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ASSESSMENT OF PROVENANCE SIGNATURES, MATURITY, WEATHERING AND THE TECTONIC SETTINGS OF STREAM SEDIMENTS FROM SHEET 202 SHARE (SW) NORTH CENTRAL NIGERIA.

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ABSTRACT

Geochemical study on the Sheet 202 Share SW stream sediments was carried out to infer their provenance, maturity, classification, tectonic setting and source-area weathering. The discriminant functions of the major oxides were plotted and revealed a mixed felsic/basic intermediate igneous provenance. The source characteristics of sediments are constrained with the Sr vs. Ba plot in which the Share SW sediments plots within the field of mature sediments. The chemical maturity of these sediments are also confirmed with the moderate Zr–Hf content since Hf and Zr are closely associated in sediments and are both concentrated in zircon. The Share Sheet 202 SW stream sediments display high La (383–1300 ppm) contents reflecting felsic input. Therefore, the La-Th-Sc ternary plot was used to determine the source of contamination of the Share SW sediments which fall within the field of granitic gneiss sources. Similarly, the discrimination diagrams of tectonic were used to evaluate the tectonic setting of the Share SW stream sediment samples with samples cluster at the passive margin. The Share SW sediments tectonic setting is of the passive continental margin, while the provenance is the intermediate igneous sediments of mature continental provenance, associated with a continental passive margin, in a recycled orogenic province.

Keywords: Chemical maturity, Felsic, Provenance, Tectonic setting, Weathering, Word count 224

INTRODUCTION

The geochemical compositions of stream sediments reflect the average composition of an entire drainage basin (Halamic et al., 2001; Reimann and Melezhik, 2001). According to Grunsky and Sutphin, (2009), geochemical studies based on the chemical analysis of active stream sediments are an effective tool with several applications. Several authors have used major element discrimination diagrams (Bhatia, 1983) to discriminate the tectonic



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settings of sedimentary basins and have been applied in topical publications (Kroonenberg, 1994; Zimmermann and Bahlburg, 2003; Armstrong-Altrin et al., 2004). According to Armstrong-Altrin and Verma (2005), caution is required in their uncritical use. The most important clues for the tectonic setting of the basin comes from the relative depletion of the most mobile elements like Ca and Na and enrichment of Si and Ti—the most immobile elements, among others. The oxides of these elements are assumed to show enrichment or depletion in quartz, K-feldspar, plagioclase feldspars, and micas. The ratio of the most immobile elements to the most mobile ones increases toward passive margins due to the relative tectonic stability (Bhatia, 1983; Kroonenberg, 1994; Zimmermann and Bahlburg, 2003; Armstrong-Altrin et al., 2004; Roser and Korsch, 1986) and hence prolonged weathering. This can be recorded in sediments as paleoclimate index (Chittleborough, 1991; Harnois, 1988; Nesbitt and Young, 1982) and high degree of sediment recycling. Major elements and selected trace elements and their elemental ratios are sensitive indicators of the source rocks, tectonic setting, paleoweathering conditions and paleoclimate of the clastic sediments (Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986; Roser and Korsch, 1988; McLennan and Taylor, 1991; McLennan et al., 1993; Sheet 202 Share SW is located in Kwara State North Central Nigeri. The study area is located in Kwara State (Figure 1) and bounded by longitudes ($4^{\circ}30'00''\text{N}$ to $4^{\circ}45'00''\text{N}$) and latitudes ($8^{\circ}30'00''\text{E}$ to $8^{\circ}45'00''\text{E}$). Prominent towns and villages within the study area include Shao, Ariori, OkeOyi, Jodoma, Babadudu, Budo-Ayan and Oloru just to mention a few. Accessibility within the study area is entirely fair enough with major roads running North - South passing through the investigated area. Main paths are also available running from one settlement to another. The drainage pattern is mainly Dendritic in which there are many rivers of different sizes. Dendritic system forms in V-shape valleys as a result of the rock types whether porous or non-porous. The drainage in the area is influenced by: lithological variations, structural elements such as faults, joints etc., and geomorphology of the area. The most outstanding characteristics of the drainage systems over the areas of Basement Complex rocks is the proliferation of many small rivers, some of which intersect the minor roads and footpaths in the area. The area has little streams which take their source from hills in the northern part. This present research is aimed at interpreting the sediment source area for weathering, provenance, tectonic setting, maturity and classification of the study area sediments based on major oxides geochemical data.

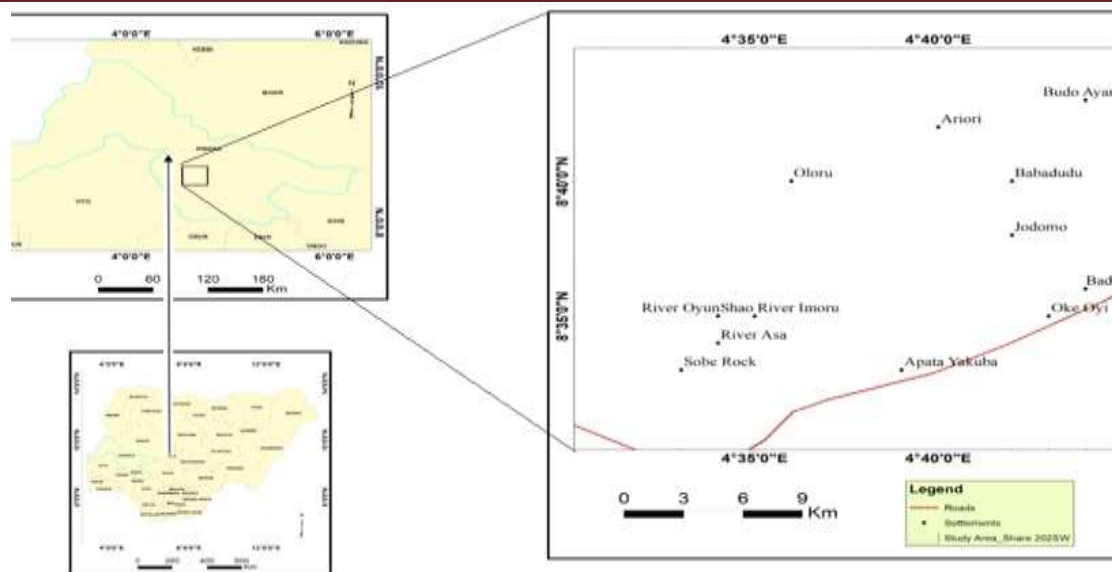


Figure 1: Location map of the study area

MATERIALS AND METHODS

Thirty eight (38) stream sediments representative samples were collected within the study area; the samples were collected using a hand auger and shovel. In carrying this out, the selections of first and second order stream were focused on with samples collected from both the active channels and the curvatures upstream (Figures 2). Sample points were designed to represent drainage catchment size in the range of 10-30km² each, with even spatial distribution across the campaign area. They were then sieved after air drying using 75 μ stainless steel mesh wire. Chemical analysis was carried at MS Analytical Laboratory Langley, Canada using the Inductively Coupled Plasma–Mass spectrophotometry (ICP-MS) technique to determine the concentration of major and trace elements in the stream sediments. Geochemical and statistical methods were used to treat the geochemical data. The statistical treatment include both univariate and multivariate statistical analysis using SPSS -17.0 software (statistical package for social science) and Microsoft excel was also used with the aim to determine the interrelationship between elements. Petrographs were used to produce ternary plottings. Plots and comparative tables were produced to aid visual identification trends in term of data variation. Correlation coefficients were developed to measure the strength of linear relationships between elemental abundance variables on a

