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Heavy mineral analysis of Nirex borehole 13B from Sellafield, west Cumbria

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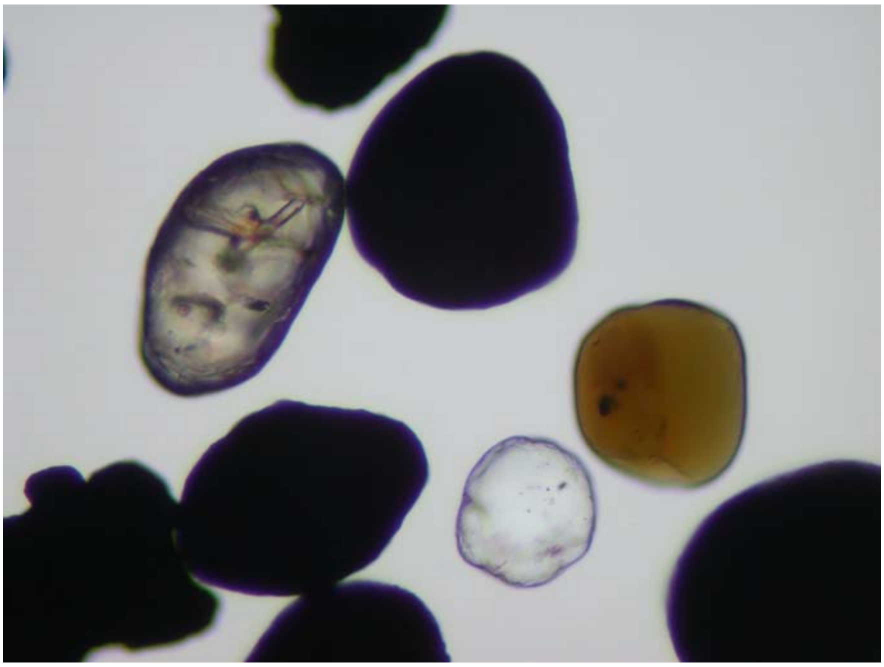
Internal Report IR/03/062



BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/03/062

Heavy mineral analysis of Nirex borehole 13B from Sellafield, west Cumbria

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Contributor/editor

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Key words

Heavy mineral analysis, Triassic, sandstone, Sellafield.

Front cover

Photomicrograph of the three most abundant non-opaque heavy mineral identified in this study (zircon, left; tourmaline, right; apatite, centre) (Ormskirk sandstone, 172.8 m).

Bibliographical reference

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This study originated from suggestions made by Neil Jones (BGS).

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Summary

Heavy mineral analysis of Nirex borehole 13B from Sellafield, west Cumbria provides the first characterisation of the heavy mineral content of the Ormskirk Sandstone and the upper ~ 100 m of the underlying Calder Sandstone Formation. These sandstones are the two upper units of the Triassic Sherwood Sandstone Group. The non-opaque heavy mineral assemblage is dominated by an assemblage of predominantly rounded to well-rounded grains of tourmaline + zircon + rutile ± apatite. Variations in ATi (apatite-tourmaline index value) define a ~60 m thick zone of apatite-poor sandstone in the uppermost part of the Ormskirk Sandstone. Comparison with previous work on the Triassic sandstones of Cheshire suggests that the upper limit of these apatite-poor sandstones may mark the site of the Hardegsen Disconformity in west Cumbria. The implications of these data for the provenance of these rocks is limited, except that there is no evidence of a change in provenance from the underlying St Bees Sandstone Formation, the lowermost unit of the Sherwood Sandstone Group. The heavy mineral data may be useful for the purposes of stratigraphical correlation of disputed sections of Triasssic rocks in this region (see Section 6, Further work for details).

