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Mineralogical analysis of further stream sediments from Nigeria

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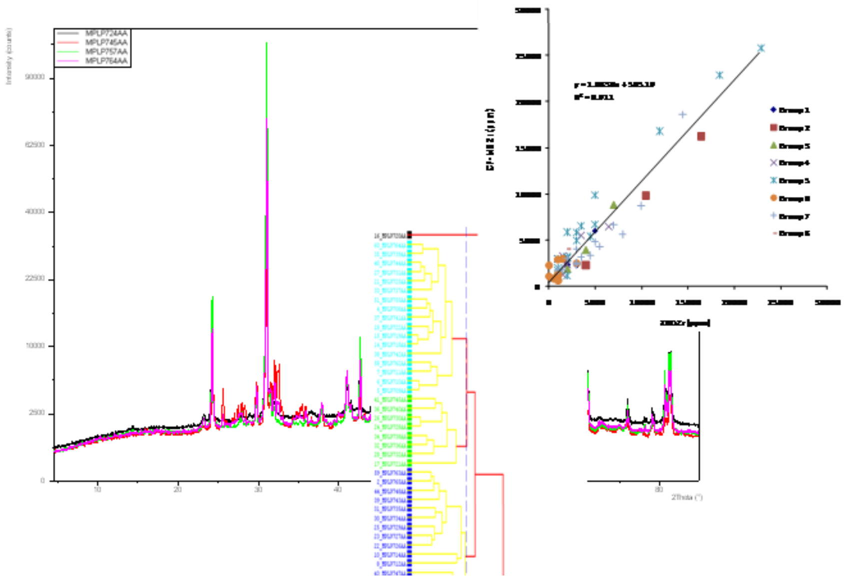
Internal Report IR/10/083



BRITISH GEOLOGICAL SURVEY

MINERALOGY, PETROLOGY & BIOSTRATIGRAPHY FACILITY
INTERNAL REPORT IR/10/083

Mineralogical analysis of further stream sediments from Nigeria

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Keywords

X-ray diffraction, stream sediments, zircon, monazite

Front cover

Montage of XRD traces, cluster dendrogram and geochemical cross-plot.

Bibliographical reference

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1 Introduction

This report presents the results of mineralogical characterisation of a further suite of sixty stream sediment samples from Nigeria. The samples were submitted for analysis by Dr Roger Key (BGS) and his team as part of the 'Technical Assistance Services for the Geochemical Mapping of Nigeria' project which aims to provide baseline geoscientific information for mineral exploration and environmental management through a study of the distribution of important metallic elements.

Particular interest was expressed in determining the hosts for the elevated levels of Zr in the stream sediments. Full sample details, including Zr geochemical data from inductively coupled plasma-mass spectrometry (ICP-MS) are listed in Table 1.

This study follows a smaller pilot study carried out on a suite of seven stream sediments samples from the same project (Kemp *et al.*, 2009).

2 X-ray diffraction analysis

2.1 PREPARATION

In order to achieve a finer and uniform particle-size for powder XRD analysis, approximately 5 g portions of the tema-milled material were micronised under deionised water for 10 minutes with 10 % (i.e. 0.5 g) corundum (American Elements, Al_2O_3, AL-OX-03-P). The addition of an internal standard allows validation of quantification data and also the detection of any amorphous species in the samples. Corundum was selected as its principle XRD peaks are suitably remote from those produced by most of the phases present in the samples and its mass absorption coefficient is similar to the sample matrix.

The corundum-spiked samples were then spray-dried following the method and apparatus described by Hillier (1999). The spray-dried materials were then front-loaded into a standard stainless steel sample holders for analysis.

2.2 ANALYSIS

Whole-rock XRD analysis was carried out using a PANalytical X'Pert Pro series diffractometer equipped with a cobalt-target tube, X'Celerator detector and operated at 45kV and 40mA. The micronised/spray-dried samples were scanned from 4.5-85°2θ at 2.76°2θ/minute. Diffraction data were initially analysed using PANalytical X'Pert Highscore Plus version 2.2a software coupled to the latest version of the International Centre for Diffraction Data (ICDD) database.

2.3 QUANTIFICATION

Following identification of the mineral species present in the sample, mineral quantification was achieved using the Rietveld refinement technique (e.g. Snyder & Bish, 1989) using PANalytical Highscore Plus software. This method avoids the need to produce synthetic mixtures and involves the least squares fitting of measured to calculated XRD profiles using a crystal structure databank. Errors for the quoted mineral concentrations are typically ±2.5% for concentrations >60 wt%, ±5% for concentrations between 60 and 30 wt%, ±10% for concentrations between 30 and 10 wt%, ±20% for concentrations between 10 and 3 wt% and ±40% for concentrations <3 wt% (Hillier *et al.*, 2001). Where a phase was detected but its concentration was indicated to be below 0.5%, it is assigned a value of <0.5%, since the error associated with quantification at such low levels becomes too large.

