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Mineralization of the stainmore depression and northern part of the askrigg block

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MINERALIZATION OF THE STAINMORE DEPRESSION

AND NORTHERN PART OF THE ASKRIGG BLOCK

ANDREW TERRY SMALL, B.Sc., (Dunelm), of GREY COLLEGE

Abstract: Pb - Zn - Cu - F - Ba mineralization occurs in Carboniferous Strata in veins and associated replacement flats. Veins are most productive when of small displacement, and in thick limestones and cherts. Mineralization is especially rich near to the horizon of the Main Limestone. Faulting and therefore vein formation is controlled by basement structure especially the Stockdale Hinge Line. Bedded cherts around the eastern part of the Stockdale Line have increased competant-reactive strata thicknesses and therefore the number of productive veins. Spatial variations of mineral occurrence have been elucidated and four zones set up to describe them:- Q Zone, quartz + chalcopyrite; F Zone, fluorite ± barite + galena ± chalcopyrite ± sphalerite ± witherite; P Zone, galena ± sphalerite ± barite ± calcite; C Zone, copper minerals ± galena ± barite ± calcite. Parageneses etc. suggest that the Q Zone is proximal and the C Zone distal to the source. This is supported by the spatial variations of yttrium in fluorite and antimony and silver in galena. Fluid inclusion homogenization temperatures are close to 100° C in the F Zone. Leachates of quartz, fluorite, sphalerite and barite show a systematic increase of Na/K ratio towards the north and east. Very low ratios are found suggesting an evaporitic source of solutions. Primary zonations are thought to be due to a proximity mechanism, although a small contribution is possible from mixing and heterogeneous source mechanisms. Recent oxidation has affected many deposits on the watersheds producing baritic gossans with lead ore, and secondary enrichment of copper mineralization in the C Zone is thought to be Permian. The zonal pattern, trace element studies etc. may prove useful in exploration and development when conditions are suitable for reopening the orefield.

PLATE 1

MINERALIZATION OF THE STAINMORE DEPRESSION

AND NORTHERN PART OF THE ASKRIGG BLOCK

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A thesis presented for the degree of Ph.D. at the

University of Durham, May 1977.

Frontispiece, Plate 1: Photomicrograph of fluorite,
(pale with few inclusions) associated with barite
(plates dark with many small inclusions). 0257, Clouds.

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"THE ORE IS WHERE THEY'VE LEFT IT." -The Author. 1977.

PREFACE.

This thesis has been compiled with tables, figures
and plates at the end of each relevent chapter and
in that order, so that the text is interupted as little
as possible. Section A is the main text, with
Sections B,C, and D for reference rather than for
straight reading.

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ACKNOWLEDGEMENTS

SECTION

A

INTRODUCTICN

In the Stainmore Depression and northern part of the Askrigg

Block, mineralization has been exploited on a large scale in parts of

Swaledale, Arkengarthdale and Wensleydale. Exploitation elsewhere in

the area has been on a smaller scale. This concentration of mineral

deposits is readily seen in Figure 1.1, which shows the production

recorded in Hunt's mineral statistics (1860-1881), the location of smelt

mills recorded in Raistrick (1975), and the mineral veins. Although

mineralization occurs in Cumbria, and Durham County, the high production

of the North Yorkshire Dales makes the name "North Yorkshire Orefield"

a suitable title for the mineralized area studied. This mineralization

is connected to the north with the Alston Orefield, and to the south

with the "Craven Orefield" centred in Wharfdale and Nidderdale.

In the North Yorkshire Orefield, mining has concentrated upon

lead ore, although a little copper and zinc, and especially in more

recent times quantities of barite, witherite and fluorite, have also

been produced. The silver content of the lead ores has been so low in

many cases (less than 2 oz./ton (60 ppm)) that it was often not extracted

and, when it was, seldom approached the maximum tenor of 10 oz./ton

($\cong$ 300 ppm). Mining began probably before the Romans arrived in Britain,

although the first real evidence is from Roman times (see Raistrick 1975).

The association of lead ore with faults and certain limestone beds may

have been recognized from the earliest times, but it is difficult to

know whether early exploration made use of such information or whether

it relied more heavily upon devining and surface evidence of lead veins.

Certainly with Phillips' account of the geology of Yorkshire (1836),

the relationship of orebodies to particular wallrocks was established,

although it was with Bradley's account of the Swaledale veins (1862)

that the matter of productivity, horizon and fault throw was fully

examined.

The geological survey of the Pennines in the second half of the 19th century produced a clear account of vein locations and to a lesser extent the mineral distributions. The important memoirs for Mallerstang (Dakyns et al, 1891) and Ingleborough (Dakyns et al, 1890) give accounts of the mineral occurrences, and in the Mallerstang memoir, the variation of horizon, ore and gangue minerals was noted from district to district, although the picture for the whole orefield was not published.

Mining activity waned considerably by the late 19th century, in part because of competition from cheap imported ore, and it was not until the geological survey had reinvestigated the Swaledale area during World War I that any further information was published. Carruthers and Strahan (1923) note that in Swaledale, veins productive around the Main Limestone were unproductive in the lower horizons, which were productive in Wensleydale. This is not entirely due to lack of trials, because after Bradley's exhortation to try the lower horizons (1862), some levels, for instance at Fell End, were driven, but were not successful. Deep horizons were productive at Gunnerside Gill, however, mineralization is restricted to beds near the Main Limestone over most of the Stainmore Trough area, except for the Dent Line. Wilson et al (1922) give an account of the barite and witherite resources in the North Yorkshire Orefield, which after more survey activity in World War II was followed up by reports upon barium resources (Dunham and Dines 1945), and fluorite resources (Dunham 1952). The integrated account of the Northern Pennines Orefield (Alston, North Yorkshire and Craven), north of Stainmore (Dunham 1948) has a valuable documentation of available information on the deposits of the northern part of the Stainmore Trough, and connects them with the well established mineral zone scheme of the Alston Orefield.

In recent years the relationship of mineralization to sub-carboniferous basement "highs" has been discussed (Bott, 1967, Dunham, 1967) and in Eire

very large deposits of sulphides have been found in association with
the downthrown side of large faults (Morrissey et al 1971). Dunham's
(1959) account of epigenetic mineralization in Yorkshire is a comprehen-
sive contribution, which especially in its revised form in 1974 contains
a synthesis of the known facts and a discussion of the origins and
controls of this mineralization.

With the Irish discoveries in mind, this Ph.D project was begun
in 1972 with the aim of discovering and understanding the relationships
of Pennine mineralization to Carboniferous hinge lines (Bott 1967).
The northern part of the Askrigg Block and Stainmore Trough was the
centre of the study, partly because little has been published regarding
the copper mineralization sporadically worked in the area, and partly
because mineralization sits astride the Stockdale Hinge Line rather than
to one side of it.

The project undertaken involved the collation of reported mineral
occurrences, a field sampling and investigation program, a laboratory
investigation of collected material and an investigation of the struc-
tural and stratigraphic controls of the mineralization. A regional
approach was developed, which was suited to the project; because of
the dangerous condition of the long abandoned workings, and the need to
investigate large scale controls. This regional approach makes it
difficult to deal with all aspects to the same depth and so the field
investigation concentrated on establishing the mineral assemblages and
collecting samples, whilst the laboratory investigation concentrated on
the trace element studies and leaching experiments. Structural and
stratigraphic investigations were largely restricted to qualitative
field observations, collation of data from available maps, papers and
theses, and, of course, drawing inferences from this information.

The acquisition of required technical laboratory skills was some-
what time-consuming and although X-Ray fluorescence analysis, electron

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microprobe analysis, fluid inclusion thermometry and computer programming were attempted it was necessary, from the time factor, to concentrate most effort into the X.R.F. analysis and computer programming.

When this Ph.D project commenced there were already ongoing projects by the Institude of Geological Sciences (prospecting for new deposits), by Dr. F. W. Smith at Durham (investigation of the geochemistry of fluorite mineralization), and by Dr. P. Rodgers at Leicester (investigation of fluid inclusions in the Pennine Orefields). The existence of these other studies had to be taken into account when deciding which aspects were to receive most attention.

This thesis is organized such that the first section (A) deals with the collected information and its interpretation, whilst section B deals with data associated with each collecting area in turn, and section C consists of appendices. A copy of a proposed publication submitted to the Institution of Mining and Metallurgy is placed in section C, and gives an account of zonation and its explanations.

FIGURE 1.1.   PRODUCTION, SMELT MILLS(□) & VEINS

LEAD PRODUCTION (RADIUS)
50,000t
40,000t
30,000t
20,000t
10,000t
0t
2,500 > ✕

0 1 2 3 4 5 KM

▲ BARNARD CASTLE

✕ RICHMOND

KIRKBY STEPHEN ✕
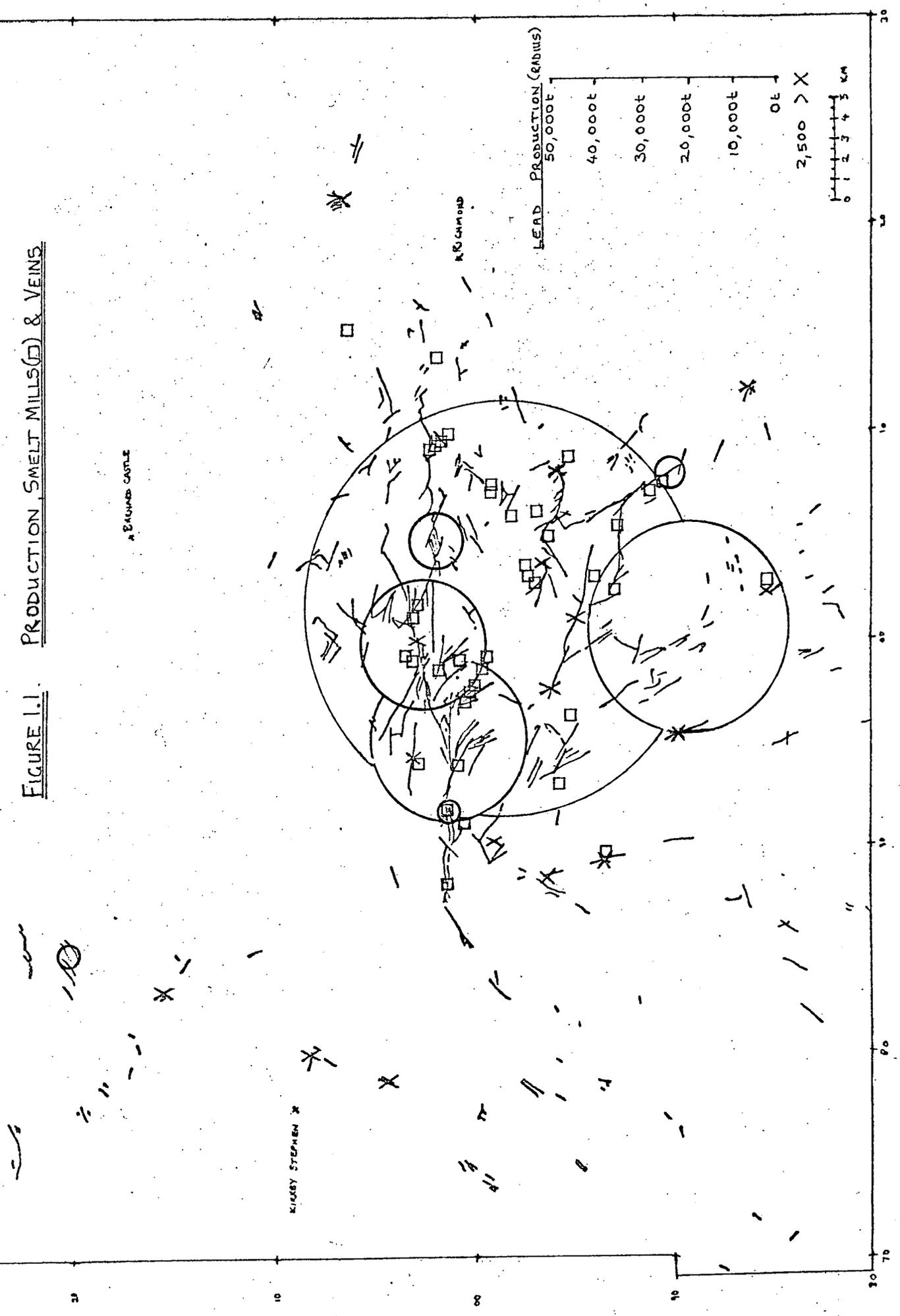
Plate 2

(a) Looking down the flue to the Old (lower) Marrick

Smelt Mill.

(b) Whim shaft at Hurst.

(c) The New (higher) Marrick Smelt Mill.

Plate 3

(a) Stodart Hush, Arkengarthdale.

(b) Inside part of Hungrey Hushes, Arkengarthdale.

(c) Large shaft tips, Arkengarthdale.

Photographs taken by Mrs. J. Small
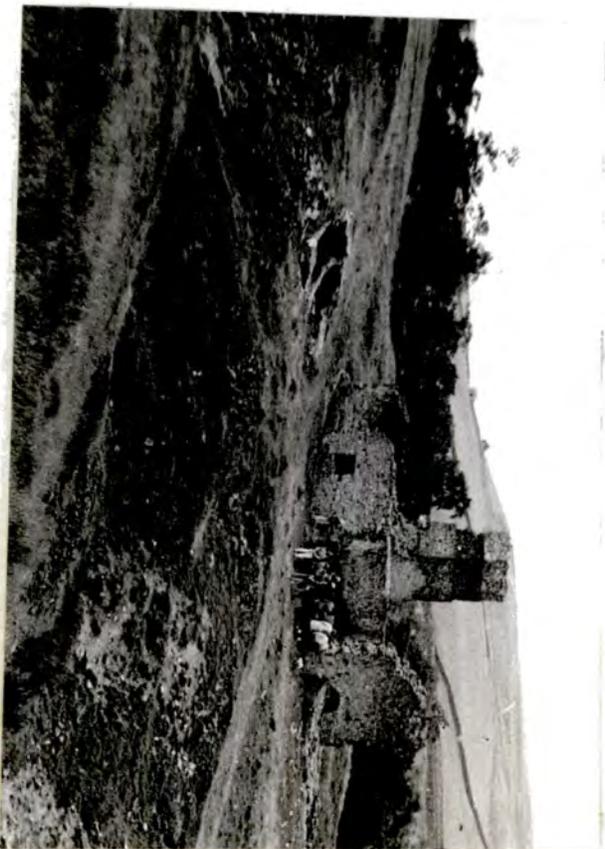
PLATE 2

PLATE 3

STRUCTURE

INTRODUCTION

The north of England is divided into a series of positive structural blocks separated by negative troughs or sedimentary basins. These structural features were initiated during the Devonian with the emplacement of low density granitic rocks below the block regions. Since the Devonian they have tended to rise relative to the adjacent troughs and even today the blocks are the elevated regions of the Pennine fell-country.

The Alston Block, mainly in County Durham, but extending into Cumbria (fig. 2.1) was first described by Trotter and Hollingworth (1928) and the Askrigg Block, in North Yorkshire, by Hudson (1938). These blocks are separated by the Stainmore Trough, an east-west region of lower ground between the Pennine uplands. To the west the Lake District block is a high upland region, of partly domal form, rimmed by outwardly thickening sediments in basins such as the Vale of Eden Trough (fig. 1).

The area of mineralization studied in this thesis, the North Yorkshire Orefield, is mostly contained within the Stainmore Trough. In the south it spreads into the northern part of the Askrigg Block, and the margin of the Alston Block forms the boundary to the north. The Dent Line of faulting and folding is the western boundary, and in the east the mineralized region ends with the Permian rocks overlying the mineralized Carboniferous strata. The general structural features of the region are shown on figure (2.1)

ALSTON BLOCK

A gravity survey over the Alston Block proved a strong negative anomaly over the region and a subsurface granite was suggested (Bott and Masson-Smith, 1957) to explain it. The subsurface granite was later

proved in the Rookhope borehole lying immediately below Lower Carbon-
iferous (Visean) strata (Dunham et al, 1965). The block was rapidly
eroded during the Devonian to unroof the Weardale granite before the
region was covered by Carboniferous sediments. During the early part
of the Lower Carboniferous the Alston Block was an island standing out
of the Carboniferous shelf sea. The island was gradually covered by
the sea as thick marine sediments were laid down in the adjacent
Stainmore Trough; it was finally inundated during the Dibunophyllum D1
Zone (late middle Visean) when sediments were laid down throughout the
block and trough region. After the Dinantian, Namurian and Westphalian
sediments were probably laid down over the Alston Block, but erosion has
removed much of this sequence from the western part of the region.
Mineralization of the Carboniferous sequence of the Alston Block started
during the late Carboniferous and continued for some 100 My according
to Dunham et al (1968). Lead-fluorite-barite mineralization is developed
with a striking zonal arrangement about subsurface granite cupolas
(Dunham, 1934, 1948) . . that are clearly the focus of mineralizing
solutions.

ASKRIGG BLOCK

The basement of geology of the Askrigg Block has been determined
from the study of Lower Palaeozoic strata in the inliers of Ingleborough
and Austwick and in the Lake District. Further information was obtained
from surveys of gravity and magnetics over the area (Bott, 1967; Myers
and Wardell, 1967). The gravity showed a negative anomaly that indic-
ated a granite mass or similar low density body underlying the area
(Bott, 1967). The magnetics indicated a belt of magnetic rocks in the
south of the block region. A model of the basement was proposed by
Bott (ibid) from the combined interpretation of the two anomalies
(fig. 2.2). The proposed Wensleydale Granite was recently found in the

Raydale borehole and proves to be of a Devonian age similar to the Weardale Granite (Dunham, 1974). The basement of the Askrigg Block is thus composed of the Wensleydale Granite overlain thickly in parts by Lower Palaeozoic rocks believed to be greywackes and slates. There is also a strongly magnetic formation in the basement on the south side of the granite that may be Lower Palaeozoic volcanic rocks or possibly plutonic rocks (Bott, 1967).

The basement rocks exposed on the block margins and Howgill Fells are quite strongly deformed and possess cleavage and fold structures trending WNW-ESE. This direction is parallel to the north and south sides of the granite intrusion and also the northern and southern bound-aries of the block.

Above the basement there are approximately 0.5 km of sedimentary rocks of Carboniferous age. They are only mildly deformed and dip gently eastward and more gently northwards and westwards from a high south and west of Askrigg (fig. 2.3). If the approximate effect of the dip of the Permian unconformity to the east is removed the Carboniferous rocks of the block dip gently west and more gently northwards from a broad high in the east of the block.

The boundaries of the Askrigg block are:

1.   The Craven Line: The North and Middle Craven Faults separate the Askrigg Block from the Bowland Trough to the south. They separate quite different facies in the Lower Carboniferous.

2.   The Dent Line: The large Dent Fault and its accompanying strong fold separate the Askrigg Block from the Lower Palaeozoic rocks of the Lake District Block to the west.

3.   The Stockdale Line: This is marked by the Stockdale Vein, an unmineralized fault throwing down northwards up to 183 m (600'). It is perhaps continued eastwards by the Old Stork Vein a rather lesser feature in terms of throw. This boundary is vague compared with the Dent and Craven Lines.

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The gravity map (fig. 2.2) reveals a basement feature which runs WNW-ESE. It is produced by the edge of the granite intrusion, but there are other reasons such as change in structural style to suspect that the boundary of the block follows this line even in the east, where no surface feature of reasonable magnitude follows the structure.

One reason for the vagueness of the boundary structure is the folding and faulting of the Stainmore Trough, which in the east have produced the high of the Middleton Tyas-Slightholme anticline, which rises above the neighbouring part of the Askrigg Block, thus obscuring the block and trough relationships.

The structure here too has been called the Stockdale Monocline, but there is only scanty evidence of this sort of structure, indeed in places the rocks are southward dipping immediately on the north side of the Stockdale Vein (fig. 2.4).

STAINMORE TROUGH

A non-magnetic basement is developed below the Stainmore Trough with no granite intrusion. The basement is probably composed of grey-wackes, slates etc. like the rocks found in the nearby Howgill Fells. It is overlain by approximately 2 km of Carboniferous rocks suggested from the gravity and magnetic surveys, and confirmed by small events seismic work (Bott, 1967; Swinburn, 1975).

Stratigraphic evidence of thickening in the trough is found by comparing the strata of the Ravenstonedale area with the Askrigg Block (Turner, 1927) and strata on both sides of the Swindale Beck fault on Roman Fell (Burgess and Harrison, 1967).

Structures in the trough are the large Middleton Tyas-Slightholme anticline and Cotherstone syncline. Both structures plunge to the east, however this plunge can be removed by subtracting the effect of the late Tertiary tilting (Reading, 1957; Wells, 1958). When this tilt is

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removed the structural high both of the Stainmore Trough and the whole
of the area studied occurs near Gilling a culmination of the Middleton
Tyas-Slightholme anticline. Other structures present in the Stainmore
Trough are the Stowgill Anticline, a complex fold-fault structure
(Turner, 1935; Rowell and Scanlon, 1957), shallow periclines north of
the Stockdale Vein, and a deep basin of Namurian and Coal Measures down-
tilted against the Butterknowle-Fault. In the N.E. Basin stratum contours
on the Main Limestone (Dunham, 1967) are not reliable because of
uncertainty on the thickness of the Namurian rocks in the area.

The thickness of sediments in the trough suggested from gravity
and seismic evidence show a thickness of around 2 km for the whole trough,
with apparently no thinning under the Middleton Tyas-Slightholme Anticline.
The evidence is unfortunately not conclusive, because of the experimental
error of the results so far obtained. This may have a significant mean-
ing in the origin of the Middleton Tyas-Slightholme structure, and the
possible occurence of evaporites in the Stainmore Trough. Salt
pseudomorphs are known in the basal Dinantian of Ravenstonedale and the
possibility of thick evaporites at this horizon in the eastern part of
the Stainmore Trough is clearly indicated. (Johnson, personal commun-
ication).

There is evidence of Lower Carboniferous evaporites from deep
boreholes in the Widmerpool and Edale Gulfs of the East Midlands
(Llewellyn & Stabbins, 1970; Dunham,K.C,1973). These are present in the lowest
rocks of the Carboniferous secuence and the palaeogeographical evidence
for the North of England suggests that similar rocks could be present
in the Stainmore Trough. The effect of Carboniferous evaporites on the
structure could be marked and is discussed later.

The Stainmore Trough is bounded by:-

1.   The Stockdale Line: Already discussed (P.7)

2.   The Dent Line: The Dent fault - echelon and folds separate

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the Stainmore Trough from the Vale of Eden Trough.

3.   The Lunedale-Butterknowle Line: Faults running east from
Roman Fell on a line often with substantial downthrow south.
They separate the Stainmore Trough from the Alston Block.   In
the east away from the effect of the Weardale Granite a gravity
anomaly due to change in depth to the basement is present and can
be used to model the basement change.

4.   The eastern boundary is not really known but for the
purposes of this thesis lies at the position of the Permian
unconformity (fig. 2.1).

FOLDING

There are strong folds along the Dent Line and elsewhere rather
more gentle structures some of them of large dimensions.   They can be
split into two groups:

1.   The Dent and associated folds:-

Stream sections through the folds of the Dent Line have been drawn
in the Mallerstang Memoir (Dakyns et al, 1891) and Turner (1935).   Where
abutting the Askrigg Block very tight folds are developed to the east
of the main Dent Fault.   In the Stainmore Trough there is a broader
though still fairly tight fold on the west of the Main Dent Fault.   Here,
however, the main fault throws down to the west into the Vale of Eden
Trough.   This is a post-Permian reversal of the original easterly down-
throw. (Turner, 1935).   In the south of the trough, where the two Dent
faults change over in their importance, there is an overturned mono-
cline, and further north a monocline is present along the east side of
the Dent Fault for most of its length.   In the southwest of the
Stainmore Trough there are several anticlines and synclines which are
roughly parallel to the Dent Line.   Similar though very gentle and small
amplitude structures are present on the Askrigg Block.   All the folds

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in this group were probably formed by a compression which has a WNW-ESE component (Turner, 1935). Similar structures in other parts of the North of England are the Hutton Monocline and Knotts Anticline (Moseley, 1972), the Silverdale Disturbance (Moseley, 1972), and the Burtreeford Disturbance (Dunham, 1948).

2. The Middleton Tyas-Slightholme Anticline and associated folds:-

These folds are broadly east-west in direction, and two are large and important, i.e. the Cotherstone Syncline, and the Middleton Tyas-Slightholme Anticline. They are both assymetric with their steepest limb on the block side of the structure. They have amplitudes of the order of 300 m (1000'). Smaller structures include the low amplitude periclines just north of the Stockdale Vein, the gentle elongate dome on the north side of the Stainmore Summit Fault, and a small anticline adjacent to the Lunedale Fault. The complex fault-fold Stowgill Structure is almost a north facing monocline for some parts of its length and is relatively steeply dipping for the Stainmore Trough area. Its general effect is to produce an anticline like structure.

It would have been difficult to produce these east-west striking folds directly from the same compression which formed the Dent Structures. A more north-south directed compression could have formed them, but presumably at some different time to the Dent Line. A north-south compression has been invoked by Reading (1957), and Wells (1958), but such a compression has not been thought important in areas to the south such as the Bowland Trough, although there are some minor east-west folds on the east side of the Derbyshire Dome.

Both the Middleton Tyas-Slightholme Anticline and the Cotherstone Syncline are gentle though large structures and could have been produced by several different mechanisms.

One perhaps unlikely method is the uneven sinking of the basement in the Stainmore Trough. This mechanism would presumably have difficulty

in explaining the way the Middleton Tyas-Slightholme Anticline rises
above the levels of the Alston and Askrigg Blocks.

Another suggestion for the origin is that evaporites, or perhaps
just gypsiferous shales have responded to the gently northerly down-
tilting of the Askrigg Block and a yoked Stainmore Trough to give a flow
movement of material from the north side of the Trough to the south.
This movement would cause the assymetric anticline and syncline to form
(fig. 2.5). It could explain why the Middleton Tyas-Slightholme Anticline
rises above the Blocks, and its continued minor activity into the Permian.
The complicated faulting in the south of the Stainmore Trough could be
part of the reason why the Middleton Tyas-Slightholme Anticline is not
represented in the west of the Trough. Another point on this matter
is that since the Ravenstonedale Gulf was probably closed in the west
and 'open' in the east and probably deeper in the east, there would
have been more chance of the structure developing in the east of the
area. The diapiric production of structures must of course remain
speculative for the moment.

FAULTING

The great majority of ore deposits worked and known are in faults
or are connected with faults. It is for this reason that faulting is
a particularly important aspect of the structure.

If a fault is not a perfectly straight plane, which is the usual
case, movements on it will tend to open up fissures, that can be miner-
alized by hydrothermal solutions. In Yoredale rocks faults tend to be
refracted in the very different rock types present. Normal vertical
movements on the faults tend to produce open fractures in the hard beds,
such as the limestones and sandstones, and sealed off fractures in the
shales (fig. 2.6). Horizontal movements on faults will also cause open
fractures by a similar method.

The faults of the area studied form patterns both in direction, density and also magnitude of throw. Unfortunately over such a large area many of the faults are interpolated and whilst it is possible to say that many faults are normal, some are reverse for instance the North Arngill Fault (Dakyns et al 1891), and yet others seem to have vertical planes, for instance two veins near the Friarfold Vein (Phillips, 1836, p.111), and perhaps most can not be distinguished.

The association of mineralization with the hard beds indicates that most veins are normal rather than reversed since a reverse throw opens fissures in the "soft" beds, however, the lateral wrench movements can not be considered unimportant in opening fractures even if difficult to distinguish in a general study. Lateral movements would be expected to leave open fissures in hard and soft in principal, but whenever possible soft beds such as shale will tend to seal up any fissures produced in them or at least break up to form "dirty" fissures.

Without much information on the nature of many faults interpretation of the patterns that can be observed must be tentative, but is interesting and could be checked by detailed studies in small areas.

Faults occur in almost all parts of the area, but are rather scarcer in two areas than elsewhere (fig. 2.7). The Askrigg Block has low density of faults and they are nearly all of small throw, but variable length. The exposure in this area is good enough to detect most faults easily especially because of the near horizontal benches which follow the "hard" horizons around the valley sides.

The north side of the Middleton Tyas-Slightholme Anticline up to the Staindrop Fault has relatively little faulting and yet again what faulting there is has small magnitude of throw. Here, however, the exposure is not very good with thick drift in parts, but the low density may still be real, at least in part, since the Main Limestone is well exposed and has a low density of faulting in it.

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A high density of faulting occurs in the southern half of the Stainmore Trough and may be exaggerated by good exposure and mining activity. Similar high density occurs in the North East Basin where coal mining and exploration has occurred. Other parts of the Stainmore Trough show moderate fault densities, and the trough as a whole has faults of small to large throw.

Faults occur in every direction in some part of the area, but there are patterns which are simple in some places and complex in others. In order to help overcome the problem of subjectivity, fault direction length statistics were collected for each 5 km square, in the southern two-thirds of the area. For standardization they were all collected from the 1" geological survey maps. They have been reproduced in the form of a compound rose diagram (fig. 2.6). Unfortunately even after using this method it is necessary to subjectively analyse the patterns because the smoothing effect of the above statistical approach makes it difficult to appreciate the rather subtle changes of fault pattern.

The Askrigg Block has a fairly simple fault pattern of mostly normal faults. The direction north east-south west occurs in the western area. It is roughly parallel to the Dent Line. Moving eastwards the direction becomes more north-south then north north west-south south east. This pattern could be produced by gently arching the basement, perhaps due to the east-west compression.

Moving northwards towards the Stockdale Line there are faults connected to the pattern of the Trough and Stockdale Line. They mostly trend west north west-east south east.

In the southern part of the Trough and along the Stockdale Line area the commonest direction of faults is west north west-east south east to north west-south east. They are very often long and are generally longer when in a west north west-east south east direction. Some of them

veer almost east-west indeed they seldom proceed uninterruptedly in one direction for more than a few miles at most. They form complex interconnecting patterns (fig. 2.9) which are similar to the wrench fault systems of North Derbyshire where it is thought that extension of fractures by wrenching has produced curved extensions and interconnections, (Firman, 1975). The system of faults in this region would also appear to be a candidate for this process.

The Stockdale Line itself perhaps runs more east-west than west north west-east south east, but only occasionally are faults observed in the east-west direction. The Stockdale Vein runs in this direction, but has extensions in the west which curve away towards the west north west, and in the Gunnerside area a strange kink occurs (fig. 2.10).

Faults with a west south west-east north east direction occur in the southern half of the Stainmore Trough, but are not so common and are generally shorter in length than the west north west-east south east faults. These faults also seem to twist around to the east-west direction at times, but their short length often makes this more difficult to establish. Many of the rich veins betwen Keld and Hurst are in this set of faults. They are often cut by the west north west-east south east faults, which appear to move them laterally, for instance between Swinner Gill and Lownathwaite the unproductive Hurrace Vein displaces the productive veins of this set. Bradley (1862) found that the east-west (west south west-east north east) set of faults have generally smaller throw than the less productive north west-south east (west north west-east south east) set, which he termed cross veins. The eastern part of the Middleton Tyas-Slightholme Anticline has a dominance of east north east-west south west faults many carrying mineralizations. This area appears to be one of reduced density of west north west-east south east faults. Some of the faults in this area such as the Feldom fault twist

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from north east-south west around to an east-west direction and perhaps even further into the north west-south east direction.

Near the Dent Line the west north west-east south east faults are often accompanied by other faults striking north west-south east and more striking north north west-south south east within a few kilometres of the Dent Fault. The age or origin of these is unknown but they certainly reflect the presence of the Dent Line.

In the northern half of the Stainmore Trough faults are com only east north east-west south west to east-west and are roughly parallel to the Lunedale-Butterknowle Line. These faults are often fairly long. In the north east basin there are also north west-south east and west north west-east south east faults, some for instance the Staindrop Fault are long.

The faulting of the Stainmore Trough seldom shows systematic sense of throw, that is it is unusual to find faults in a particular direction and area to have all down throws on the same side, however, some of the west north west-east south east faults which run along the south west side of the Middleton Tyas-Slightholme have systematic throw. They throw down to the north in the west and down to the south in the east. This reversal of throw is considered to be evidence of strike slip movement on these faults (Wells, 1958).

Folding adjacent to faults is quite an important feature in places. The Dent Fault and its accompanying monocline is the most important fault where this occurs. It constitutes some of the evidence for reversal of throw in the Brough district, since the present downthrow is down to the west, whilst the monocline faces east. The Stowgill Structure is more gentle, but shows a similar possible reversal of throw, although in this case the fault is west north west-east south east. The Stockdale Vein which is also in this general direction shows a similar reversal since

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it throws down to the north, but has a dip towards the fault on the
north side (Rowell & Scanlon, 1957). A more spectacular case is a fault
encountered in the Hard Level where the rocks on both sides dipped away
from the fault (Phillips, 1836).

Faults with exceptionally large hade have been described by
De Rance (Dakyns et al, 1891). One occurs in Mossdale and is mineralized.

In places there is a strong suggestion of a conjugate set of wrench
faults in north west-south east directions. This set occurs mostly in
the southern part of the Stainmore Trough. In the south west of the
Stainmore Trough some gentle folds appear to show minor displacement of
their axes, when cut by west north west-east south east faults. This
supports a wrench origin due to an east-west compression, and fits in
with the production of the Dent Structure which is partly affected and
partly unaffected by the faulting of this conjugate set, suggesting some
sort of contemporaneity. More evidence in favour of lateral movements
comes from the change in sense of throw of the west north west-east south
east faults in the southside of the Middleton Tyas-Slightholme Anticline,
which has been suggested to have been produced by lateral movements of
faults cutting the anticline obliquely (Wells, 1958).

This perhaps implies the pre-existence of some sort of anticline,
or modification of folding by pre-existing fractures. This origin of
faulting by east-west compression has been postulated for faults in the
north west of England (Moseley, 1972). The mechanism postulated is that
the faults were initiated in the compressive stage, but were later
activated as normal faults which is the way most faults appear today.
An important contrast occurs between the Bowland Trough where a very
good conjugate set can be seen with north-west and north-east directions,
and the Stainmore Trough, where the conjugate set is not as clear. In
the Stainmore Trough it is possible that the conjugate set has been

* and east-west (sometimes south west - north east)

modified by pre-existing minor faults parallel to the Stockdale Line

and basement weakness to produce the more west north west and east north

east and even east-west directions.

Faulting produced by vertical movements of the basement must also

be present. The basement is approximately 1½ km lower in the Trough

than on the Block, however, examination of stratum contours shows the

difference between the block and trough is not very great at the Main

Limestone horizon and even reversed where the Middleton Tyas-Slightholme

Anticline has interfered with the boundary. Basement movements began

before the growth of later conjugate wrench faults, the pattern of which

must have been controlled by the pre-existing faults. Basement movements

undoubtedly continued later than the east-west compression and three

sorts of vertical movement occurred:

1. Movements between the Alston and Askrigg Blocks and Stainmore

Trough. These began at least as early as the Tournasian and probably

continued intermittently at least into the late Namurian or early

Westphalian and on a reduced scale up to the present day. It should be

noticed that there are few if any signs of continuation of the Stockdale

Line or Lunedale Lines to the west of the Dent Line, implying contemp-

oraneous movements on these basement faults.

2. Late Carboniferous-Lower Permian movements between the Lake District

Block and the Eastern Units along the Dent Line. The movements considered

here are those connected with the production of east facing Dent Monocline

and Faults and so in large part contemporary with the east-west compression.

The thrust and fold structures at this position could be produced by

vertical block movements (Sherbon Hills, 1963, p.209), although if the

other structures of northern England are taken into account a general east-

west compression would seem to be significant, and taken with the vertical

block movements adequate to produce all the structures of the Dent Line.

3.   Perno-Trias and Tertiery block movements connected with the North
Sea Graben etc. The formation of the Vale of Eden Trough by down
tilting of the north-east margins of the Lake District Block has reversed
the throw of the Dent fault in the Brough district, and no doubt caused
movements on other faults even if no new fractures were formed. This
crustal tension probably allowed the Whin Sill dolerite to rise up the
Burtreeford Disturbance on the Alston Block.

JOINTING

        Jointing is important in that it provides permeability in the
Limestones and occasionally joints are mineralized showing the passage
of mineralizing solutions. Studies of jointing in the Carboniferous
Limestone of this area and adjacent ones have been made by Wells (1958),
Reading (1957), Wager (1931), Phillips (1836), Moseley and Ahmed (1967),
Doughty (1968), and Dunham (1933).

        Jointing of the Middleton Tyas-Slightholme Anticline was found by
Wells (1958) to consist of a conjugate set at an acute angle (one 130^c -
135°, the other at 155° - 160°) and a more variable set at 90° to the
bisector of the other set (045° - 050°). The measurements were mostly
from the Main Limestone. Reading (1957) did not find the same pattern
in the Cotherstone Syncline where there was less exposure of beds with
such well developed constant jointing. The pattern here is variable,
but generally has a strong north-east trend, and an equally strong or
stronger set in the north-west quadrant. Phillips' (1836) results were
gathered over a very wide area but mostly from the Askrigg Block. They
show a maximum in a north north west direction and two small maxima in
the east and east north east. Wager (1931) found two sets of joints at
right angles in the Great Scar Limestone of the Askrigg Block. The
direction of the joint sets varied systematically and was attributed to
rotation of the sheer stresses near to the Craven Wrench faults. The

cause of rotation perhaps still holds good although the origin of the joint sets is probably different. Dunham (1933) found similar joint sets at right angles in Weardale.

Wells attributed joint directions and intensity to a roughly north west-south east compression and north east-south west tension and considered them to have formed earlier than the folding, which he considered to have resulted from a north-south compression. Joint directions seem to be partly independent of fault directions although not completely so (Wells, 1958). Bearing in mind the gentle structure of most of the area it is perhaps unlikely that many joints result from compressive stresses except along the Dent Folds. Some (especially orthogonal joints) most probably result from the release of elastic energy stored when the rocks were at greater depth, a mechanism proposed by Price (1966) and now commonly accepted as being important. The possibility that joint directions are different from faults may result from the modification of the original stress field by faulting brought about by it, leaving residual stresses lessened in the directions allowed by the faults.

HISTORY OF STRUCTURAL EVENTS

Since the subject is complicated an attempt at putting events in some sequence is useful but inevitably fraught with difficulty. The following sequence is suggested.

1. The formation of folds and cleavage in the Caledonian basement.

2. The formation of fault system and intrusion of granites, approx. 400 My.

3. The formation of fault blocks in the lower Carboniferous under tension.

4. Formation of faults in newly deposited Carboniferous due to differential movements between blocks and troughs, i.e. hinge belts.

5. Tilting of Askrigg Block and a partially yoked Stainmore Trough accompanied by the declining effect of the hinge belts. Perhaps also the initiation of the Stainmore Folds by evaporite movement.

6. East-west compression forming the Dent Folds and conjugate fault system and joints on the Dent Folds. This was accompanied by vertical movement of the Lake District Block relative to the eastern blocks. The compression may have caused the arching of the Askrigg and Alston Blocks and initiated the faulting on them.

7. The Whin Sill and dykes, approx. 295 My were intruded sometime during or just after the formation of the Burtreeford Disturbance by the east-west compression, and probably represent an east-west tension connected with the North Sea Graben.

8. The formation of folds with east-west trends by a north-south co pression or movements of evaporites, with continued movement on pre-existing faults and possibly the formation of new faults.

9. The whole area was probably uplifted and eroded during the previous two events and continued to be until the Permian basins formed and seas spread towards the area from the east. Most joints were probably formed during this period and movements on faults and the Middleton Tyas-Slightholme Anticline probably continued to rise in a minor way. This was probably the most favourable period for mineralization.

10. The area was tilted eastwards as this part of Europe was involved in the formation of the North Sea Graben and basin. Locally the Vale of Eden Trough formed and reversed the movements of some faults and movements on many no doubt continued in this long period of tension up to the present day. Wrench movements on the Alston Block Veins are associated with this tilting (Dunham, 1948).

STRUCTURE AND MINERALIZATION

Since mineralization is dominantly associated with faults these were the prime target of past prospectors. The association of good fissures with hard beds must have been noticed early on although the mechanism by which the association was produced may not have been appreciated until the nineteenth century. The best prospects were demonstrated by Bradley (1862) to lie on faults of small throw, which are unfortunately the most difficult to find from surface evidence. The presence of thick competent beds improves the prospect of good fractures and so the presence of the thick Richmond Chert Series must have had great importance in locating the rich part of the orefield in the central parts of Swaledale and limiting greatly its development in west parts. The sorts of fissures produced in Yoredale rocks are ribbon-like, and although they must inevitably be short relative to the dimension of the orefield they must have had importance in moving solutions laterally as well as vertically, which one could normally expect to dominate hydrothermal systems. In an orefield with such a complex intergrowth of faults of varying amplitude, and in a host rock of both vertical variability of rock type and lateral changes of thickness, it would be difficult if not impossible to construct the plumbing system of the orefield except locally. Looking at the area as it probably was at the time of mineralization, in the lower Permian, one can suggest that movements of solutions would be generally eastwards perhaps with minor flow southwards up onto the Askrigg Block and westwards for a short distance up to the Dent Line. The restriction of dense fracture systems to the edge of the Stainmore Trough has been of great importance in localizing the orefield and the dominant trends of west north west and east north east have no doubt been important in the easterly flow of mineralizing solutions.

In summary mineralization is found in fault fissures, and in joints and replacement flats associated with them and more rarely in

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stockworks due to the tectonism of the Dent Disturbance. The abundance and directions of fault fissures has been strongly affected by the presence of a stable granite bearing block and adjacent less stable basin. The attitude of the rocks of the area has determined the flow of the hydrothermal solutions in some degree, and their origin may lie in the Dent and Stockdale Basement fractures. The full understanding of any individual deposit and the exploration of deposits must rely heavily upon detailed investigation of structure for success.

SOUTHERN
UPLANDS
BLOCK

CHEVIOT

NORTHUMBERLAND TROUGH

VALE OF EDEN TROUGH

ALSTON BLOCK

LAKE
DISTRICT
BLOCK

STAINMORE TROUGH

ASKRIGG BLOCK

THICK
POST-CARBONIFEROUS
ACCUMULATIONS
OF
THE
NORTH SEA
BASIN
EDGE

N. LANCS.
BASIN
(PERMIAN)

BOWLAND TROUGH

CHESHIRE
BASIN
(PERMIAN)

DERBYSHIRE
DOME

WELSH
BLOCK
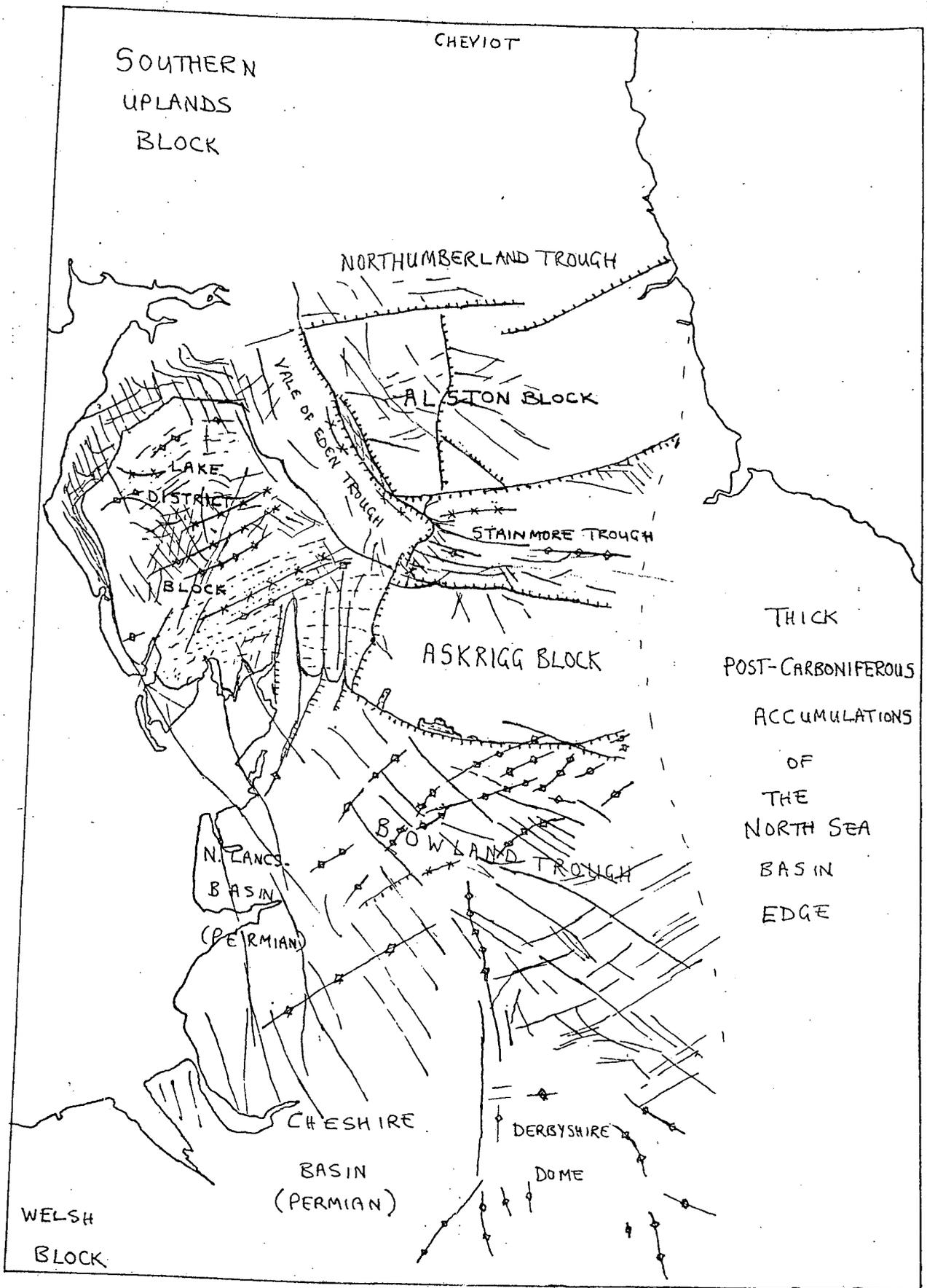
FIGURE 2.1 STRUCTURAL FEATURES OF NORTHERN ENGLAND

Based upon maps of the Geological Survey - Institute of Geological Sciences.

a, BOUGER ANOMALY MAP (in milligals)

b, MAGNETIC ANOMALY MAP (in Gamma)

c,

KEY

Permo-Trias Basin	▽ ▽ ▽ ▽ ▽ ▽ ▽ ▽	
Carboniferous Troughs	o o o o o o o o	
Undifferentiated		
Magnetic Basement	M M M M M	
Granite Cupola	c-c-c c-c c-c-c	
Magnetic Basement over granite	M l M l M l M l M	
Granite	l l l l l l l l	

d, GRAVITY MODEL

Assumed background

0·10 g/cm³

e, MAGNETIC MODEL

0·0009 cgs M

0·00025 cgs M

0·00045 cgs.

FIGURE 2.2   GEOPHYSICAL INTERPRETATION (redrawn from Bott 1967)

FIGURE 2.3 STRATUM CONTOURS ON THE MAIN LIMESTONE & MAJOR FAULTS

Based in part upon
Dunham 1974, Wells 1958,
Reading 1957, Rowell & Scanlon 1957.
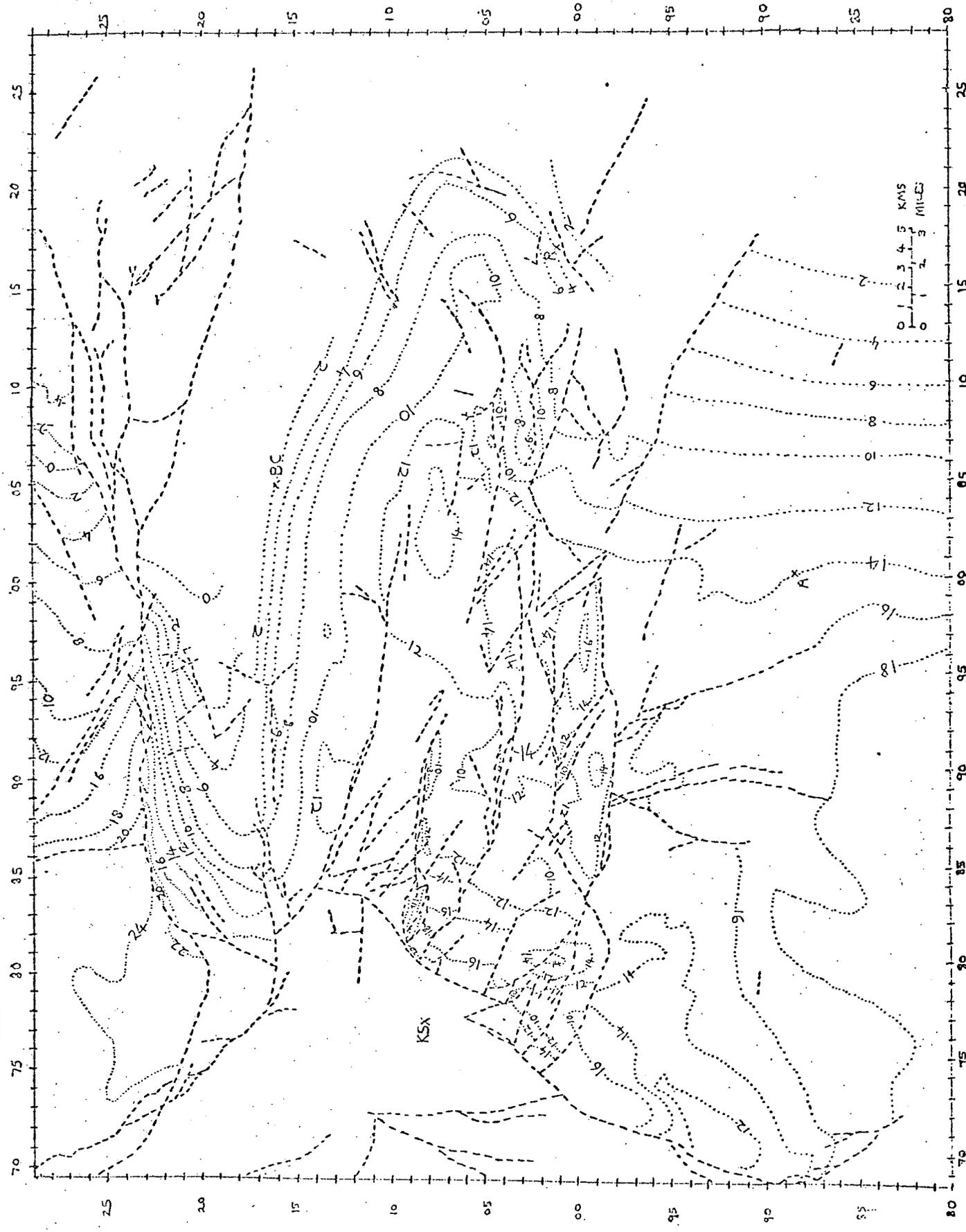
FIGURE 2.4 SECTIONS ACCROSS THE STOCKDALE VEIN

a, Section along 025° after C.T. Clough (in Dakyns et al 1891).

b, Sketch section of Stockdale Vein in Ivelet Beck. (Length ±100 m)
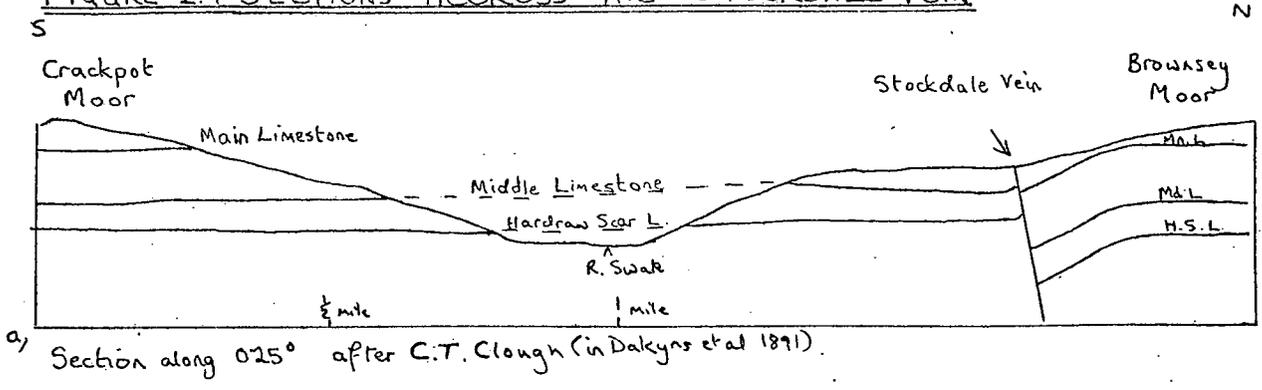
FIGURE 2.5 FORMATION OF THE MIDDLETON TYAS' ANTICLINE BY SALT MOVEMENT (SPECULATIVE)
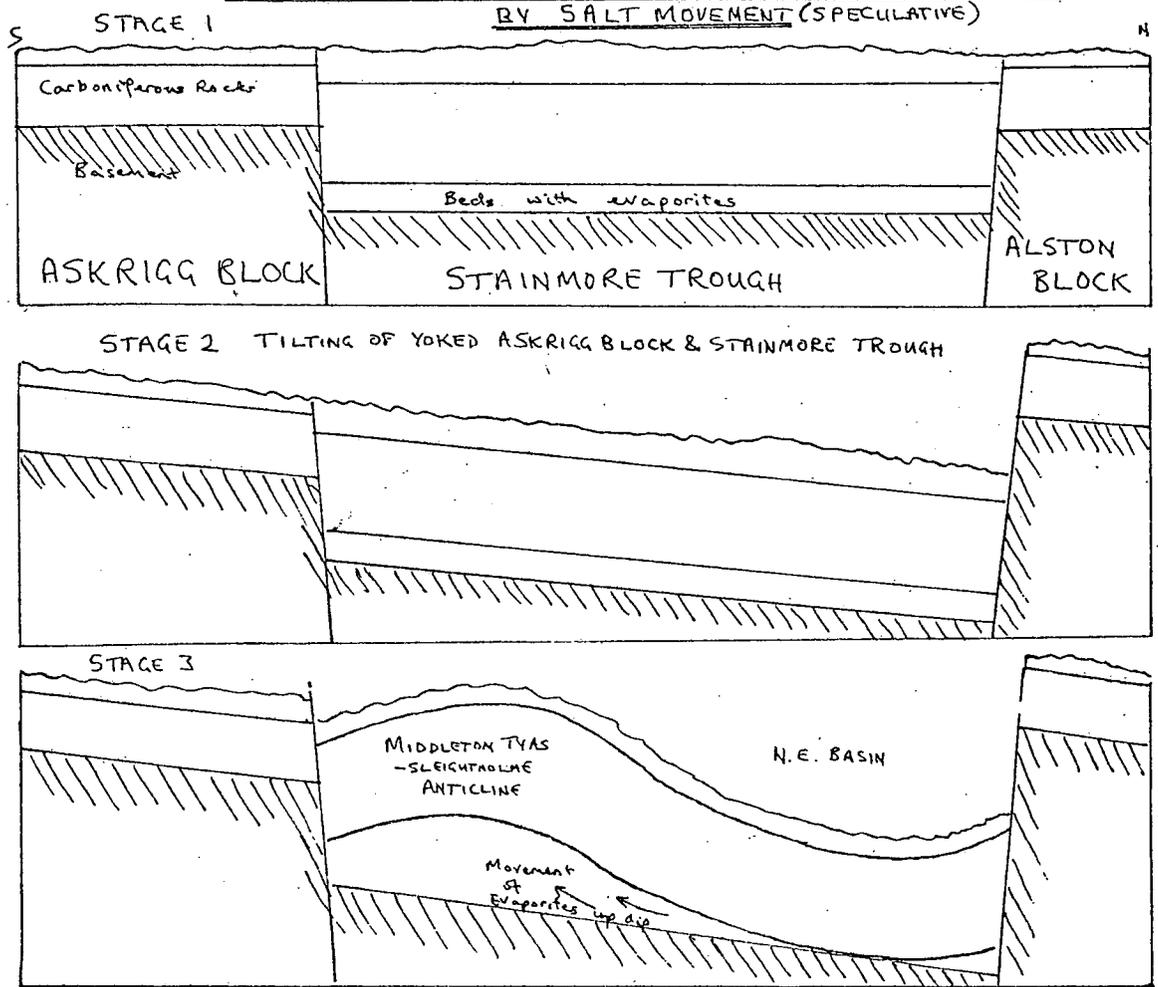
FIGURE 2.6. Fault Refraction and vein width.

a, Normal fault vein.

Shale (incompetant)
Limestone (competant)
Shale
limestone
Shale
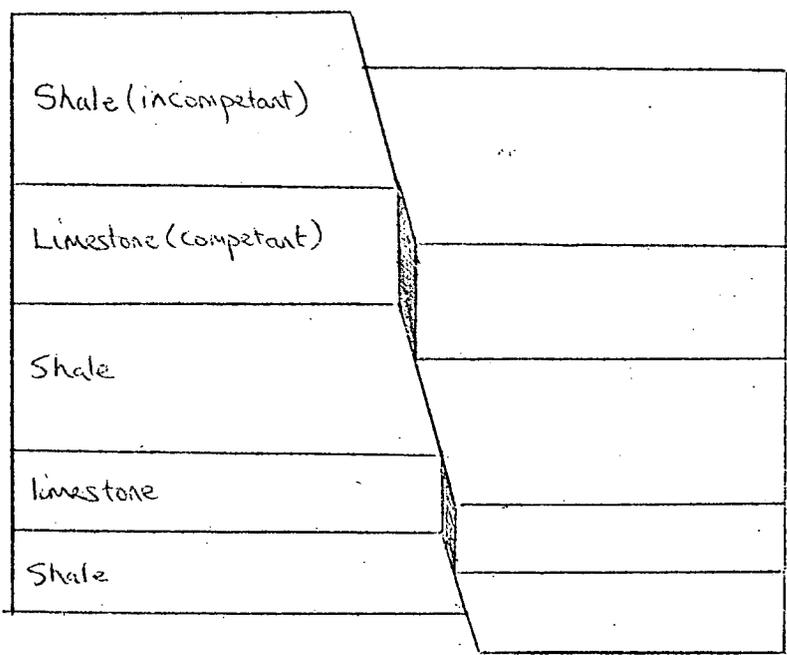
b, Strike slip fault vein.
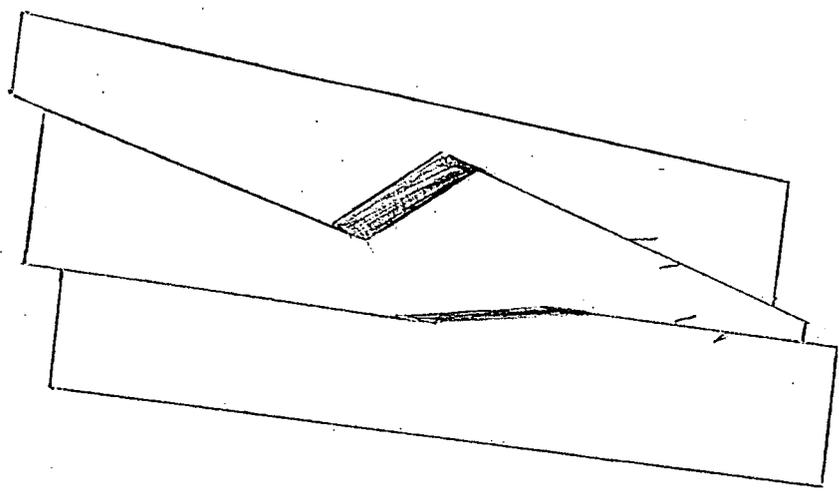
FIGURE 2.7

MAP OF FAULT DENSITY SMOOTHED BY AVERAGING OVER SQUARES 9×9 km.

KEY

- <2·2 km⁻¹
- <1·9 km⁻¹
- <1·6 km⁻¹
- <1·3 km⁻¹
- <1·0 km⁻¹
- <0·6 km⁻¹
- <0·3 km⁻¹
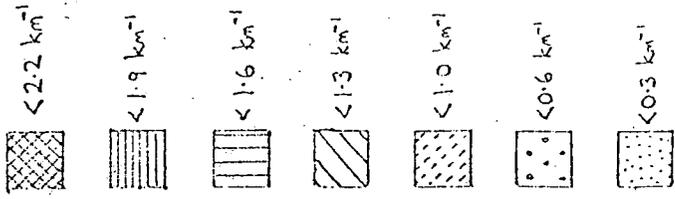
Computer program 'Smooth' was used to convert km square data for the large rectangle into the smaller matrix from which this diagram was prepared.

Fault length/km² = density (km⁻¹)
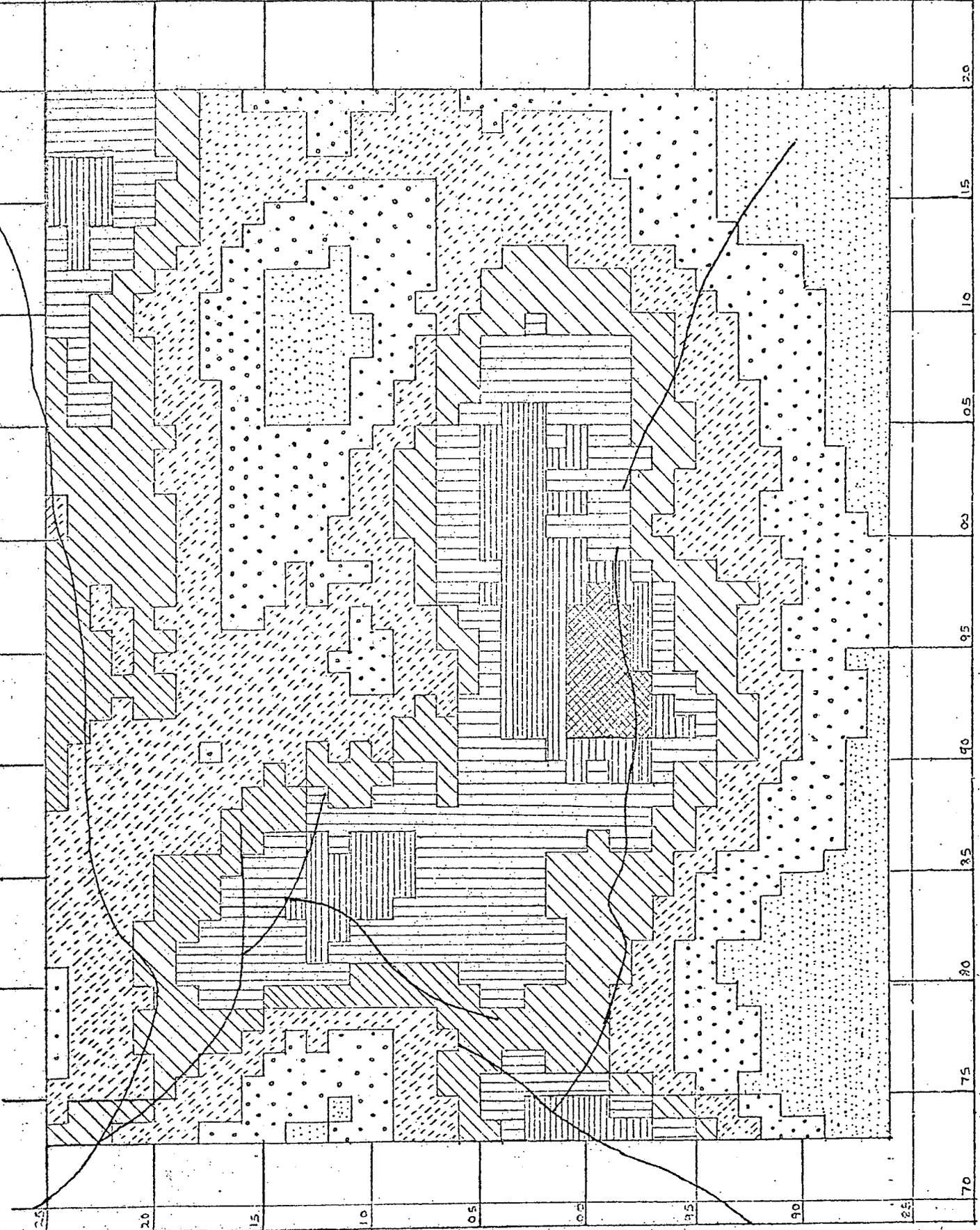
FIGURE 2.8 COMPOUND ROSE DIAGRAM OF FAULTS

ALSTON BLOCK

STAINMORE TROUGH

ASKRIGG BLOCK

Grid Scale: 0 ___ 5km

Radial Scale: 0 5 10km

a, West End
Stockdale Line

Displacement of
fold axes

STOCKDALE
VEIN

BENT FAULT

0   5 km

b, Blakethwaite Vein-Fault system

Curved extensions of a wrench

Blakethwaite Vein

0   1 km

c, Hurst Veins

En echelon faults with veins
between + changing throw of faults.

Wallnook Vein

Marske Fault

0   1 km
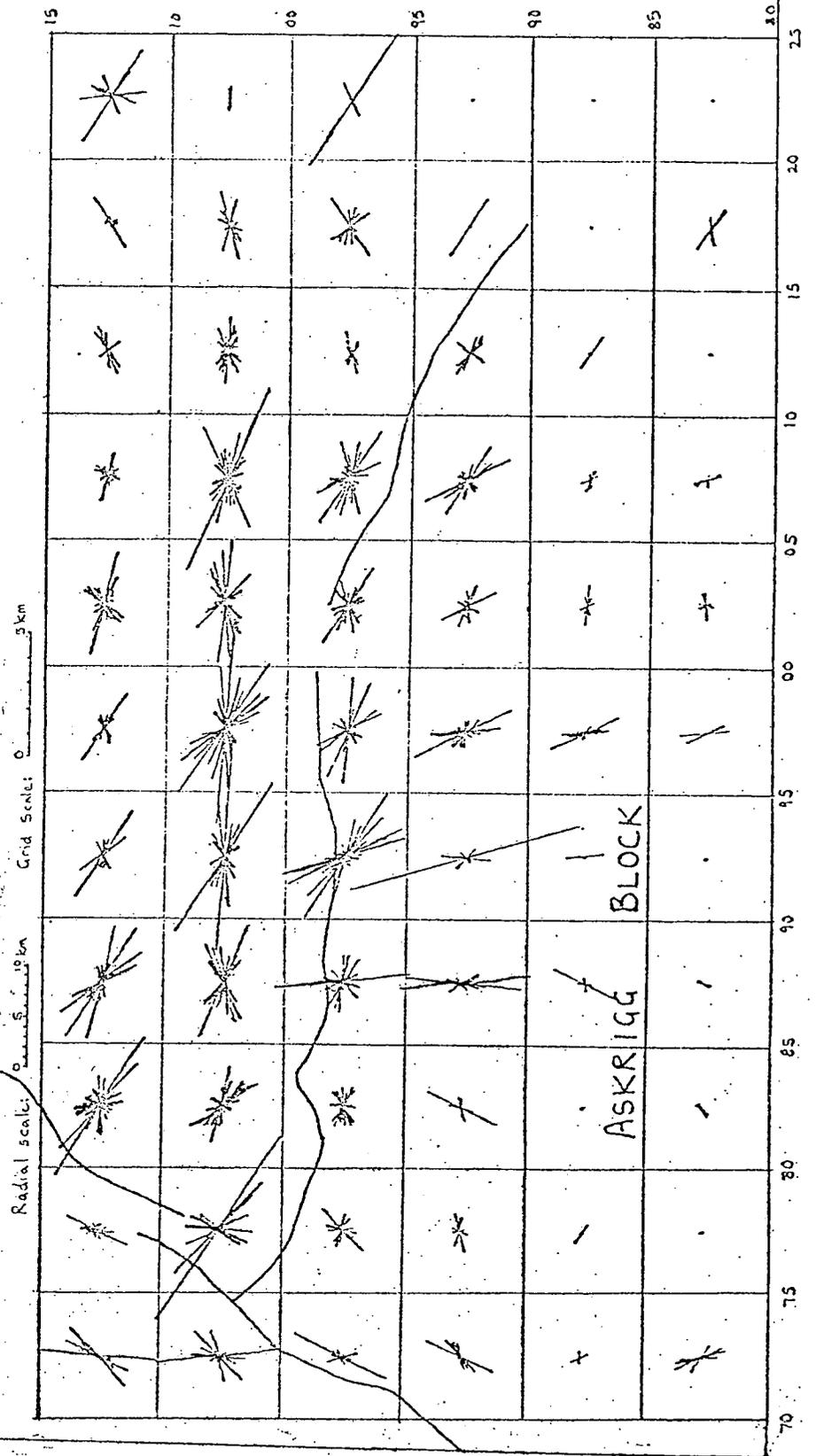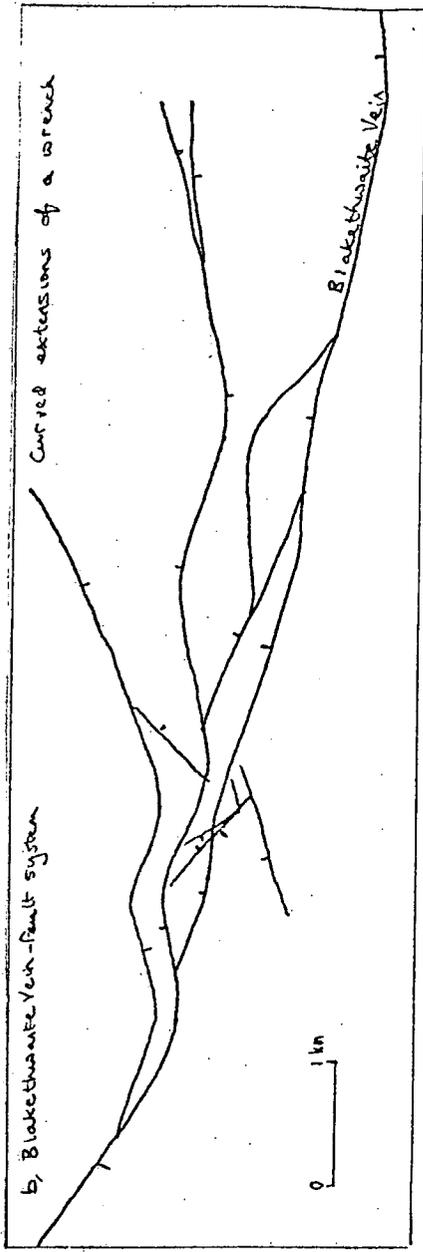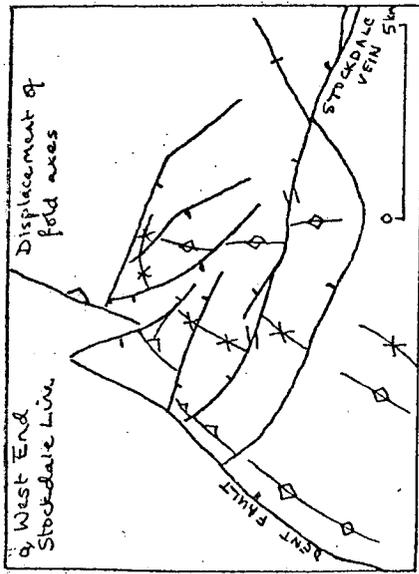
FIGURE 2.9 a, b, c: WRENCH FAULT DETAILS

b&c are redrawn from 1" Geological Survey sheets (Richmond, Kirkby Stephen).
a is based upon Rowell and Scanlon (1957)
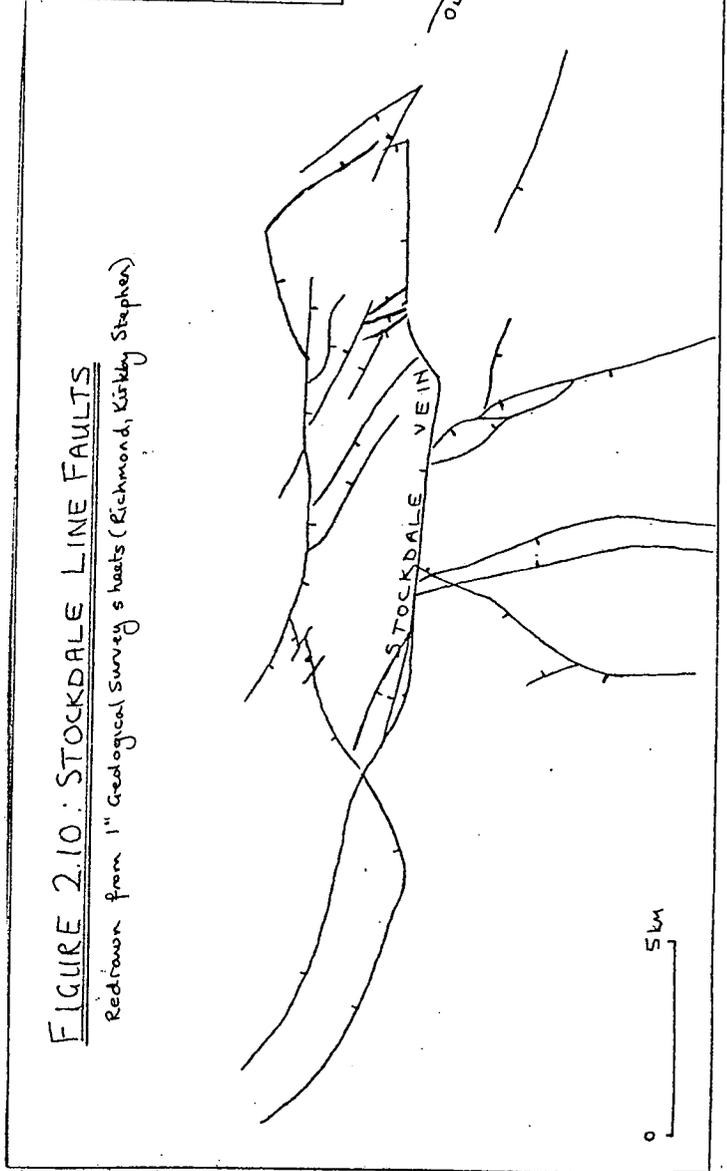
FIGURE 2.10: STOCKDALE LINE FAULTS

Redrawn from 1" Geological Survey sheets (Richmond, Kirkby Stephen)

STOCKDALE VEIN

OLD STORK VEIN

0   5 km
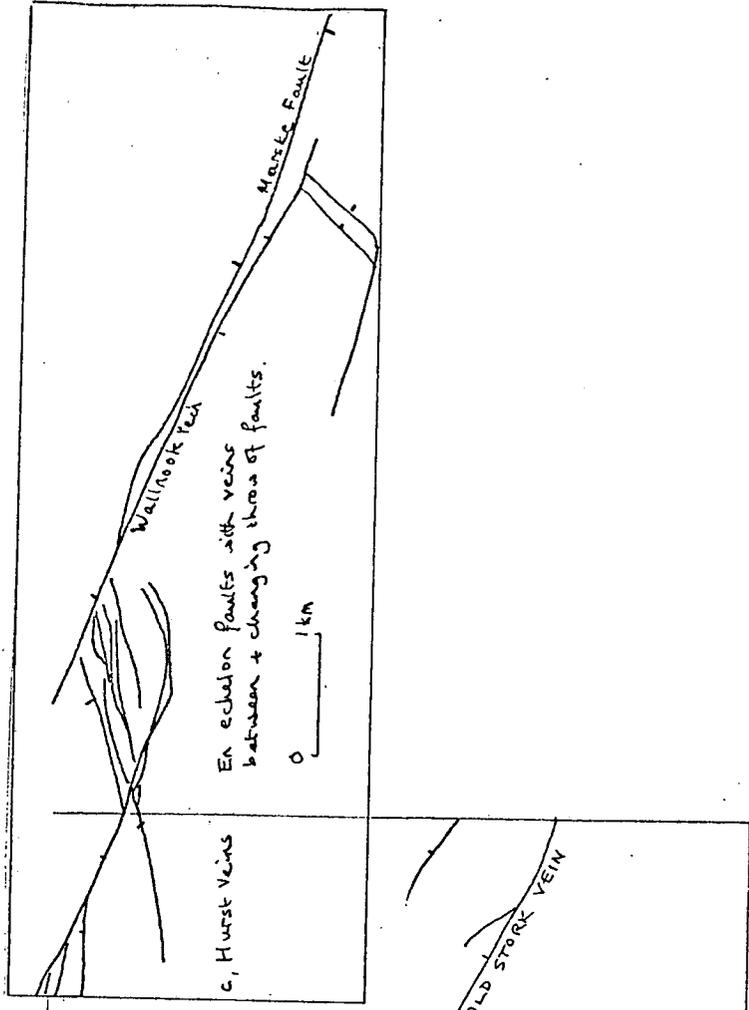
STRATIGRAPHY

INTRODUCTION

The area of the North Yorkshire Orefield is composed of Carboniferous rocks, although at its western edge the basement of lower palaezoic rocks is exposed. Permian rocks overly the Carboniferous in the Vale of Eden and also along the eastern edge of the area. The map (Fig. 3.1) shows the disposition of the principal rock divisions, and the major subsurface basement features.

