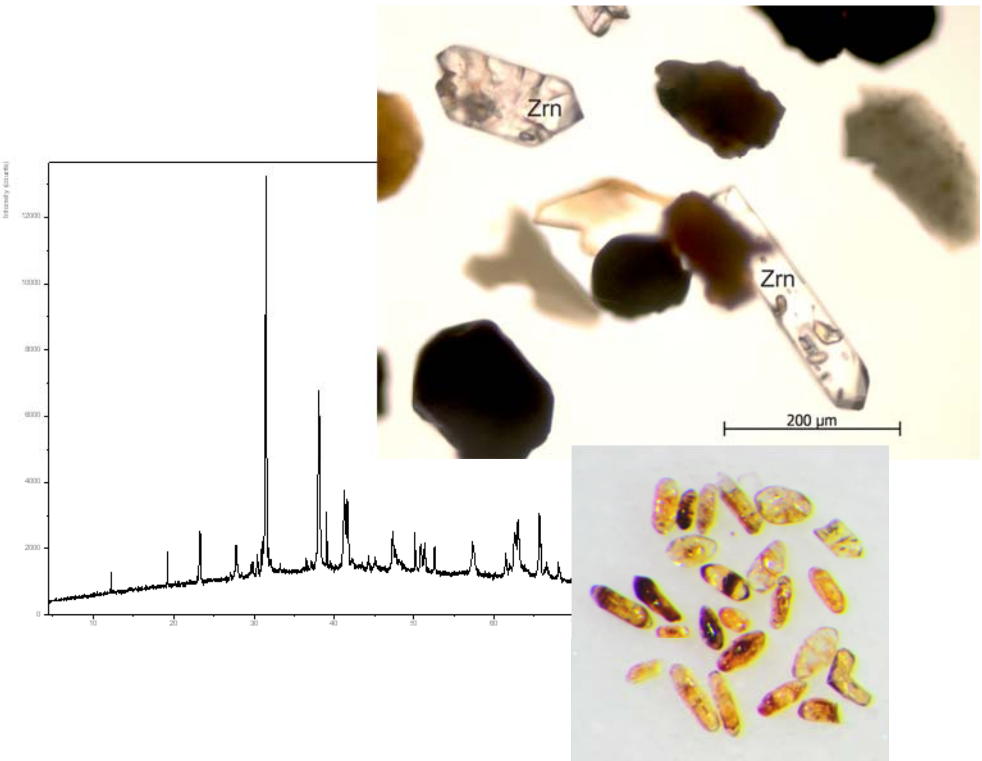
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Mineralogical analysis of heavy minerals from stream sediments, Nigeria

Mineralogy, Petrology & Biostratigraphy Facility

Internal Report IR/11/008



BRITISH GEOLOGICAL SURVEY

MINERALOGY, PETROLOGY & BIOSTRATIGRAPHY FACILITY
INTERNAL REPORT IR/11/008

Mineralogical analysis of heavy minerals from stream sediments, Nigeria

S J Kemp, D Wagner and I Mounteney

Keywords

X-ray diffraction, stream sediments, zircon, monazite

Front cover

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

Bibliographical reference

KEMP, S J, WAGNER, D AND MOUNTENEY, I. 2011. Mineralogical analysis of heavy minerals from stream sediments, Nigeria. *British Geological Survey Internal Report*, IR/11/008. 18pp.

Keyworth, Nottingham British Geological Survey 2011

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham and Edinburgh; see contact details below or shop online at www.thebgs.co.uk

The London Information Office maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.thebgs.co.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast, BT9 5BF

☎ 028-9038 8462 Fax 028-9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Sophia House, 28 Cathedral Road, Cardiff, CF11 9LJ

☎ 029–2066 0147 Fax 029–2066 0159

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Contents

TABLES

FIGURES

1 Introduction

This report presents the results of heavy media separation and the subsequent optical microscopical and mineralogical characterisation of heavy minerals separated from a suite of twenty eight stream sediment samples from Nigeria. The samples were submitted for analysis by Dr Roger Key (BGS) and his team as part of the Nigerian Geochemical Mapping Technical Assistance Project (NGMTAP) which aims to provide baseline geoscientific information for mineral exploration and environmental management through a study of the distribution of important metallic elements.

The present investigation follows an initial, pilot mineralogical study carried out on a suite of seven stream sediments samples (Kemp *et al.*, 2009) which in turn was followed by the analysis of a larger batch of sixty stream sediments (Kemp *et al.*, 2010) from the same project. Both studies sought to determine the hosts for elevated levels of zirconium (Zr) and rare earth elements (REEs) in the stream sediments. Zircon was the only Zr-bearing phase identified by XRD in the stream sediments and monazite the only REE-bearing mineral (Kemp *et al.* 2009, 2010).

However, in view of the fact that the stream sediments were predominantly composed of quartz with subordinate amounts of feldspar (various species of plagioclase and K-feldspar), both previous studies recommended that 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 separation techniques prior to further XRD analysis (Kemp *et al.* 2009, 2010).

