicates being particularly sensitive to sample preparation and analytical conditions (Hillier, 2000). The 95.6% total for SL5 indicates an unquantified fraction in the reported phase estimates. Separating phlogopite from biotite depends on Fe:Mg relations that XRD phase identification alone may not resolve (Deer et al., 2013). The recalculated oxides are based on ideal mineral formulae and omit iron, so the Harker-type plots are exploratory modal-recalculation plots rather than whole-rock geochemical trends. Finally, petrographic thin-section examination would provide the structural evidence needed to confirm the SCMR root terms, especially for SL3.

CONCLUSION

Semi-quantitative XRD data from eight samples of the Ikpeshi metasedimentary outcrop provide a consistent description of local mineralogical variability and support a cautious application of the IUGS-SCMR scheme. Six samples are classified as schists on the basis of their occurrence within the mapped schistose body, SL5 as montmorillonite quartzite, and SL3 provisionally as orthoclase-quartz granofels because its normalized quartz content (73.8 wt.%; 73.3 vol.%) falls below the 75% threshold and the available XRD data do not establish a schistose fabric. The distinction between reported and normalized XRD values is important: the displayed values for SL3 and SL5 are 74.0% and 79.0%, respectively, whereas the normalized values used for classification are 73.8% and 82.6%. Correlation, PCA and Ward clustering identify three exploratory mineralogical groupings- quartz-muscovite, phlogopite- or thoclase, and muscovite-phlogopite but these patterns should be interpreted cautiously because the dataset contains only eight samples and compositional closure can influence correlations. Harker-type diagrams showed that Al_2O_3 and K_2O decrease with SiO_2 because quartz dilutes a mica-feldspar assemblage whereas Na_2O and MgO show no significant trend. MgO is high only in the phlogopite-bearing sample. The Harker-type plots are derived from idealized mineral-mode recalculations rather than measured whole-rock analyses and therefore indicate modal dilution relationships rather than conventional igneous differentiation. The classifications remain semi-quantitative and should be strengthened by thin-section petrography. Therefore, petrographic thin-section examination is recommended.

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