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Institute of Geological Sciences

Mineral Reconnaissance Programme Report

A report prepared for the Department of Industry

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No. 14

Mineral investigations at Woodhall and Longlands in north Cumbria

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A. J. Wadge, MA, J. D. Appleton, BSc, PhD and A. D. Evans, BSc

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SUMMARY

A mineral exploration programme aimed at locating base-metal sulphide mineralization in Lower Carboniferous limestones has been carried out around Woodhall and Longlands in the northern part of the Lake District. A coordinated programme of geological mapping, soil and stream sediment sampling, I.P. and EM traverses identified several geochemical and geophysical anomalies. Auger sampling of the former showed them to be due to surface redistribution of metals from disused mines, whilst the weak geophysical anomalies in themselves do not constitute viable drilling targets.

Mineral investigations at Woodhall and Longlands in north Cumbria

A. J. Wadge, J. D. Appleton and A. D. Evans

INTRODUCTION

The Woodhall and Longlands areas lie on the northern margin of the Lake District where the open moors of the Caldbeck Fells slope down to the farmland around the fellside villages of Uldale, Caldbeck and Hesket Newmarket. Most of the streams of the area run northwards into the River Caldew although some around Longlands drain westwards into the River Ellen. Agriculture is the principal occupation, with sheep-grazing on the fells and dairy farming on the lower ground. A network of minor roads connects the villages and farms and, even on the high fells, rough tracks allow access for cross-country vehicles. Both areas lie just within the northern margin of the Lake District National Park.

GEOLOGY

The area was re-surveyed, following the 19th-century reconnaissance, in 1928-31 and a detailed account of the geology was given in the Cockermouth memoir (Eastwood and others, 1968). Some modifications to existing maps (Figs 2, 12 and 14) have been made as a result of the present work.

The Lower Ordovician rocks of the Lake District are broadly divided into a lower Skiddaw Group, consisting mainly of greywacke sediments, and an upper Borrowdale Volcanic Group which includes massive lavas and tuffs. At several localities in the north-eastern Lake District however, near Bampton, Ullswater and Threlkeld, volcanic beds occur within the Skiddaw Group, generally as tuffs and thin lavas interbedded with the mudstones.

Massive andesitic lavas, tuffs and agglomerates, totalling a thickness of more than 2000 m, underlie the northern slopes of the Caldbeck Fells. They have usually been correlated with the Borrowdale Volcanic Group of the southern Lake District and this name is retained here, although recent microfaunal evidence (Downie & Soper, 1972) suggests that the sequence is older than the Borrowdale succession and may be better correlated with the volcanic beds in the Skiddaw Group.

Throughout the Caldbeck Fells the rocks strike generally east-west and, although bedding is usually difficult to determine, they appear at outcrop to dip steeply to the north. Recent magnetic work however suggests that at shallow depths the regional dip is steeply to the south.

A large granitic batholith emplaced during the late Silurian, underlies most of the Lake District (Bott, 1974). It does not appear to extend as far north as the present areas, but part of it, the Skiddaw Granite, underlies much of the fell-country just south of the Caldbeck Fells. Since the Silurian, the Lake District has been an area of persistent uplift, characterised by shelf-sea, deltaic or continental sedimentation.

The Lower Carboniferous succession which lies unconformably upon the older rocks around the margin of the Lake District is only about 500 m thick, compared with the sequence more than 3700 m thick in the subsiding Northumbrian Trough to the north. The Lower Carboniferous rocks around Woodhall and Longlands consist largely of marine, bioclastic limestones interbedded with subordinate shales and thin sandstones. The sequence is characterised hereabouts by lateral changes in facies. There is a gradual transition along the strike of the beds from massive limestones in the west, to a Yoredale-type sequence of alternating limestones, sandstones and shales farther to the east. In addition, there may be a more abrupt change in facies from north to south as beds overlap on to the Lake District block, but lack of exposure makes this difficult to demonstrate. Boreholes at Whitrigg, west of Longlands, suggest that successively higher beds pass southwards into the basal conglomerates resting directly upon the Lower Palaeozoic rocks, and elsewhere in the district the situation appears similar, especially where Carboniferous beds high in the sequence crop out close to the Lower Palaeozoic rocks. On the published 1:50 000 geological map, intervening faults are usually invoked to explain these relationships, but in some cases the juxtaposition may be due instead to abrupt overlap.

The Carboniferous rocks dip generally northwards at 10 to 20°, although east of Woodhall they are inclined to the north-east. The dominant fault-trends are north-westwards and north-eastwards.

FORMER MINING

The mineral veins of the Caldbeck Fells have been extensively worked at least as far back as Elizabethan times and include a great variety of Pb, Zn, Cu and Ba ores. The principal workings at Roughtongill lie well to the south-west of Woodhall but the veins extend north-eastwards via Driggith mine to the Sandbeds levels on the fellside just above Woodhall (Fig. 2). There are, in addition, many other vein workings on the fells (Shaw 1975). On the lower ground no minerals have been worked except the barite vein at Ruthwaite (Eastwood and others 1968, p.242), but limited trials for Cu and Ba have been carried out from adits at Plumbland [1620 3941], Whitrigg [2010 3763] and Hegglehead [3720 3484], and thin veins of galena and barite have been intersected in limestone quarries [3158 3862] south of Caldbeck.

MINERAL POTENTIAL

The mineral prospects of the Lower Carboniferous outcrops north of the Lake District are interesting mainly because of the analogies which can be drawn between this area and some of the Irish localities at which large Pb-Zn sulphide deposits have recently been discovered and developed. The Irish deposits are located at the edges of Lower Carboniferous sedimentary basins and occur generally in rocks of Courceyan age, towards the base of the local carbonate sequence. Their origin is not fully understood; in some cases, the mineralization appears to have been syngenetic with the host sediments, whilst elsewhere it seems to have been derived from hot chloride-rich brines. The latter were probably formation waters, heated by burial in the deeper parts of the basin and then driven towards the margins by fluid pressures. Basin margins, defined by growth-faults which were active during sediment deposition, appear to have been particularly favourable localities for Irish-style mineralization, with local depositional control being effected by suitable host-rocks and cap rocks. The commonest host-rocks are carbonates, whilst the cap-rocks are usually either Carboniferous mudstones or tight rocks within the Lower Palaeozoic basement.

Several important features of the Irish mineral province are also present in North Cumbria. A deep Lower Carboniferous sedimentary basin, the Northumbrian

Trough, trends east-north-eastwards beneath the Solway Firth, the Carlisle Basin and the Bewcastle district. Rocks of Courceyan age are present in the Trough and where exposed on the north side, they consist generally of marine limestones and shales (Craig 1956) although in places these pass laterally into fluviatile sandstones laid down as deltas by rivers draining into the trough from the north-west or north-east (Day 1970, Leeder 1974). Courceyan rocks are not exposed on the south side of the Trough but are probably present beneath overlapping younger beds a few kilometres north of the present Lower Carboniferous outcrops. They are likely to be of marine carbonate facies, as there are no indications that the relief of the Lake District at that time gave rise to large northward-draining rivers (Leeder 1974). It seems reasonable to suppose, therefore, that host-rocks favourable to Irish-style mineralization are present along the southern margin of the Trough. Similarly, suitable cap-rocks are not lacking in the succession; the overlying Upper Carboniferous sequence contains a high proportion of mudstone and siltstones capable of blocking the upward migration of brines, whilst the Lower Palaeozoic rocks are generally tight and capable of greatly reducing the lateral movement of brines out of the basin. In this respect however, the massive, well-fissured volcanic rocks of the Caldbeck Fells are probably less effective as a seal than the well-lithified sediments of the Skiddaw Group.

No potential structural traps for mineralizing fluids can be identified by mapping along the southern margin of the Trough, as structures in the Carboniferous rocks are hidden beneath younger beds. But structural traps are probably present where the NE-trending folds of the Bewcastle district (Day 1970) extend south-westwards towards the southern margin of the Trough.

Despite the generally favourable environment for Irish-style mineralisation in north Cumbria, exploration is complicated by the difficulty of defining the basin margin, which lies to the north of the present Lower Carboniferous outcrops. To the east, it appears to be marked by the Stublick Fault and may continue westwards via the Gilcrux and Maryport faults, but the line is very uncertain.

On the basinward side of the margin, the potential host-rocks are generally so deeply buried that it is impracticable to attempt directly to locate mineralization in them by surface sampling. There remains therefore only the possibility of locating deposits, of the type envisaged above, on the block side of the margin, particularly in the basal Dinantian limestones, and it was to this end that the work under review was directed.

There is one further aspect of the geology of the area bearing upon the location of such deposits. K-Ar isotopic ages have been obtained (Ineson and Mitchell 1974) from clay minerals associated with the veins on the Caldbeck Fells, and these indicate mineral emplacement or rejuvenation in both mid-Permian (240 Ma) and early Jurassic (180 Ma) times. Whilst the accuracy of such illite-chlorite ages has been questioned (Shepherd and others 1976), this work seems to have established that much, if not all, of the Caldbeck Fells mineralization post-dates the deposition of the Lower Carboniferous rocks. If this is the case, then much of the mineralization of the fells may well have been emplaced by the same mechanism of brine leakage from the Trough that is envisaged for the mineralization in the Lower Carboniferous limestones. It can be further argued that the positions of the veins show where the leakage southwards through the limestones has been most effective, thereby pointing to the most promising areas for mineralization in the Lower Carboniferous outcrop. Accordingly the present investigations were located at Woodhall, where the north-easterly projection of the Driggith-Sandbeds veins intersects the limestones beneath the drift, and at Longlands where a copper vein extends northwards towards the Lower Carboniferous outcrop.

PRESENT INVESTIGATIONS

The main objective of the investigations was to locate base-metal mineralization in the lower part of the Carboniferous succession immediately above the Carboniferous-Ordovician unconformity. An ancillary objective was to trace the course of the mineral veins from the adjacent fell-sides on to the drift-covered lower ground and into the Lower Carboniferous rocks.

The field investigations began in 1972 with the detailed checking and revision of the published 6-inch geological maps of the area. Subsequently, substantial amendments to many of the geological boundaries in the drift-covered ground were made as a result of the resistivity measurements.

Standard methods were employed for the collection, preparation and analysis of the stream sediment samples (Plant 1971, Plant and Rhind 1974). Soil samples were collected with a 2.5 cm diameter soil auger from depths of about 60 cm and a Minuteman power-auger used to obtain deep till samples. Both soil and till samples were dried, sieved through 80-mesh B.S.S. and analysed for Cu, Pb and Zn by atomic absorption spectrophotometry following a hot nitric-perchloric acid attack on a 0.25 gm sub-sample. Stream sediments were analysed by the same method, except for Ba which was determined by semi-automatic X-ray fluorescence spectrometry.

The selected geophysical methods had to be capable of detecting the presence of disseminated sulphide mineralization beneath drift up to an estimated maximum thickness of 15 m, greater thicknesses being rare, as well as defining the position of any faults or veins and the position of the limestone/Lower Palaeozoic boundary. A combined induced polarization (IP) and resistivity survey was chosen as this method best fulfils the requirements. Measurements were made along parallel traverses laid out across the target areas.

The Woodhall survey began with frequency-domain IP equipment, but instrument failure necessitated completing the work with time-domain equipment, which was also used at Nether Row and Longlands. Additional IP measurements were made in 1974. Throughout the IP surveys the dipole-dipole configuration was used, the dipole length being 50 m. The frequency domain equipment was operated at frequencies of 3Hz and 0.1Hz. Electromagnetic trials using both Turam and VLF methods were carried out at Woodhall, these methods being particularly suited to tracing sulphide veins. The grounded cable used in the Turam survey was 830 m in length. Measurements were made at frequencies of 220Hz and 660Hz using receiving coils 40 m apart. The VLF instrument was tuned to the transmitting station NAA in the USA, the operating frequency being 17.8kHz. All traverses were sited as planned, except for F & G at Woodhall, which were shortened because of access difficulties. Overhead power lines and water mains cross the lower ground and two powerful television transmission masts are sited a few kilometres to the north-west, but none of the traverses was subject to interference. Details of the geophysical equipment and methods used are given in a separate report in this series (Burley and others, in preparation).

(i) Woodhall

Geology

The outcrops of the Borrowdale Volcanic Group consist of green and blue-grey, massive, aphanitic, vesicular andesites. Their bedding is obscure but they are thought to dip steeply northwards. They are probably overlain to the north by coarse tuffs, which crop out on the hills farther west, but are not exposed hereabouts.

The lowest part of the local Dinantian succession is completely drift-covered but the sequence can be inferred from adjacent outcrops. The Basement Conglomerate has not been mapped locally though its absence is not established. In nearby areas it is variable in both lithology and thickness; in the closest outcrops it consists of 15 to 30 m of coarse, red conglomerate interbedded with thin bands of red sandstone, brown limestone and red or green shale. The overlying Seventh Limestone generally consists of about 50 m of thinly bedded, grey limestone with bands of calcite mudstones and chert, whilst the Sixth Limestone is composed of massive, dark grey limestones with shale partings, totalling about 30 m. The overlying Fifth Limestone is usually about 50 m thick and has a lower part of dark grey, well-bedded limestone separated from an upper bed of pale grey, massive pseudobreccia by a 6-m parting of sandy shales.

The next bed in the sequence, the White Limestone is also largely drift-covered although its uppermost part is exposed between Woodhall and Hudscale [3363 3745]. Overall, the Limestone is about 30 m thick and consists of pale grey pseudobreccias interbedded with bands of dark grey limestone and calcite mudstone. The overlying Rough Limestone is a least 10 m thick in disused quarries north-east of Woodhall, and yields Dibunophyllum bipartitum, a characteristic fossil from this horizon. Higher in the sequence, the proportion of limestone decreases and so, correspondingly, does the sulphide-bearing potential. Accordingly, the local details of this part of the succession are not elaborated here; they are given in Eastwood and others (1968).

The main drift deposit in the area is boulder clay. Between Woodhall and the River Caldew it is moulded into drumlinoid features aligned northwest-southeast, including mounts, ridges and irregular hummocks. Thicknesses are not accurately known but are estimated at 30-40 m. Elsewhere, an extensive till-sheet covers the bed-rock and is generally 2 to 10 m thick. The boulder clay is derived from the nearby fells and contains cobbles in a sand/clay matrix, as well as large boulders several metres across. The boulder clay is generally over-consolidated and is likely to have a low permeability. On steeper slopes, the surface layers are commonly soliflucted. In addition, several isolated mounds of sand, gravel and boulders lie on the boulder clay in irregular heaps up to 10 m thick (Fig 2).