scale of -1 (perfect inverse relationship) through 0 (no relation) to +1 (perfect sympathetic relation).

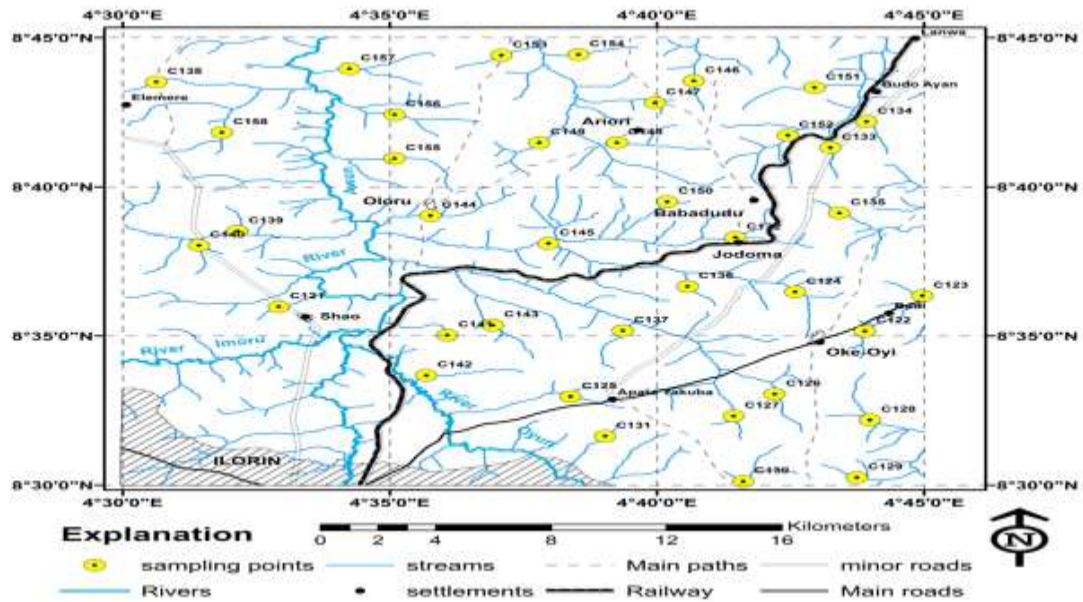


Figure 2: The study area showing the sampling points

RESULTS AND DISCUSSION

Geochemical Composition

Table 1 shows the major oxides component of Share SW stream sediments. The Fe_2O_3 (0.836–6.884%) has the highest concentration with the mean value 1.575% followed by Al_2O_3 (0.586–5.69% (Table 1).while the rest of the major oxides (CaO : 0.06–0.55%), Na_2O (0.01– 0.08%), TiO_2 : (0.05–0.45%), MgO : (0.02–0.79%) and K_2O :(0.06–0.53%) exhibit low to very low content (Table 1). This low values may be attributed to chemical destruction under oxidizing conditions during weathering or source-area composition. Low value of Na_2O in the sediments could be attributed to paucity of plagioclase feldspar in the host rock or their loss during weathering. Some ratios and weathering indices such as PIA, CIA, CIW and MIA were computed in Table 1.



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Table 1: Major oxides component (Wt %) of some selected sampling points in Share SW

Oxides wt (%)	SAMPLING POINTS									
	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10
Al ₂ O ₃	1.13	0.91	3.86	2.02	5.69	1.15	1.38	1.17	1.13	1.1
K ₂ O	0.13	0.16	0.17	0.12	0.3	0.1	0.11	0.144	0.11	0.17
MgO	0.03	0.05	0.79	0.17	0.13	0.05	0.05	0.1	0.05	0.03
Na ₂ O	0.01	0.03	0.07	0.03	0.01	0.01	0.01	0.03	0.02	0.03
TiO ₂	0.39	0.08	0.23	0.08	0.11	0.09	0.08	0.14	0.1	0.07
Fe ₂ O ₃	1.65	1.5	6.884	1.65	4.32	1.42	1.53	2.98	2.05	1.93
CaO	0.04	0.06	0.55	0.15	0.24	0.04	0.06	0.07	0.07	0.04
PIA	97.72	98.23	96.14	97.24	98.05	97.73	98.23	97.19	96.24	97.74
CIA	92.12	95.34	94.77	94.57	95.45	96.12	95.34	94.73	94.57	95.62
CIW	96.43	94.28	97.46	97.24	96.35	95.66	98.23	97.46	97.24	96.74
MIA	97.63	98.23	96.16	93.24	98.05	97.73	98.23	89.16	97.24	97.74

According to Nesbitt and Young (1982), the evaluation of the degree of chemical weathering of the sediments' source rocks can be determined by calculating the Chemical Index of Alteration (CIA), where $CIA = \text{molar} (Al_2O_3 / [Al_2O_3 + CaO + Na_2O + K_2O])$. This index works correctly when Ca, Na, and K decrease as the intensity of weathering increases (Duzgoren-Aydin et al., 2002). The Chemical Index of Weathering (CIW) proposed by Harnois, (1988) is similar to the CIA except for the exclusion of K₂O in the equation: $CIW = \text{molar} (Al_2O_3 / (Al_2O_3 + CaO + Na_2O))$. The CIA and CIW are interpreted in similar way with value of 50 for unweathered upper continental crust and roughly 100 for highly weathered materials, with complete removal of alkali and alkaline-earth elements (McLennan et al., 1983; McLennan, 1993; Mongelli et al., 1996). Low CIA values (i.e. 50 or less) also might reflect cool and / or arid conditions (Fedo et al., 1995). The intensity of the chemical weathering can also be estimated using the Plagioclase Index of Alteration (Fedo et al., 1995); in molecular proportions: $PIA = [(Al_2O_3 - K_2O) / (Al_2O_3 + CaO^* + Na_2O - K_2O)] \times 100$ where CaO* is the CaO residing only in the silicate fraction. Unweathered plagioclase has PIA value of 50 while Phanerozoic shales have PIA value of 79. The CIA values for the samples ranged between 92.12 and 96.45%, while CIW ranged from 90.44-98.83% indicating a high degree of weathering of the source materials. The PIA



