

Geophysical and testpit survey of an iron-making site, Parsonage Ground, Iron Acton [5168138323], July 1996

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Abstract

The western side of a large concentration of early iron-making slag was recorded from an area approximately 150 m south of Iron Acton church [ST 6813 8323]. The deposit appears to have been considerably disturbed and much of the investigated site may represent material washed down the western side of the ridge from an original dump near the crest. Documentary evidence, together with the abundance of iron slag on paths in the village, suggests that the former slag dumps around the village may have been quarried in post-medieval times for track and path surfacing. The slag material still remaining on site west of the crest of the hill is estimated to amount to approximately 100 tonnes, demonstrating the significance of the original dump. Similarly high concentrations of slag occur in the gardens of the housing estate which now occupies the area to the east of the crest of the ridge, with lower concentrations extending in a spread 100 m north and east of the site. The limited artefactual evidence from the trial pits included post-medieval pottery, glass, clay pipe fragments and other materials from the superficial soil layer, together with a few sherds of possibly medieval pottery from the disturbed slag deposit. The relatively large size of the dump would argue for a Roman or medieval age; the lack of any Roman artefacts would suggest the later age.

Geophysical investigation reveals evidence for the geological structure of the area and allows the position of the major Iron Acton Fault to be ascertained, and suggests the presence of a series of fault strands over a width of 30m. Although areas near the course of the fault north of the village are known to have been worked for iron ore, there was no geophysical evidence that the Iron Acton Fault itself had been mined within the study area. The iron source for the bloomery which produced the slag dump is believed to have been outside the present study area, possibly where the eastern splay fault crossed the ridge, although the bloomery may have been positioned to utilise woodland resources in the Frome Valley and employing ore from elsewhere in the district. The point at which the Iron Acton Fault reaches the crest of the ridge corresponds to the area of the Old Rectory and church, an area with large amounts of slag present, but it is not yet known whether that slag is solely the result of the spread of path-surfacing material, or whether there was a second slag dump in this area.

Detailed study of the Parsonage Ground site is supplemented by a reconnaissance analytical program of ore and slag samples from Iron Acton. The chemical properties of these are remarkably homogeneous.

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Background

Iron Acton is believed to have been the location of significant medieval iron smelting. The name Iron Acton was applied to the manor by the early 14th century. The adjacent manor of Pucklechurch is recorded as paying a heavy tax in iron in the Domesday Book. A Saxon charter of Pucklechurch (reputed to be from AD950) records a "sinder ford" apparently on the boundary with Iron Acton (Grundy 1936) and probably close to Algar's Mill (Figure 1).

Survey work during July 1996 concentrated on areas to the south of Iron Acton parish church. Bloomery slag had been found previously on the surface of a public footpath in the northeastern corner of the field corresponding to the southern half of the field numbered 248 (Parsonage Ground) on the 1842 Tithe Map and this point formed the focus of the 1996 work [ST 6813 8323].

Fieldwork included a topographic survey of the Parsonage Ground area (now subdivided by a fence into two separate fields), extending southwards into the southwestern part of the field numbered 221 on the Tithe Map (Sirs Piece; of which the eastern part is now

built over) and northwards to the gardens of the Old Rectory. A map of 1830 (BRa) shows that the eastern part of Parsonage Ground was formerly part of Clay Fields, to the east. The land up to the crest of the hill became part of the grounds of the Rectory, and an exchange of grounds brought this former part of Clay Fields into the glebe lands, in exchange for lands elsewhere in the village.

The lands to the west of Parsonage Ground form part of the estates of Chillwood Farm, which Manco (1995) has argued was the late medieval manor house for Acton Ilger. Moore (1989) argued that the original centre of Acton Ilger was immediately to the east of the church, close to the present site.

British Geological Survey maps (Bristol Special Sheet 1962; Kellaway & Welch 1993) indicate a major fault (the Iron Acton Fault) running approximately N-S running from the church southwards through the valley south of the Old Rectory. This fault is indicated as having a splay running northeastwards through Sirs Piece. The ground between the two faults is mapped as being underlain by the Pennant Coal Measures, whereas west of the Iron Acton Fault and east of the splay, the bedrock is a thick, cross-bedded sandstone body at the base of the supra-Pennant Measures (Farrington Formation). Tracing these two faults formed a major aim of the geophysical survey. The geophysical survey comprised resistivity and seismic traverses across the major fault line in Parsonage Ground, a resistivity traverse across the minor fault in Sirs Piece and a large area of detailed magnetometer survey across the area of slag.

The geophysical fieldwork was undertaken in collaboration with Dr P.J. Brabham of the Department of Earth Sciences, Cardiff University, who supervised three undergraduates undertaking their dissertation fieldwork. The geophysical surveys were therefore largely aimed at generating geological data. The archaeological fieldwork was undertaken together with Mr P Macdonald, Cardiff University, and comprised excavation of a series of small (typically 0.3 x 0.3m) test pits.

A summary note of the site has already been published (Young & Macdonald 1999).

Techniques

Topographic Survey

A detailed topographic survey of the study area was made by EDM. The survey was keyed to the benchmark on the SW corner of the church.

Seismic Survey

A seismic refraction survey was undertaken using a Bison Instruments 9000 Series Seismometer. The seismic line (S1) was taken across the northern part of Parsonage Ground. The line was 120m in length, and ran from [68109 83297] to [67993 83266]. Geophone spacing was 2m. Data were processed using Gremix.

Resistivity Profiling

Profile R1 was taken along the same line as the seismic refraction survey. The electrode spacing was 5m and the instrument was a Campus Resistivity Profiler.

Profiles 2 and 4 were taken with the same geometry, with R2 taken across the valley along the line of testpits in the southern part of Parsonage Ground ([68135 83217] to [68025 83178]), and R4 taken across the expected line of the fault splay in Sirs Piece ([68165 83158] to [68210 to 83046]). Line R3 was a shallow line taken across the ditch feature in the east of Parsonage Ground, with an electrode spacing of 0.75m, but the extremely dry superficial soil conditions led to this line having extremely poor results and it was abandoned.

The pseudosection data obtained from these lines was subsequently processed using Res2deco to obtain a model resistivity section. For profile R1, modelling included compensation for topography, but for lines R2 and R4 the data appear sufficient to plot the position of the main features without this additional processing.

Magnetometer Survey

The magnetometer survey was undertaken using Geometrics G826 total field proton magnetometers. This instrument requires temporal variation to be logged via a base station. It does not give results of sufficient sensitivity for most archaeological purposes.

Test Pits

The test pits were hand dug and with dimensions of approximately 0.3 x 0.3m. The sections were logged, and all artefacts collected. The slag collections were subsequently weighed and classified as far as possible.

Slag analysis

Reconnaissance analysis of samples of slag and ore from various parts of the area was undertaken. All samples were taken from surface finds. Three samples of ore (two from near Dowell Farm and one from a field immediately N of the village) and five of slag (one from Dowell Farm, three from just north of the village, and one from Parsonage Ground) were analysed, using XRF analysis for major elements and ICP-MS for minor and trace elements. Analyses were undertaken in the Department of Earth Sciences, Cardiff University.

