GEOCHEMISTRY OF SOILS FROM ODE IRELE AREA, SOUTHWEST NIGERIA, IMPLICATIONS: FOR PROVENANCE AND TECTONIC SETTING

Henry Y. Madukwe, Romanus A. Obasi & Olaosun Temitope
Department of Geology, Ekiti State University, Ado Ekiti, Ekiti State
NIGERIA

ABSTRACT

The study is aimed at determining the the provenance and tectonic settimg of soils from Ode Irele area of Ondo State, Nigeria. The provenance discriminant function diagram shows the samples plotting in the quartzose sedimentary provenance and mafic igneous provenance. The chondrite-normalized REE patterns for the Ode Irele soil displayed high LREE/HREE ratio, flat HREE pattern and pronounced negative Eu anomaly that is typical to that of UCC and PAAS suggesting derivation from felsic source rock. The bivariate plot of Na2O-K2O illustrates that the samples are quartz-rich, which suggests that they may be of felsic origin. The La/Co and Th/Co values of 9.94 and 6.67 respectively and the plot of La/Co vs Th/Co suggests a felsic source. The V-Ni-Th*10 ternary plot indicates derivation from felsic rocks. The TiO2 versus Zr plot, the bivariate plots of Th/Co vs. La/Sc ratios, Cr/Th against Th/Sc, Ti and Ni suggests derivation from felsic rocks. Plots of Y, Nb, Zr and Sc versus Th showed positive correlation. The incompatible element pairs Th–Y, Th–Zr, and Th–Nb show the effect of heavy mineral concentration and felsic source. The average Th/Sc nd Zr/Sc ratios of the sediment is 1.48 and 101.4 respectively, and a plot of Th against Sc shows the samples plotting around the Th/Sc = 1 axis suggesting a felsic source. The Ode Irele samples have an average Cr/V ratio of 0.8 while the Y/Ni ratio is 0.9; signifying a felsic source, also, a plot of Y/Ni vs. Cr/V follows the felsic calc-alkaline trend. Tectonic discrimination analyses using major oxides and trace and rare earth elements indicates passive margin tectonic setting.

Keywords: Ode Irele, provenance, tectonic setting, mafic, felsic.

INTRODUCTON

Major oxides and selected trace and rare earth elements and their elemental ratios are sensitive indicators of the provenance, 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; Johnsson and Basu, 1993; Condie, 1993; Nesbitt et al., 1996; Fedo, et al., 1997; Cullers and Podkovyrov, 2000; Bhatt and Ghosh, 2001). Several authors have used major element discrimination diagrams (Bhatia, 1983) to discriminate the tectonic settings of sedimentary basins and have been applied in topical publications (Kroonenberg, 1994; Zimmermann and Bahlburg, 2003; Armstrong-Altrin et al., 2004).

Rare earth elements Hf and Zr have been used to reflect the characteristics of their weathered parent rocks. Cullers, (1994) suggested that Eu/Eu* values of between 0.48 to 0.78 are indicative of felsic sources. Many geochemical parameters such as the REE patterns, ratios of LREE/HREE and European (Eu) have been used to infer the source of sediments either felsic or mafic provenance. Elements, Ni, Co, Cu Sc, and V may generally be used to describe rocks that are derived from either felsic or mafic and ultramafic sources. Cr, Ni and Co, REE and some ratios are suitable indicators of provenance studies due to their low mobility during sedimentary processes. The current research intends to identify the provenance and tectonic setting of the soil from Ode Irele utilizing major oxides, trace and rare earth elements.

MATERIALS AND METHODS

Fifteen soil samples were analysed by Laser ablation microprobe Inductively Coupled Plasma-Mass Spectrometry (La ICP-MS) method (Jackson et al., 1992) at the Central laboratory of the Stellenbosch University, South Africa. The ICP-MS instrument is a Perkin–Elmer Sciex ELAN 5100 coupled with a UV (266 nm) laser. The laser was operated with 1 mJ/pulse energy and 4 Hz frequency for silicate minerals, and 2 -Hz frequency with the laser beam focused above the sample surface for carbonates and silicate glass. Spot diameter for these analyses is 30–50 µm. NIST 610 glass was used as a calibration standard for all samples, with ^{44}Ca as an internal standard. Analytical precision is 5% at the ppm level. Details of ICP-MS and laser operating conditions have been published by Norman *et al*. (1996) and Norman (1998). The results of the analyses are reported in trace and rare earth elements. The post-Archean Australian Shale (PAAS) values were used for comparison while the REE data were normalized to the chondrite values of Taylor and McLennan (1985). The X-Ray Fluorescence Spectrometry (XRF) method was used to analyse for the major element concentrations at the Central laboratory of the Stellenbosch University, South Africa. The results are these oxides percent by weight S_IO_2, AL_2O_3, Fe_2O_3, CaO, MgO, K_2O, MgO, MgO, MnO, Na_2O, TiO_2 and LOI.

Local Geology

Figure 1 is a generalised geological map of Nigeria showing the location of the study area. Ondo State has two distinct geologic regions the sedimentary rocks in the south and the Basement rocks in the north. The study area falls in the sedimentary terrain within the eastern portion of the Dahomey Basin. The sedimentary basin of Ondo State is underlain by the Coastal Alluvium at the extreme south and along major river flood plain, the Coastal Plain Sands, the Imo Shale, Upper Coal Measures and Nkporo Shale. The sedimentary basin of Ondo State is bounded by Latitudes 5˚ 52ˈ and 7˚ 00ˈ N and Longitudes 4˚ 23ˈand 5˚ 54ˈE (Fig. 2). The terrain is flat with gently undulating topography. The Nkporo Shale is made up of shale, sandy clay and lenses of sand. The Upper Coal Measures clay/sandy clay, sand, limestone and shale. The Imo Shale Group is composed of shale while the Coastal Plain Sands have intercalations of clay/sandy clay and clayey sand/sand. The Quarternary Coastal Alluvium is composed of an alternating sequence of sand and silt/clay (Jones and Hockey, 1964 and Etu-Efeotor and Akpokodje, 1990).

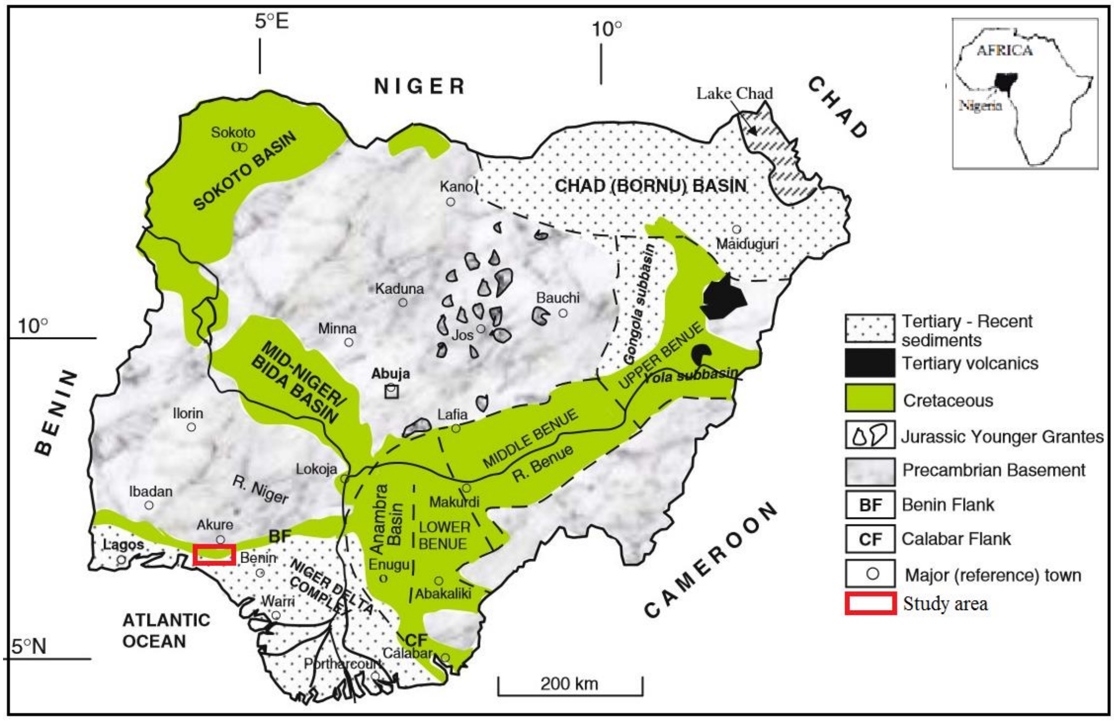

Figure 1. Geological map of Nigeria showing the study area, Basement Complex and other geological units, after Obaje (2011).