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values ranged from 96.14-98.27%, this also indicates high degree of weathering. Voicu et al. (1997) also proposed the Mineralogical Index of Alteration (MIA) as a weathering parameter calculated as: $MIA = 2*(CIA-50)$. MIA values between 0 and 20% are designated as incipient, i.e. just starting; 20-40% (weak); 40-60% (moderate) and 60-100% as intense to extreme degree of weathering. The extreme value of 100% indicates complete weathering of a primary material into its equivalent weathered product (Igwe et al., 2013). MIA values for the samples ranged between 89.16 and 98.56%, which intense weathering of the source material, this is in agreement with the CIA, CIW PIA.

Multivariate Statistical Analysis (MSA)

The correlation coefficient values of the elements, using Pearson 'correlation method for the studied stream sediment samples is given in Table 2. In this table, the strong correlation coefficient values ($r = 0.70-0.99$) moderate correlation coefficient values ($r = 0.50-0.69$) and very strong correlation coefficient values ($r = 0.80-0.99$). Au exhibits a strong positive correlation with Cu ($r = 0.78$) and a moderate correlation with Ag ($r = 0.59$). As shown in Table 2 The values of Ag increase with the values of Al_2O_3 ($r = 0.68$), K_2O ($r = 0.57$), W ($r = 0.62$), while the concentration of Bi decreases with the values of Nb ($r = -0.51$), Re ($r = -0.55$) and Th ($r = -0.54$);).Also from the correlation analysis (Table 2), Au shows high correlation only with Cu ($r = 0.78$) and moderate correlation with Ag ($r = 0.59$).Other element pairs exhibit positive correlation with their respective correspondents.



Table 2: Pearson Correlation for some selected major oxides in the stream sediment samples

Major oxides (%)	Al ₂ O ₃	Fe ₂ O ₃	CaO	K ₂ O	MgO	Na ₂ O	TiO ₂	Au (ppm)	Ag (ppm)	Cu (ppm)	Nb (ppm)	Th (ppm)	Re (ppm)
Al ₂ O ₃	1.00	0.80	0.64	0.67	0.64	0.38	0.22	0.01	0.27	0.82	0.09	0.30	0.28
Fe ₂ O ₃	0.80	1.00	0.55	0.67	0.56	0.48	0.42	0.04	0.26	0.79	0.27	0.34	0.29
CaO	0.64	0.55	1.00	0.53	0.79	0.65	0.44	0.00	0.32	0.73	0.05	0.34	-0.05
K ₂ O	0.67	0.67	0.53	1.00	0.69	0.53	0.32	0.08	0.32	0.83	0.23	0.51	0.08
MgO	0.64	0.56	0.79	0.69	1.00	0.81	0.34	0.03	0.22	0.86	-0.17	0.28	-0.21
Na ₂ O	0.38	0.48	0.65	0.53	0.81	1.00	0.33	0.09	0.05	0.69	-0.25	0.10	-0.25
TiO ₂	0.22	0.42	0.44	0.32	0.34	0.33	1.00	0.10	0.46	0.42	0.38	0.32	0.07
Au (ppm)	0.01	0.04	0.00	0.08	0.03	0.09	0.10	1.00	0.59	0.78	0.34	0.00	0.35
Ag (ppm)	0.68	0.26	0.32	0.57	0.22	0.05	0.46	0.29	1.00	0.33	-0.51	-0.54	-0.55
Cu (ppm)	0.82	0.79	0.73	0.83	0.86	0.69	0.42	0.08	0.33	1.00	0.03	0.23	0.06
Nb (ppm)	0.09	0.27	0.05	0.23	-0.17	-0.25	0.38	0.34	0.58	0.03	1.00	0.35	0.62
Th (ppm)	0.30	0.34	0.34	0.51	0.28	0.10	0.32	0.00	0.24	0.23	0.35	1.00	0.18
Re (ppm)	0.28	0.29	-0.05	0.08	-0.21	-0.25	0.07	0.35	0.36	0.06	0.62	0.18	1.00

Maturity

Figure 3 indicates that the stream sediments collected are tending towards mature sediments. The high values given from the values of Zr-Hf indicate that all the samples have low degree of clayness. The higher the Zr content the lower the degree of clayness. Chombong et al. (2013) and Soh Tamehe et al. (2018) stated that maturity of stream sediments is reflected by the Zr-Hf index. High values indicate mineralogically mature sediment samples, while low ratios represents chemically immature samples. The Zr-Hf values for the Share SW stream sediments range between 0.13 and 5.28, which is moderate; this shows that the samples are mature. According to Floyd et al., (1989), the Sr vs Ba can also be used in determining chemical maturity and mineral stability, respectively as shown in Figure 3.

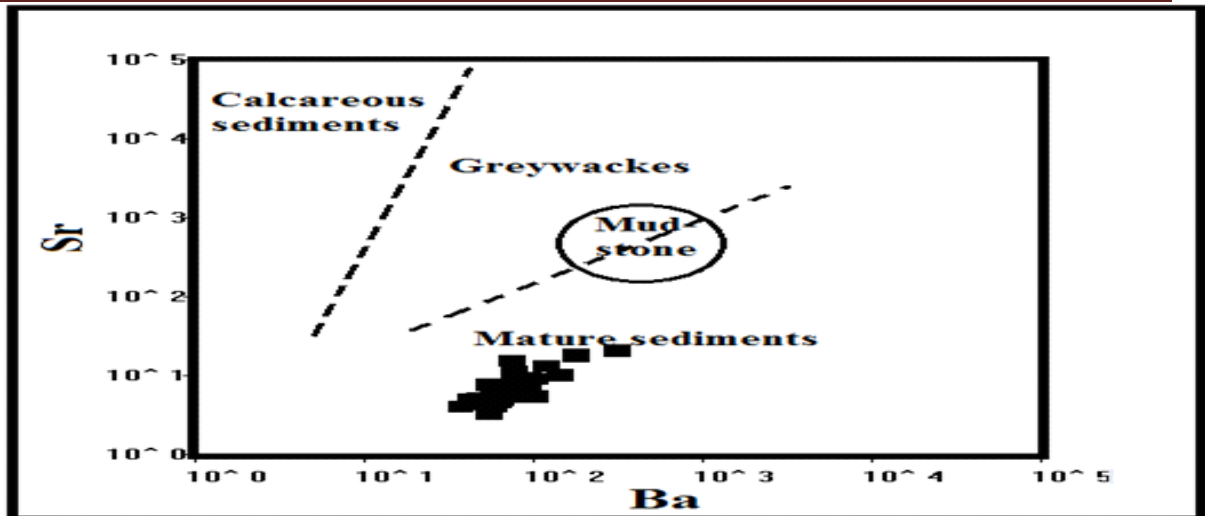


Figure 3: Bivariate Plot of Sr vs. Ba after Floyd et al. (1989) for Share SW stream sediments indicating that the sediments are matured