1 Introduction

This report presents the results of non-opaque heavy mineral analysis of Nirex borehole 13B [NY 04506 00184] from Sellafield, west Cumbria. Nirex borehole 13B cored ~ 140 m of the Ormskirk Sandstone and ~ 112 m of the underlying Calder Sandstone Formation to a total depth of ~ 270mbOD (Strong and Kemp, 1997). The purpose of this study is to provide training in heavy mineral analysis for the purposes of sandstone provenance and stratigraphic correlation. The stratigraphy of the Triassic sequence in the Sellafield area is summarised in Table 1 (after Jones and Ambrose, 1994; Barnes et al., 1994).

Table 1 : Triassic stratigraphy in the Sellafield area, west Cumbria

Group	Formation/Sandstone	Description	Facies
Sherwood Sandstone Group	**Ormskirk Sandstone Formation** This study has sampled the lowest 140 m of the sandstone.	No type section or well-defined boundaries. The section in borehole 13B is the most complete record.	Aeolian dune and interdune facies.
	Calder Sandstone Formation (CSF) This study has sampled the top 112m of the formation	Upper boundary: depth of 176.42 m in borehole 13B at the top of a ~42m thick unit of fluvial sandstones, overlain by aeolian sandstones. Lower boundary: depth of 190.35m in borehole 10B, lithological change from well-cemented, fine-grained sandstones of the SBSF, to coarser grained sandstones with features typical of aeolian processes.	Aeolian and fluvial facies with interbedding at the base.
	St Bees Sandstone Formation (SBSF)		Fluvial deposition into stacked channel units.

2 Sampling and sample preparation

Sampling (n=27) of the borehole was conducted at the BGS and samples were taken of the finer grained sandstone at 10-20 m intervals. Heavy mineral separations from the 63-125 μm fraction were performed at the BGS sample preparation facility by conventional heavy liquid techniques. Heavy mineral slides were then analysed petrographically and identifications were aided using the illustrated catalogue of Mange and Maurer (1992).

3 Heavy mineral analysis (HMA)

The study of heavy minerals, and their application to the understanding of sandstone provenance, broadly sub-divides into two techniques. Varietal studies (varietal HMA) characterise the variation in the optical characteristics of a population of a single mineral species (reviews of Mange and Maurer, 1992; Morton and Hallsworth, 1994, 1999). By contrast, studies based on mineral ratios (conventional HMA), known as index values, use the relative abundance of minerals with similar hydraulic and diagenetic behaviour (Morton and Hallsworth, 1994; 1999). It should be noted that these two techniques are not independent of each other and both techniques may be applied to the same samples. In addition, other analytical techniques can be applied to the heavy mineral assemblage once the optical characterisation has been made. An example of the integration of conventional HMA with mineral chemistry and U-Pb zircon geochronology is found in the study of Carboniferous sandstones of the Pennine Basin by Hallsworth et al. (2000).

The study of heavy mineral assemblages based on index values uses the following mineral ratios, where applicable, to characterise a set of samples (Morton and Hallsworth, 1994).

ATi	Apatite – tourmaline	100 grains minimum count
RZi/RuZi	Rutile-zircon	100 grains minimum count
RZi	TiO_2 group (rutile, anatase, brookite)- zircon	200 grains preferable
CZi	Cr-spinel – zircon	200 grains minimum count
MZi	Monazite – zircon	200 grains minimum count
GZi	Garnet – zircon	200 grains preferable

(The index values are calculated as 100 x (mineral A count /(mineral A + mineral B count)).

The best way of dealing with the TiO_2 group minerals must consider the difficulties in correctly identifying detrital varieties of the correct grain size of these minerals because secondary overgrowths may occur.

Point-counting of the slides was performed by the ribbon method of Galehouse (1971).

4 Results

Heavy mineral analysis was performed on the samples from borehole 13B by first characterising the entire assemblage by point counting 400 grains, where possible. The results are given in Table 2.