Table 1. Summary of samples submitted

Incoming sample number	BGS MPL code	UTM Zone	GRN cell	Easting	Northing	Site lithology (where outcrop)	Catchment geology	ICP-MS Zr (ppm)
2	MPLP706	31N	SW	727691	822731	-	Migmatitic Gneisses	6460
3	MPLP707	31N	SW	732208	815530	-	Older Granites	4308
17	MPLP708	31N	SW	820959	806068	Dark gray schist cut by migmatitic gneiss	Migmatitic Gneisses	2982
22	MPLP709	31N	SW	812546	814264	Migmatitic granite gneiss	Metasedimentary and Metavolcanic	25768
32	MPLP710	31N	SW	783761	781501	Biotite schist/quartzite	Migmatitic Gneisses	22853
50	MPLP711	31N	SW	736069	775130	Augen granite gneiss	Older Granites	16789
78	MPLP712	31N	SW	790953	806052	Migmatitic gneiss	Migmatitic Gneisses	3024
79	MPLP713	31N	SW	576176	779121	-	Metasedimentary and Metavolcanic	16241
85	MPLP714	31N	SW	607940	779750	-	Metasedimentary and Metavolcanic	2431
147	MPLP715	31N	SW	577675	771404	-	Metasedimentary and Metavolcanic	8806
148	MPLP716	31N	SW	618978	763114	Granite gneiss	Metasedimentary and Metavolcanic	5644
164	MPLP717	31N	SW	625003	768118	Granite gneiss	Older Granites	8729
168	MPLP718	31N	SW	516621	824537	-	Metasedimentary and Metavolcanic	6535
184	MPLP719	31N	SW	521548	822374	-	Migmatitic Gneisses	9865
198	MPLP720	31N	SW	561327	759692	-	Mesozoic and Younger strata and sediments	4033
225	MPLP721	31N	SW	551017	867734	Migmatitic gneiss	Migmatitic Gneisses	2961
228	MPLP722	31N	SW	550114	830924	-	Migmatitic Gneisses	3054
253	MPLP723	31N	SW	509294	754516	-	Mesozoic and Younger strata and sediments	1893
254	MPLP724	31N	SW	537205	782905	-	Migmatitic Gneisses	3935
279	MPLP725	31N	SW	519730	843483	-	Migmatitic Gneisses	5832

Table 1(continued). Summary of samples submitted

Incoming sample number	BGS MPL code	UTM Zone	GRN cell	Easting	Northing	Site lithology (where outcrop)	Catchment geology	ICP-MS Zr (ppm)
319	MPLP726	32N	Minna	271295	1077098	-	Migmatitic Gneisses	3328
332	MPLP727	32N	Minna	267314	1070102	-	Migmatitic Gneisses	3168
337	MPLP728	32N	Minna	249690	1046574	-	Older Granites	849
365	MPLP729	32N	Minna	272132	1075231	-	Migmatitic Gneisses	2360
368	MPLP730	32N	Minna	249054	1046757	Crse-grained granite/pegmatite intrusion	Older Granites	1075
396	MPLP731	32N	Minna	273528	1054128	Porphyritic granite	Older Granites	4973
423	MPLP732	32N	Minna	217957	1089221	-	Older Granites	2513
474	MPLP733	32N	Minna	243422	1015157	-	Mesozoic and Younger strata and sediments	9817
513	MPLP734	32N	Minna	263566	1062462	-	Older Granites	2560
539	MPLP735	32N	Minna	278328	1079211	Biotite granite (coarse-grained)	Migmatitic Gneisses	4022
568	MPLP736	32N	Minna	209679	1059161	Granite-biotite, hornblende, feldspar	Older Granites	2245
681	MPLP737	32N	Minna	269262	1058571	-	Older Granites	1175
715	MPLP738	32N	Minna	213750	1077861	Granite	Older Granites	647
814	MPLP739	32N	Minna	178995	1090114	Phyllite	Metasedimentary and Metavolcanic rocks	3172
828	MPLP740	32N	Minna	299490	1097699	-	Older Granites	2905
830	MPLP741	32N	Minna	290541	1103146	Amphibolite schist	Migmatitic Gneisses	1988
848	MPLP742	32N	Minna	261352	1121494	Fine- to medium-grained granite	Older Granites	835
850	MPLP743	32N	Minna	317820	1086233	Granite	Migmatitic Gneisses	4810
851	MPLP744	32N	Minna	194032	1097623	Schist with a lot of quartz vein	Zungeru Mylonites	1724
888	MPLP745	32N	Minna	284535	1104423	Exposure of pegmatite along stream	Migmatitic Gneisses	1285

Table 1(continued). Summary of samples submitted

Incoming sample number	BGS MPL code	UTM Zone	GRN cell	Easting	Northing	Site lithology (where outcrop)	Catchment geology	ICP-MS Zr (ppm)
909	MPLP746	32N	Minna	321315	1080470	Granite gneiss	Migmatitic Gneisses	1272
981	MPLP747	32N	Minna	254937	997118	Grey gneiss	Migmatitic Gneisses	18569
990	MPLP748	32N	Minna	188200	1092700	Quartz schist	Zungeru Mylonites	1853
1005	MPLP749	32N	Minna	319785	1109491	Metamorphic gneiss	Migmatitic Gneisses	2393
1007	MPLP750	32N	Minna	319754	1109495	-	Migmatitic Gneisses	3156
1022	MPLP751	32N	Minna	324228	1122077	Amphibolite-gneiss	Migmatitic Gneisses	5983
1024	MPLP752	32N	Minna	317241	1122534	-	Older Granites	5506
1031	MPLP753	32N	Minna	321533	1108211	Metamorphic: gneiss	Older Granites	2373
1038	MPLP754	32N	Minna	297224	1107902	-	Migmatitic Gneisses	2308
1041	MPLP755	32N	Minna	298480	1109730	Migmatitic-gneiss (biotite rich)	Older Granites	5869
1052	MPLP756	32N	Minna	329040	1098319	Migmatite-gneiss	Migmatitic Gneisses	3000
1105	MPLP757	32N	Minna	322963	1096533	Migmatite schists	Migmatitic Gneisses	2300
1109	MPLP758	32N	Minna	305985	1146366	Granite: medium- to coarse-grained.	Older Granites	2301
1116	MPLP759	32N	Minna	327129	1116024	Migmatitic gneiss	Migmatitic Gneisses	1070
1127	MPLP760	32N	Minna	330562	1079180	-	Migmatitic Gneisses	3256
1142	MPLP761	32N	Minna	332117	1090716	Pegmatitic gneiss	Migmatitic Gneisses	2270
1413	MPLP762	32N	Minna	322657	1014466	Granite	Older Granites	6713
1553	MPLP763	32N	Minna	316180	1002689	-	Migmatitic Gneisses	1748
1623	MPLP764	32N	Minna	321667	1003306	-	Migmatitic Gneisses	5406
1633	MPLP765	32N	Minna	322358	1005818	Biotite gneiss	Migmatitic Gneisses	6621

3 Results and discussion

The quantitative results of powder XRD analyses are summarised in Table 2.