Survey Results

Two earthwork features were identified within the study area: a former field boundary corresponding to the original eastern margin of the glebe land with Clay Fields, and a rock-cut ditch delimiting the copse in the SE part of Parsonage Ground. The field boundary formed a positive lynchet feature in the northern part of Parsonage Ground, but became more bank-like as it approached the crest of the fill in the southern part. The ditch feature formed a feature with a concave plan facing NW, dividing off the eastern corner of Parsonage ground from the remainder of the field. The most likely explanation for the feature is that it was intended to protect the trees of the pine plantation on the crest of the ridge in the corner of the field. It presumably, therefore, postdates construction of The Rectory, but may predate 1830 (at which date the plantation is shown on a plan).

Results from the seismic and resistivity surveys of line S1/R1 are shown in Figure 2. The seismic refraction section shows an upper layer (corresponding to the weathered zone) with a seismic velocity of 765 m/s. The weathered zone increases in thickness from about 4m at

the east of the section to 9m at the west. Below the weathered zone an abrupt second layer shows an abrupt change in seismic velocity at a point approximately 51m from the east of the section. To the east of this point the velocity in the lower layer is 2710 m/s and to the west it is 3074 m/s. The higher velocity to the west presumably indicating the more competent sandstone at the base of Farrington Formation, the lower to the east the Pennant Measures.

The resistivity profile shows steeply west-dipping discontinuities at approximately 26, 34 and 49m from the east of the section. The western of these discontinuities corresponds to that seen in the seismic section. To the west of this line, a superficial zone of very low resistivity extends 10-15m below surface, and represents the water-rich weathered zone in the valley. Immediately to the west of the major discontinuity there is a superficial zone of high resistivity (34-49m). To the east of the high resistivity zone, there is a second zone of superficial low resistivity (26-34m), extending down to about 10m. At the extreme eastern end of the section, beyond the 26m discontinuity, relatively high resistivity continues to surface.

A similar zonation was observed in R2 (Figure 3a), where it the three discontinuities in resistivity occur at 47, 69 and 82m from the eastern end of the section. The test pits along this line (TP7 to TP18) permit observation of the nature of the bedrock. TP18 lay at approximately 70m along R2 and corresponded with the position of a parchmark and showed a bedrock of intensely deformed, pelletised haematized mudstones. This suggests that the narrow resistivity high comprises the highly deformed red mudstones.

TP17, 16 and 15 lie within the 47-69m resistivity low, and are characterised by thick highly weathered subsoils. The other test pits lay within the eastern area of high resistivity, and most (except 9 and 13) show relatively solid sandstone at depths of 0.45-0.60m below surface. TPs 9 and 13 show weathered bedrock, like that of TPs 15-16, and TP13 appears to correspond to a sub-surface resistivity low.

The interpretation of these two lines is not certain. If the low resistivity superficial layers correspond to highly altered bedrock, then it suggests that the superficial layer of bedrock is altered for a considerable distance to the west and a smaller distance to the east of a narrow zone of highly deformed and haematized mudstones. The crop of these mudstones appears to correspond closely the line of the Iron Acton Fault, with its mapped course actually following the western side of the zone of mudstones, coincident with the observed change in seismic velocity at depth. One possibility is that all three lateral discontinuities in the resistivity profile represent faults; perhaps the Iron Acton fault is in reality a braided system, some 30m wide. An alternative possibility is that the low resistivity zones represent increased weathering in the fractured rocks around the fault, so the discontinuities represent weathering fronts in the sandstone, rather than the position of faults.

Line R4 (Figure 3b) shows a single discontinuity in resistivity at about 60m from the northern end of the line. To the north of this resistivity is high and relatively uniform, to the south, the superficial resistivity is markedly lowered. As with the lines discussed previously, although it seems most likely that the discontinuity is a fault (and it lies close to the mapped position of a NE-trending splay from the Iron Acton Fault), an alternative interpretation is that it

demonstrates a zone of alteration around a fault lying at some point with the low-resistivity area.

The magnetometer surveys were of limited benefit. The low sensitivity of the instrument coupled with poor technique on the part of the operators led to noisy results. Two of the areas surveyed with the magnetometer are, however, worthy of comment. Firstly a grid undertaken in the northern section of Parsonage Ground produced a linear array strong anomalies. TP24 was dug to "ground truth" this feature, which proved to be a 1" water pipe. This pipe appears to run diagonally SW across this pit, towards the dividing fence across Parsonage Piece, which it then follows to a disused utility (pump?) in a concrete building to the west of the field. The second area of interest was a series of grids positioned along the upper part of the slope in the southern section of Parsonage Ground (Figure 4). These grids were undertaken to examine whether the slag spread could be detected by this means. Although this proved not to be the case, the old field boundary was imaged (probably because of the build-up of magnetic susceptible material against its eastern face). In addition rather strong features were observed running in a N-S direction at the crest of the slope. These are tentatively interpreted as further fractures of the same set imaged in the profiles downslope. Rather less distinct are minor linear anomalies directed NE-SW and NW-SE. These are interpreted as minor bedrock joints, with accumulations of material of increased susceptibility in the weathered material on the and around the joints.

The geological significance of the results of the test-pitting have already been described. The archaeological results allowed the recognition of a deposit comprising a brown stony soil with a variable slag content across much of the surveyed area. This deposit was noticeably darker, almost black, in some pits at the very top of the slope. Lower on the slopes the deposit was brownish, with large stone fragments outnumbering slag clasts. The details of the slag distribution are described and discussed below.

The slags and ores

Distribution

The weight of slag recovered from each pit was recorded and Figure 5 shows the results of statistical analysis and surface fitting to these data, firstly normalised to unit area and secondly to unit volume of the slag-bearing deposit. Both these measures show peaks of slag distribution on the slopes above the old field boundary about 30m SW of the NE corner of the southern section of Parsonage Ground, and a relatively abrupt western termination of the main deposit against this boundary. Small amounts of slag were retrieved from across the whole study area.

Slag types

The slag material was classified as far as possible into the following categories:

1. *tapped slag: dense slag with clear multi-lobed flow structures*
2. *prills: dense single flow lobes*
3. *massive slag: dense slags without lobate structure or other clear structure*

4. *furnace slag: slags with rusty surfaces, often low density*
5. *charcoal-rich slags: slag bearing abundant impressions or inclusions of charcoal.*
6. *furnace lining*
7. *unidentifiable slag pieces*

Altogether some 34kg of slag was collected from the test pits, together with some 325g of ore. It is worth noting that not all the ore may necessarily have been derived from the smelting debris, for weathering of local bedrock may also release ore particles into the overlying soils.

Some 20kg of the collection (60%) was identifiable as tapped slag; an overall proportion similar to that seen on other smelting sites. None of the slag recovered was certainly identifiable as having been produced during smithing (either bloomsmithing or blacksmithing). The categories of slag 3-5 above, are all likely to have been produced within the smelting furnace. The material not classifiable into these classes amounted to some 17% of the total. In general, although the material was frequently rather abraded and of fairly small size, the assemblage could be considered typical of that from a bloomery smelting site.

Detailed consideration of the distribution of the most fragile material, the vitrified lining, shows (Figure 5) that this is concentrated on the crest of the hill, well above the peak of slag concentration and where the slag-bearing deposit was darkest. This provides supporting evidence that the main slag deposit is not an *in-situ* waste dump, but that it represents material reworked downslope from the primary deposit, either by natural agencies alone, or by those agencies operating during the quarrying and/or ploughing of the slag dump.

Slag & ore chemical composition

The three ore samples are rather different from one another. All are characterised by extremely low levels of impurity. SiO₂ is greatest in IA6A at only 2.79%. Al₂O₃ and MnO are extremely low. Amongst the important trace elements U is very low.