Conventional HMA

The non-opaque heavy mineral assemblage of borehole 13B is dominated by four minerals, tourmaline (30 – 88 %) + zircon (3 – 34 %) + rutile (1-6 %) ± apatite (0-51 %). In addition, rare occurrences of Cr-spinel, garnet (etched), monazite and staurolite were identified (0-2 %). Mica is a common non-opaque phase but is not considered useful for heavy mineral analysis. Other TiO_2 minerals may also be present as detrital grains. However, secondary overgrowths are common and these minerals were not included in the analysis due to the difficulty in identifying true detrital grains of the correct grain size. Secondary carbonate is variably developed in the Ormskirk Formation at depths of between 116 and 194 m. All grains are extensively rounded, particularly apatite, with original crystal morphology sometimes preserved in the zircon.

The ATi and RZi index values were calculated by counting 200 grains per slide, where possible, and the data is listed in Table 2. For those samples where the minimum count of 100 was not achieved the data are not considered further.

In the overlying Ormskirk Sandstone ATi averages 13.5, whereas in the Calder Sandstone ATi averages 44.5, a marked increase; by contrast, the average RZi values of the two formations are more similar (Ormskirk, 14.4, Calder, 18.5).

The downhole characteristics of ATi and RZi in borehole 13B show a number of features (Figure 1A). The Ormskirk Sandstone is characterised by an absence of apatite to a depth of ~ 100 m, producing ATi values of 0, and then an irregular distribution of ATi values down to the Ormskirk-Calder boundary, with a short trend of decreasing ATi as the boundary is approached. By contrast the Calder Sandstone is characterised by little variation in ATi with depth. The RZi characteristics of the two sandstones are more similar with the Ormskirk Sandstone showing more variation with depth; the Calder Sandstone has a pronounced, sharp, but poorly-defined, increase in RZi approaching the Calder-Ormskirk boundary (Figure 1A).

The results of this study are compared with those of Morton (1991) for Nirex borehole 2 from Sellafield (Figure 1B). In general the heavy mineral assemblages of the three sandstone units are similar. Only ATi values can be directly compared as Morton (1991) used a different RZi index (total TiO_2 minerals-zircon). Morton (1991, 1992, 1993) found little variation in the heavy mineral character of the St Bees Sandstone Formation in boreholes 2, 3 and 7B from Sellafield. The St Bees Sandstone is characterised by an average ATi value of 55.6 in borehole 2, with little variation with depth, and the Calder Sandstone, with considerably fewer samples, an average ATi of 29.1, including a ~10 m interval of apatite depletion (Figure 1B). The lowest part of the Calder Sandstone preserved in borehole 2 therefore has a lower average ATi (29.1) in comparison to the uppermost part of the sandstone preserved in borehole 13B (44.5).

Varietal HMA

Three varieties of zircon were identified in borehole 13B and formed the basis of a zircon varietal study. The varieties identified were a colourless zircon, pale pink zircon and a pale green/brown, turbid zircon. Each of these varieties was further sub-divided into 1) rounded to well-rounded and 2) subhedral to euhedral groups. The varieties (6) were quantified by counting 50 zircons per slide where possible (Table 2).

Colourless zircons predominate, and it is the only variety of zircon to provide observable, scattered trends with depth (Figure 2). The Calder Sandstone Formation and lower part of the Ormskirk Sandstone display trends of decreasing rounded/well rounded colourless zircons and increasing subhedral/euhedral colourless zircons. By contrast the upper part of the Ormskirk Sandstone shows scattered trends of increasing roundness of the colourless zircons.