XRD analysis indicates that the samples are predominantly composed of quartz with subordinate amounts of feldspar (plagioclase and K-feldspar), 'mica' (undifferentiated mica species possibly including muscovite, biotite, illite and illite/smectite), 'kaolin' (undifferentiated kaolin group minerals possibly including kaolinite, halloysite etc) ± traces of ilmenite, zircon, amphibole, epidote, hematite, monazite, sillimanite, pyroxene and anatase.

XRD analysis (Table 2) suggests that two different plagioclase compositions are present in the samples, one slightly more calcic than the other (plagioclase 1; $Na_{0.84}Ca_{0.16}Al_{1.16}Si_{2.84}O_8$ and plagioclase 2; $Na_{0.75}Ca_{0.25}Al_{1.26}Si_{2.74}O_8$). Similarly two different K-feldspar species were identified (K-feldspar 1; microcline and K-feldspar 2; orthoclase).

Cluster analysis of the powder diffraction data, displayed as a dendrogram (Figure 1), indicates eight distinct mineral assemblages:

- Group 1 samples (shown in yellow, sites 1022, 1031, 1038, 1109, 1116, 1142) are characterised by relatively high quartz (62-78%), moderate amounts of 'kaolin'(8-12%), K-feldspar (8-19%) and 'mica' (4-5%) and trace amounts of plagioclase, ilmenite and zircon. No ferromagnesian silicate minerals (pyroxene, epidote, amphibole) were detected in these samples. The catchment geology for these samples are predominantly migmatitic gneisses with occasional older granites. The moderate 'kaolin' concentrations together with a low plagioclase content and a lack of ferromagnesian minerals would suggest that these sediments represent relatively weathered material.
- Group 2 samples (shown in magenta, sites 79, 474 and 1105) are characterised by the highest quartz contents (65-88%) for the sample suite with variable but usually moderate amounts of plagioclase feldspar (nd-10%), ilmenite (2-6%), 'kaolin' (3-10%), K-feldspar (5-7%) and occasional anatase, 'mica', amphibole and monazite. Moderate/high zircon (1-3%) and no ferromagnesian silicate minerals. The catchment geology is highly variable and composed of sedimentary/metasedimentary/metavolcanic/migmatitic gneiss lithologies.
- Group 3 samples (shown in grey, sites 147, 253 and 254) are again characterised by high quartz (66-87%, similar to Group 2), variable but generally high 'kaolin' contents (5-22%), subordinate amounts of K-feldspar (3-5%) and plagioclase (2-4%) and occasional traces of anatase, ilmenite, amphibole and zircon. No 'mica' species were identified in these samples. As for the Group 2 samples, Group 3 samples are also characterised by variable catchment lithologies composed of sedimentary/metasedimentary/metavolcanic/ migmatitic gneiss lithologies.
- Group 4 samples (shown in brown, sites 2, 909, 1005, 1007, 1024, 1052 and 1127) are characterised by relatively moderate quartz (56-78%) and K-feldspar (12-16%) contents, variable plagioclase (1-11%) and 'kaolin' (3-12%), subordinate 'mica' (nd-6%) ± traces of zircon, pyroxene, ilmenite, amphibole, monazite and sillimanite. With the exception of one sample (site 1024), the catchment geology for these samples is exclusively formed of migmatitic gneisses.
- Group 5 samples (shown in cyan, sites 17, 22, 32, 50, 168, 184, 228, 279, 396, 681, 814, 830, 848, 851, 1041, 1413 and 1623) are most common and are generally characterised by low-medium quartz (34-72%), high K-feldspar (16-36%), moderate plagioclase (3-18%), amphibole (nd-6%), 'mica' (nd-6%), 'kaolin' (nd-4%) and traces of ilmenite,

monazite, zircon (<0.5-5%). The catchment geology for the Group 5 samples is mixed between migmatitic gneisses and older granites with some metasedimentary/ metavolcanic input. The higher feldspar and lower 'kaolin' content of these samples suggests that they represent fresher, less weathered material.