Sample IA3 shows a very high loss on ignition (16.3%); the other two samples show values of 9.76 and 9.56, which are close to the theoretical values of loss of water from goethite on ignition (10.1%). The much higher loss from IA3 is of uncertain origin. It is possible, though unlikely, that some of the iron was present as carbonate, but more likely is that there may have been an error in sample preparation and the unbound water had not been completely removed prior to the high temperature ignition.

IA 1 shows a strongly convex-up REE profile, with the MREE enriched compared with upper crust, but the LREE strongly depleted. The other two samples show lower ΣREE, and a lesser relative difference between the MREE and LREE.

	Gd _N /La _N	Gd _N /Lu _N	ΣREE
IA1	15.19	2.45	21.62
IA3	702	1.278	13.92
IA6A	5.96	1.398	10.55

Table 4. Indices of REE profile. Normalisation to upper crust after Taylor & McLennan 1981. ΣREE in ppm.

The high degree of relative depletion of the LREE in sample IA 1 (and to a lesser extent in the other two samples) is a feature noted in other ores from the Worcester Graben fault systems, but also in other areas of the orefield in botryoidally-textured samples (e.g. Young & Thomas 1999 Fig.5, sample indicated as "b" from Llanharry; Young 2000, Fig. 10.6, sample PAV6, from Gower).

The major element composition of the slag samples is typical of bloomery slags from the smelting of the goethite/haematite ores of the Bristol Channel Orefield. The analyses are quite closely grouped, with a range of SiO₂ from 17.7 to 23.3%. K₂O is quite high, with 4 of the 5 slags having >1.1%. The trace element composition is equally unremarkable, with the upper crust-normalised REE profiles very tightly clustered.

In the absence of furnace clay analyses it is not possible to do a mass balance/furnace efficiency calculation (Thomas & Young 1999).

The analytical results of the slags demonstrated that the slags formed a very homogeneous group of materials. The significance of this homogeneity is uncertain, but may possibly reflect the homogeneity of process, or alternatively that the samples had all been derived from a single site, but had been moved around the village during the employment of the slag dumps as sources of roadstone in post-medieval times.

Summary

Although the analytical studies were based on surface material, and not on stratified material tied to the Parsonage Ground site, they do include a single specimen of slag from the site. That piece of slag (1A/8/1) has a chemical composition in the centre of this tight group of analyses. Although detailed mass balance calculations of the kind promoted by Thomas & Young (1999) were not possible because of the lack of analyses of furnace lining, the available analytical data certainly appear to support modelling of the slags as products of smelting of the local ore.

Discussion

The slag dump in Parsonage Ground has been demonstrated to be the product of secondary movement of slag downslope from an original ridge-top site, and its accumulation against an ancient field boundary. No direct evidence for the date of the site was found. A Saxon to medieval date seems most likely on circumstantial evidence.

The slag assemblage indicates that the site was undertaking iron smelting in a bloomery furnace, but there is no evidence for the subsequent bloomsmithing operations. In some areas of Britain bloomsmithing was undertaken centrally, with smelting taking place in the woodlands, so such a model may be applicable here.

The geological results of the survey have confirmed the position of at least one strand of the Iron Acton fault, but also provide evidence that the fault may be complex, with several strands distributed across much of the width of Parsonage Ground. The mapped fault splay in Sirs Piece is also supported by the geophysical evidence.

The 1996 survey has clearly indicated the scale of the early iron-making in the Iron Acton area. The area surveyed is only a very small part of the known extent of iron mineralization on the Iron Acton and associated faults. Within this site future research activities might include:

- investigation of the fault surfaces by excavation of a trial trench, with the aim of being able to record the nature of the mineralization, if any, present in this area
- a high resolution magnetometer/gradiometer survey permitting recognition of archaeological features.
- a magnetic susceptibility survey

On a broader front, the investigation of other areas within the parish should be pursued, for although the area south of the village centre was the site of one, if not two, early slag dumps, in neither case would direct investigation of any bloomery site be likely to be easy because of modern buildings. To the north of Iron Acton, track surfaces around Dowell Farm (where there was a mine in the 19th century) yield abundant bloomery slag, and although this may have been "imported" from dumps elsewhere the position of the mine here does suggest the possibility of another focus of iron-making activity. The SMR records another possible trial iron mine to the west of Rangeworthy. Both the Rangeworthy and Dowell Farm sites lie within 2 km of the Roman settlement SE of Rangeworthy, and this settlement should be investigated for any evidence of Roman iron-making activities. To the east of Iron Acton, iron ores were found during building operations in Yate (Curtis 1972). Southwest of Iron Acton lies the important nineteenth century iron mine at Frampton Cotterell. These known ore occurrences mean that blooperies might occur over a wide area, particularly so as in other areas smelting is known to have taken place close to the sources of charcoal, rather than immediately on the ore sources.

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Appendix 1: Sample localities

ores

IA1	350m N Dowell farm
IA3	immediately of SE Dowell Farm
IA6A	path 200m W of Hill House

slag

IA2B	150m N Dowell Farm
IA/6/1	path 200m W of Hill House
IA/6/2	"
IA6B	"
1A/8/1	Parsonage Ground, N side of slag spread