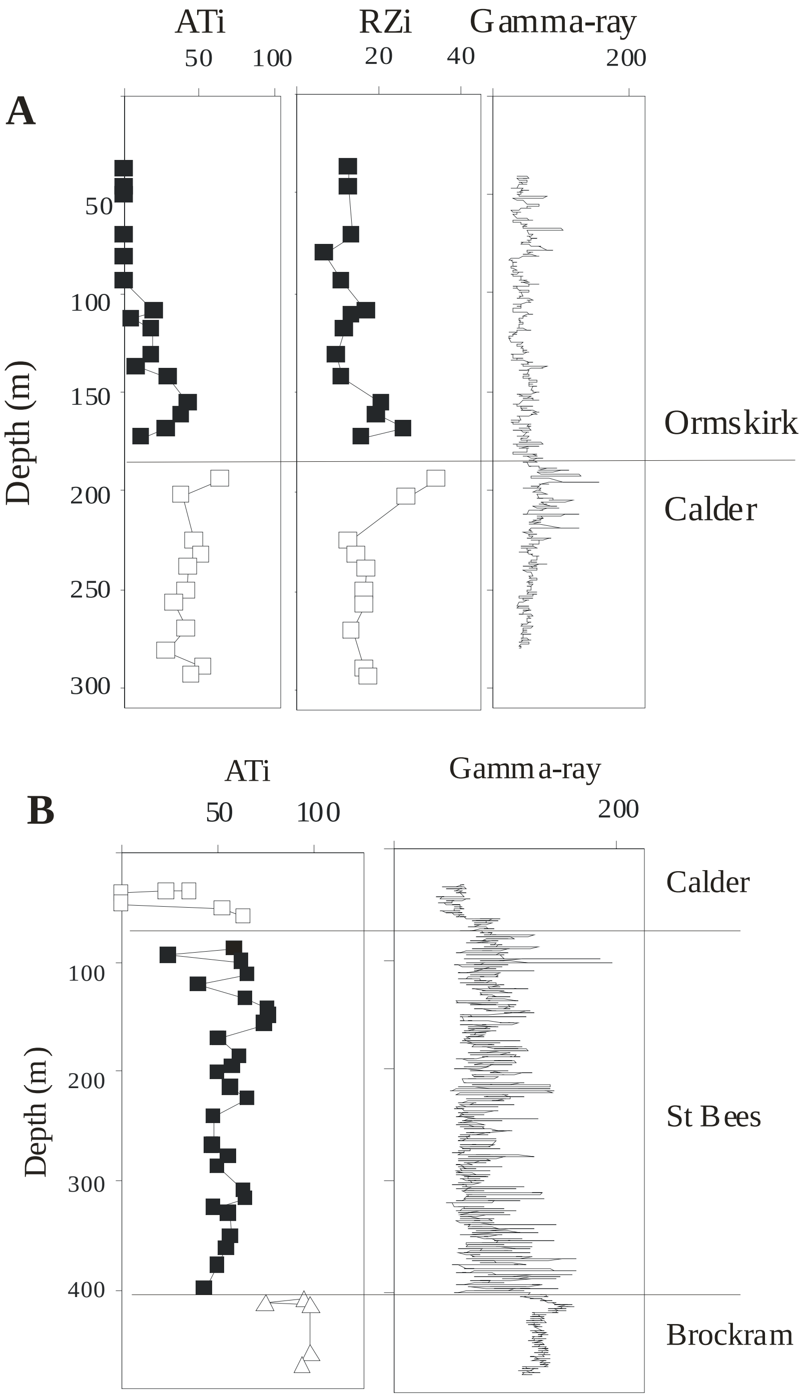

Figure 1: (A) A plot of ATi (apatite - tourmaline index value) and RZi (rutile-zircon index value) against depth (m) for borehole 13B from Sellafield, west Cumbria. (B) ATi results obtained from borehole 2 by Morton (1991) are shown for comparison. Gamma ray log data for each borehole is shown for comparison (Jones and Ambrose, 1994).