RESULTS AND DISCUSSION

Provenance

The chemical constituent of the samples studied is shown in Tables 1, 2 and 3. Inorganic geochemical data and their applications are important for provenance studies (e.g. Taylor and McLennan, 1985; Condie et al., 1992; Cullers, 1995; Armstrong-Altrin et al., 2004). According to McLennan et al., (1993), major elements provide information on both the rock composition of the provenance and the effects of sedimentary processes, such as weathering and sorting. These elucidates on the attributes of the source rocks and providing definite patterns of sedimentary history

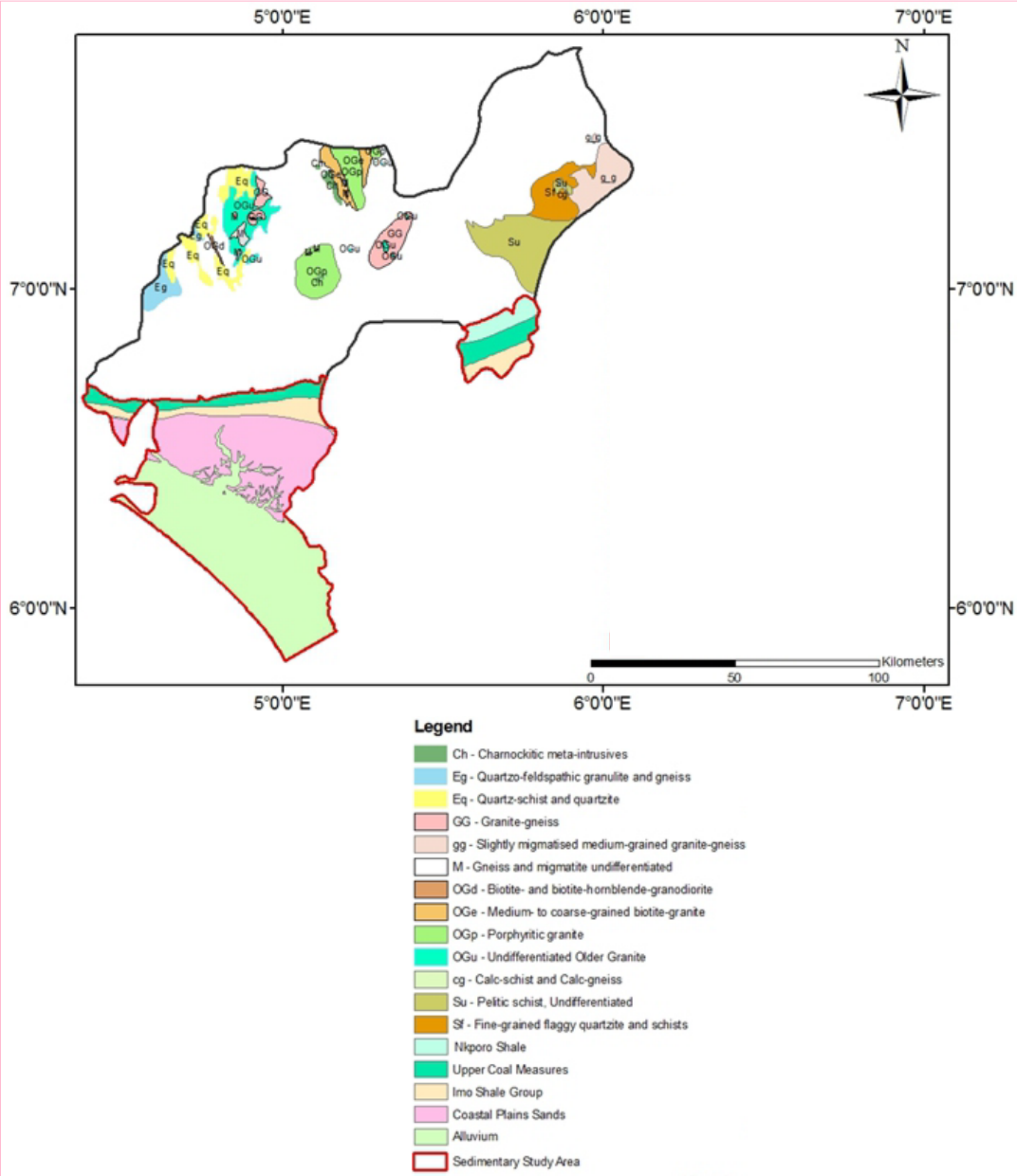

Figure 2. Generalized geologic map of Ondo State (Adapted from the Geological Survey of Nigeria (GSN, 1966)

(Dickinson, 1985, 1988). The provenance 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 (Fig. 3). The samples plotted in the quartzose sedimentary and mafic zones. According to Roser (2000), sediments recycled from felsic sources plot progressively away from the igneous source line into the quartzose field. Mean values of La/Co and Th/Co for the Ode Irele samples are 9.94 and 6.67 respectively. According to Cullers and Berendsen (1998), sands derived from

granitoid sources show higher La/Co and Th/Co values than those derived from basic sources. Figure 4 shows the samples plotting close to the granite plot, which suggests a felsic source. The bivariate plot of Na_2O-K_2O illustrates that the samples are quartz-rich, which suggests that they may be of felsic origin (Fig. 5). The ternary diagram in figure 6 shows all the samples plotting in the quartz apex, which suggests derivation from a felsic source. In the V-Ni-Th*10 (Fig. 7) ternary diagram, all the samples plotted in the felsic source area and the plot of La-Th-Sc (Fig. 8) of the analyzed samples suggest derivation from felsic rocks.
The concentration of zircon is utilised to characterize the nature and composition of source rock (Hayashi et al., 1997; Paikaray et al., 2008). Hayashi, et al. (1997) stated that the TiO_2/Zr ratios can be used to distinguish the different igneous source rock types, i.e., felsic, intermediate and mafic. The TiO_2 versus Zr plot (Fig. 9) shows most of the sediments plotting in the intermediate zone, while some appeared in the felsic zone. The bivariate plot of Th/Co *vs*. La/Sc ratios (Fig. 10) of the Ode Irele soil suggests derivation from felsic rocks.

Table 1. Major oxides geochemical composition of Ode Irele soil

OXIDES	OD1	OD2	OD3	OD4	OD5	OD6	OD7	OD8	OD9	OD10	OD11	OD12	OD13	OD14	OD15
SiO_2	59.44	81.48	66.36	65	60.29	79.76	70.97	67.75	75.06	60.97	86.65	69.87	59.86	68.72	70.67
Al_2O_3	21.14	8.32	16.44	17.37	19.86	9.53	14.11	15.85	11.2	19.16	5.86	12.52	20.49	15.53	13.99
Fe_2O_3	7.28	2.93	6.1	6.34	7.16	3.77	5.41	6.37	5.11	6.98	2.5	4.94	7.29	5.2	5.07
MnO	0.04	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.06	0.02	0.04	0.05	0.02	0.04
MgO	0.02	0	0.2	0.2	0.3	0	0	0	0.01	0.04	0	0.07	0.03	0,01	0.01
K_2O	0.08	0.06	0.1	0.07	0.09	0.05	0.07	0.08	0.06	0.1	0.04	0.12	0.09	0.08	0.08
CaO	0.06	0.12	0.05	0.08	0.11	0.02	0.05	0.03	0.06	0.1	0.05	0.27	0.09	0.02	0.18
Na_2O	0	0.01	0	0.01	0.01	0	0.02	0	0	0.01	0	0.02	0.02	0	0
TIO_2	1.66	0.98	1.66	1.79	1.76	1	1.39	1.33	1.38	1.79	0.87	1.49	1.58	1.46	0
P_2O_5	0.12	0.07	0.1	0.09	0.11	0.06	0.07	0.08	0.06	0.14	0.05	0.1	0.4	0.07	1.47