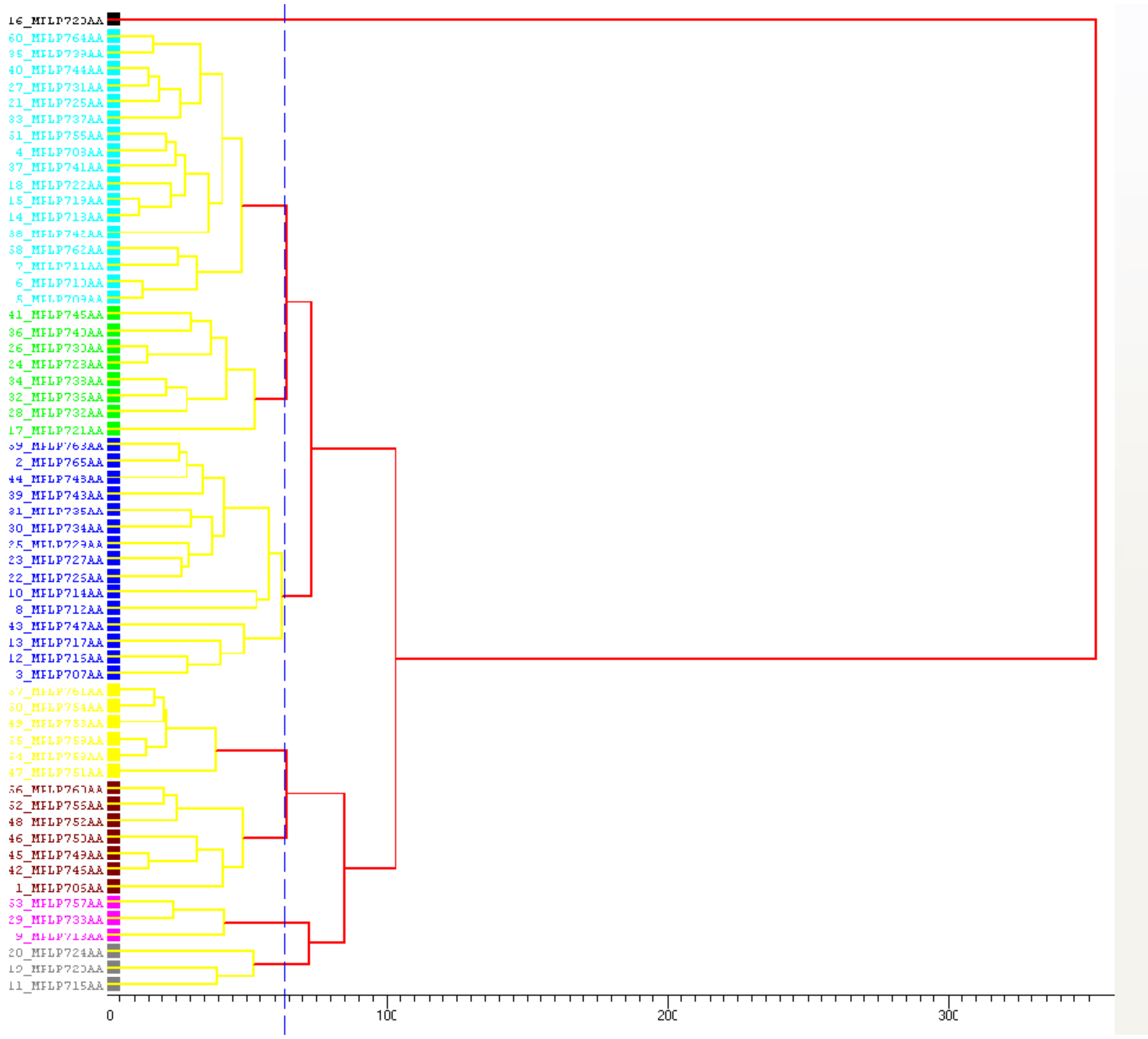

Figure 1. Cluster analysis dendrogram for the stream sediment XRD traces

- Group 6 samples (shown in green, sites 225, 337, 368, 423, 568, 715, 828 and 888) are characterised by low-moderate quartz (25-55%), high K-feldspar (16-36%), high plagioclase (18-33%) and subordinate 'mica' (3-8%). The samples are unusually characterised by minor amounts of epidote (nd-6%), occasional amphibole (nd-3%) and low zircon concentrations. Group 6 samples are typically characterised by older granite catchment lithologies with occasional migmatitic gneiss. The relatively low quartz and 'mica' content together with high feldspar (K-feldspar and plagioclase) contents are in agreement with the predicted granite-rich catchment. The presence of epidote and occasional amphiboles suggest some metamorphic alteration of the granites.
- Group 7 samples (shown in blue, sites 3, 78, 85, 148, 164, 319, 332, 365, 513, 539, 850, 981, 990, 1553 and 1633) are characterised by moderate-high amounts of quartz (48-

82%), moderate but variable K-feldspar (4-23%) and plagioclase (3-23%) and relatively high ilmenite (2-10%) contents. Moderate amounts of 'mica' (nd-11%) and 'kaolin' (nd-8%) were found together with occasional epidote (nd-7%), sillimanite (nd-5%), monazite (nd-1%), pyroxene (nd-1%), hematite (nd-2%) and zircon (<0.5-3%). The Group 7 samples are therefore similar to those in Group 6 but the Group 7 samples contain more Fe-bearing minerals (e.g. ilmenite, hematite). The catchments for these samples is again dominated by migmatitic gneiss with a few catchments of older granite and metasedimentary/ metavolcanic rocks.

- The single remaining sample (Group 8, shown in black, site 198) is clearly very different to all the other stream sediments. XRD analysis suggest that it has a very quartz-rich mineralogy (95%). Its catchment geology is formed of Mesozoic and younger strata and sediments.

Figure 1 indicates that the above defined sample groupings can be further combined into two general clusters. Groups 1, 2, 3 and 4 show broadly similar mineralogical characteristics of moderate-high amounts of quartz, low-moderate amounts of K-feldspar (microcline, no orthoclase), plagioclase and 'kaolin' together with low/no amounts of 'mica' and ferromagnesian minerals. Zircon concentrations in Groups 1-4 are variable (<0.5-3.3%). The catchment lithologies for Groups 1-4 are also variable but are predominantly formed of migmatitic gneiss.

Groups 5, 6 and 7 also show similar mineralogical features and are composed of low-moderate amounts of quartz, high amounts of K-feldspar (microcline and orthoclase) and plagioclase, moderate but variable amounts of 'mica', 'kaolin' and ilmenite together with occasional traces of epidote, amphibole, sillimanite and monazite. Zircon concentrations in Groups 5-7 are variable (nd-4.6%). The catchment lithologies for Groups 5-7 are formed of a mixture of old granites and migmatitic gneiss.

3.1 COMPARISON WITH ICP-MS GEOCHEMISTRY

It is interesting and useful to compare the results of mineralogical XRD analyses with the project ICP-MS geochemical data but a detailed interpretation is outside the scope of this limited investigation.

In terms of Zr distribution, the main aim of this study, the only Zr-bearing phase identified by XRD in the sixty stream sediment samples was zircon ($ZrSiO_4$). XRD concentrations show a good correlation with geochemical data (Figure 2, R^2 = 0.91). This concurs with the previous pilot study (Kemp *et al.*, 2009). The lower limit of zircon detection for XRD would appear to be between 500 and 1000 ppm Zr, again similar to the previous study. Zr concentrations derived from the XRD zircon contents therefore confirm that zircon is the dominant host for Zr in the stream sediments. As stated by Kemp *et al.* (2009), more accurate speciation of the heavy mineral fraction and potential identification of further Zr-bearing phases could be achieved if the quartz and feldspar component was removed using heavy media (e.g. Li-polytungstate) separation techniques prior to further XRD analysis.