Source-area Weathering

Figure 4 shows that all the samples plotted at the A end member, which suggests intense chemical weathering and transportation of the sediments. The chemical composition of weathering products in a river basin is expected to exhibit entrenched concepts on mobility of various elements during weathering (Nesbitt et al., 1980; Singh et al., 2005), and therefore to assess the state of chemical and physical weathering (Vital and Stattegger, 2000; Singh et al., 2005; Liu et al., 2007). Elemental ratios calculated with respect to Al are used to identify and evaluate the major element mobility. According to Singh et al. (2005), the ratio of the content of element X and Al_2O_3 in the sediments divided by the ratio of the same element content of upper continental crust (UCC) gives the elemental ratio. More so, since Th/U ratio (> 4.0) in sedimentary rocks reflect important weathering at the primary source (McLennan et al., 1993), the high Th/U ratios (13.147–8.94; av. : 9.157) recorded in the studied area compared with the value of UCC (Th/U = 3.89 after Rudnick and Gao (2003) and Th/U = 3.82 according to Taylor and McLennan, 1985; 1995) indicate these sediments have undergone weathering as shown by the Th/U vs. Th diagram (Figure 4b). Meanwhile, lower concentrations of Al_2O_3 (0.21–0.73%), TiO_2 (0.08–0.11%), Na_2O (0.02–0.03%), K_2O (0.03–0.07%) and the correlation between Na_2O and K_2O ($r = -0.54$) suggest some sources of contamination. The Share Sheet 202 SW stream sediments display high La (383–1300 ppm) which is higher than the average universal crustal abundance value of



39.00ppm therefore reflecting felsic input. Therefore, the La-Th-Sc ternary plot (figure 4) by Bhatia and Crook (1986) was used to determine the source of contamination of the Share SW sediments. Share SW stream sediment samples fall within the field of granitic gneiss sources (Fig. 4a). This indicates that the source of detrital contamination in the Share SW stream sediment resulted from granitic gneiss.

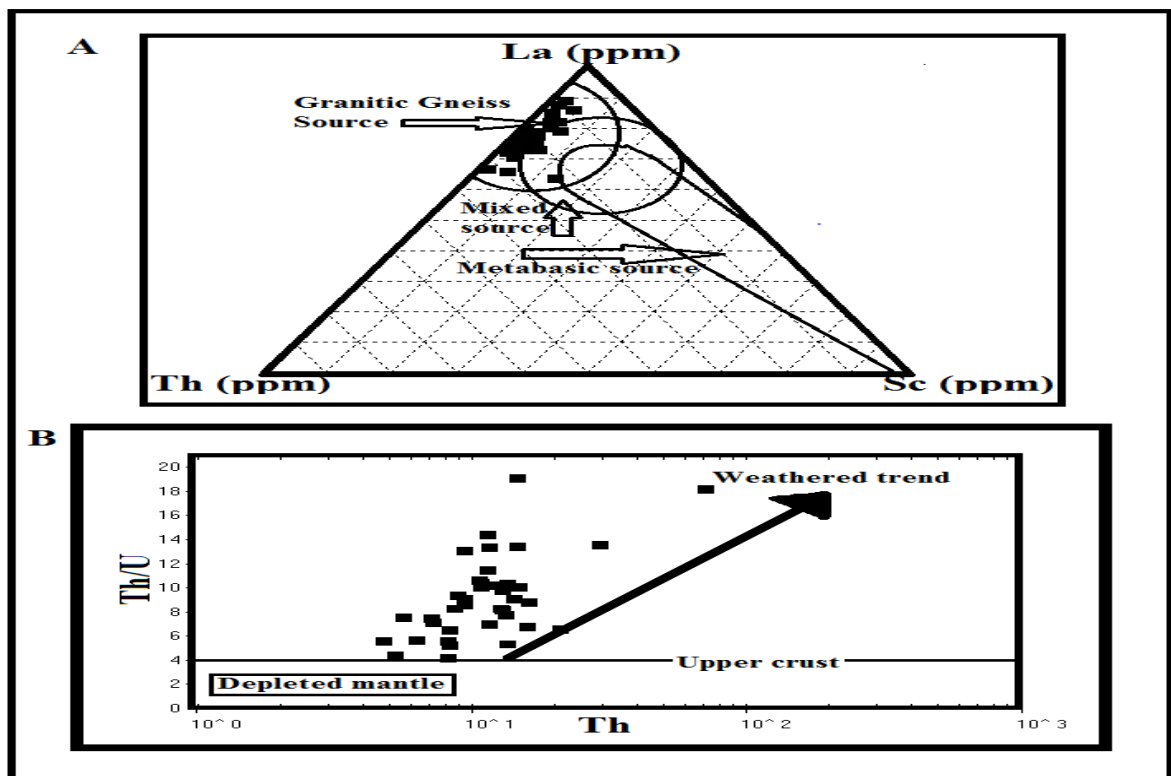


Figure 4: (A) La-Th-Sc ternary plot (Bhatia and Crook 1986) to assess the source of detrital contamination in stream sediments from Share SW. (B) Th/U vs. Th adopted from McLennan et al. (1993). Fields and trends from Gu et al. (2002). Th/U ratios higher than the upper crust value follow the weathering trend.

According to McLennan et al. (1993), the elemental ratio refers to the relative enrichment or depletion of the element, i.e., >1 indicates enrichment, <1 indicates depletion, and =1 indicates no change in the relative abundance of the element. The stream sediments have, CaO, K₂O, Na₂O, MgO, TiO₂ values less than 1, while Fe₂O₃, and Al₂O₃ have values



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greater than 1. The depletion of highly mobile Na, K and Ca, Mg and Ti elements is due to leaching during the formation of clay minerals during increased chemical weathering. The immobile Ti and the less mobile Mg elements were depleted while the immobile Fe was enriched; this suggests that they may be from a felsic source. Titanium is relatively immobile compared to other elements during sedimentary processes, and hence is a good indicator of source rock composition (McLennan et al., 1993).