Table 2. Trace elements composition of Ode Irele soil

Elements	Sc	V	Cr	Co	Ni	Cu	Zn	Rb	Sr	Y	Nb	Mo	Ba	Zr	Th	U	Pb	Ta
OD1	19.07	119	91	4.16	33.2	23.19	45.8	8.02	39	26.32	45.56	3.41	55.4	1343	25.51	4.01	29.66	2.95
OD2	10.67	55.5	51.2	3.22	17.1	12.19	23.2	6.06	21.08	15.26	23.74	1.56	33.8	974.3	14.1	2.19	14.82	1.52
OD3	15.25	104.6	83.8	4.12	25.5	15	30.9	6.96	33.49	20.46	41.99	2.97	57.8	1780	26.76	3.92	23.79	2.79
OD4	15.75	108.3	95.1	4.89	33.8	16.28	64.7	4.87	30.82	22.25	46.08	3.02	46.2	2175	29.44	4.06	23.91	3.05
OD5	16.73	117.7	88	4.9	35.7	21.8	52.6	7.67	37.4	25.05	44.88	3.17	51.6	1766	28.77	4.05	27.56	2.83
OD6	11.33	61.7	52.7	2.53	14.8	13.25	21.9	4.27	18.22	10.02	25.66	1.81	34.8	736.7	14.1	2.01	13.77	1.76
OD7	14.61	89.6	68.3	2.53	24.5	16.87	28.2	5.67	27.18	22.28	35.24	2.56	45.6	1432	21.83	3.33	20.72	2.32
OD8	16.23	94.7	78.4	4.04	36.2	23	35.2	6.33	26.94	13.7	34.56	3.04	37.9	981.1	19.35	2.76	20.56	2.23
OD9	12.94	80.6	67	3.96	12.2	29.4	50	5.14	25.45	19.04	35.61	2.83	41.1	1674	19.82	3.22	19.01	2.39
OD10	18.09	116.3	88.4	3.21	32.9	29.8	47.3	8.5	44.4	21.69	46.74	3.09	60.5	1400	25.72	4.01	29.45	3.18
OD11	10.69	43.39	45.4	5.24	14.3	8.85	24.8	3.14	13.3	14.48	20.81	1.06	24.6	1272	11.74	2.27	11.01	1.26
OD12	13.77	85	68.4	1.63	17.5	12.54	38.1	7.83	34.3	19.64	42.96	2.57	51.9	1725	22.67	3.87	18.11	3.73
OD13	17.37	110.6	91.9	2.79	36.7	37.3	60.9	9.11	39.71	21.06	36.74	3.02	54.1	1312	24.36	3.42	27.16	2.7
OD14	13.69	89.6	73.9	3.11	22.5	12.79	28.4	5.97	30.5	20.27	36.33	2.61	49.7	1454	23.82	3.62	22.57	2.48
OD15	13.94	85.2	80.2	2.99	22.8	24.4	54	10.05	34.04	25.77	44.08	2.39	47	1532	19.64	3.29	23.26	2.31
Average	14.68	90.79	74.91	3.55	25.31	19.82	40.4	6.64	30.38	19.82	37.39	2.61	46.13	4204	21.84	3.34	22.42	2.5
UCC	11	60	35	10	20	25	71	112	350	22	25	-	550	190	10.7	2.8	-	2.2
PAAS	16	150	110	23	55	50	85	160	200	27	19	-	650	210	14.6	3.1	20	-
NASC	14.9	130	125	25.7	58	-	-	125	142	35	13	-	636	200	12.3	2.66	-	1.12

To better constrain the mafic or ultramafic versus felsic character of the analysed samples, elemental ratios such as Cr/Th and Th/Sc were considered (Fig. 11). According to Hofmann et al (2003), high values of these ratios reflect enrichment in mafic-ultramafic and felsic components respectively. The Ode Irele samples fit a mixing hyperbolic curve between felsic and mafic end members with a major contribution from the felsic end member. Immobile elements, such as Ti and Ni, can be used to determine the original lithological composition of rocks and to separate immature sediments derived from a magmatic source from normal mature sediments (Floyd et al., 1989). The Ode Irele samples plots within the area of an acidic or felsic source (Fig. 12). According to Holland (1978); Bhatia and Crook (1986), elements such as Sc, Y, Ti, Zr, Th and Nb are appropriate for provenance and tectonic setting determination because of their relatively low mobility during sedimentary processes, and their short times in seawater (Holland, 1978; Taylor and McLennan, 1985; Cullers, 1988). These elements are transported quantitatively into clastic sediments during weathering and transport, and hence reflect the signature of the parent material (McLennan et al., 1983). Plots of Y, Nb, Zr and Sc versus Th showed positive correlation. The incompatible element pairs Th–Y, Th–Zr, and Th–Nb (Fig. 13) show the effect of heavy mineral concentration and felsic source. Cr/V–Y/Ni ratios also provide estimates of preferential concentration of chromium over other ferromagnesian elements (Hiscott, 1984; McLennan et al., 1993). The Cr/V ratio measures enrichment of Cr with respect to other

Table 3. Rare earth elements composition of Ode Irele soil.

Elements	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy
OD1	47.06	101.84	7.81	24.51	4.6	0.76	3.14	0.59	4.14
OD2	30.41	53.2	5.07	15.76	2.37	0.33	2.23	0.31	2.25
OD3	42.67	80.8	7.42	23.32	4.4	0.63	2.81	0.49	3.65
OD4	44.88	89..76	8.18	25.83	4.39	0.61	3.17	0.49	3.44
OD5	46.28	88.3	7.67	25.22	3.63	0.6	3.37	0.55	3.64
OD6	20.71	41.37	3.5	11.15	1.68	0.33	1.54	0.26	1.56
OD7	34.02	72.03	5.9	19.26	3.16	0.63	2.81	0.45	3.65
OD8	25.76	52.8	4.02	13.07	2.29	0.42	2	0.32	2.04
OD9	30.02	55.52	4.25	16.01	2.43	0.52	2.13	0.34	2.98
OD10	47.85	86.1	7.68	23.6	3.67	0.62	2.66	0.52	3.46
OD11	16.26	32.8	2.82	9.46	1.13	0.28	1.33	0.28	1.95
OD12	33.85	66.98	6.05	20.32	3.18	0.38	3.11	0.48	3.35
OD13	41.32	92.24	6.51	12.12	3.65	0.61	2.95	0.52	3.14
OD14	42.58	74.23	7.22	24.2	3.73	0.59	3.16	0.34	3.2
OD15	30.02	62.3	5.07	17.28	2.61	0.51	2.67	0.44	3.4
Average	38.58	70.02	5.94	18.74	3.13	0.52	2.61	0.41	3.09
UCC	30	64	7.1	26	4.5	0.88	3.8	0.64	3.5
PAAS	38	80	8.9	32	5.6	1.1	4.7	0.77	4.4

Table 3. Rare earth elements composition of Ode Irele soil (continued)

Elements	Ho	Er	Tm	Yb	Lu	LREE	HREE	LREE/HREE	ΣREE	Eu/Eu*
OD1	0.88	3.05	0.46	3.45	0.56	185.82	9.57	19.42	196.71	0.61
OD2	0.5	2.08	0.28	2.01	0.35	106.81	9.66	11.06	117.15	0.44
OD3	0.7	2.44	0.43	2.89	0.49	158.61	13.41	11.83	173.14	0.55
OD4	0.79	2.65	0.42	2.99	0.53	173.04	13.95	12.4	188.13	0.49
OD5	0.79	2.92	0.47	3.39	0.56	171.1	15.13	11.31	187.45	0.52
OD6	0.37	1.12	0.17	1.28	0.24	78.41	6.3	12.45	85.28	0.63
OD7	0.79	2.71	0.41	2.98	0.49	1`34.37	13.8	9.74	148.29	0.65
OD8	0.49	1.76	0.27	1.9	0.34	97.94	8.78	11.15	107.48	0.6
OD9	0.65	2.26	0.35	2.53	0.43	108.23	11.24	9.63	120.42	0.69
OD10	0.77	2.64	0.41	2.92	0.51	168.9	13.38	12.62	183.41	0.61
OD11	0.54	1.79	0.28	2.16	0.32	62.47	8.38	7.45	71.45	0.69
OD12	0.74	2.29	0.4	2.8	0.47	130.38	13.17	9.89	144.4	0.37
OD13	0.76	2.46	0.35	2.9	0.46	155.84	13.08	11.91	169.99	0.57
OD14	0.67	2.16	0.31	2.85	0.45	151.96	12.58	12.08	165.58	0.52
OD15	0.82	2.86	0.43	3.1	0.52	117.28	13.72	9.22	132.03	0.59
Average	0.68	2.35	0.36	2.68	0.45	133.41	11.74	11.48	146.06	0..60
UCC	0.8	2.3	0.33	2.2	0.32	131.6	13.57	9.7	146.37	0.65
PAAS	1	2.9	0.4	2.8	0.43	164.5	16.97	9.69	183	0.66

ferromagnesian elements, whereas the Y/Ni ratio evaluates the relationship between the ferromagnesian trace elements (represented by Ni) and the HREE, using Y as a proxy (McLennan et al., 1993). Y/Ni ratios generally range across values typical of intermediate to felsic calc-alkaline rocks. Sediments derived from ultrabasic sources usually have high Cr/V ratios much greater than 1 coupled with low Y/Ni less than 1 (Hiscott, 1984). The Ode Irele samples have an average Cr/V ratio of 0.8 while the Y/Ni ratio is 0.9; signifying a felsic source (Fig. 14).