Stream sediment samples

Sixteen stream sediment samples were analysed for Cu, Pb, Zn and Ba (Fig 3). The results show the presence of highly anomalous concentrations of these metals in the upper reaches of How Beck and Blea Gill and along the associated races. The values gradually diminish downstream but are still anomalous below Woodhall. A panned concentrate from How Beck yielded abundant barytes with cerrusite, bronchianite and linarite. The anomalous values are due to contamination from disused mine levels at Sandbed mine near the head of How Beck and at East Sandbed mine near the head of Blea Gill. Both mines were largely worked for barytes but also yielded Pb, Zn and Cu ores.

Soil samples

A total of 2,300 soil samples was collected at 20-m intervals along traverse lines 100 m apart and aligned NW-SE, perpendicular to possible extensions of the

Sandbed mine veins. Summary statistics (Table 1) were calculated using every tenth sample because of the limit of 250 samples which can be manipulated using the IBM Call-360 Statpack system.

Table 1

Summary statistics for Woodhall soils (n = 230)

Element	Range		Arithmetic		Log_{10} units		Geometric			
	min.	max.	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	$\bar{X} + 1\sigma$	$\bar{X} + 2\sigma$	$\bar{X} + 3\sigma$
Cu	0	1,510	31	130	1.200	0.343	16	34	77	169
Pb	10	43,000	494	3,750	1.872	0.499	74	209	589	1,656
Zn	10	3,400	119	304	1.899	0.284	79	153	293	564

The arithmetic data are positively skewed so a logarithmic transformation was applied to produce a more normal distribution before mean, standard deviation and correlation coefficients were calculated. Contoured Cu, Pb and Zn maps based on mean plus one, two and three standard deviations show the main anomalous areas [Figs 4 to 6].

The major anomalies are downslope from Sandbed mine and adjacent to How Beck and the mill-races running down to Woodhall and Hudscales. They are considered to be due to contamination from the mines. Leakage from the artificial drainage channels has been particularly effective in spreading metal-bearing material across slopes well away from the streams. Two further leats used in the last century to lead water from Carrock Beck in the south to a water-wheel at Sandbed mine may have further redistributed metals into the area, as Driggith mine was then active and presumably contaminating the Beck. A prominent Zn anomaly near Birket Beck [3298 3707] may also be due to artificial redistribution, as the stream drains the track along which Zn-bearing barytes was transported from Sandbed mine to Potts Ghyll mine. Isolated anomalies about 800 m east of Woodhall were not investigated in detail. They lie in an area of thick, drumlinised boulder clay and are considered to be too scattered to reflect bed-rock mineralization.

Cu and Zn anomalies on the flood-plain of the River Caldew reach their highest values near the river bank and are probably caused by contamination from mines upstream.

Till sampling by auger

Apart from the anomalies just below Sandbed mine, the most extensive anomaly in soil lies immediately south of Woodhall. Deep till sampling was carried out here to confirm that the soil anomalies were indeed produced by surface contamination. The till was sampled to a maximum depth of 4 m but large boulders in the drift probably prevented penetration of the auger to bed-rock in most of the holes. Twenty profiles through the boulder clay were obtained with a Minuteman power-auger (Fig 7). Cu, Pb and Zn analyses of samples from holes 16-20, to the east of the soil anomaly, show only background metal values (Fig 8), but beneath the soil anomaly itself, Pb and Zn levels decrease markedly below a depth of 1.5 m. Copper values here show little variation. These results suggest that the Pb and Zn anomalies in soil near Woodhall are caused by surface contamination, dispersed by the flooding of How Beck and Blea Gill over the intervening low ground.

IP and resistivity survey

A series of NW-SE traverses was measured, from Sandbed mine in the west to the River Caldew in the east, aimed at locating both possible extension of the Sandbed-Driggith vein and possible disseminated sulphide mineralization at the base of the Carboniferous limestone (Fig 9). As explained earlier, two different types of IP equipment were used in this area. The resistivity results from each are compatible and the values at n=4 (ie dipole centres spaced 200 m apart) have have been contoured together (Fig. 9). The IP results can be compared qualitatively, but only the time-domain chargeability values for traverses K, H, and J at n = 4 have been contoured together (Fig 10). On traverses L, M, and N, difficulty was experienced in obtaining satisfactory data at n = 4 and so the positions of chargeability anomalies at n = 3 (dipole centres 150 m apart) have been shown by bar markings. For the frequency-domain data on traverses

A, B, C, D and E and the time-domain data on traverses F and G, the positions of chargeability and frequency-effect anomalies have again been shown by bar markings, because the wide spacing between these traverses prevents satisfactory contouring. The contoured resistivity data broadly reflect the geology. The higher resistivities are due to the volcanic beds where they are covered only by thin, patchy drift, as on traverses K, A, H and J. The decreasing resistivities on the lower ground result from both thicker drift and the limestone bed-rock. At the south-eastern end of traverses B, C, D and E for example, the general decrease in values northwards coincides with the thickening of the boulder clay. In the west however, between Hudscales and Sandbed mine, the drift cover, although complete, is not so thick as to obscure the resistivity contrast between the volcanics and the limestones, so that their junction can be deduced from the resistivity data (cf. figs 2 and 9).

The contoured IP data show an area of anomalous chargeability values extending north-east from Sandbed mine as far as traverse K (Fig 10). Frequency effect anomalies on traverses B and C, and chargeability anomalies on the intervening lines L, M and N indicate that a single feature producing IP anomalies persists for over 1 km NE of the mine, and penetrates the limestone outcrop. This feature may be the extension of the Sandbed vein but the lack of a corresponding EM anomaly suggests that it is not strongly mineralized. There is no evidence of anomalies aligned along the strike of the limestones. Scattered, weak IP anomalies appear on traverses D, E, F and G, but the large spacing between these lines prevents correlation. However, consistent IP anomalies do appear at the southern ends of lines D, E and F. The broken bar markings (Fig 10) denote that these anomalies appear to extent beyond the limit of measurements. The anomalies closely correlate with the resistivity contours and they are clearly related to the volcanic rocks.

Turam survey

This was carried out over the area of strong chargeability anomaly to the north-east of Sandbed mine (Fig 10), to establish whether there was a matching EM response. Fig 11 shows the position of the grounded cable and the Turam traverses

(50W-650W). A major anomaly appears on traverses 250W-650W, with a closely related anomaly on traverses 50W and 150W, and these are due to a thin, steeply-dipping conductor. However, the Turam anomaly lies about 100 m south of the strong chargeability anomaly near Sandbed mine and diverges from it eastwards. The two anomalies are most probably caused by different features for it seems unlikely that the Turam and IP anomalies represent shallower and deeper horizons respectively within a conductor dipping gently north-westwards. Farther eastwards, there is insufficient IP cover to continue the comparison. The Turam survey also indicated a second conductor of limited downslope extent on the higher ground east of the mine (Fig 11) which seems to be the East Sandbed vein (Shaw 1975).

VLF survey

A VLF survey was carried out over the area of the Turam survey for comparison purposes. VLF measurements were made on traverses 550W, 350W, 150W and 30W-650E. The contoured VLF data shown in Fig 11 has been obtained from in-phase values using the filtering method described by Fraser (1969). The correlation between the VLF and Turam anomalies is excellent, but again no response was obtained over the chargeability anomaly. The VLF anomaly is seen to extend 400 m beyond the Turam survey area, changing direction from an ENE trend. An additional, though weak, conductor, having a NW-SE trend was located at the eastern end of the area.

(ii) Nether Row

The area lies immediately west of Woodhall (figs 2 and 12). As far as can be determined beneath the extensive drift, the stratigraphical sequence is similar to that at Woodhall, except that the Basement Conglomerate probably comes in near Potts Gill and thickens westwards, as it is exposed near Fell Side [305 376], a short distance to the west. Little is exposed of the Carboniferous sequence except near Hudscales, where the White Limestone [3300 3771] is firmly identified by a fauna which includes Davidsonina septosa, and in small quarries [3304 3785 and 3303 3810] the overlying Rough and Jew limestones are exposed.

Several short IP traverses were laid out (Fig 13) over the lower part of the Carboniferous sequence, but no geochemical sampling was undertaken as it was thought unlikely, in view of the thick drift and the widespread contamination of the water-courses from the Fellside mines found at Woodhall, that indications of bedrock mineralization would be obtained. Contoured resistivity and chargeability values at n = 4 are shown on Fig 13.

Resistivity values greater than 150 ohm metres are restricted to the area south of Hudscales where the volcanic rocks are near the surface. The low resistivities elsewhere are due in part to the limestone bedrock and also to the thick drift. The northward swing of the 100 ohm metre contour south of Nether Row probably marks the northward shift of the limestone base by faulting (Fig 12). The narrow resistivity low to the south of Hudscales continues eastwards towards Woodhall (Fig 9) and may represent a drift-filled channel in the limestone surface.

Several weak chargeability anomalies lie close to the base of the limestone succession and may mark stratigraphical horizons. They are neither consistent nor well-defined however, perhaps because of the thick drift, so they cannot with confidence be identified with any particular bed.

(iii) Longlands

Geology

The Borrowdale Volcanic Group consists mainly of green and purple andesites with subordinate bands of tuff. The dip of the massive lavas is generally obscure but northerly dips of about 70° have been recorded near the head of the Charleton Gill section, where Eycott-type andesites, characterized by large feldspar phenocrysts, are interbedded with non-porphyritic types.

The unconformable base of the Carboniferous succession is exposed in a stream NW of Longlands [2610 3631], where grey and brown, silty mudstones rest on deeply weathered volcanic rocks. The overlying Basement Conglomerate consists of 50 to 65 m of purple-red conglomerates and pebbly sandstones with thin bands of limestone and marl, the best section being in a gully north-east of Longlands [270 362]. The lithologies of the overlying limestones are described in the section on Woodhall and their local thicknesses are shown in the vertical section in Fig 14.

The main fault in the area, trending northwards to the east of Longlands throws the Carboniferous rocks down to the west by at least 50 m. The amount of its throw in the volcanic rocks, where the fault is mineralized, is unknown.

An extensive till-sheet, 2 to 10 m thick, covers most of the area and is particularly thick in the north-east. It is composed generally of boulders and cobbles in a stiff clay matrix. On the steeper slopes the drift is extensively solifluncted.

Soil survey

A total of 243 soil samples was collected along the traverse lines shown in Fig 15, aligned to cover both the N-S mineralized fault at the head of Longlands Beck the lower part of the limestone succession to the north. Contoured maps of Cu, Pb and Zn values based on mean plus one, two and three standard deviations ($\log_{10}$ transformed data) show the main anomalous zones (Figs 16-18).

Table 2

Summary statistics for Longlands soils (n = 243)

Element	Range		Arithmetic		$\log_{10}$ units		Geometric			
	min.	max.	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	$\bar{X} + 1\sigma$	$\bar{X} + 2\sigma$	$\bar{X} + 3\sigma$
Cu	5	310	41	27	1.554	0.218	36	59	98	161
Pb	20	170	54	24	1.697	0.171	50	74	109	162
Zn	20	290	84	33	1.894	0.165	78	115	168	245

Levels of Cu, Pb and Zn concentration are much lower than at Woodhall, even in the vicinity of the old workings at the head of Longland Beck. Over the Carboniferous strata, the main group of coincident Cu, Pb, Zn anomalies lies between 600 m north and 900 m north-east of Longlands Farm. The lead anomaly immediately north of the River Ellen includes one value of 120 ppm Pb which is as yet unexplained. There is a general coincidence of Cu, Pb and Zn anomalies near Charleton Gill, west of Burblethwaite. Some of the samples were taken from the alluvium adjacent to the stream and the anomalous values therefore suggest the introduction of metals from unrecorded mineralization higher up the stream.

Fig 19 shows that metal values in the upper section of Charleton Gill are as high as in Longlands Beck below the old workings, and even higher Pb-Zn values occur south of Burblethwaite, in streams draining the volcanic rocks and the Carboniferous basal conglomerate. It is not known whether these latter values indicate mineralization in the conglomerate but it is more likely that they arise from mineral veins in the drift-covered volcanic rocks to the south; similar veins have been extensively worked in the past in Dale Beck, about 1.5 km to the south-east.

Till sampling by auger

Twenty-six auger holes were drilled (Fig 19) with a Minuteman power auger to test for bed-rock mineralization to the north and north-east of Longlands farm on weak, but coincident, IP and geochemical anomalies. The relationships between metal values in the soil and those deep in the till, in 5 representative holes, are shown in Fig 20. None of the auger hole profiles showed marked increases in metal values with depth and it is therefore concluded that the soil anomalies do not reflect significant bedrock mineralization. In some cases the distribution of Zn and Cu in the profiles suggests that secondary enrichment of these metals has occurred in the B-horizon of the soil.

IP and resistivity survey

Nine combined IP and resistivity traverses (E-M) were aligned north-south to cover the lowest part of the limestone sequence (Fig 21). In addition, four short, E-trending traverses (A-D) were laid out to trace the course northwards of the mineralized fault marked at the head of Longland Beck. The resistivity and chargeability values at n = 4 on all the traverses are contoured in figs 21 and 22.

The resistivity data broadly reflect the geology. The volcanic rocks give higher values than either the limestones or the conglomerates and the lowest values are obtained over thick drift. The N-trending fault east of Longlands (Fig 14) is marked by a narrow zone of comparatively low resistivities on lines A and B, and by a pronounced northward swing of the resistivity contours on lines D and J (Fig 21). Values over 200 ohm metres at the southern ends of traverses E and G lie just within the outcrop of the volcanic rocks, whilst low resistivities near the middle of lines E, F and G are given by the Basement Conglomerate and the sandstone above the Seventh Limestone. The traverses east of line H largely overlie the drift-covered Basement Conglomerate where values are uniformly low.

The chargeability data reach anomalous values, against a background of about 5 ms in only three areas. Firstly, on traverse A, values of 10 to 15 ms were recorded close to the disused workings but the mineralization on the fault does not appear to extend as far north as line B, which has only background values. Secondly, over the limestones north of Longlands, a broad belt of above-background values were recorded on lines E to I, with marked anomalies above 20 ms on lines F and H. These were tested by deep till sampling and, as the geochemical results from these seem to preclude sulphide mineralization in the bed-rock, it seems likely that the anomalies are due to thin partings of pyritic mudstone, lying at the base of and in the middle of the Sixth Limestone. Thirdly, a single value of 33 ms was recorded on line K. Although isolated, this is unlikely to be spurious as it is accompanied by adjacent anomalies at the n = 5 dipole separation and also coincides with anomalous resistivity values. This area has not been tested by augering as it seems likely that these anomalies are also due to pyritic mudstone partings within the Sixth Limestone, beneath locally thin drift cover.