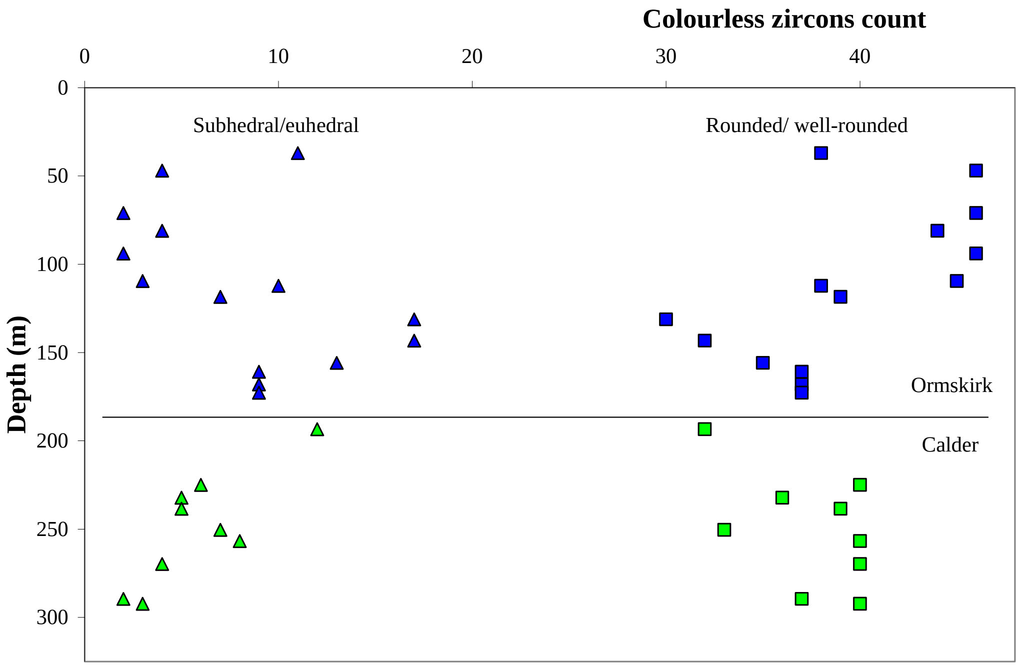

Figure 2: A plot of the abundance of colourless zircons out of a population of 50 zircons counted, sub-divided into two textural types, against depth (m).

5 Discussion

Little can be said of the provenance of the Ormskirk and Calder sandstones on the basis of the data presented in this study, because of the limited diversity or variation found in the assemblage. Their heavy mineral characteristics are broadly similar to the underlying St Bees Sandstone (Morton, 1991, 1992, 1993), suggesting little change in provenance throughout the sedimentation of the Sherwood Sandstone Group in west Cumbria.

The most noteworthy feature of the heavy mineral analysis of borehole 13B is the ~ 60 m thick interval of apatite-poor sandstone, marked by ATi values of 0, in the Ormskirk Sandstone to a borehole depth of ~100m (e.g. Figure 1A). These low ATi rocks do not correlate with any other heavy mineral characteristic and are therefore unlikely to represent a provenance signature. Morton (1986) concluded that apatite-poor and apatite-rich assemblages in the Jurassic of the North Sea, and adjacent onshore UK, are produced by the dissolution of apatite, and that such apatite dissolution is a function of depositional environment rather than burial depth. The fluid responsible for this dissolution was suggested to be a low pH meteoric groundwater related to early diagenesis and a period of sub-aerial exposure. The nature of this fluid is not well constrained however, due to the scarcity of experimental constraints. By contrast, the higher temperature fluids associated with deep burial have little or no effect on apatite dissolution (Morton, 1986). It is suggested therefore that the apatite-poor sandstones in the Ormskirk Sandstone result from the dissolution of apatite by groundwaters, during a period of Triassic sub-aerial exposure in the early stages of diagenesis.

Apatite-poor (mean ATi of 0.2) and apatite-rich (mean ATi of 61.5) assemblages occur in the Wilmslow Sandstone of the Sherwood Sandstone Group, Cheshire, where the transition from apatite-poor to apatite-rich assemblages is sharp, and the apatite-poor sandstones overly the apatite-rich where both assemblages are found together (Jones et al., 1999). This suggests that similar apatite dissolution processes may have operated in the Wilmslow Sandstone, Cheshire, and the Ormskirk Sandstone, Sellafield.

In the Cheshire Basin the apatite-poor assemblages are found in the upper part of the Wilmslow Sandstone, beneath the Hardegsen Disconformity, and it had been suggested that this disconformity may have regional significance, perhaps into the Triassic of Europe (Jones et al., 1999). However, Jones and Ambrose (1994) suggested that the Calder-Ormskirk boundary, ~ 100 m beneath the base of the apatite-poor sandstone in borehole 13B, may mark the site of the Hardegsen Disconformity in the west Cumbria region. This study indicates that the Calder-Ormskirk boundary, the proposed Hardegsen Disconformity in this region, does not mark the upper limit of apatite depletion as is the case in Cheshire.