BASEMENT

The Pre-Carboniferous basement is exposed just outside the area studied in the Lake District, the Ingleton and Horton Inliers, the Cross Fell Inlier and the Teesdale Inlier. Boreholes at Rookhope (Dunham et al 1965) and near Semer Water (Dunham, 1974) have cut the basement, which in both cases was found to be granite.

The oldest rocks exposed, and probably the oldest present in the area studied are the Ingleton Group and Skiddaw Slates. The Ingleton Group are mostly greywackes with some beds of arkose and conglomerate. Their age is uncertain, but they may be Cambrian or early Ordovician (O'Nions et al, 1973). Undoubted Ordovician rocks in northern England can be split into three groups – the Skiddaw Slate Group, the Borrowdale Volcanic Group, and the Coniston Limestone Group.

The Skiddaw Slate Group and Borrowdale Volcanic Group are present in the Lake District, the Cross Fell Inlier and the Teesdale Inlier. Skiddaw Slate has been found in the Crook Borehole and the Borrowdale Volcanics in one of the Cautley inliers (or the eastern edge of the Howgill Fells). Both units could underly the area studied especially the Skiddaw Slate Group.

The Skiddaw Slate Group consists of mudstones, siltstones and grey-wackes with some volcanic rocks near the top. Acid and intermediate lavas and tuffs, sometimes lying unconformably upon the last group, constitute the Borrowdale Volcanic Group.

A widespread unconformity is followed by the thinner sequence of calcareous mudstones and diagenetic limestone nodules which are the principal components of the Coniston Limestone Group. Sandstone, conglomerate and tuff are known to occur near the top of the sequence and unconformitites occur within the group (Ingham, J.K., and Rickards, R.B., 1974).

Silurian rocks conformably overly the C.L.G. in the Howgill Fells, and are split into three divisions:-

(a)   the Llandovery, consisting of graptolitic mudstone, and including fine greywackes higher in the sequence and Red mudstone lenses present in the Howgills;   .

(b)   the Wenlock, consisting mostly of graptolitic mudstones, but including turbidites and ending with thin limestones;

(c)   the Ludlow, beginning with thin limestones, followed by sandy turbidites, then laminated graptolitic mudstones intercollated with siltier units which make up most of the Ludlow beds.

These lower palaeozoic rocks, dominantly fine grained and well indurated were folded and faulted in the Caledonian Orogeny. The folds in the Howgill Fells trend roughly east-west, although progressively older rocks appear at surface in passing from the west, eastwards towards the Dent Line. In the Craven Inliers (Horton, Ingleton) folds trend west north west-east south east, which is a slight change of direction from the Howgill Fells, and a greater deviation from the Caledonian trend of the main body of the Lake District.

Under the Askrigg Block is a late Caledonian non porphyritic pink granite (Dunham, K.C., 1974). This granite directly underlies the Carboniferous around Semer Water where it has been proved by borehole.

The gravity anomaly of the granite and a magnetic anomaly which crosses the Askrigg Block west north west-east south east have been used to produce a model of the basement, featured in Bott, M.H.P., (1967). A granite is also present underneath the Alston Block, but absent from the basement of the Stainmore Trough. This presence of granites under the Alston and Askrigg Blocks has been an important control of sedimentation, structure, and on the Alston Block mineralization.

The magnetic anomaly can be attributed to a belt of igneous or metamorphic rocks in the basement. This belt has not been seen at surface in the Craven Inliers or the Lake District Block, where the anomaly continues, but a strong magnetic anomaly is associated with the Carrock Fell Gabbro-Granophyre complex and basic volcanics, and it is conceivable such rocks could be present under parts of the Askrigg Block.

From the evidence of the lower Palaeozoic Inliers and geophysics (Bott, M.H.P., 1967) a sketch map of suggested basement rocks (Fig. 3.2) and a block diagram of the basement "topography" (Fig. 3.3) have been prepared.

CARBONIFEROUS

All the mineralization of the North Yorkshire Orefield occurs in these rocks. The geological sections (Figs. 3 4, 5, 6) show the varying thicknesses of the divisions of Carbonferous strata. They have been constructed in part with the aid of the geophysical model of Bott (1967). Two synthesised sections of the Carboniferous (Fig. 3.7) in the Stainmore Trough and Askrigg Block, show the principal components of the area, although lateral variations are common in the higher units. The trough section is compiled from the Ravenstonedale, Kirkby Stephen and Stainmore districts, and the block section from the Semerwater Borehole, Askrigg, Kirkby Malzard and Colsterdale districts. Fig. 3.8 shows the out crops of the principal divisions of the Carboniferous rocks.

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The recent special report No. 7 of the Geological Society

(T. N. George et al, 1976) was released too late for its new nomenclature

and divisions to be incorporated in this chapter, so the older nomen-

clature has been followed.

(a) Tournaisian Strata

No mineralization has yet been reported in this division which

unconformably overlies the lower Palaeozoic rocks of the Lake District in

Ravenstonedale. The lowest strata are the Pinsky Gill Beds which are

composed of shales with salt pseudomorphs (Johnson, G.A.L, Pers.Comm. 1972),

dolomitic limestones and thin sandstones. Above these beds is a thick

feldspathic conglomerate. A thick succession of limestones then commences

and continues into the Visean. The Tournaisian limestones of the Stonegill

and Coldbeck Members are shallow water bioclastic limestones and dolo-

stones with algal nodules and stromatalites.

These strata may underly the Stainmore Trough where geophysical

evidence (Bott, 1967, Swinburn, P.M, Pers.Comm. 1975) suggests a thickness

of around 2 km for the Carboniferous Sediments of the Trough. Sections

Figs. 3.4; 5 show that the Ravenstonedale Tournaisian strata can be

accommodated with room to spare. In the vicinity of the Middleton-Tyas-

Slightholme Anticline there is even more room since the same 2 km is

suggested by geophisical interpretation. The possibility of gypsiferous

shale or true evaporites under this structure is suggested by the

palaeogeographic considerations.

No undoubted Tournaisian rocks have been found in the Raydale

Borehole (on the Askrigg Block) or in the Sedbergh area where the basal

unconformity can be observed. In the Sedbergh area, however, there is a

valley in the lower Palaeozoic basement, filled with conglomerates,sand-

stones and shales. Other similar deposits have been found overlying the

unconformity, but underlying known carboniferous rocks, around the edge

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of the Lake District Inlier. They perhaps correspond to Devonian or earliest Carboniferous Old Red Sandstone Facies terrestrial rocks, and could easily occur in undiscovered buried valleys underlying the Carboniferous of the Block and Trough. The basal beds of the Semerwater Borehole could partly belong to this facies although their location etc. would suggest that they are not Old Red Sandstone valley fills so much as transgressive marine sediments.

(b) Lower Viséan Strata

Mineralization has been observed in the uppermost parts of this succession along the Dent Line, in Upper Langstrothdale, and Dentdale. The lowest strata are the Scandal Beck Limestone, Brownber Pebble Bed, and Ravenstonedale limestone members. The limestone members are bioclastic limestone and the Pebble Bed is a thin oolitic pebbly limestone between them. These strata are present in Ravenstonedale and presumably the Stainmore Trough, but near Sedbergh and in the Raydale borehole the lowest beds may be equivalent in part to the basal beds which are thin limestones and shales with a little sandstone at Sedbergh, and thick conglomerates, sandstones and dolomitic siltstones in the Raydale borehole. A massive partly ankeritized limestone above the basal beds in the Raydale borehole may be equivalent to the top of the Ravenstonedale Limestone, but at Sedbergh the basal beds probably include the next members to be described.

In Ravenstonedale the next unit is the Ashfell sandstone which is composed of thick sandstone beds and thin limestones. The siltstone, with beds of sandstone and limestone found in the Raydale borehole is probably equivalent.

The Ashfell and Great Scar limestones are next in the sequence. A minor non sequence marks the division between the two in Ravenstonedale, but has not been reported in the Raydale borehole. The Ashfell limestone

is composed of calcarenites and micrites with thin limestones and shales. The Great Scar Limestone is bioclastic in part and pseudobrecciated near the top of the Raydale borehole.

The top of the Great Scar Limestone can be seen in many parts of the area (Fig. 3.8), but in the south of the area includes various limestones which are separated from it by northward thickening wedges of sandstone and shale. Thus the Robinson, Peghorn and Smiddy limestones are not distinguished on the Askrigg Block, and the Hawes and Gale Limestones become hard or impossible to distinguish as the Craven Line is approached.

(c) Upper Viséan Strata

These strata are commonly mineralized, especially in Wensleydale where they are well exposed (Fig. 3.8). They are made up of sedimentary rythems or cyclothems of limestone-shale-sandstone-(coal) which are repeated up the succession. Any member can be absent or repeated in a cycle which means that the succession is normally more complex in detail than the described cycle. The base of this division is the top of the Great Scar Limestone. The top is here taken as the base of the Main Limestone, although the base of the Namurian based on fossil evidence is between the Undersett and Main Limestones (Johnson et al, 1962). It is thicker in the Stainmore Trough than on the Askrigg Block (Fig. 3.7) and some cycles in the trough are highly condensed on the block. Thus the Single Post, Cockleshell, and Scar in the trough are equivalent to the Middle Limestone on the block.

The detailed stratigraphy of this cyclothemic division is difficult to describe because of the great extent of lateral facies variations. Moore (1958) has produced an important account of the strata in Wensleydale and a part of Swaledale. Similar attention has been given to the Middleton-Tyas-Slightholme anticline by Wells (1958), and Dakyns et al (1890, 1891) described the strata of the western half of the North Yorkshire Orefield.

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These valuable accounts of the stratal sequence and their correlations are based on measured sections and numerous fossils discovered. The interpretation of the strata in terms of environment of deposition, palaeogeography etc. is provided in Moore (1958), and Wells (1958). Such interpretations are not of direct importance in this work, although they are of great help in understanding the stratigraphy.

A simplified interpretation of the strata is presented as Fig.3.9. Section (a) is taken from the Kirkby Stephen 1" Geological Survey Sheet, and section (e) is from Miller and Turner (1931). Sections (b), (c), and (d) have been constructed from the detailed work of Moore (1958, sections (c) and (d)) and Wells (1958, section (b)) and reveal the great variation of cyclothems which is not shown in sections (a) and (e). Section (e) does not include the thicknesses of sandstones which are present and is portrayed in order to show the thicknesses of the cycles in comparison with the other areas.

The limestone beds are often fairly massive which is important in fault refraction, and thus in the formation of vein cavities. They are frequently crinoidal or bioclastic, although variations are common within beds, so that there are coral beds, oolitic horizons, bands of cherts, chert nodules and many other varieties. Grain size variation is also common, and shaley partings and minor erosion surfaces are also present. They are probably as important as the other features in controlling replacement mineralization which unfortunately is a relatively minor feature of the North Yorkshire Orefield. Wells (1958) records that the lowest metre or so of the Undersett Limestone is often recrystallized and dolomitized. The lowest few centimetres of Undersett Limestone is silicified in the Marske area (20 km^2) and cavities lined with quartz crystals are also reported by Wells in the 5 yard limestone. Dolomitization of the base of the Undersett Limestone is again reported by Moore (1958). The importance

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of stylolites has been recently stressed in the Derbyshire Orefield
(Worly, 1976), but their localization etc. in this orefield has not been
studied. Moore and Wells (Op. Cit.) both report that crinoidal and cherty
rocks tend to be mutually exclusive, and exceptional thicknesses of lime-
stone are often attained where there are coarse crinoidal bioherms such
as in the Gayle and Undersett Limestones.

The thick limestones are continuous over a wide area, but some of
the thinner limestone bands are "cut out" by the non calcareous measures
which occur between the principal limestones. The non-calcareous measures
are much more variable in thickness than the limestones. The limestones
were deposited away from terriginous sediment in shallow seas providing
an environment suitable for the flourishing fauna, whose skeletons make
up most of the limestones. The non-calcareous measures, however, are
composed of mostly terriginous sediment deposited in the shallow marine
and non-marine environments of a large delta system. Marine shales follow
the limestones, and are of importance in the orefield because of their
relative impermeability. They hold up percolation and produce up dip
movements of solutions both in fractures and in the rocks. Marine shales
are deposited at the front of the delta, and are followed by the advancing
delta sequence of marine, brackish, and freshwater shales, silts and sand-
stones deposited between the distributaries of the delta. The sandstones
are coarse, permeable and sometimes fairly continuous, but all of these
interdistributary beds grade laterally. Because of shifting of distrib-
utaries, and probably tectonically controlled minor changes of sea level,
the different deltaic environments can advance and retreat several times
in a cycle between two thick limestones. These changes produce the com-
plex geographical and vertical patterns of strata observed. Three further
environments which must be mentioned are:-

    1. Coarse channel deposits of the distributaries, which are

        often of quite wide lateral extent, very permeable and

massive, and frequently cut out other members of the
cyclothem.

2. Paleosoils (seatearths and ganisters) which can occur
toward the end of the cycles and can be permeable or
impermeable, but are generally thin.

3. Coals, which are a purely organic accumulation found
occasionally above the ganisters and seatearths, and
are mostly formed in a sub aerial environment.

(d) Namurian Strata

The Namurian Strata are cyclothemic like the Upper Viséan Strata.
Once again they are somewhat thicker in the Stainmore Trough than on the
Askrigg Block although this is at least partly due to the intra E_1
Grassington Grit unconformity. Sections of the Namurian Strata are por-
trayed in Fig. 3.10. The sections (a) - (f) are taken from the published
1" Geological Survey Maps and section (g) is from Ramsbottom et al (1974)
although presumably based on Wilson & Thompson (1965).

The sections show some significant differences when compared with
Fig. 3.9. Firstly limestones are present in the succession, but except
for the Main Limestone are generally thin. They are most common low in
the succession, and in the northern areas more than the southern. Secondly
substantial bedded cherts and cherty rocks are found in the succession in
the Reeth-Richmond area. Thick sandstones and grits are more common than
in the Visean and they are perhaps more laterally continuous.

The environments of deposition of the Namurian cyclothems and their
properties are similar to those of the Viséan cyclothems, except that
channel deposits, and coals are more common. The cherts are a special
feature of the Namurian in this orefield and are problematic in origin.
Wells (1955) and Hey (1956) have described their occurrences and some of
their possible origins. A replacement origin of the chert is definite

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in some cases, but not so clear in others and the accumulation of so much silica is difficult to account for by the off distributary marine precipitation mechanism suggested by Wells, or the derivation from sponges mentioned in Ramsbottom et al (1974).

Only the lower Limestones and cherts of the Namurian succession are known to be mineralized, but the Main Limestone horizon was the most profitable level at which ore was obtained throughout Swaledale.

(e) Westphalian Strata (Coal Measures)

The coal measures can not be seen in most of the orefield, having been eroded away, but are present as a small outlier near Stainmore and in the basin east of Barnard Castle away from the mineralization. The lowest beds of the coal measures are also seen on the south-eastern part of the Askrigg Block and a small coal basin is present in the Bowland Trough just south of Ingleton. At the top of the coal measures an unconformity, cuts out the late Westphalian Stephanian and early Permian, so that the thickness is of these divisions laid down in this area can not be ascertained. Near Barnard Castle 450 m of coal measures are still preserved, and at Stainmore 300 m (Fig. 3.7). At Ingleton there are around 1 km of Westphalian Strata (excluding the upper part of Westphalian B and lower part of C), so the total thickness may have been substantial over much of the orefield. The Westphalian is cyclothemic, but includes only occasional marine sediments. Thus there are thick siltstones, sandstones, seatearths, and coals, with rare thin marine shales, and no limestones.

(f) Permian Strata

Permian rocks are present in the Vale of Eden and on the eastern edge of the area. They are unconformable upon the Carboniferous rocks often with a large time interval represented (Fig. 3.11). The estimated position of the unconformity is marked on sections Figs. 3.4, 5, 6 and estimated stratum contours are marked on Fig. 3.11 which also shows the

rocks which underlay or underly the Permian unconformity. There is a marked difference between this estimate and that of Wills (1971). The angle of unconformity has been estimated by examining the known thicknesses of Carboniferous strata along the Dent Line near Stainmore and estimating the unconformity position. Also by comparing the depths of the unconformity in the Harlsey and Cleveland Hills boreholes, with the outcrop. The borehole data gives a slope of around 1:25, and the Stainmore data gives a slope of around 1:35. The lower value was considered most appropriate although the even lower value of tilt used by Wells and Reading 1:53 corresponds to the lesser late Tertiary tilt manifest in the topography, and also the plunge of the Middleton-Tyas Anticline. The Vale of Eden has a syncline of Permian and later strata, but it is also in part a depression or valley filled with sediments. Most of the area of the Stainmore Trough and Askrigg Block was probably peneplained before any sediments were deposited and the thin basal Permian breccias are all that represents the lower Permian. The upper Permian Zechstein sea must have extended over part of the area and perhaps crossed the Stainmore Trough to deposit the thin Magnesian Limestone of the Vale of Eden, which has been correlated with the thicker deposits east of the Pennines. The Middleton-Tyas Anticline acted as a positive feature during the early Zechstein and lower Permian. Other palaeogeographic evidence suggests a shoreline for the lower Magnesian Limestone not far west of the present line of unconformity, and near Middleton-Tyas the shoreline was further east than the present outcrop of Permian. (Smith, D.B., 1974) Later sediments probably spread further to the west, but it may have been Triassic times before any real thickness of sediments was laid down over the orefield. There is so little evidence it is not possible to do more than guess the thicknesses of higher strata that may have overlain the area.

STRATIGRAPHIC CONTROL OF MINERALIZATION

The mineralization of the Stainmore Trough and Askrigg Block is epigenetic and hydrothermal in origin and therefore stratigraphic control is executed through several factors:-

(a) Structural properties of the strata (sedimentary and tectonic structure)

(b) Hydrological properties of the strata (permeability and porosity to solutions)

(c) Geochemical properties of the strata (reactivity, and composition of host and source rocks)

(d) Types of mineralizing solutions available

(e) Chronological control of host rock and preservation of deposits.

(a) <u>Structural Properties</u>

Mineralization is found principally in fractures and to a lesser extent in flats along bedding structures. The shapes and sizes of fractures depend upon the character of the wall rock as well as the magnitude and direction of throw. Faults are refracted towards the normal to bedding in competent rocks and away from the normal in incompetent rocks. In the mineralized succession the competent beds are principally limestones, cherts, grits and sandstones, although shaley and flaggy varieties of these rocks are less competent. The incompetent strata are mostly shale, mudstones, seatearths, coals and siltstones. The shaley rocks are often thickest and therefore most important. If a thick competent section is present, then even faults of large throw may form good fractures. When only thin competent beds occur, in a dominantly incompetent section, then faults of modest throw may form poor fractures, with shale or other incompetent strata abutting directly against limestones or other competent strata, with no space left for mineral deposition. The occurrence of "bearing" horizons is demonstrated by Fig. 3.12 taken from Bradley (1862).

In figure 3.9 sections (b), (c) and (d) which are fairly detailed sections, have been studied to determine the proportions of the constituent rock types present.   (see table below).

Section	b		c		d		Range		Bradley
	Min	Max	Min	Max	Min	Max	Min	Max	9 chert
Limestone in %	18	23	°14	16	27	32	14	32	26
Sandstone in %	27	46	25	54.	9	31	9	54	43
Shale in %	30	55	39	61	137	60	30	61	23
Competant in %	45	70	39	61	40	63	39	70	77

This gives some impression of how variable the section can be. The figures taken from Bradley's estimate of the section in Swaledale demonstrate the high value recorded for competant strata in the richest part of the orefield, in part due to his incorporation of some minor shale bands in ··with his grits. The sections of the Namurian Strata Fig. 3.10 show that thick chert sequences can boost the proportion of competant rocks in the area on the eastern half of the Stockdale Line. The extent of cherts and isopachytes of the Richmond Chert series (Fig. 3.13) can be usefully compared with a map of the mineral veins (Fig. 3.14) when it can be seen that a greater density of veins occur in the vicinity of cherts. This may be fortuitous, but the thickness of competant strata most probably made a significant contribution to the development of veins.

Sedimentary structures control. the disposition of the various rock types and hence controls in part the effects of tectonic stresses, and the geochemical and hydrological interactions. Bedding planes, shaley partings etc. frequently act as a structural weakness or solution barrier

which may induce mineralization. Solution along these weaknesses and barriers is perhaps of greatest importance in producing replacement flats.

(b) Hydrological Properties

Expressed simply the shales are impermeable and the limestones and sandstones are to some extent permeable. The limestone permeability is due to joints, bedding and stylolites and originally in primary porosity. Dolomitization often produces a little extra porosity and permeability. The sandstone permeability is due to the intergrain pore spaces which are fairly large. Cherts have similar features to the limestones. The flow of solutions in faults is affected by wall rock so that faults with a shale-shale wallrock or shaly gangue are relatively impermeable, whereas faults with limestone-limestone wallrock are relatively permeable. This is due to absence or presence of a significant "cavity".

The net effect of the rocks and structures is for waters to move easily vertically in fractures in competant rocks and in the competant rocks themselves, but to be restricted by the shales both in fractures and rocks to movements principally along the bedding direction.

(c) Geochemical Properties

The limestones and cherts which are normally calcareous are relatively reactive to the mineralizing solutions and hence dissolution of wallrock and along bedding planes especially under shale bands or beds is an important phenomenon. Bradley records that the Main Limestone is divided into three flatting horizons presumably by shale partings. Host rock preparation such as dolomitization is well known in deposits such as Pine Point in Canada, and both the Undersett and Main Limestones have dolomitized bases over wide areas.

The purity of limestones and their constitution can significantly affect wallrock reactions. The Little Limestone and other coarsely crinoidal pure limestones should perhaps be the most reactive, but their coarse grain size makes crinoid ossicles less reactive than fine grained matrix.

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Sandstones and shales do not appear to be well mineralized and are certainly not as soluble as the limestones. The possibility of shales providing base metals or sulphide for the mineralizing solutions can not be ruled out. Ion exchange reactions common in clay minerals may be important in changing solution compositions especially connate waters.

The properties of basement rocks could also be significant in understanding solution chemistry and origin, and evaporites potentially in the Stainmore Trough should also be considered. Mineralization occurs principally in the reactive limestones and cherts in most of the Upper Viséan and E_1 Namurian Strata.

Horizon	Dent Line	Dentdale to Mallerstang	Stainmore	Swaledale	Wensleydale
Crow Limestone				✓	?
Little Limestone	Upper			✓	?
Main Limestone	horizons	✓	✓	✓	✓
Undersett Limestone	mostly			✓	✓
3 Yard Limestone	missing			?	✓
5 Yard Limestone	due to			?	✓
Middle Limestone	erosion			✓	✓
Simonstone Limestone		✓		✓	✓
Hardraw Limestone		✓		✓	✓
Great Scar Limestone	✓	✓		Not exposed	✓

(d) Types of Mineralizing Solution Available

The sedimentary host rocks and neighbouring rocks can be regarded as
at least once the source of connate waters (trapped and altered "sea"
water). The Harrogate Springs suggest that some is still present (Hudson,
1938). Connate waters from halite bearing evaporites could be expected to
be potassium rich, but others would be very poor due to fixation of potas-
sium by clays. Both would be rich enough in magnesium to dolomitize lime-
stones. The possibility of waters from deep metamorphism or igneous
activity should also be considered, but the stratigraphic evidence of the
igneous rocks of the area suggests a pre-mineralization age. The Whin
Sill on the Alston Block may be only a little older than the mineralization
and so direct contribution from igneous solutions can not be entirely
ruled out.

(e) Chronological Control of Host Rock and Preservation
of Deposits

Since the mineralization is epigenetic it can not be found in rocks
younger in age than the mineralizing event (if it was a discrete event).
Since erosion has been active since mineralization occurred, some mineral-
ization will have been lost.

The secondary enrichment and reddening phenomena underlying the
Permian unconformity suggest a late Carboniferous-early Permian age, but
the occurrence of mineralization in the Permian rocks and K/Ar ages.
(Ineson & Mitchell, 1973) argue in favour of a later, probably Triassic age.

The syngenetic Kupfershiefer-Marl Slate mineralizations suggest a
distinctly Middle Permian age, whether their origin is direct from mineral-
izing solutions or indirect from erosion of mineralization.

The chronological evidence is at present insufficiently well under-
stood to be clear on this stratigraphic control but the enrichment of
copper deposits under the Permian unconformity is clearly significant and
suggests a secondary origin.

FIGURE 3.1: PRINCIPAL ROCK DIVISIONS AND SUB-SURFACE FEATURES

Based on Bott (1967)
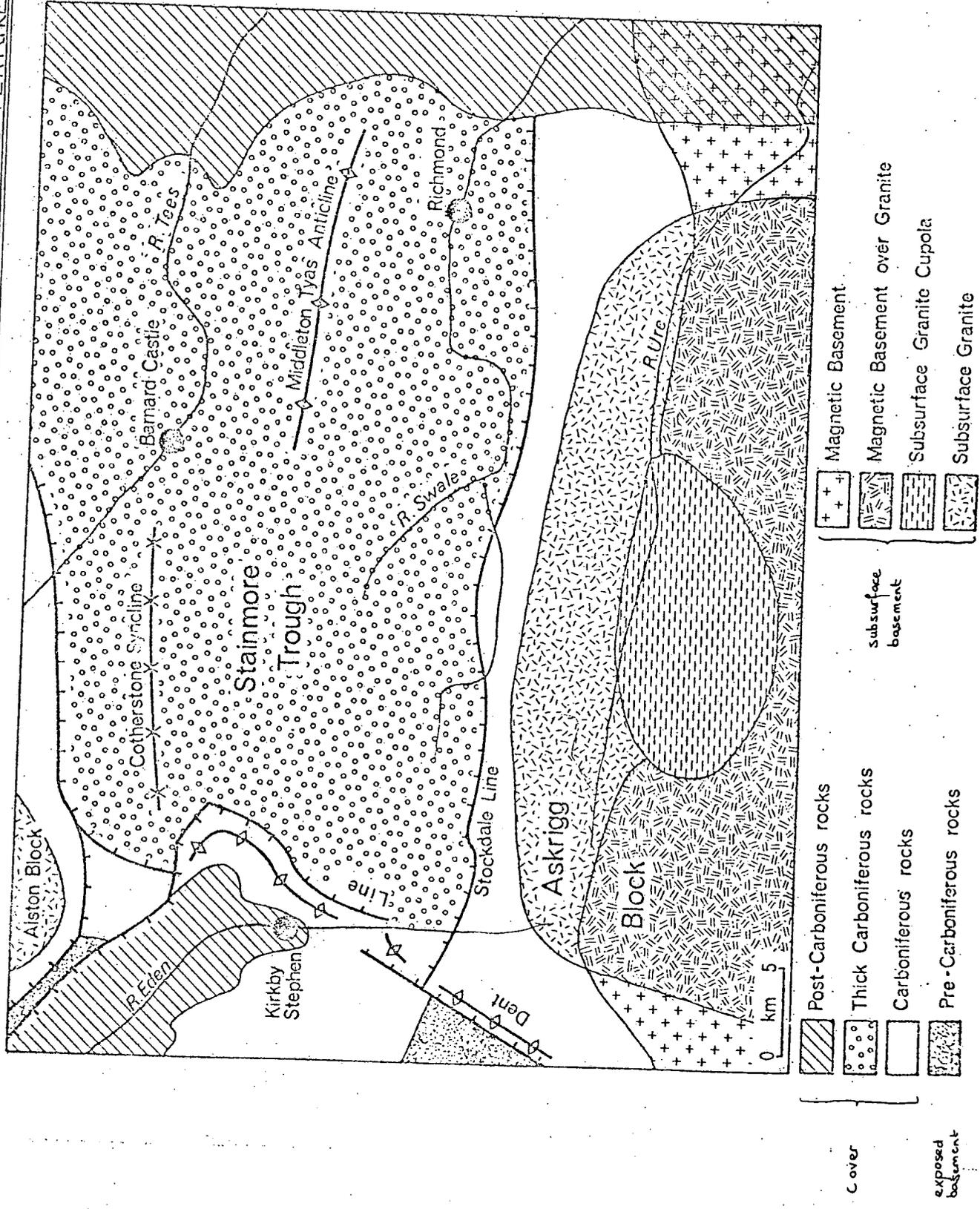
FIGURE 3.2. LOWER PALAEOZOIC OUTCROPS AND
SUGGESTED PRE-CARBONIFEROUS BASEMENT

Legend:

- —M— Magnetic Anomaly (from Moseley, 1974)
- 1   Ingleton Group
- 2   Skiddaw Slate Group
- 3   Borrowdale Volcanic Group
- 4   Coniston Limestone Group
- 5   Silurian
- 6   Granitic Rocks
- G G G   Gabbro Complex
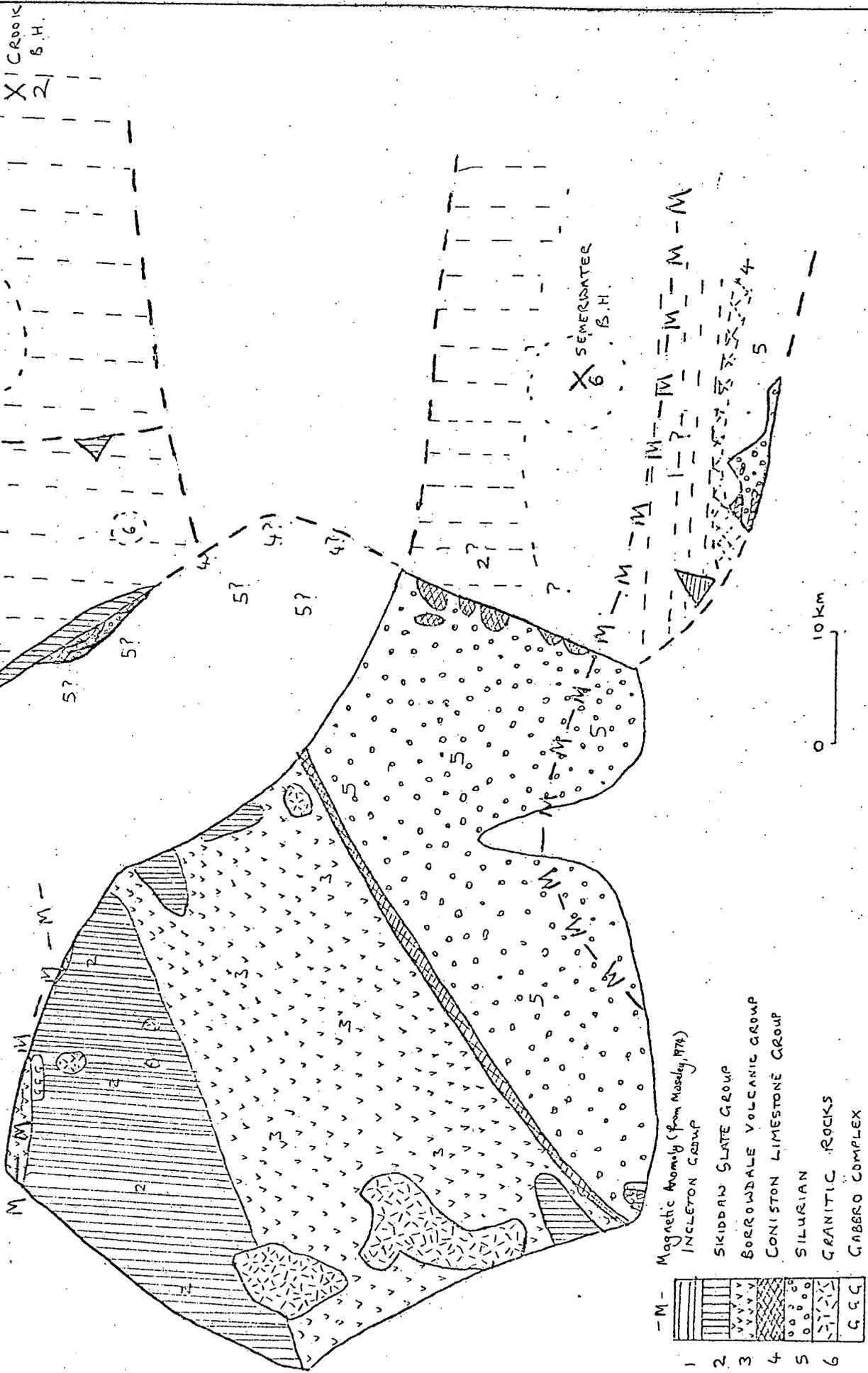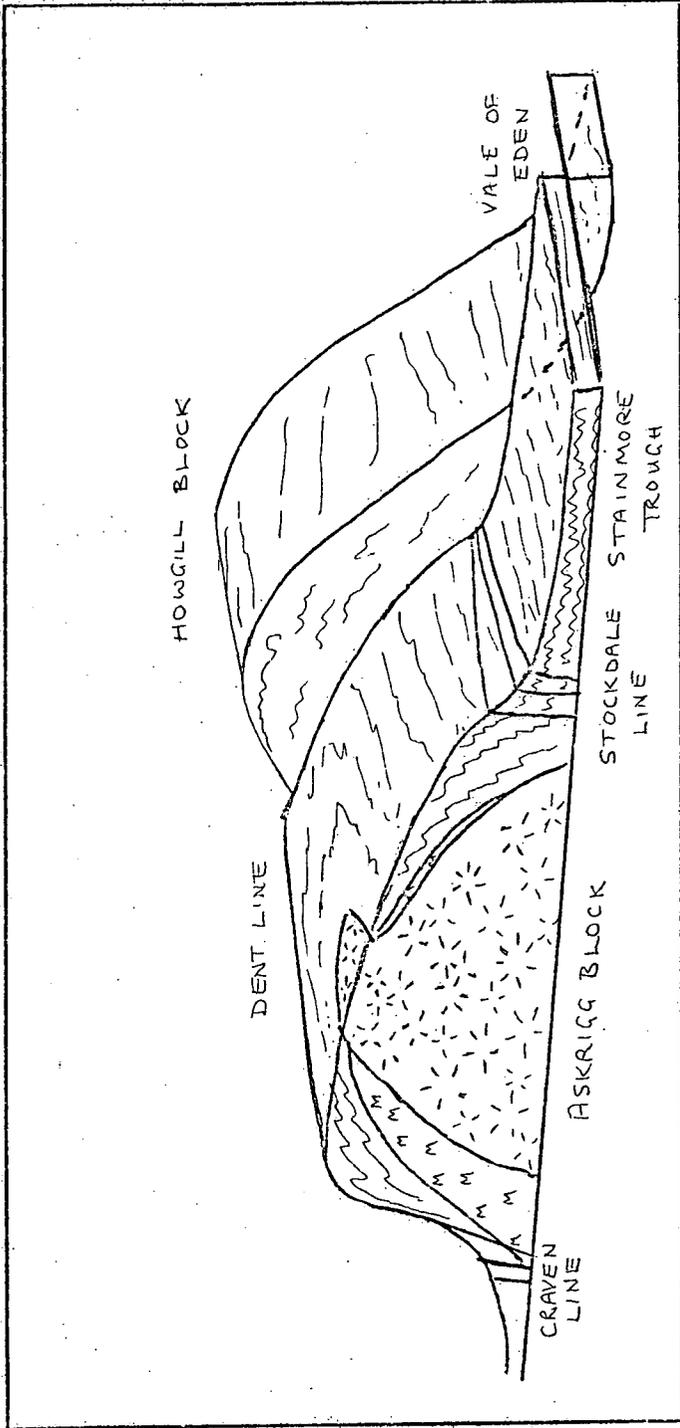
FIGURE 3.3: BASEMENT 'TOPOGRAPHY'

FIGURE 3.4 Section along grid line 370E to illustrate the stratigraphy
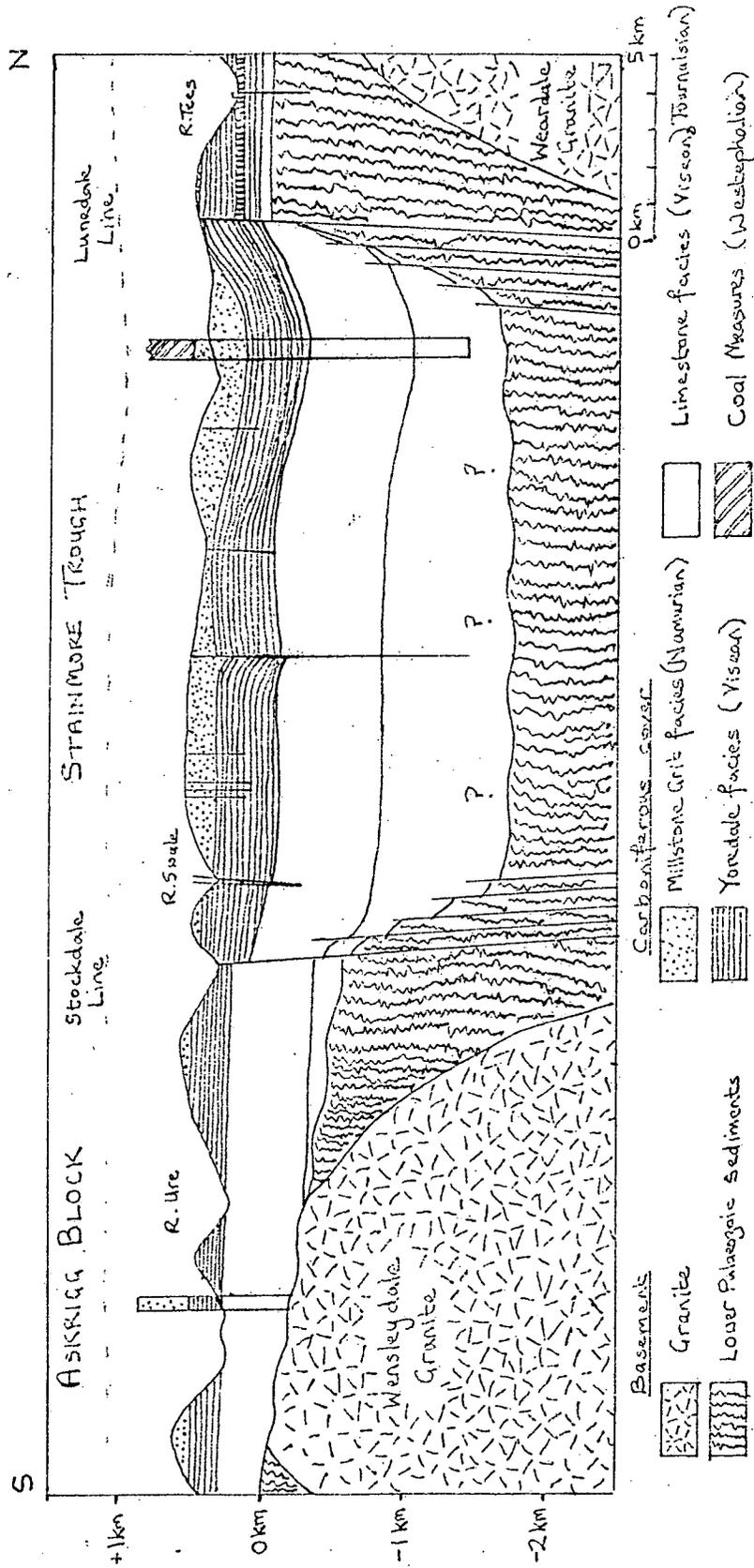
FIGURE 3.5: Section along grid line 495 N
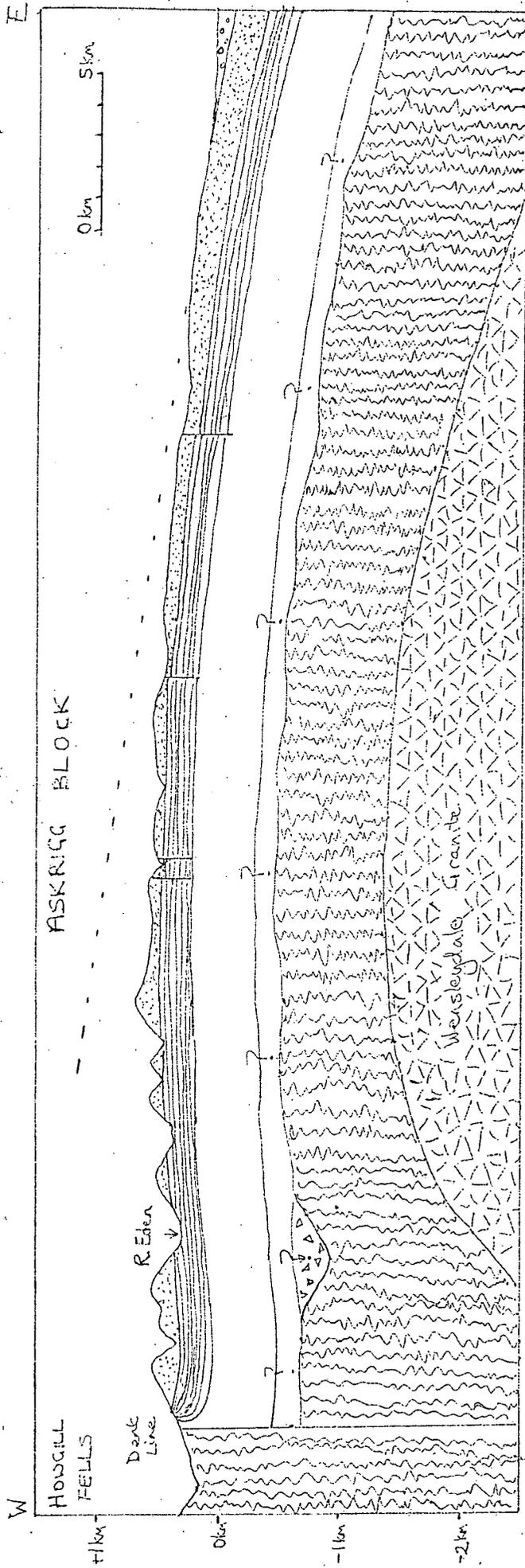
FIGURE 3.6 Section along grid line 513 N

VALE OF EDEN   Dent Line   STAINMORE TROUGH

W   E

R. Eden   R. Greta   R. Greta   R. Tees

1 km   0 km   -1 km   -2 km

0   5 km

STAINMORE TROUGH   ASKRIGG BLOCK

WESTERPHALIAN

NAMURIAN

Pesah Wood L. →

Stricegill L. →

Stonesdale L's →
Crow L. →

Little L. →

Main L.

Undersett L.

3 yard L.

5 yard L.

Scar L.
Cockleshell L.
Single Post L.

Simonstone L.

Jew L.
Lower Little L.

Smiddy L.

Peghorn L.

Great Scar L

VISEAN

Ashfell L.

Ashfell S.

Raverstonedale
L.

Scandal
Beck L.

Coldbeck L.

TOURNAISIAN

Stonegill L.

Feldspathic cngl.
Pinsky Gill Beds

← Colsterdale or Shunnerfall L.

M Chert & Richmond Cherts
Main L.

Undersett L.

3 yard L.

5 yard L.

Middle L.

Simonstone L.

Hardraw L.

Gayle L.
Hawes L's

Great Scar L

Basal beds

?

500m

0.

FIGURE 3.7: SYNTHETIC SECTIONS OF THE CARBONIFEROUS STRATA

Compiled from Geological Survey 1" sheets (Kirby Stephen & Brough), Ramsbottom (1974) and Dunham (1974)

FIGURE 3.8: GEOLOGICAL MAP OF THE STAINMORE TROUGH & PART OF THE ASKRIGG BLOCK

Permo-Trias
Westphalian
Namurian
Upper Visean
Great Scar V.
Tournaisian
Lower Palaeozoic
Whin Sill.

Based upon 1"
Geological Survey sheets
(Brough, Barnard Castle
Kirkby Stephen, Richmond
Hawes, Masham)
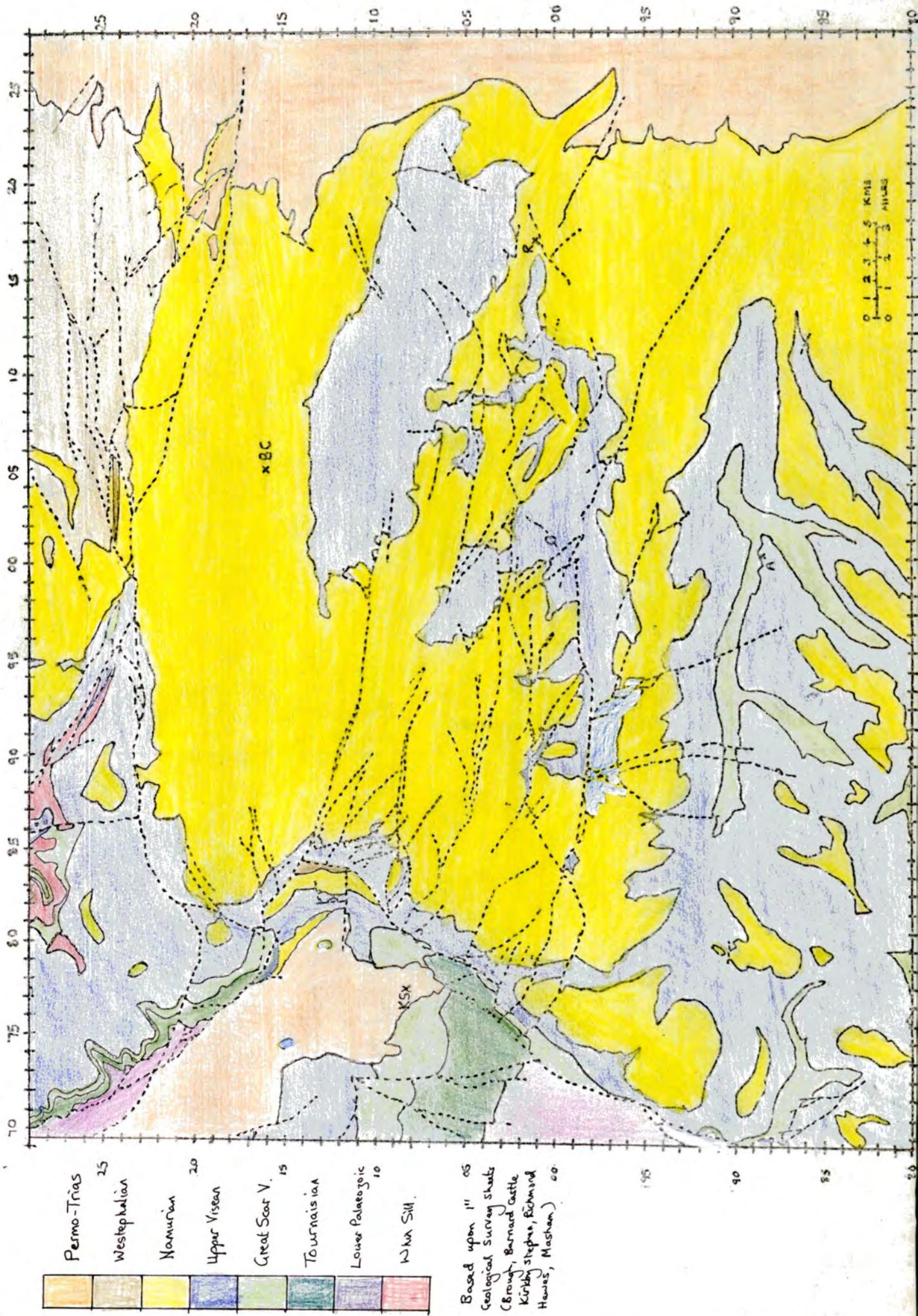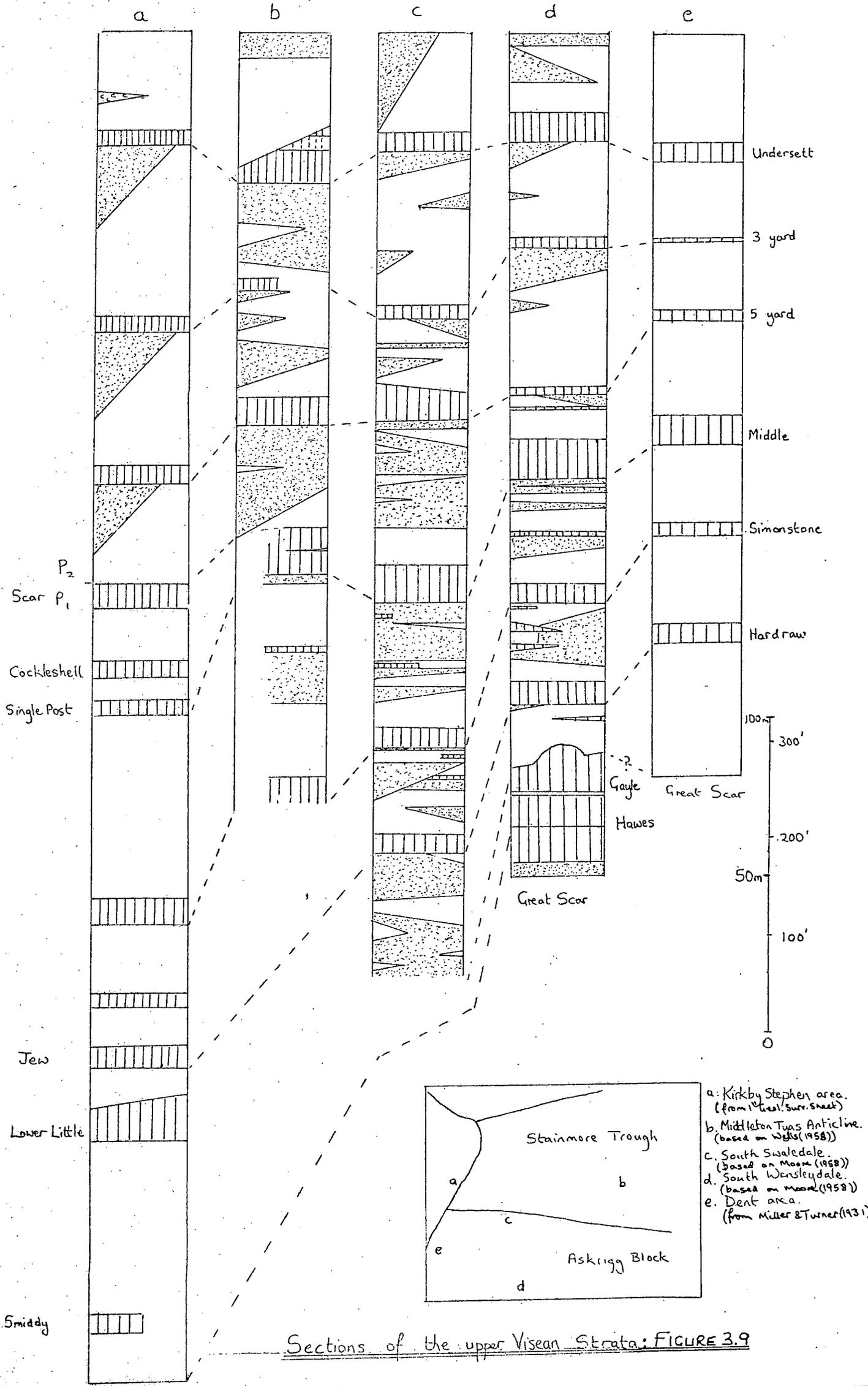
Sections of the upper Visean Strata: FIGURE 3.9

Column headers: a, b, c, d, e

Right-hand column labels (e):
Undersett
3 yard
5 yard
Middle
Simonstone
Hardraw
Great Scar

Left-hand column labels (a):
P_2
Scar P_1
Cockleshell
Single Post
Jew
Lower Little
Smiddy

Column d labels:
Gayle
Hawes
Great Scar

Scale:
100 m
300'
200'
50 m
100'
0

Inset map:
Stainmore Trough
Askrigg Block
a
b
c
d
e

Legend:
a. Kirkby Stephen area. (from 1st Geol. Surv. sheet)
b. Middleton Tyas Anticline. (based on Wells (1958))
c. South Swaledale. (based on Moore (1958))
d. South Wensleydale. (based on Moore (1958))
e. Dent area. (from Miller & Turner (1931))

FIGURE 3.10

Sections of the Namurian Strata

a–f from Geological Survey 1" Sheets and g from Ramsbottom (1974)

FIGURE 3.11: THE PERMIAN UNCONFORMITY AND MINERALIZATION

ALSTON GROUP (A.G.)

GREAT SCAR LIMESTONE

COAL MEASURES (C.M.)

MILLSTONE GRIT (M.G.)

BARNARD CASTLE +

ORTON GROUP

KIRKBY STEPHEN X 350m

150m X East Leyton

350m X Feldon

150m X Morgant

75m Middleton X

100m X Richmond

0m

100m

200m

300m

400m

500m

1,000m

1,500m

0   5 km

Legend:
— Base of Permian
–– Contour on projected base of Permian.
δ, b, β Permian on Coal Measures
⊞ Permian on Millstone Grit
x⊥x Permian on Alston Group
∆⊥∆ Permian on Gt Scar Lst.
X Mineral deposit
+ Town
Anticline
–– Fault
▥ Post-Carboniferous

FIGURE 3.12: Productivity distribution in veins of different throw in Swaledale. (After Bradley 1860)
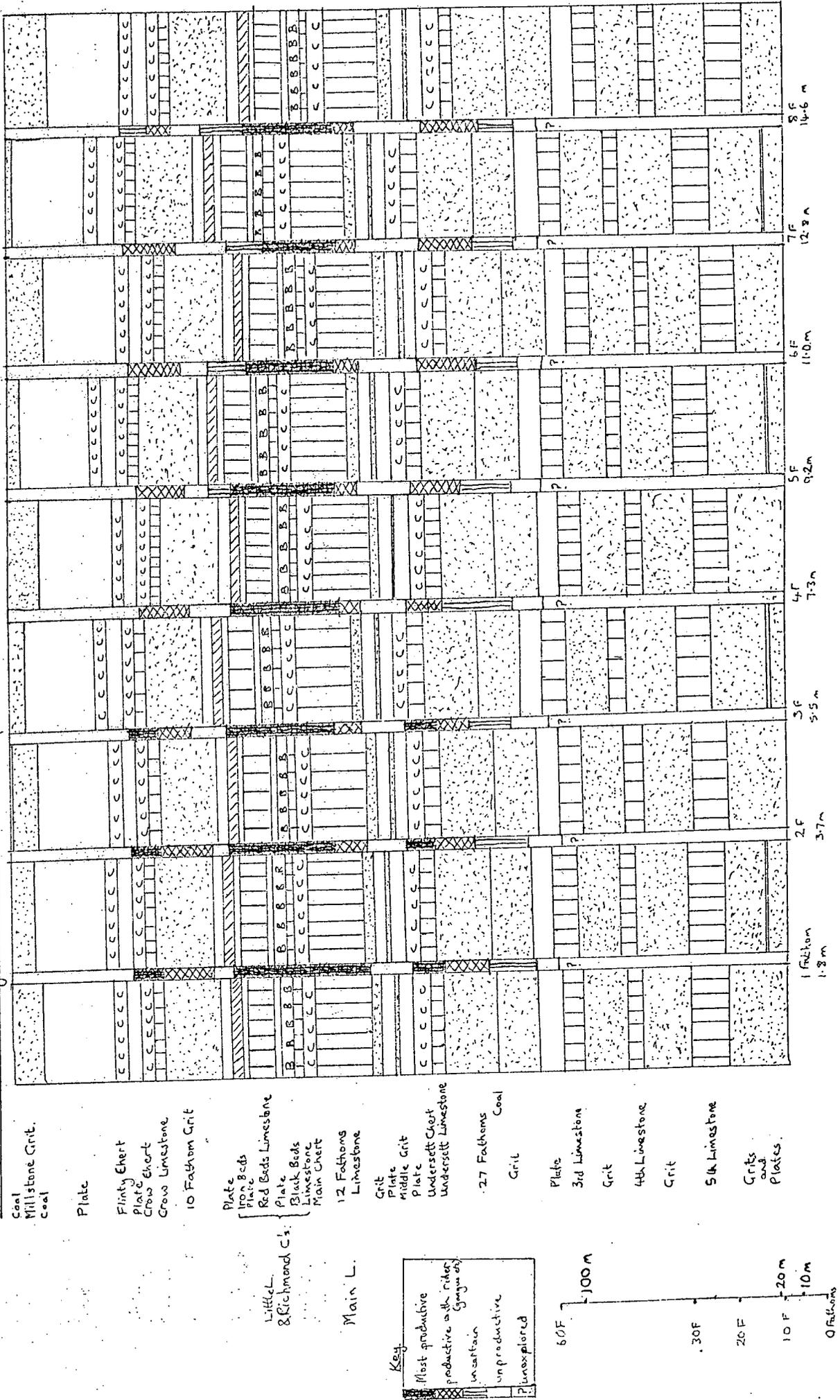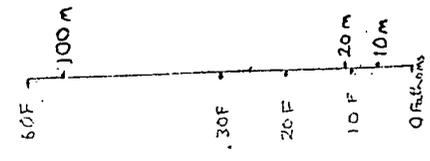
Extent of cherts (Undersett, Main, Richmond & Crow) and isopachytes for the Richmond Cherts: FIGURE 3.12

Based on Wells (1955) and 1" Geological Sheets.

x BARNARD CASTLE

outcrop of chert above
the Undersett L.

Main Chert

20m

10m

-C C

30m

40m

RICHMOND — U C

x
RICHMOND

Undersett
Chert

20m

Crow Chert

X AYSGARTH

10m

— † Richmond
Chert

KIRKBY x
STEPHEN

Outcrop
of chert
above the
Undersett L.

0   5 Km
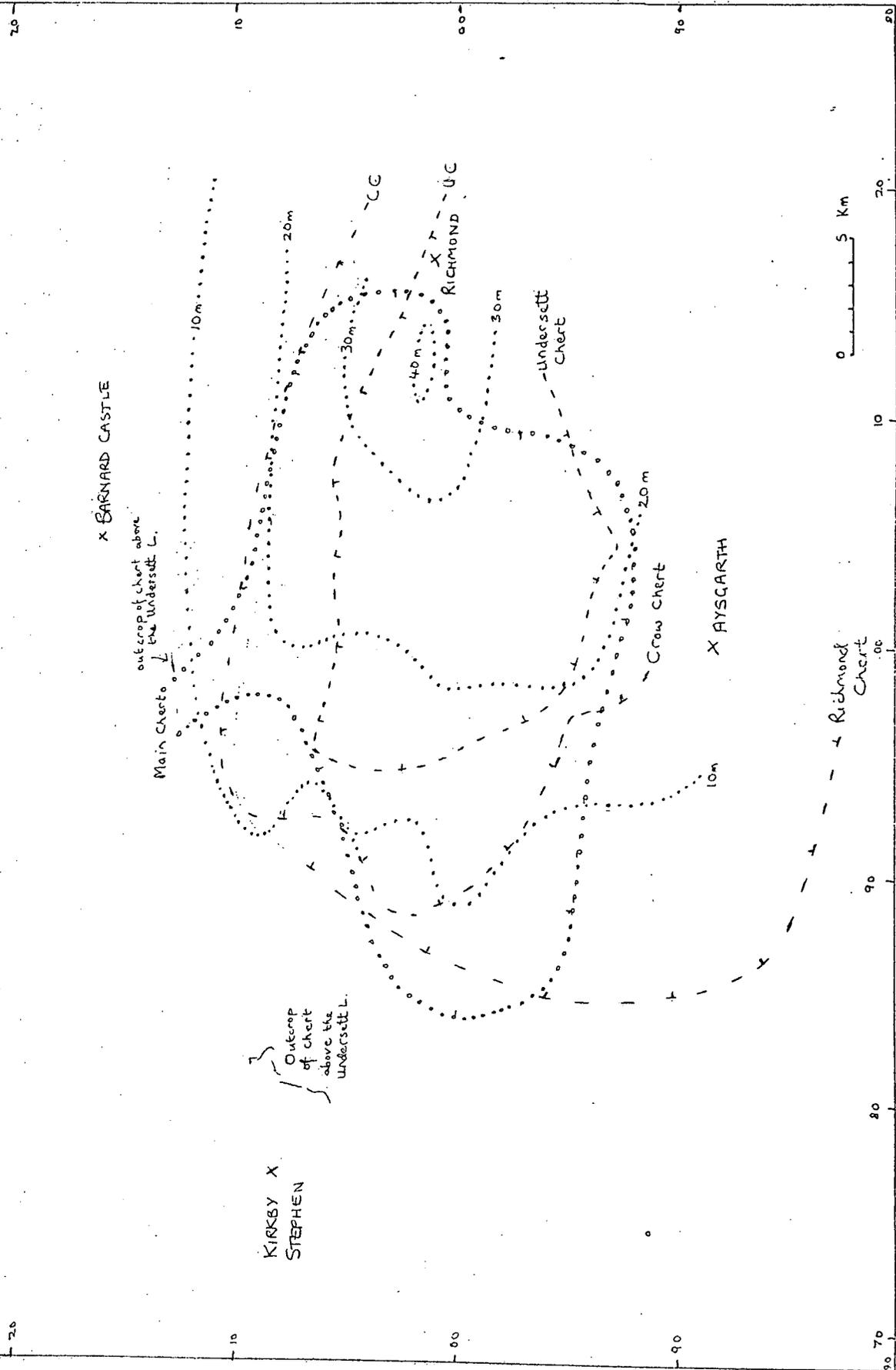
FIGURE 3.14: MAP OF THE MINERAL VEINS

Redrawn from 1" Geological Survey Sheets.

▲ BARNARD CASTLE

✗ RICHMOND

KIRKBY STEPHEN ✗

0 1 2 3 4 5 KM
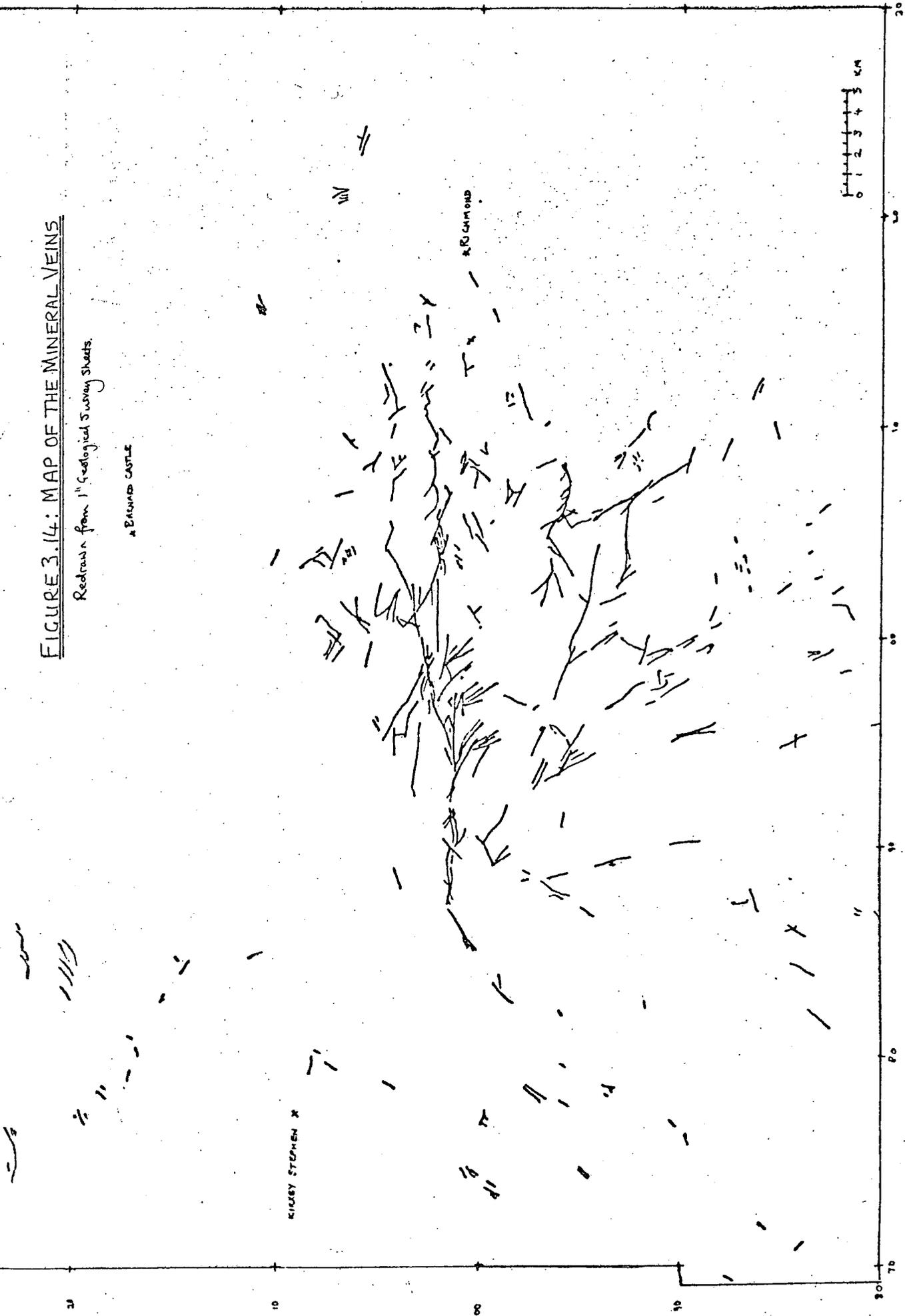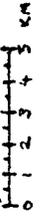
MINERAL OCCURRENCE

INTRODUCTION

The mineral zonation of the North Yorkshire Orefield is one of its most striking features. The nature of the mineral assemblages and their distribution in time and space will be discussed in this section, along with potential explanations.

MINERALS AND THEIR DISTRIBUTION

The following minerals have been found in the North Yorkshire Orefield:-

Quartz	Chalcopyrite	Pyrite
Fluorite	Tennantite-Tetrahedrite	Marcasite
Barite	Bornite	Hematite
Witherite	Chalcocite	Goethite-Limonite
Calcite	Digenite	Galena
Dolomite-Ankerite	Covellite	Cerussite
Siderite	Cuprite	Pyromorphite
Aragonite	Copper	Sphalerite
Barytocalcite	Chalcanthite	Smithsonite
Strontianite	Malachite	Hemimorphite
Gypsum	Azurite	Pyrolusite

In the text which follows mineral localities are given numbers that refer to the paragenesis tables (fig. 4.1) and map (fig. 4.2). The maps are inevitably simplified, and since there are a very large number of workings in the orefield, of which only a representative sample could be visited, the maps must show the minimum distribution. The actual distribution can not be expected to deviate significantly from that portrayed in these maps, although for instance, if new veins are discovered and investigated there might be some changes, especially in areas of few known

localities. All accessible reports of minerals have been assessed in making these maps, which has enabled slight enlargement of the distribution based on personal field investigation.

Quartz

Quartz has been found as vein fills (Fig. 4.3), as wallrock replacements (Fig. 4.3) and as chert nodules and beds in the Yoredale sequences. Stratigraphic evidence indicates that chert nodules and bedded cherts are all older than the observed mineralization. There are small veinlets of quartz sometimes of long prismatic crystals, which occur in the cherts. They are found in many places and relations observed demonstrate an origin earlier than mineralization.

Wallrock replacements by quartz are observed in the veins of the quartz+ chalcopyrite assemblage in Mallerstang (1-4), the quartz+fluorite+chalcopyrite assemblage (at Great Sleddale (6), Oughtershaw(5)), and at Mossdale Beck (14), and Cottriggs (12) of the fluorite (-quartz) assemblage. These localities form a coherent group (including Oughtershaw(5) allowing for topography) in the west of the orefield. Wallrock silicification was observed at North Stainmore (Augill Beck (7)) where a unique assemblage for this orefield is observed again in the west of the orefield. This locality is not obviously related to the others. Replacement quartz may be fine to coarse grained, but is mostly finer. Replacement generally avoids crinoid ossicles at least in its early stages. Small bypyramidal crystals are observed along bedding planes, and, within the limestone beds to a lesser extent, in some parts of the Central Pennines area and have been attributed to mineralization (Swarzacher 1958).

Quartz is observed filling veins and joints in the Mallerstang area (1-4) and at the Great Sleddale (6) and Oughtershaw(5). Allowing for topography, these localities form a coherent group. Quartz is also found filling stringers and stockworks at North Stainmore (7). Vein quarts is often massive or composed of aggregates of small pyramidal crystals.

Crustification textures are commonly observed along with vugs lined with well-formed crystals, thus demonstrating cavity filling. Quartz in the orefield is colourless to white, although there is an unconfirmed report of amethystine quartz from Grisdale Common (1) (Dakyns et al, 1891).

No compositional variation could be expected in quartz, save in its trace element content which is known to be small (Rösler & Lange 1972), and other than demonstrating negligible yttrium, and strontium, no chemical work on the quartz itself was undertaken. The leaching experiments described in Chapter A.6 involved quartz, and sodium/potassium ratios were determined for vein quartzes.

Quartz is carried in solution as hydrated silica and can be deposited by reduction of temperature or pressure, and is relatively insensitive to changes of pH and ionic strength in most geologically feasible environments (Holland, 1967). Silica is almost ubiquitous in sedimentary rocks so it is not necessary to seek a distant source for the quartz of this orefield. The metastable polymorphs of silica, e.g. crystobalite and amorphous silica are more soluble than quartz and may be significant in their contribution to hydrothermal solutions. Pressure dissolution at depth can also contribute to solutions.

In this orefield the restricted occurrence of quartz is one of the most important features of the zonation and its scarcity is probably of some importance in understanding the origin of the mineralization.

Fluorite

Fluorite has been found over a restricted area of the orefield (Fig.4.4). It is found with quartz at Great Sleddale (6), and Oughtershaw (5), without quartz or barite at Thwaite Beck (21), Arngill (22), Marble Scar (Gunnerside), Mossdale Beck (14), Worton (15), Seata (16), West Burton (17), and Keld Heads (18), and with barite over the remainder of its distribution. It is more abundant in the deeper levels and thus its distribution has been

markedly affected by topography. Fluorite occurs in the Main Limestone:-
around the edge of the quartz zone (Great Sleddale (6), Lover Gill (23),
Stags Fell (13)), between Gunnerside and Arkengarthdale (25, 26, 27, 28),
the west end of Copperthwaite Vein (29) and at Braithwaite (20). It occurs
at lower horizons in parts of Swaledale (Arngill (22), Thwaite Beck (21),
Marble Scar (Gunnerside), Friars Intake (24)), but unfortunately in
Swaledale, several promising horizons such as the Middle Limestone are not
well exposed. It occurs in the lower horizons in Wensleydale (14, 15, 16,
17, 18, 19) and in the top of the Great Scar Limestone along the southern
part of the Dent Line (8, 9, 10, 11).

Fluorite occurs as wall rock replacements in places, here dissemin-
ations are considered rather than cavity erosion and filling, though on a
moderate scale only at Longrigg (8) and Hartley Birkett (9). Cavity filling
fluorite (in veins and flats) occurs massive or as cubic crystals and is the
most common variety. Cubes of fluorite are sometimes inches across although
normally smaller.

No octahedra were found, but the octahedral cleavage of fluorite is
prominent. The predisposition of fluorite towards interpenetration twins,
and the production of inclusions in the central area of faces demonstrates
fluorite's strong growth along edges and corners, where a greater volume
of liquid is available for the diffusion of ions onto the growing crystal.
Replacement fluorite often takes on the grain size and features of the rock
it has replaced, and occasionally preserves fossils (especially corals).

Fluorite is often colourless, but is sometimes coloured pale to strong
amber. A purple colouration can occur, especially in replacements, and is
very strong at Worton (15), and occasionally strong at Friars Intake (24)
and High Longrigg (8). A paler purple, often almost a pink in colour, is
present as bands in fluorite from Hartley Birkett (9), Great Bell (10),
Seata (16) and Oughtershaw (5), and is occasionally seen in fluorite from

from the Gunnerside-Arkengarthdale Veins (25-28). Sometimes a little pale purple fluorite is found in otherwise colourless or amber fluorite areas. No fluorite of green or greeny-blue colour, so frequently seen in the Weardale Mines, has been observed and generally the fluorite of the whole orefield is less strongly coloured than Alston Block Fluorites. Colour in fluorite does not appear to bear any relationship to the mineral zonation or any other obvious feature.

Inclusions of chalcopyrite, or occasionally pyrite, are often found and produce a pleasantly spangled fluorite. There does not seem to be any geographically obvious variation in this phenomenon, but at Cottriggs (12), and Keld Heads (18), a distinct spangled fluorite is early and followed by a clear fluorite.

There were no signs of alteration or replacement of fluorite, but weathering of strongly spangled fluorite sometimes produces etched and corroded fluorites.