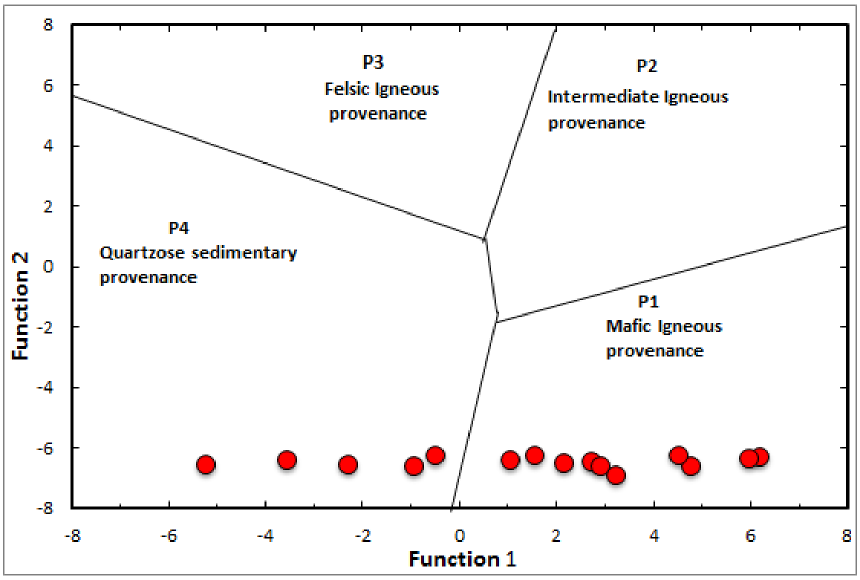

Figure 3. Discriminant function diagram using major elements for the provenance signatures of the sediments (After Roser & Korsch, 1988).

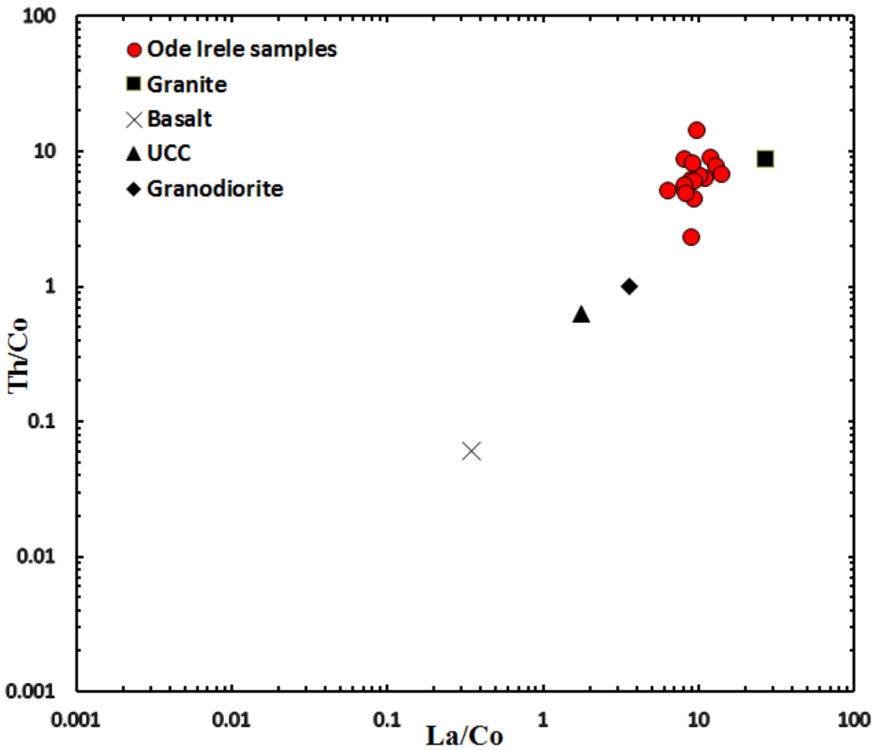

Figure 4. Source rock discrimination diagram of the stream sediments (after Cullers and Berendsen 1998), in relation to average values of granites, basalts, granodiorite (Taylor, 2015) and upper continental crust (Taylor and McLennan, 1985; 1995).

Totten et al. (2000) revealed that Th/Sc ratios near a value of 1.0 are typical of the upper continental crust which tends to be more enriched in the incompatible element Th; whereas, a more mafic component has a ratio near 0.6 and tends to be more enriched in the compatible element Sc. The Th/Sc ratio for the samples studied ranges from 1.10 and 1.87 with an average of 1.48; figure 15 also shows the samples plotting around the Th/Sc = 1 axis suggesting a felsic source.

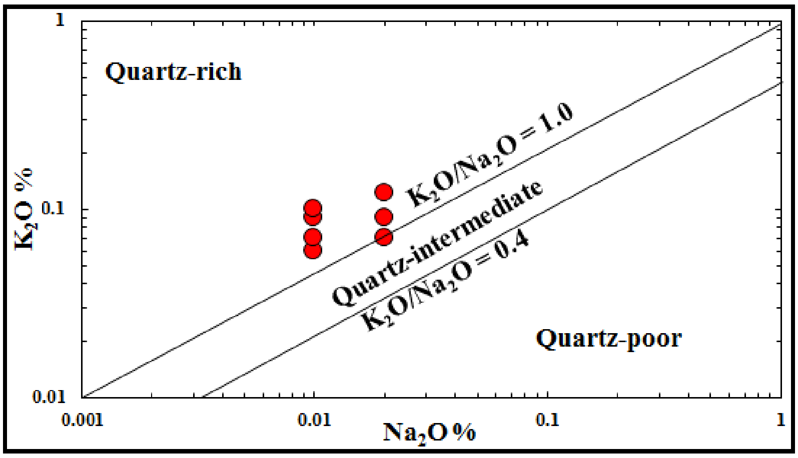

Figure 5. Bivariate Plot of Na2O versus K2O of the studied sediments showing quartz content, after Crook (1974)

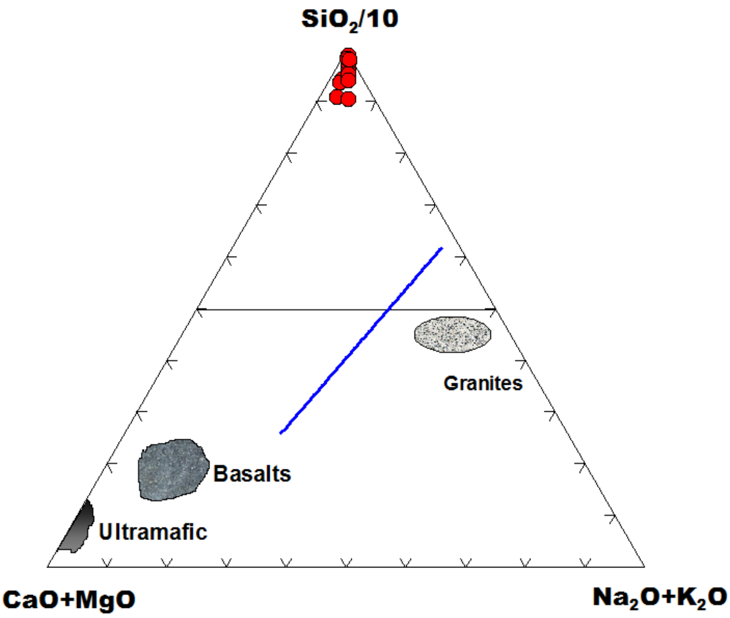

Figure 6. Plot of Na2O + K2O, SiO2/10 and CaO + MgO to illustrate possible affinities of the samples to felsic, mafic or ultramafic rocks (after Taylor and McLennan, 1985)

The Th/Sc ratio is a sensitive index of the bulk composition of the source (Taylor and McLennan, 1985). The average Th/Sc ratio of the sediment is 1.48. The Th/Sc ratio for post-Archean rocks is usually ~1, and greater than 1 for granitic rocks; for Archean and basic rocks the ratio is less than 1 (Taylor and McLennan, 1985). Zr/Sc ratio is highly sensitive to accumulation of zircon and serves as a proxy for identifying heavy mineral concentrations (Taylor and McLennan, 1985). The average Zr/Sc ratio of the sediment is 101.4, this value is greater than the UCC and PAAS values suggesting that the stream sediments are enriched in zircon, which is a component of felsic rocks. All elements involved in the ratios are also resistant to weathering processes (Taylor and McLennan, 1985; McLennan et al., 1993).