A subset of the previously analysed stream sediments (Kemp *et al.*, 2010) containing higher proportions of zircon and/or monazite were therefore selected and re-sampled from stock material (<150 µm) held at the offices of the Nigerian Geological Survey Agency, Kaduna, Nigeria by Roger Key and Dan Lapworth in late 2010. Characterisation of the heavy mineral separates was carried out as a precursor to dating studies of selected samples using laser U-Pb thermal ionisation mass spectrometry (TIMS) in the NERC Isotope Geosciences Laboratory (NIGL).

Full sample details, including Zr geochemical data from inductively coupled plasma-mass spectrometry (ICP-MS) are listed in Table 1.

2 Heavy media separation

Prior to heavy media separation, the samples were cleaned of fine particles by dispersion in deionised water and sieving on 45 µm. The >45 µm material was then fractionated using lithium heteropolytungstate (LST, density of 2.85 gcm^{-3}) heavy liquid.

The separation process produced a ‘heavy’ fraction (containing grains with a density greater than 2.85 gcm^{-3}) and a ‘light’ fraction (containing grains with a density less than 2.85 gcm^{-3}).

3 Optical microscopy

The heavy mineral fractions were examined in both transmitted and reflected light modes using an Olympus SZX10 binocular microscope. Representative digital photomicrographs were taken to illustrate the assemblages observed.

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 ($mgkg^{-1}$)
2	MPLP706	31N	SW	727691	822731	-	Migmatitic Gneisses	6460
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
78	MPLP712	31N	SW	790953	806052	Migmatitic gneiss	Migmatitic Gneisses	3024
79	MPLP713	31N	SW	576176	779121	-	Metasedimentary and Metavolcanic	16241
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
225	MPLP721	31N	SW	551017	867734	Migmatitic gneiss	Migmatitic Gneisses	2961
228	MPLP722	31N	SW	550114	830924	-	Migmatitic Gneisses	3054
279	MPLP725	31N	SW	519730	843483	-	Migmatitic Gneisses	5832
332	MPLP727	32N	Minna	267314	1070102	-	Migmatitic Gneisses	3168
365	MPLP729	32N	Minna	272132	1075231	-	Migmatitic Gneisses	2360
513	MPLP734	32N	Minna	263566	1062462	-	Older Granites	2560

continued over

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 (mgkg^{-1})
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
715	MPLP738	32N	Minna	213750	1077861	Granite	Older Granites	647
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
909	MPLP746	32N	Minna	321315	1080470	Granite gneiss	Migmatitic Gneisses	1272
1005	MPLP749	32N	Minna	319785	1109491	Metamorphic gneiss	Migmatitic Gneisses	2393
1022	MPLP751	32N	Minna	324228	1122077	Amphibolite-gneiss	Migmatitic Gneisses	5983
1041	MPLP755	32N	Minna	298480	1109730	Migmatitic-gneiss (biotite rich)	Older Granites	5869
1052	MPLP756	32N	Minna	329040	1098319	Migmatite-gneiss	Migmatitic Gneisses	3000
1413	MPLP762	32N	Minna	322657	1014466	Granite	Older Granites	6713
1633	MPLP765	32N	Minna	322358	1005818	Biotite gneiss	Migmatitic Gneisses	6621

4 X-ray diffraction analysis

4.1 PREPARATION

Due to the relatively small quantities of heavy mineral separated from the samples (typically ~1 g), and the relatively poor efficiency of the previously employed spray-drying technique, a different XRD preparation approach was necessarily adopted in this study.

Small subsamples of each heavy mineral separate were removed using a micro-riffle-splitter, ground in an agate pestle and mortar and mixed with 10% corundum (American Elements, Al_2O_3, AL-OX-03-P). As in the previous investigation, 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 powders were then mounted on a 'zero-background' silicon crystal substrate using a single drop of acetone to produce a random orientation.

4.2 ANALYSIS

Powder XRD analysis of the heavy media separates 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 ground, spiked 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.

4.3 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.

5 Results and discussion

Heavy mineral fractions were successfully isolated from all 28 samples, forming between 0.2 and 18.7% (mean 5.8%) of the stream sediment (Table 3). However, the small quantities (*c*.0.1 g) of heavy separate isolated from two of the samples (sample sites 17 and 830) was insufficient for XRD analysis and possible dating and so these were not analysed by XRD. [Interestingly both sample site 17 and 830 expose amphibolite gneiss bedrocks, R. Key *pers. comm.*]. The quantitative results of powder XRD analyses are also summarised in Table 3.

XRD analysis indicates that the heavy mineral fractions are variously composed of ilmenite, amphibole, quartz, epidote, ‘mica’ (undifferentiated mica species possibly including muscovite, biotite, illite and illite/smectite), zircon, monazite, rutile, hematite, sillimanite, plagioclase feldspar, andalusite, anatase, apatite, xenotime, ‘kaolin’ (undifferentiated kaolin group minerals possibly including kaolinite, halloysite etc) and magnetite.

Example photomicrographs are shown in Figures 1 and 2.