Little variation is known in the composition of fluorite other than of its trace content of yttrium and rare earth elements. An investigation into the yttrium content is described in Chapter A.5.

Fluorite dissolves sparingly in water to give at least a partly ionized solution. In brines the solubility is greater and is increased by raising the temperature. Below 200° C. it is probably reasonable to disregard complexes in the solubility of fluorite, but this may not apply in the situation where precipitation is from solutions which have gained their calcium and fluoride ions without the dissolution of fluorite. It is difficult to deposit significant quantities of fluorite by cooling alone if the ratio F/Ca is very different from 2.

From the experimental studies on fluorite reviewed in Holland (1967) and Smith,F.W., 74,the following methods of depositing fluorite can be suggested:-

1. Addition of excess calcium ions to a solution with fluoride ions.

2. Addition of excess fluoride ions to a solution with calcium ions.

3. Cooling of a saturated solution of calcium fluoride (F/Ca 2).

4. Change of pH (by affecting the stability of any fluoride complexes).

5. Reaction of fluoride brine with calcite (i.e. replacement).

It is unlikely perhaps that excess fluoride ions could be added to the solution from the country rock, but addition of excess calcium from the limestone country rock is a distinct possibility. The mixing of a fluoride rich/calcium poor brine with a fluoride poor/calcium rich brine would also be a possible method of depositing significant fluorite. Replacement of wallrock calcite by fluorite is easily demonstrated. A change of pH is perhaps not important at low temperatures but if complexing is significant it may have important effects. Cooling of a saturated solution of calcium fluoride may be significant if large volumes of brine have been involved, or as a contributing factor to other mechanisms, or in affecting the stability of any complexes.

The source of the fluorite in solution must be in two parts; source of calcium and fluoride ions. Calcium is abundant in the country rocks and a local origin for most of the calcium would be likely, but fluoride is not generally found in large amounts in the country rock and thus could be derived from:-

(a) sea water by connate processes of concentration, or

(b) a magmatic contribution, or

(c) dissolved apatites etc. in sediments.

Barite

Barite occurs in two very abundant forms, and several others that are less abundant, but often widespread (Fig. 4.5). The most important is massive platy barite which may be coarse, medium or fine grained. This variety of barite is most probably primary barite, although it is more

difficult to be sure of the fined grained examples. These massive varieties vary from colourless to white, to pink to red and can be clear or contain inclusions of chalcopyrite, or even galena. They are widespread in the orefield (Fig. 4.5), but the coarse variety is the less common, being found dominantly in the north western localities.

Primary massive platy aggregates often show crustiform textures and commonly contain sulphides, such as galena, grown competitively with the barite. Cockscomb aggregates were fairly common in places (e.g. Clouds) and part spheroid masses were observed in many places, e.g. Hurst (57), Longrigg (8).

The other widespread and distinctive variety is late or secondary toothy barite. This form occurs in porous to cavernous tree-like to pseudocoralline aggregates of toothy crystals of barite. The barite is mostly white in colour, though sometimes it is almost colourless and in other instances its surface is coloured yellow with iron staining. This form of barite is very abundant in certain localities, such as Watersykes Level (Gunnerside (52)), where witherite is common. It is most likely that this barite is secondary, having been produced by redistribution of barium, in many cases from witherite during oxidation. Sulphuric acid rich waters are able to react rapidly with witherite (or other carbonates) and dissolve and redistribute barite. Hence this structure and form, whilst suggesting the possibility of original witherite, could be produced by other means. The toothy variety of barite is always the youngest mineral-type observed, whenever it is found. It is common to see zoning in the crystals of these aggregates. No example of this form carrying inclusions of sulphide has been discovered. When aggregates contained a sulphide, for example, galena was occasionally observed in aggregates of toothy barite, the sulphide was always highly oxidized. In the case of galena it was coated heavily with cerrusite. There is no textural indication of original coexistence of sulphide with toothy barite.

Distinct platy or tabular crystals of barite were found on occasion and were clearly primary. They contained sulphide inclusions at times, and were sometimes earlier than squat calcites as at Middle Fell (35), or sulphides as at Keld (50, 51). At the latter locality an aggregate of bent tabular crystals of barite had interstices filled with galena.

Gossan barite was a variety commonly observed on the hill tops and was fairly abundant along the watershed between the Ure and Swale. It is generally in the form of a cavernous aggregate of mamilar sheets of barite often with limonite and occasionally containing "islands" of galena with thick rims of dark glassy cerrusite. The barite varies in colour from off-white, to yellow, to brown, to black and corresponds in some of these deposits to the limonitic jasper gossans common in many other types of deposit, where silica and silicates are more abundant. While relationships have not been studied in detail in thin section, it seems likely that the mamilar aggregates are local redistributions of the relatively low solubility barite, which may have been the primary mineral in many cases. The acid rich solutions available in gossans could cause redistribution of the barite.

A rather rare variety of barite occurred in localities with witherite and occasionally without the known presence of witherite. This form has been termed tuby barite and consists of very fine grained aggregates, forming small, long (1 or 2 cm long, 1-2 mm across) tubes after witherite fibres. Witherite is sometimes partially preserved in a cocoon of much less soluble barite. Other more complicated forms of aggregates with tube-like forms are also found "replacing" witherite. Several varieties of rather nondescript fine grained porous aggregates, of generally pure white barite, are also found in some witherite localities, and sometimes apparently "replacing" witherite. The tuby barite and rare barite pseudomorphs after pseudohexagonal witherite crystals were taken as the only certain evidence of original primary witherite if witherite is no longer present itself, though toothy barite should be regarded as a potential witherite associate.

An introductory examination of barite on the electron microprobe revealed that strontium was often present in measurable amounts (above 0.02%) and that it was far from homogeneously distributed in the crystals. A sample of late or secondary toothy barite from Watersykes level (52) was studied under the electron probe. Growth zone banding of birefringence which could be observed under polarized light was connected in some way to changing composition. A spot traverse (Fig. 4.6a & b) of a zoned crystal demonstrated wildly varying strontium values, with a strontium rich core and strontium poor exterior excepting a slightly enriched band near the crystal edge. A mechanical traverse of a nearby crystal with chart recorder output (Fig. 4.6c) gave a picture of even more extreme variations. Most points in the sample had low strontium values (i.e. $<$2,000 ppm) but occasional cores had the high values (up to 1.5%). A single specimen of toothy barite analysed by X.R.F. also gave low strontium content (Chapter A.5).

Samples of primary barite from Lunehead (33, centre of the vein), Gunnerside (25, banded with fluorite), and Hartley Longrigg (8, barite with some fluorite), were also studied. They all show strongly varying strontium content of 1.2% downwards (Fig. 4. 6d, e, f, g) but very low values are unusual, unlike in the toothy specimen from Watersykes. Strontium variations do not seem to correspond to variation of accompanying mineral (e.g. presence or absence of fluorite), and occur between adjacent crystals and within crystals, making interpretation difficult with the small amount of work done.

Barite is sparingly soluble in water and is present to a large extent as ions of barium and sulphate. Its solubility increases with temperature and with presence of dissolved salts (e.g. NaCl). It can be deposited from solutions by the following mechanisms:-

(a) Cooling of a saturated solution of barium sulphate

($Ba/SO_4 \simeq 1$) excess.

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(b) Addition of excess barium ions to sulphate solution.

(c) Addition of excess sulphate ions to barium solution.

(d) Sulphuric acid attack of witherite.

It is not possible to distinguish easily between the results of the first three, but the last method is definitely observable in the supergene environment, though unlikely to be significant in producing primary barite.

The source of sulphate ion is not known in this case, but in the Alston Orefield sulphur isotopes suggest the source may have been a Carboniferous Connate or Evaporitic brine (Solomon et al 1971). Sulphate ion can be enriched in brines by membrane filtration etc. or by oxidation of sulphide bearing brines. It can be produced in the supergene environment by oxidation of sulphides.

The source of barium is unlikely to be the country rocks, but enrichment in connate brines is a possibility, and so is addition from a magmatic source. Recrystallization of carbonates could yield barium and other elements (Shearman, 1972).

Witherite

Witherite occurs in many parts of the orefield, but mostly within the same geographical area as the barite (Fig. 4.7). It is abundant in relatively few veins, for example Baras End Vein, of the Surrender Mines, but its minor presence is widespread and indications of former presence (tuby barite) extend its distribution still further. Witherite does not survive well in supergene environments and the abundant presence of toothy barite in places probably represents witherite.

Witherite occurs commonly as massive "fibrous" aggregates sometimes in part sphere shaped, sometimes without any special shape, and sometimes as good pseudohexagonal crystals. It is generally a neutral grey-white colour with a greenish tint on occasion and a resinous lustre when fresh. It often contains inclusions of sulphides of many kinds and in large part must be considered a primary mineral.

Witherite contains small, but important amounts of strontium. Analyses of witherite are given on page *83* .

Witherite is slightly soluble in water, like calcite. Its solubility is very dependent upon the amount of carbon dioxide in solution and hence is less soluble at higher temperature, and lower carbon dioxide partial pressure. Its solubility is increased by the presence of large concentrations of alkali halides. Witherite is a rare mineral on a world scale, probably because very high ratios of Ba/Ca are required to precipitate witherite rather than calcite; furthermore barium has much lower natural abundance in the earth than calcium. The ratio required is higher at higher temperatures.

Witherite can be deposited by:-

(a) Addition of excess carbonate ions to a barium brine.

(b) Addition of excess barium to a carbonate brine

(c) Drop of partial pressure of carbon dioxide

(d) Replacement of calcite wallrock by witherite from barium rich/ calcium poor brine.

The boiling of solutions is not to be expected in brines of the low temperatures indicated from fluid inclusion, but addition of carbonate ions could be achieved by mixing brines or dissolving calcite from the wallrock. This calcite dissolving mechanism would be more likely to work at low rather than at higher temperatures. Addition of barium ions could be achieved easily only by the mixing of brines. The replacement mechanism has not been suggested by mineral relationships and so is perhaps not very likely.

Whatever the origin of the witherite its undoubted primary nature, at least in part, demonstrates the presence of some unusual solutions with very high barium/calcium ratios. This is important in understanding mineralization of the North Yorkshire Orefield.

Calcite

Calcite is one of the commonest minerals of the orefield. It has a wide distribution but is the major "gangue" mineral ovef a more restricted part of the orefield (Fig. 4.8) Calcite is an important gangue at Keld (50, 51), and in veins north and east of Arkengarthdale (53-59). Calcite occurs in many assemblages and positions in mineral sequences. It occurs in the wallrocks (limestones), in early joints (pre-mineralization), in metal-iferous veins and flats, and in post-mineralization deposits such as cave deposits. In the metaliferous veins and flats calcite commonly occurs massive, or as squat crystals. Less commonly it occurs as prismoidal, nail head, and dogs tooth crystals. It varies in colour from colourless to white, grey, and yellowish, but is mostly white. Sometimes it bears sulphide inclusions often of chalcopyrite, demonstrating deposition during mineral-ization.

In water, calcite is sparingly soluble, but its solubility increases with partial pressure of carbon dioxide. Its solubility is also increased by the addition of alkali halides, because of the effect of temperature on the CO_3, $H CO_3$, H_2CO_3, CO_2 equilibria, solubility is lower at higher temp-erature and hence calcite can not be deposited by the cooling alone of a saturated solution of calcite: indeed cooling almost guarantees increased solubility. Hence the deposition of calcite from hydrothermal solutions is a different problem to the other principal gangues (excluding witherite).

Calcite can be deposited by:-

(a) "Boiling" a solution of calcium bicarbonate i.e. lowering of $P CO_2$.

(b) Raising the pH of a solution of calcium bicarbonate.

(c) Replacement of other minerals.

(d) Redistribution of calcite from wall rock to vein etc. (fine grained dissolved, coarse deposited etc.) by pressure solution and deposition.

It is unlikely that degassing occurred in the low temperature brines
of this orefield so other mechanisms must be dominant, especially the last
mechanism of dissolving one kind of calcite in the wallrock and depositing
another in the vein.

Calcite does vary in its composition of minor elements and can give
interesting information about the ratios of metals in solution. Unfortunat-
ely time did not permit an investigation of its composition during this work.

Dolomite-Ankerite, Siderite

Dolomite-ankerite minerals are found frequently in the orefield, but
in most cases only as a wallrock replacement. In a very few cases e.g.
Cottriggs (12), Worton (15), they form vein carbonate, at least in part.
Wallrock replacements are most likely at the dolomite end of the solid
solution with only minor ankerite. The amount of dolomite produced must
be large and represents a very important stage in the mineralization.
Wallrock calcite is easily dolomitized by brines which have Ca/Mg less than
unity (sea water ≏.2). If the brine is rich in iron then a more ankeritic
replacement occurs or even a sideritic replacement. On the Alston Block
the iron rich replacements are common with some veins, but in the North
Yorkshire Orefield the magnesium replacements are more important, and
siderite is rare.

Aragonite

Aragonite is a late mineral and may be post-mineralization. It is
found largely as mamilar sheets of fibrous aggregate or occasionally as a
late filling of cavities in porous dolomitic or galena bearing wallrock.
It is seen largely on the watershed areas and its distribution (Fig. 4.8)
is probably greater than indicated since its presence was not always sought,
largely because on no occasion was it observed bearing any sulphide and only
once could its relationship to an ore or gangue mineral be ascertained.

Barytocalcite

Barytocalcite was first reported by Bradley (1862) to be present in the veins of the Old Gang Mine. There are further reports for Lane End Mine (49) and Keld (50, 51) (Dunham & Dines, 1945). None of these were confirmed, but the mineral is undoubtedly to be found in the Hard Level Gill area (Old Gang Mines etc.). This mineral and Alstonite, a similar double carbonate, are not easily distinguished in the field without the discovery of good crystals; unfortunately none were discovered in the course of this project. The geochemistry of these minerals is not published, but it is likely they require high Ba/Ca ratios like witherite, in order for deposition to occur.

Strontianite

Strontianite has been reported with witherite at the tips of Victoria Level (Hard Level Gill area), but unfortunately these tips have not been visited and its presence elsewhere has not been observed. The conditions of deposition of strontianite are unusual and it is extremely unlikely it could be deposited at temperatures above 200°C (Holland, 1967).

Gypsum

Gypsum has been found in the tips at Great Bell (10), but its appearance and associations suggest that its presence is due to the oxidation of pyritous shale in the supergene environment. Gypsum has no known close relationship to the ore minerals in the North Yorkshire Orefield.

Pyrite–Marcasite

Pyrite is found only rarely in the orefield. This is in large part due to its rapid oxidation in supergene environments. Goethite pseudomorphs are occasionally found along with unaltered pyrite in large pieces of limonite rock. Pyrite is occasionally found as inclusions in fluorite and barite, but not as importantly as chalcopyrite. Marcasite is similar to pyrite in being rarely found and easily oxidized. It is occasionally found

with galena, and goethite pseudomorphs after marcasite are found in a few localities. Marcasite is found with pyrite, and both are found most frequently in the heavily mined areas. They are probably both well distributed over the orefield, but because of their apparent scarcity it is hard to be sure if there is a pattern to their distribution. The dominant iron bearing sulphide is actually chalcopyrite.

The deposition of iron sulphides can be produced by various mechanisms similar to other sulphides and so will be considered with other sulphides later. It should here be mentioned, however, that there is a common belief that marcasite is deposited from acid solutions and it has been reported to be a supergene mineral. This would seem unlikely in the North Yorkshire Orefield since there is at least one example of galena replacing marcasite

A microprobe analysis of probable diagenetic pyrite partly replaced by bornite from East Leyton (62) showed approximately 5000 ppm copper.

Hematite, Goethite-Limonite

There are so-called hematite workings in the Longrigg (9) area just east of Kirkby Stephen, where the Carboniferous limestones are reddened beneath the Permian unconformity. True hematite like the Cumbrian hematite, is not however to be found, but there is goethite in abundance, which may have been called hematite or may grade into hematite. Goethite and limonite (goethite rocks) are common in the gossans and elsewhere as replacements, especially of chalcopyrite. Replacements of pyrite are more complete though less common, and limonite boxworks are commonly sphalerite. Powdery limonite is common as an oxidation product of dolomite-ankerite and where wallrock alteration has occurred it often shows up vein positions on scarps.

Hematite bands (or perhaps goethitic bands) are sometimes present in the vein material (generally barite) and are apparently primary. Red barite is probably coloured by fine coatings of iron oxides or hydrated oxide.

Galena PbS

Galena has been the principal ore mineral of the orefield and is widely distributed, although restricted in that it is not found in the Q zone (Fig. 4.14). Galena is sometimes rare in localities where it has been mined, because it has been extracted effectively by the miners. Galena is generally found as coarse anhedral to euhedral grains in veins, and generally as good euhedra in flats and disseminations. It commonly replaces calcite of the wallrock and forms good cubes, octahedra and combinations of them. More rarely it is fine grained, or occasionally "steely" (schistose). Galena contains rare inclusions of other sulphides, mainly chalcopyrite. The composition of galena is variable only in its minor element content (Chapter A.5).

Galena in this orefield is probably precipitated from acid sodium chloride brines near the neutral point. The lead is probably carried as chloride complexes and galena can be crystallized from such solutions near 100°C by:-

(a) Change in pH towards neutrality

(b) Cooling

(c) Dilution

(d) Increase in reduced sulphur by 1. sulphate reduction

2. mixing of solutions

An important account of the chemistry of galena and sphalerite crystallization from brines as described above, is due to Anderson (1973) and these above mechanisms probably apply also to other sulphides. An important mechanism for other sulphides is replacement of one sulphide by another.

Cerussite Pb CO_3

Cerussite is the most important oxidation produce of galena and in the gossans constitutes a high proportion of the lead. Good crystals of

cerussite were nowhere observed, and it occurs mostly as dark glassy rims to galena or in some cases as a grey vitreous heavy mineral in thoroughly secondary material. White cerussite is also observed in small amounts. X-Ray diffraction often proves useful in rapidly identifying gossan minerals. The distribution of cerussite is linked to galena, since the two are always found together. Cerussite was not examined for compositional variations.

Pyromorphite $Pb_5(P\,O_4)_3\,Cl$

Pyromorphite is a rather rare mineral in the orefield. It is an oxidation product of galena once again, but was only found in the veins between Gunnerside and Arkengarthdale. Good specimens often with barrel shaped crystals occur at the west end of the Old Rake Vein Tips. They are a dark-medium green colour. X-Ray patterns of this material revealed a much more complicated pattern than had hitherto been published. The material was analysed on the electron microprobe and Mr. R. G. Hardy obtained further high quality diffraction data, which was computer processed by him for the powder diffraction file. A copy of the pyromorphite card is reproduced here (Fig. 4.9). The analysis revealed the specimens to be of the pure phosphorus end member with no replacement by arsenic.

The exact origin of the pyromorphite is not clear since no other phosphorus minerals have been seen in the tips, but there are phosphorus minerals present in some of the limestone, and the element could have been concentrated in the biosphere and then reacted with the galena to produce this interesting mineral.

Sphalerite $(Zn, Fe)\,S$

Sphalerite is only found with galena, but in amounts varying from a trace up to a sphalerite dominance. Zinc ore has not been worked in this orefield although there are localities where substantial quantities of sphalerite are found in tips, such as at Keld (50, 51), Apedale (41). The original proportion of sphalerite is hard to estimate because it is rapidly

oxidised and removed leaving holes with limonite boxworks as the only evidence of its previous existence. In the deposits in valley bottoms, sphalerite is often important, but on the watersheds it is rare to find anything more than boxworks, although large pieces of galena sometimes preserve sphalerite within.

Sphalerite is generally massive but is occasionally found as well formed crystals. It sometimes contains inclusions of chalcopyrite, and perhaps pyrite. It is generally a brown of pale-medium shade and probably has low iron content, normal for sphalerite from low temperature deposits like these. It is possible to analyse compositional changes of sphalerite on the electron probe, but time only permitted a few estimates of cadmium, silver, mercury, and manganese by X.R.F. analysis, and no probe study was undertaken.

Sphalerite is probably precipitated by the same factors as galena, since they have extremely strong natural association and have similar chemistry (Anderson, 1973).

Smithsonite Zn CO_3

This mineral is not very common as a distinct mineral species, but is more abundant as white oxidation coatings on sphalerite. One good specimen of smithsonite in pale green mamilar layers was found at Friars Intake (24).

Hemimorphite Zn_4 Si_2 O_7 $(OH)_2$ H_2O

Although reported as a common mineral in several memoirs, this mineral was not confirmed. Most suspected specimens (pale mamilar sheet aggregates) were shown rapidly by X-Ray diffraction to be barite. The mineral may be present in the white coatings of some specimens of sphalerite. In general even such white coatings were not abundant, with limonite boxworks or holes being the principal oxidation product of sphalerite.

Pyrolusite MnO_2

Minor amounts of black dusty coatings were found in the tips at Longrigg (8). These coatings gave very weak goethite X.R.D. patterns with

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high backgrounds, suggesting the presence of a mixture largely of manganese oxide, with a little goethite. Specimens of sphalerite from Longrigg (8) and Hartley Birkett (9) show small amounts of manganese, and pyrolusite dendrites are occasionally found on joint planes in limestones and in massive barite in cracks etc.

Chalcopyrite Cu Fe S$_2$

This is perhaps the most widely found sulphide in the orefield, although its abundance is very variable. It is the principal sulphide, found with quartz, and also occurs in favourable proportions at Clouds (11) and Longrigg (8) and in the eastern copper rich area at Feldom Fault (60), Richmond (61) and East Leyton (62). It is present in lesser amounts in the rest of its area and in places occurs only as inclusions in fluorite or barite. Chalcopyrite does not occur as euhedral crystals, it is normally found massive or as anhedral grains. Specimens from East Leyton (62) show platy chalcopyrite occasionally forming radiating clusters, and small plate inclusions inside calcite and barite crystals.

Compositionally, chalcopyrite is almost constant except for its minor elements. Tin can participate in the lattice to some extent, but has not been discovered in analyses of chalcopyrite from this orefield. Tin was found in X.R.F. analyses of this mineral from Groverake Mine in Weardale. Electron probe study confirmed its presence and demonstrated an apparently unsystematic heterogeneity of concentration. No tin was found in the chalcopyrite from this orefield either by X.R.F. analysis or in two specimens investigated on the electron probe. Chalcopyrite analysed by electron probe from Hanging Level Scar Veins (0326) had 3,400 ppm Lead, 6,100 ppm Silver and around 1% Arsenic. None of these elements was found in other analyses except for a sample of chalcopyrite coexisting with Arsenopyrite from South Crofty, Cornwall, which had 1,400 ppm As. The results of minor element X.R.F. studies are on pp.

Chalcopyrite can be precipitated in the usual ways for sulphides (pH change, dilution, cooling, increase of S = replacement).

Tennantite-Tetrahedrite $(Cu, Ag)_{10} (Cu, Fe, Zn)_2 (As, Sb)_4 S_{12-13}$

Fahlore is an uncommon mineral found in two localities only. At Clouds, one vein carried tennantite and the copper ore raised included a fair proportion of this "grey copper ore". At Hanging Lund Scar trials showed chalcopyrite and a tetrahedrite. Both fahlore minerals are dark grey minerals much duller than galena. They can be easily seen in hand specimen in these localities but in view of their inconspicuous appearance they could be present in other deposits in very small amounts without being spotted in the field. Laboratory examination of the many specimens of ore minerals collected failed to extend the distribution of the fahlore mineral group, although more polished sections might have extended the distributions.

It is not possible to ascertain composition of fahlore without resorting to the electron microprobe, or other microanalytic technique. X-Ray diffraction gives approximate information on the position in the tennantite-tetrahedrite solid solution series. Analyses of the two varieties found in the North Yorkshire Orefield, demonstrated two different varieties to be present.

The analyses and proposed formulae are given overleaf.

The zonal positions of the two specimens i.e. tetrahedrite in the Q zone and tennantite in the F zone is significant, and the iron/zinc ratio reflects the same pattern. The pattern is one of progressive crystallization rather than temperature dependence.

All of the analyses show a low silver content, which is disappointing since in many overseas deposits a lot of the silver production comes from the fahlores. The low silver content confirms that this element is not abundant in this orefield. The tennantite from Clouds (11) shows a minor content of lead. This was checked thoroughly, as reports of lead in fahlore have previously been discounted as impurity. It is not easy to imagine

exactly where the lead is sited. Perhaps the (Silver I, Copper I) lattice site is most likely.

The deposition of fahlores is probably similar to the sulphides, but probably relies more upon replacement, which is commonly observed in polished sections.

Analyses –

	Tetrahedrite from Hanging Lund Scar				Tennantite from Clouds			
	Analysis 1		Analysis 2		Analysis 1		Analysis 2	
	Wt %	At %	Wt %	At %	Wt %	At %	Wt %	At %
Cu	39.74	34.95	39.7	34.3	43.63	35.04	43.5	35.20
Ag	.16	.07	.2	.08	0.09	0.04	.4	.19
Fe	2.45	2.45	2.2	2.2	4.57	4.17	4.5	4.13
Zn	4.25	3.60	4.2	3.6	2.92	2.28	3.4	2.68
Pb	.33	.08	.3	.09	1.61	0.39	1.5	.37
As	4.43	3.30	10.3	7.52	19.28	13.13	18.5	12.70
Sb	25.88	11.92	21.2	9.55	2.24	0.93	3.0	1.26
S	24.95	43.57	25.0	42.8	27.59	43.99	27.2	43.50
Totals	102.19	100	103.1	100	101.93	100	102.0	100

Formulae –

Tetrahedrite 1 $(Cu_{10.21}, Ag_{0.02})(Fe_{0.72}, Zn_{1.05}) Pb_{0.02} (As_{0.96}, Sb_{3.48}) S_{12.73}$

2 $(Cu_{10.2}, Ag_{0.02})(Fe_{0.65}, Zn_{1.07}) Pb_{0.03} (As_{2.24}, Sb_{2.84}) S_{12.74}$

Tennantite 1 $(Cu_{10.12}, Ag_{0.01})(Fe_{1.20}, Zn_{0.66}) Pb_{0.11} (As_{3.79}, Sb_{0.27}) S_{12.71}$

2 $(Cu_{10.0}, Ag_{0.05})(Fe_{1.18}, Zn_{0.76}) Pb_{0.11} (As_{3.62}, Sb_{0.35}) S_{12.65}$

Tetrahedrite 1 $(I)_{10.2} (II)_{1.77} (IV)_{0.02} (III)_{4.44} S_{13.31}$

2 $(I)_{10.2} (II)_{1.72} (IV)_{0.03} (III)_{5.08} S_{12.74}$

Tennantite 1 $(I)_{10.1}(II)_{1.86} (IV)_{.11} (III)_{4.06} S_{12.7}$

2 $(I)_{10.1} (II)_{1.94}(IV)_{.11}(III)_{3.97} S_{12.65}$

All formulae are expressed for $Cu + Ag + Fe + Zn = 12$ atoms/formula. In each case analysis 1 is a point analysis and analysis 2 an average of 5 points. In all cases the high totals probably reflect the correction data for As $L\alpha_1$ radiation.

The following atomic ratios are useful for comparisons of fahlores.

	For Tetrahedrite (1, 2)	For Tennantite (1, 2)
Cu/Ag =	500 and 430	880 and 185
Fe/Zn	.68 and .61	1.83 and 1.54
As/Sb	0.28 and .79	14 and 10

Both carry Lead 3,300 ppm in tetrahedrite and 1.6% in tennantite

Bornite $Cu_5 Fe S_4$

Bornite is not a common mineral in this orefield being found only in the eastern copper deposits at East Leyton (62), Kneeton Hall (63), and Middleton Tyas (64) (reported only). Bornite is not easily spotted in hand specimens, but, with difficulty, reflective pinky grains or films can be seen when fresh, and when tarnished "peacock" ore colours are observable. In this orefield bornite occurs as replacement of other sulphides. At East Leyton (62) diagenetic pyrite nodules have been partly converted to bornite, and at Merrybent Mine, Kneeton Hall (63) galena has been replaced by bornite. "Peacock" ore was reported in the account of the Middleton Tyas Mines (Raistrick, 1936). In polished section, bornite is a distinct fleshy pink colour. Its reflectivity when measured was anomalously low, but no further work has been carried out to ascertain why. An electronprobe analysis of bornite from East Leyton gives copper/iron atomic ratios of 4.65 and 4.87. The ideal value is 5 and these lower values reflect the replacement occurrence and consequent high iron content.

Chalcocite Cu_2S

Chalcocite has been found only in the eastern copper deposits at

Kneeton Hall (63), and Black Scar Quarry (64), it has also been reported from Middleton Tyas. In hand specimen, chalcocite is a dull grey-black sulphide mostly with malachitic coatings. In polished section, it is a bright bluish white. Chalcocite at Kneeton Hall replaces further the original galena and also the later bornite and digenite. Chalcocite at Black Scar Quarry has been found as slab in a joint and nodules by Deans and Wells (Wells, 1954). In a sample (at Durham) from the joint, a replacement origin could not be proved, but is suggested. No analyses of chalcocite were made.

Digenite $Cu_{1.97}S$

This mineral has been found in small amounts replacing bornite at East Leyton (52) and Kneeton Hall (63). It is a more blue, isotropic, less reflective mineral than chalcocite when seen in polished section. A very fine grained aggregate with similar properties was seen in a polished section from Clouds (11) to have replaced galena in places, and is also thought to be this mineral. Distinctly blue rims to chalcopyrite are occasionally seen in polished section. They are isotropic and less reflective than chalcocite and thus are presumably this mineral. (Covellite is easily distinguished by reflection pleochroism and bright interference colours). These rims are part of the supergene process, and indeed in all cases this mineral would appear to have that origin.

Covellite $Cu\ S$

This mineral has been found fairly abundantly at East Leyton (62), Kneeton Hall (63), and is also found at Black Scar Quarry (64). In hand specimen it is a black dusty mineral, but under the hand lens can often be seen to be composed of small needles frequently with malachite also present. In polished section, it is probably one of the most beautiful minerals, being bright blue to pale blue pleochroic, and with bright oranges, etc., as interference colours. It is generally found as needle like crystals or radiating bundles of them. At East Leyton it fills in cracks, etc. along

with malachite and may be a secondary precipitate. At Kneeton Hall it replaces chalcocite, etc., and is present as large sector twinned crystals. At Black Scar Quarry it occurs in nodules with malachite, as small crystals. At East Leyton it is also seen replacing bornite along its cleavages (along with chalcopyrite) and forms an interesting pattern. In learning microprobe techniques attempts were made to analyse these lamellae in bornite, but their small size prevent successful analysis. Little chemical variation would, however, be expected.

Cuprite $Cu_2 O$

This is only rarely found, but is present at Black Scar Quarry (64) in the nodules, and in traces at East Leyton. It may have been important at Middleton Tyas. In hand specimen this mineral is red, but at Black Scar Quarry it is mixed in part with limonite and thus it is impossible to see, except in polished specimen. At East Leyton (62) rare red grains are found with the black dusty covellite etc., and my be cuprite. In polished section cuprite is pale blue, with dark red internal reflections under crossed nicols. Cuprite is an oxidation product of other copper minerals.

Copper Cu

Native copper has been found only at Black Scar Quarry (64) but was apparently worked at Middleton Tyas (Raistrick 1936). It can not be seen in hand specimen, but in polished section is a very distinct bright (highly reflective) pink mineral surrounded by cuprite. Copper is produced as the height of supergene enrichment.

Chalcanthite $Cu S O_4 6H_2O$

This highly soluble mineral was reported by Wells (1954) at East Leyton (62) but was not confirmed in this study.

Malachite and Azurite

Malachite is ubiquitous in the presence of chalcopyrite. It is found as coatings and occasionally as stellate aggregates of fibres. It is the most widespread oxidation product of copper mineralization.

Azurite is also found as coatings, but is less widespread and less abundant than malachite. No explanation for this difference in abundance is obvious, but it may be connected with the plentiful supply of carbon dioxide or carbonate radical in the oxidation of the deposits of the North Yorkshire Orefield.

PARAGENESES AND RELATIONSHIPS

The suite of minerals found at any locality in the orefield has been termed a paragenises for the purposes of this work, it is slightly different from the common usage which refers to the distribution of minerals in time. One of the difficulties of this usage is that it does not take account of the many and varied assemblages, which may occur at one locality. These assemblages may have been deposited at different times and/or in different lode positions. Unfortunately working on an old orefield, with material collected largely from tips, it is difficult or unwise to do more than suggest the different assemblages that are or were present before and after the mining activity began. Attempts have been made to determine the orders of crystallization present and thus in some way to define the assemblages that are or were present. These orders of crystallization are sometimes difficult to collate; but the approximate time distribution of minerals can be recovered with varying degrees of success. They have been portrayed in the paragenesis diagrams (Fig. 4.1).

Each locality area has been given a diagram, rather than reproducing many individual tip diagrams, which would inevitably make interpretation more difficult. The locality area has been given a name, which is generally the same as the subheading in the description of deposits, and also a number which is referred to on the map of paragenesis localities (Fig.4.2), and in the text. The topmost dashed horizontal line divides crystallization sequences into wallrock replacement and vein filling. When the dashed line "dips" it is meant to indicate that replacement has begun with one mineral

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after replacement with another mineral has ceased. A lower horizontal dashed line separates primary from secondary (supergene or oxidation) minerals. The vertical lines represent the deposition of minerals during the mineralizing sequence. The top of the diagrams represent the older minerals, and the bottom the youngest. The line width gives an indication of the relative abundance of the mineral at that time. The letters denote the mineral name; so that:-

q = quarts, f = fluorite, d = dolomite, c = calcite, b = barite,

w = witherite, a = aragonite, cp = chalcopyrite, tet = tetrahedrite,

s = sphalerite, g = galena, ten = tennantite, bth = toothy barite,

btb = tuby barite, p = pyrite, m = marcasite, ce = cerussite,

bg = barite gossan, l = limonite, bo = bornite, nd = digenite,

ch = chalcocite, co = covellite, ma = malachite, ct = calcite tufa.

Most primary minerals have a vertical column to themselves. Secondary varieties are in the most appropriate columns. Unlike more conventional diagrams of crystallization sequences, in these diagrams the overlapping of mineral ranges does not necessarily mean the two minerals coexist, however, they are thought to have been crystallized at a similar stage in the mineralization. Hence interbanded fluorite and barite is represented by two vertical lines covering similar ranges, not to signify they were synchronous, but that they were deposited at closely related times. The poor quantity and quality of information that is available in many localities means that the diagrams can be of only limited accuracy, but they are an advance on just producing a list of minerals.

The paragenesis diagrams are organized in such a way that similar parageneses are found together whilst taking account of geographical proximity as much as possible. There are fourteen primary minerals, which means approximately 16,000 mathematically possible combinations of them. The number of actual parageneses is limited by the number of localities and the

geological control of parageneses, but there are still more than 41 for 62 localities. A simplification is required to help interpret them. If the parageneses are treated as if they only contained a smaller number of minerals, it is possible to produce tables showing the localities which have the different parageneses.

When restricted to five "gangue minerals" an analysis is obtained which is summarized in Table 4.1. This demonstrates that of 31 potential paragenseses, only 16 are actually represented by localities. The distribution is highly uneven within these sixteen, the most populous paragenesis being calcite + barite (16 localities), next is fluorite + calcite + barite (9 localities), and the numbers drop through the remaining 14 parageneses tabulated. The simplest explanation of the heterogeneous distribution is that minerals have different spatial distributions over the orefield, and that the widespread minerals tend to occur together in the most populous parageneses whilst the less widespread minerals occur in the lowly or unpopulous parageneses. Hence barite, calcite and fluorite dominate the populous part of the table and are the most widespread, whilst quartz and witherite dominate the unrepresented and lowly populated parageneses, and are the least widespread.

A similar restriction of the paragenesis to five "ore minerals", results in an analysis summarized in Table 4.2. This demonstrates that of 31 potential parageneses, only 13 are represented.

Of course the real explanation of the population distribution must explain the spread of the various minerals, so that it is necessary to find geological explanations for the non-existence or abundance of mineral combinations. These geological explanations must wait until the distributions are more clearly laid out both as mineral paragenesis versus locality population, and as mineral paragenesis versus geographical position. It is also necessary to turn to the more detailed observations regarding the time sequences at the localities, and the actual relationships of minerals.

If the two simplifications are combined to give an analysis of 5 ores and 5 gangue minerals, we have 41 parageneses represented out of a possible 1023 (Table 4.3) but only 63 localities to produce them. An attempt is made in Table 4.4a to simplify the last analysis into something more meaningful. All the figures regarding Tables have, so far, used the locality number so that parageneses can be referred to a map, but it is also useful to tabulate the number of localities. This has been done in Table 4.4b. Histograms to show the relationships visually are presented as Figs. 4.10, 11.

The histograms of number of areas with specified mineral occuring in each assemblage (Fig. 4.10) show the abundance and distribution of minerals in the composition space. Histogram 4.10a of total populations shows a very definite maximum in the barite-fluorite assemblage with slightly lower value in the barite+fluorite assemblage.

The ore minerals (b, c, d = ccp, sph, gal) peak at these assemblages - but in each case a different pattern is shown and corresponds to zonal expectations.

Histogram 4.10e of total populations is more uniform, but gangue minerals have less uniform distributions.

The histogram of proportion of areas of each assemblage with a specified mineral (Fig. 4.11) distort the abundance slightly but show the relationships rather better. Barite (g) is uncommon with chalcopyrite alone but is very common and uniformly occuring with other sulphide assemblages. Quartz (d) is principally associated with chalcopyrite. Fluorite (e) peaks with the sphalerite, galena, chalcopyrite assemblage, but is otherwise a little more common with chalcopyrite, and chalcopyrite with galena, than assemblages minus chalcopyrite. Witherite (f) has a peak with chalcopyrite, galena, sphalerite, and is slightly more common on the chalcopyrite side than galena. Calcite (h) peaks with sphalerite and galena, but is common over all. The sulphide relationships are also readily observed.

The simplified parageneses are marked on the map of the orefield (Fig. 4.12) to demonstrate geographic relations which are quite difficult to appreciate. The cluster of A's in the west of the orefield (Mallerstang) is perhaps the most obvious feature. This is the focus of the orefield referred to in many parts of this thesis. There is a cluster of g's and i's along the bottom of Wensleydale, and another of i's along the Dent Line, and it is possible to distinguish other groupings in other parts of the orefield.

A wider interpretation of parageneses has been given in Fig. 4.13, showing the mineral zones of the orefield. This map has been drawn with due regard for topography and also the abundance of minerals. The zones are referred to a great deal in this thesis.

By comparison with the zonal schemes of other areas (e.g. Dunham(1948) (Alston Block),Park (1955)) the Q zone would appear to be the innermost zone and is surrounded by the F, P, and C zones. The orders of crystallization and mineral relationships shortly to be described give support to this interpretation.

In the Alston Orefield, quartz and chalcopyrite are found at vein intersections in the heart of the orefield, shown to be hot spots and feeders of the veins by fluid inclusion studies of the associated fluorite (Smith, E.W., 74)

The actual relationships of minerals as observed in the laboratory and field, are summarized in part in Fig. 4.14. The diagram shows the five common primary gangue minerals. They are linked by lines which are thick and solid when probable ~~coexistence~~ simultaneous crystallization is common, thin and solid when rarer, and dashed when not known to ~~coexist~~ occur. Arrow heads point to the younger mineral in observed crystallization sequences. The size of the head indicates the number of relationships observed.

The following notes on relationships are partly summarized in Fig. 4.14.

1. Quartz and fluorite: This pair were found together commonly enough in appropriate parageneses, but quartz was nearly always earlier than the fluorite, although rarely later and perhaps coexisting.

2. Quartz and barite: These were only found together rarely and barite was always later than quartz.

3. Quartz and calcite: When found together calcite was later than quartz.

4. Quartz and witherite: Were nowhere found together.

5. Quartz and chalcopyrite: Frequently found together. Probably coexisting.

6. Quartz and galena: Only found together at Augill, but probably coexist.

7. Fluorite and witherite: This pair is not commonly found together in hand specimens, but where found fluorite is possibly coexisting at times and later on other occasions, although relationships are not clear. Co-existence would be important and since the pair can not both be deposited in equilibrium at room temperature, it may be possible with appropriate experiments to estimate minimum temperature of formation.

8. Fluorite and primary barite: This pair sometimes appear to coexist, but were more often found as separate bands, and sometimes rhythmically interbanded. In several localities most or all of the fluorite was earlier than barite.

9. Fluorite and calcite: In the fluorite zone, calcite was usually found later than fluorite and not very often in contact with it. It is unlikely that they would coexist, but if they did the F/CO_3 ratio of the solutions could be estimated if the temperature was known.

10. Fluorite and chalcopyrite: These were frequently found together and definitely coexist.

11. Fluorite and galena: Found together commonly and definitely coexist.

12. Fluorite and sphalerite: Were found together commonly and probably coexist.

13. Primary barite and witherite: These minerals were seldom found together and when they did occur the barite was later than witherite.

14. Primary barite and calcite: These minerals were often found together, but calcite was generally later than the barite. Sometimes they were inter-banded, but were not observed to coexist.

15. Primary barite and chalcopyrite: Were often found together and definitely coexist.

16. Primary barite and galena and/or sphalerite: Were often found together and definitely coexist.

17. Witherite and calcite: These were never found together and it would be unlikely that they were synchronous. Barytocalcite would be more likely to occur at least at slightly elevated temperatures.

18. Witherite and ore minerals: Were occasionally found together and definitely coexist.

19. Calcite and chalcopyrite: Often found together and definitely coexist.

20. Calcite and galena: Often found together and probably coexist.

The coexistence of minerals can sometimes be useful in establishing the relative concentrations of ions in the mineralizing solution. If calcite was found coexisting with fluorite, for instance, then it would be possible to estimate the fluoride-carbonate ratio if the temperature was known and an approximate equilibrium had been in operation during crystal-lization. It is noticeable that such coexistences of suitable "gangue" minerals are not found. The coexistince of sulphides could, in principle, be used, but is complicated by the complexing in solution etc. If a mineral pair does not coexist then the maximum or minimum relative concentrations may be determined. The principal use of this is to give some restrictions on the kind of solutions involved in mineralization. Table 4.6 gives the ion ratios which would be expected for some mineral pairs. Unfortunately the values in the table have been calculated for $25^{\circ}C$, but the sort of

ratios at 100°C are not very different unless sulphide or carbonate ions are involved. Using hydrothermal mineral assemblages to establish the kind of solutions depositing them is explained in Barton et al (1967). The solubilities and free energies used to make up the table were taken from Krauskopf (1967). One of the principal anomalies the table reveals is that fluorite and witherite should not coexist at 25°C, but the carbonate-fluoride equilibrium of calcium moves towards fluoride faster than that of barium when temperature is increased. Thus a temperature will occur when the fluorite-witherite pair is stable. This gives a minimum temperature for their coexistence. If their coexistence could definitely be proved, this would be a useful piece of evidence in deciding the temperatures of the deposits, which could be cross checked by fluid inclusion thermometry on the fluorite. Looking at Table 4.6 and the assemblages known in the orefield approximate solution data can be established. We obtain therefore (approximately only) –

$$10^{-20} < \frac{[S]}{[SO_4]} \quad \text{solution} < 10^{2.3} \quad \text{from galena and barite}$$

$$10^{-2} < \frac{[CO_3]}{[S]} \quad \text{solution} < 10^{12} \quad \text{from sphalerite and witherite}$$

$$10^{20} < \frac{[S]}{[F]^2} \quad \text{solution} \quad \text{from galena presence}$$

$$10^{-1.2} < \frac{[SO_4]}{[CO_3]} \quad \text{solution} < 10^{3.75} \quad \text{from barite and calcite}$$

$$10^{-4.1} < \frac{[SO_4]}{[F]^2} \quad \text{solution} < 10^{6} \quad \text{from fluorite and barite}$$

$$10^{2.9} < \frac{[CO_3]}{[F]^2} \quad \text{solution} \quad \text{from witherite presence (depends on temperature)}$$

$$\frac{[Cl]^2}{[S]} \quad \text{solution} < 10^{2.4} \quad \text{from galena presence}$$

$$10^{-4.6} < \frac{[Ca]}{[Ba]} \quad \text{solution} < 10^{5.4} \quad \text{from barite and fluorite presence}$$

$$\frac{[Sr]}{[Ba]} \quad \text{solution} < 10^{3.5} \quad \text{from barite presence}$$

$$10^{1.25} < \frac{[Ca]}{[Sr]} \quad \text{solution} \quad \text{from calcite presence}$$

$[Pb]/_{[Zn]}$ solution $\simeq 10^{-3.7}$ from coexistence of sphalerite and galena

$10^{-2.3} \langle [Ca]/_{[Mg]}$ solution $\simeq 10^{1}$ from presence of fluorite, and dolomite and calcite

The spatial distribution of mineral occurrence, the crystallization sequences and mineral relationships have a common relationship to some large scale control of the orefield.

Progressive crystallization of a single solution or progressive change in composition of a crystallizing solution by mixing are potential mechanisms for producing crystallization sequences. Some veins, of course, show much interbanding which is evidence of fluctuating conditions rather than the progressive change which occurs elsewhere. The zoning of minerals could be explained simply by movement of progressively crystallizing solutions which would cause deposition of some minerals close to source and others further away. It is possible to explain some features of zoning by having a spatial variation of initial solutions, but this is not a very satisfactory mechanism. Further discussion of the meaning of zonation will occur in Chapters A.5, 6, 7, when the nature of large scale control is discussed.

<u>TABLE 4.1 - ANALYSIS OF PARAGENESIS LOCALITIES USING ONLY</u>
<u>FIVE "PRIMARY GANGUE" MINERALS - q, f, c, w, b.</u>

<u>Parageneses found</u>

Minerals	Localities
c, b	35, 39, 40 41, 42, 43, 45, 47, 50, 51, 53, 54, 56, 58, 59, 60
f, c, b	8, 9, 10, 11, 12, 19, 20, 29, 30
f, c	14, 15, 16, 17, 18, 21
c	32, 37, 38, 61, 63
c, w, b	44, 46, 52, 55, 62
f, c, w, b	13, 24, 27, 28, 57
b	33, 34, 36, 48
f, w, b	23, 25, 26
q	1, 2
q, c	3, 4
f	22
q, f	5
q, b	7
f, b	31
c, w	49
q, f, b	6

<u>Parageneses not found</u>

w, q w, f w, w b, q f c, q f w, f c w, q c w, q c b, q w b, q f c w,

q f c b, q f w b, q c w b, q f c w b.

TABLE 4.2 – ANALYSIS OF PARAGENESIS LOCALITIES USING ONLY FIVE "PRIMARY ORE" MINERALS – cp, g, s, p, m

Parageneses found

Minerals	Localities
cp	1, 2, 3, 4, 5, 6, 14, 21, 31, 61, 62
g	10, 29, 32, 35, 36, 38, 39, 42, 48, 53, 58
cp, g	7, 8, 11, 23, 27, 33, 34, 45, 60, 63
cp, g, s	9, 12, 16, 18, 20, 24, 26, 55, 57
g, s	17, 30, 37, 46, 47, 52, 59
cp, g, s, p	13, 19, 25, 49
g, s, p	41, 50, 51
g, p	22, 56
g, m	40, 54
cp, g, p	15
cp, g, m	44
cp, g, p, m	43
cp, g, s, p, m	28

Parageneses not found

s, p, m, cp s, cp p, cp m, s p, s m, p m, cp s p, cp s m, cp p m, g s m, s p m, g p m, cp g s m, g s p m, cp s p m.

TABLE 4.3 – ANALYSIS OF PARAGENESIS LOCALITIES COMBINING 5 ORES AND 5 GANGUES

cp, q	1, 2	cp, g, s, f, c, w, b	24, 57
cp, q, c	3, 4	cp, g, s, p, f, w, b	25
cp, q, f	5	cp, g, s, p, f, c, w, b	13
cp, q, f, b	6	cp, g, s, p, f, c, b	19
cp, f, c	14, 21	cp, g, s, p, m, f, c, w, b	28
cp, f, b	31	cp, g, s, c, w, b	55
cp, c, w, b	62	cp, g, s, p, c, w	49
cp, c	61	g, s, f, c	17
cp, g, q, b	7	g, s, f, c, b	30
cp, g, f, c, b	8, 11	g, s, c, w, b	46, 52
cp, g, f, c, w, b	27	g, s, p, c, b	41, 50, 51
cp, g, f, w, b	23	g, s, c, b	47, 59
cp, g, c, b	45, 60	g, s, c	37
cp, g, c	63	g, p, f	22
cp, g, p, f, c	15	g, f, c, b	10, 29
cp, g, m, c, w, b	44	g, b	48, 36
cp, g, p, m, c, b	43	g, c, b	35, 39, 42, 53, 58
cp, g, b,	33, 34	g, p, c, b	56
cp, g, s, f, c	16, 18	g, m, c, b	40, 54
cp, g, s, f, c, b	9, 12, 20	g, c	32, 39
cp, g, s, f, w, b	26		

TABLE 4.4a   X = assemblage includes iron sulphide

		A	B	C	D	E
		cp	cp, g	cp, g, s	g, s	g
a	q	1, 2	–	–	–	–
b	q, c	3, 4	–	–	–	–
c	q, f	5	–	–	–	–
d	q, b	–	7	–	–	–
e	q, f, b	6	–	–	–	–
f	f	–	–	–	–	–
g	f, c	14, 21	15^x	16, 18	17	22^x
h	f, b	31	–	–	–	–
i	f, c, b	–	8, 11	9, 12, 20, 19^x	30	10, 29
j	f, w, b	–	23	25^x, 26	–	–
k	f, c, w, b	–	27	24, 57, 28^x, 13^x	–	–
l	b	–	33, 34	–	–	48, 36
m	c, b	–	43^x, 45, 60	–	47, 59, 41^x, 50^x, 51^x	35, 39, 42, 53, 58, 56^x, 40^x, 54^x
n	w, c, b	62	44^x	55	46, 52	–
o	c	61	63	–	37	32, 38
p	c, w	–	–	49	–	–

TABLE 4.4b

	A	B	C	D	E	
	cp	cp, g	cp, g, s	g, s	g	
a	2	0	0	0	0	q
b	2	0	0	0	0	q, c
c	1	0	0	0	0	q, f
d	0	1	0	0	0	q, b
e	1	0	0	0	0	q, f, c
f	0	0	0	0	1	f
g	2	1	2	1	0	f, c
h	1	0	0	0	0	f, b
i	0	2	4	1	2	f, c, b
j	0	1	2	0	0	f, w, b
k	0	1	4	0	0	f, c, w, b
l	0	2	0	0	2	b
m	0	3	0	5	8	c, b
n	1	1	1	2	0	w, c, b
o	1	1	0	1	2	c
p	0	0	1	0	0	c, w

TABLE 4.5 - NUMBER OF LOCALITIES WITH EACH SIMPLIFIED PARAGENESIS

	cp	cp, g	cp, g, s	g, s	g	Total
$q^{\pm}$	6	1	0	0	0	7
$f^{\pm}$	5	5	12	2	3	27
$w^{\pm}$	1	3	8	2	0	14
$b^{\pm}$	2	11	11	8	12	44
b-f	0	7	1	7	8	23
$c^{\pm}$	7	9	12	10	12	50
Total	11	13	14	10	15	63

TABLE 4.6: LIMITING ION RATIOS (at 25°C)

Ratio			
$\dfrac{[S^=]}{[SO_4^=]}$	Anglesite / Galena $PbSO_4 < 10^{-14.7} < PbS$	Barite $BaSO_4 < 10^{23} < BaS$	
$\dfrac{[CO_3^=]}{[S^=]}$	Galena / Cerussite $PbS < 10^{14.4} < PbCO_3$	Witherite $BaS < 10^{-2.2} < BaCO_3$	Sphalerite / Smithsonite $ZnS < 10^{12} < ZnCO_3$
$\dfrac{[F^{-2}]}{[S^=]}$	Galena $PbF_2 < 10^{20} < PbS$		
$\dfrac{[SO_4^=]}{[CO_3^=]}$	Witherite / Barite $BaCO_3 < 10^{1.2} < BaSO_4$	Calcite / Gypsum $CaCO_3 < 10^{3.75} < CaSO_4\cdot2H_2O$	
$\dfrac{[SO_4^=]}{[F^{-2}]}$	Fluorite / Gypsum $CaF_2 < 10^{6} < CaSO_4\cdot2H_2O$	Sellite / Barite $BaF_2 < 10^{-4.1} < BaSO_4$	
$\dfrac{[CO_3^=]}{[F^{-2}]}$	Fluorite / Calcite $CaF_2 < 10^{2.15} < CaCO_3$	Sellite / Witherite $BaF_2 < 10^{2.9} < BaCO_3$	
$\dfrac{[Cl^-]}{[S^=]}$	Galena $PbS < 10^{23.7} < PbCl_2$		
$\dfrac{[Ca^{++}]}{[Ba^{++}]}$	Witherite / Calcite $BaCO_3 < 10^{0.45} < CaCO_3$	Barite / Gypsum $BaSO_4 < 10^{5.4} < CaSO_4\cdot2H_2O$	Sellite / Fluorite $BaF_2 < 10^{-4.6} < CaF_2$
$\dfrac{[Sr^{++}]}{[Ba^{++}]}$	Witherite / Strontianite $BaCO_3 < 10^{-0.8} < SrCO_3$	Barite / Celestine $BaSO_4 < 10^{3.5} < SrSO_4$	
$\dfrac{[Ba^{++}]}{[Sr^{++}]}$	Strontianite / Calcite $SrCO_3 < 10^{12.5} < CaCO_3$	Celestine / Gypsum $SrSO_4 < 10^{1.9} < CaSO_4\cdot2H_2O$	Fluorite $SrF_2 < 10^{1.8} < CaF_2$
$\dfrac{[Ca^{++}]}{[Mg^{++}]}$	Fluorite $MgF_2 < 10^{-2.3} < CaF_2$	Dolomite $MgCa(CO_3)_2 < 10^{1} < CaCO_3$	
$\dfrac{[Pb^{++}]}{[Zn^{++}]}$	Sphalerite / Galena $ZnS < 10^{-3.7} < PbS$		

FIGURE 4.1 : PARAGENESIS TABLES

Grisdale Common- 1.
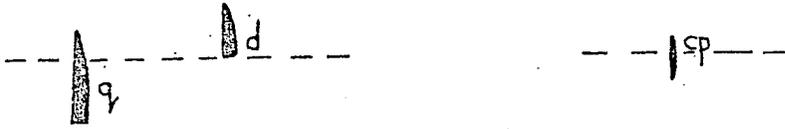
Hanging Lund Scar- 2.

Far Cote Gill- 3.

Dandra Garth- 4.
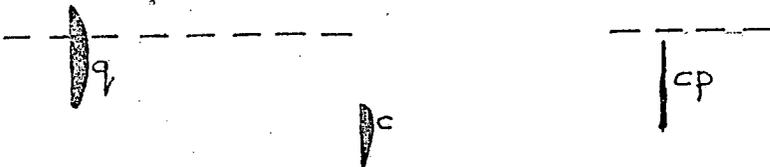
Beckermonds, Oughtershaw- 5.
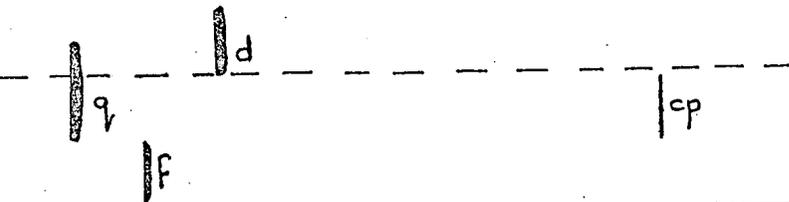
Great Sleddale- 6.
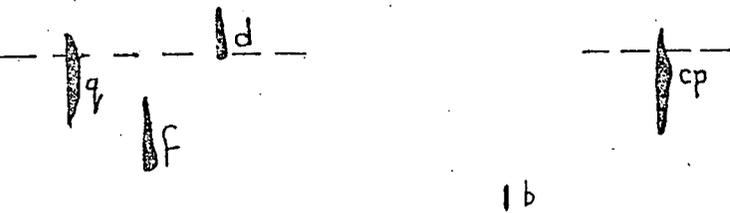
North Stainmore, Augill -7.

Longriggs- 8.

d

f

c

b

cp

g
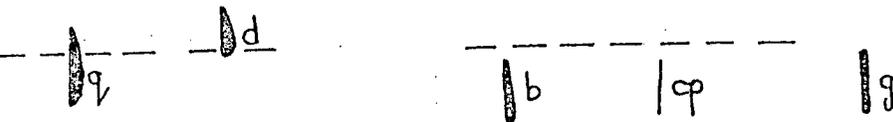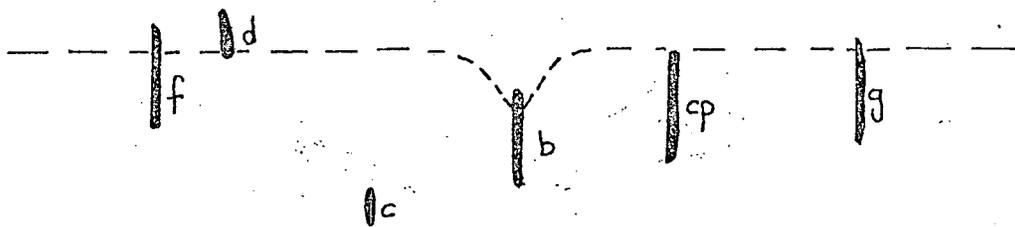
Siderite
Haematite

Hartley Birkett- 9.
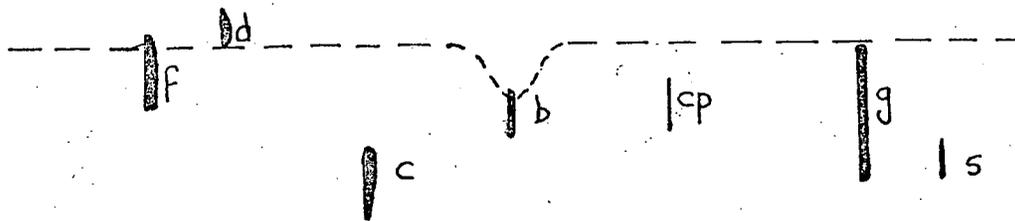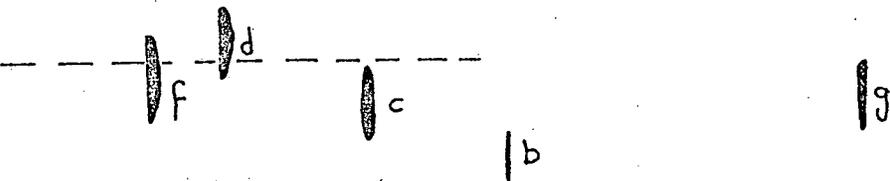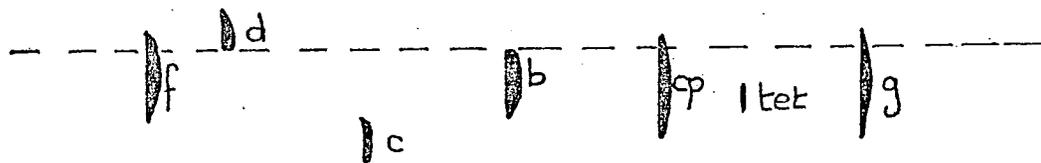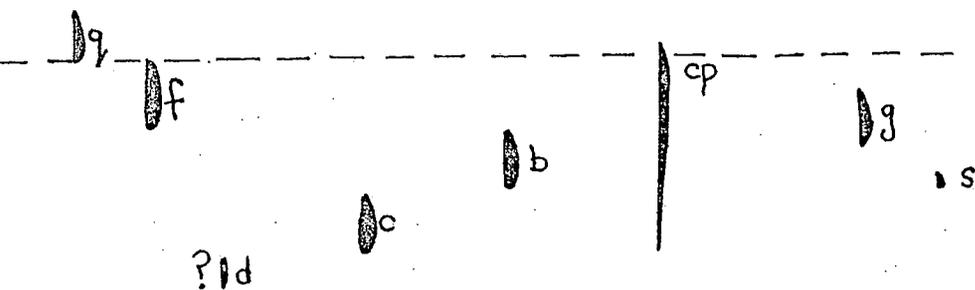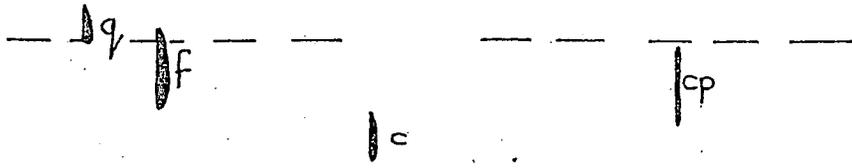
d

f

c

b

cp

g

s

Great Bell- 10.

d

f

c

b

g

Clouds- 11.

d

f

c

b

cp   tet

g

Cottriggs-12.

q

f

d

c

b

cp

g

s

Staggs Fell- 13.

f   w   c

cp

g   s   p

b

btb

bth

Mossdale Beck- 14.

q f   cp

c

Worton- 15.

f d   p

c   cp   g

Seata- 16.

f   cp   g   s

c

West Burton- 17.

f   c   g   s

Keld Heads- 18.

f d   cp   g   s

c

Wet Grooves- 19.

f   c   b   cp   g   s   p

bth

Braithwaite- 20.

f   cp   g

b

c   s
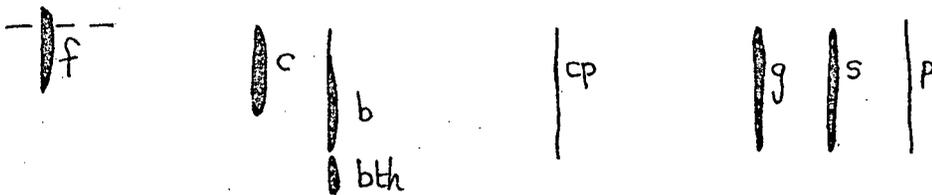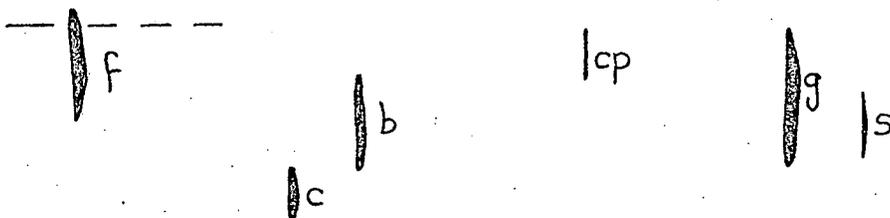
Thwaite Beck- 21.

)f   )c |cp

Arngill- 22.

− −)f − −   − −)g − − |p

Lovergill- 23.

)f |φ |g

     |w |b
     |btb |bth

Friars Intake- 24.

−)f − − |w   )b   )cp   )g |s
)c
                              − −|− Smithsonite.

Gunnerside(Old Rake, etc.)-25.

−)f ᵈd |w −   )b |cp   )g |s |p
)bth | Pyromorphite.

Old Rake(East End)- 26.

     ᵈd
)f |w   )b |cp   )g |s
 not observed
  together

Friarfold- 27

)f |w)c)b |cp   )g
)bth

Arkengarthdale—(Hungry Hushes, etc.)—28.

| d | | | | | | | | |

| f | w | c | b | cp | g | s | p | m |

bth

Copperthwaite (West End)— 29.

f

? c   b   g

High Scar Mine— 34.

d

f   b   g   s

c

Angerholme— 31.

f   b   cp

Stoneclose Gill— 32.

c   g

Lunehead— 33.

b   g

cp

Cabbish Mine—   34

b   cp   g

Middle Fell— 35.

— d — —   b   g

c

Dodd Fell- 36.

— d

b

g

ce

Wasset Fell- 37.

— d —

c

?|a

g̅ |s

ce

Providence- 38.

— d — —

c

a

g

Sargill- 39.

— d —

c

a ?b

— g —

Satron and Summerlodge Moors- 40

— d

c

?b

a

bg

g — |m

ce

Apedale Mines- 41.

— d —

c   ?b

g   s   P

Carperby- 42.

— d —

c

b

— g

Harkerside- 43.

d
c   b |cp   g |p |m
bg   ce   l

Grinton- 44.

|w c |cp   g |m
btb ct   bg   ce   l

Ellerton- 45.

d
c |cp   g
bg   ce

Cobscar- 46.

'f
|w   b   g s
c
btb   bg   l

Downholme- 47.

d
b   g s
c

Great Sleddale- 48.

b   g
l

Lane End - Pry Hill- 49.

w c |cp   g s |p

Beldi Hill- 50.

c   b   g   s   p

bth

Swinnergill- 51.

c   b   g   s   p

Gunnerside- 52.

d

w   c   b   g   s

btb   bth   Limonite
                      Hematite

Stang- 53.

— d —   c   — g —

bth

Faggergill- 54

— d — —   — — g — ? m

c

b

Windegg Level- 55.

— d — — —   cp   g   s

w

c

btb   bth

Windegg Vein- 56.

— d —   — g —   p
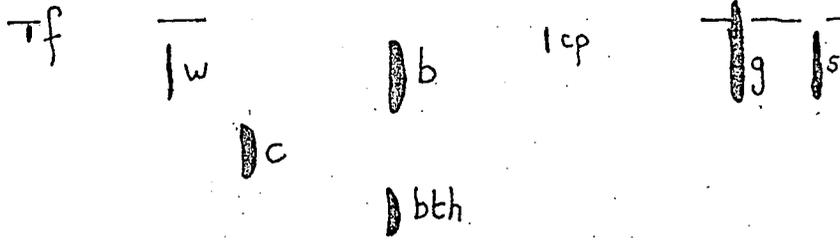
b

c

Hurst- 57.

Tf   ̅w   ▮b   ▮cp   ▮g ▮s

▮c

▮bth

Hellwith- 58.

▮c

▮b   ▮g

Cleaburn Pasture- 59.
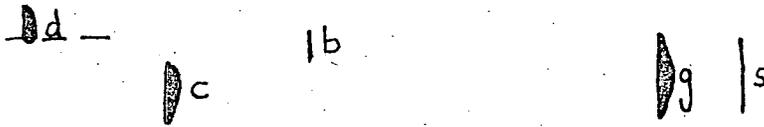
▮d —   ▮b

▮c   ▮g ▮s

Feldom Fault- 60.

—▮d — —   ▮cp

▮b

▮c   ▮g

Richmond Old Mines-61.

▮c   ▮cp

East Leyton Quarry- 62

—▮d   ̅w — —   ▮b   ▮cp

▮c

▮bpo   ▮ numerous copper minerals.

Kneaton Hall- 63.

▮c   ▮g

▮cp

▮bo
▮nd
▮ch
▮co
▮ma
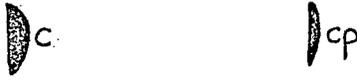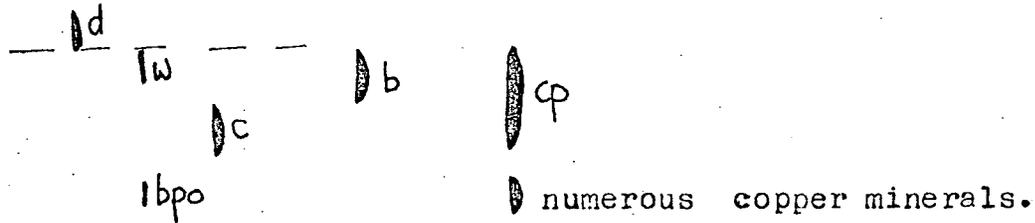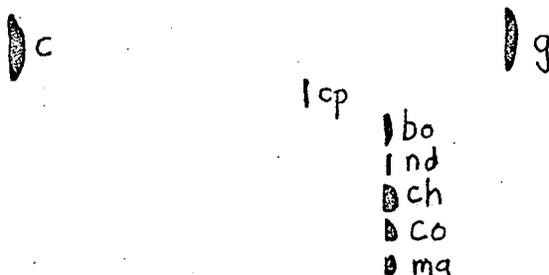
Black Scar Quarry- 64.