Appendix 2: Test pit sections

TP1	to 0.18m virtually stoneless topsoil; to 0.42m slag rich layer; to 0.62m stony, some iron pan and haematite streaks, highly weathered rock fragments	TP14	to 0.20m topsoil; to 0.47m brown stony soil with slag; to 0.54m stony soil as above, but no slag; lies on bedrock (sandstone) at 0.54m.
TP2	to 0.17m fine stoneless topsoil; to 0.55m stony, slightly sandy deposit, iron-stained at base; to 0.65m iron-cemented brash Pebbles strongly leached with iron-rich crusts.	TP15	to 0.20m topsoil; to 0.28m brown stony soil with slag; to 0.62m brown stony soil, becoming more stony downwards; lies on sandy clay with rottenstone. Augered downwards, becoming more gravelly, auger hit rock at 1.07m.
TP3	to 0.05m soft brown topsoil with coal; to 0.30m brown stony deposit with some slag; Lies on disturbed irregular bedrock (sandstone) surface at 0.35 – 0.30m.	TP16	to 0.24m topsoil; to 0.42m stony brown soil with some slag; to 0.47m stony soil becoming yellower and with more Fe-staining downwards; to 0.65m stony subsoil; to 1.65m stoneless subsoil (augered); to >1.85m gravelly subsoil (augered; not bottomed).
TP4	to 0.18m stone free dark soil; to 0.40m dark soil with abundant slag, becoming brownier down; to >0.55m brown soil with gravel and pinkish iron pan in places. No slag.	TP17	to 0.18m topsoil; to 0.26m layer rich in coke, pottery, clay pipe, coal etc (worm layer?); to 0.42m brown stony soil with slag; to 0.50m brown very stony soil without slag; to >0.81 m yellow sandy subsoil with rottenstones (augered, not bottomed).
TP5	to 0.20m soft brown almost stoneless soil with tiny slag and coal fragments; to >0.30m stony brown soil, no artefacts.	TP18	to 0.15m topsoil; to 0.33m stony brown soil; to >0.95m stiff clay, brownish, passing down into red clay with pellets of mudstone, some sheared. Not bottomed.
TP6	to 0.15m topsoil; to 0.48m slag-rich brown stony soil (more stone than slag). Clay pipe in uppermost 0.02m; lies on disturbed irregular bedrock (sandstone) surface at 0.36-0.48m.	TP19	to 0.08m topsoil; to 0.22m hard compact soil with moderate amount of stone and small black flecks; to 0.45m, as above, but no black flecks; to >0.58m stoneless subsoil, becoming reddened, not bottomed.
TP7	to 0.17m topsoil; to 0.45m slag-rich dark soil; to 0.52m brown stony soil with pink staining increasing down; lies on disturbed bedrock (sandstone) surface at 0.52m.	TP20	to 0.17m topsoil; to 0.26m dark humic stony soil, lies on bedrock (sandstone).
TP8	to 0.16m topsoil; to 0.40m brown stony soil with slag; to 0.45m brown stony soil; lies on disturbed bedrock (sandstone) surface at 0.45m.	TP21	to 0.13m topsoil; to 0.30m brown stony soil with slag; to 0.40 brown stony soil without slag; to >0.50m yellowish stone-poor Fe-rich subsoil, not bottomed.
TP9	to 0.17m topsoil (clay pipe); to 0.34m brown stony soil with slag. Blue china sherd in upper 0.05m; to >0.58m brown stoneless soil with rottenstone remnants and Fe-staining.	TP22	to 0.17m topsoil; to 0.45m brown stony soil with slag in lower part; to 0.96m stone-free subsoil with rottenstone traces (augered).
TP10	to 0.17m topsoil; to 0.36m slag rich brown soil; to 0.56m stony subsoil; lies on broken bedrock at 0.56m.	TP23	to 0.17m topsoil; to 0.48m stony brown soil, stonier downwards; to 0.88m stoneless brown soil with rottenstone gravel; lies on bedrock (sandstone?) at 0.88m
TP11	to 0.17m topsoil; to 0.50m slag-rich deposit; to 0.60m local deposit of Fe-rich sandy deposit filling hollows on; lies on irregular bedrock (sandstone) surface at 0.50 to 0.60m.	TP24	to 0.17m topsoil; to 0.45m stony brown soil with slag; lies on yellowish subsoil becoming darker and stonier with depth, not bottomed. cut by 0.69m deep trench, 0.20m wide at base, carrying 0.025m diameter metal water pipe 0.04m above base.
TP12	to 0.17m topsoil; to 0.45m stony slag-rich soil, slag decreasing below 0.30m, green glazed pottery at 0.40m; to 0.50m local deposit of sterile brown soil between upstanding areas of bedrock; lies on irregular bedrock (sandstone) surface at 0.45 – 0.50m.	TP25	to 0.17m topsoil; to 0.28m brown stony soil with slag; lies on bedrock (sandstone) at 0.28m.
TP13	to 0.17m topsoil; to 0.69m slag-rich stony soil, with iron pan at 0.38m; to >0.90m sandy soil with weathered stone fragments and Fe-staining. Not bottomed.		

oxide	LOI	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅
Ore											
IA1 Massive/Botryoidal	9.76	2.65	0.62	96.02	0.06	0.21	0.19	<	0.08	0.01	0.17
IA3 Massive	16.25	1.36	<	98.18	0.04	0.34	0.05	<	<	<	0.03
IA6A Botryoidal	9.56	3.09	0.28	95.92	0.05	0.46	0.08	<	0.03	0.02	0.07
Slag											
IA/8/1	-6.66	21.81	3.32	71.44	0.06	0.48	1.17	<	1.38	0.20	0.13
IA/6/1	-6.97	17.03	2.52	77.43	0.07	0.55	1.02	<	1.03	0.16	0.19
IA/6/2	-6.43	21.52	3.22	71.13	0.08	0.64	1.67	<	1.21	0.20	0.34
IA2B	-6.49	20.60	3.52	72.48	0.10	0.73	0.82	<	1.41	0.20	0.15
IA6B	-5.73	16.74	3.02	77.86	0.05	0.45	0.79	<	0.72	0.18	0.19

Table 1: Major elements (expressed as wt% oxides) determined by XRF normalised to 100%. LOI = loss on ignition. < = below detection

oxide	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	Volatiles	Volatiles (FeO)
Ore													
IA1	2.39	0.56	86.65	77.97	0.05	0.19	0.17	<	0.07	0.01	0.15	9.76	18.44
IA3	1.14	<	82.22	73.99	0.03	0.29	0.04	<	<	<	0.02	16.25	24.49
IA6A	2.79	0.26	86.76	78.07	0.04	0.42	0.07	<	0.03	0.02	0.06	9.56	18.25
Slag													
IA/8/1	23.27	3.55	76.20	68.57	0.06	0.52	1.24	<	1.47	0.21	0.14	-6.66	0.97
IA/6/1	18.22	2.70	82.82	74.52	0.08	0.59	1.09	<	1.10	0.17	0.21	-6.97	1.33
IA/6/2	22.90	3.43	75.71	68.12	0.08	0.68	1.78	<	1.29	0.21	0.36	-6.43	1.15
IA2B	21.94	3.75	77.18	69.45	0.10	0.78	0.87	<	1.50	0.21	0.15	-6.49	1.24
IA6B	17.70	3.19	82.32	74.07	0.05	0.47	0.83	<	0.76	0.19	0.20	-5.73	2.52

Table 2: Major elements (expressed as wt% oxides) determined by XRF. Corrected data, except for normalised peat values. Columns in grey show alternative values obtained by calculating iron as Fe(II) oxide.

element	Be	Ca	Sc	Ti	V	Cr	Mn	Co	Cu	Zn	Ga
Ore											
IA1	58.569	n.d.	1.486	n.d.	58.569	0.9773	n.d.	11.7593	0.9251	67.9838	6.4958
IA3	16.721	n.d.	0.445	n.d.	16.7213	0.1878	n.d.	45.6239	3.5303	90.728	2.2662
IA6A	7.1544	n.d.	1.044	n.d.	7.1544	2.1618	n.d.	59.2632	4.0159	96.3814	1.7695
Slag											
IA/8/1	23.9581	10500	6.571	1233	54.73	30.81	526.5	n.d.	18.18	40.26	6.301
IA/6/1	32.2058	10900	6.088	982.7	42.13	52.91	666.1	n.d.	8.233	45.81	5.233
IA/6/2	39.9187	21200	9.785	1440	58.74	39.78	788.4	n.d.	10.47	57.53	7.168
IA2B	24.0711	n.d.	5.18	n.d.	40.94	17.94	n.d.	17.94	5.45	20.84	4.98
IA6B	8.1313	n.d.	4.786	n.d.	46.07	40.87	n.d.	40.87	3.255	12.42	4.739

Table 3a: Major and trace elements (expressed as ppm) determined by ICP-MS. n.d. = not determined.

element	Rb	Sr	Y	Zr	Nb	Mo	Cd	Cs	Ba	Tl	Pb	Bi	Th	U
Ore														
IA1	2.359	n.d.	26.21	1.487	0.022	4.054	n.d.	0.35	16.6945	0.021	21.71	<	0.1816	0.509
IA3	0.148	n.d.	7.872	0.276	0.171	3.707	n.d.	0.015	2.0709	0.035	42.48	0.0148	0.025	0.69
IA6A	2.105	n.d.	10.37	2.664	0.344	24.17	n.d.	0.23	20.3054	0.034	41.2	0.2711	0.2252	1.553
Slag														
IA/8/1	33.68	409.57	16.65	78.44	3.953	1.765	0.158	2.343	387.2133	0.027	2.621	<	3.1488	2.286
IA/6/1	22.3	143.31	17.07	56.51	3.931	1.693	<	0.913	1286.486	<	2.574	<	1.7397	1.533
IA/6/2	34.27	3267.4	24.73	86.21	4.183	1.004	0.193	1.542	783.7322	<	4.152	<	2.6337	2.023
IA2B	36.06	n.d.	28.55	57.29	3.261	1.242	n.d.	1.575	323.4597	0.017	2.511	<	2.9618	3.9
IA6B	21.97	n.d.	11.64	55.05	3.1	1.982	n.d.	1.481	174.271	0.022	4.018	<	2.6719	2.23