Singh et al. (2009) noted that, there is a positive correlation between Ti and Fe (Figure. 5), Fe_2O_3 and TiO_2 in stream sediments can be expected to correlate positively due to sorting effects. Linear arrays of data points along lines extending toward the origin in binary Fe_2O_3 – TiO_2 plots demonstrate that the elements were immobile, and that they were also hydraulically fractionated in a similar manner (Young, et al., 2013). The Share SW stream sediments have $\text{TiO}_2/\text{Fe}_2\text{O}_3$ ratio between 0.15 and 1.59, which suggests concentration in the sediments of a heavy mineral phase containing Ti minerals such as, ilmenite and rutile.

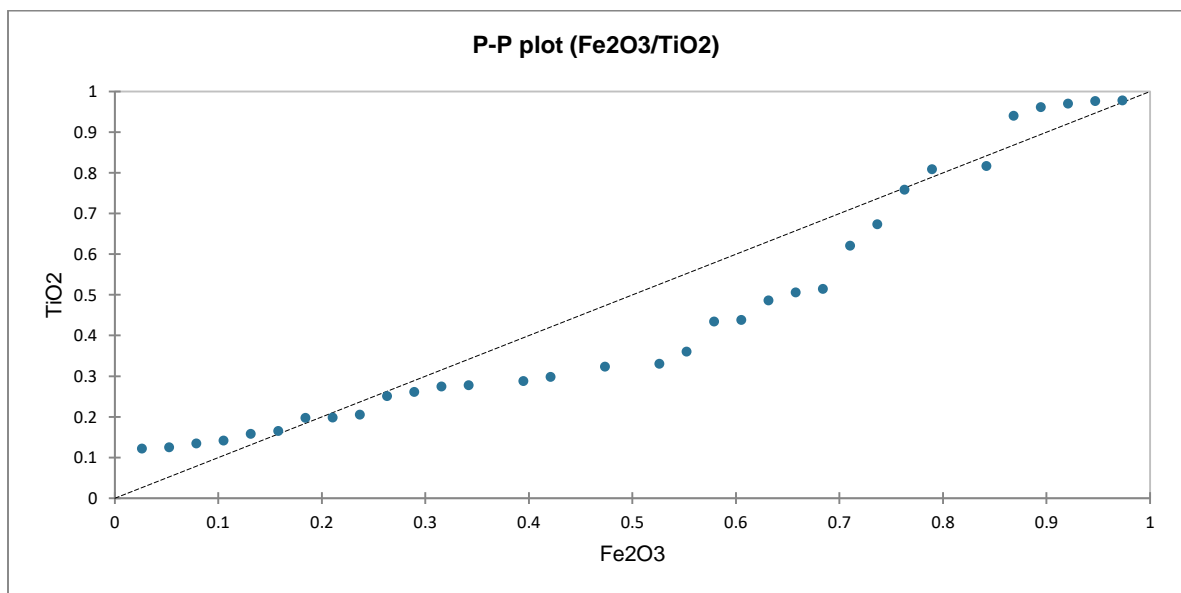


Fig. 5: Positive correlation of Fe_2O_3 – TiO_2 plots for the stream sediments



Provenance and tectonic settings

Several authors (Blatt et al., 1980; Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986 & 1988) have related sandstone geochemistry to specific tectonic environment. The discriminant function plot of Roser and Korsch (1988) defined four (4) main provenances: mafic igneous provenance; intermediate igneous provenance; felsic igneous provenance; and quartzose sedimentary provenance (Figure 6A) which shows the stream sediments samples ternary plotting in the field of mature intermediate igneous provenance, associated with a continental passive margin, intracratonic basins, or recycled orogenic provinces. Roser and Korsch (1986) created a tectonic discrimination diagram using La/Th ratio versus Hf (Figure 6) to determine the tectonic setting of clastic terrigenous sedimentary rocks. As depicted in (Figures. 7A to 7D), the ternary plot is used to discriminate between sediments deposited in the Passive Continental Margin (PM), Active Continental Margin (ACM) and the Oceanic Island Arc (OIA), just as Figure. 6 A and B also showed tectonic discrimination diagrams of Share SW stream sediments indicating the Passive Margin source.

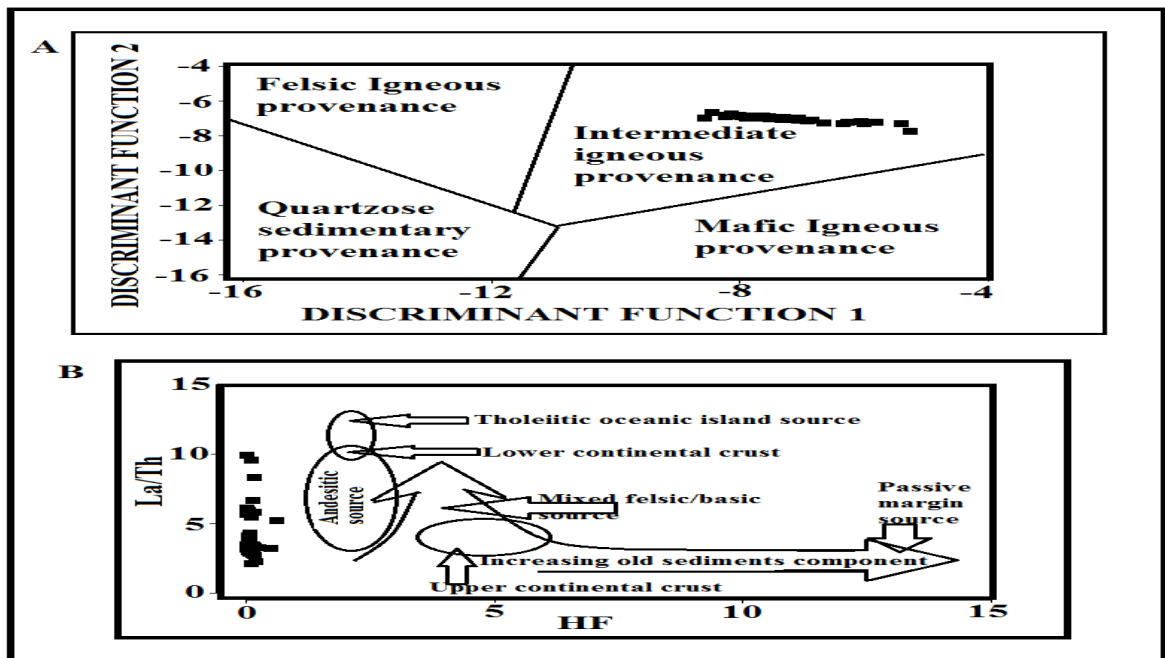


Figure. 6 A and B: Discriminant function diagram (Roser and Korsch, 1988) of major elements. The discriminant functions are: Discriminant Function 1 = $-1.773\text{TiO}_2 +$



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$0.607\text{Al}_2\text{O}_3 + 0.76\text{Fe}_2\text{O}_3$ (total) - $1.5\text{MgO} + 0.616\text{CaO} + 0.509\text{Na}_2\text{O} - 1.224\text{K}_2\text{O} - 9.09$. Discriminant Function 2 = $0.445\text{TiO}_2 + 0.07\text{Al}_2\text{O}_3 - 0.25\text{Fe}_2\text{O}_3$ (total) - $1.142\text{MgO} + 0.438\text{CaO} + 1.475\text{Na}_2\text{O} + 1.426\text{K}_2\text{O}$ - 6.861. (b) Bivariate plot of La/Th vs. Hf showing mixed provenance for the Share SW sediments (Modified after Floyd and Leveridge, 1987; Cullers, 1994).