The majority of the heavy mineral separates are dominated by ilmenite (Figure 2a, sample sites 2, 32, 79, 164, 168, 184, 279, 332, 365, 513, 539, 848, 850, 909, 1041, 1052 and 1413). Fewer heavy separates are amphibole- (sample sites 22, 225 and 228), epidote- (Figure 2c, sample sites 568 and 715) or hematite-dominated (sample site 78). A few of the samples are quartz-dominated (sample sites 1005, 1022 and 1633) which is unexpected as free quartz grains should have been removed to the light fraction during the heavy media separation. The presence of quartz in the heavy fraction would usually be explained by the presence of polymineralic (lithic) grains but these were not obvious during brief microscopic inspection. Most quartz was observed as angular, transparent monominerallic grains (e.g. Figure 2d).

A variety of zircon crystal morphologies were observed during optical microscopy. These vary from elongate, euhedral bladed crystals (e.g. Figure 1a, d, e, f and Figure 2a and b), indicative of only limited transport from their source to anhedral, equant zircons (Figure 1b, c), indicative of greater degrees of transport and recycling. More detailed analysis of zircon grain morphology for two of the samples (sample sites 568 and 715) are shown in Table 2:

Table 2. Summary of zircon grain morphology in samples from sample sites 568 and 715.

	Site 568, %zircon morphology			Site 715, %zircon morphology		
	Euhedral	**Subhedral**	**Anhedral**	**Euhedral**	**Subhedral**	**Anhedral**
Total	18.3	42.0	39.7	2.5	11.1	86.4
Rounded terminations (%)	4.7			1.0		
Euhedral terminations (%)	13.6			1.5		

No obvious relationship between zircon crystal morphology and catchment geology was established during this brief study. However, comparing zircon concentration with catchment geology suggest that the migmatitic gneiss (e.g. sample sites 2, 225, 1633, 32 etc) and metasedimentary/metavolcanic (e.g. sample sites 22 and 168) lithologies generally provide greater proportions of zircon than the older granites (e.g. sample sites 715, 164, 568 etc). The vast majority of the zircon grains examined appear colourless and unaltered. Only one or two grains had a pink colouration (e.g. Figure 2a).

Similarly the monazite crystals observed in the separates were generally subhedral suggesting lengthy transportation (Figure 1a, b, e). As noted with the zircon concentrations, monazite contents appear to increase from migmatitic gneiss (e.g. sample sites 1052, 184, 1022, 78 etc)