CONCLUSIONS

At Woodhall, it has proved difficult to use geochemical reconnaissance methods to locate bedrock mineralization in the limestones. The contamination of the fellside streams from disused mines is so extensive as to dominate all the stream sediment samples, and many of the soil samples collected on flat land near the streams. In addition, it is doubtful whether the soil results relate to bedrock values in those areas where the drift is drumlinized, which are therefore regarded as geochemically untested. Elsewhere, including those parts covered by the till-sheet, the soil sampling indicates that there is no significant bedrock mineralization. The geophysical investigations have located weak chargeability anomalies along the extension of the Sandbed Vein into the limestones but the absence of a corresponding EM anomaly suggests that any mineralization is either weak or finely disseminated. The anomalies alone are therefore considered to be inadequate as drilling targets. Within the Lower Palaeozoic rocks, at least one vein or fault, previously unknown, has been located by the EM surveys, branching eastwards off the Sandbed Vein. It is not known whether this structure carries sulphides but, in any case, this type of mineralization is not thought to be economically workable and is therefore not worthy of further evaluation.

There are fewer sampling difficulties at Longlands where there is much less contamination and the drift is generally thinner. Geochemical anomalies have been found but they are weak and deep till sampling shows the most prominent to be derived from the drift. Weak chargeabilities have also been detected but appear to be related to shale partings in the limestone. Accordingly, no viable drilling targets can be defined here.

ACKNOWLEDGEMENTS

A major part of the geophysical work was carried out by T Helliwell, I F Smith and R M Carruthers. Stream sediment, soil and deep till samples were collected by I R Wilson and M McGlashan. The Woodhall samples were analysed by N Cogger, R A Nicholson, B S Chaumoo, L M Rundle and R W Hilliard, and the Longlands samples were analysed by B P Allen and N C W Anderson.

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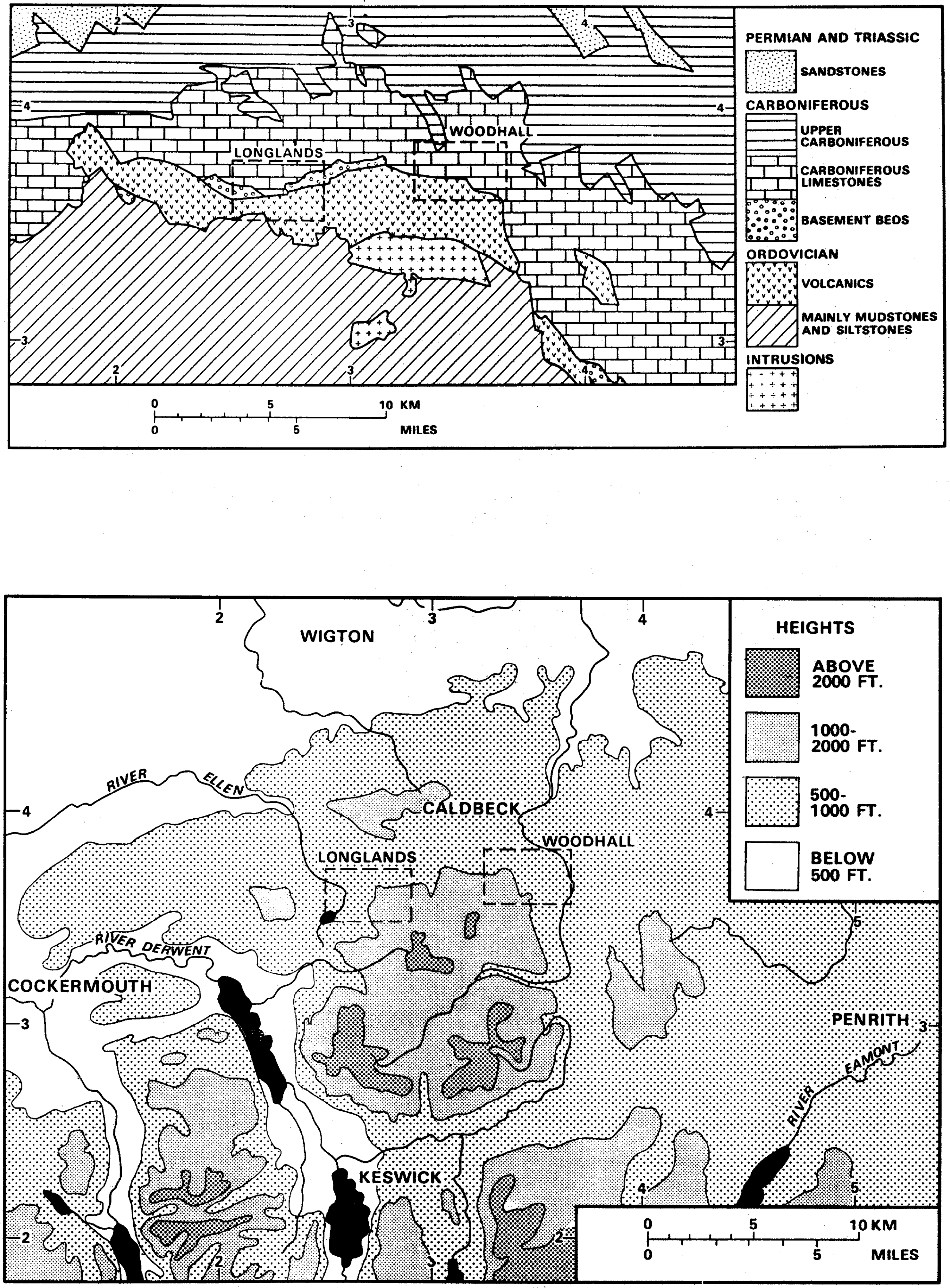