Maynard et al. (1982), Bhatia (1983), Bhatia and Crook (1986), Roser and Korsch (1986) and Kroonenberg (1994) related sediments geochemistry to specific tectonic environment. The inter trace elements in clastic sediments have also been used in discrimination diagrams of plate tectonic settings (Varga and Szakmany, 2004), these elements can be transferred quantitatively into detrital sediments during weathering and transportation to reflect the signature of the parent material (Armstrong-Altrin et al., 2004). For this study, the discrimination diagrams of tectonic settings after Bhatia (1983) and Roser and Korsch (1986) were used to evaluate the tectonic setting of the Share SW stream sediment samples. In these diagrams (Figures. 7A to 7D), nearly all samples cluster near the field of passive margin (PM) setting (Moudioh et al., 2020).

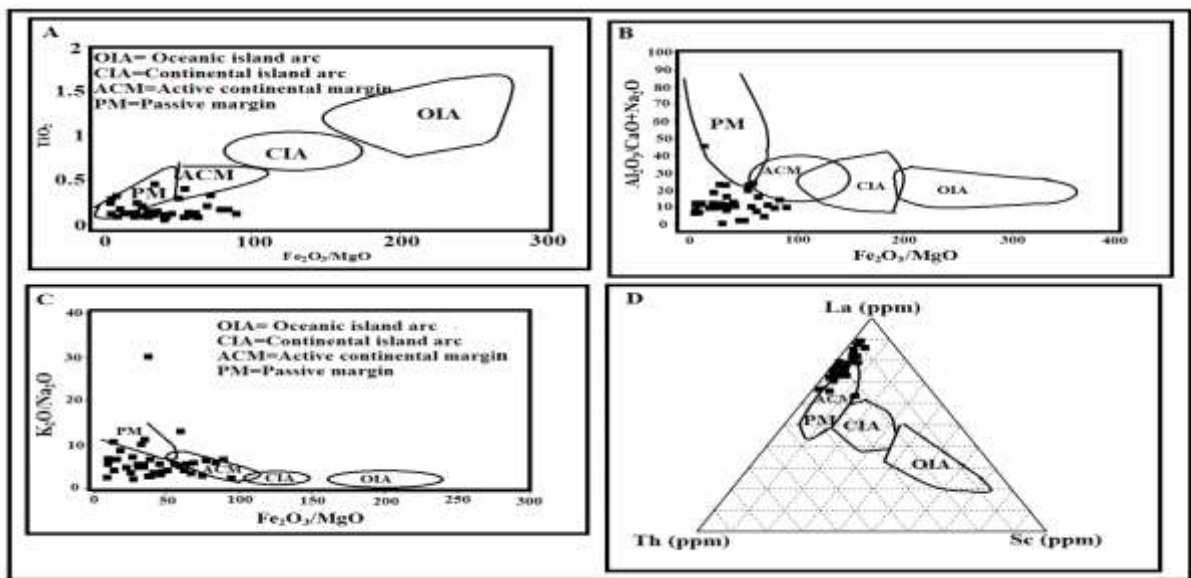


Figure 7: Tectonic discriminant diagrams for the Share stream sediment samples (A): $\text{Fe}_2\text{O}_3 + \text{MgO} - \text{TiO}_2$, (B): $\text{Fe}_2\text{O}_3^* + \text{MgO} - \text{Al}_2\text{O}_3 / (\text{CaO} + \text{Na}_2\text{O})$; Fe_2O_3^* represents total Fe expressed as Fe_2O_3 (C): $\text{Fe}_2\text{O}_3^* + \text{MgO} - \text{K}_2\text{O}/\text{Na}_2\text{O}$, (D): A ternary plot La – Th – Sc (Roser and Korsch, 1986; Bhatia, 1983))



CONCLUSION

The sediments can be classified as matured and non-calcareous. The maturity of these sediments are also confirmed with the moderate Zr–Hf content since Hf and Zr are closely associated in sediments and are both concentrated in zircon with stable mobile oxides in the sediments. The Index of Compositional Variability values also indicate that the sediments are mineralogically mature. The weathering indices indicates a high degree of weathering of the source materials. The depletion of highly mobile Na, K and Ca elements is due to leaching during the formation of clay minerals with increased chemical weathering. The immobile Fe and the less mobile Mg elements were depleted while the immobile Ti was enriched; this suggests that Fig 6 shows intermediate igneous. The Share SW stream sediments TiO₂/Fe₂O₃ ratios suggests concentration in the sediments of a heavy mineral phase containing Ti minerals such as, limonite and rutile. There is positive correlation between Ti and Fe due to sorting effects and hydraulic fractionation. The tectonic setting is the passive continental margin, while the provenance is the mixed felsic/basic sediments of mature continental provenance, associated with a continental passive margin, intracratonic basins, or recycled orogenic provinces.