Enrichment and oxidation copper minerals

KEY TO FIGURE 4.2

1. Grisedale Common
2. Hanging Lund Scar
3. Far Cote Gill
4. Dandra Garth
5. Beckermonds, Oughtershaw
6. Great Sleddale
7. North Stainmore
8. Longriggs
9. Hartley Birkett
10. Great Bell
11. Clouds
12. Cottriggs
13. Staggs Fell
14. Mossdale Beck
15. Worton
16. Seata
17. West Burton
18. Keld Heads
19. Wet Grooves
20. Braithwaite
21. Thwaite Beck
22. Arngill
23. Lovergill
24. Friars Intake
25. Gunnerside (Old Rake, etc.)
26. Old Rake (East End)
27. Friarfold
28. Arkengarthdale
    (Hungry Hushes, etc.)
29. Copperthwaite (West End)
30. High Scar Mine
31. Angerholme
32. Stoneclose Gill
33. Lunehead
34. Cabbish Mine
35. Middle Fell
36. Dodd Fell
37. Wassett Fell
38. Providence
39. Sargill
40. Satron and Summerlodge Moors
41. Apedale Mines
42. Carperby
43. Harkerside
44. Grinton
45. Ellerton
46. Cobscar
47. Downholme
48. Great Sleddale
49. Lane End - Pry Hill
50. Beldi Hill
51. Swinnergill
52. Gunnerside
53. Stang
54. Faggergill
55. Windegg Level
56. Windegg Vein
57. Hurst
58. Hellwith
59. Cleaburn Pasture
60. Feldom Fault
61. Richmond Old Mines
62. East Leyton Quarry
63. Kneaton Hall
64. Black Scar Quarry

FIGURE 4.2: PARAGENISIS LOCALITIES
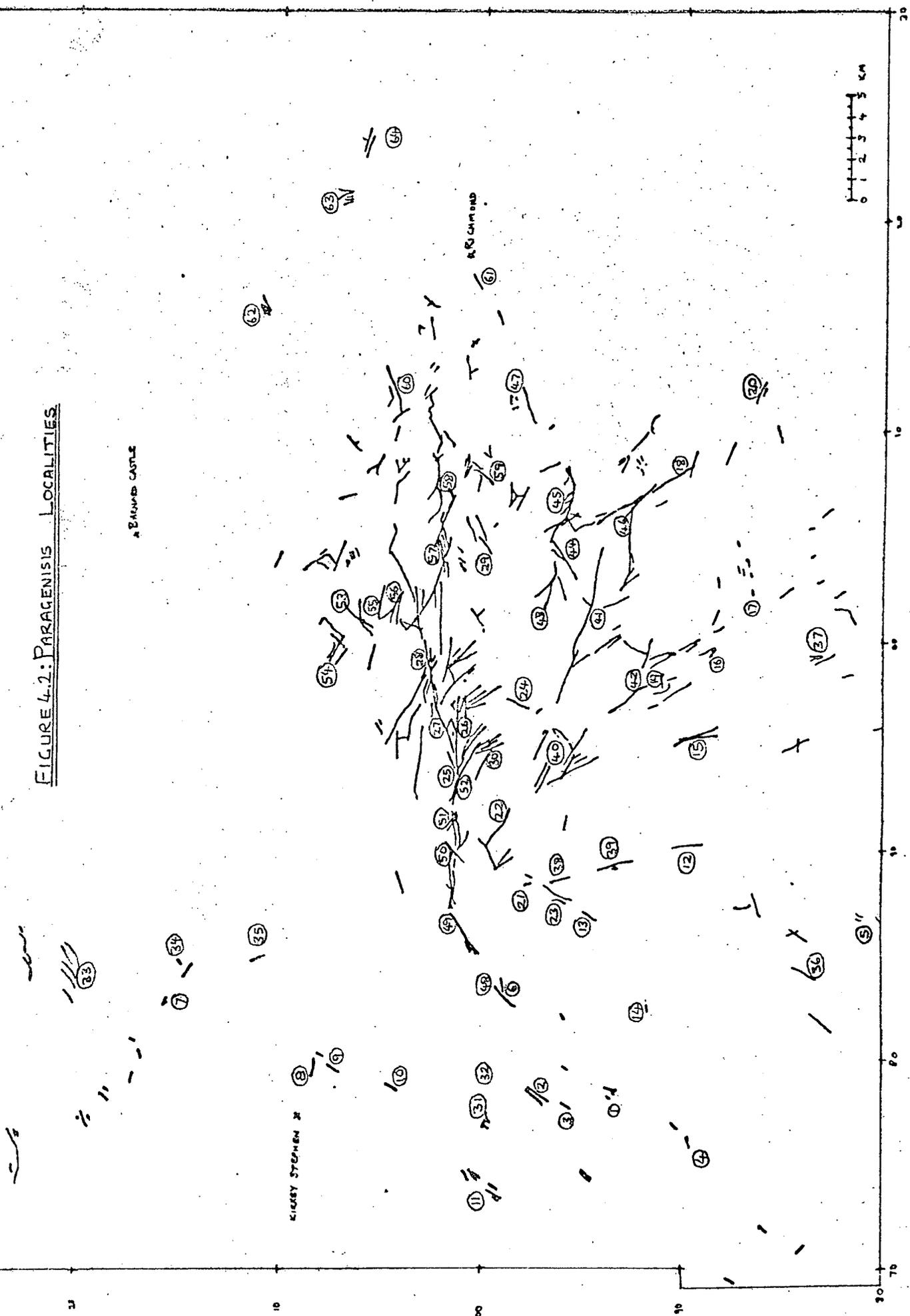
FIGURE 4.3: DISTRIBUTION OF QUARTZ

o Silicified wallrock ⊙ Vein quartz
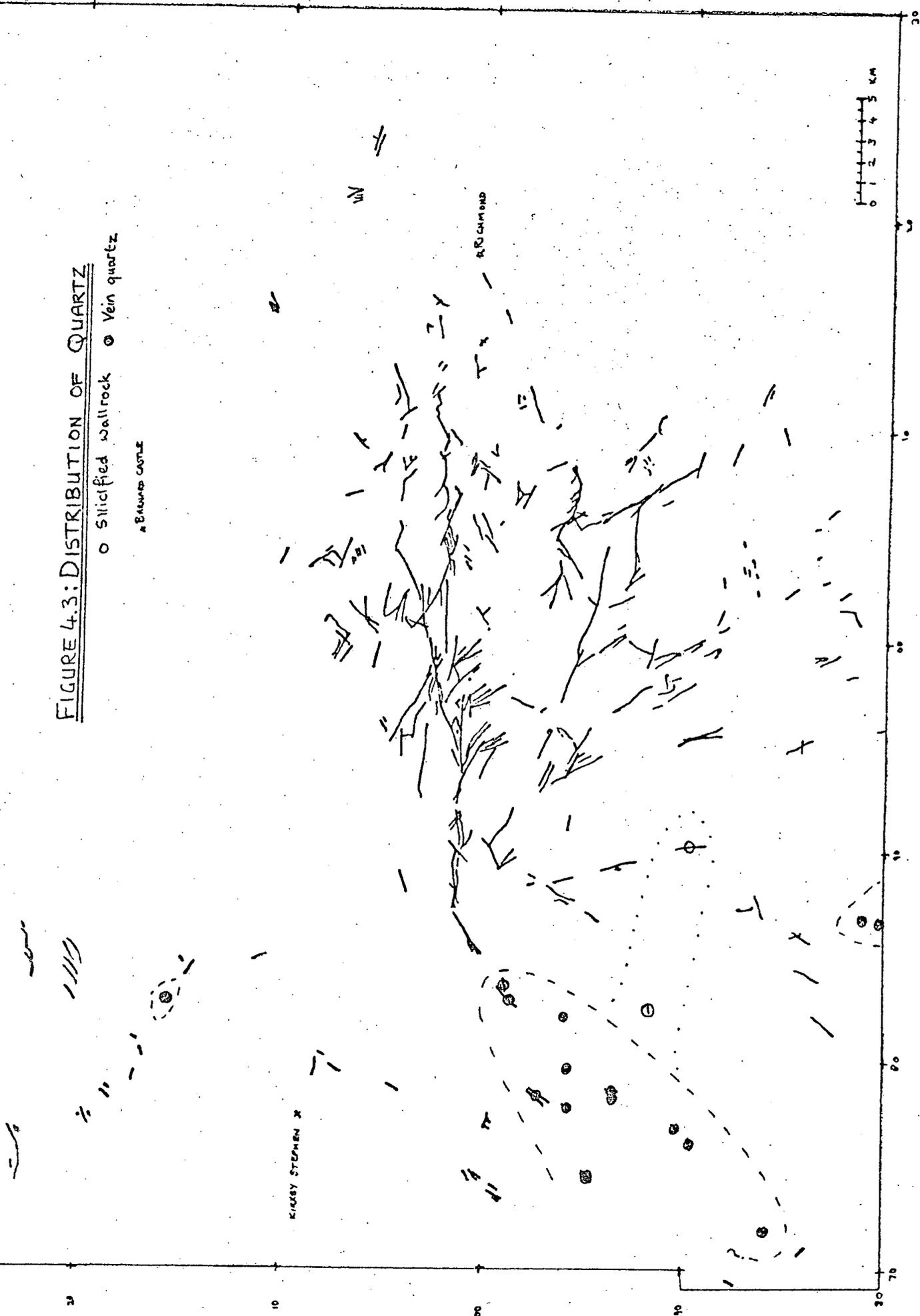
FIGURE 4.4: DISTRIBUTION OF FLUORITE

Legend:
- O Colourless
- ✳ Colourless – purple
- ⊕ Colourless – pale purple
- ⊗ Colourless – amber
- △ Interstitial in barite
- + Trace

▲ BARNARD CASTLE

▲ RICHMOND

KIRKBY STEPHEN ✕
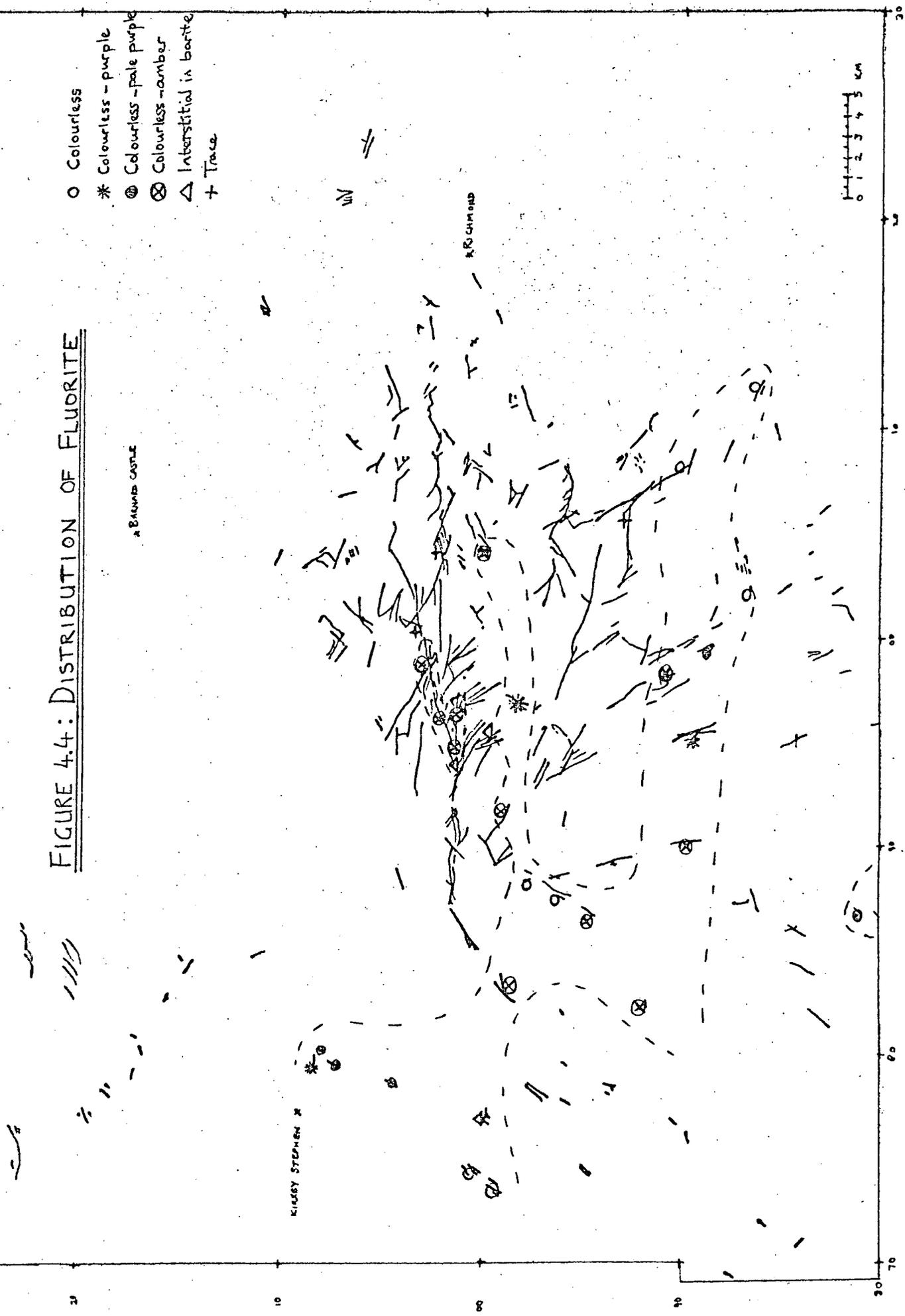
0 1 2 3 4 5 KM

FIGURE 4.5 DISTRIBUTION OF BARITE

Legend:
⊕ Primary mostly fine grained
○ Primary mostly coarse grained
△ Late toothy barite
□ Barite gossan
✳ Toby barite after witherite
+ Trace

xBARNARD CASTLE

xRICHMOND

KIRKBY STEPHEN x

0 1 2 3 4 5 km
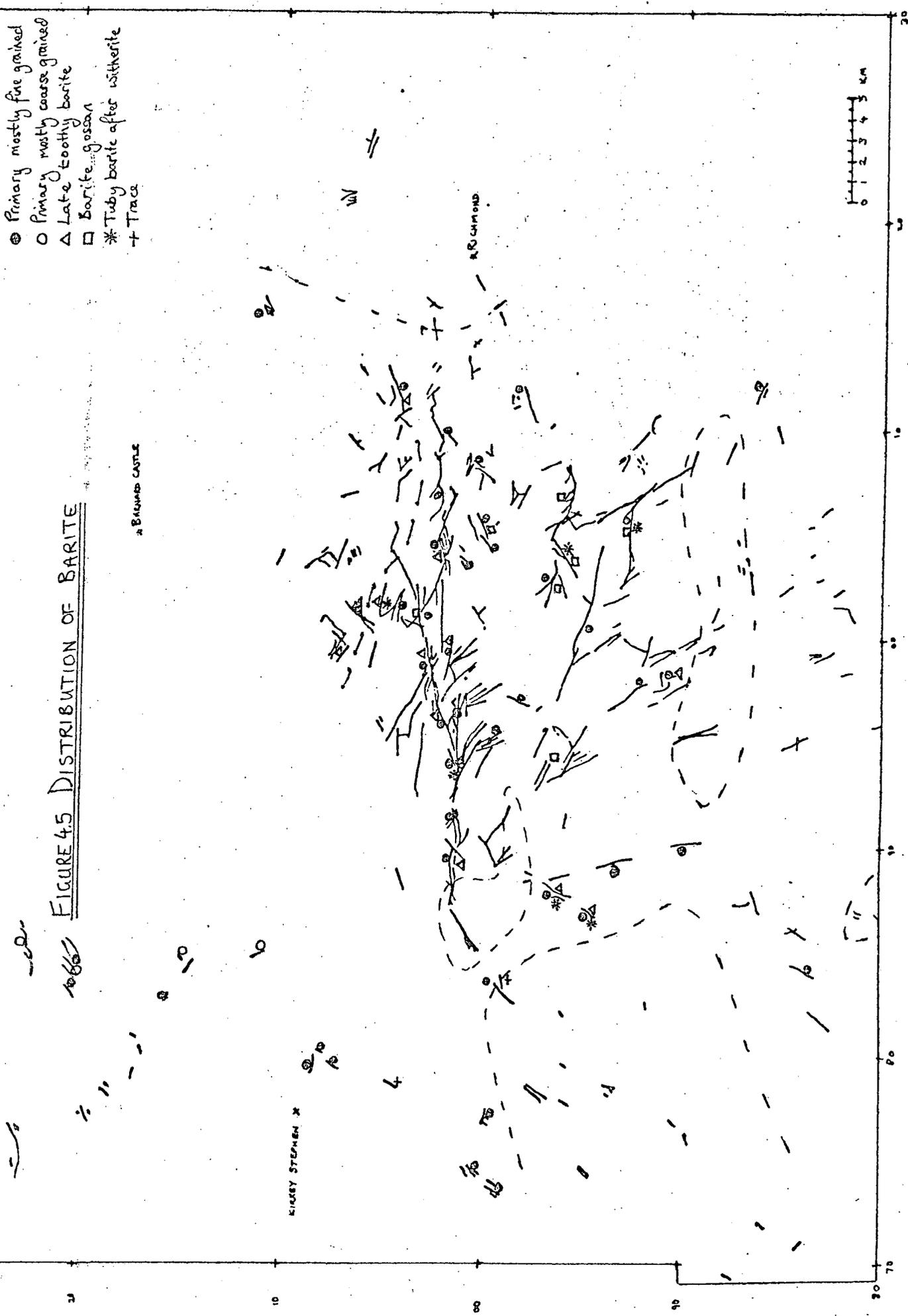
FIGURE 4.6 : STRONTIUM IN BARITE BY ELECTRON MICROPROBE (in %)

·042
·103
·026
·062
·061
·053
·40
·43
·19
·17
·16
·016

0   200μm

b

·22   ·10

a
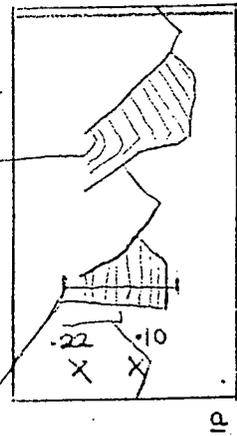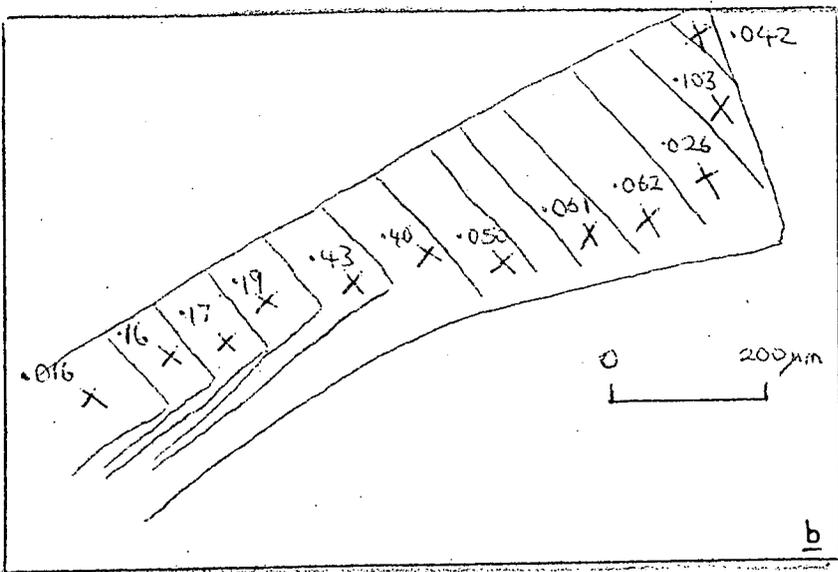
a,b,c. Toothy barite 0490 from
Watersykes Level.

0   200μm

c

·99   ·80   ·50   ·36   ·71

g
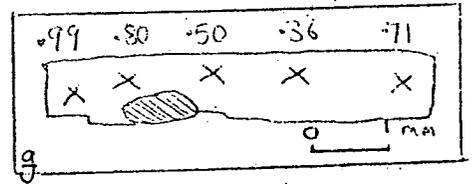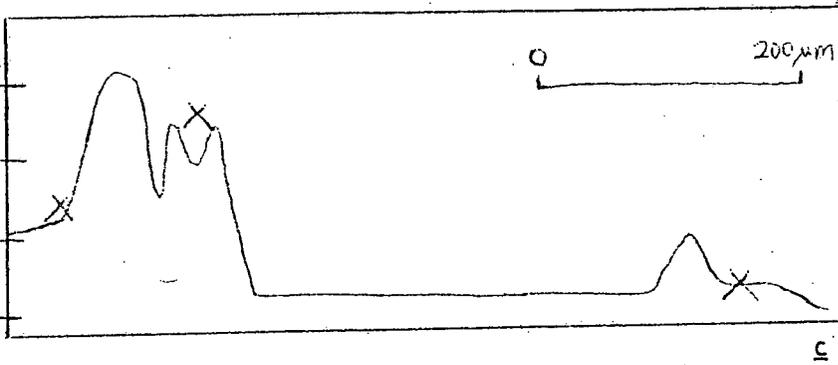
f,g. Banded barite & fluorite 0516 Old Rake Vein.

< ·15

·65
cp.
·65
·45

1·2

·65

·70

·15

0   1mm

d

Lunehead

e. 0187 Longrigg

·43
·35
·52
·36
·20
·37
·55
·75
·29
·4
·34

0   5mm

e

·61

·45
Barite
crystals
enclosed
in fluorite

·21

Direction of growth

·69
·39
·56
·59
·50

Massive barite

·49

·45
·48
·55

·33
·68   ·60

·30
·75

in fluorite

·66

·30
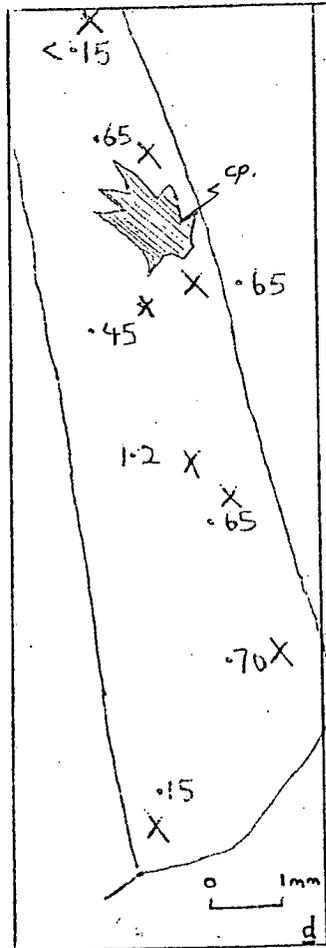
f   g
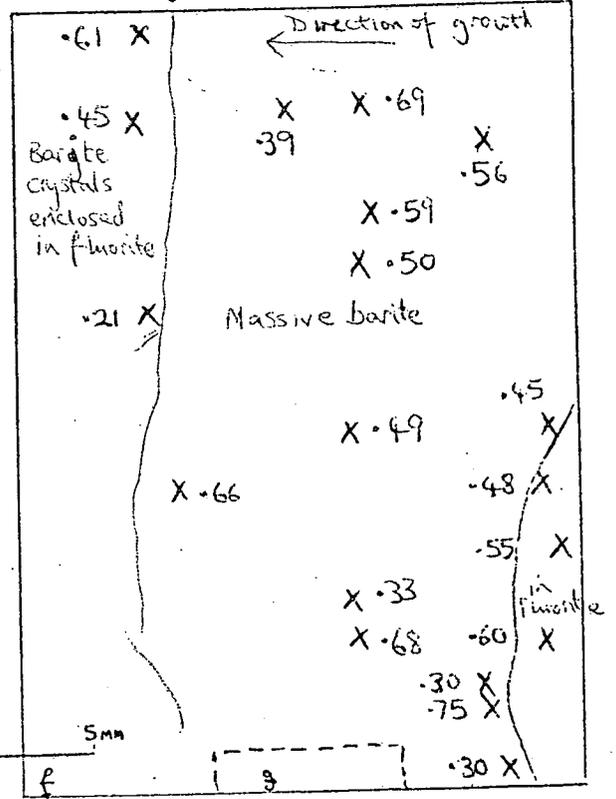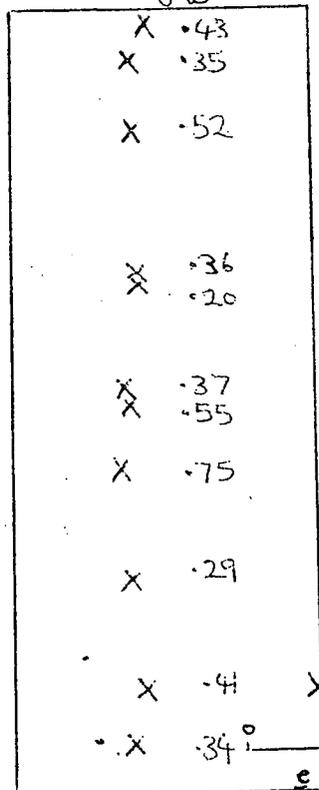
FIGURE 4.7: DISTRIBUTION OF WITHERITE
● Witherite   ○ Tuby barite alone

× BARNARD CASTLE

▲ RICHMOND

KIRKBY STEPHEN ×
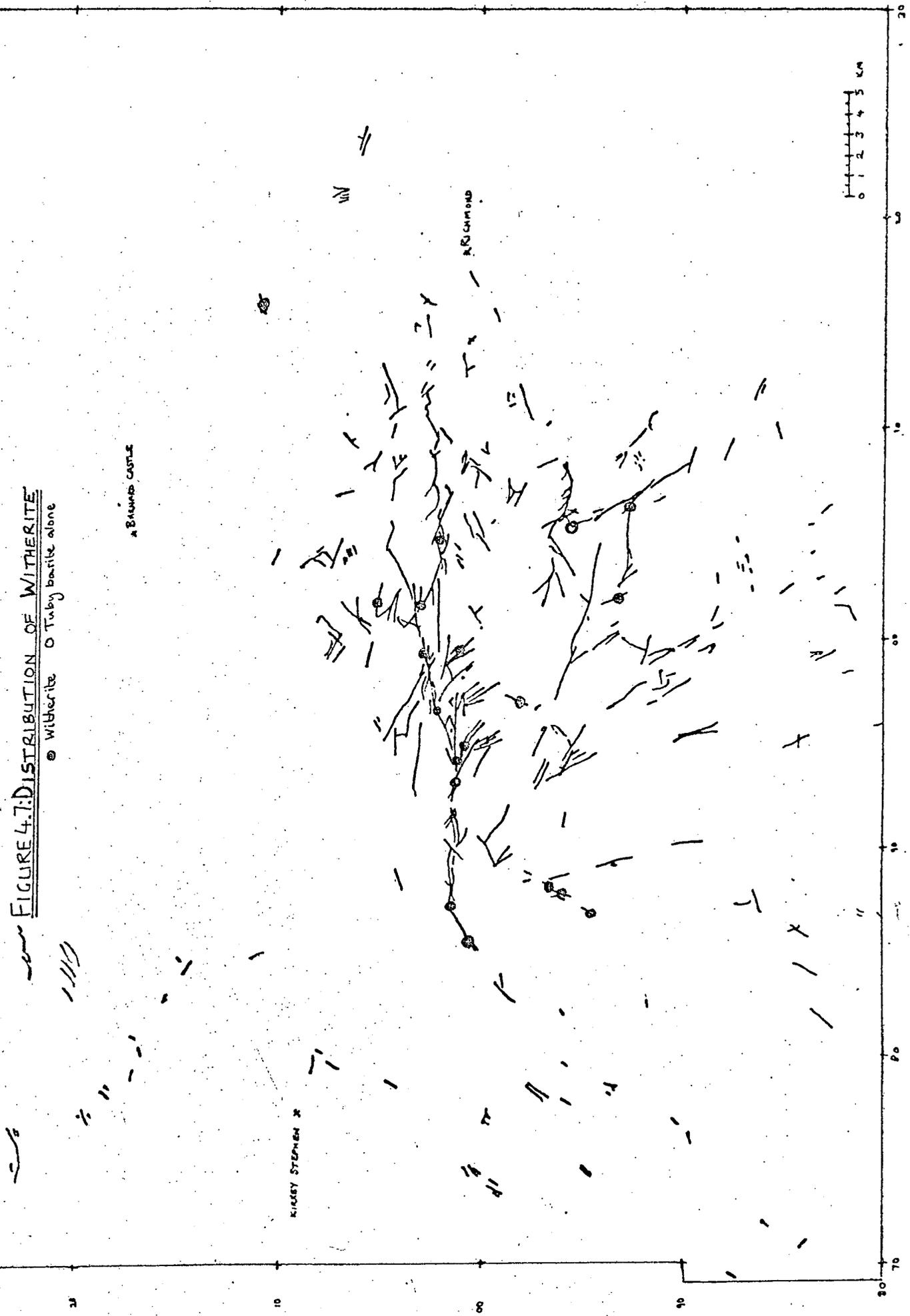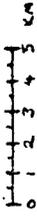
FIGURE 4.8: DISTRIBUTION OF CALCITE AND ARAGONITE

○ Calcite.   ○ Aragonite

FIGURE 4.9 (Cont'd)

Pyromorphite

$Pb_{4.99}(PO_4)_{2.99}Cl_{1.00}$

Lead chloride phosphate

d	2.93	2.96	2.88	4.98
I/I_1	100	100	80	30

Rad.		Dia.		
Cut off	λ	I/I_{cor}		
Ref.	I/I_1	Filter		
Sys.			S.G.	
a_0	b_0	c_0	A	C
α	β	γ	Z	Dx
Ref.				
ε	nωβ	εγ	Sign	
2V	D	mp	Color	
Ref.				

dA	I/I_1	hkl		dA	I/I_1	hkl
1.360	30	521,423		1.044	50	520,107
1.348	10	324		1.058	30	802
1.340	50	602,215		1.032	40	444,605
1.326	20	432		1.008	10	525
1.313	40	610,414		0.9980	10	550,633
1.297	50	611,522		0.9893	10	307
1.247	40	440		0.9836	10	615
1.220	20	531,701		0.9765	10	812
1.205	20	523		0.9721	50	723
1.183	30	514				
1.180	20	206		+ 8 ADDITIONAL LINES.		
1.170	30	532,702				
1.161	20	415				
1.145	30	710				
1.100	20	223				
1.090	10	630				
1.078	20	623,631				
1.072	10	614,801				
1.067	10	400				

FIGURE 4.9 (Cont'd)

Pyromorphite

$Pb_{4.99}(PO_4)_{2.99}Cl_{1.00}$

Lead chloride phosphate

d	2.98	2.96	2.88	4.98
I/I₁	100	100	80	30

dA	I/I₁	hkl	dA	I/I₁	hkl
1.360	30	521,423	1.044	50	326,107
1.348	10	324	1.058	30	802
1.340	50	602,215	1.032	40	444,605
1.326	20	432	1.008	10	525
1.313	40	610,414	0.9980	10	550,653
1.297	50	611,522	0.9893	10	307
1.247	40	440	0.9836	10	615
1.220	20	531,701	0.9765	10	812
1.205	20	523	0.9721	50	723
1.183	30	514			
1.180	20	206	+ 8 ADDITIONAL		
1.170	30	532,702	LINES.		
1.161	20	415			
1.145	30	710			
1.100	20	225			
1.090	10	630			
1.078	20	623,631			
1.072	15	614,801			
1.067	10	400			

Rad.   Cut off   Ref.

Dia. I/I_{cor}

Filter

λ I/I_1

Sys.   S.G.

a_0 b_0 c_0 A   C

α β γ Z D_x

Ref.

$\varepsilon\alpha$ $n\omega\beta$ $\varepsilon\gamma$ Sign

2V   mp   Color

D

Ref.

FIGURE 4.10: HISTOGRAMS OF NUMBER OF AREAS WITH SPECIFIED MINERAL OCCURRING IN EACH ASSEMBLAGE
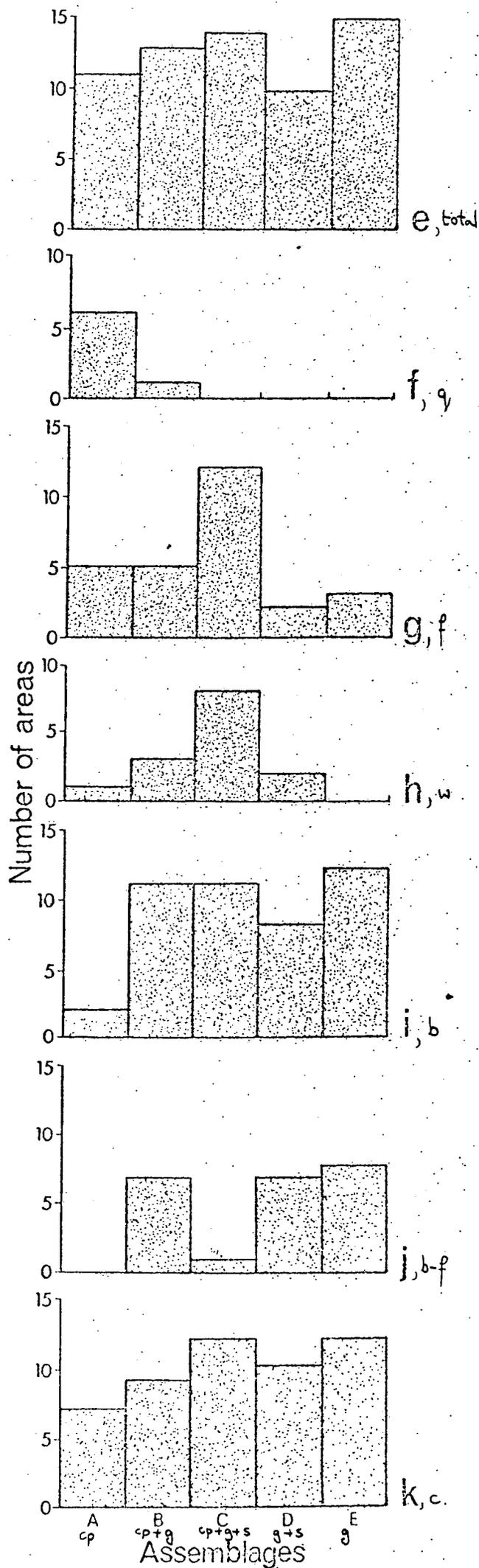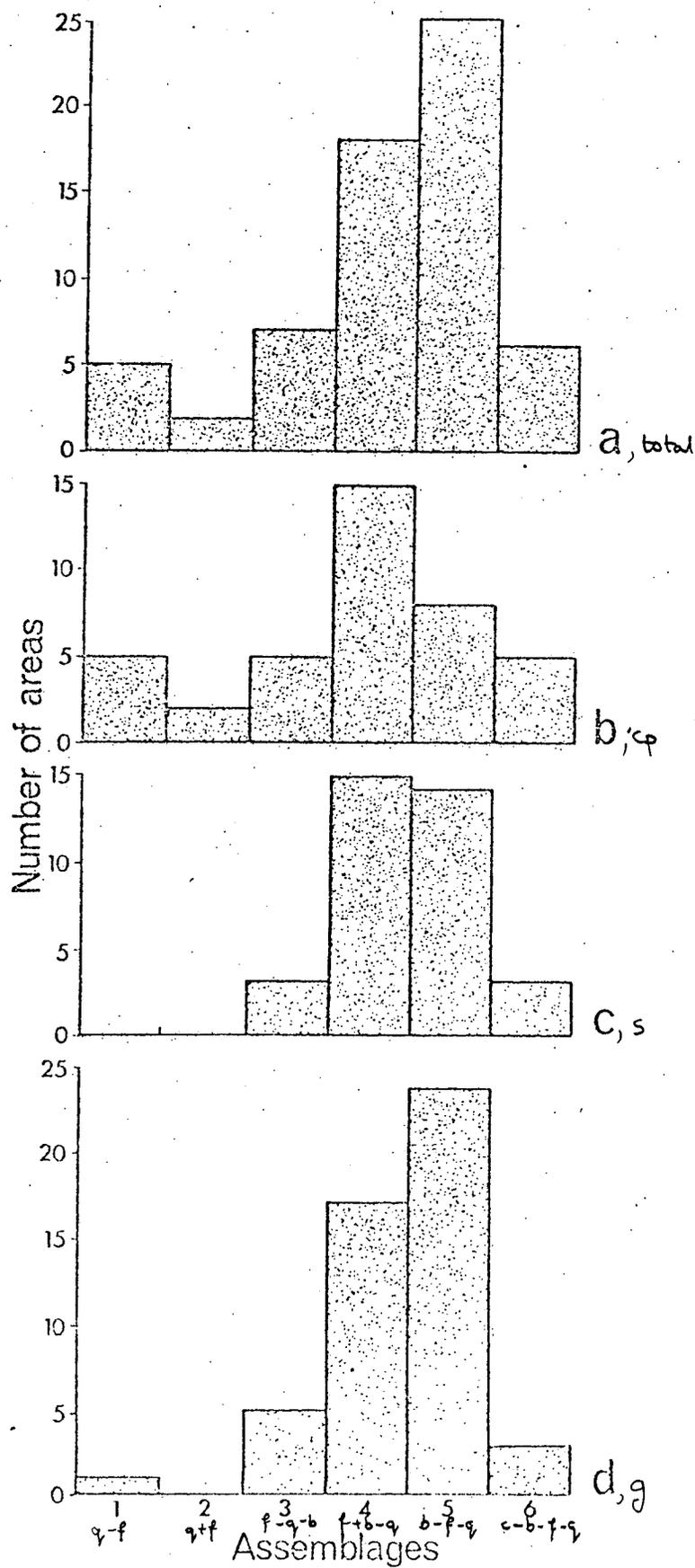
FIGURE 4.11: HISTOGRAMS OF PROPORTION OF AREAS OF EACH ASSEMBLAGE WITH A SPECIFIED MINERAL
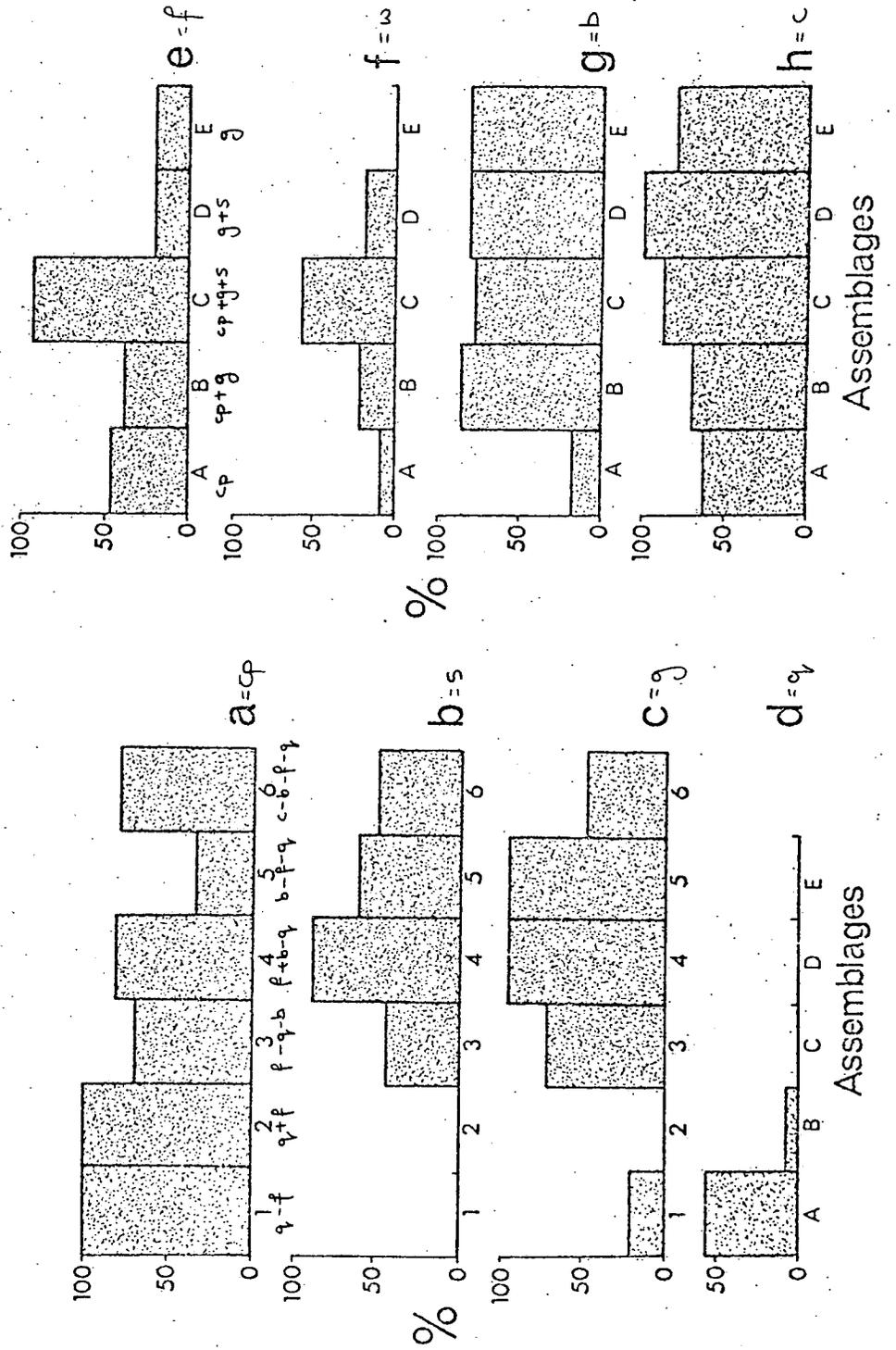
FIGURE 4.12
SIMPLIFIED PARAGENESES

A = cp.   B̃ = cp.g.   C = cp.g.s.   D = g.s.   E = g.
a = g.   b = g.c.   c = g.f.   d = g.b.
e = g.f.b.   f = f.   g = f.c.   h = f.b.
i = f.c.b.   j = f.w.b.   k = f.c.w.b.   l = b.
m = c.b.   n = w.c.b.   o = c.   p = c.b.

× BARNARD CASTLE

× RICHMOND

KIRKBY STEPHEN ×

FIGURE 4.13: MINERAL ZONES OF THE NORTH YORKSHIRE OREFIELD

Inner Q zone

Outer Q zone

Stainmore Q zone

Inner F zone

Main F zone

Outer F zone

Inner P zone

Outer P zone

C zone

●Barnard Castle

Kirkby Stephen●

●Richmond

0 km 5
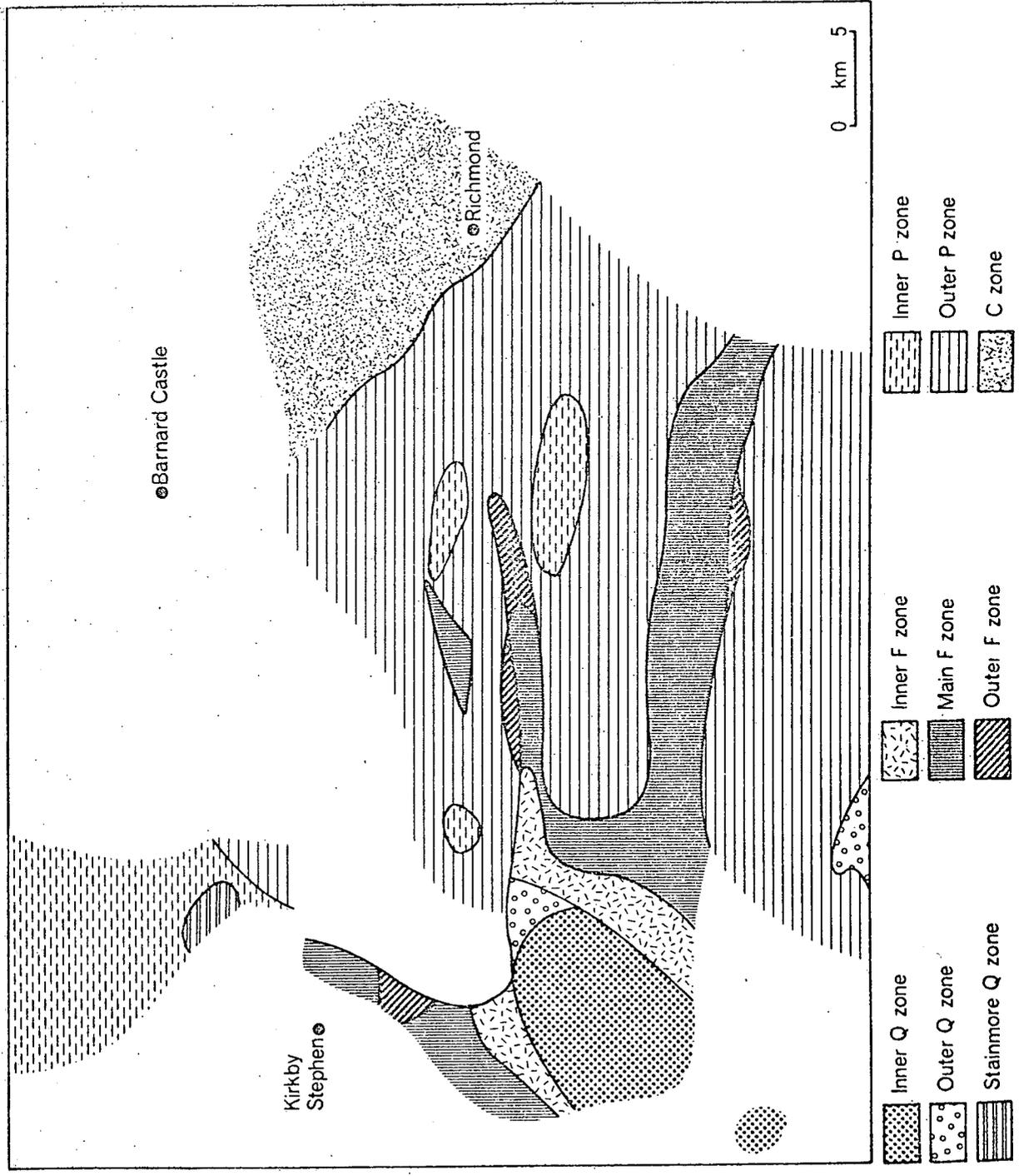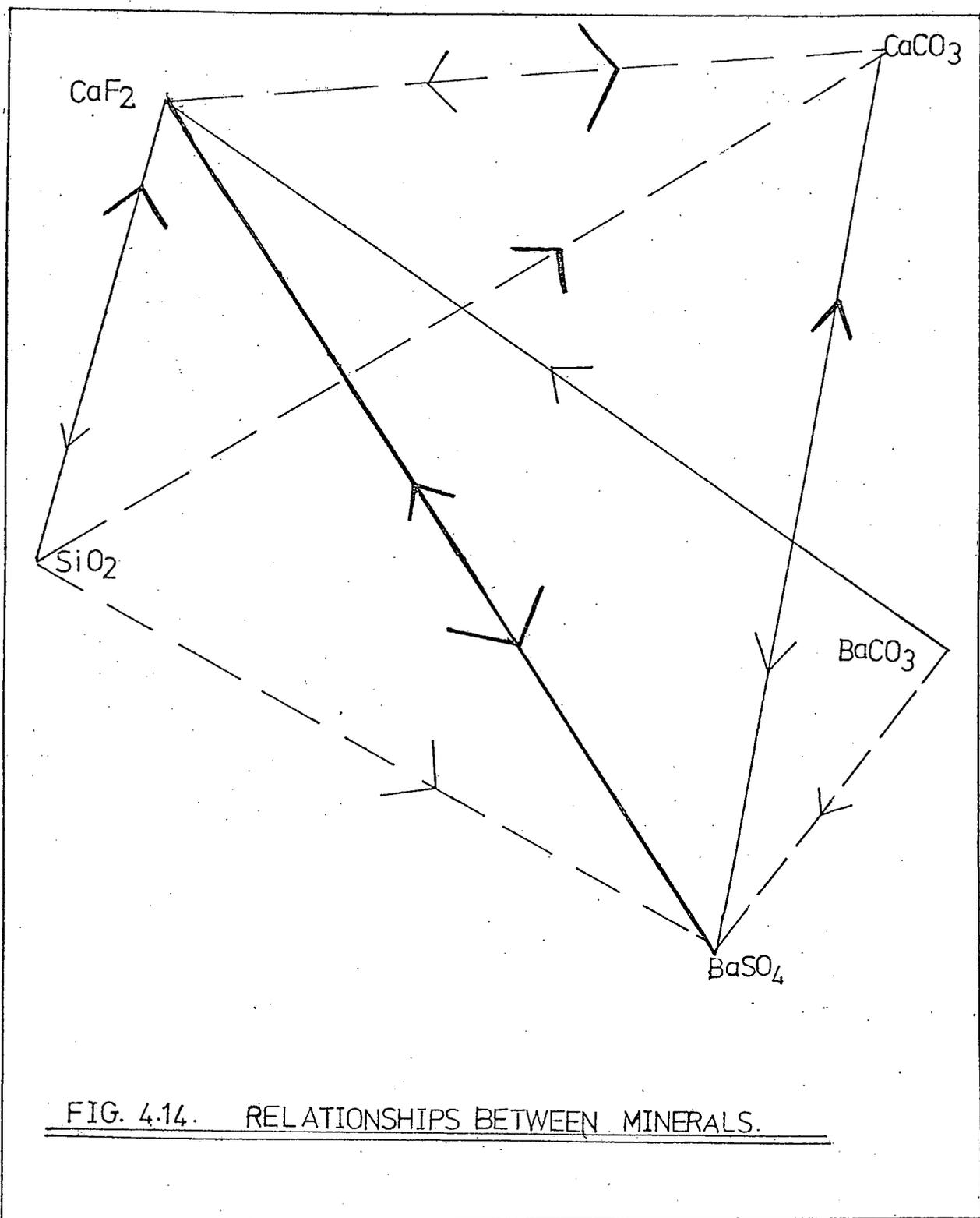
FIG. 4.14. RELATIONSHIPS BETWEEN MINERALS.

Plate 4

(a) Well formed cubes of fluorite. 0594, Hartley Birkett.

(b) Banded fluorite and primary barite. 0513, Gunnerside.

(c) Part of a spheroidal mass of primary platy barite with
    a fluorite cube, and fluorite moulds showing
    chalcopyrite in the barite. 0586, Hartley Birkett.

Plate 5

(a) Strongly zoned toothy barite aggregate. 1428, Windegg
    Level.

(b) Barite fragments in iron rich breccia. 0214, Longrigg.

(c) Porous aggregate of toothy barite viewed from the side.
    1435, Windegg Level.

(d) Platy aggregate of barite. 1425, Windegg Level.

Plate 6

(a) Witherite showing "fibrous" texture. 1410, Windegg
    Level.

(b) Witherite altering to barite. Top view, 1409, Windegg
    Level.

(c) Tuby barite after witherite, with galena badly altered
    to cerussite. 1425, Windegg Level.

(d) Side view of 1409 (Windegg Level) showing tuby
    structure of barite.
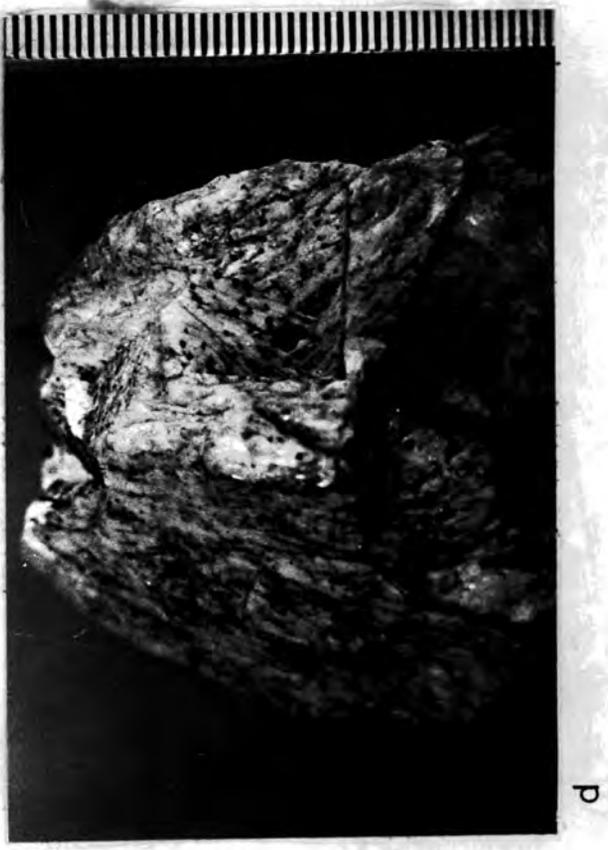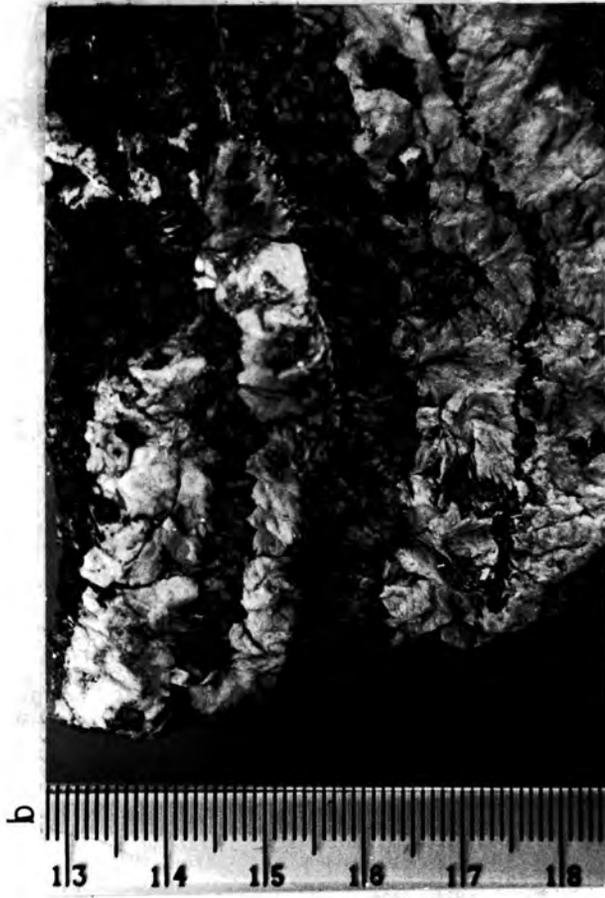
PLATE 4
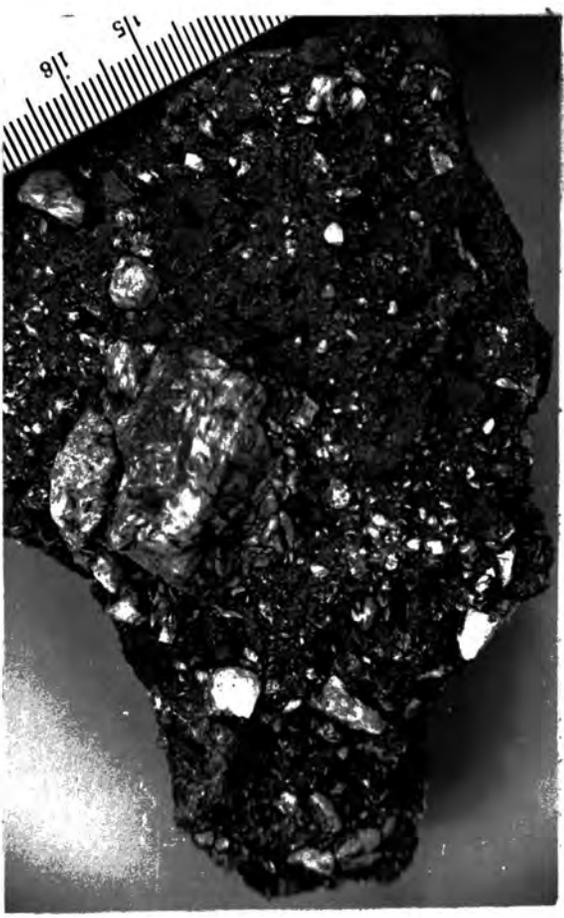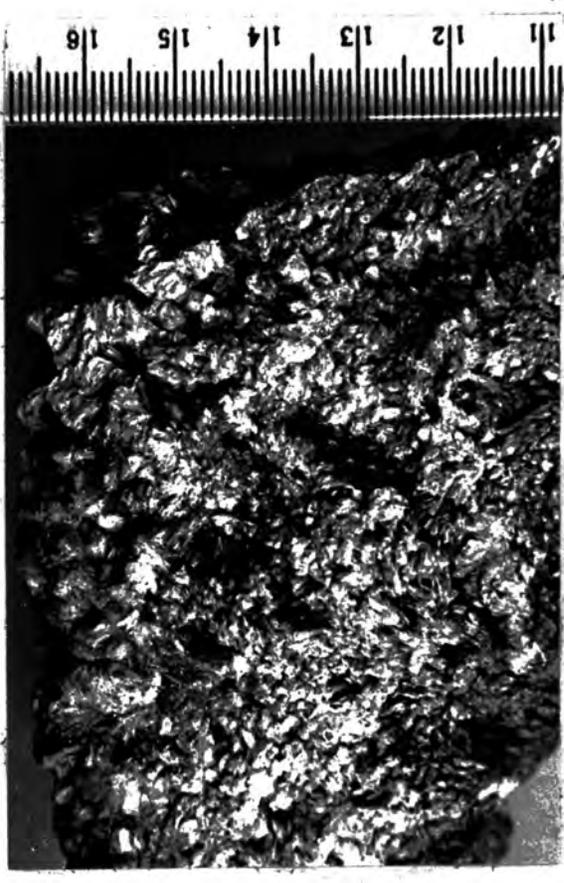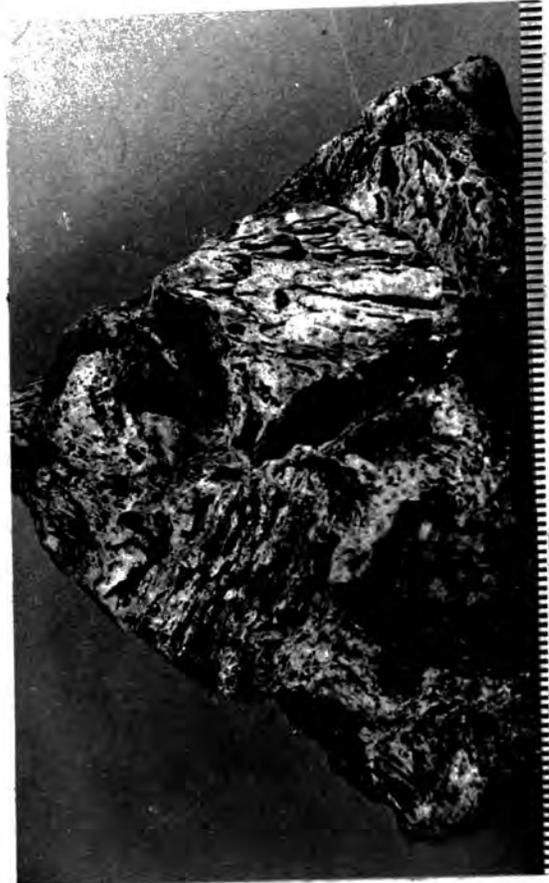
PLATE 5

PLATE 6

Plate 7

(a) Witherite with barite capping pseudo-trigonal

terminations. Side view, 1417, Windegg Level.

(b) Dolomitized Limestone with clear calcite and a joint

replacement now occupied by porous aggregate of toothy

barite.

(c) Top view of 1417 (Windegg Level) showing the

terminations.

(d) Well formed squat crystals of calcite. 1422, Windegg

Level.

Plate 8

(a) Well formed octahedra of galena. 1460, Faggergill.

(b) Galena with white skins of cerussite. 1353, Grinton.

(c) Large twisted crystal of galena (cube with octahedron

cutting corners). 1662, Downholme.

(d) Combinations of the octahedron and cube in galena.

0595, Hartley Birkett.

Plate 9

(a) Gossan (baritic and limonitic) showing boxworks after

sphalerite (and galena). 1687, Grinton.

(b) Calcite carrying grains of chalcopyrite partly altered

to goethite and malachite.

(c) Barite with limonite boxes after sphalerite and galena

partly altered to cerussite. 1663, Downholme.

(d) Goethite pseudomorphs after marcasite. 1474, Faggergill.

PLATE 7

b

a

d

1 5   1 6   1 7

c

1 5   1 6   1 7   1 8
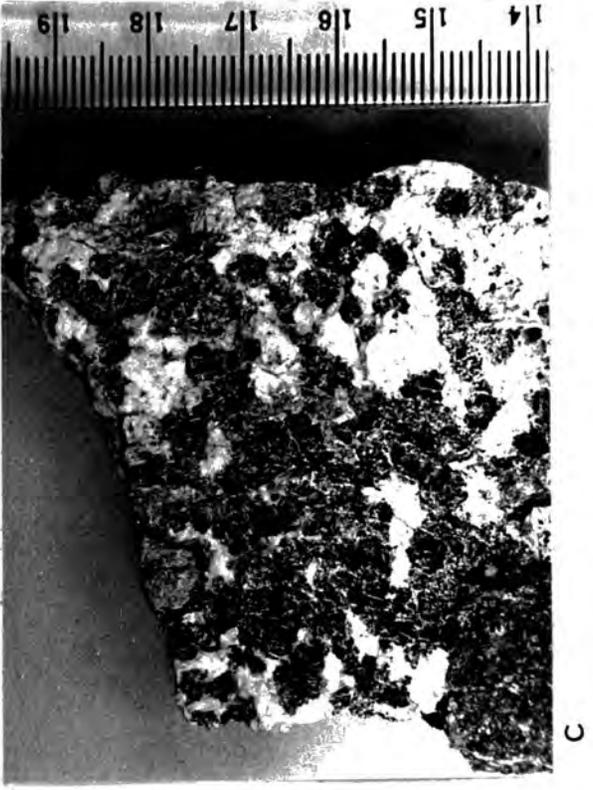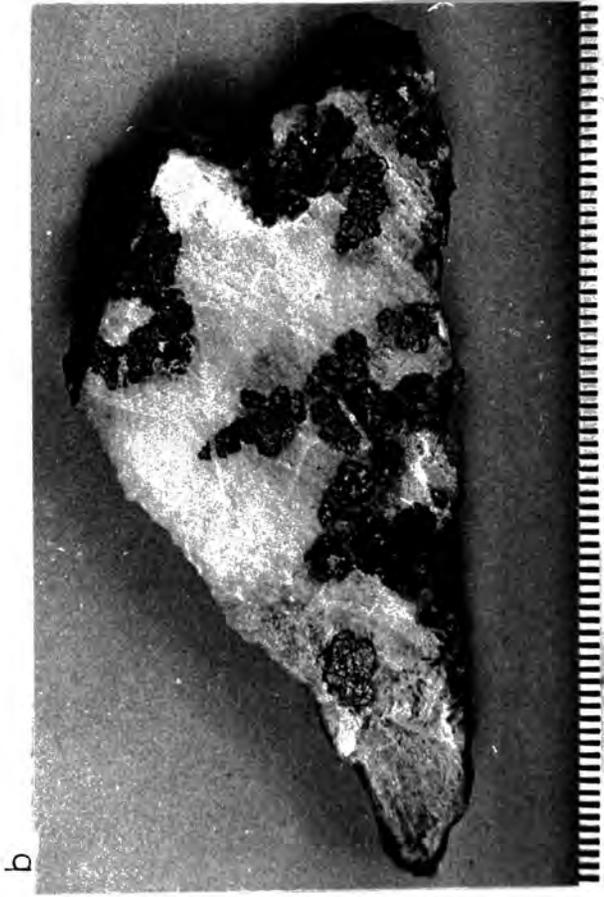
PLATE   8

PLATE 9

<u>TRACE AND MINOR ELEMENT STUDY</u>

<u>INTRODUCTION</u>

To provide a check to the hypothesis that the orefield is focused upon the western copper-quartz mineralized zone it was decided to carry out a limited minor element study on some of the materials collected in the field. The study involved fluorite, barite, witherite, calcite, galena, sphalerite, and chalcopyrite, but most effort was concentrated on galena.

Minor element studies have been carried out on British sulphides by Shazly <u>et al</u> (1957), the Alston sulphides (Bishara, 196b) and British and foreign fluorites, especially Weardale fluorites, by Smith, F.W.(1974). There are also important minor element studies on sulphides of the world (Fleischer, 1955) and other papers with useful reviews and generalizations (Loftus-Hills & Solomon, 1967). The present study was guided by the published results for deposits similar to the North Yorkshire Orefield, and by the nature and abundance of the different minerals of the orefield. High concentrations of yttrium in fluorite, and silver in galena have been correlated with feeder zones, so the geographical variations of these elements and others were expected to confirm the copper-quartz focus to the orefield. The technique adopted differs from that normally used in sulphide studies, but was considered most appropriate to use the facilities available. X.R.F. analysis and Electron Microprobe analysis were both used, but the emphasis went on the X.R.F. work because of its greater sensitivity. The electron probe results are mainly described in Chapter 4.

<u>SAMPLE PREPARATION</u>

The important considerations in sample preparation are:-

1. The need to prepare strong specimens suitable for automatic running on the X.R.F. machine. It would have been much more time-consuming, although perhaps preferable, to have used special small specimen techniques,

such as powders on mylar films etc., which would have required a completely different non-automatic running pattern in elemental analysis.

2.   The need for "infinitely" thick specimens if quantitative results are required. This necessitates large samples with a light matrix such as chalcopyrite and less with a heavy matrix such as galena.

3.   The need for a rich concentrate or pure sample of the mineral to be studied. In many cases the minor elements of interest are found most abundantly or almost entirely in the mineral studied. This reduces the need for absolute purity, although it would obviously be the ideal. The fairly simple sulphide mineralogy of the type of deposit investigated assists, because "contamination" from minerals such as suphosalts has a relatively low probability.

4.   The need for information regarding the minerals present especially any contaminant. This is connected with item 3. above, since it is hoped to attribute minor elements to minerals, it is also important because different matrices may produce interference and correction difficulties. Ideally a polished specimen of each sample should be made to allow the estimation of the amounts and nature of impurities, but the cost and time involved would have been prohibitive in this study. X.R.D. analysis of powders could, in principle be used to give information of the main minerals present, but is insensitive to small concentrations of minerals.

5.   The need to avoid inter-specimen and external contamination of specimens and the standard problems in X.R.F. such as homogeneity, etc.

The study was carried out in several stages and the kinds of sample made varied, so the actual specimen preparation will be dealt with in the order of preparation, although the results will not be given in the same order.

The first study was carried out on chalcopyrite to compare the mineral found in the western area with the eastern area and for further

comparison with some samples from Groverake Mine in Weardale, a known "feeder" zone. After examination of hand specimens and polished sections, fairly large samples (5 - 10 cm^2) from some localities were obtained simply by coarse crushing and separating by hand using a paint brush or fine spatula and binocular microscope. Unfortunately the western localities had low concentrations of small grains of chalcopyrite. Attempts were made at separating the chalcopyrite from the quartz of the western zone by rather crude gravity and flotation techniques, but with little success. After production of concentrates they were ground by hand (mortar and pestle) or in a tungsten carbine ball mill and finally pressed into pellets either neat or as thin layers backed with boric acid.

The second and third studies were specimens of galena that was found to be the only ore mineral to occur in large specimens over most of the orefield. At this stage very few large specimens of sphalerite had been discovered so there was little hope of working on "co-existing" galena and sphalerite. Galena was a very suitable mineral for study and was generally easily crushed and separated by hand. The concentrate or pure mineral was ground in and agate mortar until of very fine grain size when it could be made into pellets for use on the X.R.F. machine. In the second study quite large samples were prepared, but in the third study, since handpicking is slow, generally only small samples (1 - 3 cm^2) were prepared. This was powdered and spread evenly over one end plate of the pelletizing die and enough crushed boric acid added to provide a strong solid pellet suitable for automatic use.

The fourth study was in part combined with the leaching experiments. The leaching technique of coarse crushing, hand separating, washing, drying, fine crushing, leaching, decanting, drying of powder and analysis of leachate left a powder suitable for making good X.R.F. pressed powder

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pellets. The pellets were in the standard manner with or without a
binder depending upon the mineral, so a suite of mineral concentrates
(Fluorite, Barite, Witherite, Calcite, Sphalerite, Galena and Quartz)
could all be studied using the X.R.F. machine.

METHOD OF ANALYSIS

The pressed pellets prepared as above were processed on the Phillips
automatic X.R.F. at Durham using standard methods. The ratio method
(counting for constant number of counts on a monitor and for the same
time on three specimens, then repeating with different specimens) for
major elements (i.e. the dominant elements of the samples such as Pb, Ba,
etc). The absolute method (counting for constant time on all samples)
for trace elements and some major elements. Although the methods of
setting up the machine and analysis are fairly standard, the elements,
which were examined were often not elements normally run on the machine.
The different elements and types of matrix required much experimental
effort before analysis could be commenced. The main steps were:-

1. To examine the books of characteristic radiations and seek the
   angular positions of suitable peaks and backgrounds and get
   some idea of the likely operating conditions.

2. To prepare standards. In this case mostly from spec pure
   oxides for trace element standards and analar grade chemicals
   for major element standards.

3. To confirm and modify operating conditions and peak and back-
   ground positions, using the standards and paying close attention
   to interferences and peak-background ratios.

4. Set up the machine i.e. the automatic operating conditions.

5. Run the standards and unknowns.

6. Calibration with the standards.

7. Calculation of unknowns.

Attempts were made to analyse for the following elements with varying

degrees of success - Mg, Ca, Si, S, Sr, Mn, Va, Co, Ni, Fe, Cu, Zn, Ga,

As, Se, Ba, Y, Ag, Cd, In, Sn, Sb, Hg, Pb, Bi. The conditions used are

in the appendix, but the main results are presented in this chapter. The

reduction and correction of the raw data and calculation of final results

were performed using the computer programs appended and manually by

graphical and desk calculation techniques.

THEORY OF MINOR ELEMENT DISTRIBUTION

Loftus-Hills and Solomon (1967) in reviewing trace element studies

in sulphides point out that trace elements can enter a mineral by solid

solution, absorption, and inclusion of independent phases. They also

point out that trace elements may be present in lattice sites, by sub-

stitution with another element, or in interstitial sites, lattice defects,

growth zones, or in captured crystals of trace minerals and exsolved

mineral phases.

Burns and Fyfe (1967) give rules for establishing what substituions

could be expected. They suggest that while the magnitudes of ionic

radii of element pairs are a valuable guide to whether substitution may

occur, the use of "fundamental" atomic parameters such as electronega-

tivity are fruitless. They argue that one must examine the free energy

difference between two equibrium states not the parameters of any single

state, as has often been attempted, if one is to understand distribution.

The concentration of a trace element in a mineral can be indicative

of its concentration in the mineralizing solution. To some extent, even

when a trace mineral is present, the concentration of trace element in

the main mineral is a guide to solution concentrations. A separate

unexsolved trace mineral phase demonstrates saturation of both liquid and

main mineral with respect to trace element, so that provided equibrium

has been maintained, the concentration in the main mineral alone should

be dependent only on pressure and temperature. Equilibrium is difficult to prove and Loftus-Hills and Solomon (1967) suggest that it may not be common.※ If valency changes are involved in substitution then the activity of other components in the system may have to be taken into account, e.g. sulphur in the sphalerite geothermom eter.

Loftus-Hills and Solomon (1967) argue that minerals are seldom saturated with trace element, thus the concentrations of trace elements cannot be quantitatively temperature dependent, and are largely determined by the availability i.e. activity in solution of the trace element, and it acceptability in the mineral i.e. its distribution function between liquid and solid.

This can be expressed:

$$B \text{ solid} = f (B \text{ solution})$$

Where B solid and B solution are the activities (or approximate concentrations) of the trace element B in the mineral and depositing solution respectively and f is a monotonically increasing function of B solution. (fig. 5.1)

FIGURE 5.1
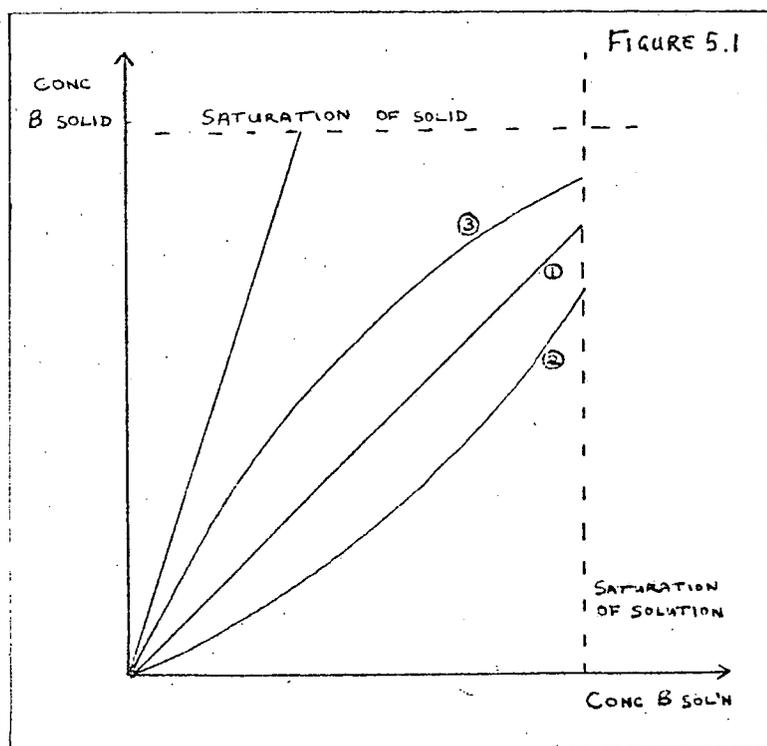
1. Direct proportionality (If concentrations approach closely to activities and if distribution coefficient is an adequate description.

2 & 3. Exponential relationships

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The function f is equivalent to the acceptability of the element in the mineral and depends upon the temperature and pressure conditions, and the free energies of the trace element in solution and the solid. It must be regarded as the equilibrium relationship although under non-equilibrium conditions its qualitative use may well be justifiable. If the function is a straight forward distribution coefficient the function will be a constant coefficient (at constant pressure and temperature). Since equilibrium is perhaps uncommon during the deposition of ore deposits the graphs would extend slightly into the areas outside of the saturation lines.

The above relationship can only really apply to a very thin layer of atoms at the edge of a crystal, because diffusion in most crystals is very slow except near their melting point.

If a crystal with major element B is growing from a solution then it would be reasonable to expect that

$$\frac{A \text{ solid}}{B \text{ solid}} = f^1 \frac{(A \text{ solution})}{(B \text{ solution})}$$

f^1 is an equilibrium relationship rather similar to the acceptability function f, and may well be approximately constant at fixed temperature, pressure, and activity of other elements.

If a small amount of solid crystallizes, then if the ratio A/B is higher in the solid deposited than in the original solution then the solution ratio will become a little lower. The converse is also true.

If the simple case is considered where f^1 is a constant coefficient, and a system closed with respect to A and B then:

$$\left(\frac{A}{B}\right)_{solid} = K \left(\frac{A}{B}\right)_{liquid}$$

When solid crystallizes progressively by any means (cooling, release of pressure, addition of other ions etc.) then the early formed crystals or zones of crystals will be rich in A if K is >1 and will be progressively

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impoverished. This is henceforth termed a depletion trend (fig. 5.2).

FIGURE 5.2
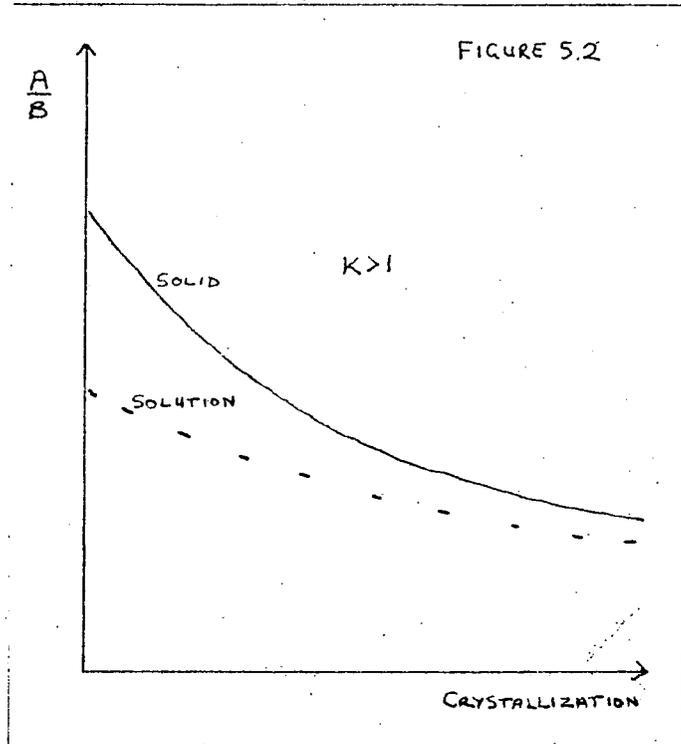
The converse also applies if $K<1$ (an enrichment trend) and a constant trend results from $K = 1$. If f^1 varies with concentration or during crystallization, because of cooling or change of pressure then the trends could be modified, but will be similar provided f^1 does not go through the $f = 1$ value when a depletion trend could change into an enrichment trend or vice versa.

If the system is opened by adding B (the major element) the trends will still occur since it will just increase precipitation. If A is added or subtracted by the crystallization or dissolution of a phase containing A but not B then the trends could be modified, but effects will be small unless the extra phase has higher concentration than the "main" phase, or is precipitated or dissolved in large amounts relative to the "main" phase. This sort of opening should be observable in the geological system if it is of importance.

The main applications of trace element studies in sulphides have been

(a) the determination of temperature of deposition

(b) the identification of metallogenic provinces

(c) the determination of environment of deposition

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The first application is fraught with difficulties though of great importance if successful. The last two are often more empirically based and are perhaps more applicable. Studies of other minerals have had many purposes, often genetic or environmental in outlook. This present study has attempted to reinforce an overt mineralogical zonation, with the cryptic variation of minor element content of minerals. It is basically involved with environment of deposition, but is not so much to distinguish one environment from another, but more to investigate the enviroment changes in one orefield. Study of environment changes in fluorite veins has been used as an exploration tool (Smith, F.W., 1974).

INTERPRETATION OF RESULTS

The results are split into the following groups:-

(a)   Fluorite

(b)   Barite

(c)   Witherite, Calcite and Quartz

(d)   Galena

(e)   Chalcopyrite

(f)   Sphalerite

(a) Fluorite

The fluorite yttrium content results (Table 5.1, fig. 5.3) show a fair degree of consistency and vary systematically being high around the inner edge of the F zone and being substantially lower around the outer edge. Yttrium substitutes for calcium in fluorite. Fluorite is also known to be rich in rare earths on occasion, but they are rather difficult to analyse in the small amounts indicated from specimens ran by Dr. F. W. Smith, so only yttrium was studied. High yttrium has been correlated with fluorite around granitic cores such as in Cornwall and is much lower in deposits where granitic influence is unlikely (Smith 1974). It is believed to be difficult to produce yttrium rich solutions simply

by leaching granites, so a magmatic origin has been tentatively suggested by Smith. The yttrium content of fluorite has been shown to be high in feeder zones of veins demonstrated by fluid inclusion temperature studies (Smith, 1974). The regional zonation here presented shows that the Q zone is indeed a feeder or core to the orefield (fig. 5.3). The correlations made by Smith demonstrate that the yttrium content of fluorite follows a depletion trend. Smith interpreted the concentration of yttrium as being due to the destruction of sensitive yttrium fluoride complexes in the feeder zones rather than substitution from a simple ionic solution of yttrium. He interpreted low yttrium concentrations in flats as evidence in favour, since slow movement of liquid in the flats would cause mostly low yttrium contents, whereas in the main fissure higher flow rates would provide more yttrium.

The samples examined show surprisingly consistant results. Variation at localities is caused by local variations in time and space since rarely could samples by collected in situ. A detailed study of some areas might have revealed useful information of a local nature.

The yttrium content of quartz, calcite, barite and witherite were all found to be low and so sample purity was not critical. Large concentrations of lead interfere with yttrium estimation to a minor extent but normal fluorite samples are quite satisfactory.

(b) Barite

The strontium content of barite was studied for a number of localities. Samples were chosen for being most probably primary barite, although in one case a sample was chosen because it was definitely late even if not secondary.

The strontium values found (Table 5.2) were widely varying even at one locality, and thus only a broad hint of a trend could be observed (Fig. 5.4o) More detailed study of each locality would be necessary for real success in understanding barite deposition with its varied habits and associations.

A plot of strontium content (Fig. 5.4) versus Na/K ratio of leachates gave an interesting pattern of results with all but one of the coarse platy barite samples falling in one field with the other samples of mostly fine-grained barite falling in a different field. Significantly many of the fine-grained barite localities have occurrences of witherite (or it has been found near by).

A negative temperature correlation is experimentally established and has been used by Dr. A. C. Dunham for interpretation of Derbyshire barite veins (Colloquium at Leicester 1973). Further work in the Swaledale Orefield could well be of value although, since saturation with strontium is unlikely because of complete solid solution between the two end members, it would be difficult to determine temperatures without the composition of the oreforming solution.

Strontium substitutes for barium, because of their similar chemistry etc., but its sulphate is more soluble than barite hence its enrichment trend.

The strontium contents of fluorite, calcite and quartz are much lower than in barite (the strontium "preferring" sites too large rather than too small), hence small amounts of these minerals do not substantially affect the analysis of strontium in barite. Witherite contains substantial amounts of strontium, but does not contaminate any of the samples analysed.