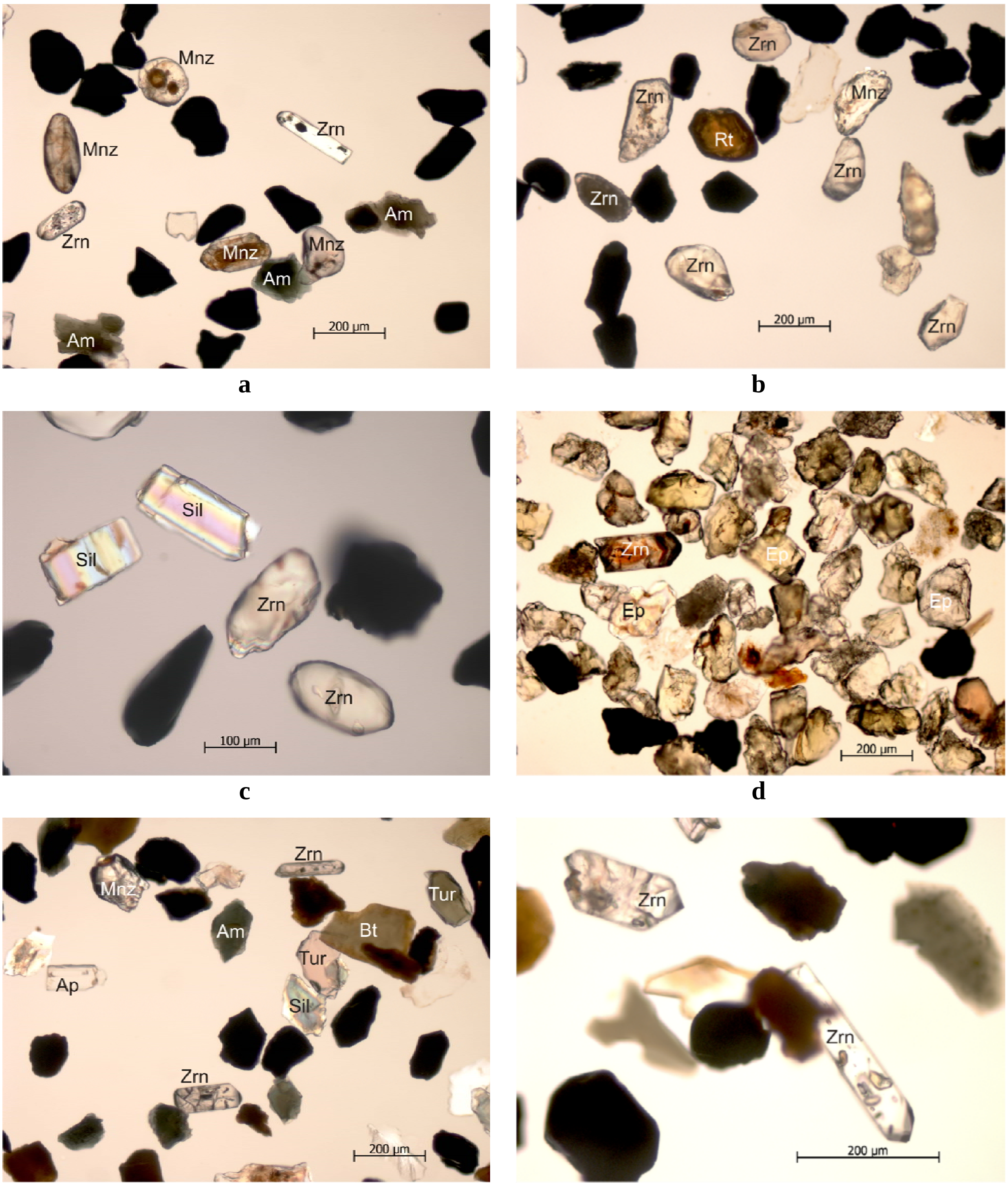
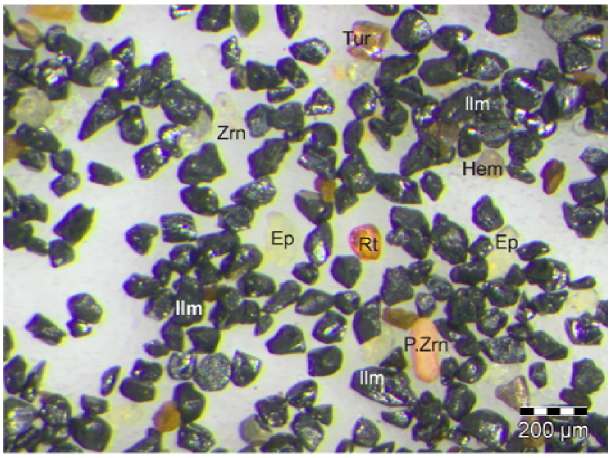
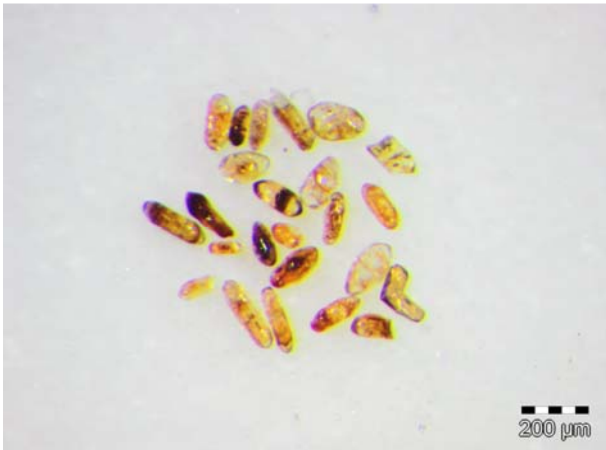


Figure 1. Example transmitted light optical photomicrographs of the heavy mineral separates

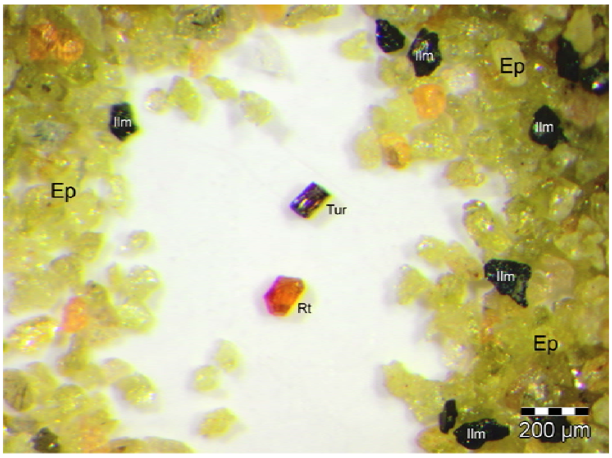
a. **Subhedral monazites (Mnz), subhedral amphiboles (Am) and bladed zircon (Zrn) with rounded terminations grains, sample site 168**
b. **Anhedral, equant zircon (Zrn), monazite (Mnz) and rutile (Rt) grains, sample site 78**
c. **Bladed, birefringent sillimanite (Sil) and rounded zircon (Zrn) grains, sample site 78**
d. **Euhedral zircon (Zrn) with angular epidote (Ep) grains, sample site 715**
e. **Euhedral apatite (Ap) and zircon (Zrn) grains with angular sillimanite (Sil), tourmaline (Tur), amphibole (Am), biotite (Bt) and subhedral monazite (Mnz), sample site 1413**
f. **Euhedral zircon (Zrn) grains, sample site 1633**