REFERENCES

- Armstrong-Altrin, J. S., Lee, Y. I., Verma, S.P., Ramasamy, S. (2004). Geochemistry of sandstones from the upper Miocene kudankulam Formation, southern India: Implication for provenance, weathering and tectonic setting. *Journal of sedimentary Research*, 74(2): 285 – 297. <http://dx.doi.org/10.1306/082803740285>
- Armstrong-Altrin, J. S., Verma, S. P. (2005). Critical evaluation of six tectonic setting discrimination diagrams using geochemical data of Neogene sediments from known tectonic settings: *Sedimentary Geology*, 177(1-2): 115-129. <http://dx.doi.org/10.1016/j.sedgeo.2005.02.004>
- Bhatia, M. R. (1983). Plate tectonics and geochemical composition of sandstone. *J. Geol.*, 91: 611-627. <http://dx.doi.org/10.1086/628815>
- Bhatia, M. R. and Crook, K. W. (1986). Trace element characteristics of reywackes and tectonic setting discrimination of sedimentary basins. *Contributions to Mineralogy and Petrology*, 92: p.181-193. <http://dx.doi.org/10.1007/bf00375292>



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- Bhatt, M. I. and Ghosh, S. K. (2001). Geochemistry of 2.51Ga old Rampur Group pelites, western Himalayas: Implications from their provenance and weathering. *Precambrian Research*, 108, 1-16. [http://dx.doi.org/10.1016/s0301-9268\(00\)00139-x](http://dx.doi.org/10.1016/s0301-9268(00)00139-x)
- Blatt, H., Middleton G. and Murray R. (1972). *Origin of sedimentary rocks; Eaglewood cliffs* New Jersey Prentice-Hall. P.634. <http://dx.doi.org/10.1017/s0016756800000558>
- Chittleborough, D. J. (1991). Indices of weathering for soils and palaeosols formed on silicate rocks: *Australian Journal of Earth Sciences*, 38, 115–120. <http://dx.doi.org/10.1080/08120099108727959>
- Chombong, N. N., Suh, C. E. & Ilouga, D. C. (2013). New detrital zircon U-Pb ages from BIF related metasediments in the Ntem Complex (Congo craton) of southern Cameroon, West Africa. *Natural Science Journal*, 5, 835-847
- Cingolani, C. A., Manassero, M. & Abre, P. (2003). Composition, provenance, and tectonic setting of Ordovician siliciclastic rocks in the San Rafael block: Southern extension of the Precordillera crustal fragment, Argentina: *Journal of South American Earth Sciences*, 16(1): 91-106. [http://dx.doi.org/10.1016/s0895-9811\(03\)00021-x](http://dx.doi.org/10.1016/s0895-9811(03)00021-x)
- Condie, K. C. (1993). Chemical composition and evolution of the upper continental crust: contrasting results from surface samples and shales. *Chemical Geology*, 104, 1-37. [http://dx.doi.org/10.1016/0009-2541\(93\)90140-e](http://dx.doi.org/10.1016/0009-2541(93)90140-e)
- Cox, R., Lowe, D. R. & Cullers, R. L. (1995). The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States: *Geochimica et Cosmochimica Acta*, vol. 59: p.2919–2940. [http://dx.doi.org/10.1016/0016-7037\(95\)00185-9](http://dx.doi.org/10.1016/0016-7037(95)00185-9)
- Cullers, R. L. & Podkovyrov, V. M. (2000). Geochemistry of the Mesoproterozoic Lakhanda shales in southeastern Yakutia, Russia: Implications for mineralogical and provenance, and recycling. *Precambrian Research*, 104, 77-93. [http://dx.doi.org/10.1016/s0301-9268\(00\)00090-5](http://dx.doi.org/10.1016/s0301-9268(00)00090-5)
- Das, B.K., Haake, B. 2003. Geochemistry of Rewalsar Lake sediments, Lesser Himalaya, India: Implications for source-area weathering, provenance and tectonic setting. *J. Geosci.*, 7: p.299–312. <http://dx.doi.org/10.1007/bf02919560>



Lapai Journal of Science and Technology, Vol. 10, No. 1 (2024)

- Dickson, I. N. R. (1985). Interpreting provenance relation from detrital modes of sandstones, in Zuffa G. Gled.), provenance of Arenites: NATO ASI Series (148, D. Reidel Publishing Company. Dordrecht, 333 – 362.
- Dickinson, W. R., Beard, L.S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., Knepp, R. A., Lindberg, F. A. & Ryberg, P. T. (1983). Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, 94, 222-235. [http://dx.doi.org/10.1130/0016-7606\(1983\)94%3C222:ponaps%3E2.0.co;2](http://dx.doi.org/10.1130/0016-7606(1983)94%3C222:ponaps%3E2.0.co;2)
- Dickson, W.R., Suczek, C.A. 1979. Plate tectonics and sandstone compositions: American Association of petroleum Geologist, 63: 2164 – 2182.
- Duzgoren-Aydin, N. S., Aydin, A. and Malpas, J. 2002. Reassessment of chemical weathering indices: case study on pyroclastic rocks of Hong Kong. Engineering Geology, 63: p.99–119. [http://dx.doi.org/10.1016/s0013-7952\(01\)00073-4](http://dx.doi.org/10.1016/s0013-7952(01)00073-4)
- Fairchild, I., Graham, H., Martin, Q., & Maurice, T. 1999. Chemical Analysis of Sedimentary Rocks in: Techniques in Sedimentology (ed. T. Maurice), p. 274-354.
- Farquhar, S. M., Pearce, J. K., Dawson, G. K. W., Golab, A., Sommacal, S., Kirste, D., Biddle, D. & Golding, S. D. (2014). A fresh approach to investigating CO₂ storage: Experimental CO₂-water-rock interactions in a low-salinity reservoir system, Chemical Geology. P. 1-70. <http://dx.doi.org/10.1016/j.chemgeo.2014.10.006>
- Fedo, C. M., Nesbitt, H. W. & Young, G. M. (1995). Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance. Geology, 23: 10, p.921- 924. [http://dx.doi.org/10.1130/0091-7613\(1995\)023%3C0921:uteopm%3E2.3.co;2](http://dx.doi.org/10.1130/0091-7613(1995)023%3C0921:uteopm%3E2.3.co;2)
- Fedo, C. M., Young, G. M., Nesbitt, H. W. & Hanchar, J. M. (1997). Potassic and sodic metasomatism in the Southern Province of the Canadian Shield: Evidence from the Paleoproterozoic Serpent Formation, Huronian Supergroup. Canada Precambrian Research, 84, 17-36. [http://dx.doi.org/10.1016/s0301-9268\(96\)00058-7](http://dx.doi.org/10.1016/s0301-9268(96)00058-7)
- Folk, R. L. (1974). Petrology of sedimentary rocks. Hemphills Austin Texas. 159pp.
- Gill, S. & Yemane, K. (1996). Implications of a lower Pennsylvanian Ultisol for equatorial Pangean climates and early, oligotrophic, forest ecosystems. Geology, Vol. 24: No.