Figure 2 illustrates that although the highest zircon concentrations are found in samples from Group 5, 7 and 2, each grouping shows highly variable zircon contents. Similarly the catchment lithology for these highest zircon contents varies from metasedimentary/metavolcanic to migmatitic gneiss and older granite. It would therefore appear that the zircon content of the stream sediments is not indicative of any one particular catchment lithology.

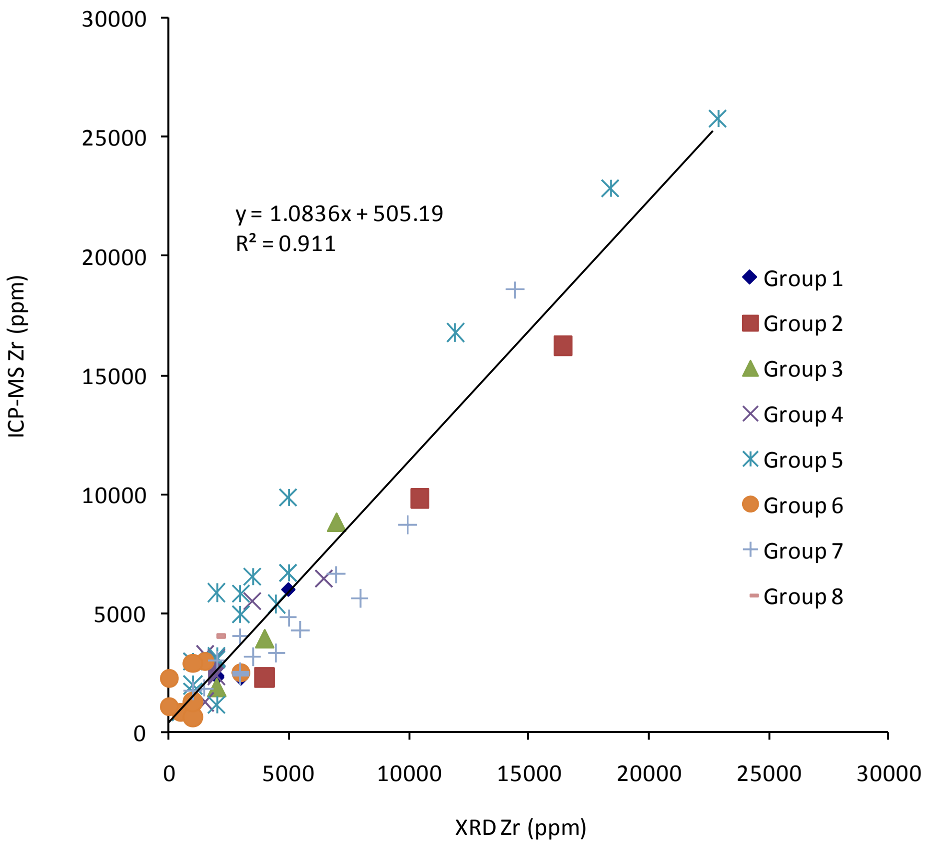

Figure 2. Correlation plot of XRD Zr (from zircon concentration) and ICP-MS Zr (both ppm) with data grouped according to XRD clusters

Other interesting correlations between mineralogy and geochemistry include the strong relationship between XRD total feldspar content and Ba with an R^2 = 0.78 (Figure 3). Ba is present in the majority of alkali feldspars and to a lesser degree in plagioclase (Deer *et al.*, 1996). Figure 3 graphically illustrates the difference in feldspar content described in the previous section; Groups 5, 6 and 7 being feldspar-rich and Groups 1-4 and 8 being feldspar-poor.

Ilmenite is the dominant Fe-bearing mineral in the stream sediments, as illustrated by the cross-plot in Figure 4. The Fe-rich nature of the Group 7 samples is very evident from this plot.

Although not illustrated here, it is also noticeable that the XRD-identified monazite concentrations show an excellent correlation with the rare earth element and phosphorus concentrations determined for the samples.