Furthermore, Jones and Ambrose (1994) noted that the Calder-Ormskirk boundary is not characterised by the effect of an unconformity in the Sellafield region. This is in agreement with the results of the zircon varietal study which suggests a similar pattern of sedimentation in the Calder Sandstone Formation and the lowermost Ormskirk Sandstone, perhaps related to the effect of mixing aeolian (more rounded grains) and fluvial (less rounded grains). It is suggested therefore that the upper boundary of the apatite-poor sandstones within the Ormskirk Sandstone could be correlated with the Hardegsen Disconformity in the Cheshire Basin if the post-depositional processes of apatite depletion are of regional extent as has been previously suggested (Jones et al., 1999).

6 Further work

- Nirex Borehole 13A [NY 04521 00146] contains the lower part of the Calder Sandstone Formation and its contact with the underlying St Bees Sandstone Formation (e.g. Jones and Ambrose, 1994). Although the previous work of Morton (1991, 1992, 1993) has characterised the St Bees Sandstone, and its contact with the Calder Sandstone, further work on borehole 13A would provide a more comprehensive section through the Sherwood Sandstone Group at Sellafield.
- Barnes et al. (1994) suggested that the Ormskirk – Calder contact identified in Sellafield borehole 13B may be found in the Triassic sandstones of the Silloth 1A borehole in the Carlisle Basin. Although the contact in borehole 13B is not characterised by well-defined heavy mineral variations, the presence of the well-defined overlying apatite-poor sandstone within the Ormskirk Sandstone could aid attempts at correlation, assuming the causative period of Triassic sub-aerial exposure was regional in extent. (Note added by Neil Jones: there may be no core for the Silloth 1A borehole).
- The existing data suggest that the Calder Sandstone, immediately above its contact with the underlying St Bees Sandstone Formation, is characterised by a short interval of apatite-poor sandstone (Morton, 1991). Again, making the same assumption as above, this may help to correlate this contact in disputed sections.
- Heavy mineral analysis of these rocks for the purposes of stratigraphical correlation may require a higher density of sampling than conducted in this study due to the subtle nature of variations in index values (e.g. ATi and RZi at the Ormskirk-Calder contact in borehole 13B).

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Table 2: Results of heavy mineral analysis of borehole 13B from Sellafield, west Cumbria