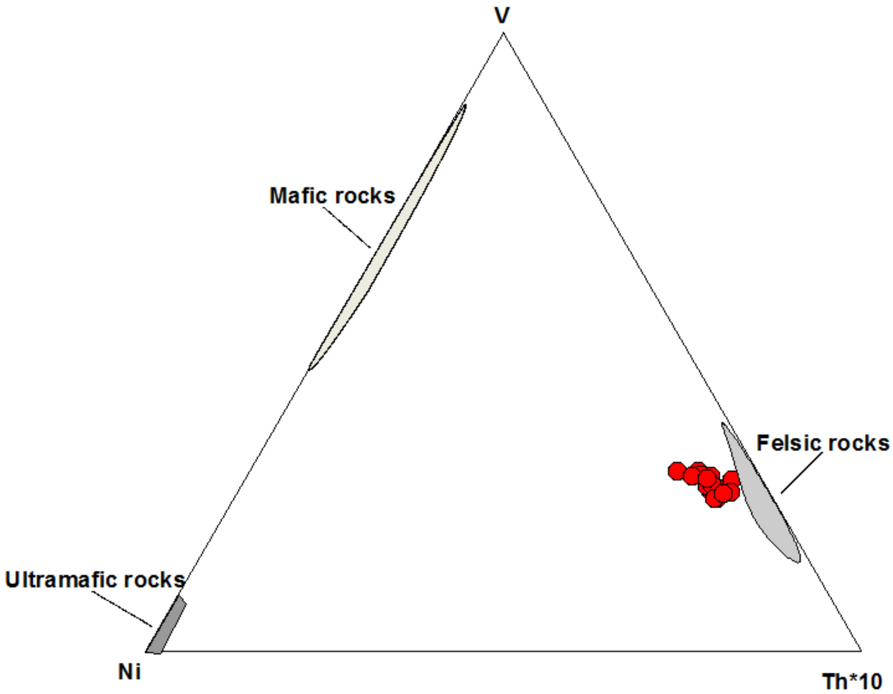

Figure 7. V-Ni-Th*10 plot of the stream sediments (Bracciali et al., 2007). Shaded areas represent composition of the felsic, mafic and ultramafic rocks.

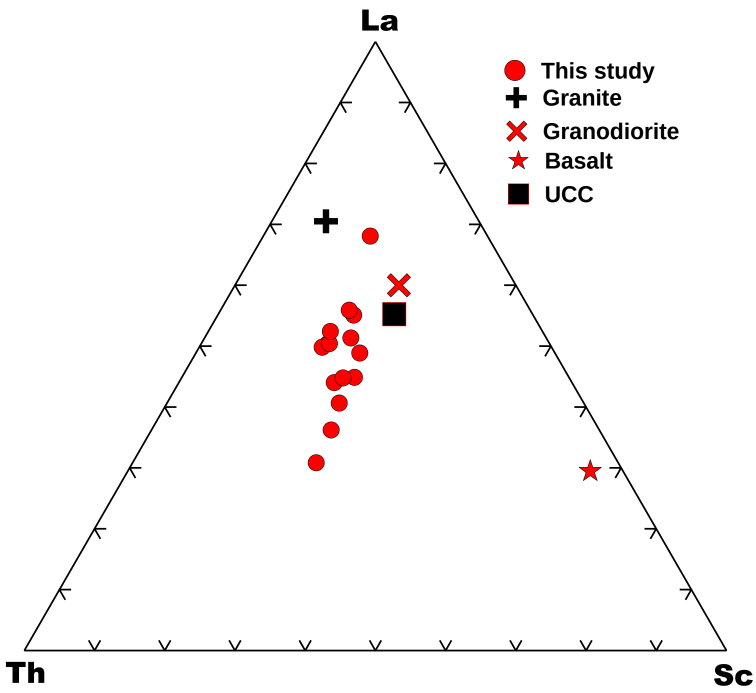

Figure 8. La-Th-Sc ternary plot of the stream sediments (after Jahn and Condie, 1995). Composition of granite, granodiorite, basalt and UCC are also plotted as references

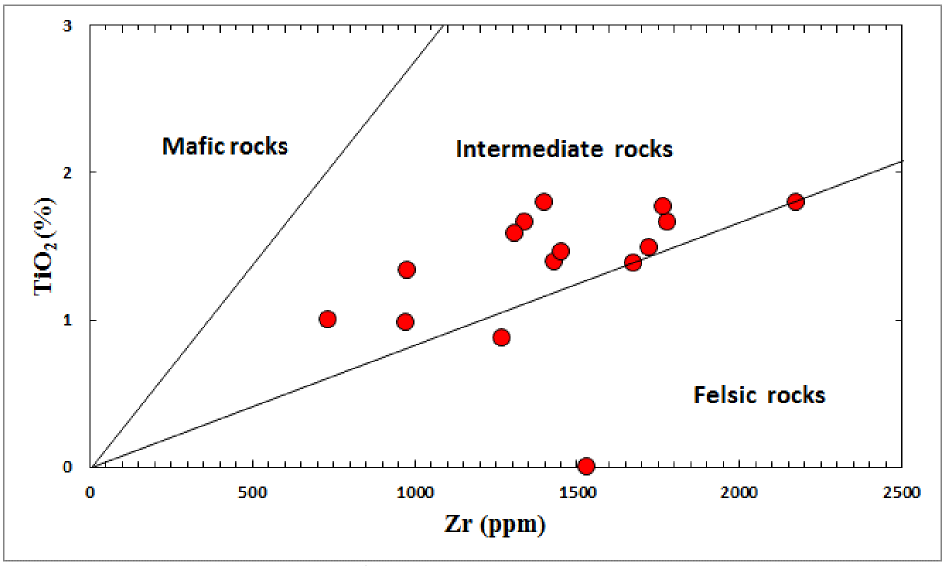

Figure 9. TiO_2-Zr plot for the Ode Irele samples (Hayashi et al., 1997).

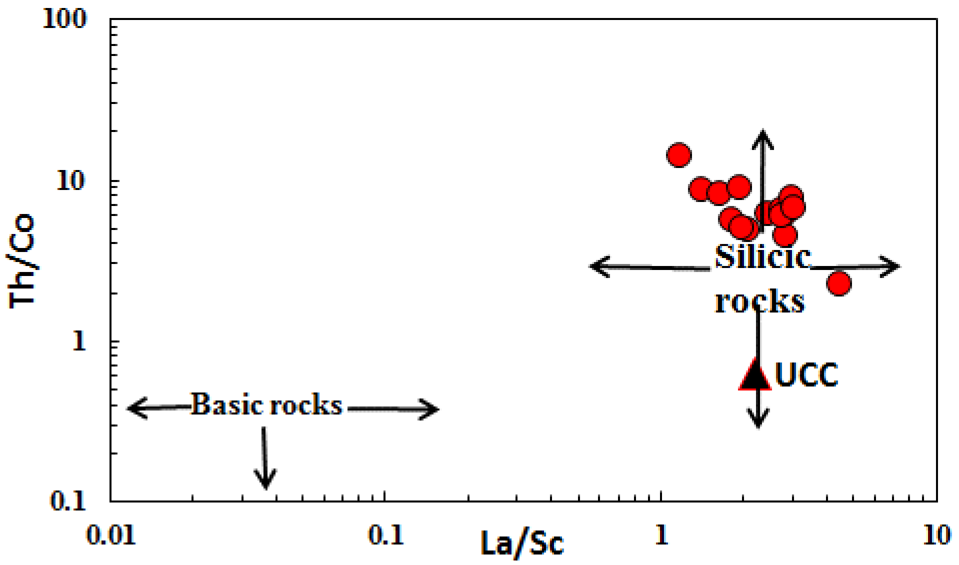

Figure 10. Th/Co versus La/Sc diagram for the Ode Irele samples (Fields after Cullers, 2000)

Figure 16 (A) shows that the stream sediments exhibit a limited range, suggesting homogenization and possibly increased maturity during transport. Higher Zr/Sc and Th/Sc ratios in some of the samples suggests limited zircon concentration (Garver et al., 1996). The broad relationship between Th/Sc and Zr/Th for the studied samples further reveals that the addition of zircon to the sediments by sorting and recycling might have important influence on these ratios (Fig. 16B).