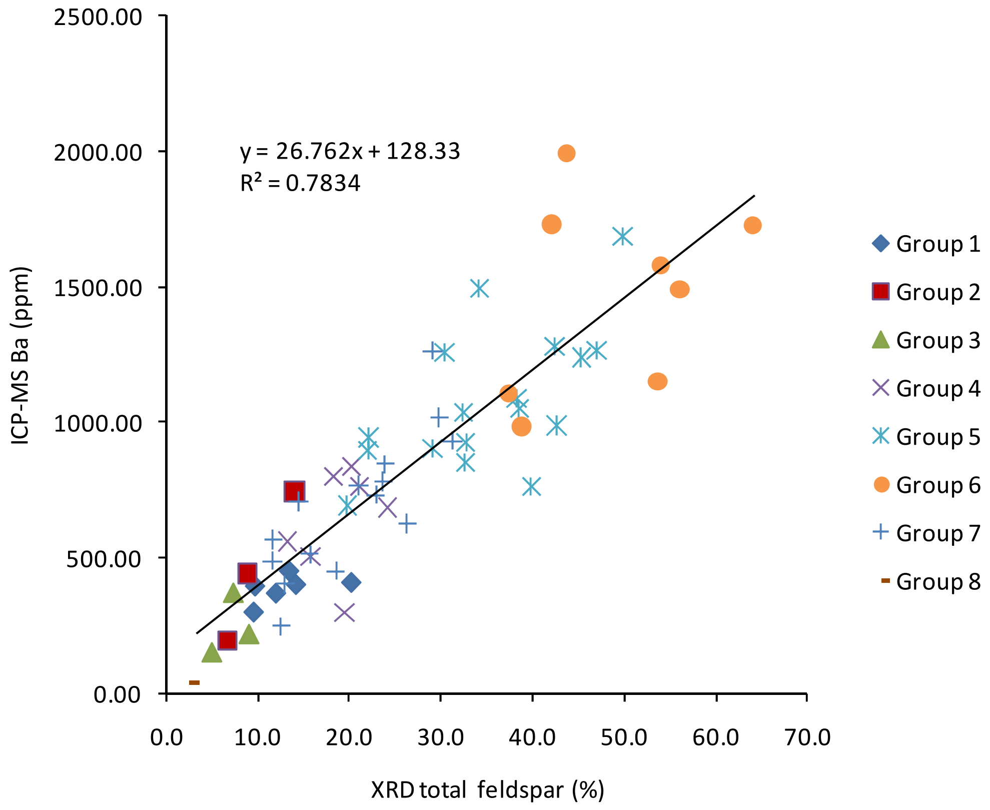

Figure 3. Correlation plot of XRD total feldspar (%) and ICP-MS Ba (ppm) with data grouped according to XRD clusters

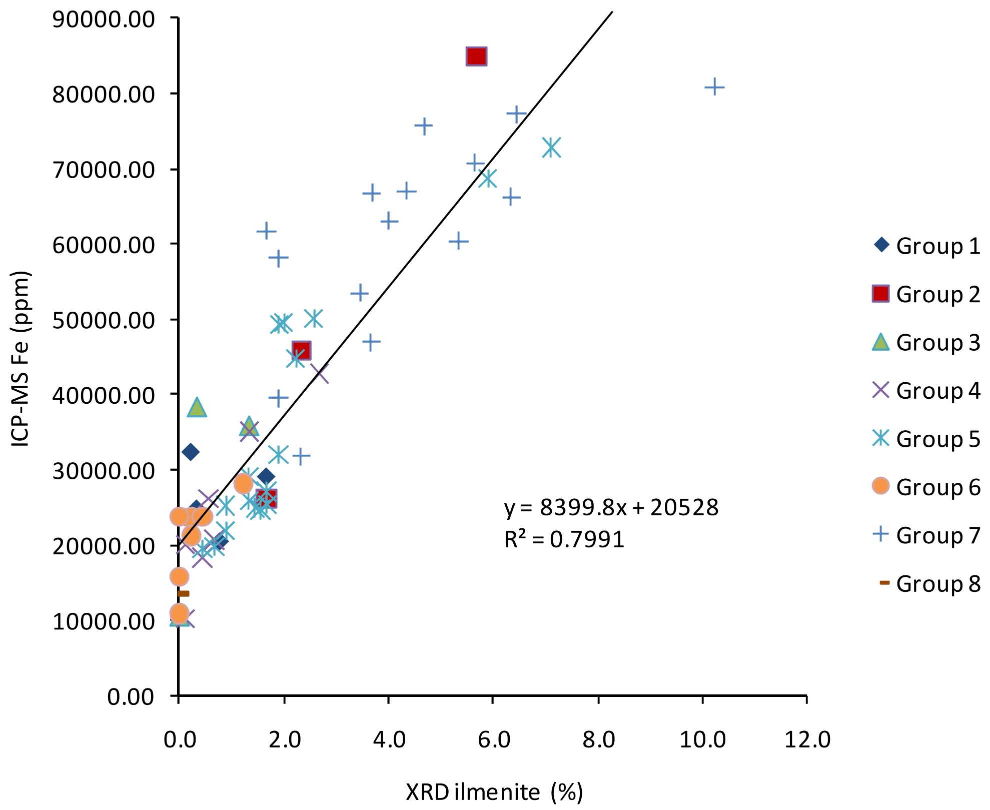

Figure 4. Correlation plot of XRD ilmenite (%) and ICP-MS Fe (ppm) with data grouped according to XRD clusters

Table 2. Summary of quantitative powder XRD analyses

Site no.	BGS MPL code	Silicates										Oxides, phosphates				Phyllosilicates	
		quartz	*plagioclase 1	*plagioclase 2	*K-feldspar 1	*K-feldspar 2	pyroxene	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	monazite	‘mica’	‘kaolin’
2	MPLP706	55.7	nd	5.0	16.1	nd	nd	nd	nd	2.8	1.3	nd	nd	2.7	nd	4.7	11.7
3	MPLP707	51.8	nd	7.0	22.8	nd	nd	nd	nd	2.9	1.1	nd	nd	6.3	nd	3.3	4.8
17	MPLP708	58.5	nd	6.5	20.8	6.8	nd	2.0	nd	nd	<0.5	nd	nd	<0.5	<0.5	2.7	1.8
22	MPLP709	33.8	nd	17.5	23.9	5.6	nd	5.7	nd	nd	4.6	nd	nd	1.9	nd	3.7	3.4
32	MPLP710	43.3	nd	15.8	21.1	8.4	nd	2.3	nd	nd	3.7	nd	nd	1.7	<0.5	3.7	nd
50	MPLP711	44.6	nd	6.5	24.1	7.9	nd	0.9	nd	nd	2.4	nd	nd	7.1	nd	3.3	3.1
78	MPLP712	57.8	nd	8.9	12.3	2.4	nd	nd	nd	5.0	<0.5	nd	2.3	1.9	1.1	6.2	1.4
79	MPLP713	65.0	nd	7.2	6.8	nd	nd	2.1	nd	nd	3.3	nd	nd	5.7	<0.5	nd	9.5
85	MPLP714	61.7	nd	11.7	11.2	nd	nd	nd	nd	nd	0.6	nd	1.3	1.7	nd	4.6	7.3
147	MPLP715	65.8	nd	4.2	4.8	nd	nd	nd	nd	nd	1.4	0.8	nd	1.3	nd	nd	21.6
148	MPLP716	56.4	nd	16.4	9.9	nd	nd	3.7	nd	nd	1.6	nd	nd	5.3	nd	nd	6.7
164	MPLP717	55.8	nd	14.0	15.1	nd	0.9	2.0	nd	nd	2.0	nd	nd	10.2	nd	nd	nd
168	MPLP718	53.5	nd	13.6	20.2	8.7	nd	1.2	nd	nd	0.7	nd	nd	1.7	0.6	nd	nd
184	MPLP719	51.6	nd	14.3	22.0	6.4	nd	nd	nd	nd	1.0	nd	nd	1.4	0.6	2.8	nd
198	MPLP720	94.9	nd	nd	2.7	nd	nd	nd	nd	nd	<0.5	nd	nd	nd	nd	nd	2.0
225	MPLP721	24.8	nd	32.9	16.1	15.0	nd	<0.5	nd	nd	<0.5	nd	nd	<0.5	nd	3.8	6.7
228	MPLP722	45.3	nd	14.4	30.6	4.9	nd	0.6	nd	nd	<0.5	nd	nd	0.7	nd	3.2	nd
253	MPLP723	77.3	nd	1.8	3.2	nd	nd	1.0	nd	nd	<0.5	0.8	nd	nd	nd	nd	15.5