Table 3b: Major and trace elements (expressed as ppm) determined by ICP-MS. < = below detection. n.d. = not determined

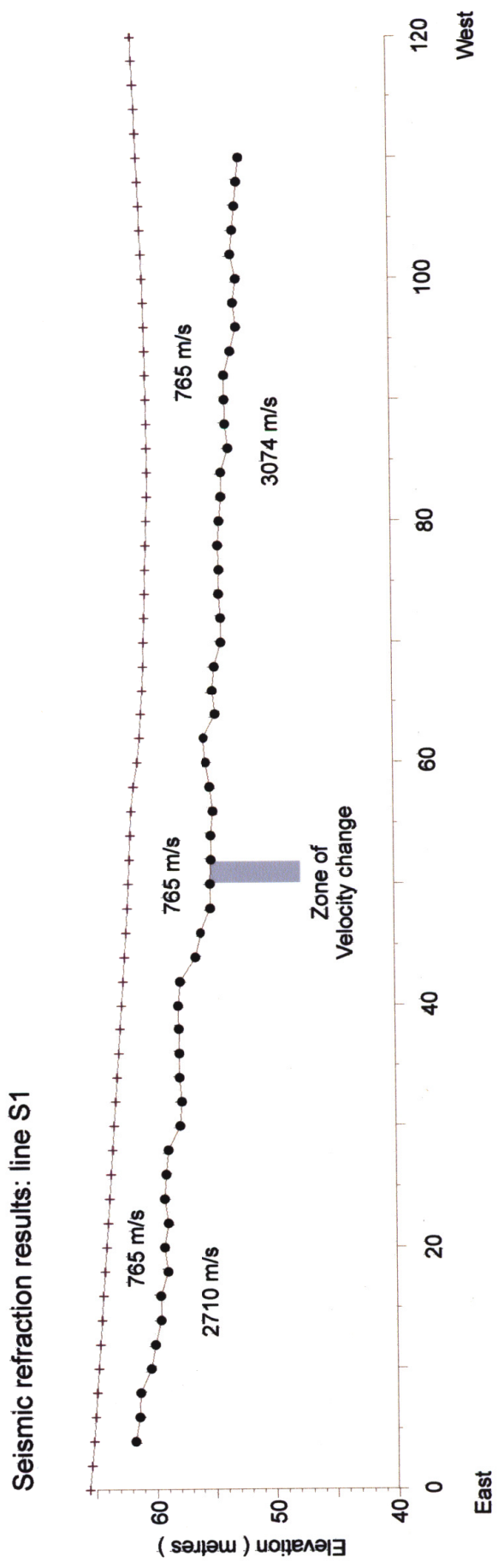
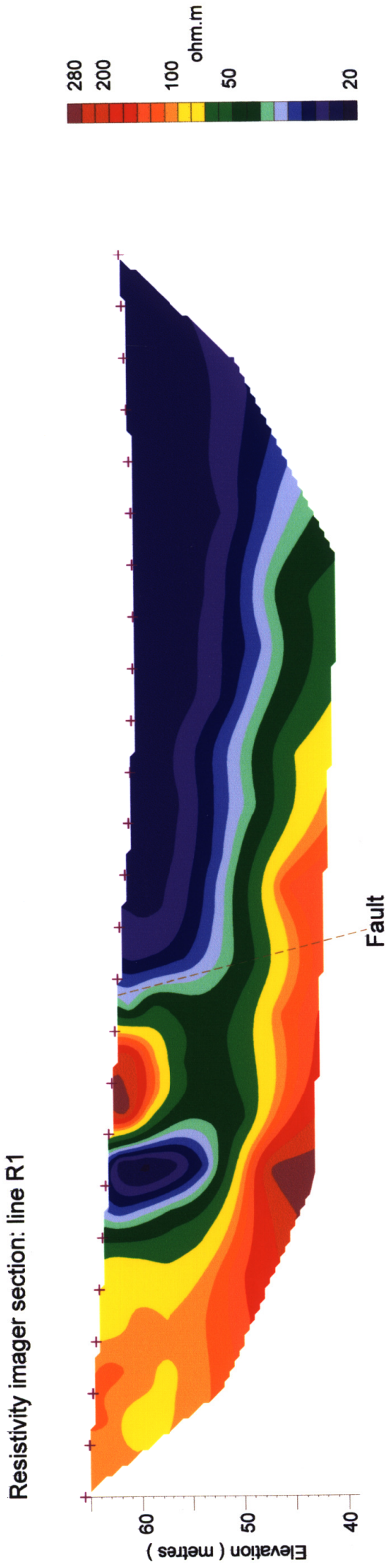
element	La 139	Ce 140	Pr 141	Nd 143	Sm 147	Eu 151	Gd 157	Tb 159	Dy 161	Ho 165	Er 167	Tm 169	Yb 172	Lu 175	ΣREE
Ore															
IA1	3.3061	12.098	1.75	8.6728	3.819	1.3928	6.3596	1.2123	6.7656	1.2355	2.7959	0.3321	1.6647	0.2188	51.6232
IA3	1.5946	4.6022	0.6214	2.6726	0.9178	0.2841	1.4172	0.2622	1.553	0.3114	0.8129	0.1107	0.6286	0.094	15.8827
IA6A	3.1566	9.0214	1.1607	5.1114	1.8867	0.5642	2.3835	0.4682	2.6567	0.4824	1.251	0.1693	1.0332	0.1439	29.4892
Slag															
IA/8/1	10.773	25.74	3.245	12.34	3.0755	0.8828	3.7692	0.6573	3.6778	0.7074	1.9154	0.2686	1.7961	0.2687	69.1163
IA/6/1	8.1405	19.333	2.3931	9.1452	2.7181	0.9946	3.5042	0.6394	3.5494	0.6821	1.8096	0.2636	1.6685	0.2531	55.0945
IA/6/2	12.828	30.635	3.9085	14.864	3.903	1.1626	4.9066	0.8695	4.8132	0.9401	2.5544	0.3756	2.1526	0.3292	84.2425
IA2B	13.827	34.37	4.295	17.471	4.4908	1.2073	5.664	0.9552	5.4636	1.0953	2.8674	0.4032	2.3489	0.3459	94.8847
IA6B	8.0736	19.132	2.2531	8.6946	2.0113	0.5426	2.3804	0.4157	2.4103	0.4752	1.3111	0.1934	1.1763	0.1749	49.2443