Garver et al. (1996) and Amstrong-Altrin (2004) suggested that when Cr is greater than 150 ppm and Ni greater than 100 ppm in abundance, it is an indication of mafic or ultramafic provenance. Interestingly, Cr (74.91) and Ni (25.31) have low concentrations relative to the conditions above and to PAAS thus confirming a felsic source. La and Th are immobile elements which are abundant in felsic than in mafic rocks. La (34.96) is higher than UCC (30.00) and slightly similar to PAAS (38.00), while Th (21.48) is higher than PAAS (14.6). Sc and Co are more concentrated in mafic than in felsic rocks (Wronliewicz and Condie, 1987; Condie et al., 1995). Cr/Th ratio can be used to infer felsic source. Cullers, (1994) suggested that Cr/Th ratio that range between 2.5 and 17. The value of Cr/Th ratio in the study area range from 3.06 to 4.08 showing a concentration within the felsic range.

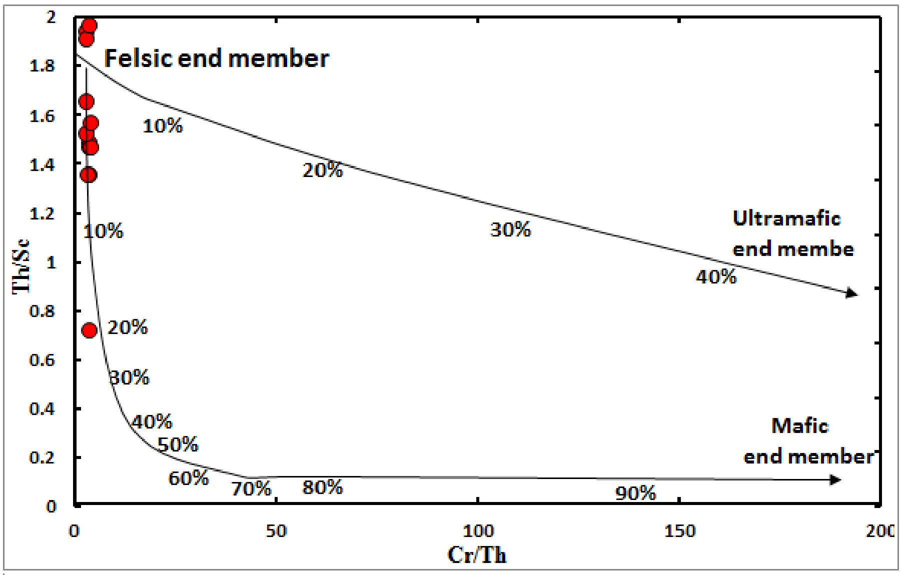

Figure 11. Plot of Th/Sc Cr/Th ratio of the studied samples (Condie and Wronkiewicz, 1990; Totten et al., 2000). Two mixing curves have been calculated between a felsic and mafic end member, and between a felsic and ultramafic end member. Percentages reported on the mixing curves represent the mafic end-member contribution to the mixing products,

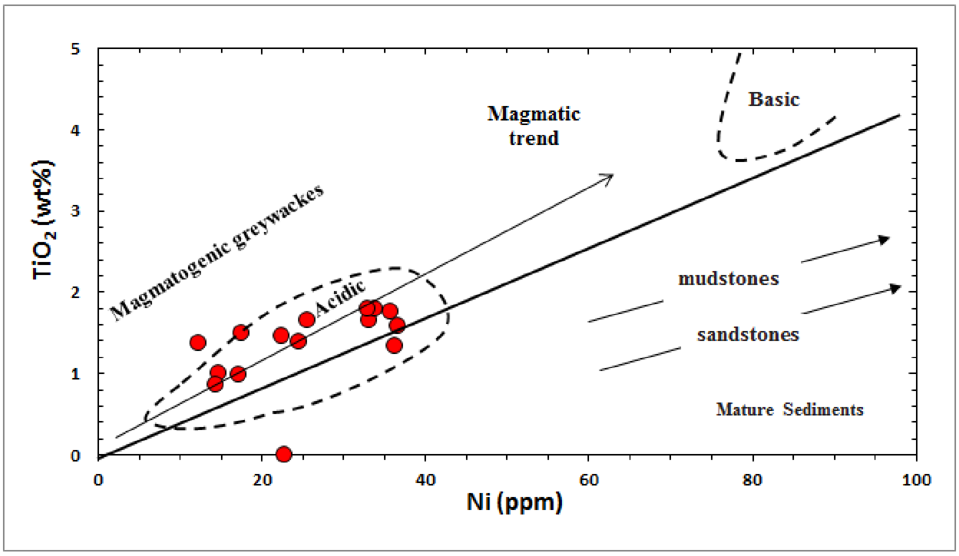

Figure 12. TiO_2 vs. Ni plot. Fields and trends after Gu et al. (2002) and Floyd et al. (1989).

The summation (ΣREE) of the REEs ranges between 85.28 and 196.71 ppm (Average = 146.06 ppm) and relatively close to the average upper continental crust (Taylor and McLennan, 1985). The values of the Light rare elements (LREE) varies from 78.41 to 185.82 ppm with an average of 133.41 and this is relatively close to the UCC (131.60), while the heavy REEs (HREE) contents vary between 6.30 and 15.13 ppm (Average=11.74). The ratio of LREE/ HREE ranges from 7.45 to 19.42 ppm (Average =11.48). Many geochemical parameters such as the REE patterns, ratios of LREE/HREE and European (Eu) have been used to infer the source of sedimentary rocks and sediments of either felsic or mafic provenance (Mongelli et al.,1998; Culler, 2002). The chondrite-normalized pattern is typical of sediments and sedimentary rocks which are enriched in light REE (LREE) with flat heavy REE (HREE) and negative Eu anomaly (Borges et al., 2008). The LREE is enriched relative to HREE. The relative enrichment of the incompatible elements (LREEs 133.11) and Th (21.84) relative to UCC (10.7) and PAAS (14.6) respectively over depleted compatible elements of Co (3.56) and Sc (14.68) relative to PAAS (23) and (16) respectively for Co and Sc in the

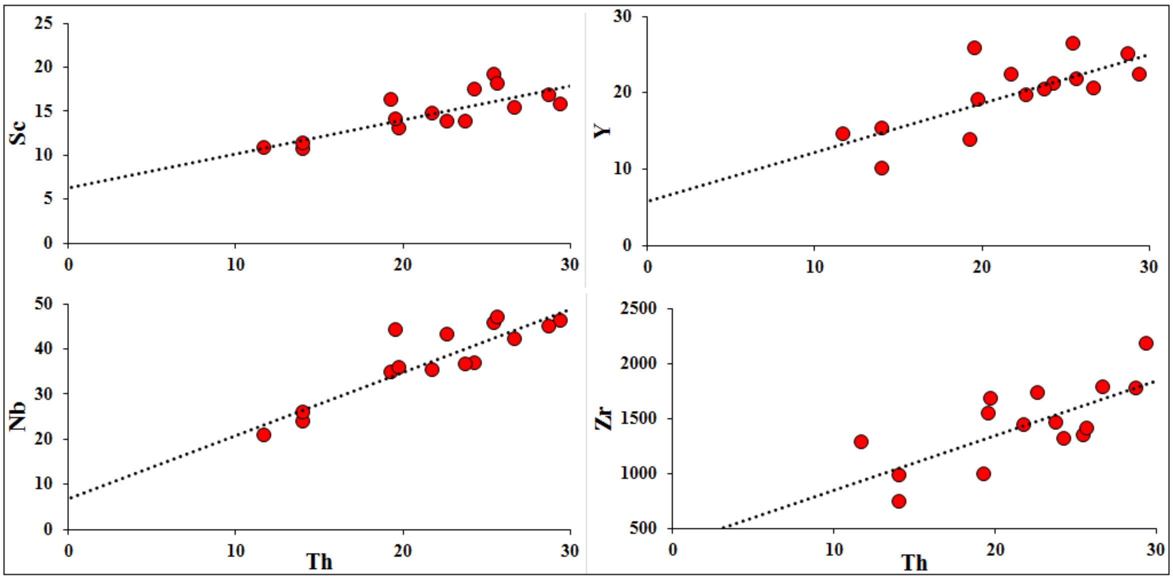

Figure.13. Plots of Sc, Y, Nb and Zr versus Th for the Ode Irele samples.