Table 3. Summary of quantitative powder XRD analyses (continued)

Site no.	BGS MPL code	Silicates										Oxides, phosphates				Phyllosilicates	
		quartz	*plagioclase 1	*plagioclase 2	*K-feldspar 1	*K-feldspar 2	pyroxene	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	monazite	'mica'	'kaolin'
254	MPLP724	86.8	nd	1.9	5.4	nd	nd	nd	nd	nd	0.8	nd	nd	<0.5	nd	nd	4.8
279	MPLP725	62.5	nd	12.9	16.8	2.8	nd	0.8	nd	nd	0.6	nd	nd	1.3	nd	2.4	nd
319	MPLP726	72.1	nd	8.3	4.2	nd	nd	1.0	nd	nd	0.9	nd	nd	3.4	nd	5.7	4.3
332	MPLP727	81.8	nd	3.0	8.7	nd	nd	nd	nd	nd	0.7	nd	nd	3.7	nd	nd	2.2
337	MPLP728	54.9	18.4	nd	19.0	nd	nd	nd	1.9	nd	<0.5	nd	nd	<0.5	nd	5.5	nd
365	MPLP729	66.8	nd	6.9	6.1	nd	nd	nd	nd	nd	0.6	nd	nd	6.4	nd	9.8	3.4
368	MPLP730	48.3	20.7	nd	18.1	nd	nd	nd	3.9	nd	nd	nd	nd	<0.5	nd	7.9	0.7
396	MPLP731	72.0	5.9	nd	16.2	nd	nd	nd	nd	nd	0.6	nd	nd	1.6	<0.5	3.7	nd
423	MPLP732	33.8	26.9	nd	27.1	nd	nd	2.6	6.3	nd	0.6	nd	nd	nd	nd	2.8	nd
474	MPLP733	78.1	2.7	nd	6.2	nd	nd	nd	nd	nd	2.1	<0.5	nd	2.3	<0.5	4.0	4.0
513	MPLP734	59.1	nd	9.1	6.6	nd	nd	nd	4.5	nd	0.6	nd	nd	4.0	nd	7.9	8.2
539	MPLP735	71.8	nd	6.1	5.6	nd	nd	nd	nd	nd	0.6	nd	nd	1.9	nd	9.6	4.6
568	MPLP736	51.1	22.3	nd	21.4	nd	nd	nd	2.4	nd	nd	nd	nd	nd	nd	2.7	nd
681	MPLP737	53.1	15.1	nd	17.6	nd	nd	<0.5	3.3	nd	<0.5	nd	nd	2.6	nd	5.7	2.0
715	MPLP738	48.4	22.5	nd	19.5	nd	nd	nd	5.7	nd	<0.5	nd	nd	nd	<0.5	3.4	nd
814	MPLP739	70.8	4.9	nd	14.9	nd	nd	0.9	nd	nd	<0.5	nd	nd	2.0	nd	5.1	1.0
828	MPLP740	43.0	17.7	nd	35.9	nd	nd	nd	nd	nd	<0.5	nd	nd	nd	nd	3.1	nd
830	MPLP741	54.8	2.7	nd	35.6	nd	nd	nd	nd	1.3	<0.5	nd	nd	0.9	<0.5	3.8	0.6

Table 4. Summary of quantitative powder XRD analyses (continued)