(c) Witherite, Calcite and Quartz

The few samples of witherite analysed (Table 5.3) revealed consistent high strontium content reflecting in part the lower minimum Sr/Ba ratio required for precipitation of strontianite compared with celestine ($10^{-0.8}$ cf $10^{3.5}$ at $25^{o}C$). The fairly similar amounts in high strontium barite and witherite is perhaps significant, but would require more work to prove and understand. This work could be undertaken on the microprobe as the strontium contents involved are readily detectable, but in this

study only a little probe work was undertaken on barite and none on witherite owing to limitations on time. (See Chapter 4)

Calcite contained a low concentration of strontium (below standard range) and no measurable yttrium. Manganese did not appear to be present in large amounts (i.e. > .2%), but dolomite-ankerite was sometimes found in veins suggesting that a magnesium-iron presence in calcite would be worth investigating. The low strontium reflects the large size of strontium atoms relative to calcium.

The two samples of quartz analysed did not reveal measurable quantities of strontium or yttrium or even barium. No solid solution by these elements would be expected in quartz, so these results were not surprising.

(d) Galena

Only two trace elements could be definitely attributed to galena. They were antimony and silver (Table 5.4). Cadmium was sometimes found in the trial run of 40 specimens and correlated with high zinc intensity due to sphalerite traces. Searches for bismuth and arsenic failed to detect significant amounts of bismuth (less than 20 ppm) and demonstrated the futility of attempting X.R.F. analysis of small concentrations of arsenic in the suspected or known presence of lead. Examination of polished specimens suggested that little or no sulphosalt was present except at two localities in the west where sulphosalt could also be observed in the hand specimens. This does not, however, preclude the occurrence of trace amounts of this mineral group in the galena samples. If trace amounts of antimony and silver are due to sulphosalt traces, one would not generally expect the spatial variations observed, and even if sulphosalt traces were causing the variations the results would still be significant, though more difficult to understand.

Variability of trace element concentration would be expected from three main sources:

1. Variation of concentration with time at any locality

2. Variation due to position in the orefield

3. Variation due to vertical position and horizontal position of the sample in the deposit

Further complications or variations could be expected:

1. If sulphosalts or other minerals containing the traces are present in samples. This would probably produce erratic results.

2. If another phase, with elements such as cadmium, that can interfere with the analysis of the traces, was present in significant amounts. The results which could be affected have been marked in the table and amount to a small percentage of the results.

3. If analytical errors are of similar magnitude to the amount of minor element observed.

If position in the orefield is significant the variation caused by it must be greater in magnitude than variation due to position in time and space in any particular body. Since it was often impossible to find out much about the latter parameters, the presence of large magnitude changes in the areal sense was of great importance, because it was difficult to take account of the other variables.

Graphs of silver content versus antimony content (Figs. 5.5-15) are useful in that they demonstrate quite well the variability of particular locality areas and the differences between areas. A scatter diagram (fig. 5.5) with most of the results plotted shows:

1. High density at low concentrations

2. Low density of high concentrations

3. A low ratio of Ag/Sb (mostly <0.1)

4. A fairly wide scatter of results

5. A positive correlation of silver and antimony.

The fairly low average concentrations probably reflect the low natural abundances of silver and antimony compared with lead, and their depletion trends during galena deposition, which removes them from the system early.

The low silver to antimony ratio seems to relate to the greater natural abundance of antimony.

Silver I has a very similar sized ion to lead II, and antimony III has a rather smaller sized ion, but both ions could replace lead. Further investigation is required to fully explain the substitution. The different valencies of silver and antimony may mean that attempts at temperature determinations would require knowledge of sulphur partial pressure (activity) like the sphalerite "geothermometer" (Barton & Toulmin , 1966). The difficulty of demonstrating saturation with silver and antimony would be greater than with iron in sphalerite, because of the general lack of accompanying silver and antimony minerals.

The positive correlation of silver and antimony results from their common depletion trend and implies a common source.

The general graph of antimony versus silver (fig. 5.5) shows a wide scatter, but graphs for individual mine areas show a more consistent trend although odd analyses sometimes occur and often correlate with a high zinc analysis although the correlation works backwards less well. High silver and antimony valves are more prone to be erratic which may suggest the presence of trace minerals. The plots from the western deposits (fig. 5.5) demonstrate a systematic change of slope of a similar trend in passing from copper bearing deposits to non-copper bearing (Clouds, Longrigg, Hartley Birkett). The plot for the Keld veins (fig. 5.7) is a good example of close proximity to a trend from fairly widely scattered

collecting points. The very low concentration deposits are mostly very
consistent in results, e.g. Faggergill and Stang (Fig. 5.11).

There is a geographic trend (Fig. 5.16) with the high antimony
values dominantly around the inner edge of the galena zone and decreasing
outwards more strongly northwards than eastwards. Very low values are
found in the north and east, corresponding to the low values of sedimentary
syngenetic galena from the Permian collected by T. Deans and published
by El Shazly et al (1957).

Silver values show a similar trend (Fig. 5.17), but with less precision.
There is a marked assymetry in the orefield, which corresponds roughly with
the mineralogical zoning.

The trace element trends are like the mineralogical zoning in
showing a relationship to horizon, in that the low horizons of Wensleydale
show higher values than the higher horizon on the adjacent hill tips,
demonstrating a vertical variation.

The fluorite zone does not correspond exactly with the high trace
element values, but in a general way shows higher values than the outer
barite/calcite zones. Notable exceptions i.e. high trace values without
significant fluorite presence occur at Pry Hill, Keld, Providence and
Sargill, all close to the "core" of the orefield. On pages 77-80
a simple model for trace element concentrations of minerals during crystal-
lizing sequences of closed systems and the effect of opening a system in
various ways was examined. The significant geographical trends in the
orefield could potentially be explained by the following hypotheses, which
incorporate in some degree the simple trend mechanism suggested.
Hypothesis (a): Geographical variation of hydrothermal solution composition
with dominant vertical movement. This hypothesis begs the question to
some degree by passing the variations to the netherworld and almost beyond
the powers of investigation. It suggests the possibility of the depth to

the source of the solutions varying systematically, presumably deepening

in the outer areas of low concentrations. Alternatively it could suggest

the possibility of increased concentrations in solutes from a hot core

area, where lead can not precipitate at depth. This would lead to a

contrast with peripheral cooler areas where solutions rising vertically

from the same depth would presumably precipitate the lead earlier.

This relies on temperature alone being the main cause of deposition. A

systematic change of source rock could have some effect in principle.

Hypothesis (b): Rising of solutions in a core area with subsequent

movement upwards and outwards resulting in a depletion trend as crystal-

lization proceeds. There must be an important lateral movement for this

hypothesis to work.

Hypothesis (c): "Hybridization" by lateral mixing of solutions each

containing lead but with different concentrations of minor elements.

This is not a particularly simple or satisfying mechanism unless mixing

of solutions has already been established or suspected.

Hypothesis (d): "Hybridization" by vertical mixing of solutions each

containing lead, but with geographical variation of minor elements such

that mixing produces the variations observed. This hypothesis is far

from simple or satisfying.

Hypothesis (e): Variation of pressure and/or temperature at the site of

deposition causing the variation of concentration in the galena. This

hypothesis requires either (1) saturation of the galena with trace

elements, which would be suggested by the presence of another mineral

phase rich in the trace element. This is not observed, but could occur

if only trace amounts of another mineral phase are present; or (2) the

systematic variation of the distribution coefficients with temperature

and pressure. It is unlikely that changes would be substantial enough

to produce the variations observed bearing in mind the low temperature

variation observed. The concentration of antimony changes by three orders of magnitude from "core" to "rim" of the orefield.

Of the hypotheses suggested (a) and (b) are most probable though (c) can not be ruled out. Variations suggested in (e) could complement (a) or (b), but are unlikely to be the main cause of geographical variations.

(e) Chalcopyrite

The results for chalcopyrite (Table 5.5) are not quantitative in many cases, because of the relatively poor quality pellets that could be made for X.R.F. analysis. There are, however, certain points of interest in the results even if they really require a deeper investigation.

Chalcopyrite for Groverake Mine was collected by Dr. F. W. Smith and was found to be associated with quartz and a little fluorite. Fairly pure hand picked samples were made into thick pellets and when analysed demonstrated high concentrations of tin (up to 2250 ppm). The high tin values were confirmed by electron probe microanalysis where a distinct heterogeneity of tin content was observed, although there was no evidence of trace mineral or simple zoning causing the variations. Silver analyses were consistent (80 - 150 ppm) as were nickel (10 - 40 ppm), but cobalt (0 - 200) and zinc (0 - 600) were somethat erratic. Cobalt and zinc valves correlate roughly, but other elements showed little relationship to each other. The assemblage as a whole is considered fairly distinctive and probably characteristic of the fairly high temperature ($> 200^{o}C$) feeder zones on the Alston Block.

A few reasonably pure specimens of chalcopyrite from East Leyton Quarry revealed a quite different set of results. There was no detectable tin, silver, antimony or zinc. Nickel was low (0 - 10 ppm) as was cobalt (0 - 20 ppm). Thus a generally low trace element content was revealed and must be significant in demonstrating a different environment (trace

element availability etc.) to the Groverake feeder. Chalcopyrite from East Leyton may in part be a late or secondary replacement of pyrite although the specimens analysed appear to be primary chalcopyrite from polished section study.

A thin X.R.F. sample from Richmond gave no detectable tin, silver, antimony, zinc, nickel or cobalt and was thus at least consistent, although higher detection limits of thin samples will play its part. A zinc rich sample of chalcopyrite from Hartley Longrigg (perhaps 25% sphalerite) gave no measurable tin, silver, antimony, or nickel but yielded 100 ppm cobalt. The absence of tin etc. is probably more significant than the cobalt analysis which could be due to sphalerite.

Suites of concentrates from Great Sleddale (suspected to be the core of the orefield) and the Feldom fault yielded no detectable tin, antimony, or silver, but amounts of cobalt, nickel and zinc. The concentrations of these elements were greater in the Great Sleddale samples but it was not established what mineral these elements were connected with.

Four samples from one specimen collected at KneetonHall were composed mainly of an assemblage of copper minerals and calcite. (Galena, barite, chalcocite, covellite, chalcopyrite, malachite and calcite.) They gave no detectable tin and only small amounts of nickel. High silver valves are noteworthy and a confirmed very high cobalt valve. The mineralogical causes of these concentrations could not be established from the limited work undertaken.

Three samples from Clouds consisted of (a) galena, (b) chalcopyrite and galena and barite, (c) tennantite and chalcopyrite. No tin was detected. High antimony is connected with the tennantite in one case and apparently the galena in another case. It is lower than one would perhaps expect for a sample rich in tennantite, but the tennantite was very poor in antimony (see Chapter 4). Zinc probably represents only the zinc of the tennantite and silver that in solid solution with galena.

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It is clear that tin is not present in large amounts in the samples studied from the North Askrigg-Stainmore Orefield, but might still be expected in the core of the orefield if similarities with the Alston Orefield are real. More detailed and patient work on the electron microprobe could reveal enrichments of tin so far undetected, but it is possible that nearly all the tin was removed from the system early in the mineralization. In this case it is perhaps only present at greater depths than exposure has so far revealed. It is not possible to be very conclusive about the other minor elements although the generally low silver valves are probably significant, perhaps indicating the low availability of silver for chalcopyrite over most of the orefield and its preference for galena as a host.

Further work on chalcopyrite in the orefield will probably require the use of sensitive techniques such as neutron activation analysis if reliable results are to be obtained, although emission spectrometry and electron probe studies could all have their parts to play.

The observation of high tin concentrations in chalcopyrite from the Alston Block may provide evidence of a connection between the Hercynian mineralization of Devon and Cornwall and that of the Alston Block, rather like the extension of the tin province of the Appalachians by high tin chalcopyrites (Tilden & Brown, 1974).

(f) Sphalerite

The results of minor element studies (Table 5.6) on sphalerite concentrates are reasonably consistent and show high levels of cadmium (0.17 - 1.4% calculated for 100% sphalerite), moderate to low silver, and low cobalt, nickel and manganese. The results are presented in two groups - (1) the results of fairly rich concentrates, i.e. quantitative analysis; (2) the results of samples of other minerals such as fluorite but carrying substantial zinc, therefore only semi quantitative. The

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results from the two groups seem to be comparable on the whole although two poor estimates are asterisked.

Cadmium values are variable but mostly around 0.5%. Two very high values (1.1 and 1.4%) were found near Aysgarth in Wensleydale, but an ordinary value was also found there (0.5 (and 0.4%) from 0680). The similar chemistry of cadmium and zinc is thought to account for their close relationship in nature. Greenockite (Cd S) is known to occur with sphalerite in some parts of the world. Its presence in this orefield can not yet be confirmed and so like iron and manganese all the cadmium is probably locked in the sphalerite in solid solution. No definite geo-graphical variation is discernable from these samples (fig. 5.18).

Silver values vary from below detection up to ≌ 300 ppm and is perhaps negatively correlated with cadmium,[*] i.e. high cadmium specimens have low silver and low cadmium specimens have high silver. Geographical variation is not very clear (fig. 5.18) but localities are mostly consistent in being high or low in its samples, so that Hartley Birkett, Apedale and Cobscar have fairly low values while the rest have higher values.

The occasional cobalt and nickel detections are sporadic and probably insignificant. Manganese was found in only three samples all from Hartley Birkett, which is significant, but of unknown meaning.

Mercury was detected in one case, sample 0707 from Wet Grooves, which also had a remarkably high cadmium content. Cinnabar has been reported from (Pately Bridge (Braithwaite et al 1963) and in small amounts in sphalerite from the Alston Block (Bishara 1966).

Iron content could not be estimated, although it would be easy to carry out on the microprobe. No black completely opaque high iron sphalerites were observed, indeed many were distinctly pale.

* Fig 5.19

TABLE 5.1 – FLUORITE ANALYSES

Locality	Specimen No.	X.R.F. No.	Ca %	Y ppm*	Mean
Hartley Longrigg	0186	0012	53.9	75	65
Hartley Longrigg	0195	0019	57.3	40	
Hartley Birkett	0590	0009	37.6	10+	
Hartley Birkett	0590	0014	39.1	20+	
Hartley Birkett	0600	0013	39.5	10+	
Hartley Birkett	0603	X25	67.1	35	35
Hartley Birkett	0599	X32	67.8	35	
Bells	0292	0016	67.3	30	30
Clouds	0264	0007	63.4	55	
Clouds	0309	0008	67.8	35	
Clouds	0339	0010	66.9	45	
Clouds	0360	0011	57.9	60	
Clouds	0350	0015	46.0	65	59
Clouds	0361	0017	66.5	30	
Clouds	0361	X4	52.4	80	
Clouds	0361	X26	67.8	30	
Clouds	0361	X27	67.8	30	
Great Sleddale	0413	0018	67.2	270	275
Great Sleddale	0415	X35	66.3	280	
Mossdale Beck	MD1	MD1	67.6	220	220
Stags Fell	0757	X13	50.9	210	210
Lover Gill	0791	X1	67.8	150	150

TABLE 5.1 (Cont.)

Thwaite Beck	TB1	X30	67.8	120	120
Cottriggs	0872	X15	66.8	110	
Cottriggs	COTT	X8	66.5	110	110
Langstrothdale	0946	X33	33.2	130	130
Arngill	1657	X14	56.6	75	
Arngill	1656	X24	67.8	65	70
Warton	0857	X16	65.1	35	35
Gunnerside	0478	X5	67.8	35	
Gunnerside	0478	X29	52.6	65	50
Friars Intake	FINT	X28	64.8	85	85
Wet Grooves	0706	X10	67.8	45	
Wet Grooves	0649	X17	52.7	80	63
Seata	1073	X7	67.8	40	40
West Burton	0871	X18	67.3	45	45
Arkengarthdale	1700	X9	67.8	70	
Arkengarthdale	1700	X19	67.8	65	
Arkengarthdale	1700A	X20	67.8	65	67
Arkengarthdale	1706	X21	67.8	65	
Arkengarthdale	1710	X23	67.8	70	
Kelds Head	1081	X6	67.8	45	45
Braithwaite	1106	X31	42.1	70	70
Copperthwaite	1231A	X11	67.3	80	
Copperthwaite	1231B	X12	67.2	80	80

NOTE: * Yttrium valves calculated for pure fluorite

+ Poor analysis

TABLE 5.2 – BARITE DATA

Locality	Specimen No.	X.R.F. No.	Sr	Na/K Ratio	Comment
Closehouse	CH01	X45	0.30	21	Very coarse platy
Cabbish Mine	0902	X46	0.25 ⎤ .9	24	Very coarse platy
Cabbish Mine	0913	X53	1.55 ⎦	50	Coarse platy
Middle Fell	0924	X43	0.25	34	Very coarse platy
Hartley Birkett	0583	X58	0.80	1.6	Fine grained massive platy
Clouds	0346	X49	0.42	1.6	Fine grained massive platy
Angerholme	0820	X42	1.40		Fine grained massive platy
Angerholme	0820D	X48	1.40	4.7	Fine grained massive platy
Keld	1050	X44	1.30	33	Coarse platy
Staggs Fell	0766	X36	.36	1.9	Fine grained massive platy
Cottriggs	0884	X59	.55 ⎤ .55	5.0	Fine grained massive platy
Cottriggs	0884D	X60	.55 ⎦	5.0	Fine grained massive platy

TABLE 5.2 (Cont.)

Windegg	1498	X55	0.85	4.7	Coarse platy
Arkengarthdale	0453	X39	1.40	19	Fine grained massive platy
Friars Intake	0745	X54	1.42	1.1	Fine grained massive platy
Copperthwaite	1241	X50	0.60	6.3	Medium grained massive platy
Hurst	1534	X57	1.65	39	Fine grained massive platy
Hurst	1534D	X52	1.80		
Wet Grooves	0687	X51	1.70	1.4	Coarse platy
East Leyton	0067	X46	0.38	7.0	Medium grained massive platy
Feldom	0851	X37	0.94	53	Coarse platy
Feldom	0085	X40	1.30	56	Coarse platy
Kelds Head	1086	X56	1.14	15	Fine grained massive platy
Braithwaite	1096	X41	1.40	0.64	Fine grained massive platy
Hurst	1546	X38	0.08	1.3	Toothy late or secondary

TABLE 5.3 - WITHERITE

Locality	Specimen No.	X.R.F. No.	Sr %
Windegg	WLO1	X 69	1.55
Windegg	WLO1D	X 70	1.55
Windegg Level	1710	X 74	1.40
Cobscar	1950	X 71	2.35
Hurst	HUO1	X 72	1.6
Hurst	HUO1D	X 73	1.55

TABLE 5.4 - GALENA ANALYSES

Locality	X.R.F. No.	Specimen No.	Ag ppm	Sb ppm	Zn[1]	Cd ppm
Clouds	0026	0378	79	906	L	0
	0028	0378	78	910	L	0
	0050		99	1130	.5	25
	0051	0356	101	1792	L	0
	0057A	0321	153	1612	L	0
	*0057B	0374	126	1477	8	400
	0067	0320Y	202	2819	L	–
Longrigg	0052	0186	89	1373	L	0
	0053	0204	104	1662	L	0
	0054	0181	70	1255	L	0
Hartley Birkett	*0020	0613	127	1665	12	1200
	0048	0593	88	2265	L	0
	0049	0606	57	1730	.25	25
	0055	0568	63	1944	L	0
	0056	0556	63	1526	L	0
Cabbish Mine	0165	0900	12	663	L	–
	0126	0913	0	560	L	–
Lunehead	0025	0248	52	912	L	0
	0062	0264	19	579	L	0
	0063	0346	68	1769	L	0

NOTE: [1] Estimate of maximum value in %

TABLE 5.4 (Cont.)

Closehouse	0058	0545	69	2248	L	0
	0059	0548	35	2831	L	0
	0060	0533	26	1718	L	0
	0061	0535	54	2063	L	0
Cow Green	0022	CG1	90	1228	L	0
Faggergill	0145	1449	17	0	L	-
	0146	1451	9	0	L	-
	0147	1450	3	10	L	-
	0148	1462	0	18	L	-
	*0149	1466	0	50	2	-
	*0150	1465	0	62	3	-
	0151	1468	13	28	L	-
	0152	1469	0	0	L	-
	0153	1471	0	71	L	-
Stang	0139	1395	0	0	L	-
	0140	1396	3	4	L	-
	0141	1397	11	16	L	-
Windegg Level	0142	1432	0	128	L	-
	0143	1433	18	293	L	-
Windegg Fault	*0222	1520	158	298	2	-
	0223	1508	61	223	L	-
	0224	1492	25	484	L	-
	0225	1487	36	950	L	-
	0226	1477	47	1495	L	-

TABLE 5.4 (Cont.)

Pry Hill	0229	1666	41	2751	L	-
	0274	1666	109	2750	L	-
Keld	0154	1047b	21	747	.25	-
	0155	1047	35	656	L	-
	0156	1046	47	783	L	-
	*0157	1036	54	1016	2	-
	*0158	1018	70	686	2	-
	*0159	1017	86	1182	2	-
	0160	1011	78	483	.25	-
	0161	1009	20	187	.5	-
	*0162	1005	42	403	1	-
	*0163	0988	27	361	1	-
	0164	0990	18	384	.25	-
	*0228	1664	20	342	4	-
Gunnerside	0021	0521	57	745	1	75
	0024	0500	37	2459	L	0
	0027	0484	33	110	L	0
	0209	1625	17	17	L	-
	0210	1619	40	486	L	-
	0211	1614	30	91	L	-
	*0212	1609	46	92	3	-
	0213	1604	0	498	L	-
	0214	1596	25	839	L	-
	0215	1591	1	178	L	-

TABLE 5.4 (Cont.)

Friarfold	0216	1583	31	1538	L	-
	0217	1577	28	1262	L	-
	0218	1573	7	1401	L	-
	0219	1569	80	1945	L	-
	0220	1564	28	711	L	-
	0221	1560	15	192	.5	-
Arkengarthdale	0233	1705	21	1497	L	-
	0234	1714	11	385	L	-
	0235	1715	0	588	L	-
	0236	1733	40	719	L	-
	0237	1719	0	299	L	-
	*0239	1761	113	818	2	-
	0240	1737	7	580	L	-
	*0241	1728	48	199	1	-
	0242	1724	19	431	L	-
	0243	1741	22	81	L	-
	0244	1781	19	187	L	-
	0245	1786	22	295	L	-
	*0246	1746	30	87	2	-
	0247	1756	6	545	L	-
	0072	0454	0	193	L	0
	0073	0460	21	471	L	25
	0074	No No.	28	457	.25	0
	0075	No No.	10	424	.25	0

TABLE 5.4 (Cont.)

Hurst	*0069	0161	0	28	4	200
	0070	0160	0	0	.5	0
	0071	0160	0	0	L	50
	0197	1558	17	435	.5	-
	*0198	1549	164	3	1	-
	0199	1543	38	466	.5	-
	0200	1539	30	826	L	-
	0201	1534	72	1721	L	-
	0202	1529	54	916	L	-
Hellwith	0248	1834	22	113	L	-
	0249	1838	0	226	.25	-
Feldom Fault	0083	0132	0	26	L	0
	0271	0071	0	0	L	-
	0272	0084	0	0	L	-
	0277	0132	1	6	L	-
Arngill	0231	1562	26	2868	L	-
Friars Intake	0098	No No.	0	676	.5	25
	0120	0736	0	689	L	-
	0121	0742	14	1051	L	-
	*0122	1649	22	2039	2	-
	0123	1645	11	1547	L	-
	*0124	1640A	52	1716	7	-

TABLE 5.4 (Cont.)

Copperthwaite	0131	1243	18	745	L	–
	0132	1233	10	968	L	–
	0133	1217	2	303	.75	–
	*0134	1193	37	83	5	–
	0135	1213	30	477	.5	–
	0136	1201	39	212	1	–
	0137	1246	50	804	L	–
	0138	1253	35	991	.75	–
	0144	1215	18	429	L	–
Cleaburn Pasture	*0167	1187	7	125	2	–
	*0168	1186	17	437	9	–
	0169	1179	18	290	L	–
	0170	1177	6	189	L	–
	0171	1170	2	207	.75	–
	0172	1164	39	255	.5	–
	0173	1158	38	374	L	–
	0174	1153	10	278	.5	–
	0175	1148	7	238	L	–
	0176	1141	2	123	L	–
	0177	1138	3	88	L	–
	0178	1130	3	283	L	–
	0179	1125	3	230	L	–
	0180	1118	2	86	L	–

TABLE 5.4 (Cont.)

Lover Gill Vein	*0181	0763	73	2000	1	-
	*0182	0767	93	2022	3	-
	0095	No No.	142	3966	L	25
	*0184	0779	25	3010	2	-
	0096	No No.	199	1968	L	50
	0183	0756	1966	2347	L	-
	0097	0756	2052	2607	L	0
Providence Mine	0185	0800	36	1926	L	-
	*0094	No No.	249	811	1	700
Sargill Mine	0130	0964	127	1258	.5	-
Satronside	0203	1324	32	620	L	-
	0204	1313	30	569	.5	-
	0205	1309	178	1076	.25	-
	0206	1300A	46	1080	L	-
	0207	1290	0	485	L	-
Apedale	0261	1901	9	252	L	-
	0262	1881	38	389	L	-
Harkerside	0189	1383	25	907	L	-
	*0190	1378	22	102	6	-
	0191	1370	14	100	.75	-
	0192	1365	16	89	L	-
	0193	1362	21	126	L	-
	0194	1346	19	41	.25	-
	0195	1338	14	89	L	-
	0196	1335	7	181	.25	-

TABLE 5.4 (Cont.)

Grinton	0230	1672	27	21	L	–
	0227	1691	20	273	.5	–
	0276	1684	9	235	L	–
	0023	0473	19	278	L	0
Ellerton	0250	1797	1	178	L	–
	*0251	1802	23	436	3	–
	0252	1806	10	273	L	–
	0253	1815	59	641	L	–
	0254	1821	27	528	L	–
	0255	1825	0	250	L	–
	0256	1829	19	267	L	–
Cobscar	0259	1857	48	783	L	–
	0260	1848	19	838	L	–
	0263	1874	60	991	L	–
	0264	1875	55	449	L	–
	0265	1868	42	432	L	–
Downholme	0232	1660	0	95	L	–
	0238	1659	2	89	L	–
	0270	1660A	62	86	L	–
	0275	1661	0	81	L	–
Cottriggs	0127	0872	32	1695	L	–
	0269	0869	1407	1954	L	–
Seata	0128	1074	33	1738	L	–

TABLE 5.4 (Cont.)

Wet Grooves	0086	FWS	51	870	.5	25
	0089	0697	49	807	L	0
	*0091	0651	183	1647	24	1200
	0092	0623	36	1763	L	0
	0093	0614	37	2832	L	0
West Burton	0125	0870	21	1280	L	-
Kelds Head	0166	1093a	23	1466	L	-
Braithwaite	0129	1099	0	720	L	-
Dodd Fell	0186	1631	40	135	L	-
	0187	1630	31	507	.25	-
	0188	1635	34	151	L	-
Wasset Fell	0257	1842	0	791	L	-
	0258	1843	21	668	L	-

TABLE 5.5 - CHALCOPYRITE ANALYSES

Locality	Specimen No.	X.R.F. No.	Sn ppm dl = 50	Ag ppm dl = 20	Ni ppm dl = 5	Co ppm dl = 20	Zn ppm dl = 20
Groveräke Mine (collected by F. W. Smith)	No. 5F	0001	150	90	35	100	250
	No. 5F	0002	650	150	25	50	70
	No. 5F	0004	600	150	25	150	250
	103	0029	2050	80	35	200	600
	87	0032	1020	120	40	175	250
	461	0034	1570	110	40	50	100
	No. 9	0035	2250	140	10	0	0
East Leyton	0001	0005	0	0	10	20	0
	W6693	0030	0	0	5	20	0
	W6693	0031	0	0	5	0	0
	W6704	0033	0	0	0	0	0
Richmond	0234	0064	0	0	0	0	0
Kneeton Hall	0064	0006	0	440	15	20	100
	0064	0045	0	>500	10	0	250
	0064	0046	0	140	0	20	0
	0064	0047	0	>500	10	500	250

TABLE 5.5 (cont.)

Locality	Specimen No.	X.R.F. No.	Sn ppm dl = 50	Sb ppm	Ag ppm dl = 20	Ni ppm dl = 5	Co ppm dl = 20	Zn ppm dl = 20
Clouds	0320	0066	0	114	0	0	20	>1000
	0320	0067	0	257	50	0	30	100
	0326	0068	0	245	0	0	20	>6000
Hartley	0184	0065	0	0	0	0	100	25%
Great Sleddale	0412	0036	0	0	0	40	150	1600
	0413	0037	0	0	0	15	18	700
	0412	0039	0	0	0	20	100	1200
	0412	0040	0	0	0	30	175	2000
	0412	0041	0	0	0	10	25	100
	0398	0042	0	0	0	90	300	4000
	0398	0043	0	0	0	90	275	4000
	0398	0044	0	0	0	140	250	2500

TABLE 5.5 (Cont.)

Feldom Fault							
0141	0076	0	0	0	15	10	80
0141	0077	0	0	0	30	15	250
0141	0078	0	0	0	15	18	80
0085	0079	0	0	0	15	10	1300
0085	0080	0	0	0	30	12	2000
0085	0087	0	0	0	35	30	4000

TABLE 5.6 - SPHALERITE ANALYSES

Locality	Specimen No.	X.R.F. No.	Cd %[1]	Zn %	Ag ppm	Co ppm	Ni ppm	Mn ppm
Gunnerside	1600	X2	0.38	59.5	261	0	0	0
Gunnerside	0478	X80	0.56	39.2	79	38	0	0
Cobscar	1951	X75	0.69	55.6	84	0	0	0
Wet Grooves	0680	X77	0.51	66.1	210	0	0	0
Wet Grooves[2]	0707	X82	1.40	65.6	24	0	0	0
Keld	1037	X78	0.53	49.6	184	0	105	0
Apedale	1881A	X79	0.50	62.1	1	11	0	0
Apedale	1881B	X83	0.48	64.3	16	0	0	0
Seata	1075	X81	1.10	56.8	51	34	19	0

NOTES: [1] Values calculated for 100% sphalerite

[2] Hg 80 ppm

TABLE 5.6 (Cont.)

Hartley Birkett	0566	X84	0.64	49.9	14	0	0	1200
Hartley Birkett	0590	OO14	0.59	21.3	32	0	0	1000
Hartley Birkett	0566	0099	0.5	65.	19	-	-	-
Hartley Birkett	0566	X85	*0.27	7.2	*79	0	0	640
Clouds	0361D	X4	0.42	14.2	37	63	0	0
Arngill	1657	X14	0.17	10.6	54	31	0	0
Gunnerside	0478	X29	0.42	13.9	65	28	0	0
Staggs Fell	0766	X36	*0.32	16.0	*288	122	87	0
Wet Grooves	0680	OO90	0.4	65	192	0	0	0

FIGURE 5.3: YTTRIUM CONTENT OF FLUORITE (P.P.M.)
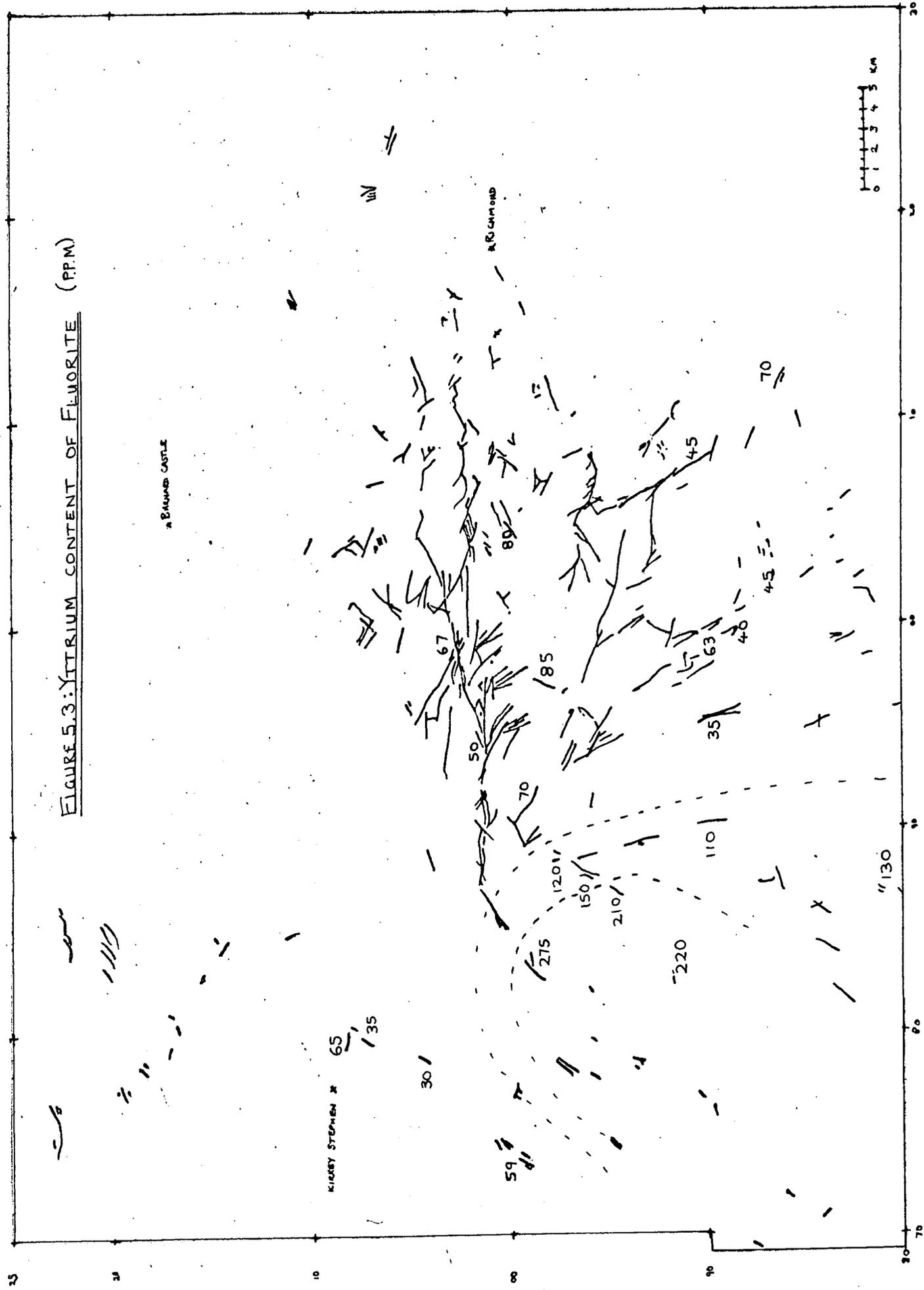
FIGURE 5.4 STRONTIUM CONTENT VERSUS SODIUM/POTASSIUM RATIO

ω Localities with witherite   C.P. Course platy sample
S Secondary
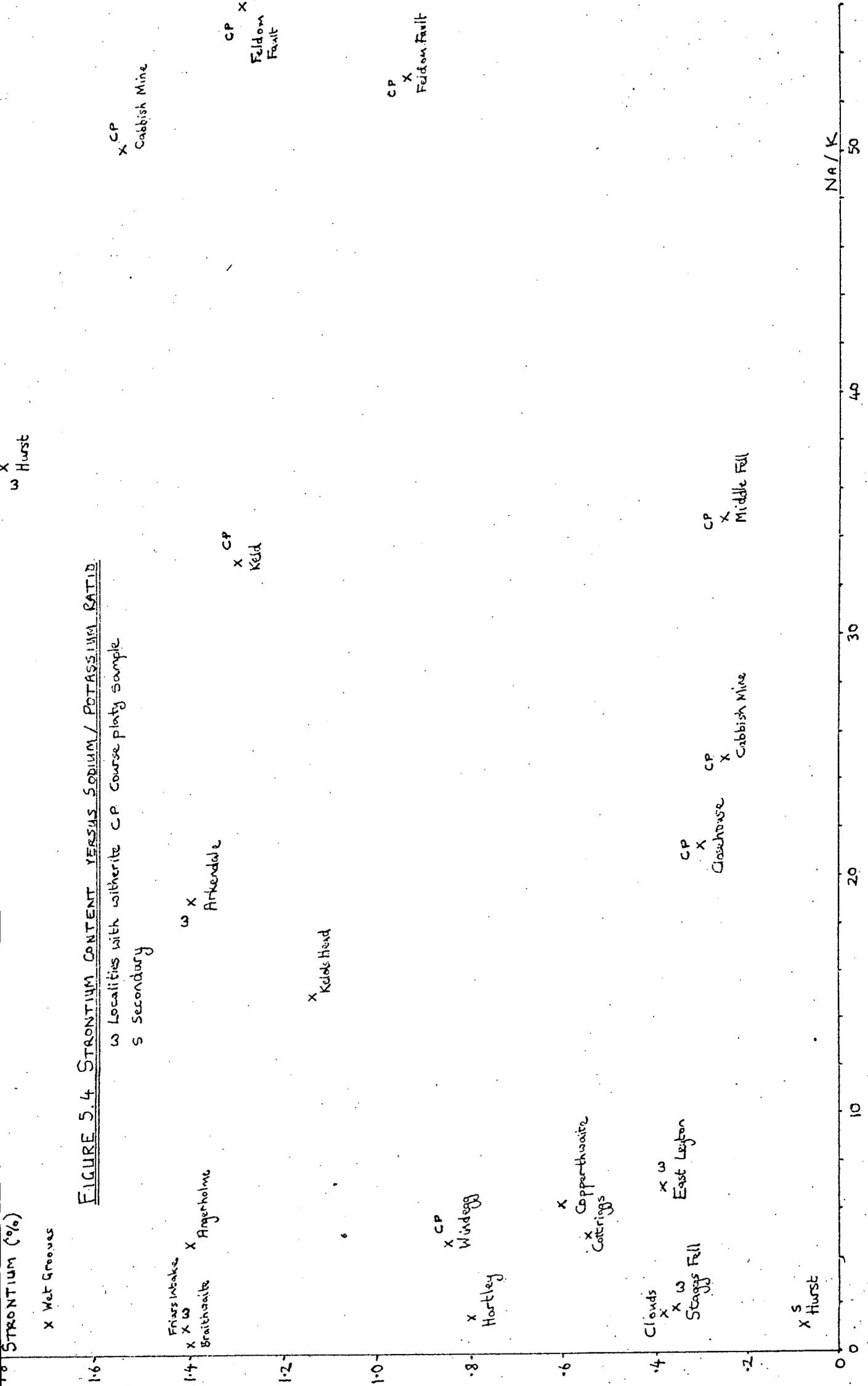
FIGURE 5.4a STRONTIUM CONTENT OF BARITE (%)
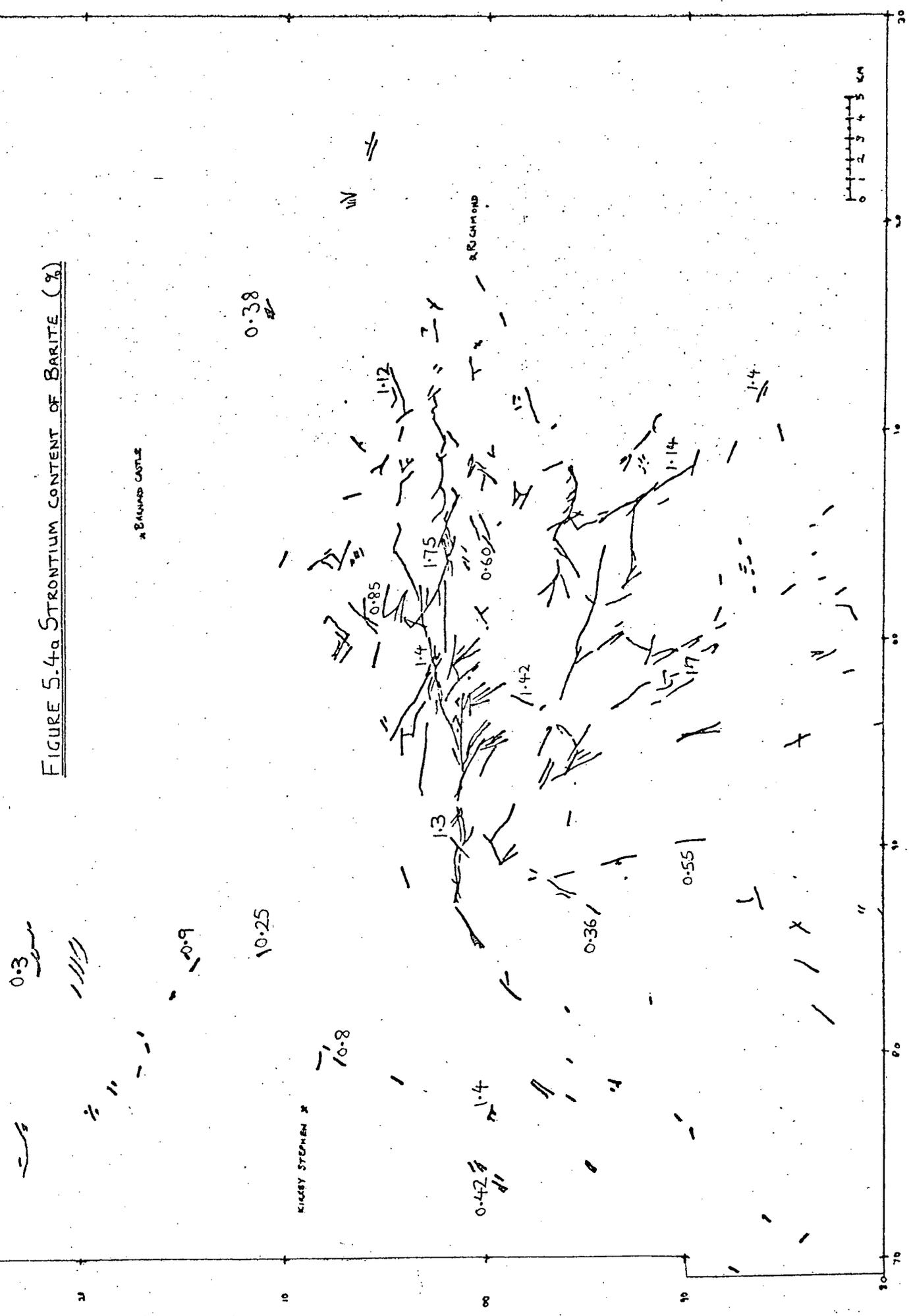
FIGURE 5.5 SILVER VERSUS ANTIMONY FOR ALL GALENAS (IN RANGE)

FIGURE 5.6: SILVER — ANTIMONY FOR WESTERN LOCALITIES

x Clouds   ⊙ Longrigg   • Hartley Birkett

Silver (ppm)
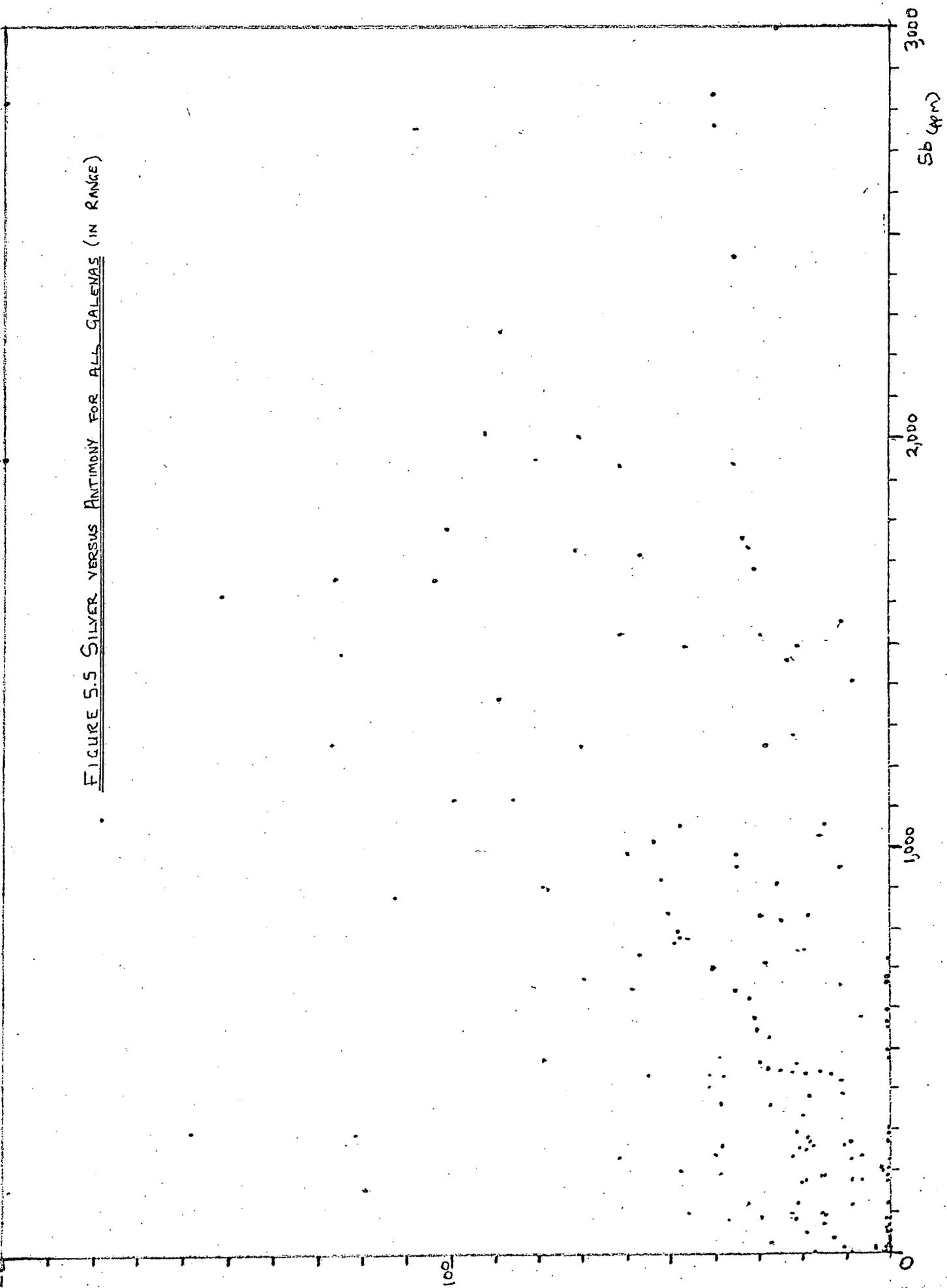
Antimony (ppm)

SILVER (PPM)

FIGURE 5.7 SILVER - ANTIMONY FOR PRY HILL (□) AND KELD (X)

ANTIMONY (PPM)

X STAGGS FELL   + LOVERGILL HUSH   □ HUSH GILL   △ PROVIDENCE   ✳ SARGILL   • SATRONSIDE   ○ COTTRIGGS
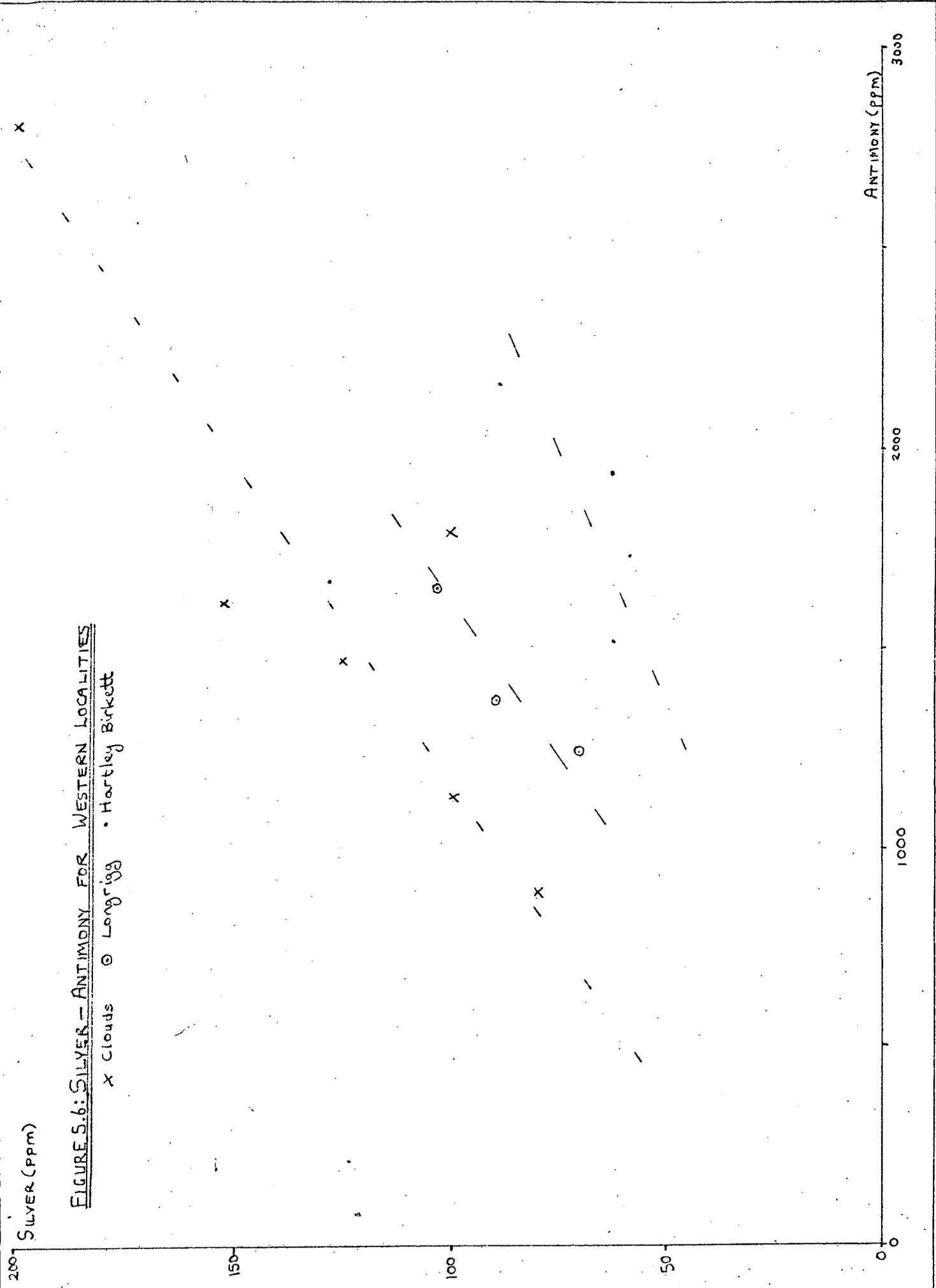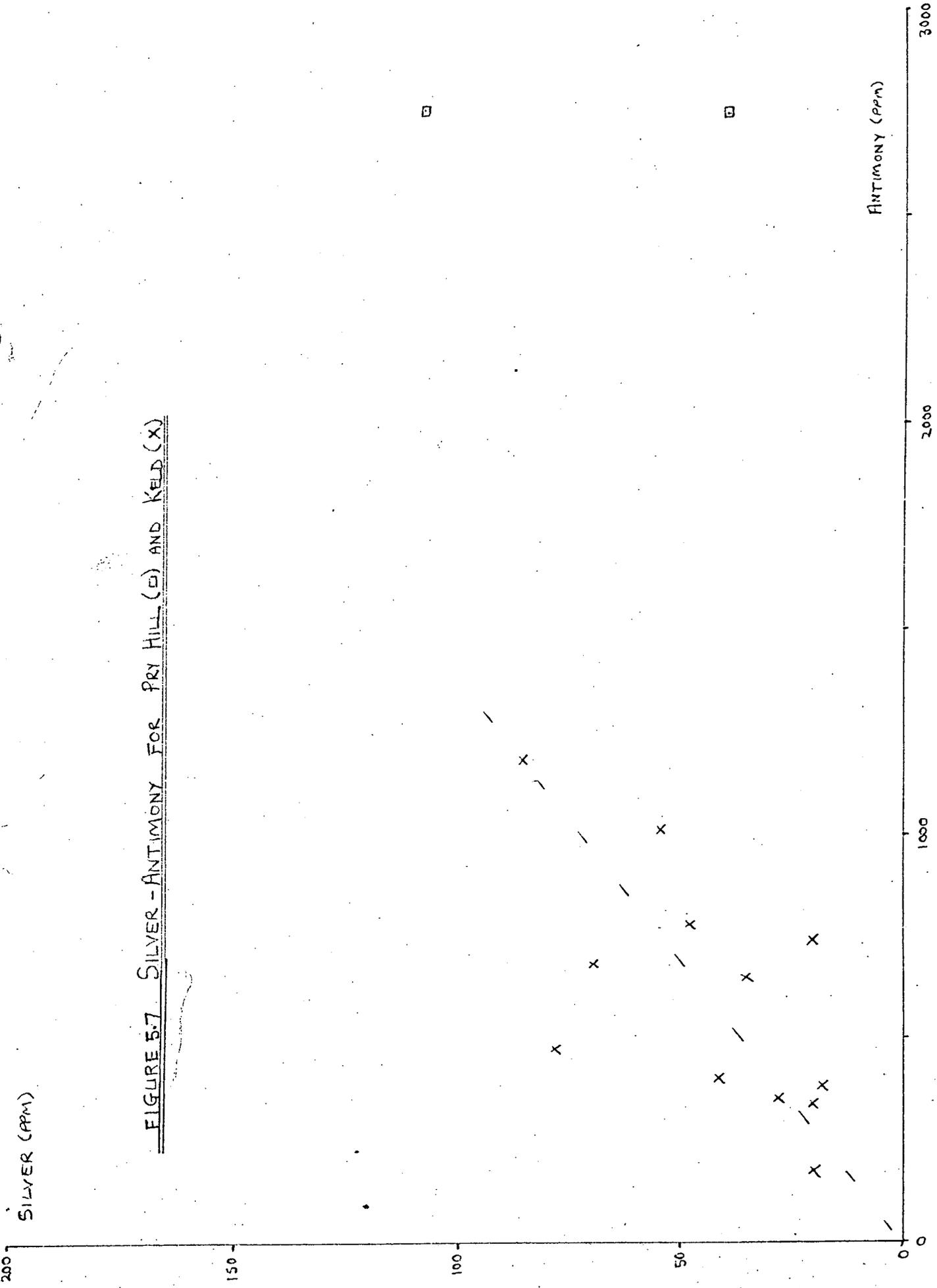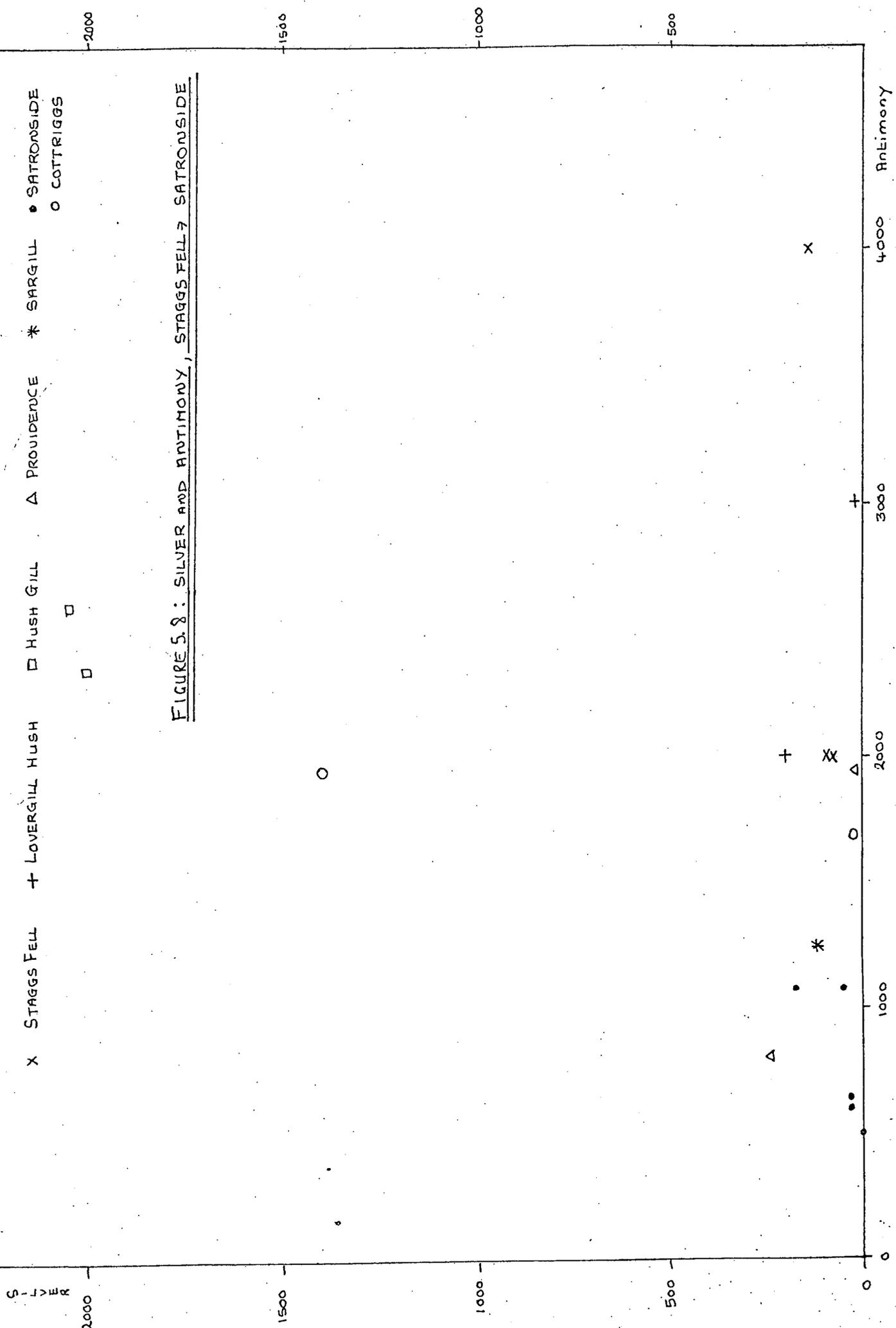
FIGURE 5.8: SILVER AND ANTIMONY, STAGGS FELL & SATRONSIDE

Antimony

S I L V E R

FIGURE 5.9 SILVER AND ANTIMONY, HARKERSIDE → COBSCAR

X HARKERSIDE   • GRINTON   ○ ELLERTON   + COBSCAR   △ APEDALE
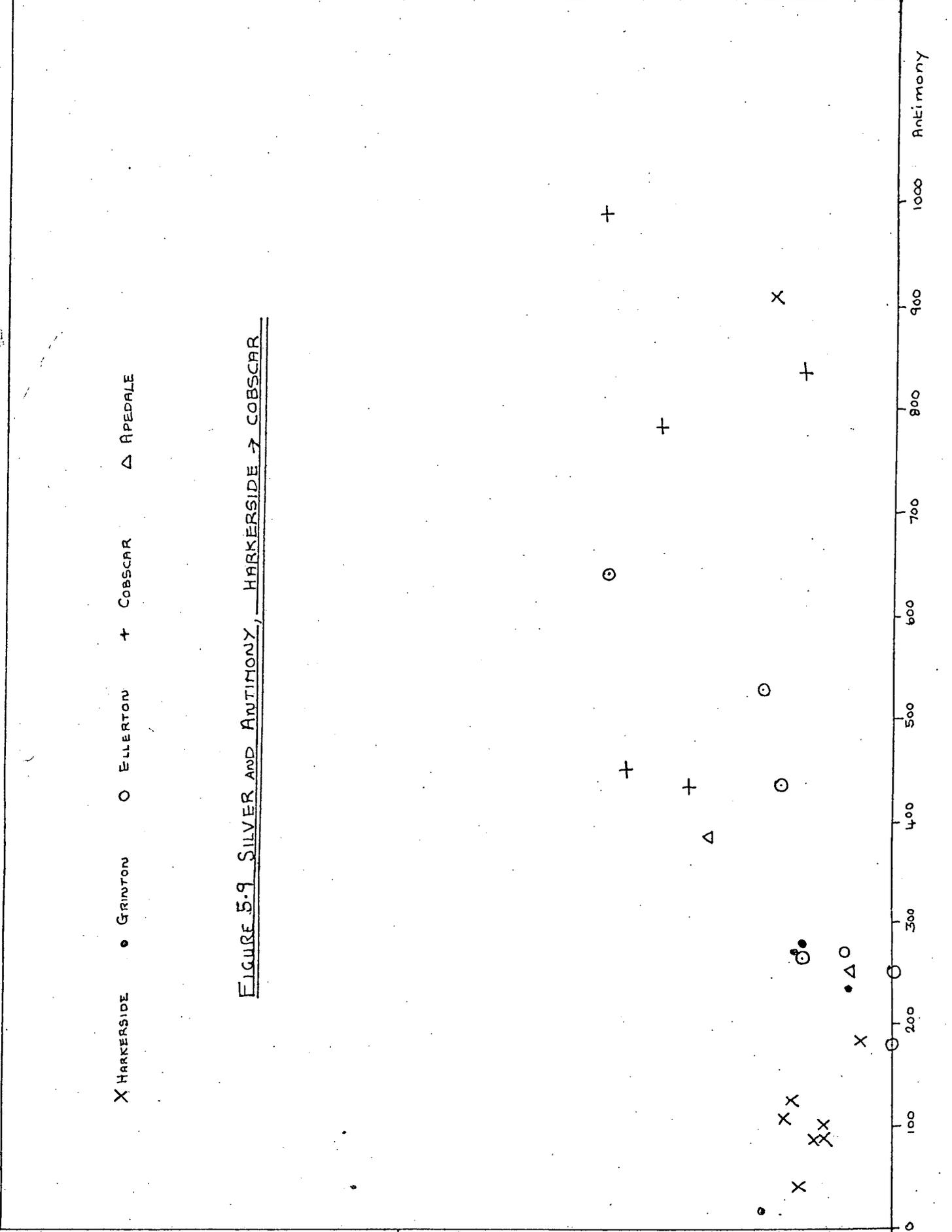
FIGURE 5.10 SILVER - ANTIMONY FOR ARNGILL - CLEABURN PASTURE
× Friars Intake + Copperthwaite • Cleaburn Pasture ▣ Arngill.
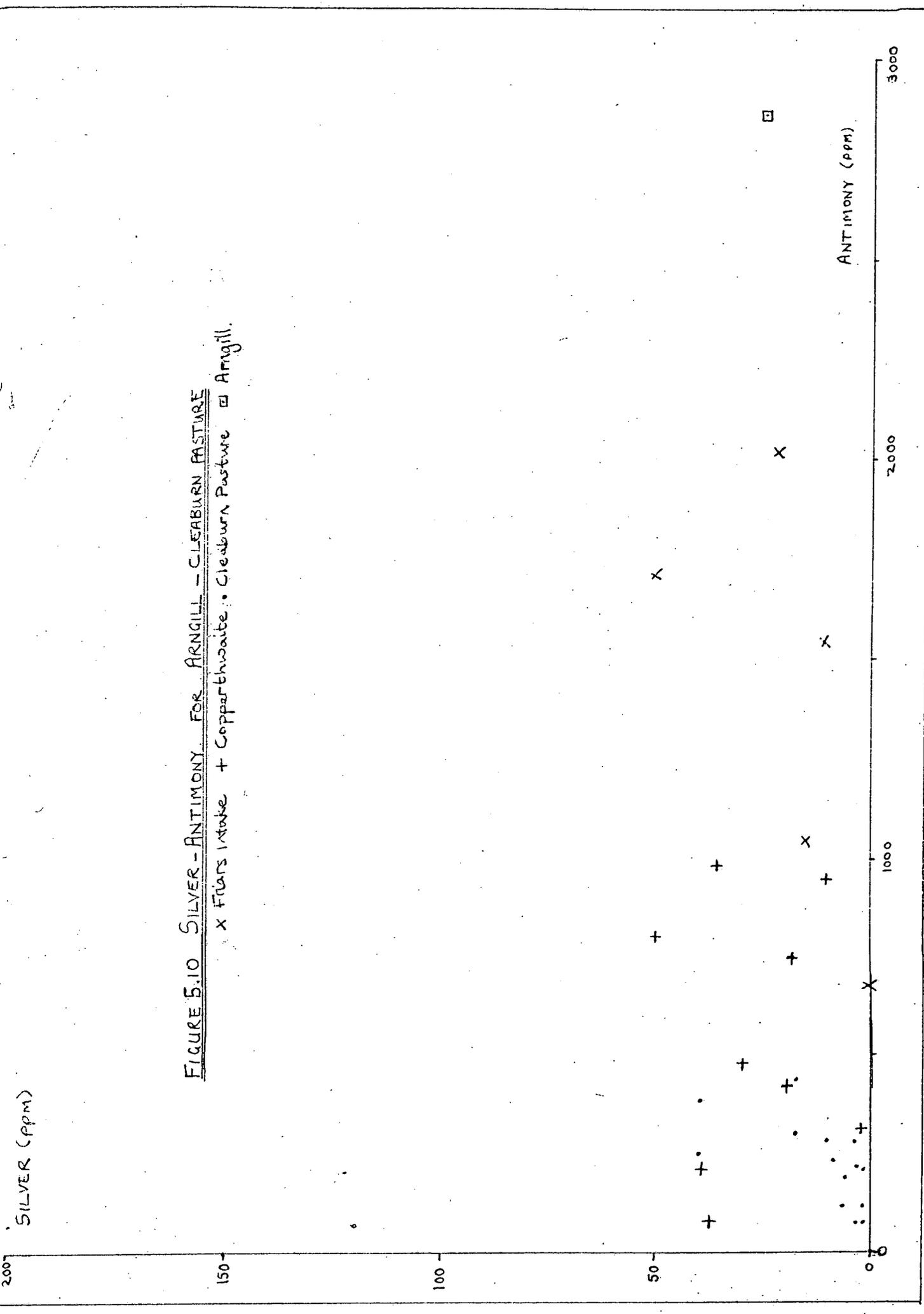
FIGURE 5.11 SILVER - ANTIMONY FOR WENSLEYDALE

⊗ Cottriggs , ⊙ Scata , ✕ Wet Grooves , ● West Burton , ⊡ Kelds Head , △ Braithwaite , + Dodd Fell , ○ Wasset Fell .

SILVER (PPM)

ANTIMONY (PPM)

FIGURE 5.12 SILVER–ANTIMONY FOR GUNNERSIDE – ARKENDALE

•Gunnerside ×Friarfold ⊙Arkengarthdale.
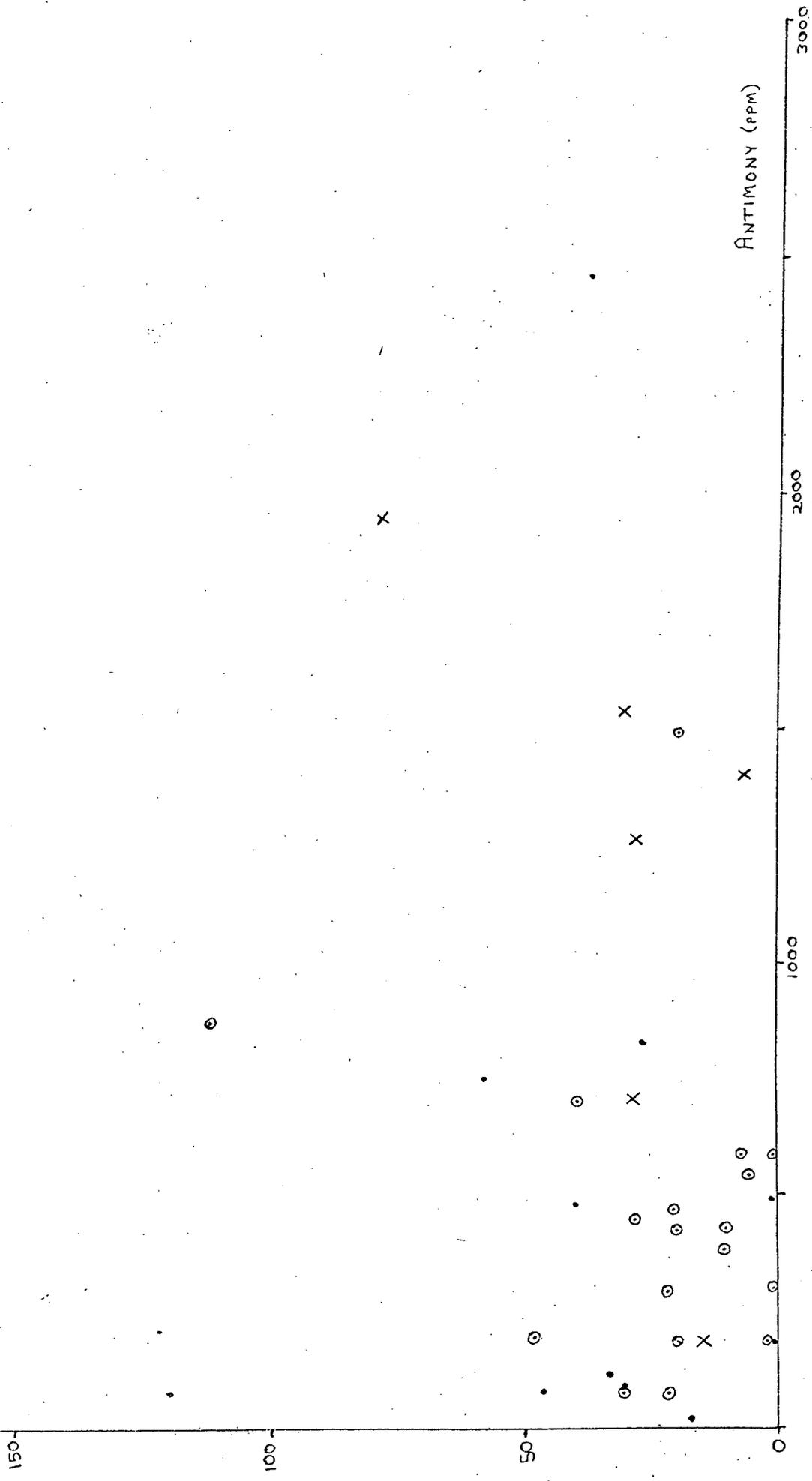
SILVER (PPM)

ANTIMONY (PPM)

FIGURE 5.13 SILVER - ANTIMONY HURST TO FELDOM

X Hurst   ⊙ Hellwith   • Feldom Fault (at origin)

FIGURE 5.14 SILVER – ANTIMONY FOR THE NORTH SIDE OF ARKENDALE.
⊙ Windegg Fault × Windegg Lead • Faggergill and Stang.

SILVER (PPM)

FIG. 5.15 SILVER - ANTIMONY FOR THE NORTH WEST.