Lapai Journal of Science and Technology, Vol. 10, No. 1 (2024)

10, p. 905-908. [http://dx.doi.org/10.1130/0091-7613\(1996\)024%3C0905:ioalpu%3E2.3.co;2](http://dx.doi.org/10.1130/0091-7613(1996)024%3C0905:ioalpu%3E2.3.co;2)

- Grunsky, E. C., Drew, L. J. & Sutphin, D. M. (2009). Process recognition in multi-element soil and stream-sediment geochemical data. *Appl. Geochem.* 24, 1602–1616. <http://dx.doi.org/10.1016/j.apgeochem.2009.04.024>
- Gu, X.X., Liu, J. M., Zheng, M. H., Tang, J. X. & Qi, L. (2002). Provenance and Tectonic setting of the Proterozoic turbidites in Hunan, South China: Geochemical Evidence: *Journal of Sedimentary Research*, v. 72, p.393–407. <http://dx.doi.org/10.1306/081601720393>
- Halamic, J., Peh, Z., Bukovec, D., Miko, S. & Galovic, L. (2001). A factor model of the relationship between stream sediment geochemistry and adjacent drainage basin lithology, Medvednica Mt., Croatia. *Geol. Croat.* 54 (1), 37–51.
- Harnois, L. (1988). The C. I. W. index: a new chemical index of weathering. *Sedimentary Geology*, 55: p.319–322. [http://dx.doi.org/10.1016/0037-0738\(88\)90137-6](http://dx.doi.org/10.1016/0037-0738(88)90137-6)
- Hendry, J. P. & Trewin, N. H. (1993). Calcite-cemented layers in Deep-marine sandstones: Lower Cretaceous Scapa field, Witch Ground Graben, North Sea. *AAPG*
- Igwe, E. O., Amoke, G. U. & Ngwu, C. N. (2013). Provenance and Tectonic Setting of Amasiri Sandstone (Turonian) in Ugep Area, Southern Benue Trough, Nigeria: Evidences from Petrography and Geochemistry. *Global Journal of Science Frontier Research Environment & Earth Science*. Volume 13 Issue 2 Version 1.0: 32-40.
- Lindsey, D. A. (1999). An Evaluation of Alternative Chemical Classifications of Sandstones. United State Geological Survey Open-File Report, 99-346: 23pp.
- Liu, Z., Colin, C., Huang, W., Le, K.P., Tong, S., Chen, Z. & Trentesaux, A. (2007). Climatic and tectonic controls on weathering in South China and the Indochina Peninsula: clay mineralogical and geochemical investigations from the Pearl, Red, and Mekong drainage basins. <http://dx.doi.org/10.1029/2006gc001490>
- Maynard, J. B., Valloni, R. & Yu, H. S. (1982). Composition of modern deep-sea sands from arc-related basins: in Leggett, J.K., eds., *Trench forearc geology: sedimentation and tectonics on modern and ancient active plate margins*. *Geol. Soc. Lond. Spec. Pub.* 10: 551–561



Lapai Journal of Science and Technology, Vol. 10, No. 1 (2024)

- McLennan, S. M. (1993). Weathering and global denudation. *J. Geol.*, 101: p.295–303. <http://dx.doi.org/10.1086/648222>
- McLennan, S. M. & Taylor, S. R. (1991). Sedimentary rocks and crustal evolution: Tectonic setting and secular trends. *Journal of Geology*, 99, 1-21. <http://dx.doi.org/10.1086/629470>
- McLennan, S. M., Taylor, S. R. & Eriksson, K. A. (1983). Geochemistry of Archean shales from the Pilbara Supergroup, Western Australia. *Geochim. Cosmochim. Acta*, 47: p.1211–1222. [http://dx.doi.org/10.1016/0016-7037\(83\)90063-7](http://dx.doi.org/10.1016/0016-7037(83)90063-7)
- Nesbitt, H. W. & Young, G. M. (1982). Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, 299: 715–717. <http://dx.doi.org/10.1038/299715a0>
- Nesbitt, L. H. W., Mackovics, G. & Price, R. C. (1980). Chemical processes affecting alkali sand alkaline Earth during continental weathering. *Geochim. Cosmochim. Acta*, 44: p.1659–1666. [http://dx.doi.org/10.1016/0016-7037\(80\)90218-5](http://dx.doi.org/10.1016/0016-7037(80)90218-5)
- Nesbitt, L. H. W., Young, G. M., McLennan, S. M. & Keays, R. R. (1996). Effects of chemical weathering and sorting on the petrogenesis of siliclastic sediments, with implications for provenance studies. *Journal of Geology*, 104, 525-542. <http://dx.doi.org/10.1086/629850>
- Reimann, C. & Melezhik, V. (2001). Metallogenic provinces, geochemical provinces and regional geology—what causes large-scale patterns in low density geochemical maps of the C-horizon of podzols in Arctic Europe? *Appl. Geochem.* 16, 963–983. [http://dx.doi.org/10.1016/s0883-2927\(00\)00064-0](http://dx.doi.org/10.1016/s0883-2927(00)00064-0)
- Roser, B. P. & Korsch, R. J. (1986). Determination of tectonic setting of sandstone-mudstone suites using SiO₂ content and K₂O/Na₂O ratio. *J. Geol.*, 94: p.635-650. <http://dx.doi.org/10.1086/629071>
- Roser, B. P. & Korsch, R. J. (1988). Provenance signature of sandstone-mudstone suite determined using discriminant function analysis of major element data. *Chem. Geol.*, 67: p.119-139. [http://dx.doi.org/10.1016/0009-2541\(88\)90010-1](http://dx.doi.org/10.1016/0009-2541(88)90010-1)
- Singh, M., Sharma, M. & Tobschall, H. L. (2005). Weathering of the Ganga alluvial plain, northern India: implications from fluvial geochemistry of the Gomati River. *Appl. Geochem*, 20: p.1–21. <http://dx.doi.org/10.1016/j.apgeochem.2004.07.005>



Lapai Journal of Science and Technology, Vol. 10, No. 1 (2024)

- Singh, P. (2009). Major, trace and REE geochemistry of the Ganga River sediments: influence of provenance and sedimentary processes. *Chem. Geol.* 266, 242–255. <http://dx.doi.org/10.1016/j.chemgeo.2009.06.013>
- Suttner, L. J., Dutta, P. K. (1986). Alluvial sandstone composition and paleoclimate. L. Framework mineralogy. *Journal of sedimentary petrology*, Vol. 56: p. 329-345. <http://dx.doi.org/10.1306/212f8909-2b24-11d7-8648000102c1865d>
- Vital, H. & Stattegger, K. (2000). Major and trace elements of stream sediments from the lowermost Amazon River. *Chem. Geol.*, 168: p.151–168. [http://dx.doi.org/10.1016/s0009-2541\(00\)00191-1](http://dx.doi.org/10.1016/s0009-2541(00)00191-1)
- Young, S. M., Pitawala, A. & Ishiga, H. (2013). Geochemical characteristics of stream sediments, sediment fractions, soils, and basement rocks from the Mahaweli River and its catchment, Sri Lanka. *Chemie der Erde* 73, 357– 371. <http://dx.doi.org/10.1016/j.chemer.2012.09.003>