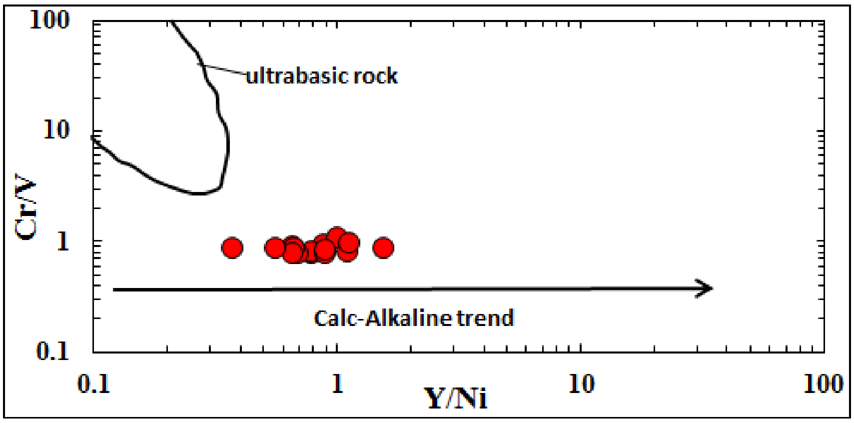

Figure 14. Cr/V–Y/Ni plots for the Ode Irele samples (After McLennan et al., 1993). Ultrabasic field after Ortiz and Roser, 2006.

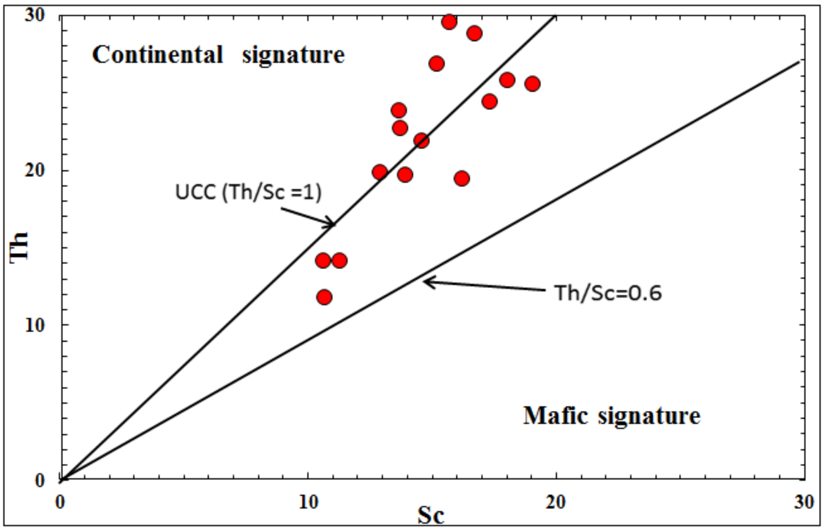

Figure 15. Th vs. Sc plot. Fields and trends from Totten et al. (2000).

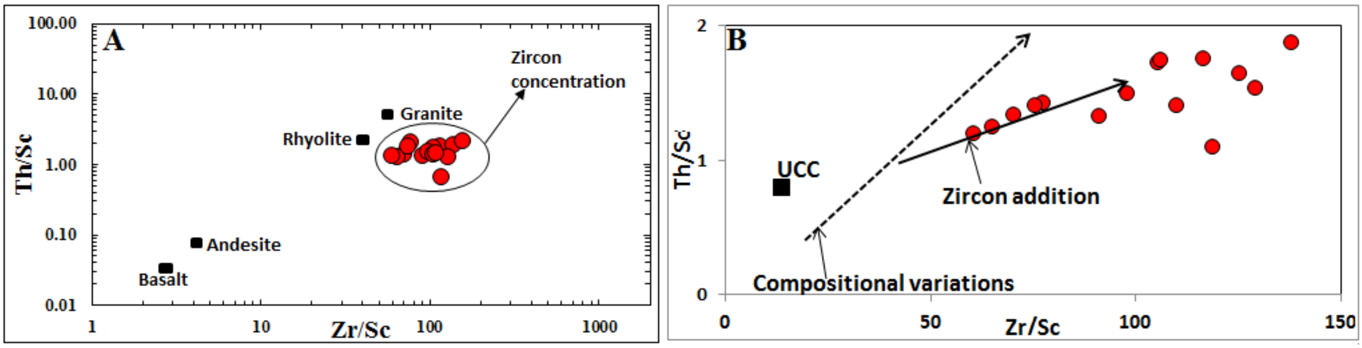

Figure 16. (A) and (B): Zr/Sc–Th/Sc ratio for the stream sediments showing zircon concentration (circle) and typical source rock compositions (McLennan et al., 1993).

soil shows relatively felsic provenance (McLennan and Taylor, 1991; Awwiller, 1994). The chondrite-normalized REE patterns (Fig. 17) for the Ode Irele soil are similar to that displayed by upper continental crust and PAAS (Taylor and McLennan, 1985). The Eu* anomaly of the Ode Irele soil is negative and ranges between 0.37 and 0.65 (average 0.60) and being typical to that of UCC (0.65) and PAAS (0.66). The Eu* anomaly in sedimentary rocks is usually regarded as being derived from igneous source rocks (Mclennan and Taylor, 1991; Awwiller, 1994).

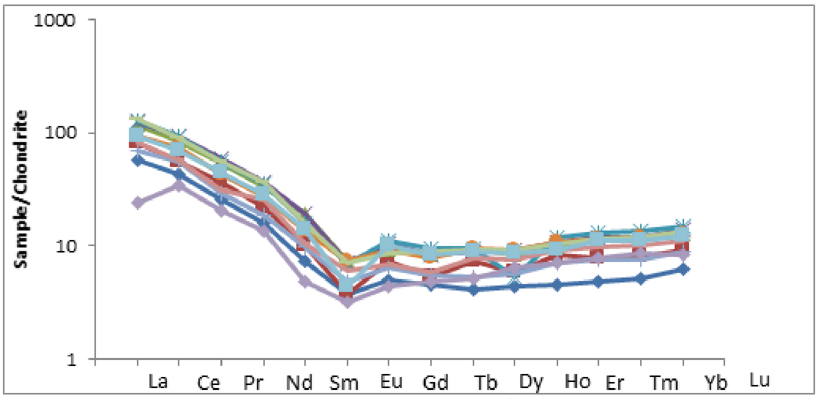

Figure 17. Chondrite-normalized REE pattern for the Ode Irele samples.

Tectonic setting

Several authors have related sandstone geochemistry to specific tectonic environment. Inert trace elements in clastic sediments have also been used effectively in discrimination diagrams of plate tectonic settings, these elements are probably transferred quantitatively into detrital sediments during weathering and transportation, reflecting the signature of the parent material (Armstrong-Altrin et al., 2004). Figures 18 and 19 are tectonic classification diagrams based on Bhatia (1983), the Ode Irele samples plotted mainly in the passive margin zone. Roser and Korsch (1986), consider passive margin sediments are largely quartz-rich sediments derived from plate interiors or stable continental areas and deposited in stable intracratonic basins or on passive continental margins.

Figures 20(a), (b) and (c) are tectonic discrimination diagrams based on trace and rare earth elements of the Ode Irele samples, it shows the plots in the passive margin zone figures 20(a) and (b), while figure 20(c) plotted in the continental island arc zone, this might be due to secondary enrichment of certain elements.