Site no.	BGS MPL code	Silicates										Oxides, phosphates				Phyllosilicates	
		quartz	*plagioclase 1	*plagioclase 2	*K-feldspar 1	*K-feldspar 2	pyroxene	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	monazite	'mica'	'kaolin'
848	MPLP742	57.4	8.6	nd	24.1	nd	nd	nd	nd	nd	<0.5	nd	nd	1.3	nd	4.4	4.0
850	MPLP743	65.4	nd	6.6	14.4	nd	nd	0.7	nd	nd	1.0	nd	nd	4.7	<0.5	4.3	2.8
851	MPLP744	60.6	10.2	nd	18.9	nd	nd	2.2	nd	nd	<0.5	nd	nd	2.2	nd	4.4	1.2
888	MPLP745	37.8	25.3	nd	30.7	nd	nd	nd	nd	nd	<0.5	nd	nd	1.2	nd	4.6	<0.5
909	MPLP746	70.2	4.3	nd	15.9	nd	nd	nd	nd	nd	<0.5	nd	nd	0.6	<0.5	4.5	4.1
981	MPLP747	48.2	nd	22.9	8.3	nd	nd	2.2	6.8	nd	2.9	nd	nd	3.7	nd	5.0	nd
990	MPLP748	64.5	8.0	nd	10.5	nd	nd	1.2	nd	nd	<0.5	nd	0.8	5.7	nd	6.7	2.3
1005	MPLP749	71.7	nd	3.0	15.3	nd	nd	<0.5	nd	nd	<0.5	nd	nd	0.7	nd	5.0	3.4
1007	MPLP750	63.3	10.7	nd	13.5	nd	nd	nd	nd	nd	<0.5	nd	nd	1.3	nd	6.2	4.6
1022	MPLP751	71.1	nd	1.1	8.4	nd	nd	nd	nd	nd	1.0	nd	nd	1.7	<0.5	5.2	11.1
1024	MPLP752	77.5	nd	0.9	12.4	nd	nd	nd	nd	nd	0.7	nd	nd	<0.5	nd	3.2	4.9
1031	MPLP753	73.1	nd	1.4	10.6	nd	nd	nd	nd	nd	<0.5	nd	nd	0.8	nd	4.8	8.9
1038	MPLP754	78.1	nd	1.0	8.7	nd	nd	nd	nd	nd	<0.5	nd	nd	<0.5	nd	3.8	7.8
1041	MPLP755	63.9	nd	6.8	23.6	nd	nd	nd	nd	nd	<0.5	nd	nd	0.9	nd	3.8	0.6
1052	MPLP756	69.4	nd	3.7	15.8	nd	nd	nd	nd	nd	<0.5	nd	nd	<0.5	nd	5.1	5.7
1105	MPLP757	87.6	nd	1.3	5.3	nd	nd	nd	nd	nd	0.8	nd	nd	1.7	nd	nd	3.3
1109	MPLP758	61.6	nd	1.2	19.1	nd	nd	nd	nd	nd	0.6	nd	nd	<0.5	nd	5.3	12.1
1116	MPLP759	72.9	nd	2.0	12.2	nd	nd	nd	nd	nd	<0.5	nd	nd	<0.5	nd	4.1	8.3

Table 5. Summary of quantitative powder XRD analyses (continued)

Site no.	BGS MPL code	Silicates										Oxides, phosphates				Phyllosilicates	
		quartz	*plagioclase 1	*plagioclase 2	*K-feldspar 1	*K-feldspar 2	pyroxene	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	monazite	'mica'	'kaolin'
1127	MPLP760	78.4	nd	1.1	14.6	nd	0.7	nd	nd	nd	<0.5	nd	nd	<0.5	nd	nd	4.8
1142	MPLP761	69.4	nd	1.9	11.6	nd	nd	nd	nd	nd	0.6	0.6	nd	<0.5	nd	4.3	11.3
1413	MPLP762	44.0	nd	8.6	31.3	nd	nd	1.9	nd	nd	1.0	nd	nd	5.9	nd	5.3	2.0
1553	MPLP763	73.0	nd	5.0	9.4	nd	nd	nd	nd	nd	<0.5	nd	nd	2.3	nd	8.5	1.4
1623	MPLP764	67.2	nd	6.6	15.6	nd	nd	1.0	nd	nd	0.9	nd	nd	1.9	nd	5.3	1.6
1633	MPLP765	53.6	nd	8.8	15.1	nd	nd	1.7	nd	nd	1.4	nd	nd	4.3	<0.5	11.0	3.8

KEY

*plagioclase 1 = $Na_{0.84}Ca_{0.16}Al_{1.16}Si_{2.84}O_8$
*plagioclase 2 = $Na_{0.75}Ca_{0.25}Al_{1.26}Si_{2.74}O_8$
*K-feldspar 1 = microcline
*K-feldspar 2 = orthoclase
nd = not detected
'mica' = undifferentiated mica species, possibly including muscovite, biotite, illite, illite/smectite
'kaolin' = undifferentiated kaolin-group species, possibly including kaolinite, halloysite etc

4 Summary

- XRD analyses have been completed on a suite of sixty stream sediment samples from Nigeria.
- XRD analysis indicates similar assemblages to those observed by Kemp *et al.* (2009) which are predominantly composed of quartz with subordinate amounts of feldspar (various species of plagioclase and K-feldspar), 'mica' (undifferentiated mica species possibly including muscovite, biotite, illite and illite/smectite), 'kaolin' (undifferentiated kaolin group minerals possibly including kaolinite, halloysite etc) ± traces of ilmenite, zircon, amphibole, epidote, hematite, monazite, sillimanite, pyroxene and anatase.
- Cluster analysis of XRD data indicates eight specific mineralogical groups which can be combined to produce two clusters with similar characteristics.
- Groups 1, 2, 3 and 4 show broadly similar mineralogical characteristics of moderate-high amounts of quartz, low-moderate amounts of K-feldspar (microcline, no orthoclase), plagioclase and 'kaolin' together with low/no amounts of 'mica' and ferromagnesian minerals and variable zircon concentrations. These samples typically correspond to catchments composed of migmatitic gneiss lithologies.
- Groups 5, 6 and 7 are composed of low-moderate amounts of quartz, high amounts of K-feldspar (microcline and orthoclase) and plagioclase, moderate but variable amounts of 'mica', 'kaolin' and ilmenite together with occasional traces of epidote, amphibole, sillimanite, monazite and variable zircon concentrations. These samples appear to be derived from a mixture of old granites and migmatitic gneiss catchment lithologies.
- The XRD data shows some interesting correlations with previously produced geochemical analyses.
- Zircon was the only Zr-bearing phase identified by XRD in the stream sediments and its concentration shows an excellent correlation with Zr from geochemical analysis. Trace quantities of other Zr-bearing minerals (e.g. baddeleyite) may also be present but are below XRD detection limits. The variable zircon content of the stream sediments suggest that its presence is not indicative of any one particular catchment lithology.
- More accurate speciation of the heavy mineral fraction and potential identification of further Zr-bearing phases could be achieved if the quartz and feldspar component was removed using heavy media (e.g. Li-polytungstate) separation techniques prior to further XRD analysis.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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