Fig. 1 Regional geology and topography

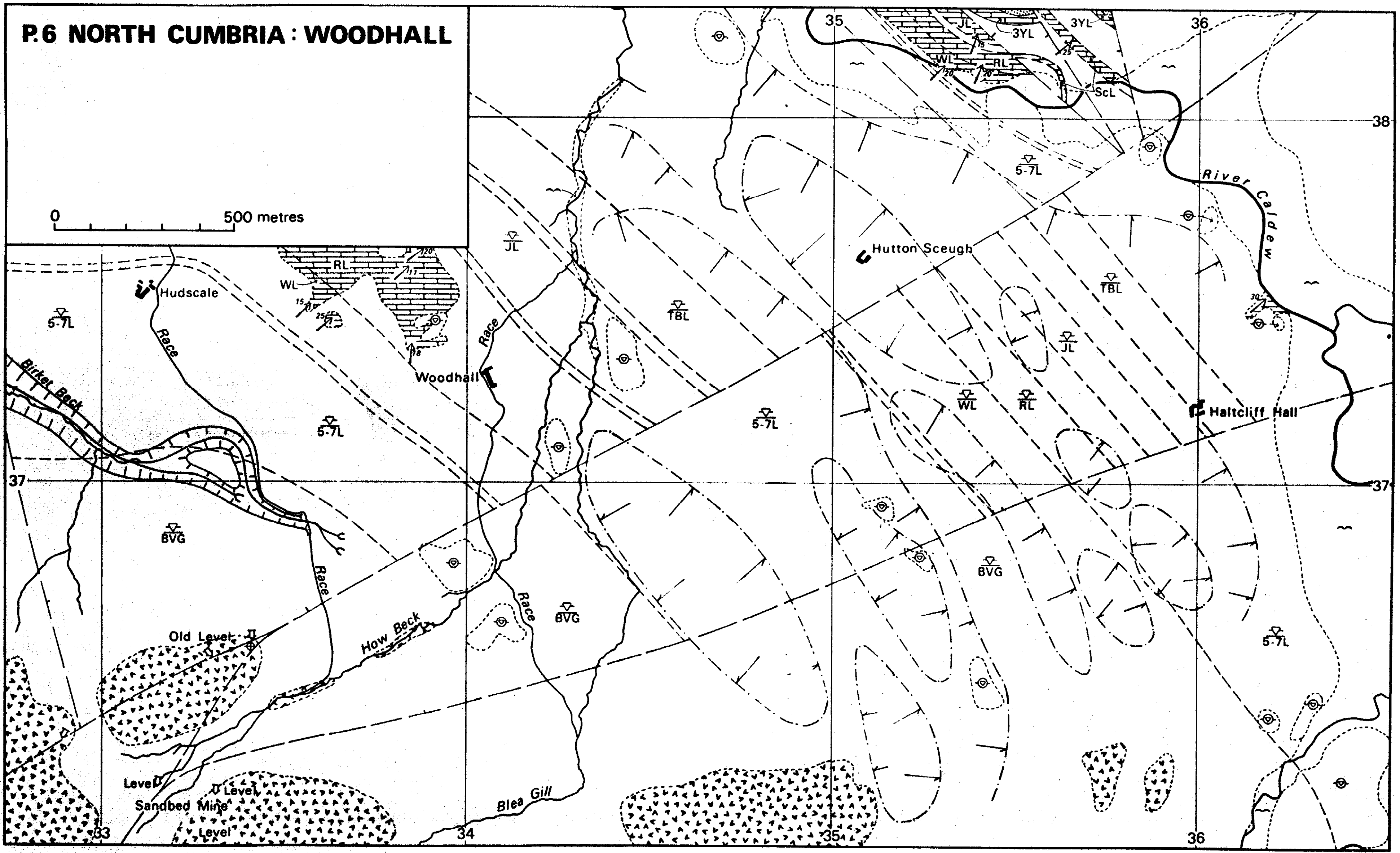

Fig. 2 Geology of the area around Woodhall

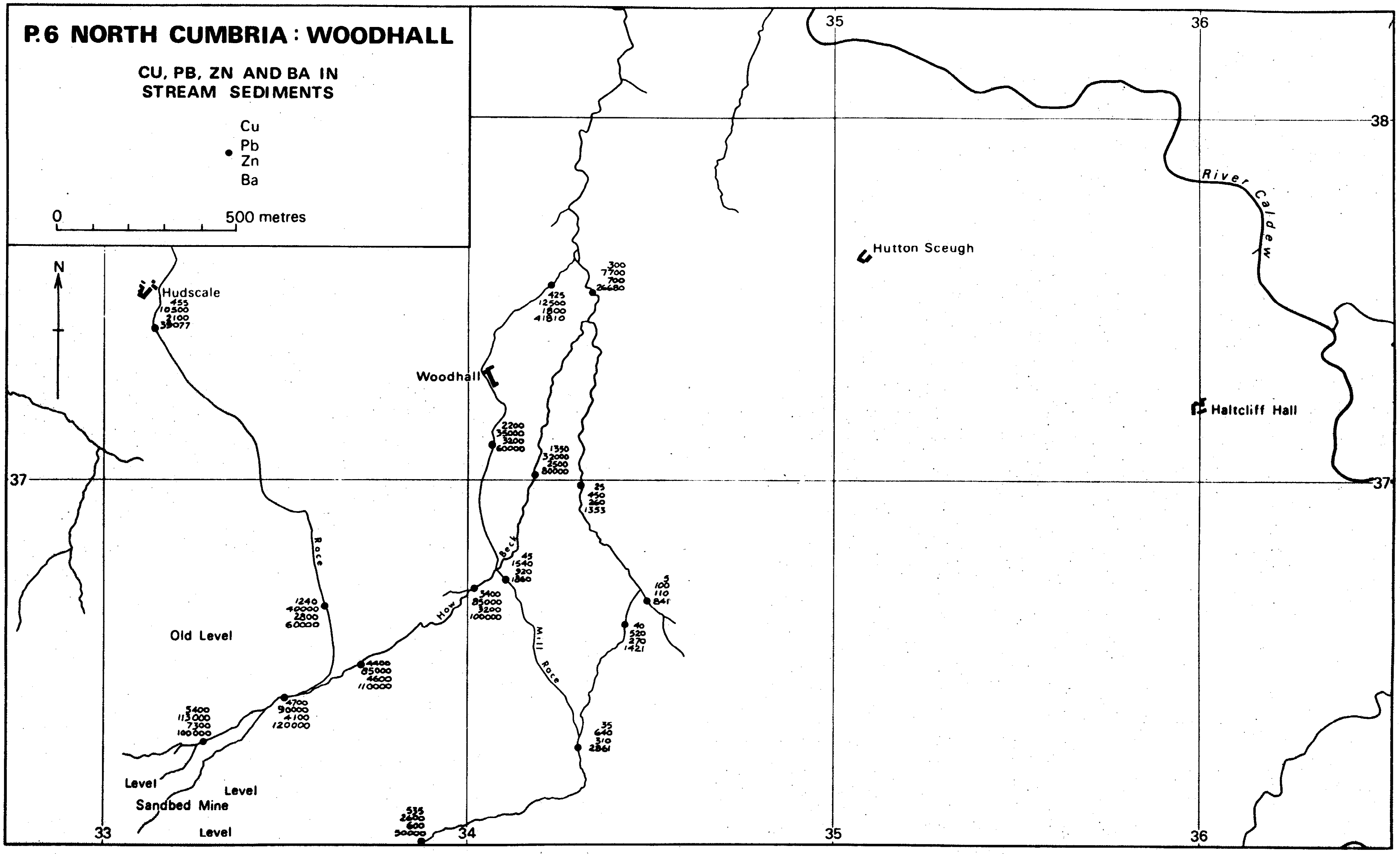

Fig. 3 Cu, Pb, Zn and Ba values in -100 mesh stream sediments, Woodhall

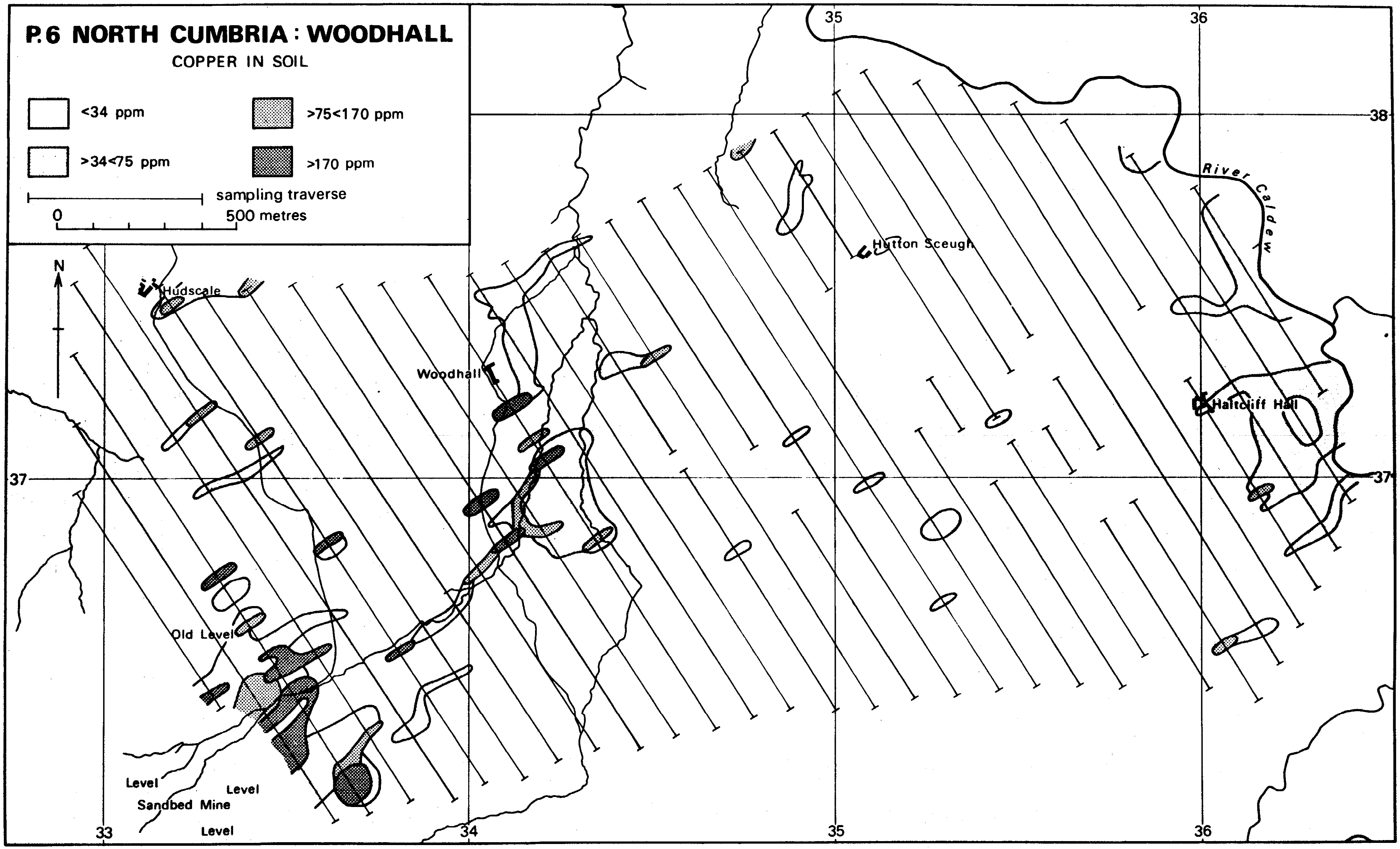

Fig. 4 Distribution of Cu values in soil, Woodhall

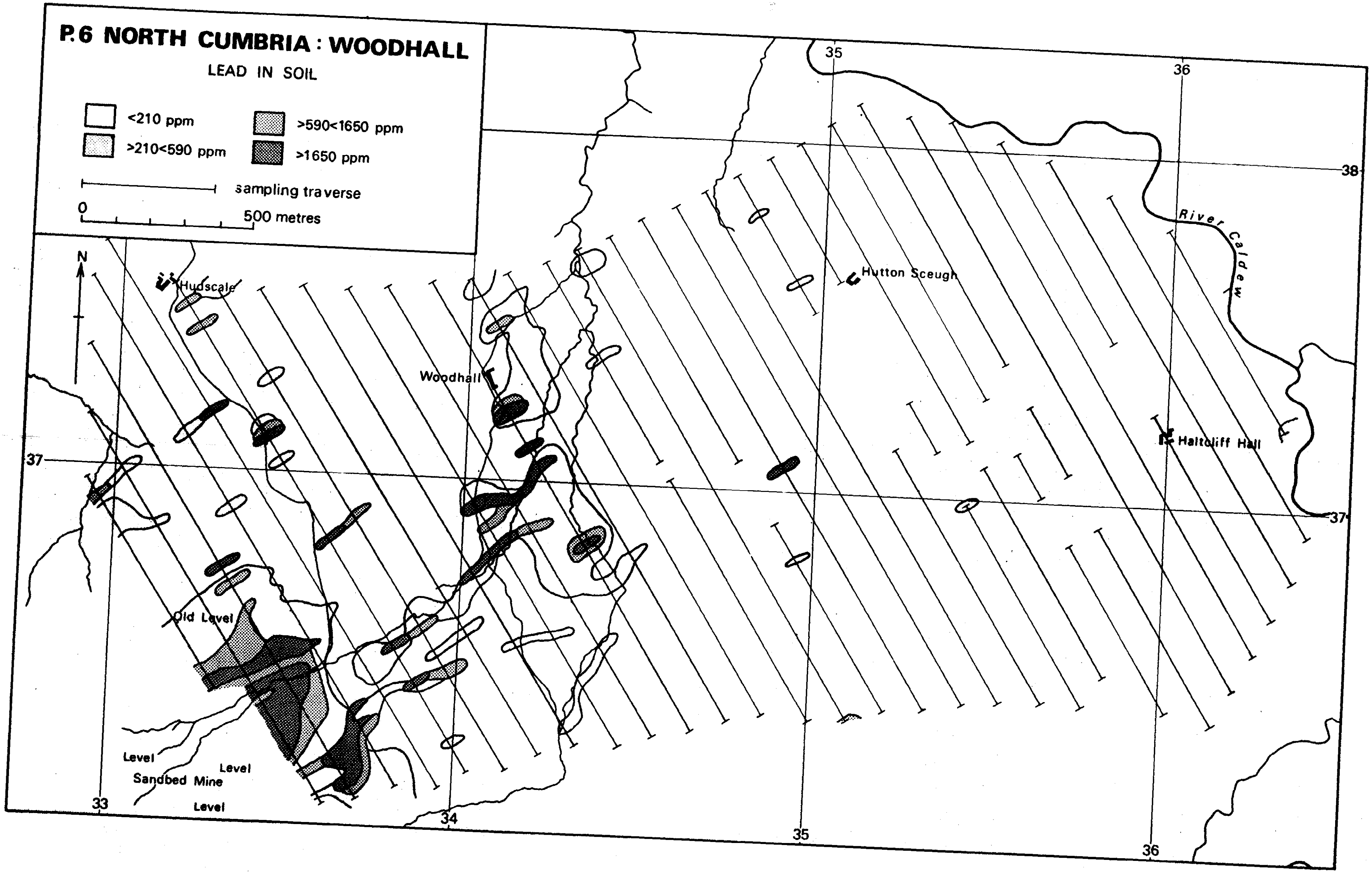

Fig. 5 Distribution of Pb values in soil, Woodhall

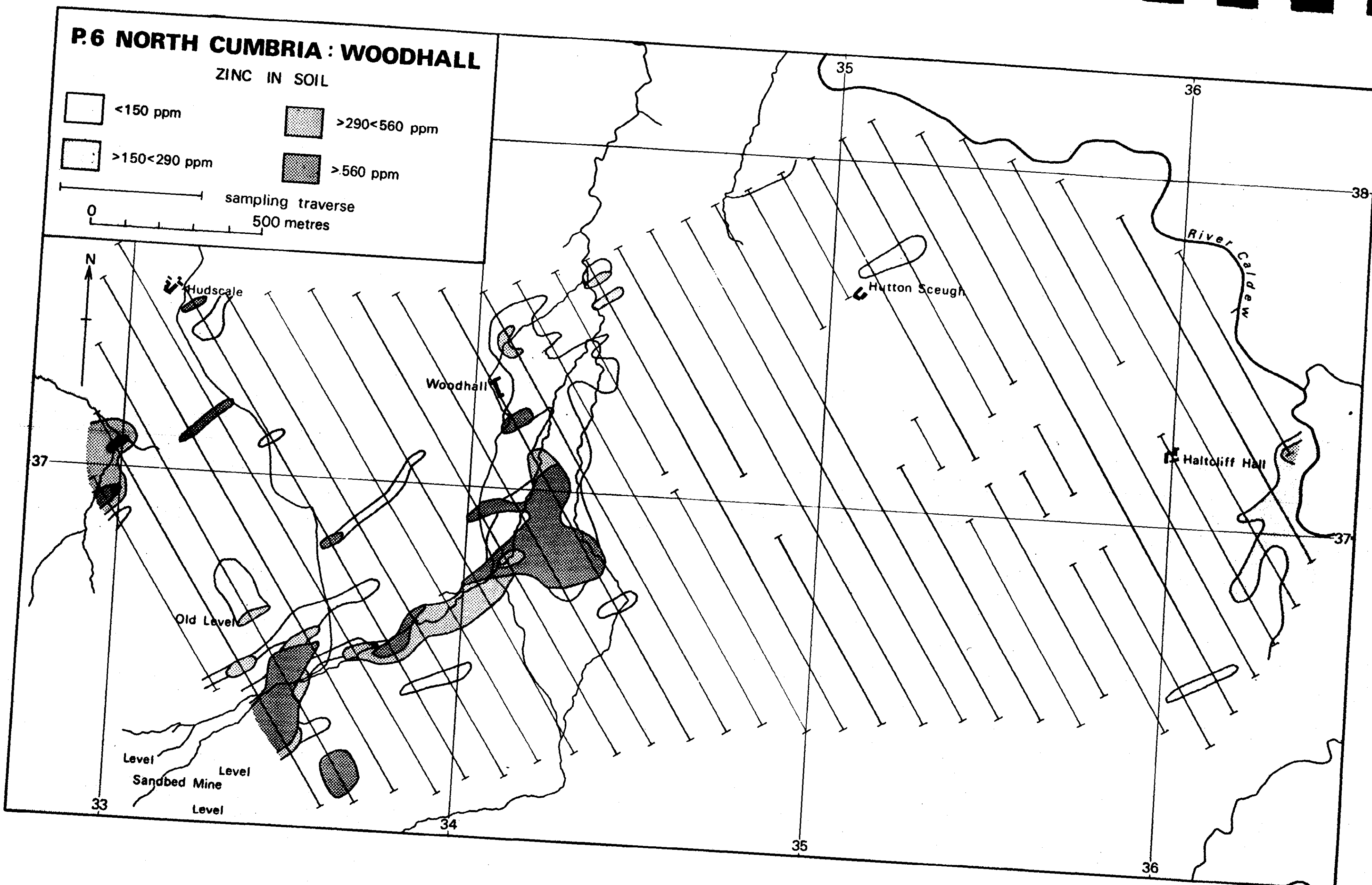

Fig. 6 Distribution of Zn values in soil, Woodhall

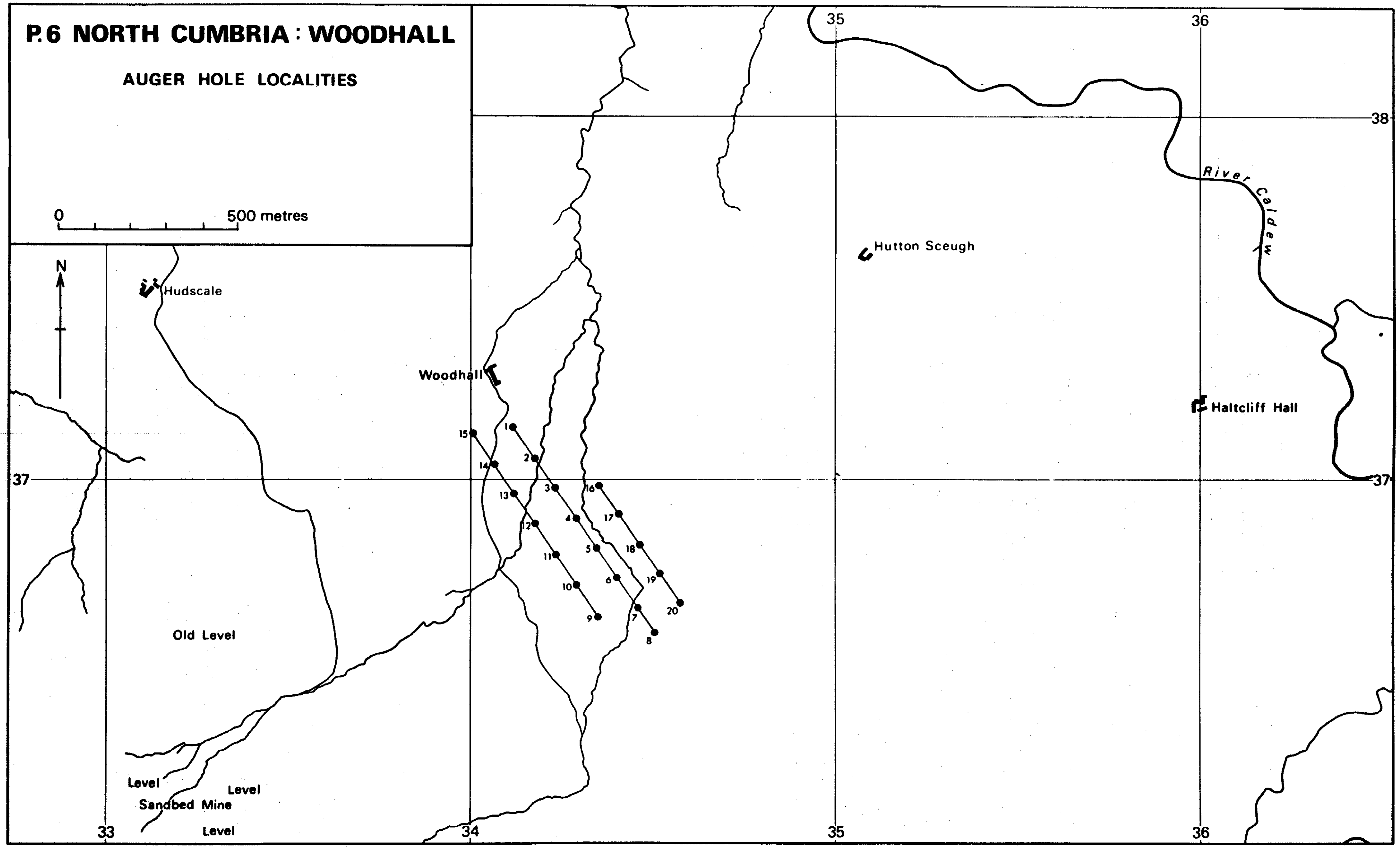