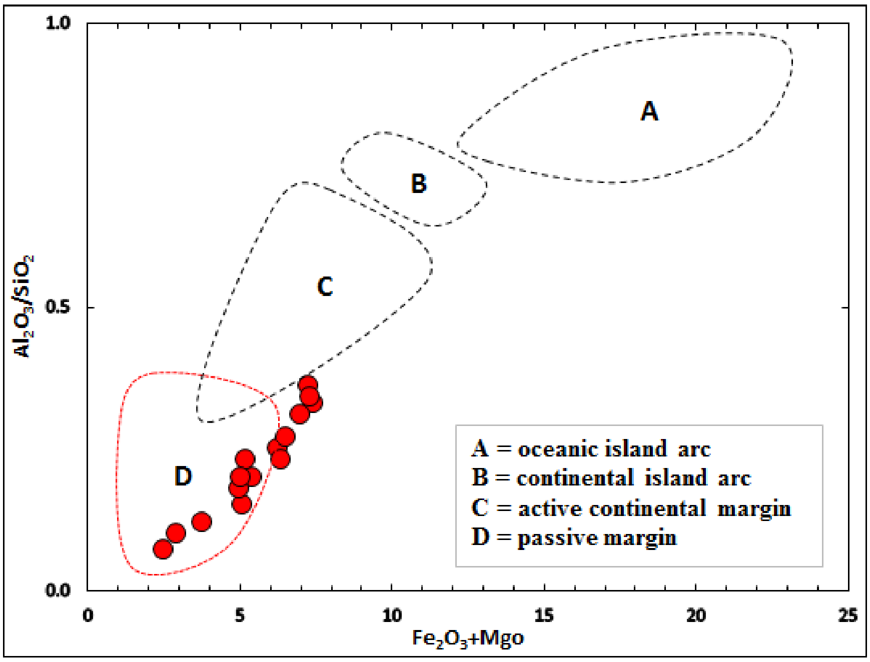

Figure 18. Tectonic setting discrimination plot of Al_2O_3/SiO_2 versus Fe_2O_3 + MgO, after Bhatia (1983).

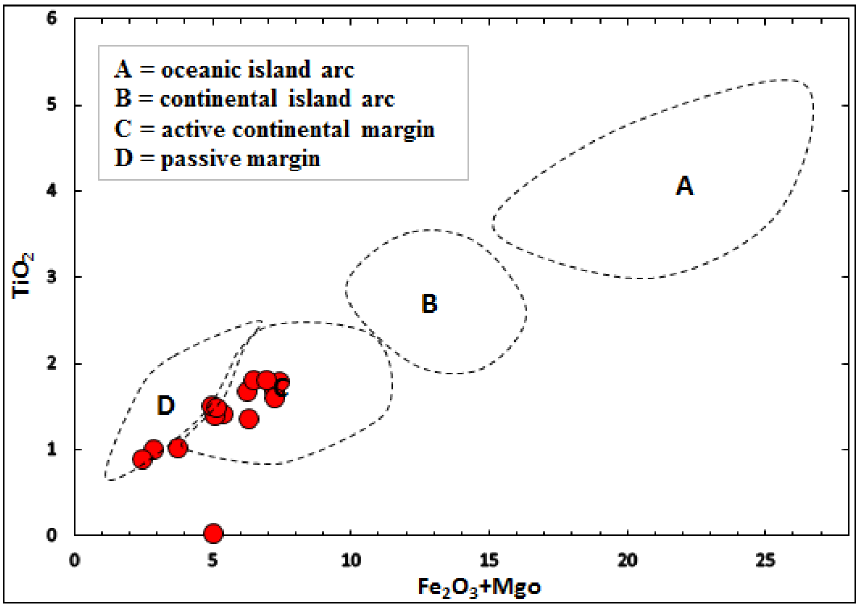

Figure 19. Tectonic setting discrimination plot of TiO_2 versus Fe_2O_3 + MgO of the studied samples. Dashed lines denote the major fields representing various tectonic settings (after Bhatia 1983).

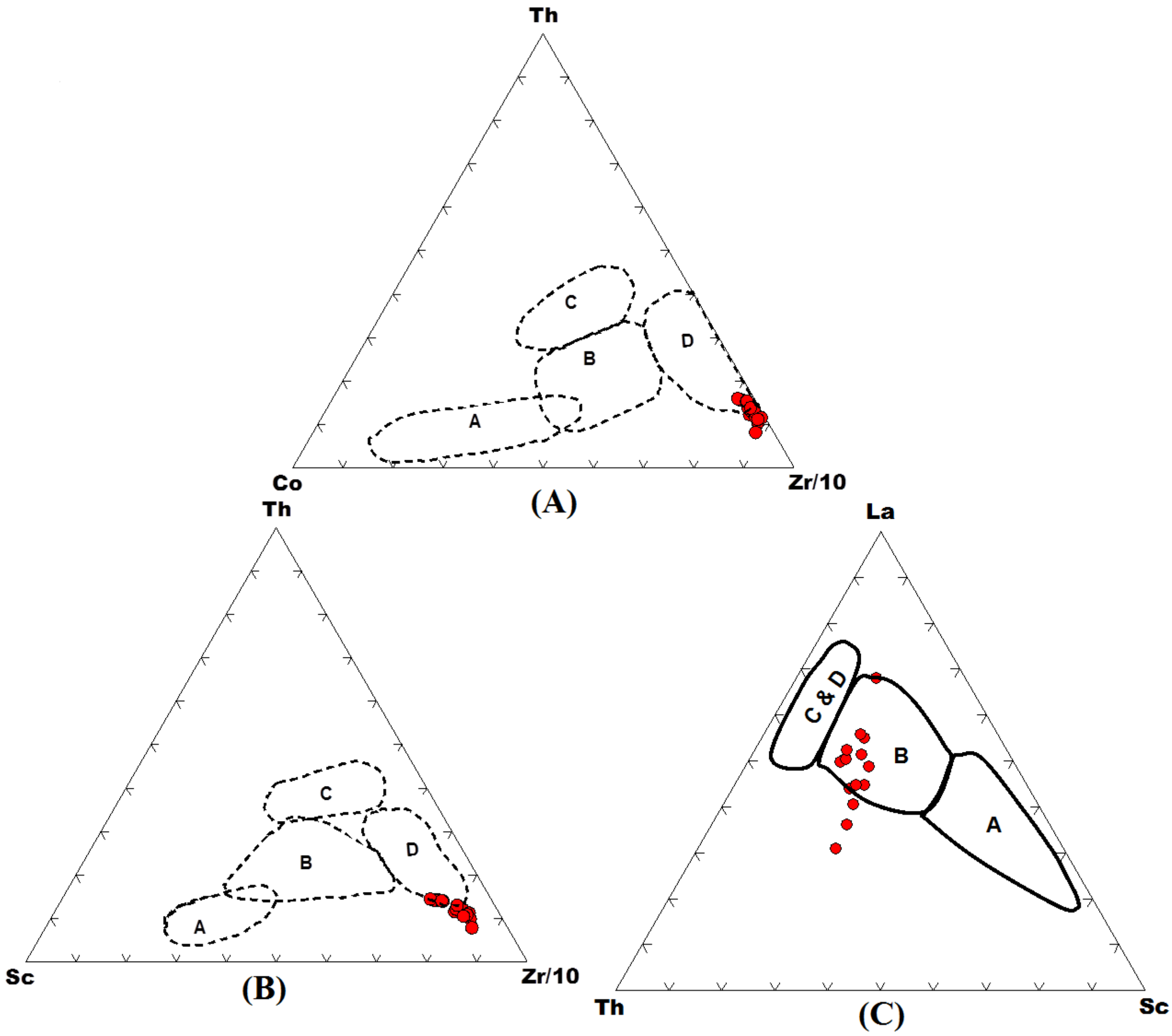

Figure 20 (a): Th - Co - Zr/10 plot; (b): Th - Sc - Zr/10 plot and La – Th – Sc plot of the Ode Irele samples. All fields from Bhatia and Cook (1986): A = oceanic island arc; B = continental island arc; C = active continental margin; D = passive margin

CONCLUSION

The tectonic setting and source-area composition of sediment samples from Ode Irele area of Ondo State, Nigeria was investigated. The tectonic setting for the Ode Irele samples indicates passive margin tectonic setting, which emanated from discrimination analyses using major oxides, trace and rare earth elements. The chondrite-normalized REE patterns for the Ode Irele soil displayed high LREE/HREE ratio, flat HREE pattern and pronounced negative Eu anomaly that is typical to that of UCC and PAAS suggesting derivation from felsic source rock. Several graphical plots (La/Co vs Th/Co;V-Ni-Th*10 ternary plot;TiO_2 versus Zr plot; Th/Co vs. La/Sc ratios; Cr/Th vs Th/Sc; Ti and Ni; Th against Sc; Y/Ni vs. Cr/V) indicates that the Ode Irele samples are from a felsic source rock. The value of some trace element ratios (Th/Sc, Zr/Sc, Y/Ni, Cr/V, La/Co, Th/Co) also suggests derivation from felsic rocks.

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