Table 3c: Rare earth elements (expressed as ppm) determined by ICP-MS

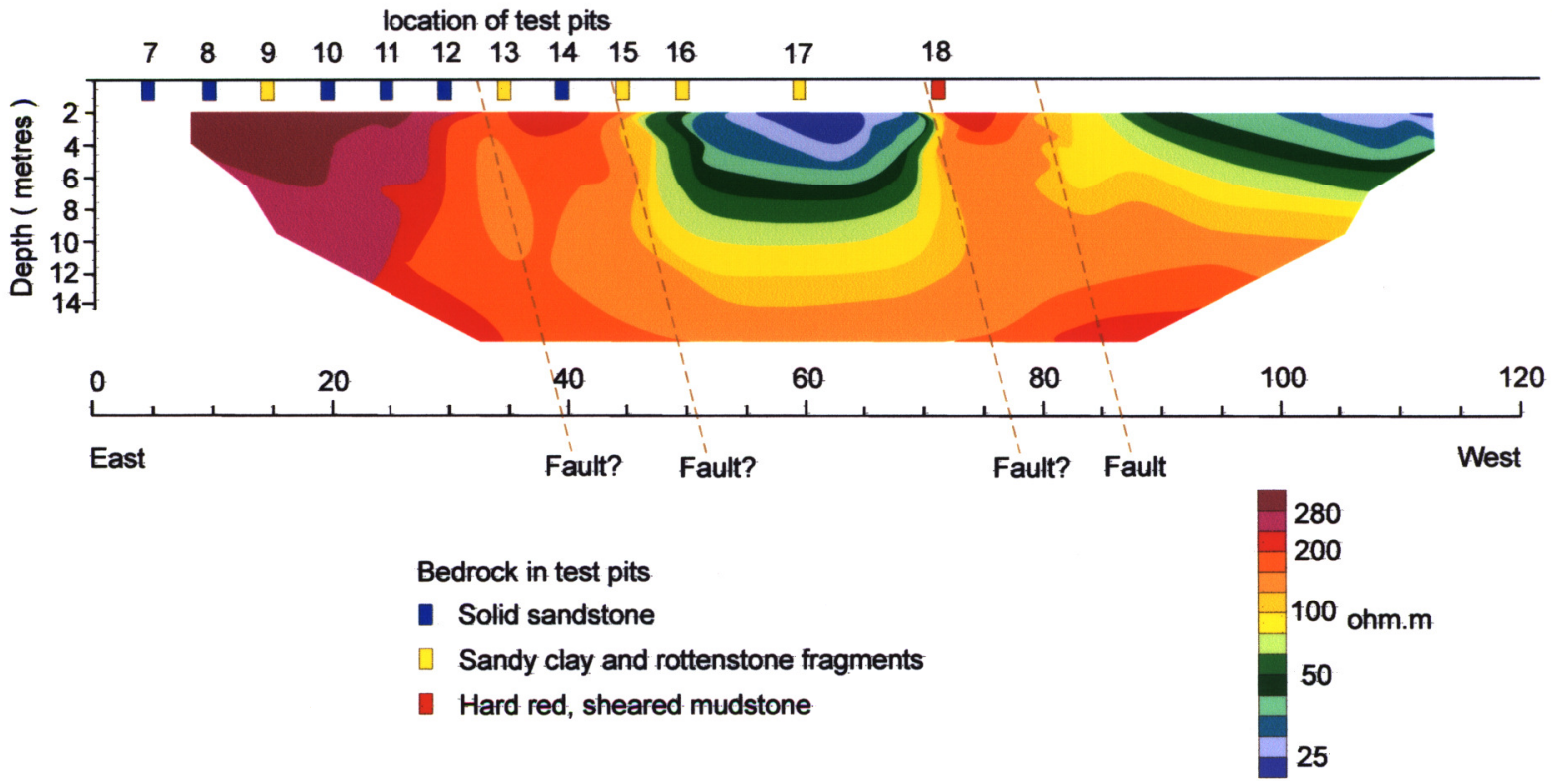


Figure 1

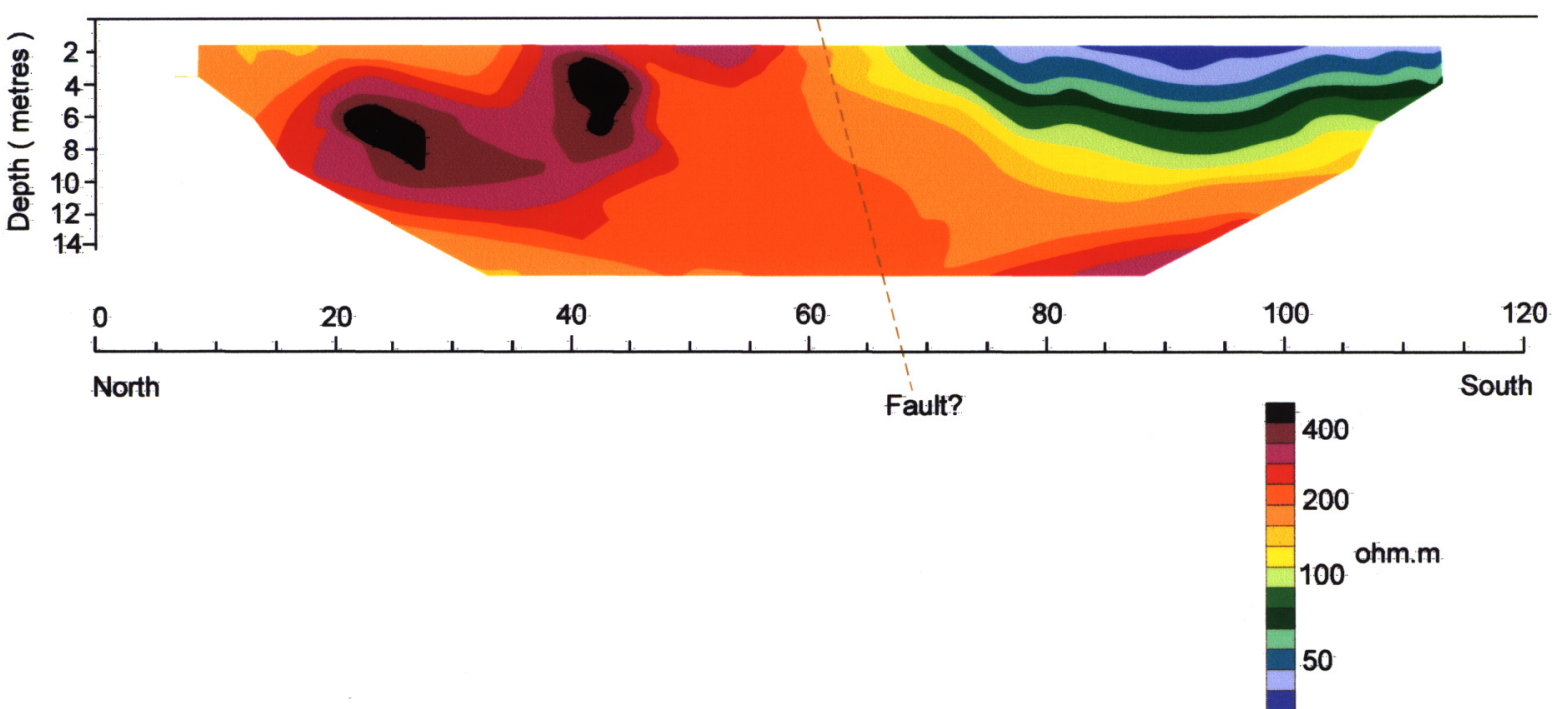
Figure 2.