Fig. 7 Location of auger holes, Woodhall

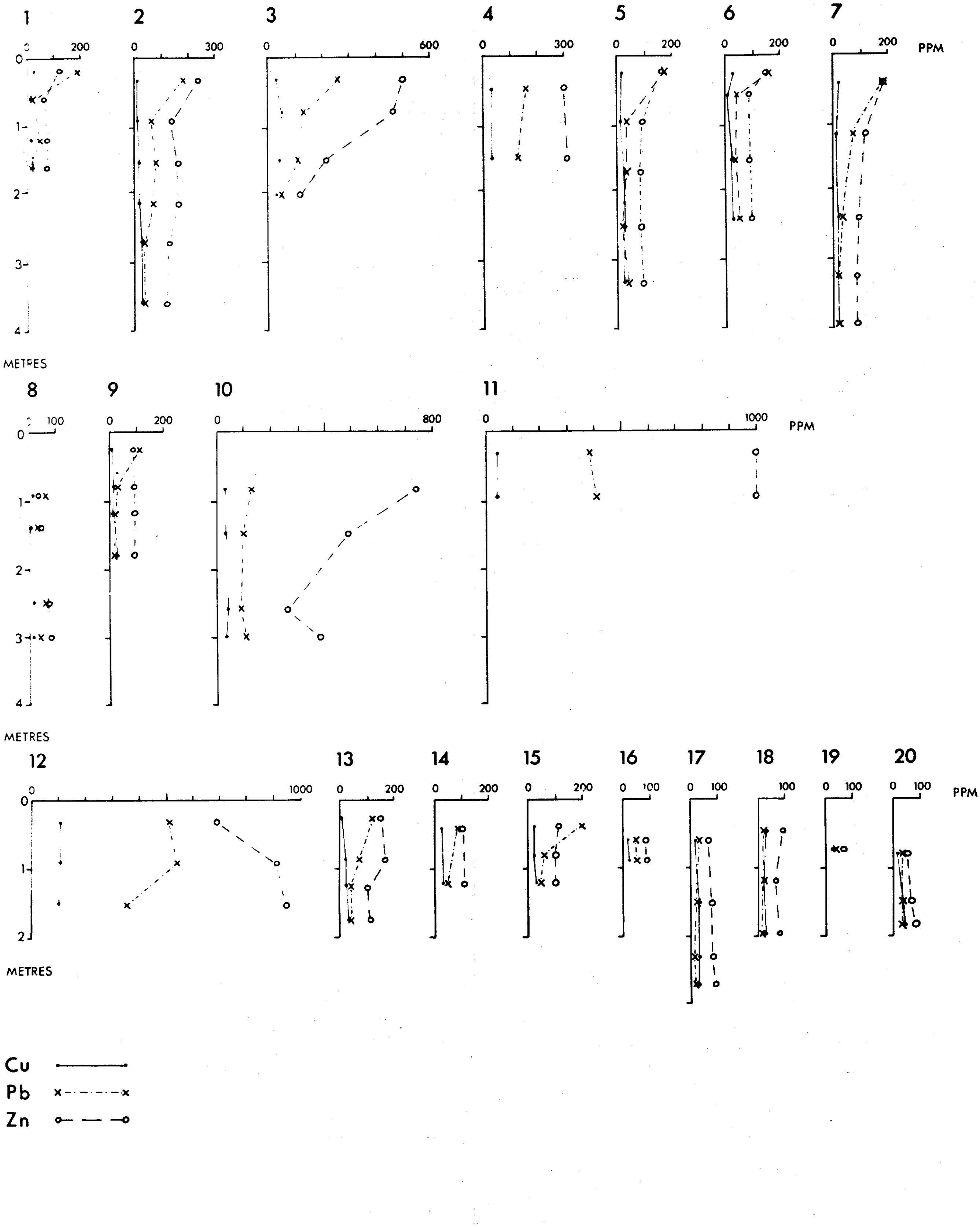

Fig. 8 Cu, Pb and Zn values from auger holes, Woodhall

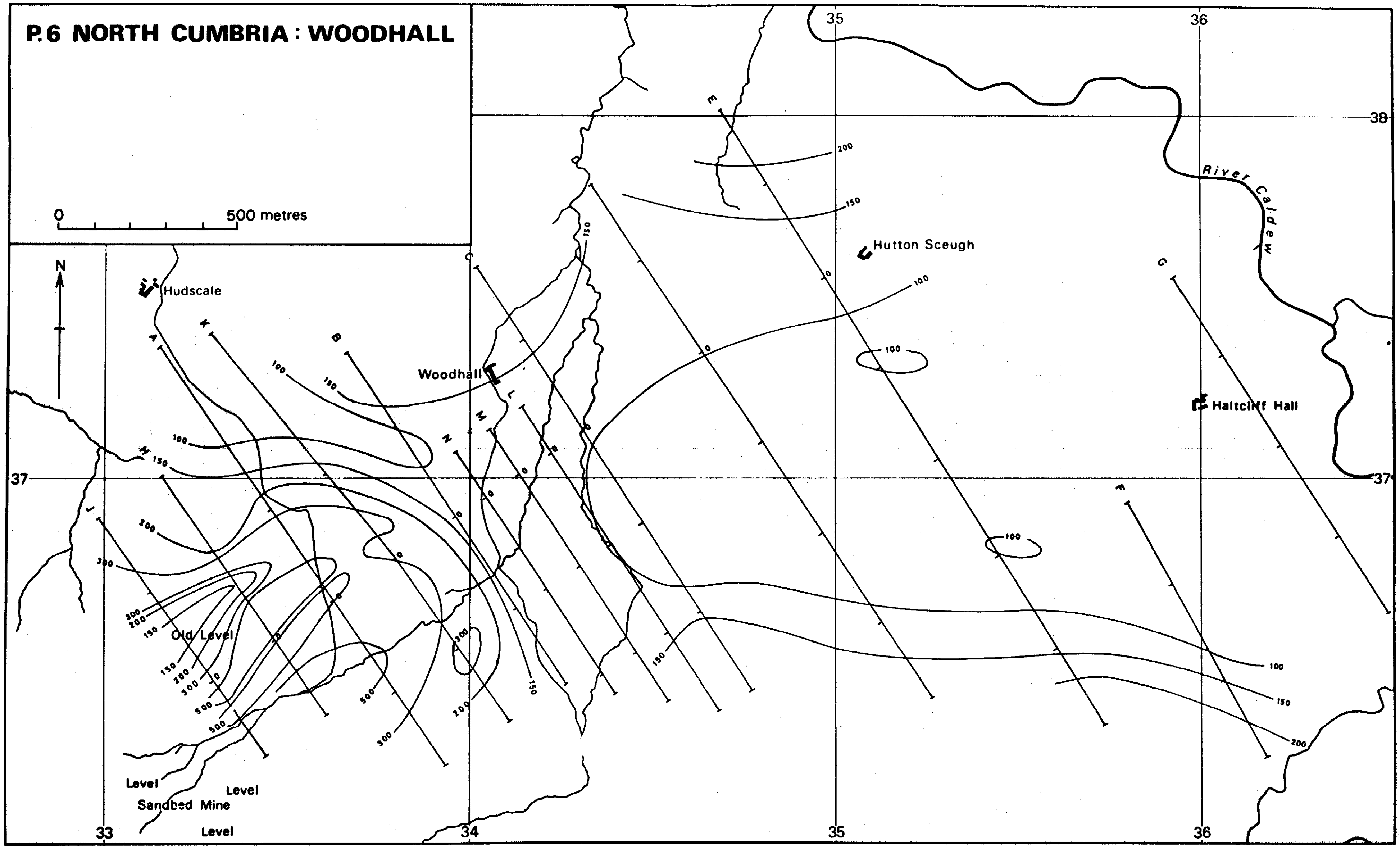

Fig. 9 Apparent resistivities in ohm metres at n - 4, Woodhall

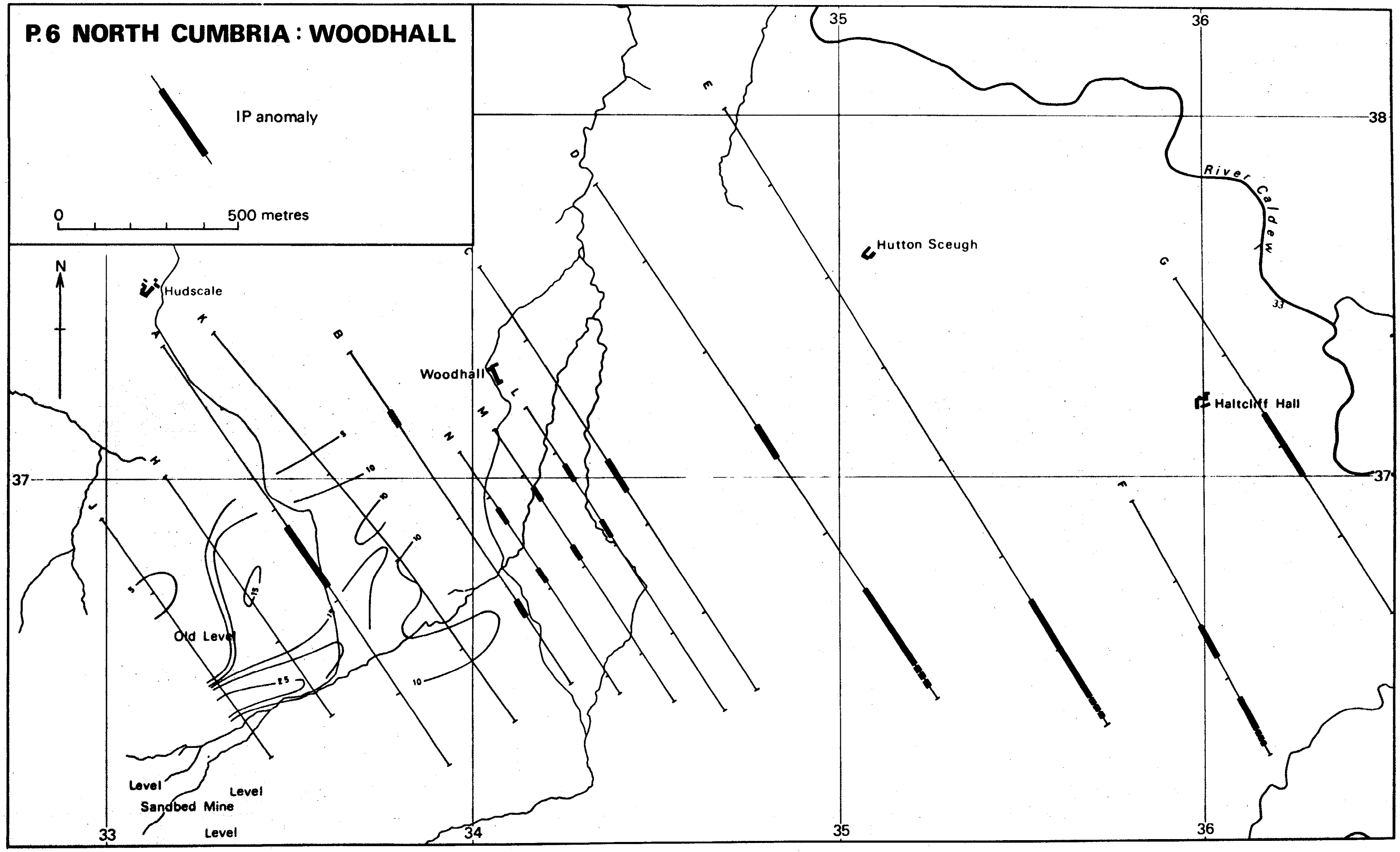

Fig. 10 Chargeabilities in milliseconds at n = 4 on lines H, J and K, and other IP anomalies, Woodhall

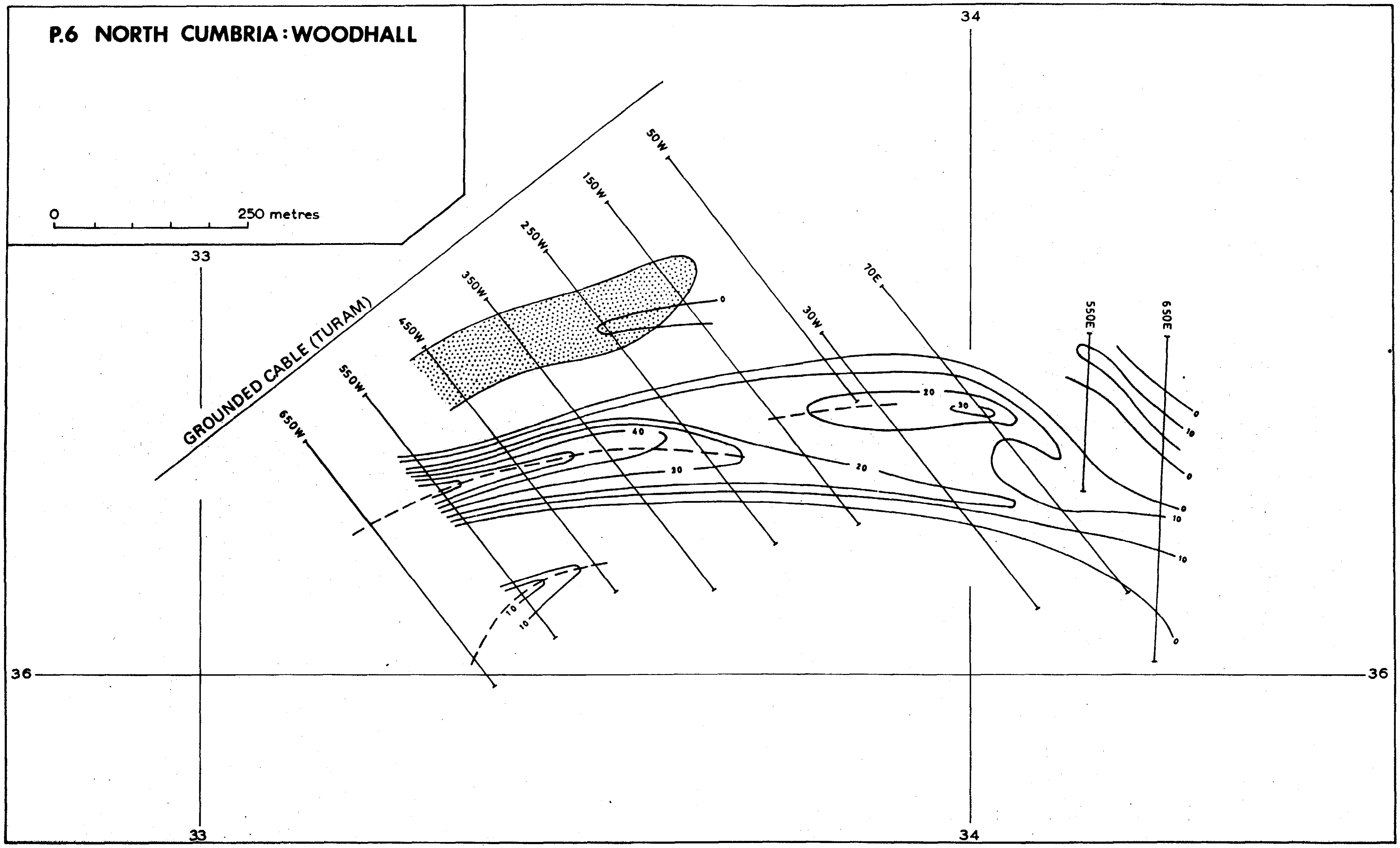

Fig. 11 Filtered VLF data, Woodhall; positive values only are contoured. Broken lines mark Turam anomalies