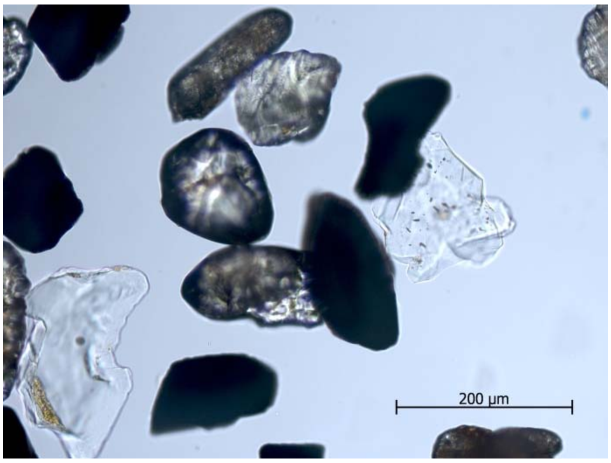
a



b



c



d

Figure 2. Example reflected light optical photomicrographs of the heavy mineral separates

a. **Heavy mineral separate dominated by grey, subhedral ilmenite (Ilm) grains with rare, euhedral pink zircon (P. Zrn) and epidote (Ep), rutile (Rt), tourmaline (Tur) and hematite grains, sample site 79**
b. **Picked, generally euhedral zircon grains, sample site 168**
c. **Heavy mineral separate dominated by pale green, subangular epidote (Ep) grains with ilmenite (Ilm) and occasional rutile (Rt) and tourmaline (Tur), sample site 715**
d. **Transmitted light photomicrograph showing examples of glassy, subangular quartz grains, sample site 1633.**

and metasedimentary/metavolcanic (e.g. sample sites 22 and 168) catchments compared to the older granite sources (e.g. sample sites 164 and 715).

The results of cluster analysis of the powder diffraction data, as carried out in the previous investigations (Kemp *et al.* 2009, 2010), is displayed as a dendrogram (Figure 3) and indicates nine distinct mineral assemblages:

- Group 1 samples (shown in yellow, sample sites 568, 715 from the Minna cell) are characterised by very high epidote (73-77%), moderate amounts of 'mica' (7-10%) and quartz (*c.*10%) and minor/trace amounts of zircon, amphibole, ilmenite, monazite and occasional xenotime. The catchment geology for both these samples are older granites. As shown by the dendrogram, these heavy separates are very different to those obtained from the remaining samples.