(a) Resistivity imager section: line R2



(b) Resistivity imager section: line R4



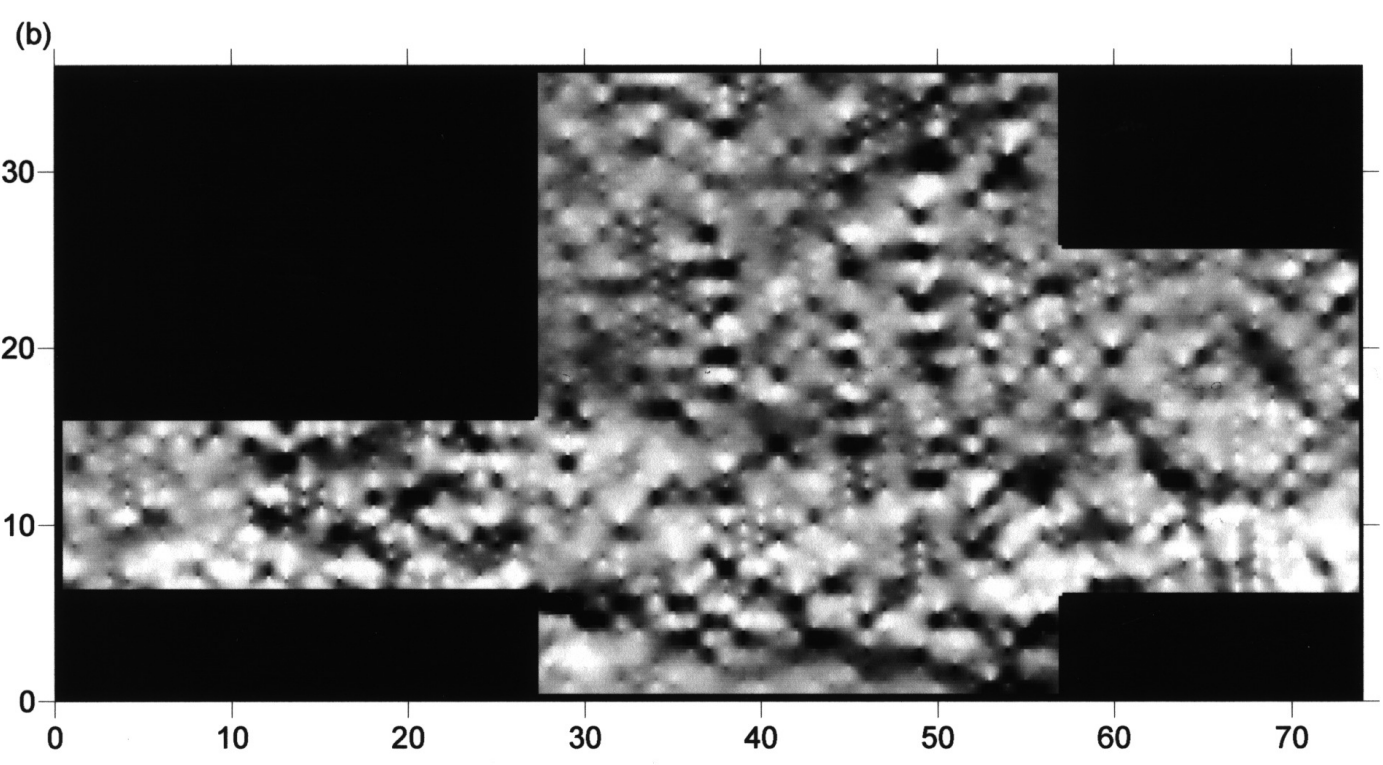
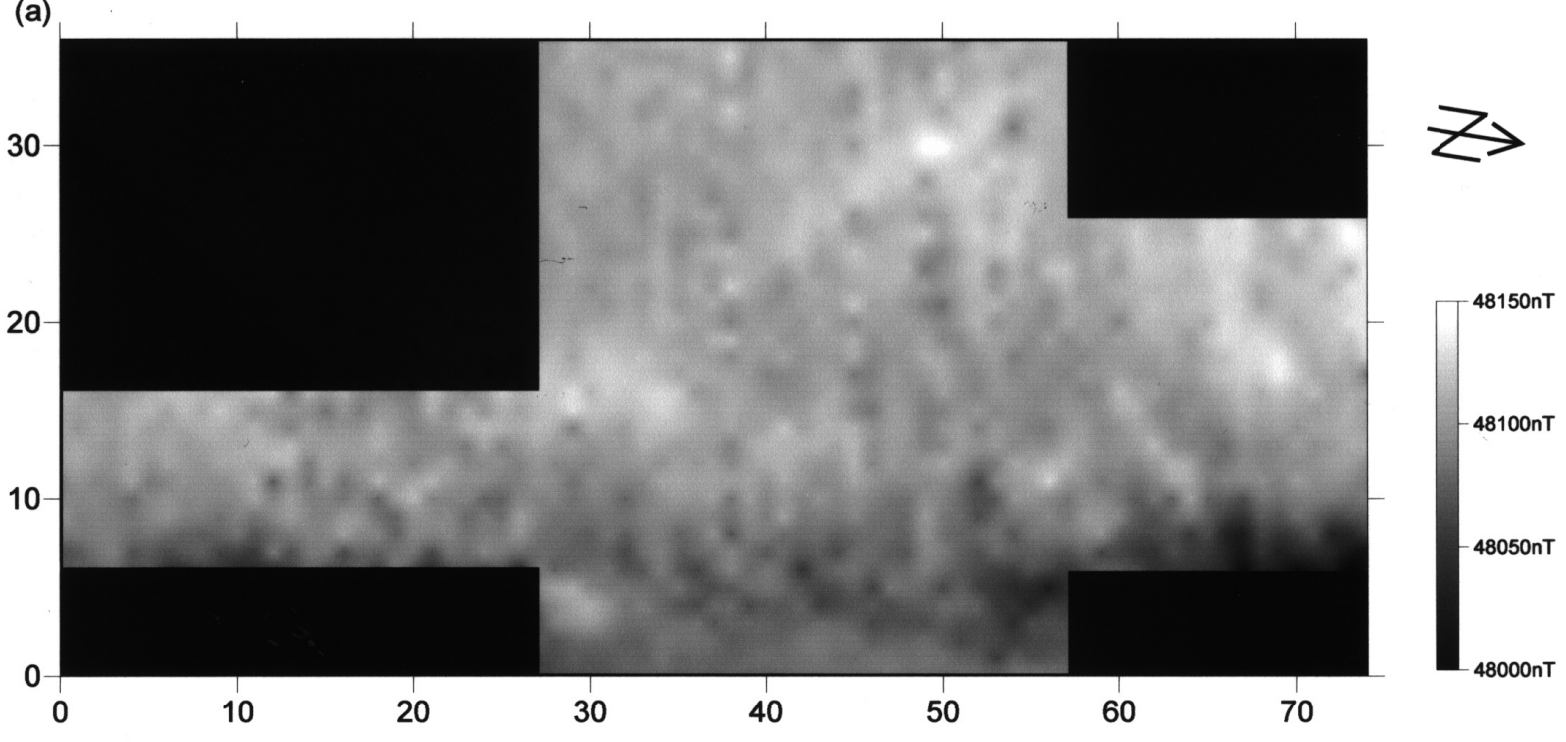


Figure 4. Results of proton magnetometer survey, main area. Location of survey given on Fig. 1.
(a) total magnetic field, greyscale as shown, north to right.
(b) shaded relief image, illuminated from east (bottom) along survey lines.

Figure 5.