• Lunehead   x Closehouse   ▫ Cow Green   ○ Cabbish Mine

ANTIMONY (PPM)
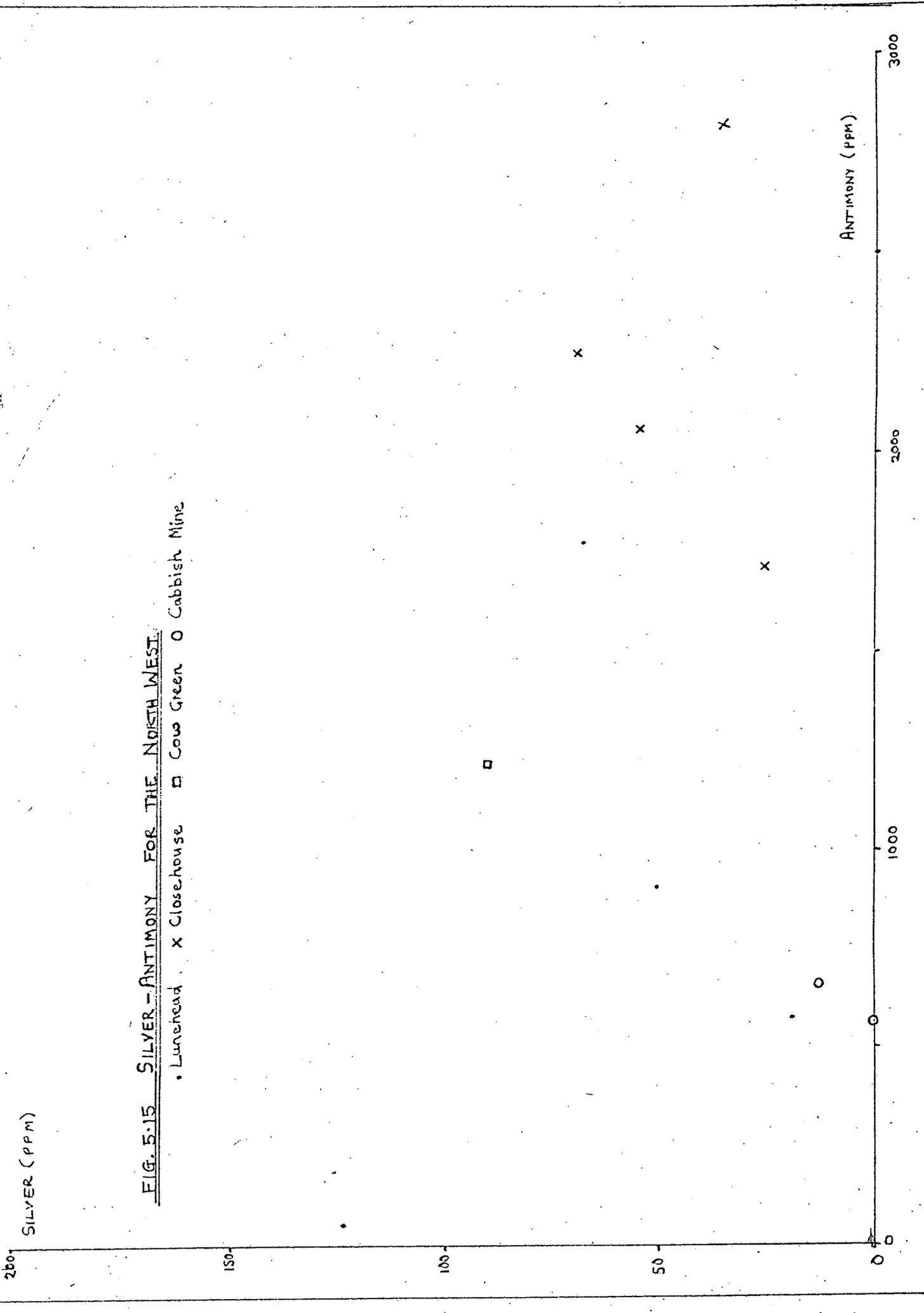
FIGURE 5.16   DISTRIBUTION OF ANTIMONY IN GALENA (ppm)
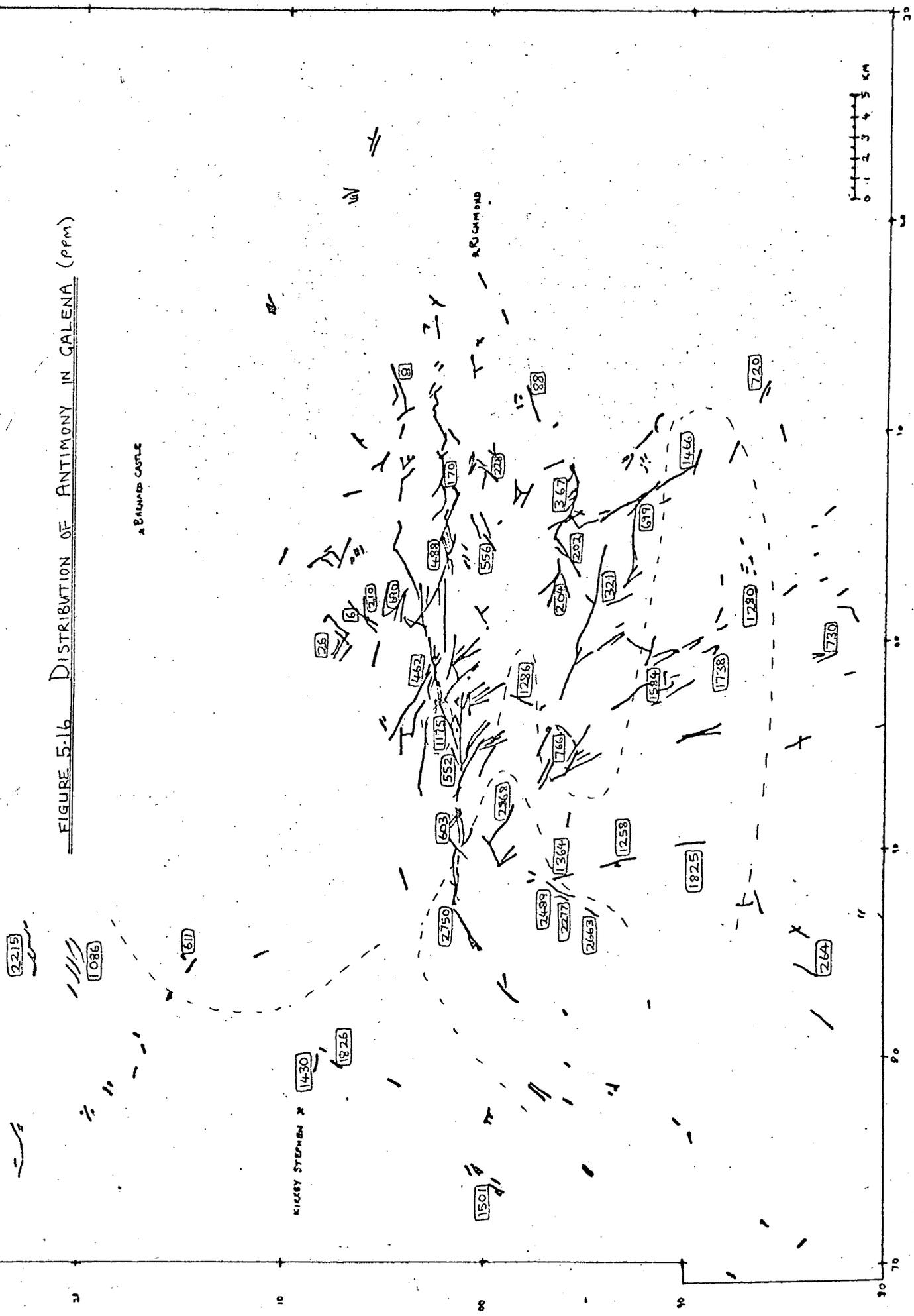
FIGURE 5.17 DISTRIBUTION OF SILVER IN GALENA (ppm)
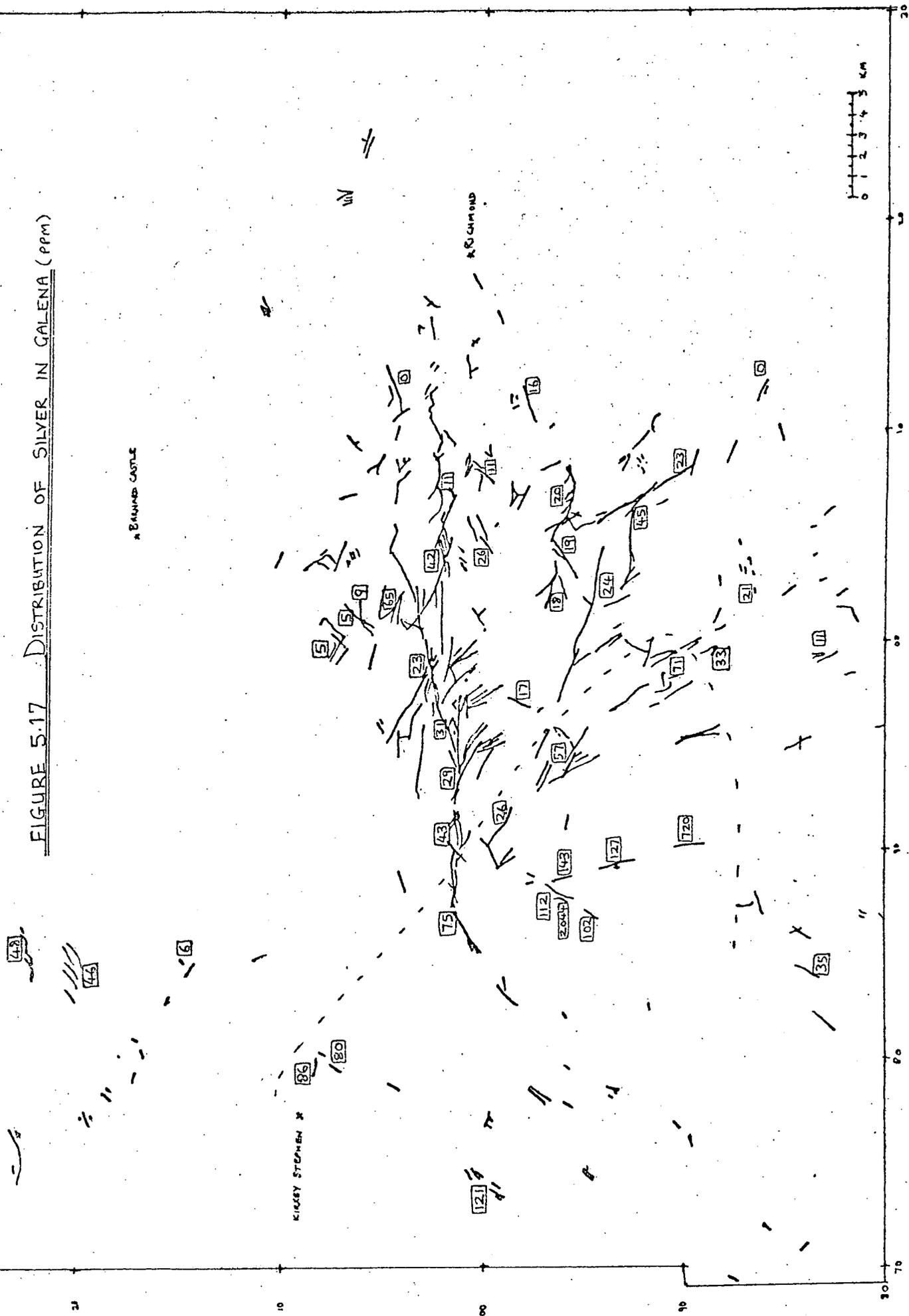
FIGURE 5.18 SILVER (Ag) AND CADMIUM (Cd) CONTENT OF SPHALERITE
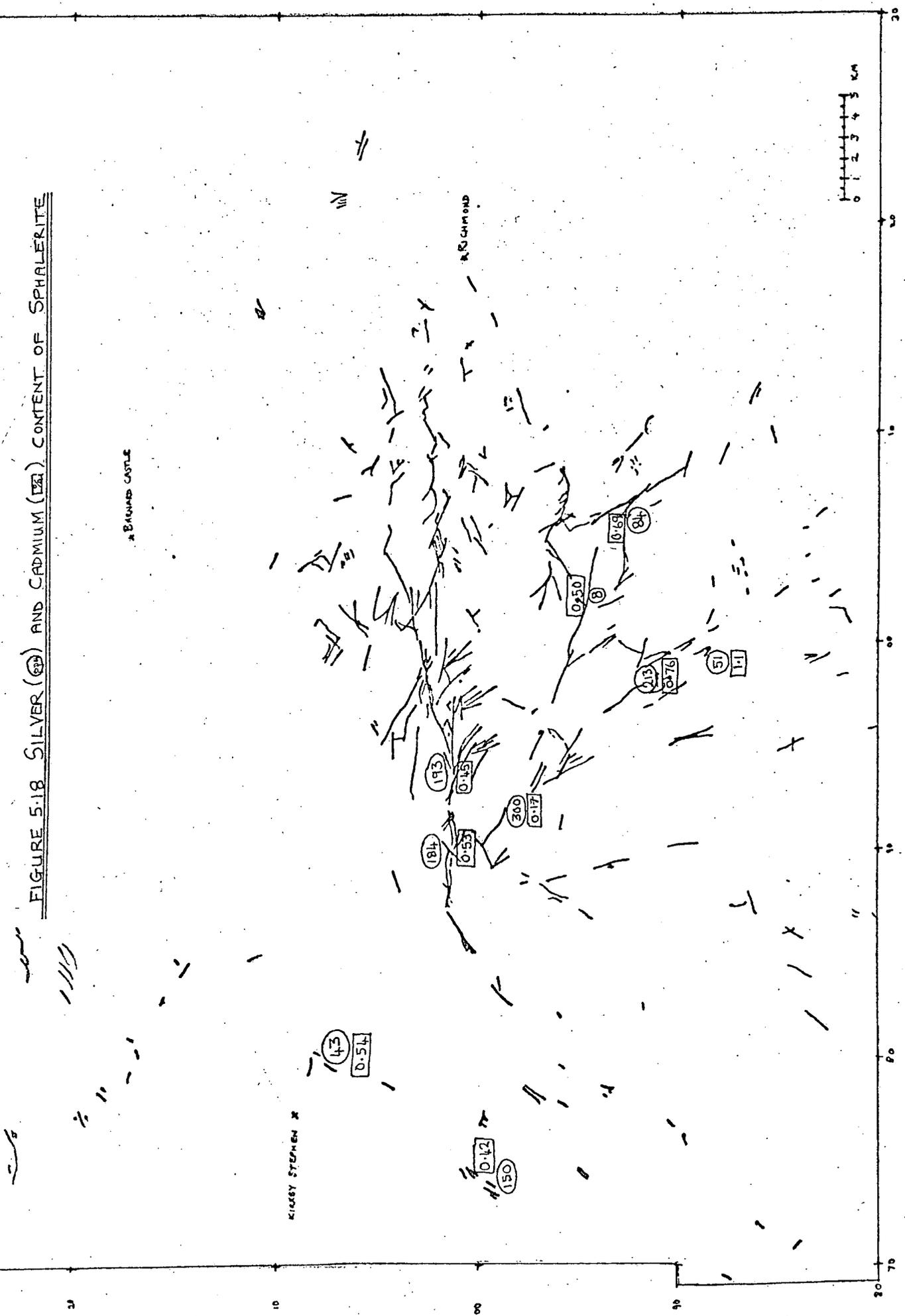
FIGURE 5.19   SILVER ~ CADMIUM IN SPHALERITE
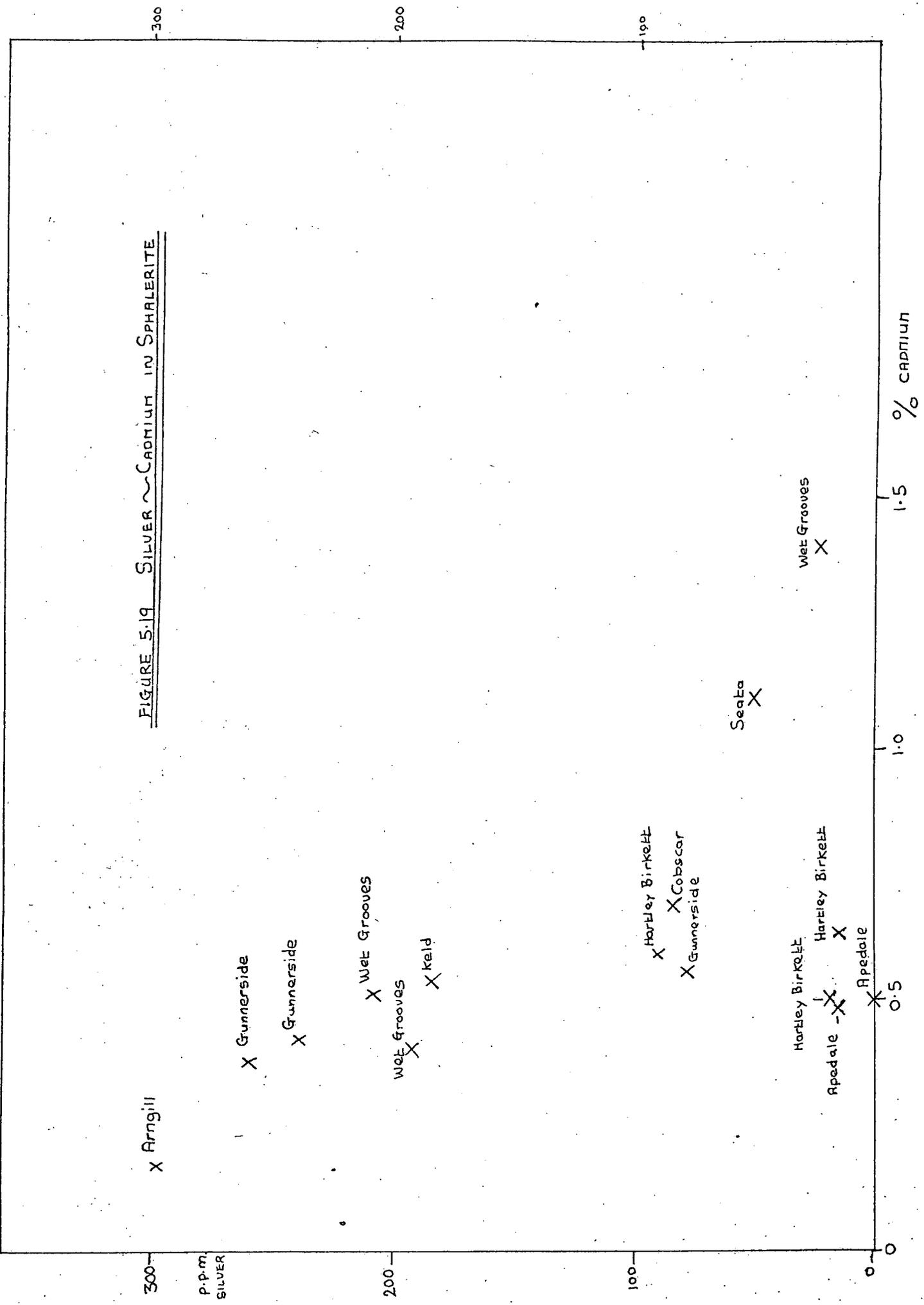
EVIDENCE FROM INCLUSIONS

INTRODUCTION

In the North Yorkshire Orefield three kinds of inclusion have been observed in the crystals of minerals collected. The first kind are solid inclusions of foreign mineral in the crystal. The second are single phase liquid inclusions and the third are two phase liquid-gas inclusions.

Inclusions form in several different ways. The solid inclusions result from the deposition on the growing surface of the primary mineral either of a growing or fully grown grain of another mineral, or the growth of an initial tiny nucleus of a grain of foreign mineral formed on the growing surface. It is difficult to be certain of the origin of some solid inclusions especially when the host mineral and inclusions have similar chemstry, e.g. sphalerite-pyrite, where exolution of one from the other is also a likely mechanism. The solid inclusions of the North Yorkshire Orefield are mostly restricted to the following pairs of minerals:

Fluorite - sulphide inclusions, commonly chalcopyrite

Barite - sulphide inclusions, commonly chalcopyrite

Calcite - sulphide inclusions, (chalcopyrite)

Sphalerite - sulphide inclusions, (chalcopyrite)

Except for the last pair of minerals the associations can be used to demonstrate simultaneous crystalization of the sulphide and gangue species.

Liquid inclusions can form when for some reason the mineral does not grow uniformly, the crystal first forms a cup and then closes around trapped liquid. These inclusions are termed primary inclusions in that they formed syngenetically with the crystal surrounding them. In fluorite the most useful mineral for fluid inclusion studies, growth is normally

strong and prolonged at the crystal corners and edges but weak in the centre of faces. This state of affairs encourages the production of many ramifying inclusions in zones away from the position of former corners and edges, and is perhaps instrumental in the interpenetrating twinning of fluorite so commonly observed. The best inclusions for fluid inclusion studies are often away from the dense zone of inclusions because there they are more often isolated, of simpler shape and more easily observable.

Primary liquid inclusions can also form by the capture of liquid during the growth of two or more crystals along their common boundaries.

Secondary liquid inclusions formed after the growth of the mineral surrounding them can be produced by healing fractures. Pseudo secondary inclusions are secondary inclusions which formed before the completion of the growth of the crystal. Secondary inclusions can be easily distinguished when formed along cleavages, but the distinction of pseudo-secondary inclusions is more difficult, since it relies upon the original fracture not continuing into the outer parts of the crystal and such evidence is often difficult to produce. Many inclusions are diffuclt to place into a category, but the more isolated inclusions are very unlikely to be secondary inclusions and so are good to work on. All of the liquid inclusions are samples of the solutions available at the time of formation and so, in the case of primary inclusions, they are samples of the original mineralizing solutions.

Two phase inclusions are commonly liquid inclusions that formed at elevated temperatures. During cooling both the liquid inclusion and mineral will contract. If sufficient cooling takes place, the difference in contraction rates produces a situation in which the liquid can no longer fill the space available. A bubble filled with vapour and once dissolved gases neucleates producing the two phase gas-liquid inclusions

so commonly observed. Processes such as dissolution of the mineral or crystallization of daughter minerals are well known, but are not evident in the low temperature inclusions of the Swaledale Orefield.

Geologically rare cases are known where primary inclusions of boiling liquids have trapped primary gas and liquid simultaneously. Two phase inclusions can also form by the cooling of original monophase gaseous inclusions, these are from pneumatolitic minerals and such inclusions, which can be established experimentally, provide real evidence of this rare category of minerals.

A spurious, but not uncommon form of two phase inclusion is the leaked monophase liquid inclusion, where some liquid has been lost, perhaps by a later heating, or stressing of a mineral with good cleavage.

Other kinds of inclusions such as two phase liquid and various three phase inclusions are all known in different mineral deposits, but have not been observed in the specimens from the North Yorkshire Orefield.

There are valuable accounts of the study of fluid inclusions such as Yermakov (1965), Smith,FG(1963) and Roedder (1968), which were consulted during this work.

HOMOGENIZATION TEMPERATURES, AND SALINITIES

Homogenization temperatures are estimates of the temperature of formation of primary inclusions and therefore their host mineral. These estimates can be obtained by several methods, although the only practical method has turned out to be the reheating of polyphase inclusions until they return to their original single phase state. This method is easy to perform on two phase gas-liquid inclusions, where the homogenization can be relatively rapid, i.e. at most a few hours for a run, but difficult on polyphase gas-liquid-solid inclusions, where a run may require several days because of difficulty in dissolving daughter minerals. This method can be used to calibrate other methods such as measurement of the phase volume ratio at room temperature 20°C and decrepitation methods.

The decrepitation method relies on inclusions exploding when heated much above their homogenization temperature. A decrepigram can be produced by visually counting the rate of explosions at different temperatures, when a crushed mineral of standard grain size is heated, or by using a microphone and amplifier to record electronically the rate of explosion. This method is fraught with great difficulties both of interpretation and standardization, although it is a potential method for opaque minerals, which can not be seen homogenizing in transmitted light.

The apparatus required for homogenization determination is a special thermally insulated and heatable stage, which allows light to pass through the mineral and up into the optical system. The temperature of the mineral is commonly monitored by a thermocouple. The objective of the microscope must have a long focal length to reduce distortion by the heat from the stage, and so there are severe limits on the field of view and magnification. The system used in the Durham Department of Geological Sciences has been described by Smith, F.W. (1974). It suffers from several handicaps:

1.   Low stage mobility

2.   Non-polarizing optics

3.   Upper temperature limits of around 350 - 400°C

4.   Low magnification available

5.   Low light intensity

These handicaps mean that there is a great restriction on the material which can be used. Thus material must have large inclusions because of the magnification. It must have low birefringence because of the non-polarizing optics, and it should be only very weakly coloured and transparent, because of the light intensity.

Other criteria to be fulfilled for the material to be of use are:

1.   That there should be primary inclusions, which are not necked down, i.e. unaltered in continuity, since they were formed. If one inclusion splits on cooling into several different inclusions, then normally they will produce different homogenization temperatures in no way representing the original primary temperature.

2.   There should be primary polyphase inclusions and the phases should be clearly discernable at room temperature.

An examination of possible materials after the preparation of limited numbers of specimens revealed the following unpromising picture:

(a) Sulphides

Of the sulphide minerals present, only sphalerite was transparent enough to allow observation of any inclusions. Sphalerite was, however, still ordinarily too strongly coloured for the discovery of many inclusions, even using ordinary microscopes, but primary inclusions were found in the more transparent patches of 2 out of 6 specimens finally prepared.

(b) Carbonates

Of the carbonates, calcite and witherite, many of the tiny inclusions observed may be secondary inclusions following cleavage. A few large inclusions which were found could not be observed in non-polarizing optics, because of the very high birefringence. The abundant inclusions produce the milkiness of most calcite observed.

(c) Sulphates

Barite was often very rich in inclusions, which again produces the milky appearance. Sometimes it is possible to observe in hand specimens of toothy barite bands rich and poor in inclusions. The inclusions are unfortunately often too densely packed to observe adequately and are mostly too small to work on. A single specimen of coarse clear barite

yielded inclusions of large size. Preparation of the specimen un-
fortunately caused leakage, but cleavage flakes revealed the original
monophase liquid inclusions.

(d) Quartz

Quartz samples carried inclusions, but they were too small to see
clearly even on an ordinary microscope.

(e) Fluorite

Fluorite was the only mineral found which had abundant inclusions
suitable for study, although even fluorite had problems, such as inter-
connections, and such high density of complicated shaped inclusions as
as to prohibit their use. Most of the inclusions were obviously primary
even if unusable. Some specimens were dominated by sulphide inclusions,
both as fairly round grains and also as long ribbons showing growth with
the fluorite crystal, and had no or only very few fluid inclusions.

The survey of materials thus demonstrated that only fluorite was a
really suitable mineral for use. The study of fluorite inclusions had
already been started (Smith 1974 , Rodgers ,1975), but a few samples from
less well-known fluorite localities were studied to see if anything could
be added to the broad picture.

The experimental procedure was to select material collected in the
field and study it with the hand lens or binocular microscope. Potential
material was then prepared for examination by cutting a slice of the
mineral, embedding it in resin and polishing both sides so that it could
be examined in transmitted light. The final wafer had to be less than
1 or 2 mm thick, so that problems regarding heating the specimen and
accurate knowledge of its temperature did not occur. A thin wafer reduces
the number of inclusions available, but makes them more observable. With
some minerals it is possible to look at cleavage fragment, but the
octahedral cleavage of fluorite tends to restrict its use in this mineral.

The preparatory techniques should avoid heating the specimen, as much as possible, because heating above homogenization temperature can cause leaking of inclusions and therefore inconsistent results. Unfortunately although precautions were taken to ensure slow setting resin, the technique of sticking specimens to the polishing mounts with lakeside resin may have produced temperatures high enough to cause leakage of some original monophase inclusions.

The pressures and heating associated with cutting and polishing could perhaps also cause leakage in highly cleavable materials like barite. Leakage can normally be distinguished by very variable phase ratio and the presence of "dry" (generally sharp and dark) inclusions, and was not observed in fluorites except after some homogenization runs. After preparation, wafers were examined on a swift petrological microscope and inclusions were located and their probable origins ascertained. The wafers were then broken into small pieces to enable them to fit into the heating stage. A maximum dimension of 5 mm was found to be practical. Unfortunately many good inclusions are lost and some specimens are beyond use after this stage. The pieces with suitable inclusions were set up in the heating stage so that the maximum number of suitable primary inclusions were in the field of view. A drawing of the inclusions is then made and the heating run begun, by turning on the heating coils and heating at about $3^{\circ}C/min$. until approaching homogenization when the rate is reduced to about $1^{\circ}C/min$. A heating run can thus take anything up to an hour for temperatures on the range encountered. After homogenization of all the primaries in view the stage was cooled by removing the glass lid and blowing in air gently.

After use the fragment often has to be discarded, because if inclusions are heated much beyond their homogenization temperature, which is generally the case for some inclusions, they may leak. This means

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later runs demonstrate a higher minimum temperature and more variable
phase ratio results. The inability to use fragments again and necessity
to break wafers often means that valuable primary inclusions are destroyed
before they can be used. It is possible to re-run on one inclusion or a
group with the same homogenization temperature if they are not heated
more than a few degrees above homogenization, but it is not wise to re-
run a fragment for different inclusions.

Some experienced Russian workers (Yermakov (1965)) are happy to
use the results from individual inclusions, but it is preferable to use
as many as practical, although it was found difficult in this study to
provide reasonable numbers of inclusions.

The relatively small numbers of results obtained are tabulated
(Table 6.1) with the results of Smith (1974) for comparison beneath.
The results of Rodgers are not yet available, but from talks given by him
to the Mineral Deposits Studies Group he has obtained a slightly higher
and wider range of temperatures from a larger number of samples, and also
found no other mineral suitable for this sort of work.

The range of temperatures obtained are roughly comparable with
Smith's and indicate a lower temperature of fluorite than often present
in the Alston Orefield (Sawkins, 1966, Smith, 1974). A pressure correction
of around +30° C has been suggested (Smith, 1974) but it is difficult to
assess the original depth to the deposits, and the need for correction in
"open fractures" has been questioned (Yermakov,1965). Even allowing for
the correction of +30° C the highest temperature here recorded only rises
to 150° C, which is around 10° less than suggested by Rodgers.

It had been anticipated that higher temperatures might have been
recorded from the localities such as Great Sleddale, Cottriggs and Hush
Gill, which are near to the core of the orefield, but the fairly low temp-
eratures recorded here suggest that it is not possible to establish any
isotherms between the different zones of the orefield in this regional study.

TABLE 6.1 - HOMOGENIZATION RESULTS FOR THE
NORTH YORKSHIRE OREFIELD FROM THIS STUDY AND FROM SMITH (1974)

Specimen	Locality	Mean Homogenization Temperature °C	No. of inclusions	Worker
0872	Cottriggs	85.6	6	ATS
0855	Warton	107.6	5	ATS
0856	Warton	120.1	4	ATS
0649	Wet Grooves	88.4	6	ATS
0700	Wet Grooves	95.0	9	ATS
0706	Wet Grooves	91.0	10	ATS
0754	Hush Gill	92.0	23	ATS
0413	Gt. Sleddale	97.5	5	ATS
0415	Gt. Sleddale	102	6	ATS
0605	Hartley Birkett	90.5	12	ATS
0186	Longrigg	90.0	29	ATS
356	Kelds Head	86.2	12	FWS
617	Seata	95.2	21	FWS
645	Clouds	77.5	11	FWS
766	Old Rake	97.5	13	FWS
823	Hartley Birkett	92.5	10	FWS
828	Hartley Birkett	93.4	17	FWS

Attempts at obtaining visual decrepitation temperatures of galena were made with Dr. Smith, but high temperatures (200° C - 400° C) were required before decrepitation occurred. The small amount of decrepitation, perhaps due to the good cleavage and consequent easy leaking of

inclusions, and the difficulty of accurately standardizing the technique
prohibited any reasonable estimates of true temperature of formation
from being obtained.

Freezing stage data on salinities, obtained by observing the
depression of freezing point by dissolved salts in the inclusions, was
not obtained in this study, but Smith (1974) and Rodgers (1975) have
both obtained relative salinities of 15 - 20% by weight of Sodium
Chloride equivalent.

LEACHING EXPERIMENTS

Breaking open fluid inclusions and studying the liquids and gases
extracted can reveal much about the nature of ore forming solutions,
since it is widely accepted that fluid inclusions are the only samples
of prehistoric mineralizing solutions we can examine. It is for this
reason that many sophisticated extraction experiments have been performed
though mostly in the United States and the Soviet Union. Techniques
commonly used involve crushing of minerals under vacuum and extracting
the contents by vacuum line to investigate the gases and liquids, and
leaching by water or other solvents to obtain the information on dissolved
salts and daughter minerals. Sometimes workers have been fortunate enough
to have large inclusions, e.g. visible to the naked eye, some even centi-
metres across. They have been able to break into the individual inclusions
by drilling, laser beams etc., and have applied standard and non-standard
microchemical techniques to the extracted liquids.

Two relatively simple experiments were examined in this project.
Unfortunately one of them, crushing minerals in reagents under the micro-
scope, did not progress past the stage of manufacture of a crushing "stage"
since long delay in manufacture allowed no time for testing. The other
experiment was a leaching technique previously used in Durham and else-
where.

The leaching experiments were carried out as follows:-

1. The mineral sample was prepared as pure as reasonable by breaking the sample with a hammer and handpicking the mineral.

2. The mineral was then washed and dried in an oven at about 50° C. From this time onwards contact with the skin or any other possible sources of sodium or potassium contaminant was avoided.

3. The dried mineral was crushed in a tungsten carbide ball mill containing two balls, which was run for 25 minutes, which produced a powder about as fine as can be obtained by the mill.

4. The powder was stored in plastic storage bottles until ready for leaching, etc.

5. A roughly similar volume of distilled water was added to the powder in the storage bottle and the mixture shaken on a mechanical shaker for approximately 45 minutes, easily adequate time for the dissolution of salts.

6. The mixture was left to settle out and the resulting generally clear liquid extracted using a dropping pipette and stored until determination.

7. The sodium and potassium were determined on a flame photometer against standard solutions made up from analar spectrometric standard solutions diluted by the same distilled water as that used for leaching the sample.

8. The results were read off graphs of the standards and studied.

It should be emphasized that this technique is a rapid form enforced by the lack of time for a more careful form. In the above procedure the drying is carried out at 50° C or less to ensure that leakage of inclusions before crushing is minimized. During crushing the temperature of the powder rises to hand hot or even hotter and presumably some of the water of the fluid inclusions is lost by evaporation, but this is not harmful to the experiment. Several kinds of control were carried out

For instance -

(a)   Duplicate samples from stage 1. were taken through the procedure to check on intersample contamination in crushing and variability.

(b)   Duplicate powders from stage 3. were taken through the procedure to check on intersample contamination in the leaching and separation of liquid, and the variability of determination.

(c)   Blank distilled water was run from stage 5. to the end to check on contamination from containers.

The standard solutions were prepared by standard volumetric procedure from the spectrometric standard solutions which contain hydrochloric acid. This causes a slightly reduced reading for the more concentrated standards, but a reduction is also expected because of the "saturation" of the flame at higher concentrations. The standards used were 0, 2, 4, 8, 20 ppm for Potassium, and 0, 2, 4, 8, 20, 40 for Sodium. Some samples of leachate were so concentrated they had to be diluted to come into the range of standards, but since the ratio is the important parameter to be determined it does not matter, just as the exact quantity of water added at stage 5. is immaterial.

Some samples were found to be very weak and they would normally have been concentrated by quiet evaporation, but time precluded the use of this technique, similarly precluded was the use of a more stable and sensitive photometer or atomic absorption spectrometer and weaker standards. Very weak standards were prepared, but did not calibrate well perhaps due to contamination, and so were abandoned.

PHILOSOPHY OF LEACHING TECHNIQUE AND INTERPRETATION OF RESULTS

The technique is based upon the presence of primary fluid inclusions synchronous or almost synchronous with crystallization of the mineral.

In techniques relying upon the physical properties of the inclusions such as freezing or homogenization, one often has the advantage of seeing

each inclusion and determining something about its origin, which will bear upon the parameter determined, since only undoubted primary inclusions will be expected to give simply interpretable results. Many samples, however, have inclusions that are primary, but are knocked down, or are so densely packed, or so complicated as to prevent clear viewing of them, or complicate almost beyond use the results of physical methods upon them. The inclusions of this type often contribute to the parameters obtained by leaching experiments. Unfortunately secondary inclusions formed much later than the crystallization of the mineral also contribute to the parameter. Although it can be anticipated,that since later solutions will have been less concentrated than the primary solutions, their effect may be reduced unless their total volume far outweighs the volume of primary liquid.

The contribution of secondary solutions is one of the largest problems of interpretation. It is not altogether hopeless, however, because fluid inclusion discs of the specimen to be leached can reveal the sort of inclusions predominant, although volume estimations are very difficult. Decrepitation results could also conceivably give an indication of this information.

Another complication not met with in these experiments, but potentially present is where the mineral of interest or a mineral contaminating the sample contains an element to be determined, for instance a clay mineral could conceivably add an ion to the leachate or even a silicate mineral when freshly crushed might yield up ions. It is therefore important to remember that a sodium/potassium ratio determined by this technique is not necessarily from the uncontaminated primary hydrothermal solution which crystallized the mineral from which the leachate was obtained.

It is common practice in analysis to add dilate ammonium carbonate to the solution to be determined by photometry and to filter before estimation of the elements. This adds two more stages to the operation, but

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also precipitates out and removes interfering elements such as iron and aluminium. Addition of ammonium hydroxide to leachate was found to yield no or virtually no cloudiness, suggesting that insufficient interfering element was present to be either filtered out or to interfere with the estimations.

In view of the complications regarding interpretation it would be useful to have:

1. Several samples from each collecting point (which is difficult for many reasons).

2. Samples of different minerals for each point.

3. Microscopic information on the inclusions.

4. Decrepitation results for the samples.

5. Standard material types to make comparisons easier, for instance coarse platy barite for each locality rather than a variety of types.

Of course these refinements would require much time and effort in both finding samples if they are available, and in processing the increased variety and quantity of material, however the results from such a thorough integrated study would be of more value than those presented here.

LEACHATE RESULTS AND INTERPRETATION

The results of the experiments have been tabulated and show the results grouped according to mineral (Table 6.2).

The first group of analyzed leachates were from fluorite. They show a wide range of sodium/potassium ratios (1.0 - 25) but are mostly less than 10. The total sodium and potassium concentrations vary from 7 - 53 ppm and are fairly well scattered although most are medium.

The results indicate a gradual rise in the ratio in moving from south west to north east with the highest values being recorded in the

Gunnerside-Arkengarthdale veins in the Main Limestone (Fig. 6.1). The high concentrations demonstrate the large number of primary inclusions present in fluorite, which can be observed under the microscope.

The second group of results were from barite and show a wider range of both sodium/potassium ratio (0.64-56) and a wider range of concentration (1.1-50 ppm). The concentration is, however, usually lower than in the case of fluorite, but are still quite scattered. Large clear crystals or coarsely crystalline barite provides the highest totals and the fine-grained varieties generally have low totals. The barite samples were deliberately selected primary barite and just one late or secondary barite sample was included. The one sample of late barite gave a much lower ratio and total (1.3, 1.8 ppm) than primary material from the same locality (39, 8.0 ppm) demonstrating the different solutions involved in the fluid inclusions of the two specimens. Thus it was decided to look at just the geographical variation of sodium/potassium ratio of specimens giving high totals (Fig. 6.2). They mostly had high ratios, but several samples did have substantially lower ratios. Again on this limited number of suitable results there is a suggestion of increase in moving from south west to north east. If the results of material with low totals is included (except for the one late or secondary barite), it still gives the same trend.

The trend when including the low totals could be a reflection of type of material, although it should be noted that not all fine-grained barite gave low results nor did all coarse barites give high results. This gives a better basis for joint interpretation of the results. Barite is often cloudy with inclusions, but the fine-grained massive barite seems to carry either a smaller volume of them, or is dominated by secondary inclusions, with lower concentration of salts.

Two samples of quartz were leached and gave low ratios (7.8, 3.2) and high totals (44,21 ppm). The low ratios conform to the south west-north east trending increase, and are consistent with the geographically near fluorites (Fig. 6.1).

Calcite samples were leached and produced variable ratios though mostly low (0.66 - 8.3) and the totals were variable, but occasionally high (3.9 - 35 ppm). It is difficult to make much of these results, but the high totals again yield the highest ratios.

The low ratio results would not be expected on the proposed geographical trend (Fig. 6.3) and it is possible some systematic analytic error has been incurred or that the results are largely due to secondary inclusions. If an analytic error is present the calcite results can only be considered in isolation as relative values and there is not much that can be said about them. If no analytic error is present then the influence of secondary inclusions may be significant and it is worth noting in this context the very good cleavage of calcite.

The results of four witherite samples have fairly low totals (4.3 - 9.8 ppm) and also low or very low ratios (0.4 - 2.3). These results would not be expected on the proposed geographical trend (Fig. 6.4). Analytic error is also a possibility here and it should be noted that witherite is 100 times as soluble as barite.

Two series of oremineral samples were leached - sphalerite and galena. The sphalerite samples have high totals (16 - 56 ppm) and variable ratios (1.1 - 20). They correspond closely to the pattern shown by fluorite and probably represent the primary solutions fairly well. (Fig. 6.3). The galena samples have generally high totals (4.3 - 57 ppm) and low to very low ratios. These results do not conform to the proposed trend (Fig. 6.4). Analytic error here is rather unlikely, but it should be noticed that galena has a very good cleavage and so may be predisposed

to the influence of secondary inclusions, although the high totals do not favour this hypothesis too well.

The close similarity shown by duplicates of various kinds shows that any significant analytic error must be due directly to the minerals being studied, and that further work on this matter could be useful, especially if it is desired to get good results from calcite or witherite.

From the collected results of the different minerals it is suggested that the sodium/potassium ratio of primary fluid inclusions increase in a general way from south west to north east in a pattern reflecting the mineral zonation. It is further suggested that the good cleavage of some minerals may make them so well disposed to the formation of secondary inclusions that it is difficult to obtain from them information regarding the primary inclusions.

The sodium/potassium ratio for fluorite is generally lower than for barite, which corresponds to the pattern found on the Alston Block by Sawkins (1966). The results from this orefield show this trend is a geographical trend at least in part independent of mineral species since the zonation is suggested by several mineral species. This could not be deduced on the Alston Block where it is rare to find fluorite and barite in the same localities and where other mineral species had not been determined.

If the geographical trend is accepted and considered with the other information then the mineralizing solutions must have had different compositions with respect to sodium and potassium in different areas. Depending upon the proposed zoning mechanism it is possible to argue in many ways, but certain points must be borne in mind. Firstly, no minerals of sodium or potassium have been found in the mineral deposits so any variation produced during movement of solutions could only be caused by wallrock reactions or mixing of different solutions. Secondly, both

fluorite and barite are deposited from both high ratio and low ratio solutions. Thirdly, many of the results have such low ratios that ordinary connate brines would not be a suitable agent. Even residual sea water interstitial to halite bearing evaporites may not be able to produce sufficiently low values (i.e. less than 5).

These results support two hypotheses quite well:

1. Mixing hypothesis - Low ratio brines rise mostly in the "central" zones and mix with high ratio brines from the "outer" zones.

2. Reaction hypothesis - Low ratio brines rise mostly in the "central" zones and react with wallrocks which preferentially absorb potassium producing the high ratio brines in the "outer" zones.

Number	Locality	K ppm	Na ppm	Total ppm	Na/K	Comments
Fluorite						
0361	Clouds	6.2	26	32	4.2	-
0415	Great Sleddale	3.6	20	24	5.6	Small cubes, pure, amber
0478A	Gunnerside	2.0	41	53	25	Massive, white, banded, and little sphalerite
0478B	Gunnerside	1.5	34	36	23	Massive, white, banded, and little sphalerite, duplicate
0599	Hartley Birkett	2.0	8.0	10	4.0	-
0603	Hartley Birkett	5.5	5.6	11	1.0	-
0791	Lover Gill	3.2	39	42	1.2	Massive, white, sheared, diluted
TB01	Thwaite Beck	3.2	39	42	1.2	Small cubes, white, and little calcite
1106	Braithwaite	6.0	8.8	15	1.5	Massive, white, and little barite
1081	Kelds Head	2.3	34	36	15	Massive, white
0757	Stags Fell	5.6	12	17	2.1	-
FINT	Friars Intake	8.0	16	24	2.1	-
0857	Warton	6.0	8.0	14	1.3	Massive, blue, and little dolomite and galena
MD1	Mossdale Beck	4.0	28	32	6.9	Cubes, amber, clear

TABLE 6.2 (Cont.)

COTT	Cottriggs	7.0	22	29	3.1	Large cubes, colourless, and sulphide inclusions
1073	Seata	1.8	20	22	11	Cubes, pinkish, clear
0706	Wet Grooves	5.0	5.2	10	1.0	-
0649	Wet Grooves	2.9	4.3	7	1.5	-
0946	Oughtershaw	5.3	17	23	3.3	Small cubes, colourless, and little quartz, and limestone
0872	Cottriggs	2.0	18	20	9.2	Large cubes, colourless, and sulphide inclusions
1656	Arngill	3.0	4.3	7.3	1.4	Large cubes, colourless - ambery
1657	Arngill	7.9	29	37	3.6	Large cubes, colourless - ambery
0871	West Burton	4.4	29	33	6.6	-
1231A	Copperthwaite	1.9	26	28	14	Massive, fine-grained, white
1231B	Copperthwaite	2.6	32	35	13	Massive, fine-grained, duplicate
1700	Arkengarthdale	3.8	48	53	13	Specimen 1
1700A	Arkengarthdale	2.4	31	33	13	Specimen 2
1700B	Arkengarthdale	4.3	53	58	12	Specimen 2, duplicate
1706	Arkengarthdale	1.2	12	13	9.6	-

TABLE 6.2 (Cont.)

1710	Arkengarthdale	2.1	48	50	23	-
Barite						
0884	Cottriggs	0.3	1.0	1.3	3.3	Massive, fine-grained, platy, white
		(0.3)	1.5	1.8	5.0	Massive, fine-grained, platy, white, re-run for low Na
0884D	Cottriggs	0.3	1.3	1.6	4.3	Massive, fine-grained, platy, white, duplicate
		(0.3)	1.2	1.8	4.0	Massive, fine-grained, platy, white, re-run for low Na
0583	Hartley Birkett	0.3	0.5	0.8	1.6	Massive, fine-grained, platy, white
		(0.3)	0.5	0.8	1.6	Massive, fine-grained, platy, white, re-run for low Na
1086	Kelds Head	2.3	35	37	15	Massive, fine-grained, platy, white, and little fluorite and galena
1096	Braithwaite	5.6	3.6	9.2	0.64	Massive, fine-grained, platy, white, and little sphalerite
0453	Arkengarthdale	6.4	7.6	8.0	1.9	Massive, fine-grained, platy, white
1498	Windegg	4.2	20	24	4.7	Coarse, platy, white
0851A	Feldom	0.2	10.5	11	53	Coarse, platy, pink
0851B	Feldom	0.1	5.6	5.7	56	Coarse, platy, white
0067	East Leyton	0.4	2.8	3.2	7.0	Medium, platy, white, and little copper minerals

TABLE 6.2 (Cont.)

Sample	Location					Description
0820	Angerholme	0.3	1.4	1.7	4.7	Massive, fine-grained, platy, white, and little copper minerals
0820D	Angerholme	0.1	1.0	1.1	10	Massive, fine-grained, platy, white, and little copper minerals, duplicate.
0913	Cabbish Mine	0.3	15	15	50	Large crystal, white
0902	Cabbish Mine	2.0	48	50	24	Large crystal, white
0924	Middle Fell	0.3	10	11	34	Large crystal, colourless, and little sulphide inclusions
CHO1	Closehouse	0.2	4.2	4.4	21	Large crystal, colourless, clear
1241	Copperthwaite	0.4	2.0	2.4	5.0	Massive, medium-grained
		(0.4)	2.5	2.9	6.3	Massive, medium-grained, re-run
0687	Wet Grooves	6.1	8.7	15	1.4	-
1545	Hurst	0.8	1.0	1.8	1.3	Toothy, white, late or secondary
		(0.8)	1.0	1.8	1.3	Toothy, white, late or secondary, re-run
1534	Hurst	0.2	7.7	7.9	39	Massive, fine-grained, pink
		(0.2)	7.8	8.0	39	Massive, fine-grained, pink, re-run
1534D	Hurst	0.1	2.8	2.9	28	Massive, fine-grained, pink, duplicate
		(0.1)	3.3	3.4	33	Massive, fine-grained, pink, re-run

TABLE 6.2 (Cont.)

ID	Location					Description
0346	Clouds	0.5	0.8	1.3	1.6	Massive, fine-grained, white and pink, and little fluorite
		(0.5)	0.7	1.2	1.4	Massive, fine-grained, white and pink, and little fluorite, re-run
0766	Stags Fell	1.3	2.5	3.8	1.9	Massive, fine-grained, white, and little limonite
0743	Friar Intake	1.7	1.8	2.9	1.1	Massive, fine-grained, white, and little galena
		(1.7)	2.0	3.7	1.2	Massive, fine-grained, white, and little galena, re-run
1050	Keld	1.2	40	41	33	Large plates, white
Witherite						
WLO1	Windegg Level	2.1	2.2	4.3	1.1	Massive, "Fibrous", banded, white – colourless
WLO1D	Windegg Level	3.8	4	7.8	1.1	Massive, "Fibrous", banded, white – colourless, duplicate
WLO2	Windegg Level	0.7	1.6	2.3	2.3	Massive, white, pure
1950	Cobscar	6.2	3.6	9.8	0.58	Massive, white, pure
HUO1	Hurst	2.6	1.4	4.0	0.54	Massive, white – colourless, and very little barite
HUO1D	Hurst	4.9	2	6.9	0.41	Massive, white – colourless, and very little barite, duplicate

TABLE 6.2 (Cont.)

Calcite

1510	Windegg	2.4	1.5	3.9	0.63	Massive, clear
		(2.4)	1.8	4.2	0.75	Massive, clear, re-run
0064	Kneaton Hall	8.3	27	35	3.3	Small crystals, clear – white, and galena and copper minerals
1558	Hurst	3.0	2.3	5.3	0.77	Large crystal, clear
		(3.0)	2.9	5.9	0.97	Large crystal, clear, re-run
1123	Cleaburn Pasture	5.0	28	33	5.6	Massive, pink – white
1445	Faggergill	3.3	1.5	4.8	0.46	White, and little barite
		(3.3)	2.2	5.5	0.66	White, and little barite, re-run
0814	Richmond	3.8	4.8	8.6	1.3	Nail heads, clear, and chalcopyrite inclusions
		(3.8)	4.6	8.4	1.2	Nail heads, clear, and chalcopyrite inclusions, re-run
0401	Stang	1.8	15	17	8.3	Large crystal, white

Quartz

0444	High Ing	5.0	39	44	7.8	Colourless, and little chalcopyrite
0444D	High Ing	6.0	21	27	3.5	Colourless, and little chalcopyrite, duplicate

TABLE 6.2 (Cont.)

DG1	Dandra Garth	4.9	16	21	3.2	Colourless, clear
Sphalerite						
0707	Wet Grooves	8.9	15	24	1.7	Massive, dark, pure
1075	Seata	11	21	32	2.0	Massive, and little fluorite and galena
1037	Keld	5.6	24	29	4.2	Massive, pale, and little calcite
1600	Gunnerside	0.9	18	19	20	Massive, dark, and little barite
1951	Cobscar	16	22	37	1.4	Massive
1881	Apedale	22	23	45	1.1	Massive, dark
1881D	Apedale	20	36	56	1.8	Massive, dark, duplicate
0566	Hartley Birkett	9.1	25	35	2.7	Massive, brown, and little galena
0478	Gunnerside	2.8	50	53	18	Massive, banded, and little fluorite
0680	Wet Grooves	2.0	14	16	6.8	Massive
Galena						
1149	Cleaburn Pasture	9.0	4.8	14	0.53	Cubes
		(9.0)	5.7	15	0.63	Cubes, re-run
0566	Hartley Birkett	9.0	21	30	2.3	Large crystals

TABLE 6.2 (Cont.)

1456	Faggergill	8.7	16	25	1.8	Large crystals
1666	Pry Hill	14	7.0	21	0.52	-
1882	Apedale	25	7.0	57	0.28	
KHS1	Kelds Head	2.9	1.4	4.3	0.48	Massive, and little calcite

FIGURE 6.1

Sodium/Potassium Ratios of Fluorite and Quartz

O Fluorite □ Quartz
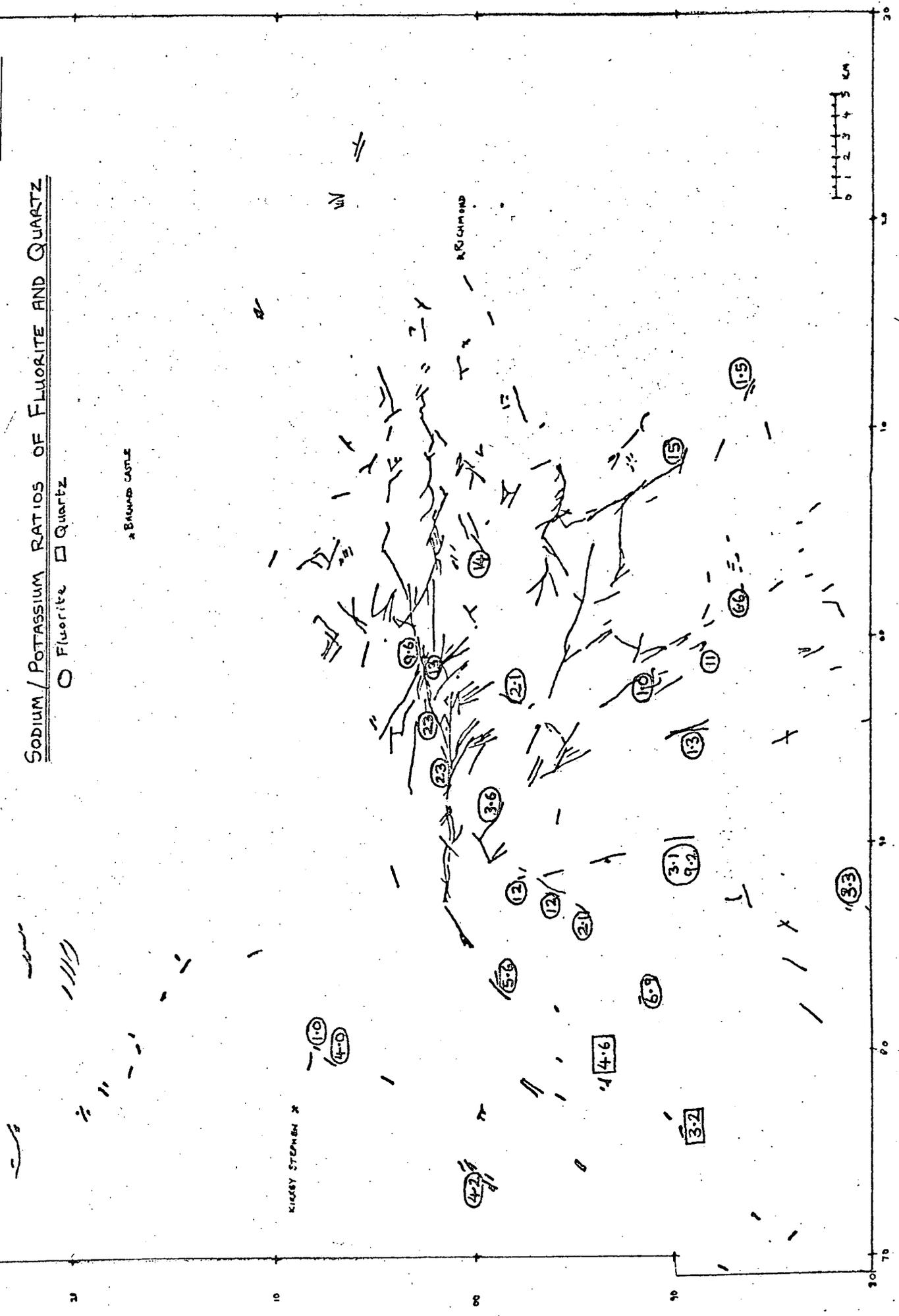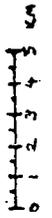
FIGURE 6.2

SODIUM / POTASSIUM RATIOS OF BARITE
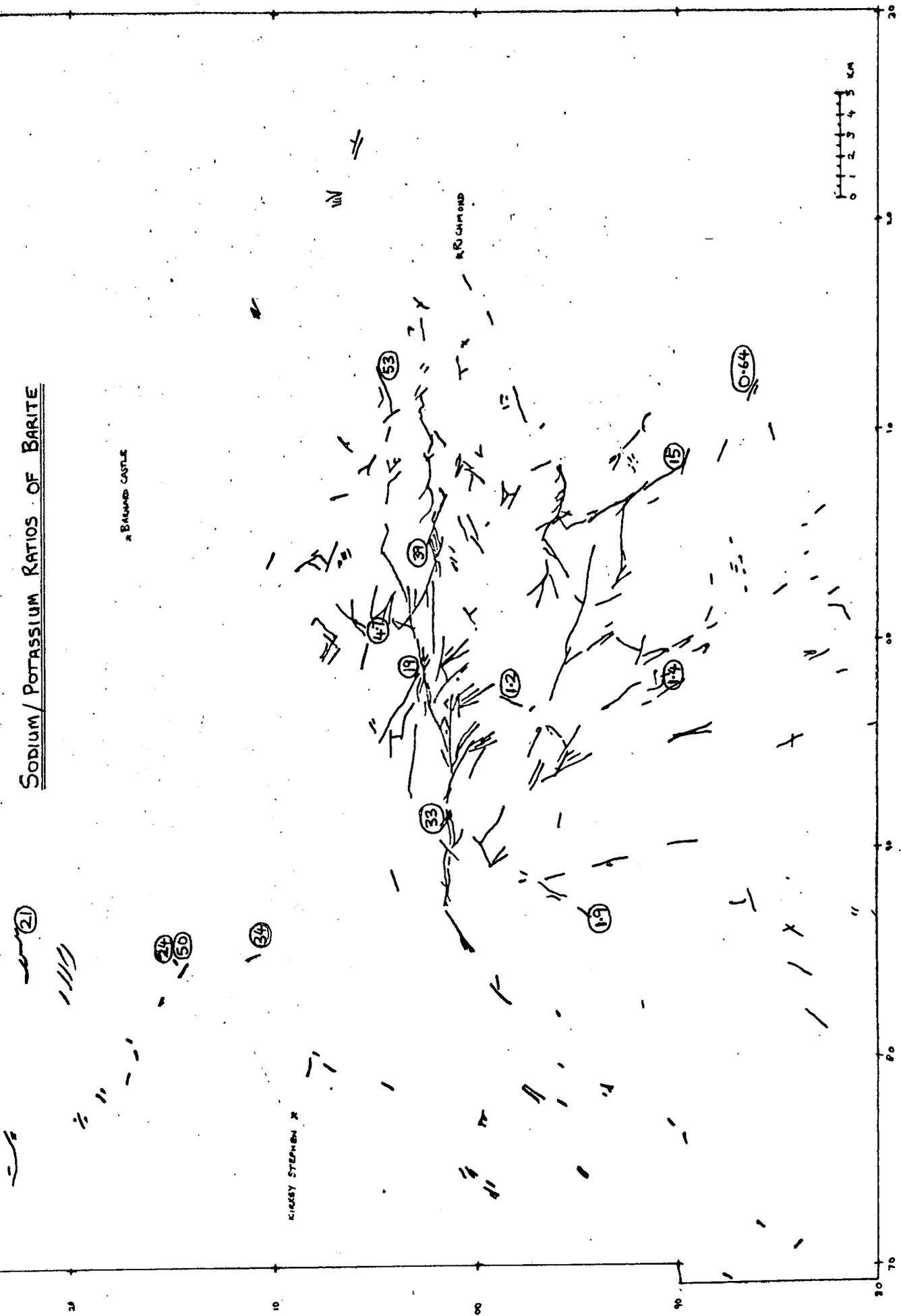
FIGURE 6.3

SODIUM / POTASSIUM RATIOS OF CALCITE (◯) AND SPHALERITE (▢)

FIGURE 6.4

SODIUM/POTASSIUM RATIOS OF GALENA (○) AND WITHERITE (□)
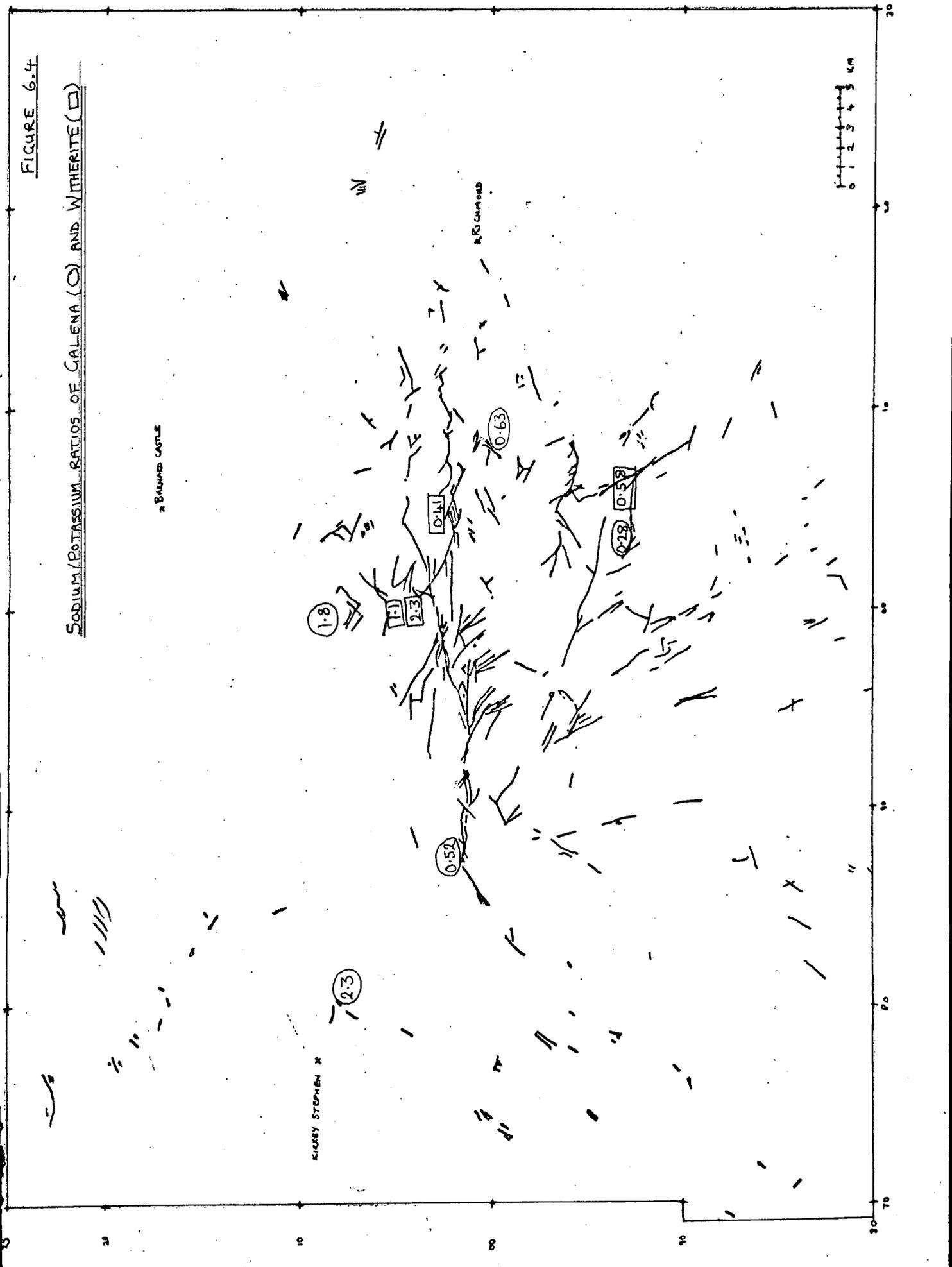
Plate 10

Replacement fluorite carrying solid inclusions of quartz.
0292, Great Bell.

Plate 11

As Plate 10, but refocussed to show wispy fluid inclusions
with bubbles.

Plate 12

(a) Quartz showing rare "large" fluid inclusions, two with

   bubbles in this plane. 0382, Far Cote Gill.

(b) Primary fluid inclusions in barite. C224, Middle Fell.

(c) Growth zone of monophase primary fluid inclusions in

   barite. 0924, Middle Fell.

(d) Single well formed inclusion of two phases in fluorite.

   0706, Wet Grooves.

Plate 13

(a) Zone of badly necked secondary inclusions in a partially

   arealled cleavage plane in fluorite. 0706, Wet Grooves.

(b) Highly necked down fluid inclusion, with bubble due to

   leakage. 0924, Middle Fell.

(c) Zone of small simple secondary monophase fluid

   inclusions in fluorite. 0706, Wet Grooves.

(d) Necked inclusion with bubble in fluorite. 0706, Wet

   Grooves.

<u>Plate 14</u>

(a) Barite and fluorite showing small fluid inclusions
"Close. up". 0519, Gunnerside.

(b) Pyrite inclusions in fluorite. 0869, West Burton.

(c) Barite and fluorite showing inclusions and close
association of minerals. 0519, Gunnerside.

(d) A plate shaped inclusion of chalcopyrite in calcite
from East Leyton.

PLATE 10   0   50   100μ

PLATE 11. 0 ————— 50 ————— 100μ

a 0 ___ 100μ

b 0 ___ 100μ

c 0 ___ 100μ

d 0 ___ 50 ___ 100μ
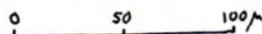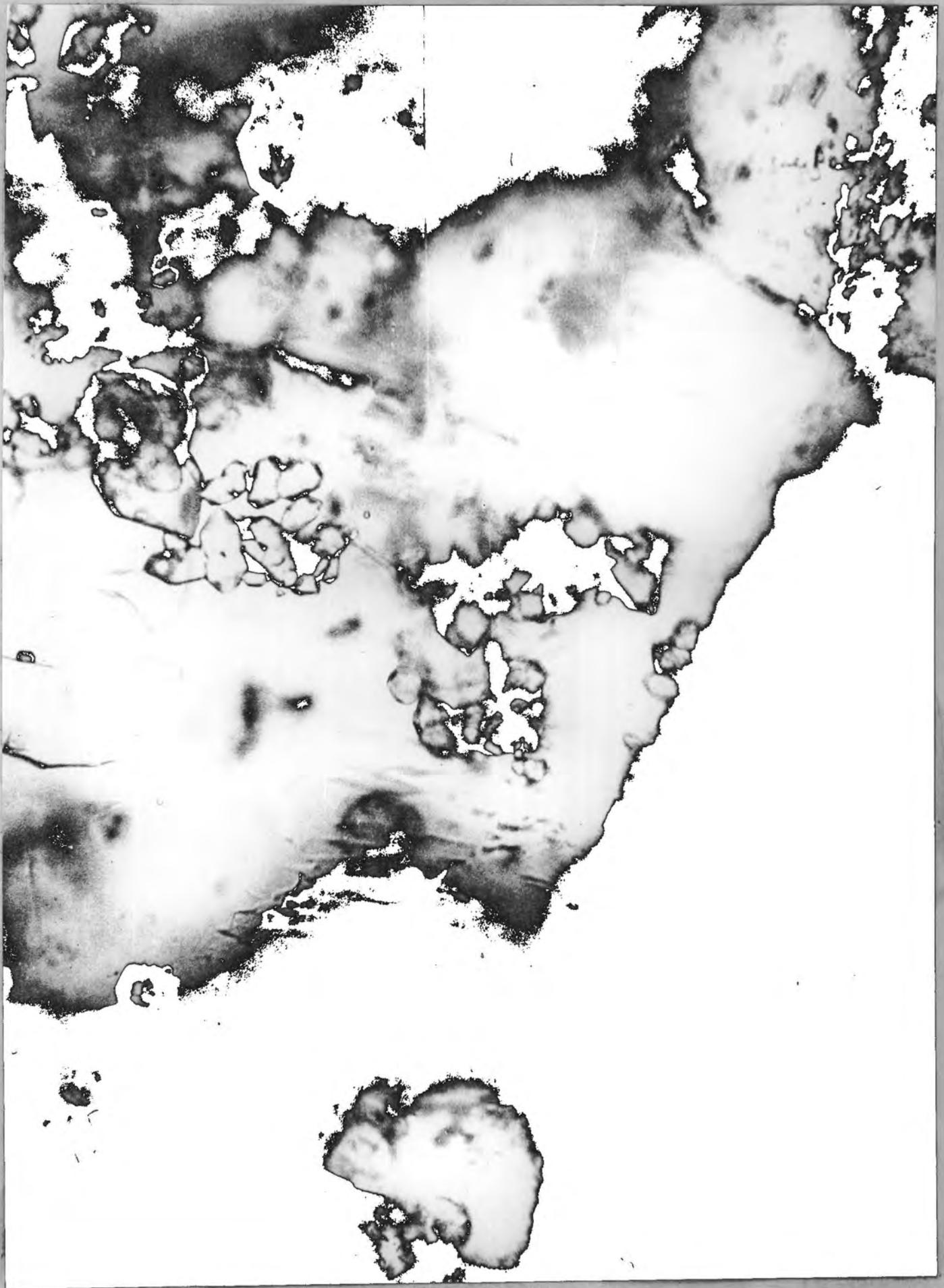
PLATE 12

PLATE 13

PLATE 14
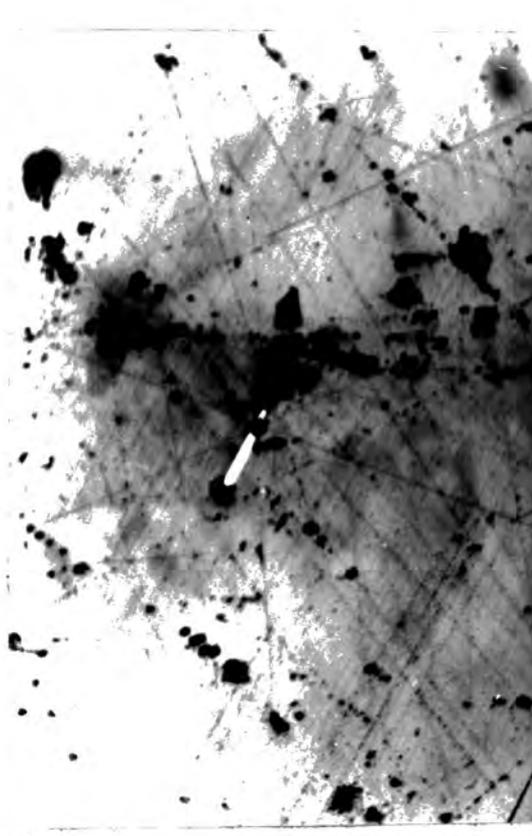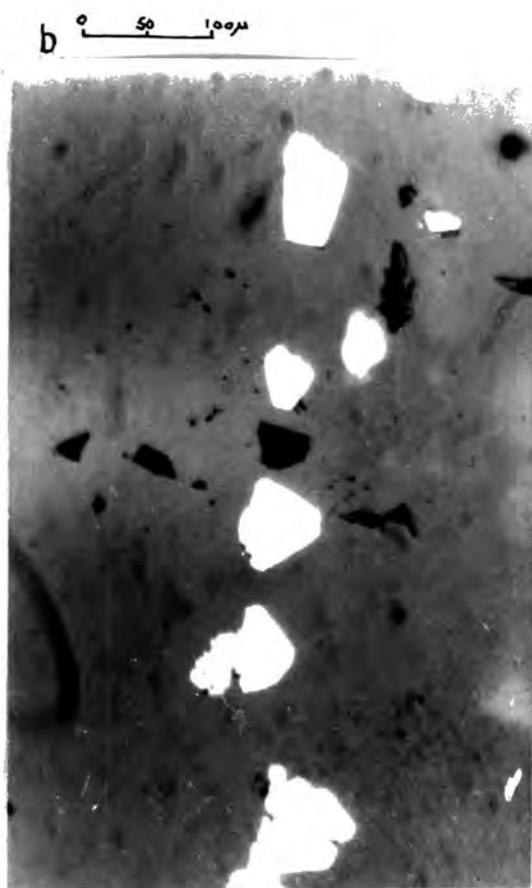
CONCLUSIONS

The occurrence of mineralization in fault veins and less commonly
as replacement flats associated with them, in all the bearing beds
(limestones and cherts) from the Great Scar Limestone to the Crow Chert
was established in the North Yorkshire Orefield before this century.
In the present study certain features of the stratigraphical and
structural controls have been brought forward to explain the shape and
position of the orefield. A pronounced mineral zonation has been
elucidated and it has been supported by geochemical investigations into
the trace element and fluid inclusion content of minerals. Features of
some of the copper mineralization suggest a secondary enrichment per-
haps related to the Permian unconformity.

Since mineralization is found in fault veins a major control of
the orefield is the existence of such fractures. The centre of the
Askrigg Block is noticeably deficient in faulting, but the edges,
especially the northern edge and to a lesser extent the southern edge,
do have a high fault density (Chapter A.2), which is favourable to
mineralization. Faults with small throw produce the best veins (Bradley,
1862) thus the major faults such as the Stockdale Vein associated with
the Hinge Line are not good prospects, however, the minor faulting
accompanying the major faults can be well mineralized. The faults which
are found on the block have small throw and are frequently mineralized,
but they are continuous only near the block edge. Good flats have been
worked in the block area where veins have small throw, but also occur
with lesser frequency in the other areas.

The normally gentle dip of the Carboniferous rocks is important in
the lateral spreading of solutions confined in horizontally elongate
veins or aquifers by impermeable shaley horizons. In the block area,

where faults have small throw, solution movements will frequently have had a large horizontal component. In areas of dense faulting the fissure systems tend to be discontinuous laterally and intersections are common, thus vertical movements here will have been more important. Confinement of solutions to a horizontal movement is perhaps more conducive to flatting than vertical movements unless rocks have been prepared by shattering etc.

Stratigraphical control is largely executed by the variation of the competant-reactive strata thickness. In the vicinity of the Stockdale Hinge Line bedded cherts occur in the sequence (Dakyns et al, 1891, Wells 1955, Hey 1956). Their striking relationship to the eastern portion of the Stockdale Line (Chapter 3) could be sedimentologically controlled, or be due to early solution movements through the Stockdale Line - basin edge environment. It is also conceivable that hydrothermal activity may have been associated with the Stockdale Line at an early stage and contributed to their formation. The bedded chert section increases in thickness eastwards along the Stockdale Line and is a major factor in increasing the competant-reactive strata thickness near to the horizon of the Main Limestone in the Swaledale area. This means that faults of moderate to large throw can form good enough fractures for mineralization in Swaledale, but not elsewhere, for instance along the western escarpment.

The southward thinning of non-calcareous measures in the Lower Carboniferous succession improves the competant-reactive section in this direction, but its effects are counteracted by the lack of available faults of moderate (to large) throw, and reduction of total fault density.

The association of mineralization with the bearing beds, generally limestone and chert, was recognized early (Phillips, 1836), and partly explained in terms of competance. The restriction of important concentrations to the strata around the Main Limestone has been explained in

terms of the control of upward percolating solutions by the first thick shale (Dunham, 1974), but the full explanation for important concentrations of mineralization occurring in the upper part of the Lower Carboniferous limestone succession throughout Britain may be more dependant upon the reactivity of the limestone and the type of formation waters which were generated in the Lower Carboniferous.

The primary mineralogical zonation (Chapter A.4) displayed by both the sulphides and non-sulphides is one of the important features of this and indeed other Pennine Orefield (Dunham, K.C. 1934, 1948, and Firman and Bagshaw, 1975). The composition of the mineral zones in the form of a pseudo-paragenesis diagram is shown in Fig. 7.1.

Sulphide zonation reflects the stability of base metal complexes and their concentration, but can indicate the source of solutions so that copper is normally found closer to the source than lead, whilst the position of zinc is less characteristic (Park, 1955). The sulphide zonation in this orefield is unfortunately two-ended with respect to copper, which makes the simple interpretation ambiguous or two-sourced, especially since chalcopyrite is found earlier than the lead at both ends of the orefield. Trace element studies designed to distinguish the chalcopyrite rich zones were not very successful, although some chalcopyrite from the core of the Alston Orefield was easily distinguished by its high tin content, which can perhaps be attributed to an extension of the Hercynian tin province into the Pennines rather like the extension of a tin province of the Appallachians proposed by Tilden and Brown (1974). Electron probe analysis of a chalcopyrite from the Q Zone of the North Yorkshire Orefield did come up with high lead, silver, and arsenic, although no tin was detectable, thus implying a more "primitive" origin for the Q Zone than for the C Zone. The position of tetrahedrite in the Q Zone and plumbiferous tennantite in the F Zone is a good piece of evidence in favour of a source in the Q Zone.

Zonation of the non-sulphides does not directly indicate the source, but when combined with the order of crystallization information, the Q Zone is again indicated as the core zone with the F Zone and P Zone following outwards. This conclusion could also be reached by comparison with the Alston Block (Dunham, 1948). Zonation of mineral occurrence is easily accomplished by progressive crystallization of a moving solution. The movements of course determine the spatial position-ing of zones, whilst the order and composition of zones is determined by the starting solution composition and to some extent the method of precipitation. Mechanisms of zonation are discussed in the potential contribution (C.4).

The primary mineral zonation is supported by the spatial variation of trace element concentrations in galena and fluorite (Chapter A.5). The yttrium content of fluorite is a good indicator of proximity to source (Smith, F.W., 1974). Antimony and to a lesser extent silver in galena are similar indicators of proximity to source. Mechanisms for producing the depletion trends involved are described in Chapter A.5, where both closed and open systems are discussed. Trace element results for barite and sphalerite could not be interpreted in this manner, but the negative correlation of silver with cadmium in sphalerite suggests that cadmium could perhaps be used as an inverse indicator of proximity to source if sufficient samples were used, although the large amounts present may not be so amenable to the mechanisms so far proposed.

Primary zoning in the North Yorkshire Orefield is focussed about the inner Q Zone which occupies an area from just south of the Stockdale Line in Mallerstang to Dentdale in horizons deepening southwards. This focus and the patterning of the zonation are not directly attributable to the Semerwater Cupola of Wensleydale Granite, the Stockdale Line, the Dent Line, or the intersection of Stockdale and Dent Lines. The structural and stratigraphic controls of solution movements mentioned

earlier make it impossible to source the whole orefield from the
Q Zone if movements are restricted to the known veins, however, if
movements occurred within the strata then the zonation could be produced,
providing that post Permian tilting is removed (see Chapter A.3). The
presence of the F Zone "inlier" in between Gunnerside and Arkengarthdale
probably reflects a stronger vertical component to solution flow than
usual, because of the high fault density.