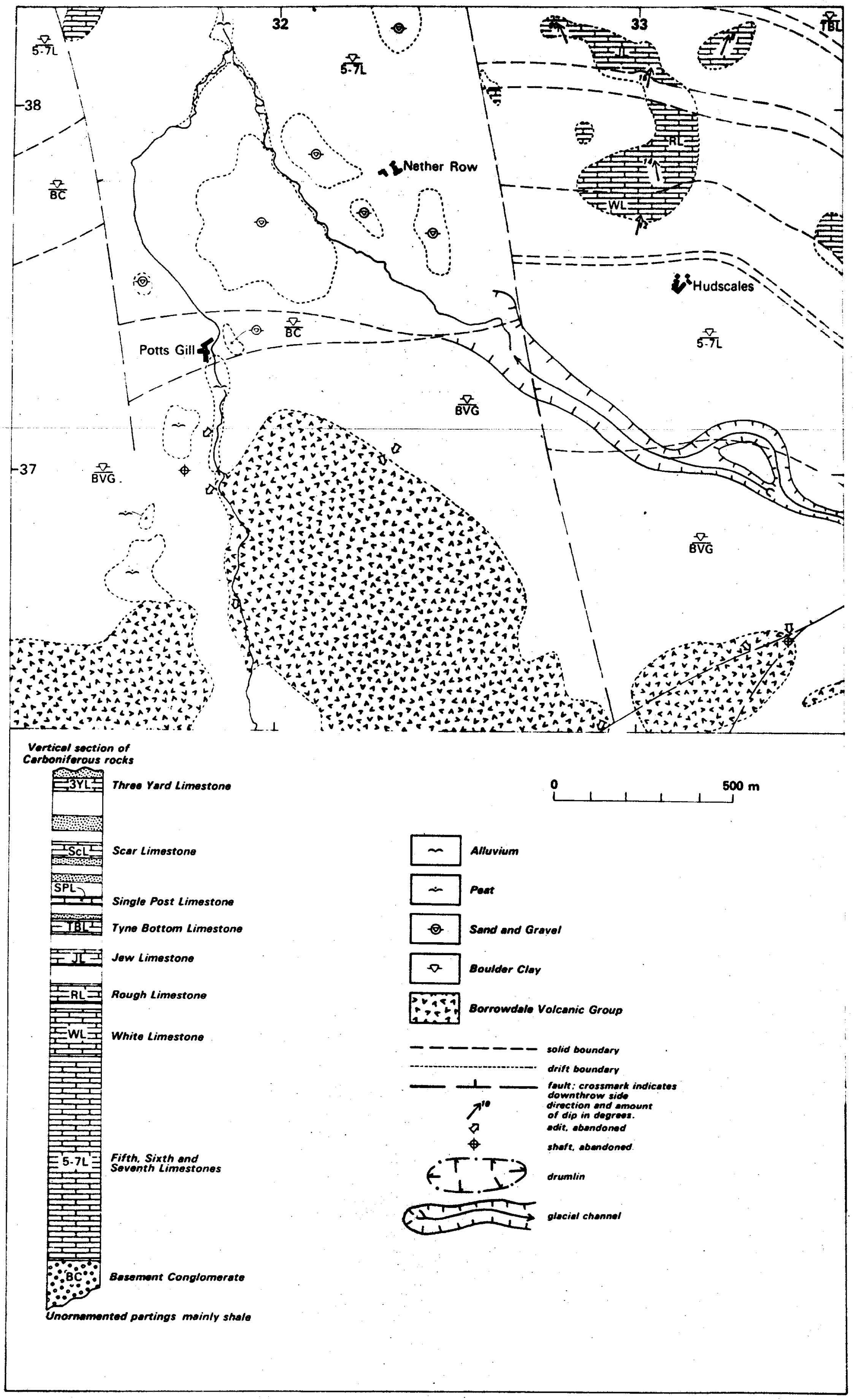

Fig. 12 Geology of the area around Nether Row

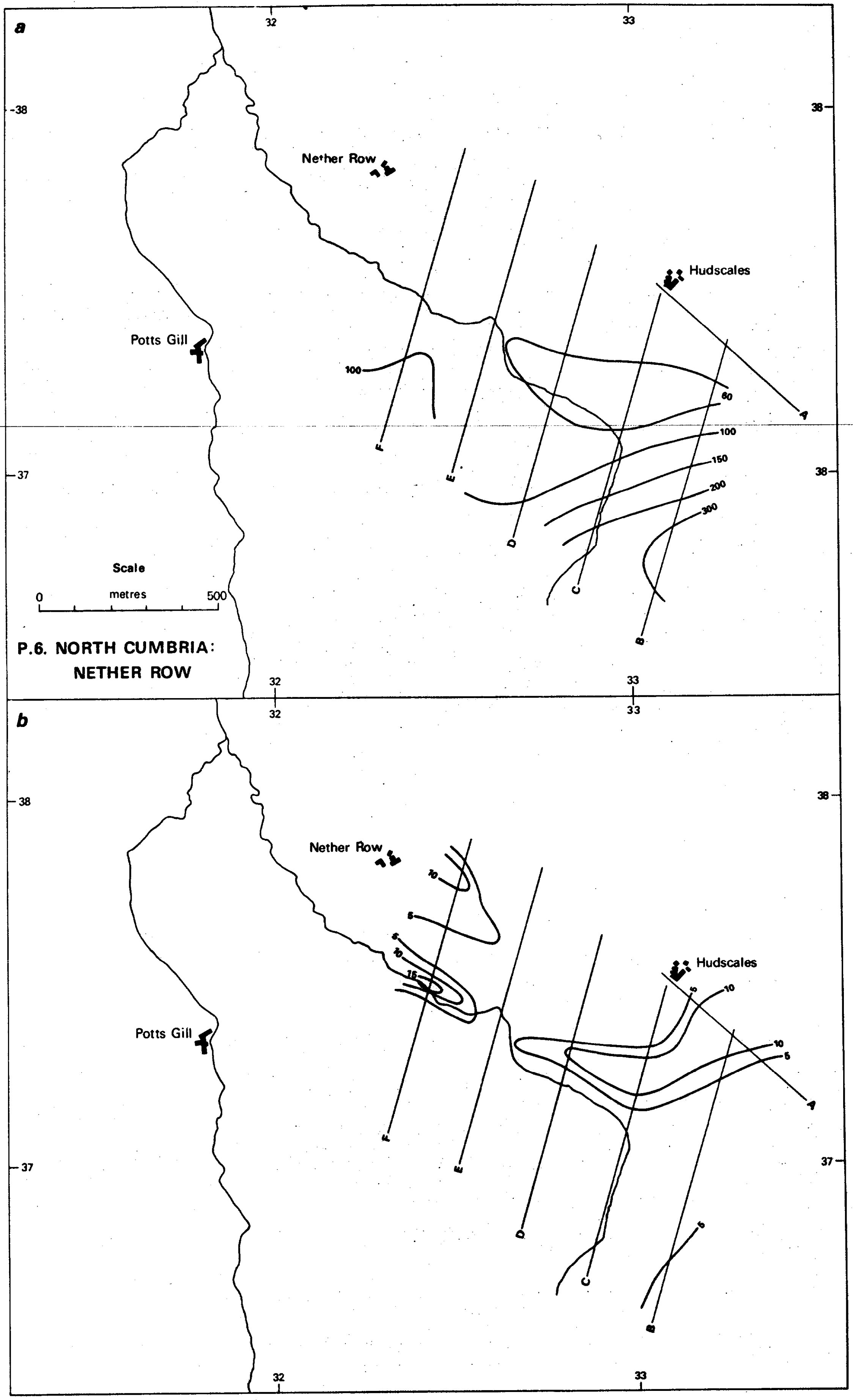

Fig. 13 (a) Apparent resistivities in ohm metres at n - 4, Nether Row

(b) Chargeabilities in milliseconds at n - 4, Nether Row

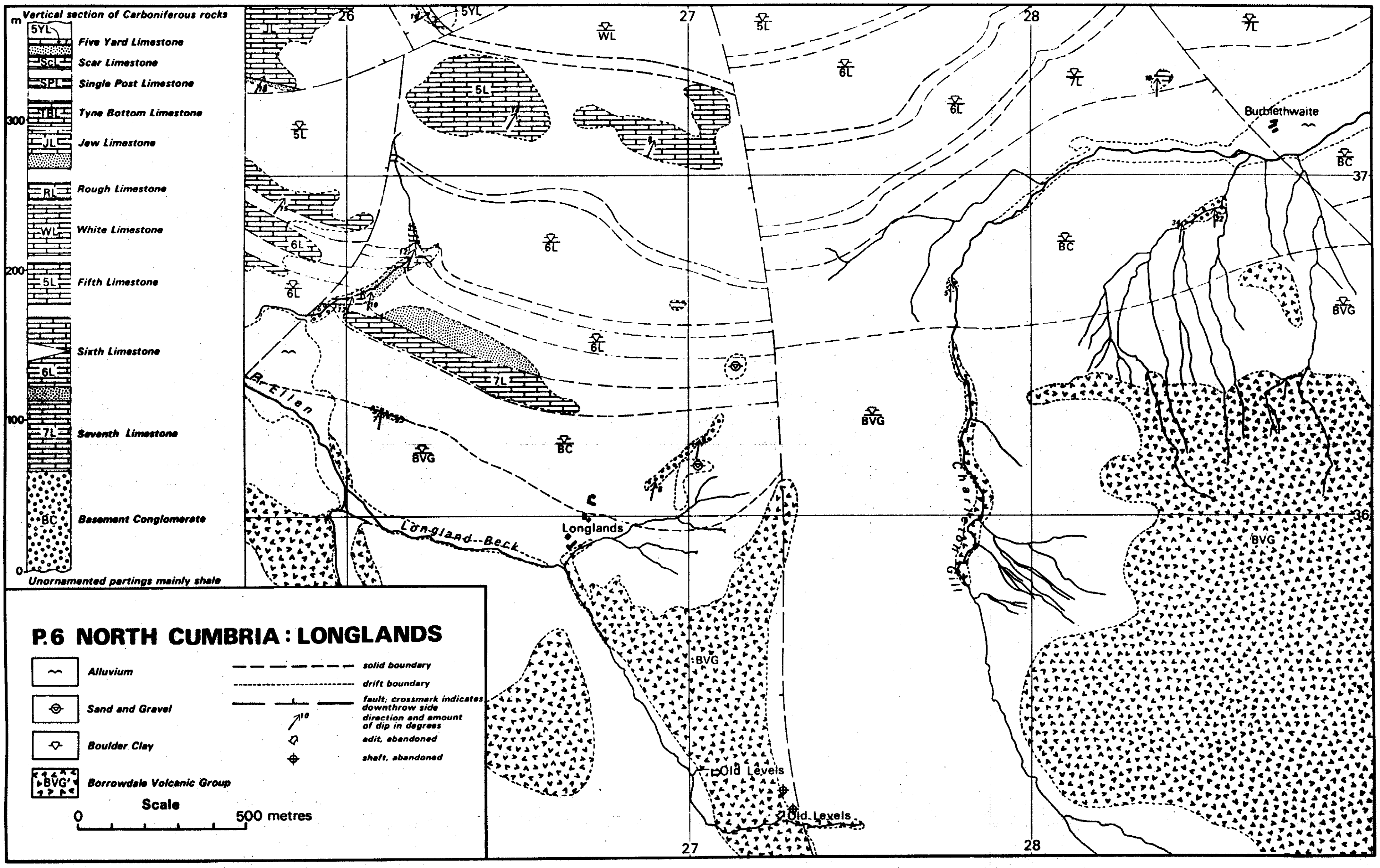

Fig.14 Geology of the area near Longlands

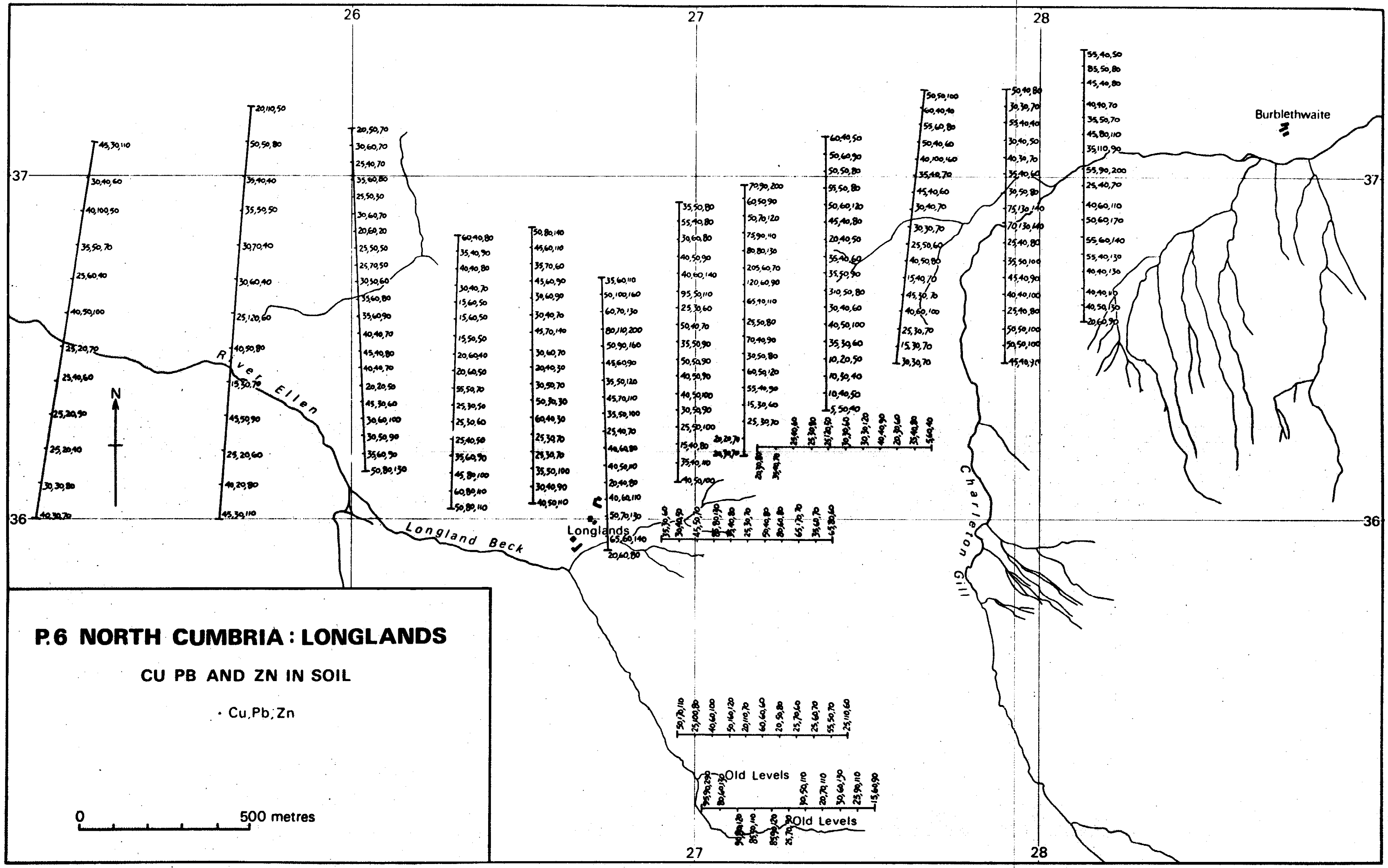

Fig. 15 Cu, Pb and Zn values in soil, Longlands