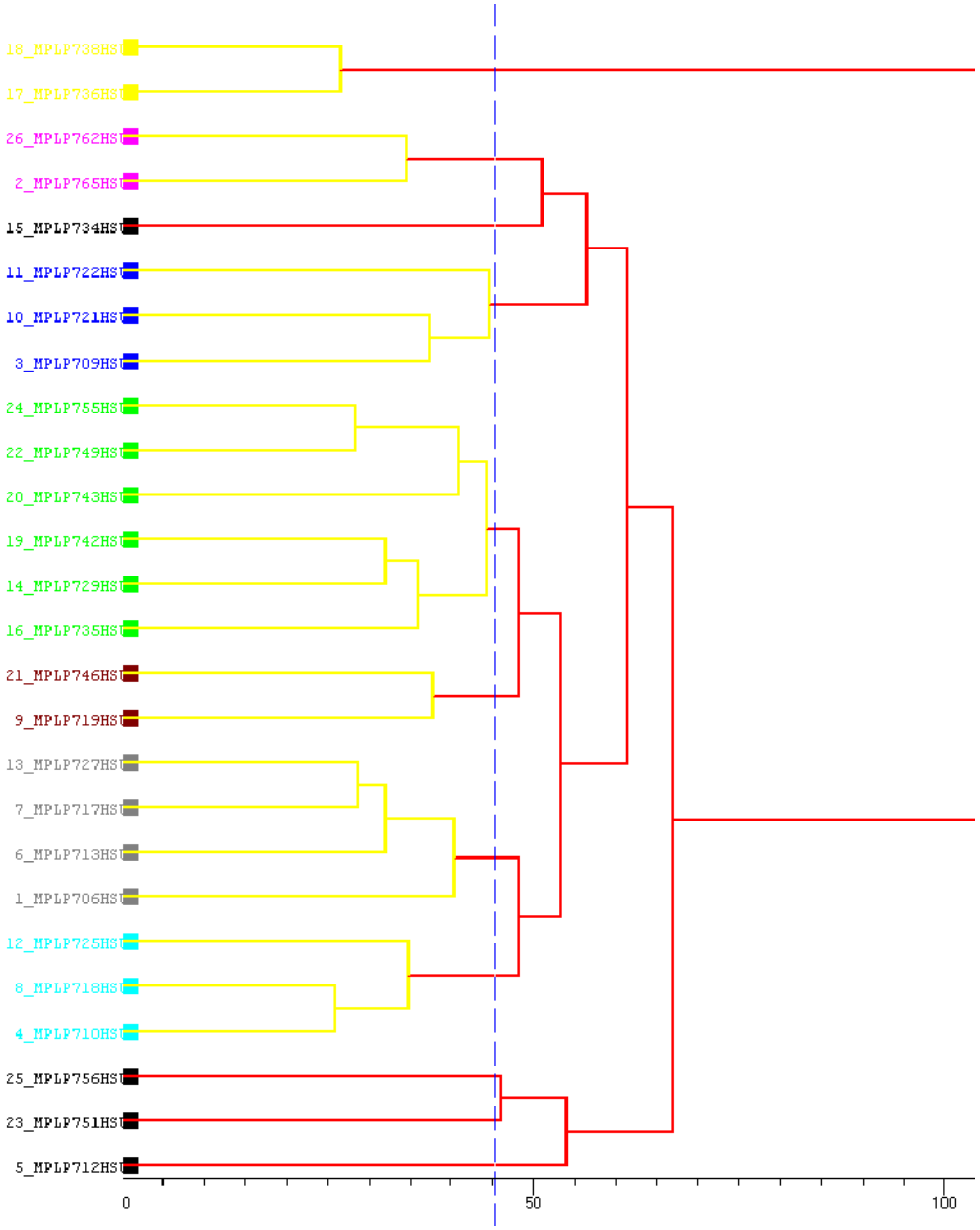


Figure 3. Cluster analysis dendrogram for the heavy mineral fraction XRD traces

- Group 2 samples (shown in cyan, sample sites 32, 168 and 279 from the SW cell) are characterised by high levels of ilmenite (40-47%) and amphibole (29-34%), moderate/trace amounts of zircon (3-9%), quartz (4-7%), monazite (2-7%), rutile (2-4%) ± epidote, anatase, 'mica' and sillimanite. The catchment geology is predominantly migmatitic gneiss with metasedimentary/metavolcanic lithologies.
- Group 3 samples (shown in magenta, sample sites 1413 and 1633 from the Minna cell) are also characterised by slightly lower levels of ilmenite (27-33%) and amphibole (18-25%) than the Group 2 samples but generally higher levels of 'mica' (11-16%), quartz (10-13%), zircon (7-13%) and occasional traces of anatase, hematite, magnetite, rutile and sillimanite. Group 3 heavy mineral separates are the only samples to contain minor amounts of andalusite. Group 3 samples are also characterised by variable catchment lithologies composed of older granite and migmatitic gneiss lithologies.

- Group 4 samples (shown in brown, sites 184 and 909) are characterised by relatively high ilmenite (39-58%), moderate amounts of amphibole (15%), quartz (6-14%), monazite (6-10%), zircon (4-5%) and rutile (3-5%) ± moderate/trace amounts of 'mica', anatase, apatite and 'kaolin'. Both samples catchment areas are formed of migmatitic gneisses.
- Group 5 samples (shown in grey, sample sites 2, 79, 164 and 332) are generally characterised by very high levels of ilmenite (42-87%) but otherwise a very variable mineralogy including zircon (1-26%), rutile (2-5%) ± amphibole, plagioclase feldspar, anatase, apatite, epidote, monazite, quartz and sillimanite. The catchment geology for the Group 5 samples is also very variable with migmatitic gneiss, older granites and metasedimentary/ metavolcanic sources.
- Group 6 samples (shown in green, sample sites 365, 539, 848, 850, 1005 and 1041 from the Minna cell) are also characterised by high levels of ilmenite (27-53%), moderate amounts of quartz (8-46%), amphibole (nd-16%), 'mica' (3-25%), sporadic epidote (nd-12%) ±traces of zircon, monazite, rutile, anatase, apatite, plagioclase and sillimanite. Group 6 samples are typically characterised by migmatitic gneiss with a few older granite catchment lithologies with occasional migmatitic gneiss.
- Group 7 samples (shown in blue, sites 22, 225 and 228 from the SW cell) are characterised by high amounts of amphibole (40-50%), moderate amounts of ilmenite (19-29%) and zircon (6-16%) and minor/trace amounts of monazite, rutile, quartz with occasional plagioclase, epidote, hematite and magnetite. The catchments for these samples are migmatitic gneiss and metasedimentary/ metavolcanic rocks.
- Group 8 samples (shown in black, sample sites 78, 1022 and 1052) all contain significant ilmenite (18-30%) and minor monazite (8-20%), amphibole (5-17%), 'mica' (6-13%), zircon (3-8%) but differ in their hematite (nd-32%), quartz (nd-51%), epidote (nd-8%), sillimanite (nd-8%), rutile (nd-5%) and xenotime (nd-4%). The catchment geology for the Group 8 samples are all migmatitic gneiss.
- The single remaining sample (Group 9, shown in black, site 513, Minna cell) is predominantly composed of ilmenite with subordinate epidote, amphibole and minor 'mica', zircon, quartz, monazite, hematite and rutile. Its catchment geology is formed of older granites.

Figure 3 indicates that the above defined sample groupings can be further combined into four general clusters.

Cluster 1, composed of Group 1 only, is very distinct as it is dominated by epidote with low proportions of zircon (mean *c.*2%) and is sourced from older granites in the Minna cell.

Cluster 2 (Groups 3, 7 and 9) samples are predominantly composed of ilmenite and amphibole and have higher proportions of zircon (mean *c.*10%) but are sourced from a range of catchments.

Cluster 3 (Groups 2, 4, 5 and 6) accounts for 15 of the 26 samples. These are also predominantly composed of ilmenite and amphibole but form a slightly different cluster owing to their elevated quartz content and lower zircon content (mean *c.*5%). This cluster is predominantly supplied from migmatitic gneiss catchments.

Cluster 4, composed of Group 8 only, is described above.