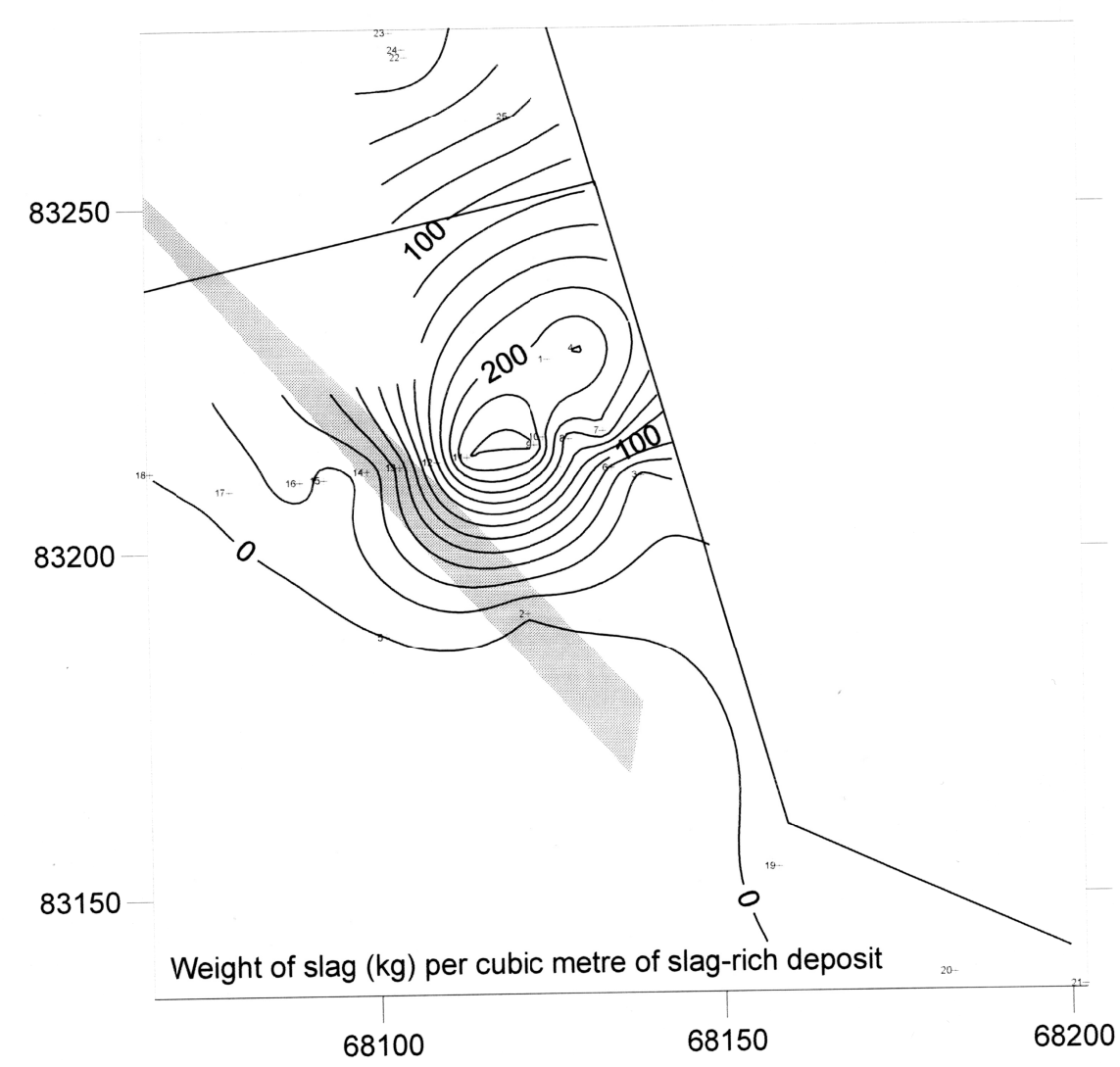
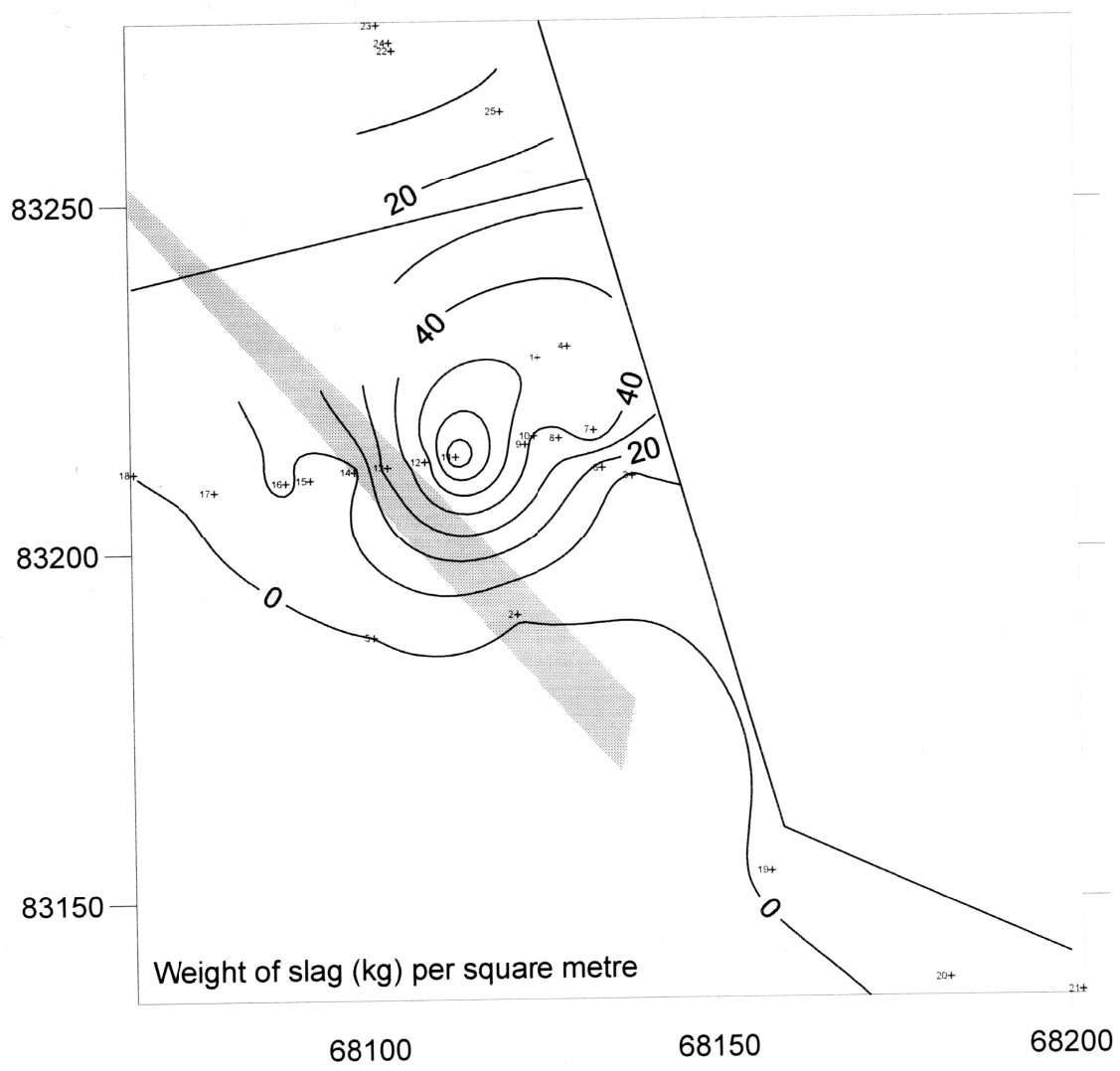


Figure 6