Determinations of homogenization temperature of fluid inclusions
in fluorite using the heating stage microscope revealed temperatures
in the vicinity of 100° C, but single phase inclusions in barite from
the P Zone, and in calcite from the C Zone indicate that temperatures
below 70° C may have operated at least in the later stages of mineral-
ization. F. W. Smith (1974) has recorded salinities of 15 - 20%
sodium chloride equivalent from inclusions in fluorite and with such
saline solutions in mind it is interesting to note the extremely high
potassium contents displayed by the Na/K ratios determined by leaching
experiments (Chapter A.6). Na/K ratios show systematic increase in
travelling from south west to north east, both within individual minerals
and in changing from fluorite and quartz to barite. Sphalerite results
are similar to fluorite, but galena results were all anomolously low and
calcite and witherite were similarly anomolous. These results suggest
either two solutions and mixing as Sawkins (1966) believed to have
occurred in the Alston Orefield, or reaction of solutions with silicate
wallrocks to produce less potassium rich brines (Fig. 7.3). All Na/K
ratios are on the high to very high side for connate brines (White 1966),
but at least some of the barite samples are on the correct side of sea
water. Such potassium rich brines could have been magmatic, in contact
with alkali silicates at high temperature, or evaporitic (Fig. 7.2).
The evaporitic origin is perhaps preferable, because no acid magmatism
of the appropriate age is present in the area to supply magmatic solutions,

and the zonation and mineral temperatures argue against a close relation-
ship of the pre-Carboniferous (Devonian) Wensleysdale Granite with a
mineralizing brine of originally connate origin (see Appendix C.4).
Unfortunately there is no certainty to the hypothesis that there are
evaporites (necessarily halite bearing) in the Stainmore Trough, but
their presence is suggested by halite pseudomorphs in the Tournasian
rocks of Ravenstonedale (Personal Comm. G. A. L. Johnson, 1972), the
palaeogeography, and by the long life and form of the Middleton-Tyas-
Sleightholme Anticline (Chapters A.2, 3). The role of Carboniferous
evaporites or formation waters was suggested tentatively by Solomon
et al (1971) from sulphur isotope studies of the barite of the Alston
Orefield, and a homogeneous radiogenically enriched source was suggested
for lead isotopes by Coomer and Ford (1975); this would be most approp-
riate to a sedimentary source of lead.

The Na/K ratios of primary barite samples is related to their
strontium contents in such a way that fine grained barites (mostly from
localities where or near where witherite is present) and coarse grained
barites (mostly from the Stainmore Trough deposits) occur in different
Na/K versus Sr field (Chapter A.5).

The common dolomitization often with galenafication of wallrock is
an important feature of some parts of the orefield. It indicates the
sort of magnesium/calcium ratio in the brine which could be expected
from a sea water derivative (Chapter A.4). The presence of primary
witherite attests unusually high Barium/Calcium ratio in some solutions
and of course the lead, zinc, copper and fluorine must all have been
significantly concentrated in the solutions. The relatively small amount
of quartz in the orefield, perhaps suggests an importance of connate
rather than magmatic solutions.

Secondary zonation or spatial variation of mineralogy is also
noticeable in the Orefield. In the watershed deposits of the P Zone for

instance, there is abundant evidence of workings in gossan. The gossan is often of porous mamillar sheet aggregates of barite crystals mixed to varying extents with limonite and galena with thick cerussite rims. The metallurgical problems of separation of galena and sphalerite were not present in these deposits.

Toothy barite is often present in deposits in the F and P Zones and although its secondary nature is perhaps not fully proven, its associations and form are suggestive of this origin (Chapter A.4). Toothy barite has a low although erratic strontium content and the only sample leached gave a very very low concentration of sodium and potassium indicating very different solutions to those which formed the definitely primary minerals (fluorite etc.). The identification of barite definitely formed from witherite is a difficult task since only tuby barite, and witherite pseudomorphs are categoric evidence. Banded toothy barite samples may be after banded witherite, but this is not proven. Sphalerite is absent from most gossans except in large pieces of galena, only limonitic boxworks are preserved normally and hemimorphite may be generally absent because of the small amounts of quartz present. Pyrite and marcasite are normally only preserved in goethite, as is chalcopyrite although malachite is often present with it.

Mineral deposits of the C Zone near the Permian Unconformity (Fig. 7.2) range from primary at Feldom Fault (1), and Richmond (3), through slightly enriched at East Leyton (4), to highly enriched in the deposits of Kneeton Hall (6), Middleton-Tyas (7) and Black Scar Quarry (8). The highly enriched deposits occur in the Undersett Limestone, perhaps below mineralization originally present in the Main Limestone. The deposits worked were highly irregular and contained the copper rich minerals described in Chapter A.4, in one case partly as replacements of primary galena. Secondary enrichment is thought to be due to supergene processes acting during the Late Carboniferous lower

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Permian interval. The account of workings at Longrigg proceeding from hematite, to copper ore, to lead ore (Dakyns et al, 1891) are again suggestive of enrichment just below the Permian unconformity (Fig. 3.9) which has produced widespread reddenning in that area.

Conclusions of a technical nature can be summarized:-

(a) Microprobe analysis of strontium in barite should be a useful tool in studying its geochemistry etc.

(b) X.R.F. analysis of fluorite and galena concentrates can yield rapid results which could be used to guide exploration in partly worked deposits as described by F. W. Smith (1974).

(c) X.R.F. correcting procedures based upon mass absorption corrections must be treated with caution when heavy and light element mixtures are involved.

(d) Rapid leaching experiments can provide information of direct relevance to the origin of minerals, but results must be interpreted with caution.

The North Yorkshire Orefield has been controlled by structural and stratigraphic factors which are themselves controlled by the Pre-Carboniferous basement and its structural properties. Ore forming fluids have probably risen from depth mostly in the north west corner of the Askrigg Block and moved updip where impermeable shales have restricted vertical movement. Progressive crystallization has enabled mineral zonation to be produced by the solution movements. The mineral zonation is parallelled by a cryptic zonation of trace element concentrations in fluorite and galena. The mineralizing solutions were at temperatures not much above 100° in the core of the orefield but were probably less away from this centre. Solutions were rich in Pb, Zn, Cu, Ba, F, Mg, and K. Na/K ratios of the solutions suggest an evaporitic brine source of solutions and the zonation of this parameter is probably best explained in terms of an equilibration with alkali silicates in the near surface environment.

Finally the present work suggests that concentrations of economic minerals are still to be found in the North Yorkshire Orefield, since past exploitation has concentrated on lead ore in the most readily accessible veins, relatively near to the surface and often in the valley sides. Only a few of the veins have been tried in depth below the valley floors. The mineral zones, trace element studies and knowledge of structural controls could be used as guides during exploration and development when the orefield is reopened.

FIGURE 7.1 PSEUDO-PARAGENESIS DIAGRAM

	Q Zone	F Zone	P Zone	C Zone
Tetrahedrite				
Chalcopyrite				
Tennantite				
Galena				
Sphalerite				
Pyrite & Marcasite				
Quartz				
Fluorite				
Witherite				
Barite				
Calcite				
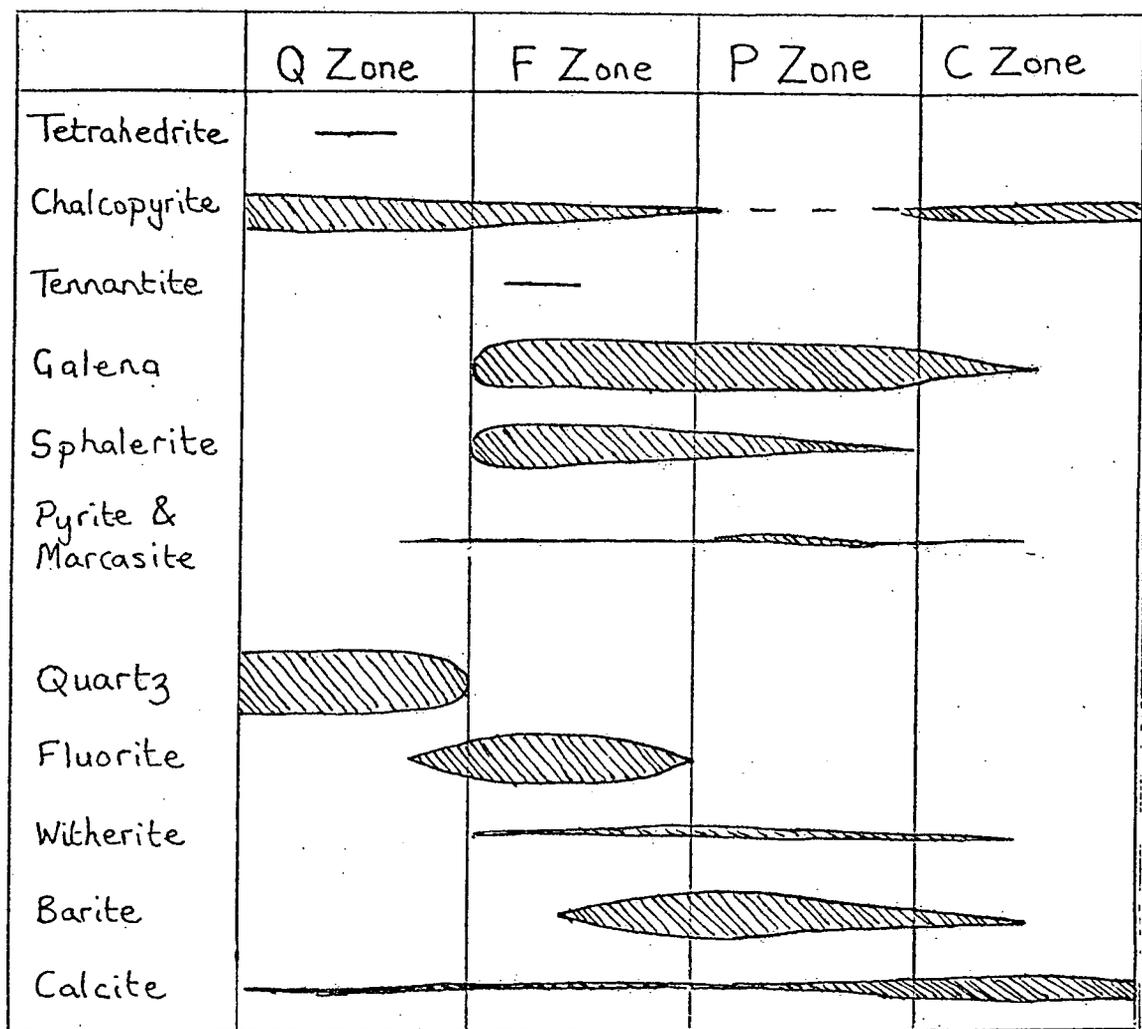
FIGURE 7.2. POTENTIAL MINERALIZING SOLUTIONS
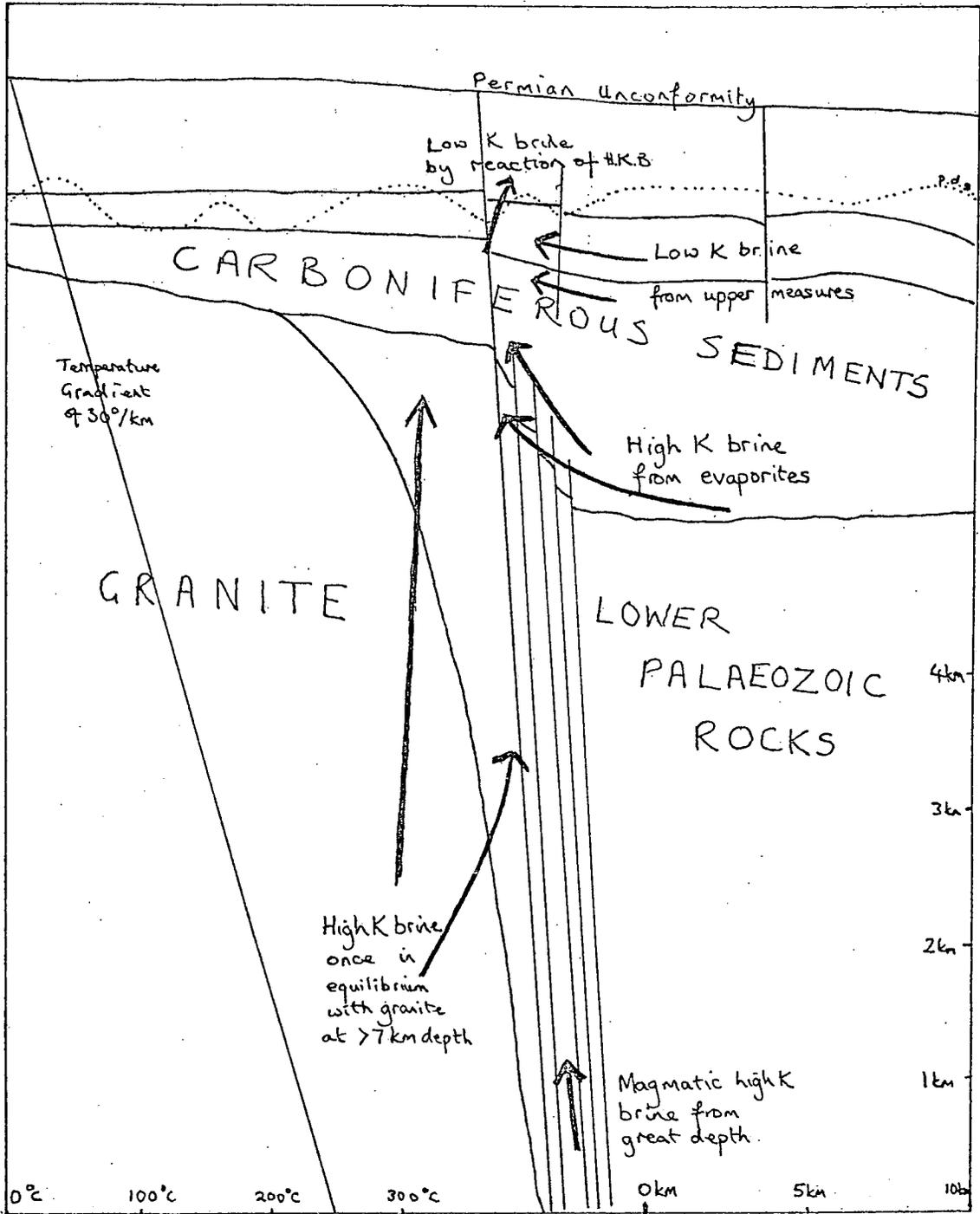
FIGURE 7.3 MINERALIZATION OF THE C-ZONE
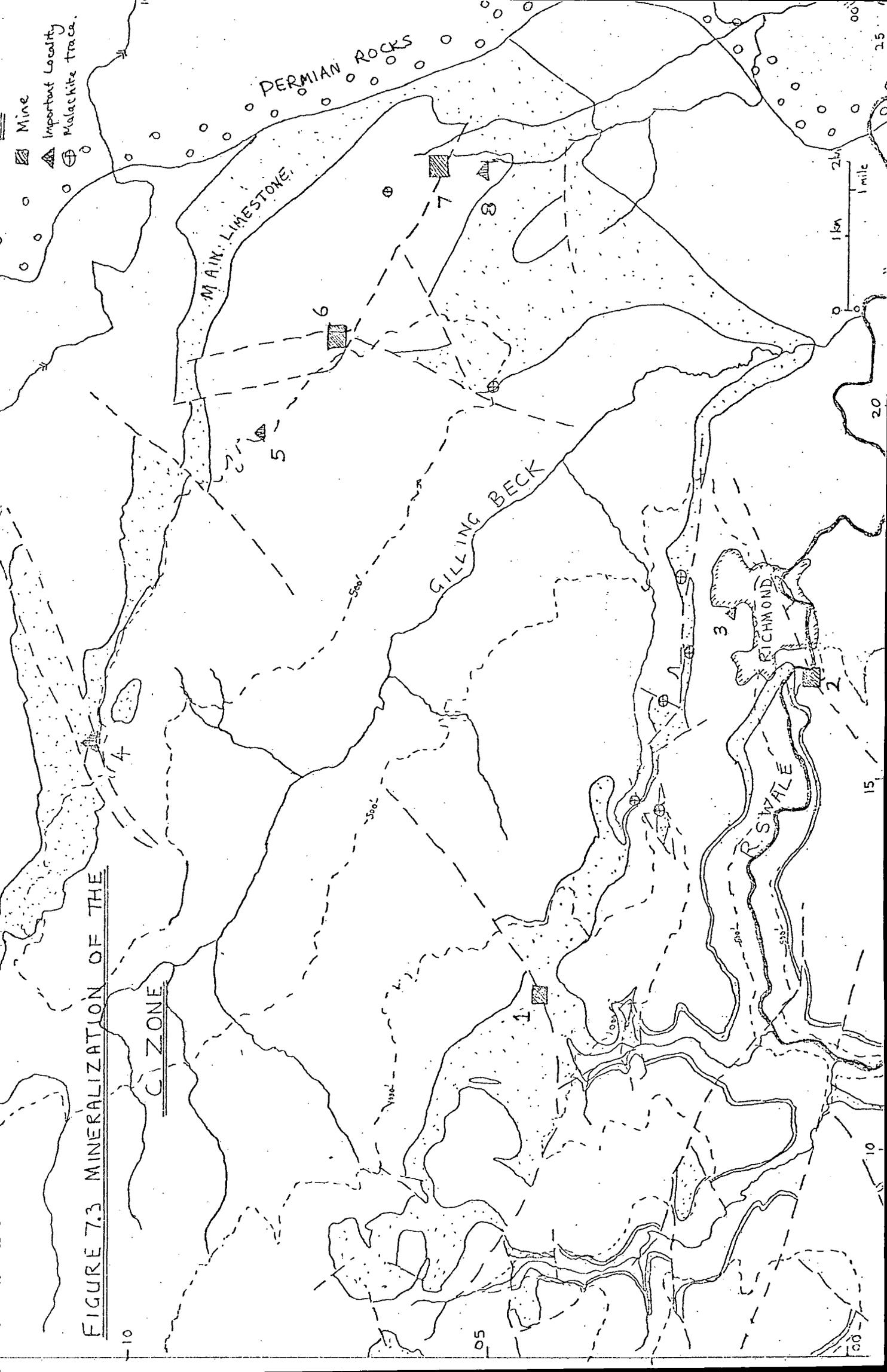
SECTION

B

INNER G ZONE

GRISDALE COMMON VEINS, GRISDALE

Grid Ref: SD783934   Altitude: 410 m (1350')

Structure: 3 veins, (a) in direction 060° (b) in direction 070°,

  (c) in direction 020°, all of small throw.

Mineralization: Quartz, chalcopyrite.

Wallrock alteration: Dolomitization, silicification.

Stratigraphic Horizon: Main Limestone

Visible workings: 1 trial shaft enters silicified limestone at a point

along a vein that stands as a rounded ridge above the limestone bench

which is grassed over. As well as protruding above the generally

smooth surface the vein at outcrop is covered with a coarse vegetation

largely of heather, making a striking contrast with the surrounding

limestone grassland.

Underground workings: None

Date of working: Unknown, pre-1891.

Details of mineralization: Two veins (a and b) are seen on the limestone

bench, and are both marked by a strong vegetation change. One is

referred to as containing amethystine quartz in Dakyns (et al 1891),

but none was found. Both veins were examined and carry good quartz

crystals (short pyramidal) in druzes in more massive vein quartz

surrounded by silicified crinoidal limestone. In each case the veins

are at most a metre wide.

A third vein on the edge of the scarp (c) is rather more spectacular

being more than 6 m wide. It is mostly filled with massive quartz

though in parts it contains quantities of silicified limestone. The

vein shows shearing and movements postdating the mineralization, but the

total movement does not seem to be large. The downthrow shown on the 1"

geological map indicates that the fault must be reversed since outcrops reveal a westerly hade of around $10^\circ - 20^\circ$. The dolomitization associated with this vein is also wide, as revealed in an adjacent small quarry. The dolomite replaces the non-crinoidal part of the limestone first. Quartz and chalcopyrite then replace the altered limestone, although not to any distance from the vein. This occurs commonly in the silicified limestone included in the vein. The main vein (c) is filled with quartz with a few scattered chalcopyrite crystals. The dolomite is partly oxidised and replaced by limonite and the chalcopyrite is often replaced with goethite and malachite. Decalcified silicified crinoidal limestone samples show malachite replacement of crinoid ossicles.

Specimens: C436 - 0446 from vein (c)

0446 - 0451 from vein (b)

HANGING LUND SCAR VEINS, MALLERSTANG

Grid Ref: SD783975   Altitude: 400 - 420 m (1300' - 1375')

Structure: 2 veins, directions 060°, length of vein seen 300 m.

Mineralization: Quarts, chalcopyrite, tetrahedrite, and secondary minerals.

Wallrock Alteration: Silicification

Stratigraphic Horizon: Main Limestone

Visible Workings: A few shallow shafts on the veins show no great vein width (1 m max.) and from the size of the tips these workings could have rewarded the miners with only little ore. The dumps contain a moderate proportion of quartz bearing very fine flecks of chalcopyrite and occasionally tetrahedrite. One small fault is revealed by a shallow drop of the limestone pavement to the north. Shallow workings entered the vein at this point.

Underground Workings: From surface evidence the workings are unlikely to have been very deep.

Details of Mineralization: The workings at (a) show a partly crinoidal limestone replaced by silica near the vein. The vein is filled (at least in part) with a breccia of silicified limestone, sandstone and coal. The cavities remaining are filled by quartz with chalcopyrite specks (small angular grains) and tetrahedrite in places. Both ore minerals have been weathered. The chalcopyrite gives goethite, malachite and azurite, while the tetrahedrite gives an amorphous sap green powdery mineral, probably a stabilized iron 2 hydroxide. This sap green mineral fluoresces strongly in Cu Ka radiation and under the binocular microscope can be seen grading in to limonite. The coal present in the breccia most likely represents coal from beneath the Main Limestone or even the Undersett Limestone, which has been carried up the vein by the rising hydrothermal solutions.

Some pieces of porous aggregate of white quartz crystals about 1 mm across were found at (a). They have had their original small sulphide specks rapidly oxidized to malachite and goethite. These specimens probably represent an open part of the vein as they are devoid of host rock fragments.

The workings at (b) lower down the hill than (a) seem to have been a small level and shaft. The tips reveal pieces of fault breccia of silicified limestone filled with fine grained quartz, chalcopyrite and tetrahedrite with cavities lined with clear quartz crystals. Some of the crinoidal limestone shows replacement by chalcopyrite and quartz. Secondary minerals include azurite and malachite.

Workings at (c) are on a parallel vein and show a silicified vein edge with a prior replacement of the limestone by tetrahedrite and chalcopyrite. The cavities have been lined with quartz. These workings are not as extensive as those at (a) and little ore can have been obtained.

On the limestone cliff of Hanging Lund Scar mineralized joints can

be found bearing quartz crystals occasionally with flecks of chalcopyrite.

The quartz found in all these places is dominantly pyramidal.

Specimens: 0423 - 0430 & 0441 from tips at (a) SD783977

0431 - 0432   (c) SD783978

0433 - 0435   (b) SD781975

DANDRA GARTH VEIN, GARSDALE

Grid Ref: SD755897   Altitude: 230 m (750')

Structure: Vein striking 060°, of small downthrow south.

Mineralization: Quartz, chalcopyrite, calcite.

Wallrock Alteration: Silicification.

Stratigraphic Horizon: Hardraw Scar Limestone.

Workings: None.

Details of Mineralization: A vein of brecciated dark crinoidal silicified limestone filled with quartz is visible in the cliff just above the road at Dandra Garth. Joints parallel to the vein are also filled with quartz. The vein also crosses Blea Gill about 25 m from the road.

Specimens of joints show quartz replacing limestone, but not the crinoids, which tend to become weathered out at a later date. Chalcopyrite is present and as at Hanging Lund Scar (p.121) in angular grains scattered through the quartz crystal aggregate, though here rather sparsely. The quartz crystals are colourless, and clear and pyramidal, forming occasional small vugs.

The vein breccia is filled with quartz crystals and a little chalcopyrite. A vug in the breccia was found to be lined with nail heads of calcite. Chalcopyrite is deposited on that and is replaced by geothite with some malachite. Good crystals of chalcopyrite largely pseudomorphed by goethite are also present in another cavity on top of quartz crystals. Chalcopyrite occurs in one specimen both on quartz and in the later calcite.

Crustiform textures of quartz are common in the breccia filling.

There has been some shearing of the vein since the deposition of the quartz.

The vein does not appear to continue into the shale beneath the limestone.

Specimens: DG1 - 10

FAR COTE GILL, MALLERSTANG

Grid Ref: SD773967   Altitude: 410 m (1350')

Structure: A vein of small throw striking 020°.

Mineralization: Quartz, chalcopyrite.

Wallrock Alteration: Silicification.

Workings: A small hush, to expose the vein in the Main Limestone only.

Date of Workings: Unknown.

Details of Mineralization: The vein is of quartz carrying specks of chalcopyrite. The Main Limestone has been silicified and in part dis-solved away to give irregular vugs now lined with clear pyramidal crystals of quartz and specks of chalcopyrite.

In the small quarry by the road at the railway bridge mineralized joints orientated 040° - 060° carry quartz crystals with calcite. The calcite may in this case be later than the mineralization.

Specimens: C382

COVENTREE VEINS, DENTDALE

Grid Ref: SD716861   Altitude: 185 m (611')

Structure: A vein direction unknown.

Mineralization: Quartz, chalcopyrite.

Stratigraphic Horizon: Great Scar Limestone.

Workings: In the gill which comes down from Coventree atrial in a copper bearing quartz lode about 150 m below the road to Dent was reported by Dakyns et al (1891).

Details of Mineralization: The trial was not found, but whilst following

the Deepdale Beck a number of boulders bearing quartz and an irregular

joint filled with clear pyramidal quartz were found. Small specks of

chalcopyrite occur rarely in the quartz aggregate.

Other Localities (not visited)

WILD CAT HOLE, WEST GILL, COTTERDALE

Grid Ref: SD821961   Altitude: 430 m (1400')

Structure: Vein of small throw striking 045°.

Mineralization: Chalcopyrite, quartz.

Stratigraphic Horizon: Main Limestone.

Workings: A small trial shaft.

Date of Workings: Unknown.

Details: Scanlon (1956) in his thesis confirms the 6" geological survey

map in having found a fault bearing quartz and chalcopyrite.

WASHER GILL, MALLERSTANG

Grid Ref: SD793957   Altitude: 410 m (1350')

Structure: Vein of small throw striking 025°.

Mineralization: Quartz, chalcopyrite.

Stratigraphic Horizon: Main Limestone.

Workings: None reported.

Details: A fault with throw of a few feet crosses Washer Gill and cuts

the Main Limestone. It bears quartz and chalcopyrite according to

Scanlon (1956).

ROWTHEY GILL, ULDALE

Grid Ref: SD743949   Altitude: 380 m (1250')

Structure: Four faults all of small throw striking 065° form parallel

veins.

Mineralization: Quartz, chalcopyrite.

Stratigraphic Horizon: Main Limestone.

Details: Two small faults with throw of around 1 metre are close together about 100 m S.E. of a sheepfold. Another fault 25 m further S.E. throws the strata down to the south by about 6 m. The last fault is 30 m further S.E. and throws the strata down to the north by about 12 m.

The faults are all seen in the gill and in this gill the Main Limestone is thinner than over most of the area, being only 9 m (30') thick. A thin black chert here occurs above the limestone (Dakyns et al 1891).

The faults bear "Quartz in finely crystallized hexagonal pyramids with a little copper ore distributed throughout". The copper ore was considered to have been chalcopyrite, but now decomposed in part to malachite and azurite (presumably with goethite).

SCAR HOUSE VEINS, GARSDALE

Grid Ref: SD770904   Altitude: 260 m (850')

Structure: 2 veins of small throw running 035° and 030°.

Mineralization: Quartz, chalcopyrite.

Stratigraphic Horizon: The Hardraw Scar and Simonstone Limestones.

Workings: None recorded

Details: A quartz lode running 035° crosses the river near Scar House in the Hardraw Scar Limestone and the other running 027° is exposed in Assey Gill in the Simonstone Limestone. The quartz of both lodes is speckled with chalcopyrite. (See Dakyns (1891)).

OUTER Q ZONE

BECKERMONDS AND OUGHTERSHAW VEINS, UPPER LANGSTROTHDALE

Grid Ref: Beckermonds SD872803   Oughtershaw SD875814

Altitude: Beckermonds 360 m (1175') Oughtershaw 320 m (1050')

Structure: 2 veins direction 025° occupy faults of small throw or master joints.

Mineralization: Quartz, chalcopyrite, fluorite.

Wallrock Alteration: Silicification, dolomitization.

Stratigraphic Horizon: Great Scar Limestone.

Workings: None.

Details of Mineralization: Oughtershaw vein was visited and shows a small (1 m) mineralized zone of mineralized ground trending 025° following some sort of weakness which would seem to be strong joints rather than anything else. The zone is seen in the outcrops beside the stream just behind the barn visible from the road. The mineralized zone is found to consist of highly dolomitized limestone with less intense silicification, and minerals filling or partly filling ramifying cavities following joints and bedding. Small (<1 cm) pyramidal clear colourless quartz crystals completely occupy the narrow cavities especially when vertical. Small (<1 cm) fluorite cubes with pale purple tint are found in some of the more open horizontal cavities and accompanying the fluorite, but earlier than it, are clear quartz crystals up to 1 cm across. Quartz is accompanied and followed by occasional crystals of chalcopyrite now often altered to goethite and malachite. Alteration has also affected the dolomite and has left rhomb-shaped limonite boxworks in part.

Specimens: 0939 - 0953

N.B. Beckermonds vein is probably similar to Oughtershaw from what little is said in Dakyns et al (1891).

GREAT SLEDDALE COPPER VEINS, ANGRAM COMMON

Grid Ref: (a) SD836992 (b) SD830991 (c) SD833994

Altitude: (a) 450 m (1475') (b) 480 m (1575') (c) 520 m (1700')

Structure: Veins striking 060° and 100°.

Mineralization: Quartz, fluorite, calcite, barite, chalcopyrite.

Wallrock Alteration: Dolomitization, silicification.

Stratigraphic Horizon: Mostly in the Main Limestone.

Workings: There is a small shaft at (a), a large tip and level at (b),
now blocked, and a level and shaft at (c) half-way up the west hush
called Hush Gutter. There is also an east hush and a small shaft (d) in
the P zone (p.112).

Date of Workings: Raistrick (1936) refers to trials in the mid-eighteenth
century.

Details of Mineralization:

Locality (a) - There is a closed shaft on the south side of the Great
Sleddale Beck. The shaft is situated along a fault that cuts the Main
Limestone, which is a crinoidal limestone. Joints in the stream have
silicified edges and contain quartz. Tips at the shaft and large blocks
nearby, probably from the shaft, were examined and specimens retrieved.
These specimens show a fault breccia of silicified crinoidal limestone
and small fragments of siltstone. The breccia is filled with quartz
crystals, with a little later pale-ambery fluorite on top in some vugs,
and more rarely with small quantities of late barite on quartz and
fluorite. One joint of thin plates of white barite was seen to postdate
both quartz and calcite which appears to be younger than the quartz.
Fine grained quartz filling the breccia may be grey or colourless, but
is generally rich in chalcopyrite. It is not clear whether it has defin-
itely replaced limestone or not.

Small vugs are generally lined with quartz and sometimes fluorite
crystals. The quartz and fluorite are partly synchronous, but much of

the fluorite seems to be later than the quartz. The rarer barite is present as small blades grown on fluorite crystals. One specimen was found with a quartz and fluorite layer followed by a later quartz layer.

In the river bed between localities (a) and (b) joints with directions 060° and 150° in the Main Limestone are silicified. Some joints have silicified walls, but are filled with massive calcite.

Locality (b) - At this point there is a conspicuous tip by the cliff marking a fault parallel to the stream bank. This would seem to mark a level mouth now covered over with rubble. The tip shows silicified limestone breccia filled with quartz, much of it very fine-grained, but some larger crystals are present. The quartz fill bears abundant small angular grains of chalcopyrite, much of which is now replaced with goethite and malachite.

Some small vugs are lined with quartz crystals, and in a few cases with later fluorite. A few small plates of barite on the fluorite and quartz can be found. Tiny malachite masses grown on barite and more commonly on earlier minerals are abundant. Fluorite is largely later than quartz and no definite example of quartz grown on fluorite was observed.

The large west hush called Hush Gutter coming straight down the hillside at right angles to the beck cuts the Main Limestone near its bottom end, and at (c) a shaft and a level (open) are present. The tips are probably mixed and on the whole contain mostly shaley rocks, but some specimens of silicified limestone breccia and vein minerals were found. Both the workings must commence between 15 and 23 m above the top of the Main Limestone.

The specimens show a little silicified limestone and a quartz fill, with vugs lined with quartz, later fluorite and chalcopyrite. Some

quartz is contemporaneous or later than fluorite, but mostly fluorite
is later than quartz.

Some of the chalcopyrite has been replaced with goethite, malachite
and azurite. Azurite aggregates are partly covered by malachite.

The quartz in vugs occurs as clear colourless pyramidal crystals.

Specimens: (a) 0412 - 0422

(b) 0398 - 0411

(c) 0390 - 0397

Q ZONE - STAINMORE

North Stainmore Mine, Augill Beck

Grid Ref: NY823156   Altitude: 290 m (950')

Structure: Stockworks connected with the Dent Fault, which strikes 110° west of the beck and 130° east of the beck and has very large downthrow to the west.

Stratigraphic Horizon: Great Scar Limestone.

Mineralization: Quartz, barite, chalcopyrite, galena, pyrite, sphalerite.

Wallrock Alteration: Dolomitization, silicification.

Workings: Levels, opencuts and shafts are extensive near the Augill Beck, which is in a gorge in this area.

Production:

Year	Ore	Lead	Silver
1855	18 tons 8 cwt.	14 tons 0 cwt.	140 oz.
1856	84 tons 0 cwt.	64 tons 0 cwt.	640 oz.
1857	80 tons 0 cwt.	60 tons 19 cwt.	609 oz.
1858	21 tons 11 cwt.	15 tons 10 cwt.	135 oz.
1859	20 tons 15 cwt.	14 tons 18 cwt.	148 oz.
1860	46 tons 0 cwt.	36 tons 0 cwt.	360 oz.
1861	41 tons 4 cwt.	31 tons 19 cwt.	312 oz.
1862	40 tons 0 cwt.	31 tons 0 cwt.	310 oz.
1863	34 tons 4 cwt.	27 tons 6 cwt.	274 oz.
1864	25 tons 0 cwt.	17 tons 10 cwt.	102 oz.

Production is notable for the high silver content (10 oz/ton = 300 ppm).

Details of Mineralization: The tip material and exposures show extensive stockworks of quartz and barite in dolomitized and silicified limestone. The barite is often pink and always of the massive platy variety. Galena occurs commonly in the stockworks and chalcopyrite is similarly found. Sphalerite and pyrite are present but more rarely important in the tip material.

Specimens: Collected, but not numbered or examined in detail.

F ZONE - DENT LINE

HIGH LONGRIGG VEINS, HARTLEY

Locality	(a)	(b)	(c)	(d)
Grid Ref.	NY798095	NY801090	NY801090	NY802085
Altitude	305 m (1000')	365 m (1200')	365 m (1200')	365 m (1200')
Specimens	0169-0184 0221-0225 0272-0278	0185-0213 0216-0220	0214-0215	0167-0168

Structure: Two or more veins (one at 120°) with replacements, have small throw.

Mineralization: Fluorite, barite, calcite, galena, chalcopyrite, hematite, and secondary copper minerals.

Wallrock Alteration: Domomitization, fluoritization.

Stratigraphic Horizon: Great Scar and Robinson Limestones.

Workings: There was a small copper and lead mine at (a) with several shafts and a small hush. The workings are not extensive from the size of the tips, but they were probably backfilled.

At localities (b) and (c) there was a small mine referred to as the Eden Valley Mine - plans are deposited with Mines Record Office, London.

Date of Working: 1873 - 1879 recorded.

Production: Iron ore - figures not known.

Lead ore - figures only for 1877.

135 tons ore, 101 tons 15 cwt. lead, 504 oz. silver

Copper ore - none recorded but mentioned in Dakyns et al (1891) figures unknown.

Details of Mineralization: In Dakyns et al (1891) it is reported that in mining a hematite body east of Hartley first hematite was raised then copper ore, then lead ore. This report suggests some sort of supergene process

since in this area the hematite is distinctly related to the Permian Unconformity.

The tips at locality (a) are the largest and contain abundant barite with secondary copper minerals and a little fluorite.

Specimens reveal dolomitized limestone with vugs lined with pale fluorite and chalcopyrite (now largely goethite and malachite) and with later barite on top. Masses of radiating thin white plates of barite up to 15 cm long were seen in the small hush. They contain many green spots of malachite staining and also grey spots and bands of pyrolusite and goethite. A few small pieces of galena were fould at locality (a) and also specimens of goethite with malachite and azurite crusts surrounding unaltered chalcopyrite.

The tips of the Eden Valley Mine, localities (b) and (c), are not so rich in gangue, but more varied than at locality (a). They reveal the following sequence of events:- replacement by dolomite (mild), then fluorite (strong), then barite (less commonly present). Then followed a cavity filling stage of fluorite, then fluorite with barite, then barite, then calcite and finally replacement by siderite.

The fluorite is purple when of the replacement variety and of a paler colour when filling cavities. The barite forms platy stellate aggregates of crystals in replacements and almost mamilar aggregates of thin plates in cavity fillings; it is generally coarser in the cavity fillings.

Chalcopyrite is commonly found as specks within the barite and inclusions of sulphide, possibly chalcopyrite, occur with fluorite crystals in cavity fillings. Goethite pseudomorphs in part are after chalcopyrite identified by the almost cubic and wedge shaped forms, and malachite skins. Some of the goethite, however, could represent original pyrite.

Fluorite was clearly crystallizing at some stage after the formation of barite since in one specimen a band of fluorite in crustiform barite has been found.

Calcite crystals are all cavity filling. One vug lined with clear calcite has long prismoidal crystals.

Galena occurs as the occasional crystal in the replacements. Replacement galena only occurs with barite presence, but barite often occurs without galena. Galena also occurs with cavity filling fluorite.

Some barite is iron stained (with hematite and goethite), and iron stained specimens of limestone are abundant on the tips of this mine. One specimen of breccia shows pieces of white barite filled with red iron rich matrix.

On the slopes east of Little Longrigg there is much hematite stained limestone and small joints and veinlets of calcite and barite. The barite veins would seem to be later than some calcite joints.

Locality	Grid Ref.	Altitude	Specimens
(a)	NY796072	305 m (1000')	0549-0556
(b)	NY796072	305 m (1000')	0557-0574
(c)	NY796072	305 m (1000')	0575-0577
(d)	NY802077	400 m (1300')	0578-0582
(e)	NY803078	380 m (1250')	0583-0593
(f)	NY803079	365 M (1200')	0594-0606
(g)	NY804083	335 m (1100')	0607-0612

Structure: Replacements connected with steeply dipping rocks and faults of the east facing monocline of the Dent Line.

Mineralization: Fluorite, barite, calcite, galena, sphalerite, chalcopyrite.

Wallrock Alteration: Dolomitization, fluoritization, baritization, galenafication, sphaleritization, calcitization.

Stratigraphic Horizon: Top of the Great Scar Limestone, Robinson Limestone and Peghorn Limestone.

Workings: There are many workings; the most important were probably Ladthwaite Level which has large tips, and the opencuts and shafts around Birkett Hill and Beck.

Date of Working: 1870 - 1880 recorded.

Production: Only 1877 has figures. Lead ore - 15 tons 6 cwt., lead - 12 tons, silver - 60 oz. This must represent only a fraction of the production considering the amount of work done.

Details of Mineralization: Localities (a), (b), (c) - Ladthwaite Level. At this collecting point there is much dolomitized limestone. It has been partially affected by other replacements which would appear to be later than the dolomite. These replacements include all the primary minerals

found except chalcopyrite.

Stockworks of dolomitized limestone fragments filled with galena, sphalerite, fluorite, barite and calcite occur. There are solution cavities lined or filled with fluorite, with and without galena, followed by white barite with and without chalcopyrite and/or synchronous galena, followed by calcite with or without sphalerite and/or galena. The calcite with galena and sphalerite can be of prismoidal type. In the absence of galena and sphalerite "squat" varieties of calcite crystals are developed.

The above sequence probably applies to replacements and stockworks, but generally only a few stages are present in any one specimen even of the cavities.

A shaft (d) on Hartley Birkett Hill yielded specimens of dolomitized limestone bearing cavities lined with barite, then clear to white nail head calcites. Chalcopyrite flecks are present both in the late barite and in the early calcite. Some of the chalcopyrite is now altered to goethite and malachite.

At localities (e), (f), (g), opencuts and other workings on Birkett Hill and near Birkett Beck.

Specimens of porous fluoritized limestone are common. Some still have some unfluoritized dolomitized limestone. Others contain replacement barite (white), and specimens from locality (g) are sometimes loaded with galena. Good fluorite cubes and thin platy aggregates of barite probably came from cavities. Some good cubes of fluorite are pinkish and contain roundish inclusions of chalcopyrite. Some of the barite contains many inclusions now of goethite with malachitic 'aureoles' but probably chalcopyrite originally.

One specimen of cavernous altered limestone has vugs lined with transucent yellowy brown to clear colourless calcite crystals of the "squat" kind. Some of the crystals have colourless cores, others colourless rims and yet others are completely clear.

The workings on Birkett Hill seem largely to have worked pockets of replacement ore, and opencuts in replacements are to be found along with shafts and exploration hushes. Success was probably very erratic in mines in this region.

GREAT BELL, NATEBY

Locality	Grid Ref.	Altitude	Specimens
(a)	NY876042	305 m (1000')	0279-0293
(b)	NY787046	365 m (1200')	0294-0297

Structure: Stockworks and replacements associated with the vertical strata and faults of the Dent Line.

Mineralization: Fluorite, barite, calcite, galena, dolomite.

Wallrock Alteration: Fluoritization, dolomitization.

Stratigraphic Horizon: Great Scar Limestone.

Workings: Two levels, three hushes and several shafts are obvious. One level was just an unsuccessful trial by the look of the tips, which reveal no mineralization. The hushes do not appear to have been any more successful in exposing ore either. The tips of the main level, however, are relatively large and bear mineralization which is also observed in the open cut near the top of the hill and the shaft nearby.

Date of Workings: 1866 - 1880? recorded.

Production: Figures only recorded in 1866. Lead ore - 39 tons, 4 cwt., lead - 26 tons, 3 cwt.

1880 has a record for Belds mine which could be a spelling error on Bells Mine. Lead ore - 7 tons 12 cwt., lead - 5 tons 15 cwt.

Details of Mineralization: Specimens of interest mineralogically are uncommon at this locality.

In the tips of the main level (locality (a)) fluoritized limestone is present. The fluorite is mostly colourless but a little is pale purple. There is also later joint filling fluorite and later white platy barite. One specimen shows calcite with later barite in a small vein. A specimen of white massive calcite contains cubes of galena and another of a stockwork

in dolomitized limestone filled with calcite and galena. Gypsum crystals were found in some specimens from a part of the tip bearing shale as well as mineralized limestone. It is probably of secondary origin. A small veinlet is lined with dolomite then fluorite then calcite.

Specimens from the open cut and shaft at locality (b) reveal dolomitized limestone fluoritized in part with pale blue to colourless fluorite and stockworks filled with calcite and pale purple fluorite. A speck of galena was found in one specimen of white calcite cavity filling. One vein of calcite is filled with large colourless squat calcite crystals surrounded by more toothy crystals.

Pyrite was observed in nodules from the shale at locality (a) and also as a little patch in sandstone from the same place.

CLOUDS MINES, CLOUDS

Locality	Grid Ref.	Altitude	Workings	Specimens
(a)	SD73679987	425 m (1400')	Opencut	0345-0348
(b)	SD73629980	425 m (1400')	Opencut	0349-0352
(c)	SD73599966	425 m (1400')	Level	0353-0360
(d)	SD73479928	380 m (1250')	Opencut	0361-0362
(e)	SD73429930	380 m (1250')	Opencut	0303-0305
(f)	SD73569947	410 m (1350')	Opencut	0364, 0313-0319
(g)	SD73609966	425 m (1400')	Opencut	0363-0364
(h)	SD73459965	395 m (1300')	Opencut	0373
(i)	SD73459923	380 m (1250')	Opencut	0307-0312
(j)	SD73559917	380 m (1250')	Exposure in beck	0378
(k)	SD73439913	365 m (1200')	Opencut	0379
(l)	SD73429914	360 m (1175')	Opencut	0380
(m)	SD73759989	350 m (1150')	Short levels	0366-0372
(n)	SD74059965	435 m (1425')	Large pothole	0374
(o)	SD74169994	440 m (1450')	Showing in soil	0365
(p)	NY74900100	365 m (1200')	Hushes, a level and shaft	0327-0340
(q)	NY74630068	395 m (1300')	Opencut and shaft	0298-0302
(r)	NY74400022	460 m (1500')	Shafts	0320-0326 0251-0262
(s)	NY74250004	450 m (1475')	Opencut	0341-0344
(t)	NY74250015	440 m (1450')	Level	0264-0271

Structure: Many small veins.

Mineralization: Fluorite, barite, calcite, galena, chalcopyrite, tennantite, and secondary minerals.

Wallrock Alteration: Dolomitization and rarer fluoritization, galenafication etc.

Stratigraphic Horizon: Great Scar and Peghorn Limestones.

Workings: Two levels, a few short levels, several shafts, and many opencuts. Workings were probably mostly superficial from the size of the tips. There are many small workings rather than one large one.

Date of Workings: 1870 - 1876 recorded.

Production: None recorded, but Dakyns et al (1891) records that as well as galena and chalcopyrite some grey copper ore (fahlore, tennantite) was raised.

Details of Mineralization: Localities (a), (b), (g) Fell End Clouds veins lie in the core of the anticline. A little breccia is present but the fissures were probably fairly clean. They are mineralized with barite banded at times and mostly thin white platy aggregates. The barite is sometimes banded with chalcopyrite inclusions, and sometimes banded with fluorite which in at least one instance is present in the core of the vein but not at the edge of the vein. Some good fluorite cubes have good growth zones of chalcopyrite inclusions which are often elongate as opposed to the inclusions in barite. A little galena is present as cubes at times. It would appear to be more strongly associated with the fluorite than the barite. The opencuts on the main vein show it to have been irregular and no wider than 1.5 m wide and probably much less in places.

A specimen from level tailings at (c) probably came from the same veins and shows banded barite with a band rich in galena followed immediately by a band with fluorite.

Workings in the Fell End Clouds veins (d), (e), (f), (h), (i), occur in the core of the anticline at its southern end. Breccia is again found and is filled, as are the open cavities, with intergrown barite and fluorite. Some of the barite is pink, and some contains chalcopyrite specks now partly

altered to malachite and goethite. A little galena is again present and mostly occurs with fluorite. There are some joints filled with calcite that are older than the fluorite and galena mineralization. These can also be seen in the Doren Beck (j) nearby where a long 2 cm wide or less vein of galena and fluorite cuts a conjugate set of joints. A loose block of breccia has slicken sides indicating that movements continued during or after mineralization.

Locality (m) Fell End Clouds veins. At this point a few short levels enter the limestone scarp and thin flats possibly with similarly thin joints were worked. White platy barite with or without chalcopyrite specks is intergrown with fluorite, and specimens of calcite whose relationships are unknown also occur.

Locality (n) Deep Moss. A large pothole at this point exposes a reversed fault with a little calcite and galena mineralization partly replacing the limestone.

High Stenerskeugh Level (p). There are several short hushes and a level with a flooded shaft nearby. The tips are fairly large by Clouds standards. They bear specimens of limestone breccia filled with fluorite. Some fluorite seems to be replacing the limestone which is grey and massive. There are some vugs containing good cubes of fluorite and a little galena followed by calcite nailheads. There are also specimens of recrystallized and dolomitized limestone with disseminated galena and chalcopyrite. A specimen of fluorite with chalcopyrite grains and inclusions occurs with later white calcite which has occasional chalcopyrite grains at the crystal boundaries.

There are also specimens of limestone with stockworks of fluorite and calcite with galena and chalcopyrite in places. Sometimes the gangue is absent, but galena and chalcopyrite are still present, and occasionally intergrown. There is much limonite and malachite. Tennantite is also present in small amounts.

Stenerskeügh Clouds North vein (o). A 500 m vein worked by shallow opencut and shafts carries limestone breccia in parts, with a little barite, fluorite and chalcopyrite specks largely in the barite. Some specimens are banded with fluorite and barite with chalcopyrite specks, and one has a tiny vug lined with squat calcite crystals of very pale blue colour and much pale malachite. There is a little dolomitization.

Clouds central vein old shafts (r). There are specimens of barite sometimes intergrown with fluorite, sometimes later than fluorite, and sometimes without the presence of fluorite. With the gangue are galena, chalcopyrite, and tennantite. One specimen has barite (fine-grained and massive) followed by large galena crystals, then fluorite, then barite with galena. A cavity is lined with fluorite and galena followed by barite and calcite. Some chalcopyrite looks as if it was either rolled out or grew flat, and at times tennantite looks as if replacing chalcopyrite. The shafts were probably not very deep, but workings here are fairly extensive.

Level at Dale Slack (t). Specimens are hard to find here, but include fluorite with chalcopyrite and tennantite, and later calcite. One specimen shows small yellow cubes of fluorite with much chalcopyrite, followed by a little barite, then by massive white to pink calcite. Chalcopyrite in the above specimen occurs throughout the barite and early calcite. Galena is also present, at times with fluorite and at others with calcite. Some of the calcite occurs as squat crystals.

Opencut (s). A small shaft and opencut were worked here. Their tips reveal stockworks in the hard compact limestone bearing fluorite and barite intergrown, and also with galena, which is also found at (o) where the soil bears ore minerals.

OTHER LOCALITIES

Several mines mentioned in Hunt (1860 - 1881), but of unknown position are all in the area of this zone. They are called by the following names:

Bayle Hill Mine, Henry Pease & Co. 1871

London Lead Co. 1872 - 1877

Bugle Hill Mine, Henry Pease Co. 1864 - 1873

Belds Mine, J. Kearton Co. 1879 - 1880, probably Bells Mine

Mallerstang Mine 1871 - 1880 has figures for 1871, 1873

1873   Lead ore - 15 tons 2 cwt., lead - 11 tons 3 cwt.,

Silver 77 oz.

1871   Lead ore - 24 tons 14 cwt., lead - 18 tons 10 cwt.,

Silver 129 oz.

A shaft near the Wharton Tunnel, grid ref. NY771036 bears calcite, fluorite and galena according to G. A. L. Johnson (personal communication) and could conceivably be one of these mines, but it is perhaps more likely that at least the first two are just parts of either the Hartley or the Clouds Workings.

Mallerstang presents perhaps the greatest problem and its high silver content, 7 oz/ton lead, makes it particularly interesting.

F ZONE - WENSLEYDALE

COTTRIGGS, UPPER WENSLEYDALE

Grid Ref: SD902900   Altitude: 260 m (875')

Structure: Vein striking 000°.

Mineralization: Dolomite, fluorite, barite, calcite, chalcopyrite, galena, sphalerite.

Wallrock Alteration: Silicification.

Stratigraphic Horizon: Great Scar Limestone, Hawes Limestone.

Workings: Level enters the hillside from the valley floor close to the Mine house. A fairly large tip of limestone, much of it silicified, is present at the entrance to the level.

Age of Workings: Unknown, but probably mid to late 19th century.

Details of Mineralization: The tips have pieces of vein breccia filled with minerals, but leaving occasional vugs. The limestone, which composes the breccia, has been silicified and in places disseminated with chalcopyrite close to the open vein. The spaces are filled with fluorite rich in chalcopyrite inclusions and with chalcopyrite grains. The fluorite is pale amber in colour, and is spangled close to the vein edge, but clearer away from it. Following the early fluorite with chalcopyrite the same minerals continue with the addition of galena. Next the chalcopyrite becomes less abundant. Following the fluorite is barite, massive platy and generally white, often with many small chalcopyrite inclusions. After the barite comes calcite, pink to white, and massive, sometimes containing chalcopyrite inclusions. Calcite is seen to rest directly upon fluorite, probably because vugs made inaccessible by the growth of fluorite, were reopened at a later stage, by movement in the vein, or dissolution of the fluorite, although there is no evidence for the latter. Occasionally the calcite is found as tree-like aggregates of squat crystals, with scattered fragments of barite aggregate. This supports the mechanical opening hypothesis. Some tufa-like pink calcite coating fluorite is also present.

Sphalerite is present in barite generally just before the onset of calcite deposition. One piece of breccia shows that movement and opening up of the vein occurred between the deposition of chalcopyrite rich fluorite and the deposition of later clear fluorite. Some vein dolomite occurs and is apparently late since saddle-shaped crystals have grown upon calcite. In other cases the dolomite forms the cement and in part the replacement of a breccia of silicified limestone.

The limestone is fairly massive and crinoidal, the crinoids being generally unsilicified, as is the case in the Q zone.

Specimens: 0872 - 0899.

MOSSDALE BECK VEINS, UPPER WENSLEYDALE

Grid Ref: SD826917 and SD824914.

Altitude: 290 m (950') and 305 m (1000')

Structure: Two veins of unusual character being of very shallow dip in shale. Strike 020°.

Mineralization: Fluorite, calcite, chalcopyrite.

Wallrock Alteration: Silicification, fluoritization.

Stratigraphic Horizon: Simonstone Limestone, Middle Limestone and its underlying sandstone.

Workings: None.

Details of Mineralization: In the stream near the railway bridge the Simonstone Limestone has a vein of fluorite with calcite in vugs. It is not a sharp vein, but rather more a zone rich in vugs parallel to the stream and dipping at a quite shallow angle. The limestone is silicified around some of the vugs, and weakly fluoritized round others. They are lined with amber fluorite, in crystals up to 3 cm along their edge. Many fluorites bear chalcopyrite inclusions, whilst others are clear. Some of the clear crystals have chalcopyrite crystals grown on top of them. Some vugs carry nailhead crystals of colourless calcite up to 3 cm across.

Further upstream amongst the loose blocks close to the waterfall in the Middle Limestone, specimens carrying mineralization can be found. Brownish, probably dolomitized limestone has joints filled with nailhead calcite slightly later fluorite in amber crystals. These are probably connected with the nearby fault.

Some pieces of gannister breccia carry cubes of pale fluorite and at times much limonite.

Specimens: MB1 - 10.

WORTON VEINS, MIDDLE WENSLEYDALE

Grid Ref: SD954896   Altitude: 245 m (800')

Structure: Two veins, (a) 170° small throw eastwards (thickness of Simonstone Limestone), (b) 150° larger throw, downwestwards (thickness of Middle Limestone). A further fault striking almost due north is marked on the one inch map, but is apparently unmineralized. All three faults meet at the point where the level goes into the hillside.

Mineralization: Dolomite, fluorite, calcite, galena, chalcopyrite (rare).

Wallrock Alteration: Dolomitization, fluoritization.

Stratigraphic Horizon: The level enters the Hardraw Scar Limestone, but the 1" geological survey map shows veins mineralized from the Great Scar Limestone to the Five Yard Limestone.

Workings: A level now closed enters the scarp of the Hardraw Scar Limestone probably just above its base. A fairly large tip now grassed over is present just outside its entrance.

Date of Workings: 1869 - 1881 recorded.

Production:

Date	Lead Ore	Lead	Silver
1875	108 tons 0 cwt.	81 tons 0 cwt.	240 oz.
1876	117 tons 7 cwt.	88 tons 0 cwt.	-
1877	38 tons 5 cwt.	28 tons 10 cwt.	-
1880	23 tons 12 cwt.	17 tons 14 cwt.	-
1881	34 tons 0 cwt.	23 tons 12 cwt.	-

Details of Mineralization: The few specimens retrieved show a dolomitized vein breccia filled with pinky brown dolomite forming many vugs some filled with colourless massive calcite. Deep purple fluorite is present inter-grown with dolomite. They are probably synchronous in part but relationships are not particularly clear, and indicate both younger and older ages for the fluorite. A few grains of pyrite were present in a piece of fluoritized limestone, and one crystal of chalcopyrite was seen in a calcite crystal.

A specimen in the collection at Durham presented by W. B. R. King shows dolomite filled breccia with vugs lined with good crystals of dolomite. The breccia filling is generally rather cavernous. One vug has a large crystal of galena grown in it, and in places much colourless misty calcite with galena is present and of probable later origin than the dolomite.

Specimens: 0852 - 0858.

SEATA MINE, AYSGARTH

Grid Ref: SD995883   Altitude: 230 m (750')

Structure: A large flat associated with a vein striking 160°.

Mineralization: Fluorite, sphalerite, galena, chalcopyrite, calcite and secondary minerals.

Wallrock Alteration: Dolomitization, fluoritized, sphaleritized.

Stratigraphic Horizon: Hardraw Scar Limestone.

Workings: A level enters the hillside at the point referenced and at its entrance are tips of similar size to Cottriggs, and Worton. According to historical information the workings were in flats.

Date of Workings: 18th century.

Production: Not known.

Details of Mineralization: Specimens from the tip reveal dolomitized, fluoritized, and sphaleritized limestone with vugs lined or filled with fluorite, sometimes clear and colourless, and sometimes with pink edges. The fluorite may be rich in inclusions of sulphide. Sphalerite and galena both accompany the fluorite. Some of the sphalerite has been coated with a crust of bluish white secondary zinc mineral. Some of the sphalerite in large pieces contained specks of chalcopyrite and occasional cubes of galena. Later than the fluorite there is a filling or lining of calcite in squat crystals which occurs only in places. Although some specimens rich in galena were found the dominant sulphide was sphalerite.

Specimens: 1057 - 1076.

WEST BURTON VEIN, LOWER WALDENDALE

Grid Ref: SE018869   Altitude: 170 m (550')

Structure: A vein of small throw 'strike 093°.

Mineralization: Fluorite, calcite, sphalerite, galena.

Wallrock Alteration: Fluoritization.

Stratigraphic Horizon: Great Scar Limestone.

Workings: Dunham (1952) records a level on the west bank of the Walden Beck at West Burton. This level could not be seen, but the west bank of the stream is walled opposite some small tips, which were examined. A plan of the workings is in the Mines Records Office.

Date of Workings: 1864 – 1881 recorded, but greater range likely (see Braithwaite).

Production:

Date	Lead Ore		Lead	
1864	400 tons	0 cwt.	280 tons	0 cwt.
1865	99 tons	0 cwt.	70 tons	0 cwt.
1866	94 tons	0 cwt.	63 tons	0 cwt.
1867	50 tons	0 cwt.	33 tons	0 cwt.
1876	7 tons	18 cwt.	5 tons	17 cwt.
1877	21 tons	10 cwt.	15 tons	7 cwt.
1880	31 tons	0 cwt.	23 tons	5 cwt.
1881	28 tons	19 cwt.	20 tons	10 cwt.

Details of Mineralization: Limestone and sandstone are found on the tip and bot carry mineralization. The limestone is occasionally fluoritized, and sometimes sphalerite and galena are found with it in this form. Vugs in the limestone contain fluorite, sometimes clear, others with dark (carbonaceous?) inclusions. Sphalerite and galena are both found with this fluorite. Squat crystals of calcite and massive calcite are fairly common. In one case grey massive calcite preceded fluorite.

The sandstone contains joints with pale fluorite, which is the variety dominant here.

Ore minerals are not particularly abundant in these tips.

Production of the neighbourhood was sufficient to induce the building of a smelt mill nearby.

Specimens: 0859 - 0871.

BRAITHWAITE VEIN, EAST WITTON

Grid Ref: SE118859   Altitude: 183 m (600')

Structure: One or two veins direction 130° - 160°, of modest downthrow east.

Mineralization: Fluorite, barite, calcite, galena, sphalerite.

Wallrock Alteration: A little recrystallization was observed along with traces of dolomitization, fluoritization and baritization.

Stratigraphic Horizon: Main Limestone.

Workings: Many small tips from shallow shafts are present near Braithwaite Hall, and a drainage adit from the riverbank is also recorded (Dunham 1952).

Date of Working: 1854 - 1872 recorded, but longer span suggested since there is a record of ore from here being smelted at West Burton after 1700.

Production:

Date	Lead Ore	Lead	Silver
1854	96 tons 9 cwt.	70 tons 0 cwt.	-
1855	67 tons 2 cwt.	39 tons 0 cwt.	273 oz.
1856	74 tons 7 cwt.	55 tons 0 cwt.	302 oz.
1857	91 tons 17 cwt.	65 tons 0 cwt.	445 oz.
1858	17 tons 18 cwt.	12 tons 10 cwt.	87 oz.
1859	36 tons 10 cwt.	25 tons 9 cwt.	178 oz.
1860	59 tons 2 cwt.	41 tons 0 cwt.	287 oz.
1861	77 tons 2 cwt.	53 tons 10 cwt.	374 oz.
1862	27 tons 0 cwt.	18 tons 15 cwt.	131 oz.
1863	7 tons 0 cwt.	4 tons 17 cwt.	-
1864	-	-	-
1865	16 tons 4 cwt.	11 tons 15 cwt.	81 oz.
1866	15 tons 12 cwt.	10 tons 16 cwt.	75 oz.

1867 - 1872, no figures given

Details of Mineralization: The tips at Braithwaite Hall were examined and samples collected from three places on the tips and one specimen from an adjacent dry stone wall.

The tips contain breccia of limestone, chert and a little coal filled with minerals.

Colourless fluorite occurs massive or as cubes and crystallized first. Barite with interstitial fluorite and occasional sphalerite crystals occur next followed by fine-grained massive white platy barite. Finally there is a little massive calcite, pale grey, pinkish and white.

Galena is found both with fluorite and barite, and some fluorite contains inclusions of chalcopyrite which is also found as rare crystals. There are indications of a little replacement, but it is by no means a common occurrence for the minerals here.

Specimens: 1, 1095 - 1108; 2, 1108 - 1111; 3, 1102 - 1107; from wall 1112.

KELD HEADS VEIN, PRESTON UNDER SCAR

Grid Ref: SE081906   Altitude: 183 m (600')

Structure: Vein of small throw striking 160°.

Mineralization: Dolomite, fluorite, calcite, galena, sphalerite, chalcopyrite.

Wallrock Alteration: Not observed.

Stratigraphic Horizon: From the Middle Limestone up to the Main Limestone and into the overlying cherts. The level here examined is in the Five yard Limestone.

Workings: Large tips from the level occur near the railway crossing at Preston Under Scar.

Date of Workings: 1866 - 1881 recorded, but the vein was worked as far back as the 12th century (Clough (1962)).

Production:

Date	Lead ore			Lead			Silver
1866	500	tons	0 cwt.	334	tons	0 cwt.	-
1867	498	tons	16 cwt.	300	tons	0 cwt.	-
1868	432	tons	0 cwt.	340	tons	0 cwt.	-
1869	532	tons	0 cwt.	340	tons	0 cwt.	-
1870	528	tons	15 cwt.	396	tons	0 cwt.	-
1871	525	tons	0 cwt.	394	tons	0 cwt.	-
1872	558	tons	0 cwt.	418	tons	10 cwt.	-
1873	424	tons	8 cwt.	318	tons	6 cwt.	-
1874	367	tons	10 cwt.	293	tons	0 cwt.	-
1875	87	tons	7 cwt.	60	tons	0 cwt.	180 oz.
1876	256	tons	7 cwt.	184	tons	2 cwt.	576 oz.
1877	232	tons	13 cwt.	201	tons	11 cwt.	600 oz.
1878	186	tons	16 cwt.	131	tons	11 cwt.	394 oz.
1880	316	tons	0 cwt.	250	tons	0 cwt.	790 oz.
1881	241	tons	6 cwt.	184	tons	0 cwt.	360 oz.

Details of Mineralization: The tips at the level crossing were examined
and the following sequence of minerals was observed:-

1. Dolomite (yellowy brown saddle-shaped crystals)

2. Colourless fluorite with chalcopyrite inclusions

3. Colourless fluorite with no inclusions

4. Calcite (toothy crystals and stumpy prismoidal crystals)

Galena is fairly abundant and occurs with fluorite along with
sphalerite and oxidation products. No barite was seen.

Specimens: 1077 - 1094.

WET GROOVES MINES, AYSGARTH

Each part will be dealt with under the locality heading.

Date of Working: From the name Grooves could be an ancient working, but records are only available for 1862 - 1878. This was probably the site of greatest activity in the dale in the 17th century (Raistrick and Jennings (1965)).

Production:	Name	Date	Lead Ore	Lead
	Wet Grooves	1862	3 tons 0 cwt.	2 tons 0 cwt.
	" "	1864	6 tons 0 cwt.	3 tons 12 cwt.
	Haw Bank	1866	2 tons 10 cwt.	1 ton 17 cwt.
	Woodhall	1868	6 tons 11 cwt.	4 tons 16 cwt.
	"	1870	4 tons 2 cwt.	3 tons 1 cwt.
	"	1871	2 tons 6 cwt.	1 ton 15 cwt.
	Wet Grooves	1872	4 tons 14 cwt.	3 tons 10 cwt.
	" "	1875	27 tons 3 cwt.	20 tons 0 cwt.
	" "	1876	74 tons 15 cwt.	55 tons 0 cwt.

These figures can represent only a fraction of the real production.

Localities 1 - 3 are dealt with on page (216) in the P Zone.

Localities 4 and 5

Grid Ref: SD982906   Altitude: 297 m (975')

Structure: One vein at 170° and probably another at 090° both of small throw. Also a few small veins some unworked (mostly gangue) of little or no throw.

Stratigraphic Horizon: Undersett Limestone and Sandstone beneath it.

Workings: Hushes are present here and probably were the dominant form of working although small shafts are present, and small levels.

Mineralization: Calcite, fluorite, barite, sphalerite, pyrite, galena.

Wallrock Alteration: Not observed.

Details of Mineralization: Tips here are fairly large and are composed mainly of sandstone and some limestone, with subordinate veinstuff. Sandstone is largely in big blocks, whereas the limestone is generally as small pieces. The dominant gangue is calcite. The calcite occurs as squat rhombohedrons, as more toothy crystals and also massive. When as good crystals it is often clear, but otherwise it tends to be translucent white. The calcite is often accompanied by much sphalerite. One specimen shows clear calcite crystals rimmed with sulphide inclusions probably pyrite, and with sphalerite on its edges. On top of this there is white calcite followed by a coating of 2 mm of fine-grained platy white barite. Another specimen with calcite followed by barite shows a coating of fine-grained white platy barite followed by coarse heavily-zoned misty white barite. Banded fine-grained barite occurs followed by coarse platy barite. The banded barite is grey or white, and contains a little sphalerite. Fluorite occurs, though rather more rarely, than the other gangue minerals. One specimen shows fluorite filling the interstices of long toothy crystals of calcite. Another specimen shows a layer of fluorite coating a layer of galena and sphalerite on a joint face.

Some cavernous fan aggregates of toothy barite, possibly secondary or very late, were also found.

Galena is fairly abundant.

Localities 6 and 6(a)

Grid Ref: SD987903   Altitude: 290 m (950')

Structure: Replacements or rather fillings of solution cavities, veins and veinlets, in a very disturbed mass of limestone, sandstone and shale.

Mineralization: Calcite, fluorite, barite, sphalerite and galena, pyrite, chalcopyrite.

Wallrock Alteration: A little fluoritization was observed.

Stratigraphic Horizon: Three Yard and Five Yard Limestones, and the sandstone and shale between.

Workings: Many small levels and shafts.

Details of Mineralization: Locality 6 is the workings at the upstanding mass of disturbed rock and 6(a) is a small seiving plant and its tips which have been in use in recent times for fluorite extraction.

The veins and veinlets show variable order of deposition at least with respect to fluorite and calcite, although barite always appears to be last to be deposited. One vug seen had good crystals of fluorite growing into it followed by good nail head spar and prismoidal. Another vein showed calcite to be present through most of the vein, but especially at the edge of the vein where it is accompanied with sphalerite. At the centre of the vein there is fluorite.

A specimen of limestone is partly replaced by fluorite and vugs are lined with colourless fluorite cubes with probable pyrite inclusions and finally coated with barite and sulphide now oxidized but possibly pyrite. Some fairly large cubes of amber fluorite are zoned with inclusions of sulphide, some are probably chalcopyrite and are coated with malchite.

Some calcite with galena and sphalerite was found. The sphalerite is coated with malachite in places due to the presence of small grains of chalcopyrite.

Galena is found with fluorite and barite as well as calcite, and sphalerite is found similarly.

There are good specimens of platy barite, forming open aggregates at times. They are generally white but some are colourless and misty and some are coated with yellow iron staining. Some of the barite forms aggregates resembling the fan shaped toothy aggregates interpreted as late or even secondary at times.

Localities 7 and 8

Grid Ref: SD987900   Altitude: 274 m (900')

Structure: A small vein of no throw striking at 070°.

Mineralization: Barite, calcite, fluorite, galena, sphalerite, pyrite.

Wallrock Alteration: None observed.

Stratigraphic Horizon: Middle Limestone.

Workings: A small opencut at the top of Haw Bank worked the vein but from its size it could not have been a big money spinner.

Details of Mineralization: At the opencut a few pieces of vein stuff were found. They are rich in fine-grained white platy massive aggregates sometimes forming part spheres. Galena occurs along with a white alteration product, probably cerrusite. The barite contains goethite pseudomorphs after sulphide, probably pyrite.

One specimen from the opencut has a little colourless fluorite deposited after the barite of which the specimen is largely composed.

On the scree beneath the opencut specimens were found, though not abundantly. These were largely of barite although fluorite with galena and cerrusite were also found. One specimen of banded rock shows dominant barite with a sphalerite band, a fluorite band, a band rich in galena, and occasional interstitial fluorite and some galena grains in the otherwise massive fine-grained white barite.

Locality 9

Grid Ref: SD987897   Altitude: 213 m (700')

Structure: Possibly the same mineralized ground as locality 6, but at a lower level.

Mineralization: Calcite, fluorite, sphalerite, barite, galena.

Wallrock Alteration: Fluoritized limestone.

Workings: A level enters the base of Haw Bank, and quite large tips are present at its entrance.

Stratigraphic Horizon: Simonstone Limestone.

Details of Mineralization: Specimens of mineralized country rock show occasionally fluoritized limestone followed by fluorite with galena, and

and sphalerite followed by barite. The fluorite is colourless and has a low density of sulphide inclusions. Sphalerite is dark brown to reddish brown and was seen directly upon micaceous sandstone. Calcite is very abundant and has contemporaneous sphalerite and galena with it. Fluorite and barite are also both common. Fan aggregates of toothy barite are also fairly common, but galena is only rarely found.

Locality 10

Grid Ref: SD981903   Altitude: 229 m (750')

Structure: Possibly the Dister Force Vein of small throw striking 150°.

Mineralization: Calcite, barite, sphalerite, galena, fluorite.

Wallrock Alteration: Sphaleritization, galenification.

Stratigraphic Horizon: Simonstone Limestone.

Workings: A drainage level enters the bank here and quite large tips are present although no fines were found.

Details of Mineralization: Calcite is the common vein mineral here. It is pale pink to white and massive and contains sphalerite at times. Large plates of barite (misty-white) form an open aggregate at times, but generally the barite is of the cavernous toothy kind indicating a late origin. Some barite occurs with calcite, but most is later than it.

Galena is present but is not as common as sphalerite. Disseminated galena and sphalerite are both found occasionally. A little fluorite was found with fine-grained white massive barite.

Specimen numbers: Locality 4, 0634 - 0651

Locality 5, 0652 - 0653

Locality 6, 0698 - 0684

Locality 6a,0654 - 0668

Locality 7, 0685 - 0691

Locality 8, 0692 - 0697

Locality 9, 0698 - 0710

Locality 10,0700 - 0722

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STAGS FELL VEIN, ABBOTSIDE COMMON

Locality	Grid Ref:	Altitude	Specimens
Stags Fell Grove Mine	SD946865	442 m (1450')	0757-0776
Hush Gill	SD945867	503 m (1650')	0750-0756

Structure: A vein of strike 000° - 040° and downthrow west of more than 30 m (100'). Perhaps also flats which are present at Lover Gill.

Mineralization: Calcite, fluorite, witherite, barite, sphalerite, galena, chalcopyrite, pyrite.

Wallrock Alteration: Not observed, except for a little early replacement fluorite.

Stratigraphic Horizon: Main Limestone, and the rocks thrown against it.

Workings: At Stags Fell Grove Mine there is a level which entered the hillside at a level just below the base of the Main Limestone and above the Undersett Limestone. It has a fairly large tip with it.

Hush Gill has a T-shaped hush system and a level which enters the first sandstone above the Main Limestone.

Date of Workings: Probably 18th century to the 19th century.

Production: No figures available.

Details of Mineralization: The tips of Stags Fell Grove Mine are mostly shale and sandstone which probably represents the barren ground through which the level had to be driven before the vein was reached. There is, however, a little crinoidal limestone and some vein stuff.

The dominant gangue is fluorite both massive and as crystals. There is also quite a lot of barite, with galena, sphalerite, pyrite and chalcopyrite also present, along with calcite and witherite.

Squat crystals of calcite would seem to be the earliest phase of mineralization other than a little replacement fluorite. The calcite is followed by fluorite, then late small plates of barite.

Chalcopyrite inclusions are found in some of the calcite and fluorite. Fluorite is often massive and sheared indicating post-mineralization movements on the vein.

Witherite with secondary tuby barite occurs with fluorite at times and often contains abundant sphalerite and a little pyrite.

Galena sometimes in quite large pieces was found and on one occasion with diagonal trains of inclusions of pyrite or chalcopyrite.

Specimens of cavernous fan aggregates of toothy barite are quite common, and may be derived from the witherite.

The workings at Hush Gill were examined and specimens were collected from the very small tips of vein stuff. The dumps contained mostly sandstone but small grains of amberish fluorite were common and on occasion they contain small inclusions of chalcopyrite.

One small specimen of galena was found at Hush Gill. It is anomolously rich in silver, but no silver mineral was found in polished sections.

F ZONE - SWALEDALE

ARN GILL VEIN, IVELET MOOR

Grid Ref: SD912992   Altitude: 305 m (1000')

Structure: Flats associated with the East Arngill Vein, which strikes 140° near the Adelaide Level, and 110° further south, and has a throw of 6 m (18'). The West Arngill Vein was also tried but found unproductive. It strikes at 130° and has a throw of 13 m (42'), and is thought to be reversed.

Mineralization: Adelaide Level - Fluorite, galena, pyrite.

Upper Level - Calcite, limonite, malachite.