If the average heavy mineral compositions are compared for the two sampled cells, it is clear that the SW cell is enriched in amphibole, hematite, ilmenite, rutile, sillimanite and zircon compared to the Minna cell where samples are enriched in epidote, 'mica' and quartz.

Table 3. Summary of quantitative powder XRD analyses

Site no.	BGS MPL code	Heavy mineral separate		Silicates							Oxides						Phosphates			Phyllosilicates	
		Wt. (g)	%	quartz	plagioclase	andalusite	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	magnetite	rutile	apatite	monazite	xenotime	'mica'	'kaolin'
2	MPLP706	0.6	5.0	nd	nd	nd	7.8	nd	15.5	25.7	1.4	nd	42.1	nd	2.8	4.7	nd	nd	nd	nd
17	MPLP708	0.1	0.2	Insufficient heavy mineral separate available																
22	MPLP709	1.1	9.0	3.5	nd	nd	49.9	nd	nd	14.0	nd	5.0	19.3	1.6	3.6	nd	3.1	nd	nd	nd
32	MPLP710	1.2	3.6	4.7	nd	nd	33.9	6.2	nd	9.2	nd	nd	40.1	nd	1.7	nd	4.2	nd	nd	nd
78	MPLP712	1.0	8.6	nd	nd	nd	5.3	8.3	8.3	2.8	nd	32.0	17.6	nd	4.6	nd	7.4	3.8	9.9	nd
79	MPLP713	1.8	6.6	3.8	nd	nd	nd	nd	nd	2.5	nd	nd	86.8	nd	5.0	nd	1.9	nd	nd	nd
164	MPLP717	2.0	7.8	11.0	4.8	nd	13.6	nd	nd	1.3	nd	nd	65.9	nd	2.0	nd	1.4	nd	nd	nd
168	MPLP718	2.5	7.3	4.0	nd	nd	31.0	nd	nd	7.4	1.0	nd	47.4	nd	2.0	nd	7.2	nd	nd	nd
184	MPLP719	1.3	3.8	6.2	nd	nd	15.2	nd	nd	3.7	1.4	nd	58.3	nd	5.3	nd	9.9	nd	nd	nd
225	MPLP721	1.2	3.9	nd	nd	nd	49.9	nd	nd	16.0	nd	nd	28.5	nd	2.9	nd	2.7	nd	nd	nd
228	MPLP722	0.8	2.7	2.7	4.9	nd	40.2	15.9	nd	6.1	nd	nd	23.6	nd	3.5	nd	3.1	nd	nd	nd
279	MPLP725	1.5	5.0	7.2	nd	nd	29.1	6.0	3.4	3.1	1.2	nd	40.4	nd	3.5	nd	1.7	nd	4.4	nd
332	MPLP727	4.6	11.9	4.2	nd	nd	nd	12.1	nd	7.2	0.4	nd	69.3	nd	3.0	nd	3.8	nd	nd	nd
365	MPLP729	3.0	12.0	8.7	nd	nd	15.5	nd	nd	3.2	0.9	nd	51.8	nd	1.9	nd	2.0	nd	16	nd
513	MPLP734	1.9	7.6	4.1	nd	nd	14.8	20.6	nd	4.3	nd	2.4	40.2	nd	1.5	nd	2.7	nd	9.4	nd

continued over

Table 2. Summary of quantitative powder XRD analyses (continued)

Site no.	BGS MPL code	Heavy mineral separate		Silicates							Oxides					Phosphates			Phyllosilicates	
		Wt. (g)	%	quartz	plagioclase	andalusite	amphibole	epidote	sillimanite	zircon	anatase	hematite	ilmenite	magnetite	rutile	apatite	monazite	xenotime	'mica'	'kaolin'
539	MPLP735	0.8	2.7	17.0	nd	nd	nd	7.1	nd	4.1	1.0	3.5	37.6	nd	2.2	nd	2.9	nd	24.6	nd
568	MPLP736	1.5	4.4	9.5	nd	nd	1.8	72.8	nd	2.1	nd	nd	1.1	nd	nd	nd	1.9	0.9	9.9	nd
715	MPLP738	2.2	6.3	9.8	nd	nd	2.6	77.1	nd	1.3	nd	nd	1.2	nd	nd	nd	1.1	nd	6.9	nd
830	MPLP741	0.1	1.3	Insufficient heavy mineral separate available																
848	MPLP742	1.0	3.2	7.5	nd	nd	15.5	12.4	nd	2.4	nd	2.3	42.1	nd	nd	nd	3.6	nd	14.2	nd
850	MPLP743	0.5	6.9	29.3	3.7	nd	5.9	nd	nd	0.9	1.0	nd	52.6	nd	1.4	nd	0.7	nd	2.8	1.7
909	MPLP746	0.6	2.4	13.8	nd	nd	15.0	nd	nd	4.7	1.9	nd	39.2	nd	2.6	1.6	6.4	nd	12.4	2.4
1005	MPLP749	0.3	0.8	46.1	nd	nd	6.8	nd	5.2	1.3	1.0	nd	27.1	nd	2.6	2.1	1.7	nd	6.1	nd
1022	MPLP751	1.6	5.7	51.0	nd	nd	6.6	nd	nd	8.2	nd	nd	18.2	nd	nd	nd	7.4	3.0	5.6	nd
1041	MPLP755	1.3	4.1	25.4	nd	nd	7.0	nd	nd	5.3	nd	nd	45.6	nd	3.2	nd	3.2	nd	10.3	nd
1052	MPLP756	0.3	0.9	13.0	nd	nd	17.0	nd	nd	2.5	nd	nd	30.0	nd	4.8	nd	19.6	nd	13.1	nd
1413	MPLP762	5.3	18.7	9.5	nd	2.0	17.9	7.9	6.3	6.6	nd	3.5	32.5	1.0	2.0	nd	2.8	nd	15.9	nd
1633	MPLP765	2.9	11.2	13.0	nd	5.2	24.7	nd	nd	13.1	1.3	0.9	27.3	nd	0.6	nd	3.2	nd	10.7	nd