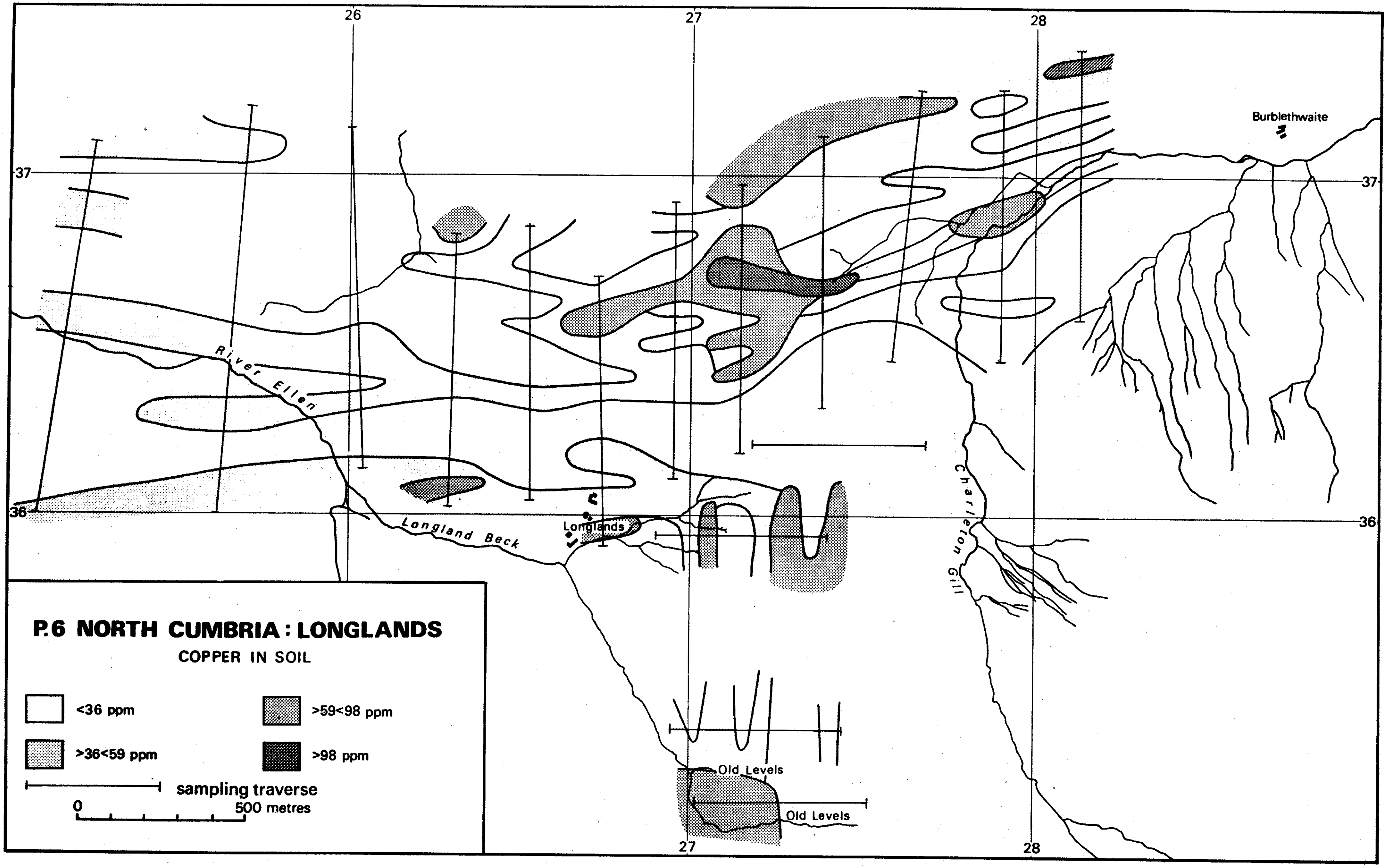

Fig. 16 Distribution of Cu values in soil, Longlands

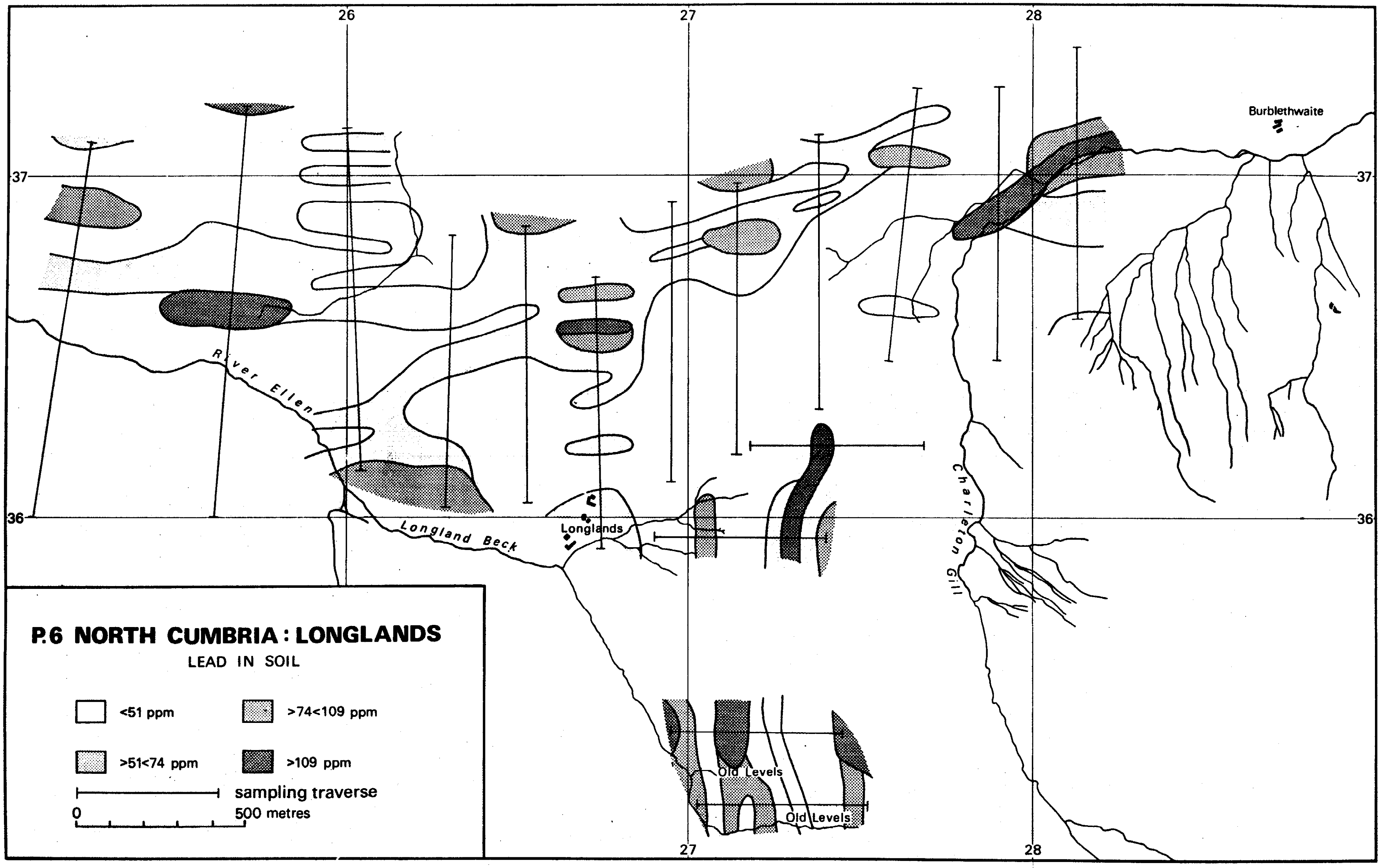

Fig. 17 Distribution of Pb values in soil, Longlands

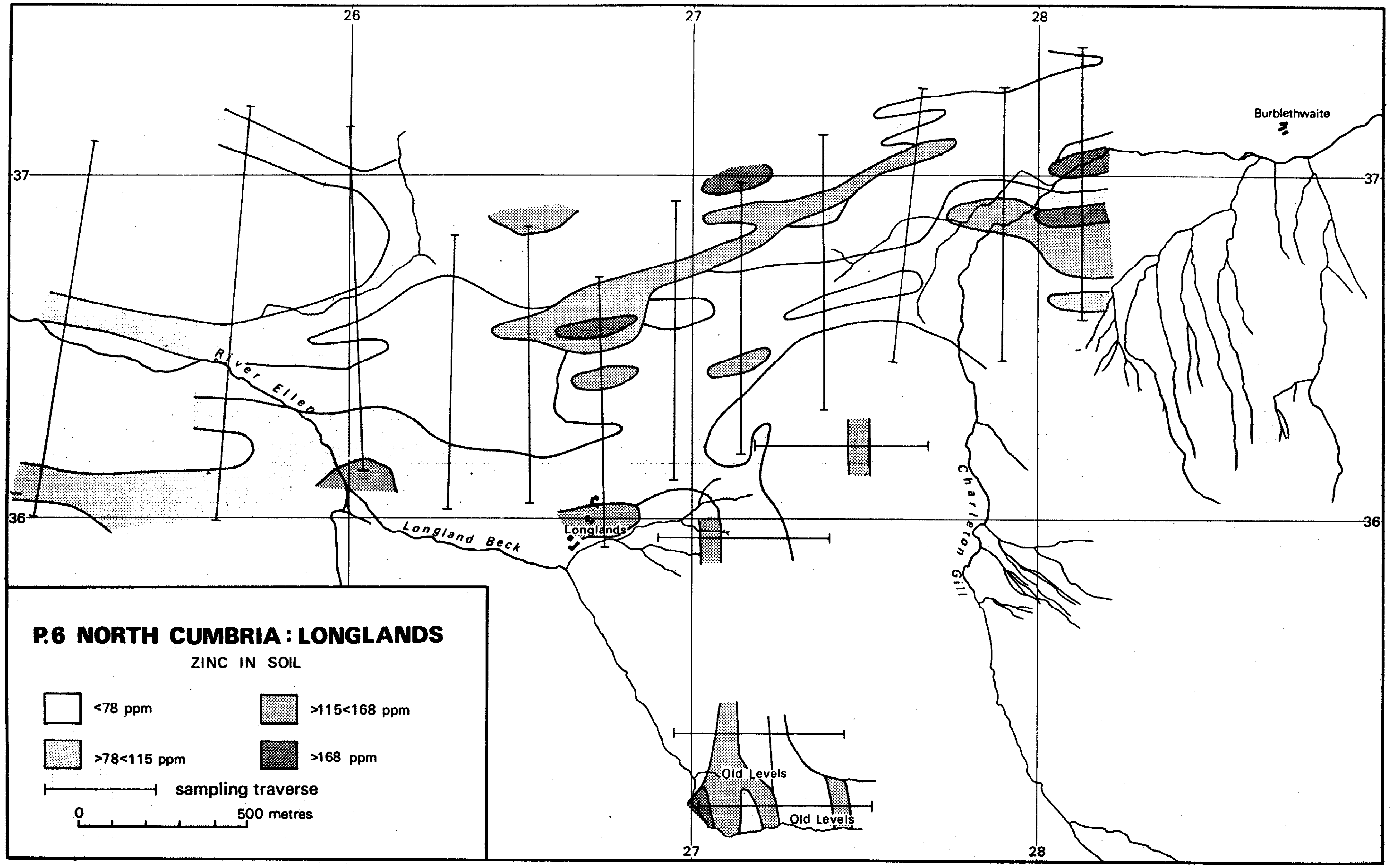

Fig. 18 Distribution of Zn values in soil, Longlands

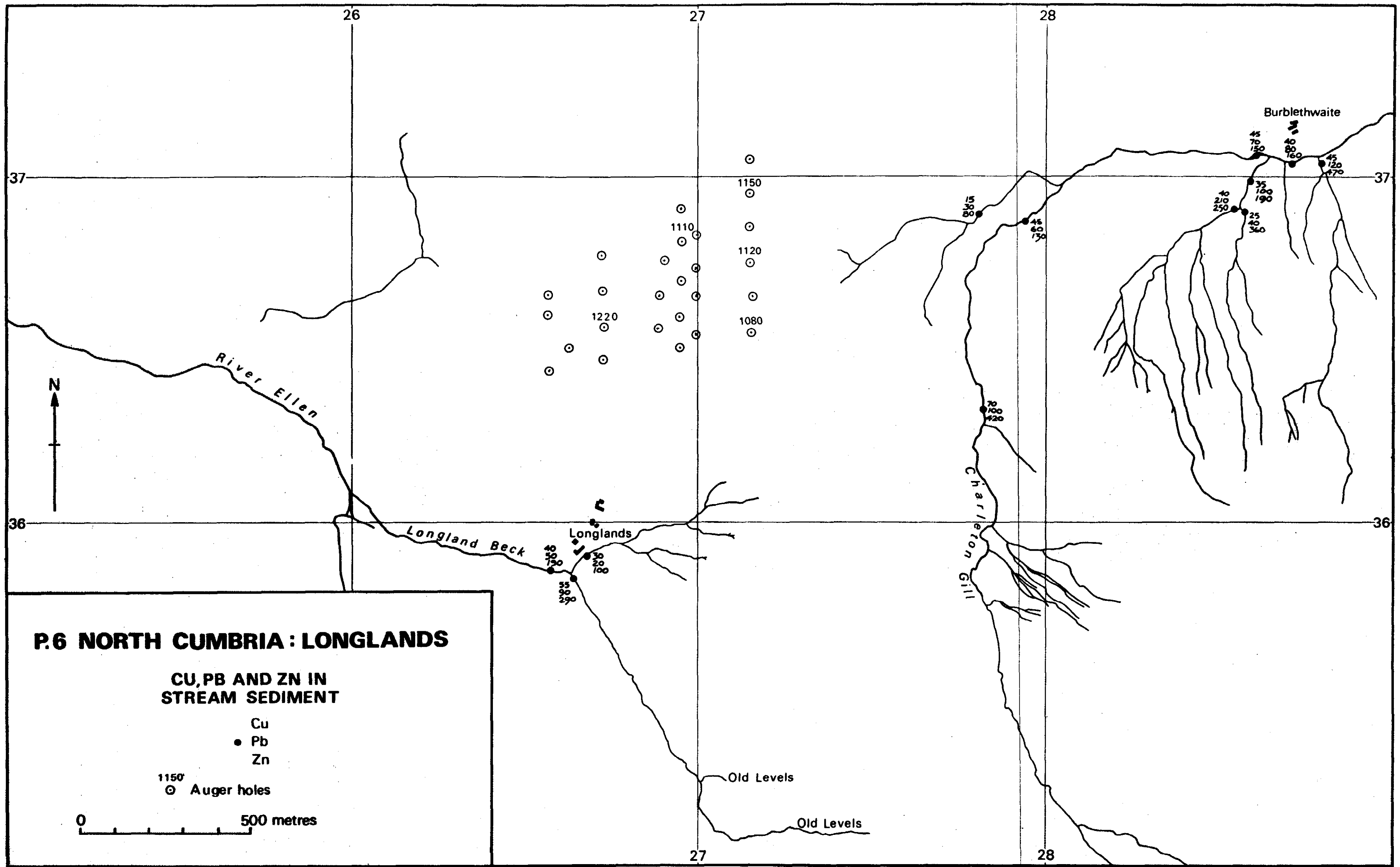

Fig. 19 Cu, Pb and Zn values in -100 mesh stream sediments, and the location of auger holes, Longlands