Depth (m)	Depth mbOD	Fm	MPL code	Ap	Tur	Zrn	Rt	Chr	Grt	Mnz	St	Count	RZi	Count	ATi	Count	1	2	3	4	5	6	Count
37	-13.50	Ormskirk	H160	-	63.8	29.8	6.3	-	-	-	-	400	12.5	200	0.0	200	38	11	0	2	0	0	51
47	-23.50	Ormskirk	H161	-	76.8	19.5	3.8	-	-	-	-	400	13.0	200	0.0	200	46	4	0	0	0	0	50
50	-26.50	Ormskirk	H162	-	82.6	10.7	4.1	1.7	0.8	-	-	121	21.2	33	0.0	174	na	na	na	na	na	na	
71	-47.50	Ormskirk	H163	1.01	72	25	2	-	-	-	-	296	13.5	200	0.0	200	46	2	1	1	0	0	50
81	-57.50	Ormskirk	H164	-	78.3	18.8	2.8	0.3	-	-	-	400	6.5	200	0.0	200	44	4	0	1	1	0	50
94	-70.50	Ormskirk	H165	-	74.8	21.5	2.5	0.3	1	-	-	400	11.0	200	0.0	200	46	2	0	2	0	0	50
109.5	-86.00	Ormskirk	H166	18	71	9	2	-	-	-	-	400	17.0	200	20.0	200	45	3	0	0	2	0	50
112.3	-88.75	Ormskirk	H167	3.75	72.8	19	4.3	0.3	-	-	-	400	13.5	200	5.5	200	38	10	0	2	0	0	50
118.5	-95.00	Ormskirk	H168	14.3	66	17.3	2.3	0.3	-	-	-	400	11.5	200	18.5	200	39	7	1	3	0	0	50
131.2	-107.70	Ormskirk	H169	16.5	62.3	19.5	1.8	-	-	-	-	400	10.0	200	18.0	200	30	17	0	0	2	1	50
136.7	-113.15	Ormskirk	H170	8.25	87.8	3	1	-	-	-	-	400	5.9	34	7.5	200	na	na	na	na	na	na	
143.3	-119.75	Ormskirk	H171	19	56.3	22	2.8	-	-	-	-	400	11.0	200	29.5	200	32	17	0	0	1	0	50
155.9	-132.40	Ormskirk	H172	28.8	46	21.3	4	-	-	-	-	400	20.5	200	42.5	200	35	13	0	0	1	1	50
160.9	-137.40	Ormskirk	H173	36.3	44.3	15.5	4	-	-	-	-	400	19.5	200	37.5	200	37	9	0	0	2	2	50
168.1	-144.60	Ormskirk	H174	16.3	62.3	18.3	3.3	-	-	-	-	400	26.0	200	27.5	200	37	9	1	1	1	1	50
172.8	-149.25	Ormskirk	H175	9.9	49.8	33.9	6	0.3	-	-	-	333	16.0	200	11.5	200	37	9	1	1	1	1	50
193.5	-170.00	Calder	H176	50.8	34.5	11.3	3.5	-	-	-	-	400	34.0	200	65.5	200	32	12	0	1	5	0	50
202.5	-179.00	Calder	H177	27.5	64.3	6	2.3	-	-	-	-	400	26.7	105	38.0	200	na	na	na	na	na	na	
225	-201.50	Calder	H179	25.3	45	24.5	5.3	-	-	-	-	400	13.0	200	46.0	200	40	6	0	1	3	0	50
232.2	-208.70	Calder	H180	41.5	40	16.8	1.5	-	-	-	0.3	400	14.5	200	51.0	200	36	5	0	2	4	3	50
238.5	-215.00	Calder	H181	38	47	10.3	4.5	-	0.3	-	-	400	17.0	200	44.0	200	39	5	2	2	2	0	50
250.5	-227.00	Calder	H182	26.5	53.8	15.8	4	-	-	-	-	400	16.5	200	41.5	200	33	7	0	0	7	3	50
256.8	-233.25	Calder	H183	21	51.3	23.3	4.5	-	-	-	-	400	16.2	200	34.0	200	40	8	0	0	2	0	50
269.8	-246.25	Calder	H184	33.8	51.3	13	1.5	-	-	-	0.5	400	13.1	198	41.0	200	40	4	0	1	5	0	50
280.5	-257.00	Calder	H185	25.5	65.8	6.75	1.3	-	-	-	0.5	400	11.5	87	28.5	200	na	na	na	na	na	na	
289.5	-266.00	Calder	H186	39	29.8	26	5.5	-	-	-	-	400	16.5	200	54.0	200	37	2	0	0	10	1	50
292.3	-268.80	Calder	H187	33.8	45.3	18.8	2.3	-	-	-	-	400	17.5	200	45.5	200	40	3	0	0	7	0	50

na = not analysed. RZi = 100*rutile count/(rutile+zircon count); ATi = 100*apatite count/(apatite+tourmaline count).
Minerals: Ap = apatite; Tur = tourmaline; Zrn = zircon; Rt = rutile; Chr = Cr-spinel; Grt = garnet; Mnz = monazite; St = staurolite;

Zircon varieties: 1: Colourless (rounded); 2: Colourless (euhedral); 3: Pink (rounded); 4: Pink (euhedral); 5: Pale green/brown/turbid (rounded); 6: Pale green/brown/turbid (euhedral).