KEY

nd = not detected
'mica' = undifferentiated mica species, possibly including muscovite, biotite, illite, illite/smectite
'kaolin' = undifferentiated kaolin-group species, possibly including kaolinite, halloysite etc

6 Summary

- Heavy mineral separates have been successfully isolated from a suite of twenty eight stream sediment samples from Nigeria. The separates have been examined optically and also analysed by XRD where sufficient material was available.
- Heavy mineral separates form between 0.2 and 18.7% (mean 5.8%) of the stream sediment samples.
- XRD analysis indicates that the heavy mineral separates are variously composed of ilmenite, amphibole, quartz, epidote, 'mica' (undifferentiated mica species possibly including muscovite, biotite, illite and illite/smectite), zircon, monazite, rutile, hematite, sillimanite, plagioclase feldspar, andalusite, anatase, apatite, xenotime, 'kaolin' (undifferentiated kaolin group minerals possibly including kaolinite, halloysite etc) and magnetite.
- Zircon crystals exhibit a range of morphologies from euhedral, suggesting limited transport from their source, to anhedral, indicative of greater degrees of transport and recycling. No obvious relationship between zircon crystal morphology and catchment geology was established during this study. However, the migmatitic gneiss and metasedimentary/metavolcanic lithologies appear to provide greater proportions of zircon than the older granites. Most of the zircon grains appear colourless and unaltered and only rarely exhibit a pink colouration.
- Monazite crystals are generally subhedral suggesting lengthy transportation and also show greater concentrations in samples derived from migmatitic gneiss, metasedimentary/metavolcanic catchments compared to the older granite sources.
- Cluster analysis of XRD traces indicates nine specific mineralogical groups which can be combined to produce four clusters with similar characteristics.
- Cluster 1 (Group 1 from sample sites 568 and 715, Minna cell) is very distinct as the samples are dominated by epidote with low proportions of zircon (mean *c.*2%) and are sourced from older granites.
- Cluster 2 (Groups 3, 7 and 9 from sample sites 22, 225, 228, 513, 1413 and 1633) are predominantly composed of ilmenite and amphibole have higher proportions of zircon (mean *c.*10%) but are sourced from a range of catchments.
- Cluster 3 (Groups 2, 4, 5 and 6 from sample sites 2, 32, 79, 164, 168, 184, 279, 332, 365, 539, 848, 850, 909, 1005 and 1041) accounts for the majority of the samples which are also predominantly composed of ilmenite and amphibole but form a slightly different cluster owing to their elevated quartz content and lower zircon content (mean c.5%). This cluster is predominantly supplied from migmatitic gneiss catchments.
- Cluster 4 (Group 8 from sample sites 78, 1022 and 1052) are more variable assemblages with significant ilmenite, monazite, amphibole, 'mica', zircon (mean c.5%) and occasional major amounts of hematite and quartz. Their catchments geology is migmatitic gneiss in all cases.
- The average heavy mineral compositions for the two sampled cells indicate that the SW cell is enriched in amphibole, hematite, ilmenite, rutile, sillimanite and zircon compared to the Minna cell where samples are enriched in epidote, 'mica' and quartz.

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.

HILLIER, S., SUZUKI, K. AND COTTER-HOWELLS, J. 2001. Quantitative determination of Cerussite (lead carbonate) by X-ray powder diffraction and inferences for lead speciation and transport in stream sediments from a former lead mining area of Scotland. *Applied Geochemistry*, 16, 597-608.

KEMP, S.J., WAGNER, D. AND MOUNTENEY, I. 2009. Mineralogical analysis of stream sediments from Nigeria. *British Geological Survey Internal Report*, IR/09/040. 21pp.

KEMP, S.J., WAGNER, D. AND MOUNTENEY, I. 2010. Mineralogical analysis of further stream sediments from Nigeria. *British Geological Survey Internal Report*, IR/10/083. 21pp.

SNYDER, R.L. AND BISH, D.L. 1989. Quantitative analysis. In: Bish, D.L., Post, J.E. (Eds), *Modern Powder Diffraction, Reviews in Mineralogy*, Volume 20, Mineralogical Society of America, USA, pp. 101-144 (Chapter 5).