Fig. 19 Cu, Pb and Zn values in -100 mesh stream sediments, and the location of auger holes, Longlands

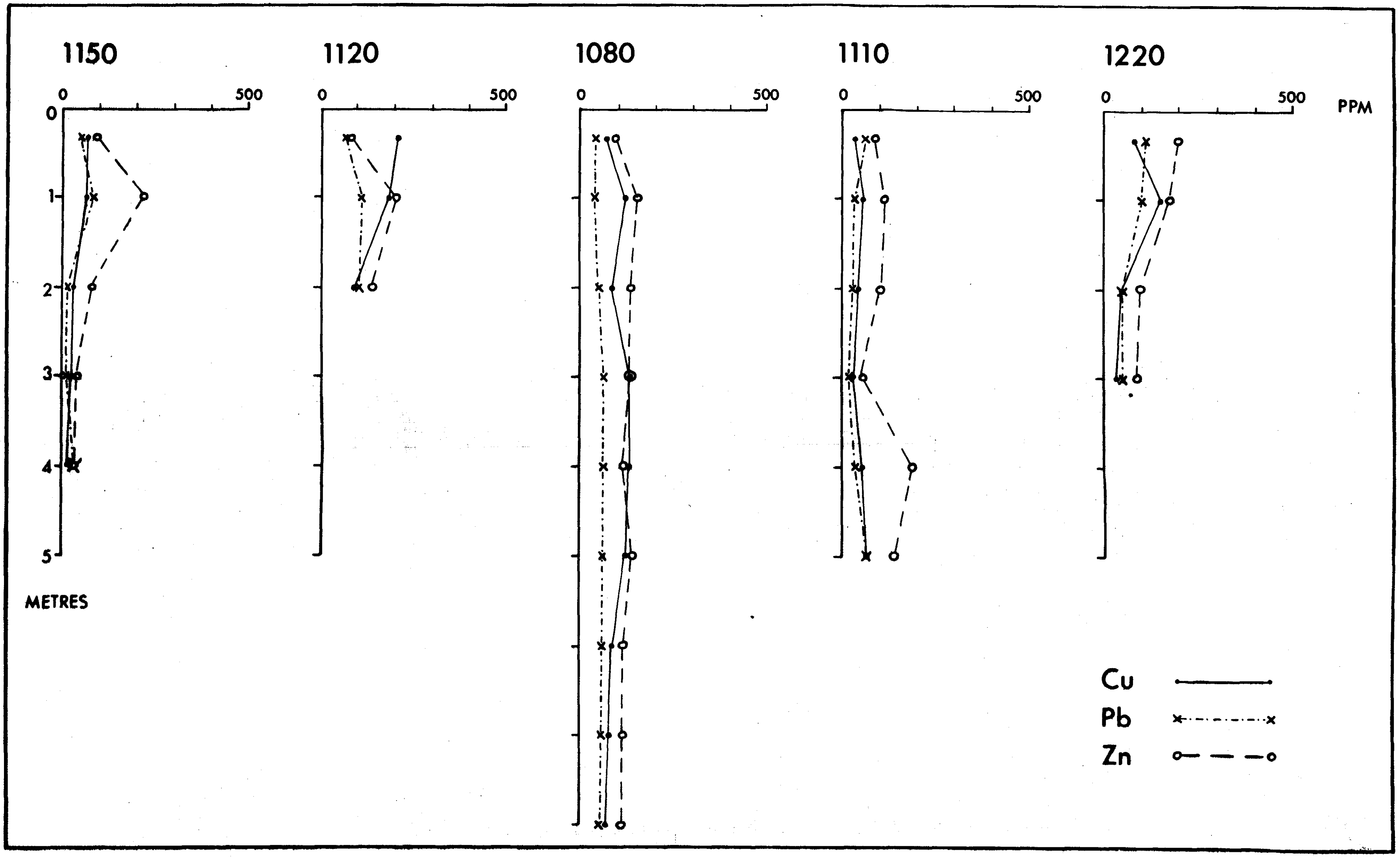

Fig. 20 Cu, Pb and Zn values in auger holes, Longlands

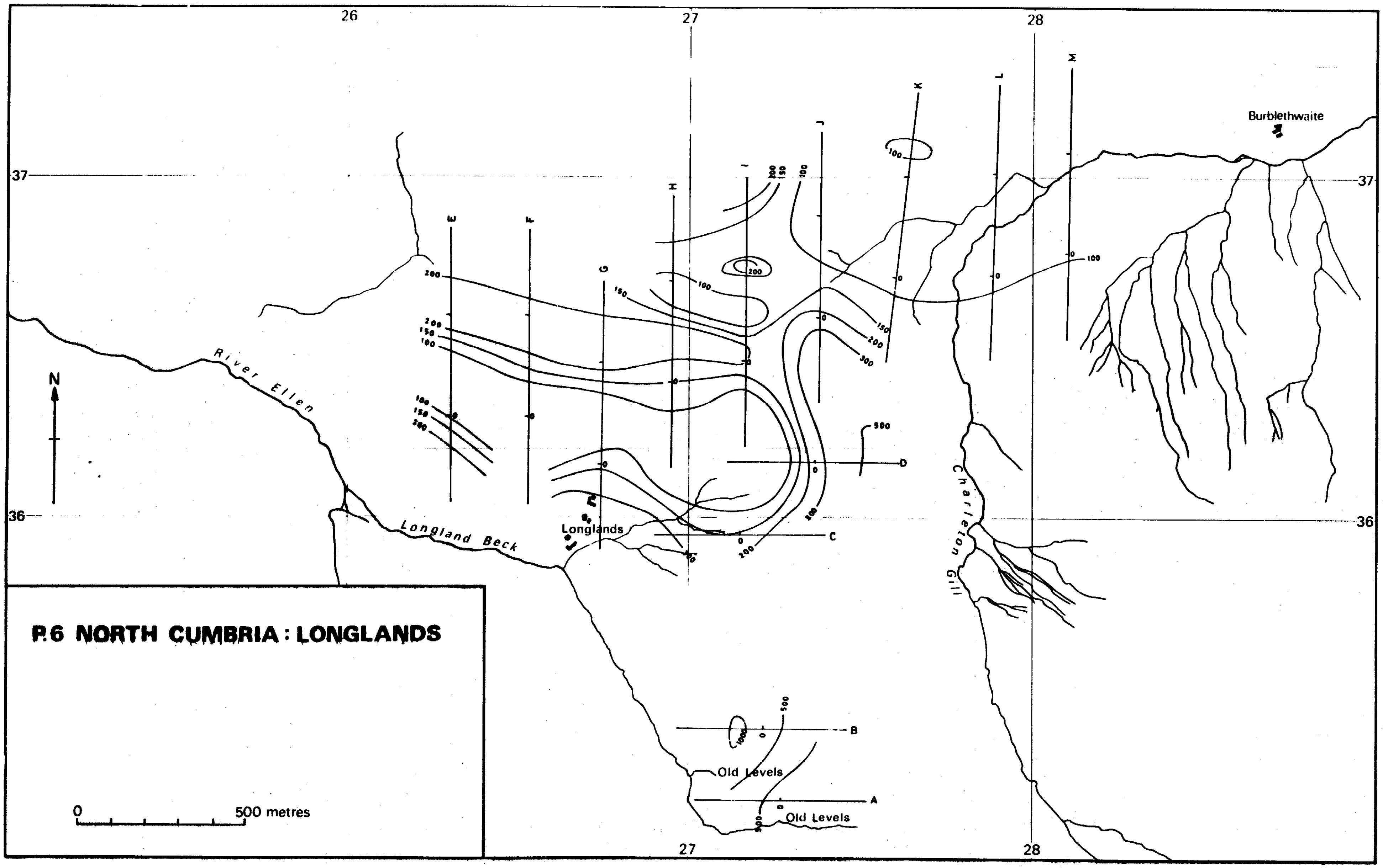

Fig. 21 Apparent resistivities in ohm metres at n - 4, Longlands

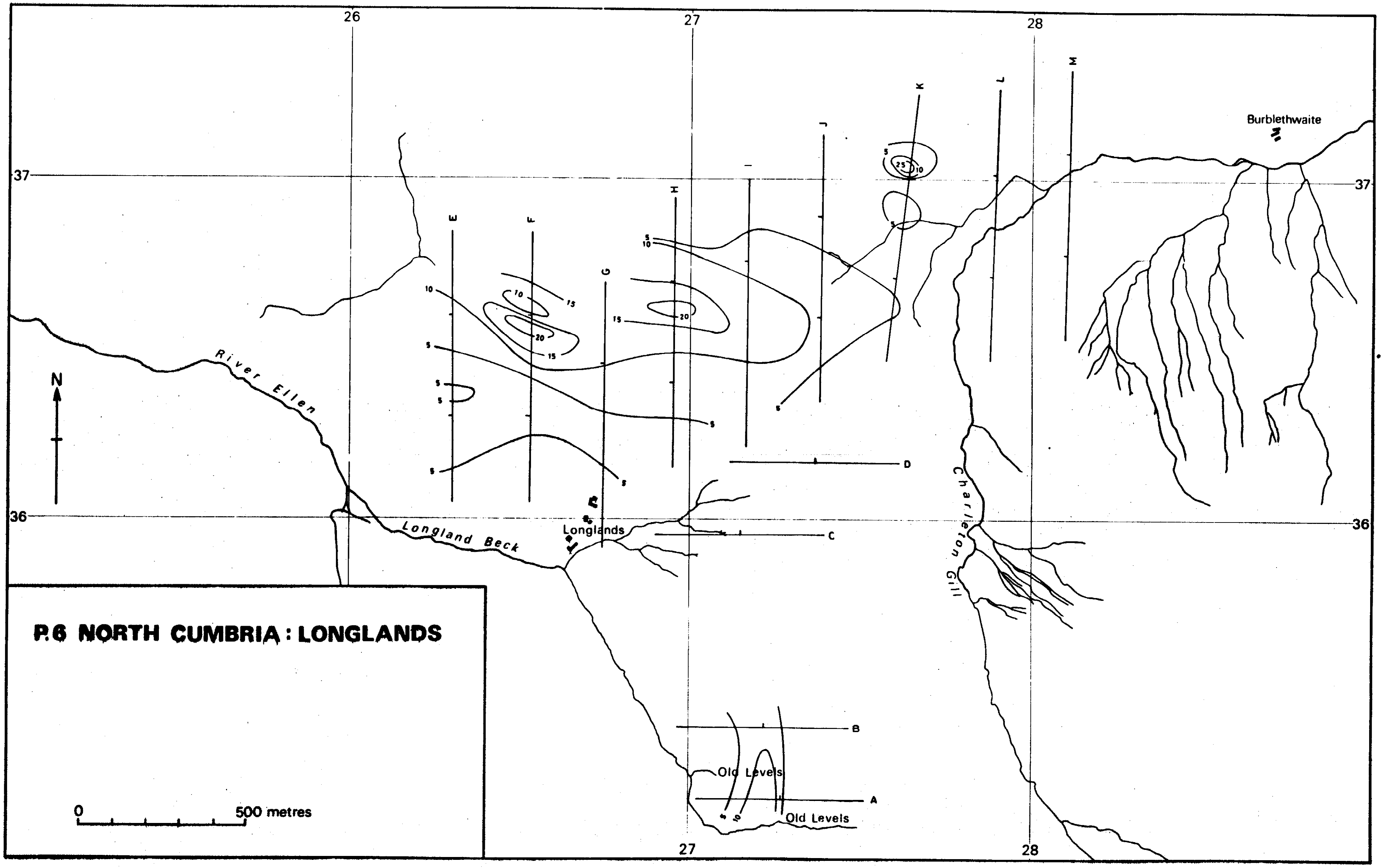

Fig. 22. Chargeabilities in milliseconds at n = 4, Longlands