Wallrock Alteration: Fluoritization, galenafication.

Stratigraphic Horizon: Adelaide Level Flats, Undersett Limestone and chert. Upper Level, Main Limestone.

Workings: There are three levels at the Undersett Limestone, the largest being the Adelaide Level, which has a largish tip.

Higher up there are workings whose exact form is not certain. There are smallish tips and a hush-like terrain, which may conceal a level. In West Arn Gill there is a level called the Eliza Level, but records show it to have been unproductive.

Date of Workings: The West Gill Level was started in 1811, and was in 1866 reopened by the A. D. Company and named the Eliza Level.

In the early eighteen hundreds a level was driven to drain higher shaft workings. In 1865 the A. D. Company drove the Adelaide Level at the lower horizon. The most recent workings were from 1918 - 1920.

Production: The West Gill Mines were unproductive, but the East Gill Mines worked rich flats giving ore worth £12,000 in one venture and no doubt more earlier. The 20th century venture got out thirty tons of ore before water problems became too severe.

Details of Mineralization: The tips of the Adelaide Level contain lime-stone bearing vugs and replacements of very pale amber to colourless fluorite mostly with sulphide inclusions. Galena is present at times with the fluorite and some specimens show replacement by both fluorite and galena.

One specimen was of Dibunophyllum, which was replaced by fluorite. First the coral was replaced then the cavity fill of calcite was dissolved away leaving a vug lined with fluorite and galena.

The higher level had little in the way of mineralization except for a little limestone breccia filled with calcite, limonite and malachite, indicating the likely presence of traces of chalcopyrite.

Specimens: Adelaide Level, 1652 - 1657

Upper Level, 1658.

Locality	Grid Ref.	Altitude	Horizon	Specimens
1. Lover Gill "Flat"	SD879962	457 m (1500')	Undersett Limestone	0777-781
2. Lover Gill Hush	SD879963	442 m (1450')	Undersett Limestone	0782-787
3. South Level	SD879964	404 m (1325')	Undersett Limestone	0788-789
4. Lover Gill Shafts	SD781964	450 m (1475')	Undersett Limestone	0790-796
5. North Hush & Adit	SD783967	411 m (1350')	Undersett Limestone	0805-806
6. Thwaite Beck	SD791982	290 m (950')	Hardraw Scar Limestone	TB1-5

Structure: A vein striking $040°$, of downthrow west around 30 m (100') and a flat.

Mineralization: Fluorite, witherite, barite, calcite, galena, chalcopyrite, sphalerite?

Wallrock Alteration: Not observed.

Workings: At Lover Gill Hush there are shafts and tips of fines etc. on the south side of the hush and suspected position of the vein. This could have been the flat recorded in Dunham (1952). In general the tips are not large, but the Lover Gill Hush is quite a large structure indicating that quite a lot of effort was expended.

Date of Workings: Probably 19th century but not marked on Bradley's Map (1860).

Production: The following figures from Hunt are either for Lover Gill Vein, Providence Mine, or The Satron Side Mine. The latter is not suggested by their location so much as by the absence of the figures for them if they were still working.

Date	Lead Ore	Lead
1867	228 tons 8 cwt.	170 tons 0 cwt.
1868	233 tons 19 cwt.	175 tons 0 cwt.
1871	50 tons 16 cwt.	38 tons 2 cwt.

Details of Mineralization:

1.   Lover Gill "Flat". The small tips here are rich in cavernous fan aggregates of toothy barite and also contain a modest amount of galena and rarer fluorite. The fluorite has inclusions of chalcopyrite and a specimen collected is sheared and filled with small fragments of fluorite and barite plates. Sheared fluorite argues against a flat.

2.   Lover Gill Hush. A small tip here is very rich in fan aggregates of barite and contains occasional pieces of massive fluorite often sheared and filled with fluorite or perhaps more abundantly barite.

3.   South Level. There is a moderate-sized tip here outside a level which enters the sandstone of the hillside to reach the vein around 50 m (160') below the hush workings. The tip is mostly of the sandstone and no limestone was seen. The veinstuff is composed of similar fluorite breccia with fine-grained barite fill and cavity lining. Cavernous fan aggregates of barite occur around cores of fluorite and also around empty 'domes' which occasionally show tube structures of witherite.

4.   Lover Gill Shafts. There are small tips here referred to in Dakyns et al (1891 p.170). They show the vein to be either in two parts, or to have a reversed throw because the break in the Lover Gill where the vein crosses it, is to the west of these shafts.

The tips are dominated by fan aggregates of barite. One specimen retrieved is composed of yellow and clear witherite altered in part to barite and with beautiful roseate clusters of clear colourless barite crystals of late, though not necessarily secondary, origin.

5.   North Hush and Adit. A small hush now grassed over is present here, and a small trial level nearby enters the hillside, and has a small tip

mostly of shale, but with some limestone and veinstuff.

Secondary or late fan aggregates and pillary aggregates with stellate cross sections, all of barite occur here and sometimes have limonite on them. One specimen of fluorite fragments held in a barite matrix was found here.

Limonite boxworks found indicate the original presence of sphalerite and possibly pyrite.

6.   Thwaite Beck. In the bed of the beck here are joints and fractures thought to connect with the Lover Gill Vein which contain calcite and in places fluorite in colourless cubes. Crystals of chalcopyrite occur with the fluorite though rather sparsely.

FRIARS INTAKE, LOW ROW PASTURE (SMARBER MINE)

Grid Ref: SD973976   Altitude: 244 m (800') - 335 m (1100')

Structure: A vein strike 020°, its throw is probably less than 8 m (26') down to the west.

Mineralization: Fluorite, calcite, witherite, barite, sphalerite, galena, chalcopyrite, smithsonite.

Wallrock Alteration: A little fluoritization.

Stratigraphic Horizon: Lower Level - Hardraw Scar Limestone, or perhaps Simonstone Limestone.

Upper Level - Simonstone Limestone, or perhaps Middle Limestone.

Shafts - Middle Limestone.

Workings: Just above the road from Low Row to Gunnerside there is a large tip and level in the Hardraw Scar Limestone. This level was drive in 1878, and apparently was driven nearly half a mile with only little success. The Upper Level was driven ih 1736 by Abram Fryer and Partners, and was apparently more successful even though it is in the Simonstone Limestone, which is only 8 m thick, whereas the Hardraw Scar Limestone is more than 15 m (50'). The Upper Shafts were probably the oldest workings if the normal succession was followed, but one has a proper winding house suggesting a later date. No record of the success of these workings could be found.

Details of Mineralization: The Lower Level tips are composed largely of limestone although a little sandstone is present and indeed in the scarp which the level enters the succession is shale followed by limestone followed by sandstone then more limestone. If the limestone here was the Hardraw Scar then one would expect the thick sandstone directly beneath it, and along with its lack of productivity one wonders if it really is the Hardraw Scar and not the Simonstone.

The tip contains fairly common veinstuff with common fluorite, barite, galena and some calcite and other minerals.

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The sequence of mineralization is not simple as is shown by a banded sample that shows mineralization of fine-grained white platy barite, with a few inclusions of sulphide, followed by greyish barite mixed with fluorite containing many inclusions, mostly of chalcopyrite. This is then followed by more barite with few inclusions, then rich in inclusions and with fluorite and sphalerite. Finally the remaining gaps are filled with massive grey to white calcite with inclusions of chalcopyrite on cleavage planes. There are large grains of chalcopyrite near the boundary of the barite and calcite.

Galena occurs in the massive barite sometimes as cubes or dominant crystals and sometimes filling the interstices. Bands of fluorite are common and though often pale can be blue-purple. The host rock from here is occasionally a little fluoritized.

The Upper Level reveals rather similar minerals but with the addition of witherite which could also have been present in the Lower Level since it is hard to spot. Also present here is a little botrioidal greenish smithsonite.

The Upper Shafts workings in the Middle Limestone were reported by Dunham (1952) not to contain fluorite, but the mineral was found here, along with barite, sphalerite, galena, and calcite.

The highest tips not far from Green Sike were grassed over, but material round about was largely sandstone. The highest bearing tips carried shale as well as limestone.

Specimens: Lower Level, 0723 - 0749   Altitude: 244 m (800')

Upper Level, 1648 - 1657   Altitude: 274 m (900')

Upper Shafts 1. 1640 - 1644   Altitude: 335 m (1100')

2. 1645 - 1647   Altitude: 305 m (1000')

GUNNERSIDE VEINS, GUNNERSIDE GILL

Locality	Grid Ref.	Altitude	Horizon
1. Sir Francis Level	NY940000	335 m (1100')	Bearing beds from Middle Limestone upwards
2. Bunton Hush	NY943013	503 m (1650')	Ten Fathom Grit and cherts
3. Old Rake Vein Tips	NY947015	564 m (1850')	Crow Limestone, Ten Fathom Grit, and Main Limestone
4. Old Rake Vein Tips	NY949014	564 m (1850')	Cherts and Main Limestone
5. Bunton Level	NY940012	412 m (1350')	Bearing beds from Undersett Limestone upwards
6. North Hush Lownathwaite	NY935013	488 m (1600')	Main Limestone and horizons across fault
7. High Scar Mine	SD956992	488 m (1600')	Main Limestone and cherts above

Mineralization	Specimens
1. Witherite, barite, fluorite, sphalerite, galena, pyrite	0476-0482
2. Barite, fluorite, pyrite, pyromorphite	0494-0498
3. Barite, fluorite, galena, chalcopyrite, limonite	0499-0506, 1622-1524
4. Barite, fluorite, galena, sphalerite, pyromorphite	0507-0529
5. Barite, fluorite, calcite, sphalerite, galena, chalcopyrite	0527-0529
6. Barite, fluorite, witherite, galena, sphalerite	1600-1603
7. Barite, fluorite, calcite, galena, sphalerite	1625-1629

Structure: These workings work the Old Rake Vein, the Friarfold Vein, the westward continuation of the Old Rake Vein System, and the Kinning Vein.

The Old Rake Vein strikes 090° ahd has a throw which varies from almost 0 m in its accompanying strings up to 9 m (30') in places. The Friarfold Vein has a strike of 070° and a variable throw, which is only a few metres at Gunnerside Gill but further east is as much as 51 m (168').

North Vein has a strike of 080° and has a variable throw varying from nothing up to 22 m (72'), although the low value of throw probably only refers to the attendant strings. This vein is the westward extension of the Old Rake Vein, and the Friarfold Vein.

The Kinning Vein has a strike of 140° and a throw of 6 m (18'). Wallrock Alterations: Dolomitization, and galenafication have been observed only at localities 4 and 7.

Workings: The Gunnerside Gill area is one of the most heavily mined parts of the orefield and there are many levels, shaft, and hush workings probably dating from earliest times.

The Sir Francis Level is the deepest level being driven in the Middle Limestone. It was driven in the mid 19th century to unwater many earlier workings and also provide access to the deeper ore bearing horizons. It was a fairly successful venture and in the workings were several hydraulic engines, which were partly used to pump out a shaft which was sunk in the Lownathwaite Workings to reach even deeper horizons than the level reached. The level was a joint venture of the A. D. Company and the Old Gang Company, its driving is described in Raistrick (1975).

The North Hush is probably an ancient working, as would be the Bunton and attendant hushes.

The various tips on the Old Rake Vein are from many shafts both deep and shallow, the deeper ones presumably being the youngest. The workings were probably started early on, but no doubt continued on into the 19th century.

The High Scar Mine is a level into the hillside not far south of Winterings Edge where old "bail hill smelters" have been found, however, the level is a much later construction, and is probably a relic of the 19th century.

Production: Figures for the area are available, but a break-down into the fluorite bearing veins and non fluorite bearing veins is not, indeed a break-down into veins is not available. Suffice it to say that this was one of the most important mining areas.

Details of Mineralization:

1.   Sir Francis Level. Specimens from here contained much witherite. The witherite occurs massive and as crystals in vugs. The crystals are of pseudohexagonal pyramids some forming short toothy crystals and others forming barrel-shaped or more squat crystals.

Sometimes the witherite has inclusions of pyrite and at times has zones of inclusions in "hexagonal" crystals.

Grains of galena and bands rich in sphalerite or at times pyrite also occur in the witherite.

There is a little barite occuring as thin and thick plates in vugs in the witherite.

Fluorite is present and is associated with sphalerite.

The Geological Survey Wartime Pamphlet on Barium Minerals (Dunham & Dines 1946) has details of a sampling survey in which it was found that the amount of fluorite in the dumps was at its highest in the dumps of the Sir Francis Level at 19% as opposed to the 2 - 8% value present in the Old Rake Vein and the Friarfold Vein.

The amount of witherite was also found to be large in these tips with 32% Barium Carbonate. 5% zinc was also recorded.

2.   Bunton Hush. Many pieces of massive white to pinkish barite in large thin plates are present here in the hush amongst a rubble largely of sandstone and chert.

Amber fluorite with low density of sulphide inclusions is also present largely as small pieces, and occasionally there is a little purple tinged fluorite.

Fan aggregates of toothy barite are also common.

Some good barrel-shaped crystals of pyromorphite were found here. The mineral was analysed on the Electron Microprobe, and found to be at the phosphorus end of the solid solution series between pyromorphite and mimetite.

3 & 4. Old Rake Vein Tips. Both sampling points on the vein show the same minerals etc.

Fluorite is common on the tips and is largely pale amber although pale purple is also present. It is often without sulphide inclusions, although some has chalcopyrite inclusions.

Pink and white massive thin platy barite is also common on the tips as is the cavernous fan aggregates of toothy barite.

One specimen of dolomitic limestone has a vein or joint edge of fluorite with galena crystals competing for growing space, followed by pinkish thin platy massive barite.

Small amounts of pyromorphite were also found here. A piece of very pure replacement chert containing a smallish vug lined with long prismoidal crystals of quartz was also found. This quartz appears to be earlier than the mineralization.

5. Bunton Level. The large tip at the entrance to Bunton Level was examined and specimens retrieved.

A specimen of a breccia of fragments of black siltstone, limestone and clay is filled with veinstuff. Firstly there is barite which is as white to pink thin platy massive bands followed by a layer of galena crystals then fluorite. There is some evidence of replacement in the form of disseminated barite and sphalerite.

Other specimens include pink banded massive barite with bands of galena and sphalerite, and white to grey massive calcite with white to pink platy massive barite bearing much chalcopyrite as inclusions.

6.　　North Hush Lownathwaite. In tips and amongst the rubble of the hush there are specimens of massive pink to white platy barite sometimes with brown sphalerite. A specimen of radiating tuby barite after witherite was found along with a porous fine-grained aggregate of barite probably of secondary origin.

One specimen of barite rich in galena and sphalerite was found to have patches of interstitial fluorite and this may well have been present in other specimens, since this is not an obvious occurrence and is easily missed. However this is probably important in showing that even at this stratigraphic horizon there is still fluorite in the westward extension of the Old Rake Vein System.

7.　　High Scar Mine. Just south of High Scar is an old level with large tips. The tips contain dolomitized limestone, and one specimen of a breccia was collected. The breccia contains fragments of chert, limestone, and galena etc. in a matrix of calcite.

White massive barite is present as is white massive calcite. Mamilar coating calcite is also present and is probably of modern origin.

Galena occurs as bands in the barite and limonite boxworks probably after sphalerite are occasionally present.

Bands of interstitial fluorite also occur in the barite and yet again are probably quite significant.

HARD LEVEL GILL VEINS, HARD LEVEL GILL

Locality	Grid Ref.	Altitude	Horizons at "shaft tops"
a. Forefield Rake	NY971025	527 m (1875')	Upper Howgate Edge Grit against Crow Chert
b. Forefield Rake	NY966024	564 m (1850')	Lower Howgate Edge Grit against Crow Limestone and Chert
c. Forefield Rake	NY963023	533 m (1750')	Lower Howgate Edge Grit against Crow Limestone and Chert
d. Friarfold Rake	NY959022	509 m (1650')	Richmond Cherts against Ten Fathom Grit
e. Friarfold Rake	NY957021	525 m (1725')	Richmond Cherts against Ten Fathom Grit
f. Friarfold Rake	NY950018	556 m (1825')	Ten Fathom Grit against Ten Fathom Grit
g. Friarfold Rake	NY948017	564 m (1850')	Ten Fathom Grit against Ten Fathom Grit
h. Friarfold Rake	NY944017	564 m (1850')	Ten Fathom Grit against Ten Fathom Grit
i. Old Rake	NY955014	541 m (1775')	Crow Limestone and Chert and Ten Fathom Grit against Richmond Cherts
j. North Rake	NY962015	533 m (1750')	Crow Limestone and Chert and Ten Fathom Grit against Richmond Cherts
k. North Rake	NY962017	472 m (1550')	Main Limestone
l. Dane Vein	NY960018	487 m (1600')	Richmond Cherts

Locality	Workings	Specimens
a.	"Deep" shafts with large tips	0560-0563
b.	"Deep" shafts with large tips	1564-1568
c.	"Deep" shafts with large tips	1569-1572
d.	"Deep" shafts with large tips	1577-1580
e.	"Deep" shafts with large tips	1573-1576
f.	"Deep" shafts with large tips	0518-0523
g.	"Deep" shafts with large tips	0524-0526
h.	"Deep" shafts with large tips	1619-1621
i.	Shafts and Hushes with large tips	0512-0516
j.	Shafts and Hushes with large tips	0517
k.	Shafts and Hushes with large tips	1585-1588
l.	Level	1581-1584

Structures: Friarfold Vein - Strike 070°, throw up to 51 m (168') down south.

Old Rake Vein - Strike 090°, throw up to 9 m (30') down south.

North Rake Vein - Strike 070°, throw less than 2 m (6') (Bradley (1862))

down north

Dane Vein - Strike 120°, throw little or nothing.

There are many others in the area but they have not been sampled.

Mineralization: Fluorite, barite, witherite, calcite, galena, sphalerite,

chalcopyrite.

Wallrock Alteration: Not observed.

Workings: The workings sampled are indicated in the table. There are also

large tips all around Hard Level Gill from small and large shafts that worked

the numerous other veins such as the Healaugh Side Vein, and from Levels that

worked the Old Rake Vein, the North Rake Vein, the Friarfold Vein, the

Healaugh Side Vein and connected with all the surrounding veins in

Arkengarthdale etc. There are many miles of level and working from

Gunnerside Gill to Arkengarthdale.

Date of Workings: These workings, like the Gunnerside Gill and
Arkengarthdale workings are probably very ancient in origin going back at
least as far as the Romans and continuing on a small scale from those
times probably until the 18th century when the activity became more intense.
The 18th and 19th centuries were the times of rapid exploitation of the
veins and all the important levels were probably driven during this period.
After about 1890 there was only little work and this century the work has
been sporadic and on the smallest of scales.

At the present time there are small tip processing operations for
barite, which is apparently used for the paper making industry.
Production: There are no separate figures for the veins in this area, but
the figures for Old Gang which are reported in Hunt (1869) and include
workings in Gunnerside Gill and also workings from a different Zone are
presented below to give some idea of the size of the workings.

Year	Lead Ore	Lead	Silver
1868	2,172 tons 0 cwt.	1,596 tons 0 cwt.	-
1869	3,328 tons 0 cwt.	2,300 tons 0 cwt.	-
1870	2,532 tons 13 cwt.	1,772 tons 8 cwt.	-
1871	2,321 tons 13 cwt.	1,740 tons 0 cwt.	-
1872	2,759 tons 16 cwt.	2,069 tons 17 cwt.	-
1873	2,635 tons 16 cwt.	1,969 tons 0 cwt.	-
1874	2,250 tons 7 cwt.	1,687 tons 5 cwt.	-
1875	1,378 tons 9 cwt.	1,033 tons 10 cwt.	-
1876	1,046 tons 3 cwt.	690 tons 12 cwt.	1,380 oz.
1877	1,075 tons 9 cwt.	753 tons 0 cwt.	-
1878	910 tons 14 cwt.	628 tons 14 cwt.	1,258 oz.
1880	650 tons 12 cwt.	488 tons 0 cwt.	1,200 oz.
1881	294 tons 3 cwt.	210 tons 0 cwt.	500 oz.

In 1892 twelve tons of witherite was mined from Lucky String of the Old Rake Vein System.

The figures for other years are probably included in the figures for Swaledale and Arkengarthdale from 1853 – 1866 which reach as much as 4,000 tons of Lead in one year.

Details of Mineralization:

The mineralization at the various collecting sites was very similar although there were slight differences such as the presence of witherite, which was found in the Friarfold Vein at collecting point h. (see note), at d. (a little in 'barite boxworks'), and in the North Rake Vein at k.

1. The Friarfold Vein: The tips along this vein contain much veinstuff which has much barites in two main forms - 1, the massive platy white-pink variety occasionally coarse and platy; 2, the cavernous fan aggregates of toothy crystals. The other forms are rather less common, one of them being a fine-grained porous aggregate, the other being a sort of rare boxwork structure of barite surrounding holes, where witherite was once present and is occasionally found at d. (a low altitude point).

With the barites there is common fluorite although Dunham and Dines (1945) sampling shows it to contain generally less than 8% of this mineral. The mineral is found massive or in clear crystals of colourless to amber appearance. Sometimes the fluorite contains chalcopyrite inclusions.

Calcite is also found and according to the figures of Dunham and Dines amounts up to 29%. It was found in large prismoidal crystals at b.

Galena is found with all the three gangue minerals above mentioned, and sphalerite is found with the barite occasionally.

The relationships of the minerals is not always clear, but banded specimens showing repeated barite-fluorite banding are common enough showing rather unstable conditions.

Witherite was found in one specimen to have been intergrown with massive fluorite although its place has now largely been taken by feathery barite of the 'barite boxworks' described above.

Sometimes fluorite and primary barite are found intergrown, and the relationship of fluorite being later than the barite is common.

One sample of calcite crystals with a thin coating of fine-grained platy barite was found but generally its relationship to the other minerals is obscure.

Breccias and "cockade" style veinstuff have both been found.

2.   The Old Rake and North Rake Veins: Here we find the same minerals as in the Friarfold Vein, and again the veinstuff is commonlybanded.

There is common white to pink massive platy barite banded with fluorite. The fluorite is occasionally pale lilac, but more commonly yellowish or colourless. It sometimes contains sulphide inclusions.

A dolomitized vein edge followed by fine-grained white platy massive barite, and then pale purplish fluorite was found at k. At the same locality some massive witherite was found and also in the form of little pyramids and barrels in vugs. The witherite is sometimes speckled with chalcopyrite inclusions and blob aggregates of malachite occur in vugs on witherite.

There is also galena in with the massive witherite, and one specimen of large pseudohexagonal pyramids of witherite contains abundant sphalerite.

Secondary or late porous aggregates of barite are also found along Old Rake and North Rake Veins. Some aragonite was seen on both the Old Rake - North Rake Veins and the Friarfold Vein. These veins are important localities for baryto-calcite first reported by Bradley. Also reported here is strontianite with witherite which was probably extracted from the Watersykes Sun Vein (Caruthers etc. (1923), which however is probably, like its associate the Watersykes Vein, in a different zone.

According to Caruthers et al (1923) 4 feet wide irregular bodies of witherite containing a little galena and sphalerite in their centres were worked in 1892.

3.   The Dane Vein: Here again are the same minerals except that no witherite was found. There is both primary massive barite and porous secondary or late barite.

ARKENGARTHDALE VEINS, ARKENGARTHDALE

Locality	Grid Ref.	Altitude	Horizon of Entrance	Vein	Workings
a.) Sun Shaft b.) Sun Shaft	NY983027	526 m (1725')	Upper Howgate Edge Grit, against Crow Limestone and Chert	Gt. Blackside Vein	Shafts
c. Dam Rigg Mines	NY982027	533 m (1750')	Crow Limestone etc. against Ten Fathom Grit	Dam Rigg Vein	Deep shafts
d. Dam Rigg Mines	NY979028	541 m (1775')	Crow Limestone etc. against Ten Fathom Grit	Dam Rigg Vein	Deep shafts
e. Stodart & Hungrey Hushes	NY985029	488 m (1600')	Crow Limestone etc. against Ten Fathom Grit	Dam Rigg Vein	Hushes
f. Black Whim	NY979025	518 m (1700')	Upper Howgate Edge Grit, against Crow Limestone and Chert	Gt. Blackside Vein	Shaft, Hushes and Levels
g. Wetshaw Shafts	NY981023	503 m (1650')	Howgate Edge Grit against higher beds	Turf Moor Vein	Deep shafts
h. Wetshaw Shafts	NY983023	503 m (1650')	Howgate Edge Grit against higher beds	Turf Moor Vein	Deep shafts
i. Moulds Top Mine	NY985022	511 m (1675')	Howgate Edge Grit against higher beds	Turf Moor Vein	Deep shafts

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	Grid ref.	Depth	Horizon	Vein	Deep shafts
j. Moulds Top Mine	NY988021	503 m (1650')	Howgate Edge Grit against higher beds	Turf Moor Vein	
k. Stemple Whim	NY989024	488 m (1600')	Howgate Edge Grit	Stemple Vein	Shaft
l.) Hungrey Hushes	NY988028	480 m (1575')	Ten Fathom Grit - Howgate Edge Grit against lower beds, e.g. Main Limestone, Richmond Chert etc.	Gt. Blackside Vein	Hushes
m.) Hungrey Hushes	NY989029	457 m (1500')		Gt. Blackside Vein	Hushes
n. Justice Level	NY992027	427 m (1400')	Ten Fathom Grit	Gt. Blackside Vein	Level
o. Underedge Level	NY991029	411 m (1350')	Three Yard Limestone	Gt. Blackside Vein	Level
p. Band Level	NY996029	358 m (1175')	Main Limestone	Gt. Blackside Vein	Level
q. Moulds Old Level	NY997025	543 m (1125')	Main Limestone	Many veins	Level
r. Turf Moor Hush	NY997021	581 m (1250')	Main Limestone - Ten Fathom Grit	Turf Moor Vein	Level

Locality	Mineralization	Specimens
a, b.	Fluorite, barite, galena, chalcopyrite	1700-1705 1706-1709
c.	Fluorite, barite, calcite, galena, chalcopyrite	1710-1714
d.	Fluorite, barite, calcite, galena,	1715-1718
e.	Fluorite, barite, calcite, galena, chalcopyrite	0452-0468
f.	Fluorite, barite, calcite, galena	1724-1727
g.	Fluorite, barite, calcite, galena	1728-1732
h.	Fluorite, barite, calcite, galena	1733-1736
i.	Fluorite, barite, galena, chalcopyrite	1737-1740
j.	Fluorite, barite, calcite, galena, chalcopyrite	1741-1745
k.	Fluorite, barite, calcite, galena	1746-1750
l.	Fluorite, barite, calcite, galena, chalcopyrite	1751-1755
m.	Fluorite, barite, calcite, galena	1756-1760
n.	Fluorite, barite, galena, chalcopyrite	1761-1765
o.	Fluorite, barite, galena	1766-1770
p.	Fluorite, barite, galena	1771-1773
q.	Fluorite, barite, calcite, galena chalcopyrite, pyrite, marcasite	1774-1785
r.	Fluorite, barite, galena, chalcopyrite,	1786-1792

Structure: The bodies worked were all veins. The most important being the Great Blackside Vein which strikes at 080° and has a throw of 73 m (240'), the Dam Rigg Vein strike 110° and throw 22m (72'), the Turf Moor Vein or Moulds Vein with strike 100° and throw of 48 m (156'), and the Stemple Vein of strike 100° and little or no throw. These veins and the other important veins nearby probably had small strings associated with them.

Wallrock Alteration: Only dolomitization observed, and possibly a little replacement fluorite from Underedge Level (o).

Workings: The workings in this area are amongst the most extensive in the orefield. The sampling points are spread fairly well over the area, but there are still quite a number of levels and shafts that might be usefully sampled in the future.

Date of Workings: These mines are of ancient origin but reached their heyday in the late 18th and early 19th centuries. Work continued through most of the 19th century but today there are only tip working operations for fluorite, barite, and roadstone.

Production: The figures from Hunt(op cit) are detailed below to give some idea of the size of operations.

Year	Lead Ore	Lead	Silver
1868	1,596 tons 4 cwt.	1,257 tons 0 cwt.	-
1869	1,617 tons 0 cwt.	1,230 tons 0 cwt.	-
1870	935 tons 0 cwt.	700 tons 0 cwt.	-
1871	800 tons 0 cwt.	629 tons 10 cwt.	-
1872	601 tons 0 cwt.	450 tons 15 cwt.	-
1873	601 tons 12 cwt.	451 tons 4 cwt.	-
1874	1,265 tons 8 cwt.	790 tons 17 cwt.	-
1875	1,479 tons 1 cwt.	1,027 tons 0 cwt.	4,148 oz.
1876	1,259 tons 18 cwt.	882 tons 0 cwt.	3,528 oz.
1877	1,974 tons 13 cwt.	1,482 tons 0 cwt.	2,223 oz.
1878	2,459 tons 0 cwt.	1,967 tons 5 cwt.	2,950 oz.
1880	1,657 tons 5 cwt.	1,244 tons 15 cwt.	1,830 oz.
1881	1,959 tons 12 cwt.	1,469 tons 1 cwt.	2,938 oz.

Details of Mineralization: The Sun Shaft (a, b.) – Not far from the flue chimney of the Arkengarthdale smelters are some large shaft tips which sometimes contain much fluorite, along with barite often of toothy type, but with a reasonable proportion of the massive pink to white variety.

There is also a lot of limestone on the tips, some of it dolomitized.

The fluorite is pale ambery to colourless on the whole, and can be clear or carry many inclusions of chalcopyrite.

Specimens of banded barite and fluorite occur and galena accompanies both barite and fluorite.

The Dam Rigg Lead Mines (c, d) - A broad line of shafts, mostly deep, follows the Dam Rigg Vein and the tips from these show fluorite near the confluence with the Great Blackside Vein, although it is absent away from this point. There is also much barite on these tips.

The fluorite is pale ambery to colourless and occurs as cubes and massive. A little purplish fluorite is occasionally seen and the colour may be due to surface radiation. Sometimes the fluorite carries chalcopyrite inclusions.

The barite is often massive and pink to white. One interesting specimen shows large white blades of barite broken into a breccia and filled with pink massive barite. Some vugs in this specimen are lined with mamilar calcite.

Galena is present and associated with fluorite, barite and calcite. Calcite is found massive and white, as aggregates of small yellow grains and also as prismoidal crystals which line some vugs.

Stodart and Hungrey Hushes (e) - Here there are various small tips and pieces of veinstuff which occur in the Hushes. They often contain fluorite and barite, and more occasionally calcite and/or galena.

Banded specimens are common and show as many as four bands of fluorite and five bands of barite in one small specimen demonstrating the unstable conditions of deposition.

The fluorite is normal in being pale yellow to colourless and is clear or with chalcopyrite inclusions.

The barite is of the massive variety when banded and with fluorite, but there is also toothy barite.

Calcite occurs as crystals both prismoidal and squat varieties, and also massive. Its colour is white to yellowy to transparent.

The instability is shown by the following orders of crystalization which were observed in specimens from this group of collecting points:-

1. Fluorite followed by platy barite.

2. Yellowy white calcite followed by pale fluorite with some chalcopyrite inclusions.

3. Pale fluorite with inclusions of chalcopyrite followed by barite, some of which is toothy followed by prismoidal calcite crystals which line many remaining vugs.

4. Barite -fluorite -barite -fluorite -barite -fluorite -barite.

5. Clear large calcite crystals, followed by pinkish calcite with goethite and malachite (presumably once chalcopyrite), with a later filling of toothy barite.

6. Calcite crystals followed by barite, followed by pale amber cubes of fluorite.

7. Massive calcite followed by pink barite with galena.

Black Whim (f) - In the vicinity of Black Whim there are several levels, a hush, and a row of shafts as well as the whim shaft itself.

The tips as a whole show relatively little veinstuff except near the bottom of the Hush were an area of fine tailings carry good fluorite and a lot of barite. Galena is present, and also calcite but neither is very abundant. Pink to white massive barite occurs sometimes with bands of galena and sometimes with bands of fluorite.

Fluorite commonly occurs massive and one specimen shows a slightly sheared piece of fluorite followed by cavernous toothy white barite.

White calcite occurs as crystals and in one case as a fibrous mamilar aggregate on one edge of a specimen of apparently brecciated fluorite, galena, and a little pink barite.

Wetshaw Shafts (g, h) and Moulds Top Mine (i, j) - The large tips associated with deep shafts entering the Turf Moor Vein were examined and sampled. They show much fluorite, common barite, a little calcite and galena.

The fluorite is yellowish, purplish, white or colourless. It varies from clear to rich in inclusions of chalcopyrite.

Barite is found massive, coloured white to pink, and often in banded pieces.

Massive white calcite is found and is generally a late mineral.

Galena is present in association with barite, and fluorite.

The following orders of deposition show the sort of variation in crystalizing phase that took place:-

1. Massive barite-sparse galena-massive fluorite-sparse galena-massive fluorite-massive galena-massive barite.

2. White fluorite and barite intergrown in irregular areas and containing occasional small sulphide inclusions.

3. Fluorite-barite-fluorite-barite-fluorite-barite, both the fluorite and the barite contain sulphide inclusions although they occur more dominantly in the fluorite. A little galena is present in one of the barite bands.

4. Fluorite with inclusions-galena-barite with occasional limonite boxworks.

5. Fluorite-galena-fibrous white calcite.

Stemple Whim workings carry ambery coloured calcite, and fluorite, massive white to pink barite, and galena. The fluorite is generally very pale.

Only one mineral succession was observed in the specimens viewed. This was barite followed by galena followed by fluorite, but this probably represents only one of the many sequences that one could expect.

The workings on the Great Blackside Vein from Hungrey Hushes down to the Band Level all carry similar minerals and the results of examining these tips follows:-

Fluorite is common in these tips and in some, especially in the fines, there is dominant fluorite. It is generally of the pale amber to colourless variety, and occurs as crystals, and also massive often showing many fractures and indications of post mineralization movements. The fluorite often contains abundant chalcopyrite inclusions.

There is some very fine-grained fluorite which is a little purplish in colour and potentially of replacement origin. It occurs with vug filling fluorite and a little "replacement" galena, now largely replaced by cerrusite.

Barite is also common and occurs both massive and as porous to cavernous aggregates of toothy crystals. When massive it is of pink to white colour.

Massive calcite occurs and is colourless to white.

Banded specimens are again common, the bands being composed of different coloured barite, with or without fluorite bands, galena bands, or even calcite bands. A specimen of intergrown platy barite and interstitial, and cube varieties of fluorite was collected. This specimen also has a lot of galena.

Moulds Old Level tips are probably from many veins and their contents show similar minerals to the other localities. As well as the usual massive and toothy barite, pale fluorite, and galena, other minerals were found which include goethite pseudomorphs after marcasite and possibly pyrite, marcasite, ambery and white calcite and a trace of sphalerite.

One banded specimen of barite intergrown with interstitial fluorite, has grains of galena, sphalerite, and some good crystals of marcasite.

Another banded specimen of barite has much galena and small pyrite grains.

There are also inclusions of chalcopyrite in some fluorite.

At Turf Moor Hush the tips contain mostly barite both massive and toothy but fluorite and galena are also present.

The fluorite is pale and clear or with occasional inclusions of chalcopyrite.

There is some unusual barite in the form of large tubes of toothy crystals looking rather like colonies of syringopora. Some of the porous barite aggregates contain galena with thick oxidized skins of cerrusite.

Some well-formed goethite pseudomorphs of platy character are after marcasite.

COPPERTHWAITE VEIN, FREMINGTON EDGE

Grid Ref: (a) NZ052001, (b) NZ050000, (c) NZ050001, (d) NZ052003,
(e) NZ049006

Altitude: All are at 427 m (1400') except for (e) which is not a primary working.

Structure: The Copperthwaite Vein is a vein of strike 070° and throw of 7 m (24'). The vein is accompanied by other small veins and indeed the line of the vein may be the result of several on echelon veins.

Mineralization: Fluorite, barite, calcite, galena.

Wallrock Alteration: Dolomitization.

Stratigraphic Horizon: The Copperthwaite Vein was worked in the bearing horizons from the Undersett Limestone up into the Richmond Cherts. The horizons worked at the fluorite bearing end of the vein cover this range although only the horizons above the Main Limestone were probably worked for the sampled tips.

Workings: The workings are largely small shafts down into the Richmond Cherts, but there are small levels on the side of the Fremington Edge which worked the vein at lower horizons, successful only as far down as the Undersett Limestone.

Date of Workings: These mines were being worked at least as far back as 1504, but how long the work continued is not known.

Production: Not known.

Details of Mineralization: In the tips of the four sampling sites along with limestone and chert, there is veinstuff of fluorite and barite, with some calcite, galena.

The fluorite occurs in contact with both the limestone and the cherts.

Fluorite here is pale amber in colour and both massive and as cubes, it is generally clear of inclusions of sulphide.

Galena is found with all the gangue minerals.

Barite is commonly of the cavernous fine-grained mamilar variety which is abundant in the gossans of veins.

Specimen Numbers: (a) 1225-1228, (b) 1229-1230, (c) 1231-1234, (d) 1236-1238, (e) 1256-1262.

OTHER PLACES WITH FLUORITE

Fluorite has been found as trace amounts at the Great Blackside
Vein near Langthwaite Scar, in workings at Hurst, and at Cobscar. In the
bed of the Swale at Marble Scar fluorite, calcite, and galena have been
reported to occur (Dakyns et al (1891)), in several strings in the lime-
stone below the Hardraw Scar Limestone.

The first three localities are dealt with in the Barite Zone, the
fourth is not dealt with further, and a fifth locality at Mallerstang is
dealt with below.

ANGERHOLME VEINS, WILD BOAR FELL

Grid Ref: NY772995   Altitude: 457 m (1500')

Structure: Small veins striking 065° of small throw.

Mineralization: Barite, chalcopyrite, fluorite.

Stratigraphic Horizon: Main Limestone and the sandstone underneath it.

Date of Workings: Not known, but probably 18th - 19th centuries.

Workings: A trial shaft vein working and a small exploration hush. A
vein is revealed here by a marked vegetation change. The shaft explored
the vein in the limestone and the hush explored it in the sandstone.

Wallrock Alteration: Not observed.

Details of Mineralization: The veinstuff collected at the shaft by
Dr. G. A. L. Johnson was examined and found to be composed of massive
white barite rich in chalcopyrite inclusions. The chalcopyrite was largely
oxidized to malachite and goethite.

The veinstuff found in joints in the sandstone again collected by
Dr. Johnson was found to contain fluorite as well as the minerals found in
the limestone. The fluorite was found to be present as an interstitial
mineral in the centre of some joints showing it to be a later mineral than
most of the barite.

Specimens: 0819-0825 Trial hush, AN 1-10 from the trial shaft.

NOTE: At this locality the Main Limestone is tilted up towards the High

Dolphinsty Fault, the inverse of the tilt expected from drag on

the fault.

P ZONE - SOUTH OF RIVER URE

DODD FELL VEINS, DODD FELL

Grid Refs: Bardale Head Veins SD863845   Altitude: 579 m (1900')

          Dodd Fell Vein   SD843836   579 m (1900')

          Cam Houses Vein   SD815827   654 m (1850')

Structure: The bodies are veins all of small throw with the following

strikes -   Bardale Head Veins $030°$, $010°$

            Dodd Fell Vein $030°$

            Cam Houses Vein $050°$

all could be master joints.

Stratigraphic Horizon: All at the Main Limestone, although the one at Dodd

Fell is marked on the 1 inch Geological Survey Map (50) as continuing up

into the overlying shale and sandstone the Lower Howgate Edge Grit.

Mineralization: Calcite, barite, galena, cerrusite.

Wallrock Alteration: Dolomitization, galenafication, recrystalization of

calcite.

Workings: At Bardale Head near the road are pits forming a line following

the veins and a small probably just trial level in the slope to the north

of the bend in the road.

      At Dodd Fell there are a short line of pits which worked a small vein

but none is of any size.

      At Cam Houses a long search failed to locate any workings or trace of

the vein.

Date of Workings: Very small and so could be of any age as far back as the

Roman period since a Roman road passes close by.

Details of Mineralization: No veinstuff could be found at Bardale Head, and

the vein at Cam Houses could not be found so the scant veinstuff found at

Dodd Fell Vein is the only indication of what is present.

The tips at Dodd Fell Vein reveal much dolomitized limestone, some of which contains a little disseminated galena and some patches of recrystallized calcite. The Main Limestone is a massive crinoidal limestone here and in most places.

A small amount of vein material showed a little galena and very fine grained white massive barite. The galena is often altered to cerrusite. Specimens: 1630-1636

WASSET FELL VEIN, WASSET FELL

Grid Ref: SD992832   Altitude: 472 m (1550')

Structure: Small veins of little or no throw trending 150° - 170°, could be just master joints.

Stratigraphic Horizon: Main Limestone, and the underlying sandstone.

Mineralization: Barite, calcite, aragonite, galena, sphalerite, cerrusite, siderite.

Wallrock Alteration: Dolomitization, galenafication.

Workings: There are many shafts and a small hush at the grid reference points and shafts at a point some half kilometre to the south west.

Date of Workings: Not known, but could be of 15th - 19th century.

Details of Mineralization: The tips show much dolomitized limestone and some veinstuff. Dolomitized limestone is sometimes found to contain disseminated galena and bear anastomosing cavities now filled with aragonite.

The galena in this locality is often heavily altered to cerrusite.

One piece of sandstone was found which carried galena, sphalerite, and calcite (in clear squat crystals) upon one side.

Limonite is quite common and in some specimens shows boxworks of triangular to rounded boxes probably after a sulphide (chalcopyrite?), and a little siderite is also present in the dolomitized limestone.

Specimens: 1842-1856.

OTHER VEINS ON THE SOUTH SIDE OF THE URE

Working from west to east there are the following localities recorded as bearing minerals other than calcite and quartz.

Great Combe on Crag Fell

In the 'Marble' Quarry near Great Combe there is a joint filled with calcite ('calcspar') bearing traces of chalcopyrite. (Dakyns et al (1890). Grid Ref: SD703837   Altitude: 533 m (1750')   Horizon: Main Limestone.

Wether Fell

On the hilltop of Wether Fell the Geological Survey 1 inch map shows two veins presumably containing galena. They are near the Roman Road which goes down to Bainbridge and could have been mined then.

No details are available for these veins other than that they are in the Main Limestone and are of small throw and strike 080°, 000°. They could well be like the vein at Dodd Fell.

Thoralby Common

On the hilltop of Thoralby Common two veins are marked on the Geological Survey Map ranging from the Main Limestone into the Richmond Chert Series. The veins have little or no throw and strike 090°, and 160°. No details of the mineralization is known but the Ordnance Survey Map marks on the presence of a mine (presumably lead).

Walden Head

A small vein of little or no throw in the Main Limestone is marked as lead bearing on the Geological Survey Map 51. Little is known other than that a shaft is marked on the Ordnance Survey Map. Workings in this dale (Waldendale) were known to have sent their lead ore to West Burton Smelt Mill in the early 17th century.

The following data is taken largely from Dr. A. A. Wilson's thesis.

Petticoat Rake

Grid Ref: SE016818   Strike: 065-072, in the Richmond Chert Series. There are three lines of shallow shafts and bell pits. The tips being

practically barren of ores. The veins have little or no throw and they are roughly parallel to the direction of the joints in the area.

Central Coverdale

". . . occasional scattered lead workings occur, but . . . rarely if ever profitable."

Their locations are as follows:-

Gammersgill Moor Mines:	SE032833	411 m (1350')	Main Limestone
Swineside Mine:	SE064827	305 m (1000')	Main Limestone
Turn Beck Mine:	SE055834	259 m (850')	Middle Limestone

Flamstone Pin

Grid Ref: SE102852   Strike 080°. Richmond Chert Series and shales of the Grassington Grit Group

Some shallow shafts mark the direction of a vein here.

Dovescar Plain, Penhill

Grid Ref: SE035869.

Here there are scattered trial shafts and one row of shallow shafts sunk in the Richmond Chert Series. One small shaft at the Grid Reference point shows traces of galena.

Chance Hill – Lead Mine

Grid Ref: SE023847

"Shafts and diggings occur in a poor vein."

Middleham Low Moor Vein

A vein of moderate throw is shown on the Geological Survey 1 inch Sheet 51 to carry galena, a short search failed to find the vein.

Caldbergh Vein

A vein is marked here on the Geological Survey Sheet 51. It is of small throw and strikes 080°. Grid Ref: SE098852.

P ZONE - SWALE-URE WATERSHED

PROVIDENCE VEIN, MUKER COMMON

Grid Ref: SD887966   Altitude: 472 m (1550')

Structure: A vein of moderate throw perhaps 15 m (50') and strike 170°
with a flat named the "Modesty Flat".

Stratigraphic Horizon: The Main Limestone.

Mineralization: Dolomite, calcite, aragonite, galena.

Wallrock Alteration: Much dolomitization.

Workings: A level with tip.

Date of Workings: Around 1880.

Production: Not known.

Details of Mineralization: The tip at the level mouth was examined and
found to be composed of dolomitized limestone with joint planes lined with
calcite and galena. There was probably much good clean galena as several
pure flat pieces were found. Some of the limestone has vugs, which are
lined with dolomite crystals and followed by calcite and galena.

Some of the galena was found to be fine grained and tough.

A little aragonite was found and probably was a late lining of the
cavities. The aragonite occurred as radiating fibrous aggregates.

Specimens: 0796-0802

SARGILL VEIN, ABBOTSIDE COMMON

Grid Ref: SD896928   Altitude: 472 m (1550')

Structure: A vein of throw 22m (72') striking 170°, probably a continuation of the Providence Vein, and a small cross vein, the Weir Vein, followed underground.

Stratigraphic Horizon: Main Limestone.

Mineralization: Dolomite, calcite, aragonite, barite, goethite, galena.

Wallrock Alteration: Dolomitization, galenafication.

Workings: Some large tips are associated with a level entering the hillside just below the level of the Main Limestone (on the downthrow side). The plans of the workings are in the Mines Record Office. There was sufficient output to require the building of a small smelt mill.

Date of Workings: The workings were opened close to 1850 and "paid well" for about ten years, but by 1870 the smelt mill had to be closed owing to lack of ore.

Production: The mine is reported as working from 1864 - 1872, but figures are only given for 1864 when 11 tons 18 cwt. of ore was raised and smelted to give 8 tons and 6 cwt. of lead.

Details of Mineralization: Tips of the mine are largely composed of limestone although there is some gritstone, which overlies the Main Limestone here.

The limestone is often dolomitized, showing well formed crystals at the edges of joints and fractures. There is some disseminated galena in porous dolomitized limestone, and flat pieces of pure galena are common. Calcite, limonite and perhaps hematite are also on the tips.

Clear calcite filling limestone breccia occasionally carries a little galena, and at times late aragonite.

Barite is present as thick (1.5 cm) sheets of mamilar platy aggregate, and its appearance indicates a late or secondary origin.

Specimens: 0954-0968

SATRON AND SUMMERLODGE VEINS, SUMMERLODGE MOOR

Locality	Grid Refs.	Altitude	Specimens
a. Simon Grooves	SD942952	518 m (1700')	1280-1284
b. Summerlodge Moor	SD950952	518 m (1700')	1285-1291
c. Summerlodge Moor	SD950952	518 m (1700')	1292-1304
d. Satron Moor	SD943956	518 m (1700')	1305-1308
e. Satron Moor	SD943956	518 m (1700')	1309
f. Satron Moor	SD943956	518 m (1700')	1310-1320
g. Hill Top Mines	SD942963	488 m (1600')	1321-1326

Structure: Veins and flats associated with them. The flats reported to have been very rich for the Orefield.

There are four veins striking 160° mined mostly at the Beezy Hill Mines which were not visited. They mostly have small throw except for the western most one.

There are five veins striking approximately 120°. These sometimes have moderate throws say less than 15 m (50') but often have very little throw.

Another vein strikes 050°, and two veins more running over Satron High Wall strike with a direction that changes from 040° to 160°. There is scant evidence for mineralization in the lowest part of the latter veins (striking 160°). These veins yet again have only smallish throws.

Stratigraphic Horizon: The workings are largely in the Main Limestone and Richmond Chert Series but the veins are marked as extending into the Crow Beds above and down as far as the Hardraw Scar Limestone; no evidence of the latter extension could be found.

Mineralization: Barite, calcite, aragonite, galena, goethite, marcasite, cerrusite.

Wallrock Alteration: Dolomitization, galenafication.

Workings: There are many small workings in this area. The largest of them are probably around the Spout Gill Level (SE937966), the Beezy Hill Mines (SE946943) which perhaps are also called Askrigg Moor Mines, and the Summerlodge Moor Mines. There are hushes in the Satron Low Walls and near Oxnop Level, but for most part the workings are small shallow shaft workings.

The workings were fairly successful and required the building of the Spout Gill Smelt Mill in 1735. The mines were rich enough for one shaft to produce £40,000 worth of ore in a year. Ore was brought from all of the veins above mentioned and also from Beldi Hill Mines, near Keld.

Date of Workings: 17th, 18th and 19th centuries.

Production: The figures for Askrigg Moor Mines from Hunt (1860-1881) are given below.

Date	Ore	Lead
1864	11 tons 10 cwt.	8 tons 6 cwt.
1865	4 tons 8 cwt.	3 tons 2 cwt.
1866	2 tons 15 cwt.	1 ton 18 cwt.
1867	37 tons 0 cwt.	25 tons 18 cwt.
1868	12 tons 3 cwt.	8 tons 0 cwt.

Details of Mineralization: The tips are composed largely of dolomitized limestone, with some chert and shale. The "veinstuff" is largely galena and calcite with much aragonite at times, and some barite in places.

The barite is generally of the gossan variety, that is mamilar sheets forming cavernous aggregates with much limonite at times.

Aragonite occurs as pieces of banded fibrous radiating aggregate. Its relationship to other minerals is not clear, but it is probably a late mineral bearing in mind the large size of the pieces.

Calcite is present and although it is mostly found as isolated pieces, it is occasionally found with other minerals. It has been seen to fill solution cavities after dolomitization and galenafication and also to fill a breccia of dolomitized limestone when it is accompanied by galena.

One specimen shows small clear yellowish barite plates lining a vug in dolomitized limestone filled by aragonite.

Galena is quite abundant in pure often flat pieces and also as disseminations and replacements of dolomitized limestone. Replacement galena often occurs as good crystals.

WHITASIDE, BELDON, AND EAST BOLTON VEINS

Grid ref: Apedale Mine SE015947   Altitude 411 m (1350')

Structure: There are many veins, the most important being -

1. The Whitaside Vein, strike 110°, throw 22 m (72')

2. The Apedale Vein, strike 115°, throw perhaps 9 m (30')

3. The Virgin String Vein, strike 150°, of little or no throw

4. The Bobscar Vein, strike 160°, throw perhaps 18 m (60')

5. Brownfield Vein, strike 150°, throw 16 m (54') or more

in the north and less in the south.

Mineralization: Calcite, barite, witherite, galena, sphalerite, pyrite.

Wallrock Alteration: Not observed.

Workings: The area has many mines especially in the following areas:-

1. Along the Brownfield Vein

2. Near the Virgin Mine

3. Along the Apedale Vein

There are hushes, shafts and levels in the area, they no doubt worked

small strings and flats. Two flats mentioned in Bradley (1862) are the

Mudd's Float, and the Murton Float all in the Whitaside area.

Dakyns et al (1891) mention that much of the ore in the Brownfield area

was obtained from flats and in strings running north east on the west side

of the main vein. One of the strings apparently had a throw of 2 or 3

metres.

Date of Workings: The area was probably mined from at least as early as

the 17th century, up to the end of the 19th century, although its heyday

will have probably been in the 19th century.

Production: Four mining companies are recorded in Hunt, one for Apedale,

one for Whitaside, one for Bolton Park and one for the Virgin Mine.

Figures for the Virgin Mine are only given for 1866 although it is in

the list of mines for 1866-1875.

In 1866 it produced 5 tons of ore and 3 tons 5 cwts. of lead.

According to Backhouse (1905) quoted in Clough (1962) the mine
ceased to mine lead in 1836 so the above figures could either be from tip
workings, or the mine could have been temporarily reopened.

In 1890 the mine was reopened for the exploitation of barite and the
mine was known to have produced much white ore (barite?) known locally as
"Grey Gaim" (Backhouse 1905) in Clough (1962).

Whitaside Mines have figures for 1862 and 1872, but are recorded from
1862-1878.

Date	Ore	Lead
1862	47 tons 0 cwt.	30 tons 0 cwt.
1872	12 tons 19 cwt.	9 tons 15 cwt.

Bolton Park Mines are given figures for 1866-1870 but mentioned until
1875.

Date	Ore	Lead
1866	475 tons 12 cwt.	356 tons 14 cwts.
1867	46 tons 0 cwt.	34 tons 0 cwt.
1868	15 tons 0 cwt.	10 tons 16 cwt.
1869	2o tons 0 cwt.	15 tons 0 cwt.
1870	20 tons 0 cwt.	15 tons 0 cwt.

Apedale Mines

Date	Ore	Lead	Silver
1866	8 tons 0 cwt.	5 tons 10 cwt.	-
1876	50 tons 0 cwt.	37 tons 10 cwt.	185 oz.
1877	113 tons 0 cwt.	65 tons 0 cwt.	110 oz.
1878	100 tons 0 cwt.	60 tons 0 cwt.	100 oz.
1880	45 tons 17 cwt.	34 tons 0 cwt.	25 oz.
1881	70 tons 15 cwt.	56 tons 10 cwt.	40 oz.

Apedale also has the only recorded figures for zinc produced -

35 tons 5 cwt. ore, and 15 tons 17 cwt. zinc.

Details of Mineralization: Only Apedale Mines and a small mine near

Whitaside Tarn were visited.

Nothing of any interest was found at the small level tip just north

of the road from Askrigg to Healaugh at SE976957.

At the tips of the Apedale Mines at SE015947 there were many good

pieces of veinstuff rich in sphalerite and sometimes galena with calcite

and barite accompanying the ore minerals.

The barite is massive and white, and the calcite is massive or a

later encrusting layering of prismoidal calcite.

Dolomitized limestone and sandstone breccias are filled with sphalerite,

galena and calcite and some pyrite is present and apparently older than the

calcite.

There are reports of large quantities of witherite at the Virgin Mine

(Dunham and Dines 1945)

Specimens: 1881-1910.

HARKERSIDE VEINS, HARKERSIDE MOOR

Locality	Grid Ref.	Altitude	Specimens
a. Harkerside Hushes	SE018972	465 m (1525')	1383-1393, 1394
b. Grovebeck Vein Shafts	SE022962	495 m (1625')	1341-1348
c. Grovebeck Vein	SE023961	503 m (1650')	1349-1351
d. Grovebeck Vein	SE023963	480 m (1575')	1352-1364
e. Grovebeck Vein	SE024964	465 m (1525')	1365-1369
f. Grovebeck Vein	SE024965	449 m (1475')	1327-1331
g. Grovebeck Vein	SE026965	449 m (1475')	1370
h. Grovebeck Level	SE028967	427 m (1400')	1371-1382
i. How Hill Shafts	SE035965	449 m (1475')	1332-1340

Structure: Several veins and rich flats associated with them.

Harkers Vein has a strike of 110° and a throw which would appear to vary from about 15 m (48') down to little or no throw. According to Bradley (1862) this was productive, in flats, in all the principal bearing beds with no gangue, although the last part is probably not quite true.

The Grovebeck vein (or Groovebeck Vein a name more reminiscent of the mining) has a strike of 060° and little or no throw. Flats were apparently worked in the Main Limestone and the Undersett Limestone with no gangue, but the workings richest in veinstuff would seem to have been in the beds between the Richmond Chert and the Crow Chert. The Grovebeck Level probably worked the lower flats and also the Harkers Vein Flats.

A vein called the Water String Vein joins the south end of the Grovebeck Vein and strikes at 090°, there is only one surface shaft in it and so it may have been largely worked by the Grovebeck Level.

A vein of strike 140° and small throw runs over the top of High Harker Hill and links with the Harkers Vein. There are no signs of surface workings but it could have been reached underground.

Mineralization: Galena, barite, pyrite, marcasite, chalcopyrite, calcite.

Wallrock Alteration: Dolomitization.

Stratigraphic Horizon: The horizons of the sampled tips are as follows:-

a. Main Limestone and the Richmond Cherts above

b, c, d, could have worked the Crow Limestone, but

e, f, and g. probably worked the Little Limestone and Richmond Cherts.

h. probably worked the Main and Undersett Limestones and their Cherts.

i. worked the Main Limestone.

Workings: The workings have been described in the section on structure. At Grovebeck level there are quite large tips.

Date of Workings: Probably from at least the 17th century through until the closing years of the 19th century.

Production: No figures are available.

Details of Mineralization: Nearly all the tips are poor in veinstuff and that present, especially at the shafts, is very often gossan.

The gossan is composed largely of barite in mamilar sheets forming cavernous rocks in which the occasional piece of galena is found.

The barite is of many colours, dominantly brown to black and along with its heavy nature gives the appearance of being rich in ore minerals which it is not. Limonite is a very abundant constituent of the gossan, but barite-limonite boxworks are the only common structures and these seldom bear an obvious relationship to the original minerals.

Some gossan is very galena rich, it may have been this that was mined and so now much depleated in the tips. The galena very often has thick cerrusite rims, but it has withstood the weathering better than the other sulphides, and carbonates etc. making its exploitation a little easier.

Some goethite pseudomorphs rather rounded unfortunately probably represent original pyrite or marcasite.

There are some large pieces of barite in a few places notably at Grovebeck Level and Harkerside Hushes and there is some pink and white

massive barite of primary origin. Sometimes it is seen to fill breccias, and occasionally is accompanied by galena.

Calcite is found massive and accompanied by galena, and some calcite is also present filling breccias of dolomitized limestone.

Traces of malachite are present in some pieces of gossan and probably represent small amounts of chalcopyrite originally present.

GRINTON VEINS, GRINTON MOOR

Locality	Grid Ref.	Altitude	Specimens
a. How Rake Veins	SE028957	504 m (1650')	1672-1675
b. How Rake Veins	SE029957	504 m (1650')	1676-1679
c. How Rake Veins	SE032958	480 m (1575')	1680-1683
d. How Rake Veins	SE033959	465 m (1525')	1684-1687
e. How Rake Veins	SE034960	457 m (1500')	1688-1690
f. How Rake Veins	SE035962	430 m (1425')	1691-1694
g. How Rake Veins	SE038963	419 m (1375')	1695-1697
h. Wellington Vein	SE052962	352 m (1150')	0468-0475

Structure: Veins and rich flats. All the veins sampled have little or no throw. The How Vein strikes 070° and the Wellington Vein strikes 060°

Stratigraphic Horizon: The Undersett and Main Limestones and Richmond Chert Series.

Mineralization: Barite, witherite, calcite, galena, marcasite, limonite, malachite.

Wallrock Alteration: Dolomitization, and galenafication.

Workings: Veins and flats worked by many shafts and two levels.

Date of Workings: Probably at least as early as 13th century.

Production: Figures for 1872 and 1873 add to only just over 3 tons which must have little relationship to past production.

Details of Mineralization: The veinstuff found at all localities is almost identical and composed largely of gossan, which is rich in cavernous mamilar dark barite with some limonite and occasional pieces of galena often rimmed with cerrusite. Occasionally tuby barite and cavities representing original witherite can be seen, and some limonite boxworks indicate the former presence of sphalerite. Calcite is found in the gossan and occasionally as

crystals sometimes clear and squat, sometimes pyramids and in one case as a mass of beefy calcite with radiating fibrous structure.

Some compact tough "steely" galena is present. It has a schistone appearance and occasionally contains bands of marcasite. A little malachite was found and indicates the original presence of chalcopyrite.

ELLERTON VEINS, ELLERTON MOOR

Locality	Grid Ref.	Altitude	Specimens
a. Redway Head Vein	SE058952	398 m (1275')	1797-1801
b. Redway Head Vein – Wellington Vein	SE058960	396 m (1300')	1802-1805
c. Old Stork Vein	SE062961	381 m (1250')	1811-1814
d. Jammy Raw's Rake Vein	SE063962	366 m (1200')	1806-1810
e. Old Stork Vein	SE070958	381 m (1250')	
f. East End Vein	SE069957	396 m (1300')	1815-1820
g. East End Vein	SE071957	389 m (1275')	1821-1824
h. East End Vein	SE072957	381 m (1250')	1825-1828

Structure: Flats and veins. The veins mostly have little or no throw except for the Old Stork Vein which strikes 114° and throws down to the north about 44 m (144'). Redway Head Vein strikes 157° and Wellington Vein 063°.

Stratigraphic Horizon: Bearing beds from the Undersett Limestone to the Crow Limestone although dominantly the Main and Little Limestones. Undersett workings have not been sampled.

Mineralization: Calcite, barite, galena, perhaps sphalerite.

Wallrock Alteration: Dolomitization and galenafication.

Workings: These veins were worked by several levels on the steep north facing slopes, but by many smaller shaft working near the moor top. A level on Wellington Vein is referred to in Grinton Veins.

Date of Workings: Probably from 13th century onwards.

Production:

Year	Ore	Lead	Silver
1872	114 tons 0 cwt.	85 tons 10 cwt.	-
1873	84 tons 6 cwt.	63 tons 0 cwt.	-
1874	4 tons 18 cwt.	3 tons 13 cwt.	-
1875	15 tons 16 cwt.	11 tons 15 cwt.	45 oz.

Details of Mineralization: The vein material found in the tips was very similar in each locality.   It was largely gossan composed of mamilar barite, and here rather more limonite than further west.   There is a lot of calcite sometimes containing galena and occasionally boxworks after galena and some probably after sphalerite.   The galena is often partly converted to cerrusite, and can be found in good nuggets and crystals.   No barite of definite primary nature was seen.   A trace of malachite was found at Jammy Raw's Rake Vein.

COBSCAR VEINS, REDMIRE

Locality	Grid Ref.	Altitude	Specimens
a. Smelter Shaft	SE062919	350 m (1150')	1950-1970
b. Cobscar Rake	SE058920	358 m (1175')	1858-1873
c. Cobscar Rake	SE054920	350 m (1150')	1874-1880
d. Cobscar Hushes	SE045919		

Structure: Veins of small throw – Cobscar Vein 092°, Chaytor Rake Vein and branch vein 145°.

Stratigraphic Horizon: Main Limestone and Richmond Chert Series.

Mineralization: Barite, witherite, fluorite, calcite, sphalerite, galena.

Wallrock Alteration: Not observed.

Workings: Cobscar Hushes and Rake, deep shaft near smelter, Stopmire and Chaytor Rakes. Along the rakes the workings were open casts and shafts.

Date of Workings: Probably pre-1700 up to mid or late 19th century.

Production: If "Crennia Mines" are the Cranehow Bolton Mines then the figures for Keld Heads and Crennia will include the total for this area. The large smelt mill is indicative of the likely production.

Details of Mineralization: Minerals found at the different collecting points were fairly similar and were quite rich in barite not just of the gossan variety found further north, but also of massive primary nature. Witherite is also present though not abundant, and tuby barite is occasionally found. Calcite occurs white and massive and sometimes is seen filling cavities in barite. A few crystals of squat calcite were found. A trace of clear to purple fluorite was found at locality c. with primary barite and sphalerite. Sphalerite is plentiful and found with the massive barite. Limonite boxworks after sphalerite are also found. Galena is present, and at times is found as bands of grains in massive barite, sometimes accompanied by sphalerite. Locality d. yeilded only a little platy barite.

DOWNHOLME VEINS, DOWNHOLME

Grid Ref: SE112984   Altitude: 230 m (750')

Structure: Two veins marked on 1 inch Geological Survey Map, striking
083° and 073°.

Stratigraphic Horizon: Main Limestone

Mineralization: Barite, calcite, galena.

Wallrock Alteration: Dolomitization.

Workings: A small level and tip was the only working observed.

Date of Working: Perhaps as old as 1396, although the level suggest a
younger age.

Production: Unknown.

Details of Mineralization: Good crystals of galena were found here.
Barite is present and is massive and white, occasionally carrying a little
galena. Limonite boxworks indicate the original present of sphalerite and
galena. Some of the galena "cubes" are distorted, but the reason for this
could not be ascertained.

Specimens: 1659-1663.

CARPERBY VEINS, CARPERBY. ("WET GROOVES")

Locality	Grid Ref.	Altitude	Specimens
a.	SD987914	400 m (1312')	0613-0620
b.	SD988914	405 m (1325')	0626-0633
c.	SD983908	335 m (1100')	0621-0625

Structure: Workings at locality a. could have been in joints, but at locality b. where workings are more substantial the vein of little or no throw strikes 150° and appears to link up with the Brownfield Vein. At locality c. there is a fault of probably small but unknown throw with strike 090°.

Stratigraphic Horizon: a. and b. are in the Main Limestone. c. is in the Undersett Limestone and the sandstone beneath.

Mineralization: Calcite, barite, domite, galena.

Wallrock Alteration: Dolomitization, galenafication.

Workings: Shallow pits and open cuts at localities a. and b. At c. tips and works obscure the presence of original workings, perhaps shafts.

Date of Workings: Unknown.

Production: Unknown.

Details of Mineralization: At localities a. and b. the crinoidal Main Limestone has been slightly dolomitized and carries disseminated galena in places. Joints show small amounts of platy barite and massive occasionally "fibrous" calcite, as well as galena.

The locality c. - there are many specimens of breccia sometimes mixed sandstone and limestone. They are cemented with calcite and galena. Galena crystals, coatings and impregnations are found on both dolomitized limestone and the more abundant sandstone. A little platy barite was seen in a small veinlet with galena, calcite and dolomite. A trace of altered iron sulphide was also found.

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P ZONE - NORTH OF RIVER SWALE

Faggergill Veins, Faggergill Moor

Locality	Grid Ref.	Altitude	Specimens
Main Levels (No. 1, 2)	NY988072	411 m (1350')	1445-1461
West Level (No. 3)	NY985070	411 m (1350')	1471-1476
(a) Eastern Shafts	NY990070	442- m (1459-')	1462-1464
(b) and Levels		442 m (1450')	1465-1467
(c)		442+ m (1450+')	1468-1470

Structure: Various veins of very small throw. Old Faggergill Vein, strike 125°, New Faggergill Vein, strike 125°, and several other strings in the same direction. Flats associated with the small veins encountered in the West Level.

Stratigraphic Horizon: Main Limestone and chert.

Workings: The Main Level worked the New Vein and associated vein complex. It has a very large tip and was active into the start of the 20th century. The West Level does not appear to work any vein marked on the 1" geological map, but the vein worked must have had a small throw. It has a substantial tip. The Eastern shafts and Levels work the Old Vein and are the older workings. A small group of grassed over shafts, north west of the Main Level, perhaps represent the Medieval workings on the Old Vein.

Mineralization: Calcite, barite, galena, pyrite, marcasite, cerussite.

Wallrock Alteration: Dolomitization, galenafication.

Details of Mineralization: The tips have much dolomitized limestone, limestone and a little chert. The commonest minerals are galena and calcite. Galena is found as good crystals (cube-octahedron combinations etc.), massive, and disseminated. In many cases no other mineral is seen

with it. Calcite is found massive and as good crystals including highly twinned triangular pyramids. It can be white-colourless and is often accompanied by galena and sometimes with late coatings of barite plates. Goethite pseudomorphs of marcasite and perhaps pyrite are to be found, although most goethite and limonite, which are both common, has a less clear origin. Cerussite rims to galena are common especially in limonite rich specimens which occur commonly in dolomitic gossan. A few specimens of toothy barite can be found but are not common, and massive barite is absent.

<u>Stang Mine, Stang</u>

Grid Ref: NY010060   Altitude: 427 m (1400')

Structure: Black Vein strike 040°, of small downthrow west, and Stang
Vein strike 080°, of small downthrow north. Stang Vein (in Bradley (1862))
is recorded as unproductive with a throw of 33 m (108'); this can not be
the same vein as that marked "Stang Vein" on the 1" geological map.

Stratigraphic Horizon: Main Limestone.

Workings: A large level worked towards the end of the last century.

Mineralization: Calcite, galena.

Wallrock Alteration: Dolomitization, galenafication.

Details of Mineralization: A large tip of dolomitized limestone and shale
has abundant calcite, mostly white and massive although some is clear.
Occasional limestone breccias are filled with calcite and galena, but
mostly galena is found as replacements along joints, or as separate massive
pieces. Some cube-octahedrom crystals can be found in the dolomitized
limestone. Two rare specimens of banded-fan aggregates of toothy barite
were found, and perhaps suggest a little original witherite.

Specimens: 1395-1406.

Windegg Mine, Moresdale Ridge Vein, Booze Moor

Grid Ref: NY012052   Altitude: 457 m (1500')

Structure: The Moresdale Ridge Vein is a very long fault (11 km)

running 010°. It has a widely varying throw but in the vicinity of the

Windegg Mine it may be approximately 15 m down to the north. In the

east the throw is reversed, with large down throw to the south. Bradley

reports it to be unproductive near Hurst, with a throw of 55-75 m.

Stratigraphic Horizon: Probably the Main Limestone with cherts and grits

above.

Workings: There are several hushes and two levels one of them having a

tip of large dimensions. The large level was probably worked late in the

19th century.

Mineralization: Witherite, calcite, barite, galena, sphalerite, chalcopy-

rite.

Wallrock Alteration: Dolomitization.

Details of Mineralization: The tips consist mainly of limestone, which is

often dolomitized. Calcite, witherite and much late or secondary toothy

barite are found on the tips. The witherite occurs massive when it is

often banded, or as pseudohexagonal crystals. It is replaced to varying

extents by tuby barite aggregates and porous soft white-yellowy barite-

carbonate aggregates. Galena with cerussite rims has been found in masses

of secondary white fine grained barite with tuby structures, in places,

after witherite, and chalcopyrite has been seen as small crystals in

crystals of witherite. Galena has also been seen in specimens of other

kinds of secondary barite, but is generally found as isolated pieces.

Sphalerite was occasionally seen with galena in porous barite. Calcite is

found and is often white or colourless and is frequently covered with small

plates or fan aggregates of barite, although occasionally clear calcite

fills the gaps in cavernous aggregates of toothy barite. No definite

primary massive barite with unaltered sulphides was found.

Specimens: South Hush, top 1409-1416, middle 1417-1421, bottom 1442-1423;

Windegg Level, 1424-1435; Alcock Hush, 1436-1444.

Great Sleddale Veins, Angram Common

Grid Ref: SD834995   Altitude: 518 m (1700')

Structure: Vein strike 060° of great throw.

Stratigraphic Horizon: Ten fathom grit on upthrown side.

Mineralization: Barite, galena, limonite.

Wallrock Alteration: Not observed.

Workings: A small overgrown tip by a boarded-over shaft is near to
Leaden Haw Gill Hush. Part of the Great Sleddale mines, copper. mines
excepting this working.

Date of Working: 18th Century trials.

Details of Mineralization: The tip yielded a single piece of coarse
sandstone with an impregnation and veinlets of barite, galena and
limonite.

Specimen: 0385

Lane End and Pry Hill Veins, Upper Swaledale

Locality	Grid Ref.	Altitude	Specimens
Lane End Mine	NY856008	366 m (1200')	0386-0388
Pry Hill Mine	NY868014	443 m (1125')	1666-1671

Structure: Several veins running almost parallel at 055° and probably offset by some short cross veins at 135°. Three veins at Pry Hill Mine have the following throws:- North Vein, 15 m (48'); Middle Vein, 13 m (42'); South Vein, not known. At Lane End the North Vein has a throw of 15 m (48') again, but the others are not known.

Mineralization: Witherite, calcite, (barytocalcite), galena, sphalerite, chalcopyrite, pyrite.

Stratigraphic Horizon: Main Limestone and cherts at Pry Hill and Ten Fathom Grit at Lane End.

Workings: Earliest workings in the area were perhaps 18th Century, but these mines date from the early 19th Century. Water problems caused their closure. No production figures are available.

Details of Mineralization: Specimens from both localities yielded clear white massive witherite, containing galena, and small grains of chalcopyrite, pyrite and sphalerite. A little calcite is also present and in one specimen from Lane End would seem to be partly earlier than the witherite. Barytocalcite was recorded in Dunham and Dines (1945), but no fluorite or barite has been recorded.

Beldi Hill Veins, Keld

Locality	Grid Ref.	Altitude	Specimens	Horizon
Level (a)	NY900010	335 m (1100')	0985-0986	Main Limestone and Cherts
Landy Level	NY901009	335 m (1100')	0987-0995	Main Limestone and Cherts
Beldi Hill Hushes	NY902012	396 m (1300')	1048-1036	Main Limestone and Cherts
Beldi Hill Level	NY903011	396 m (1300')	1041-1047	Main Limestone and Cherts
Plate Holes Level	NY903008	305 m (1000')	1664-1665	Undersett Limestone
Beldi Hill Top Level	NY906009	411 m (1350')	1028-1040	Main Limestone and Cherts

Structure: Several veins diverge from near where the Beldi Hill Hushes flow into the Old Field Hush. The Old Field Hush follows near the Hurrace Vein, which has a throw around 15 m (48') down to the south, and a strike 120°. Bradley (1862) believed this vein to be barren. Three or four veins striking 045-090° converge into the hushes. They appear to be the North, Middle, Sun and Cockrake veins of Swinnergill, but because of attendant strings and changes in direction it is not a simple and exact correlation.

Mineralization: Calcite, barite, witherite, sphalerite, galena, pyrite.

Wallrock Alteration: Not observed.

Workings: Old Field Hush was worked from an early date until 1862, and produced much good ore, but this may not have been from the Hurrace Vein, but from intersecting veins. The levels were driven between 1700-1880 and work ceased about 1882. The workings were extensive, but no production figures are available.

Details of Mineralization: Only clear nail-head calcite was found at Level (a), but at the nearby Landy Level massive and nail-head is sometimes coated with large toothy crystals of barite, and sphalerite and galena are to be found in massive barite. In the Beldi Hill Hushes there are large amounts of limestone in blocks. Limestone breccia filled with pink and white barite and calcite is common, and often has galena and sphalerite in the filling. One piece of breccia was composed of limestone and massive white calcite fragments filled with pink massive barite with occasional grains of sphalerite scattered in the filling and also sphalerite rims around many calcite fragments. Similar breccias and minerals are present in the tips from Beldi Hill Level, where galena pieces are common. A breccia from here showed a filling of dog tooth calcite followed by thin layers of barite. Beldi Hill Top Level has large tips of limestone with common galena, sphalerite, calcite and also a little pyrite and some late barite. A little early barite contains sphalerite. Although witherite has been said to contain witherite, only galena and sphalerite could be found.

Swinnergill Veins, Swinnergill

Locality	Grid Ref.	Altitude	Specimens
Parkes Level	NY911009	366 m (1200')	-
North Vein Hush	NY912013	427 m (1400')	0996-1002
West Level	NY911013	427 m (1400')	1003-1010
West Hoppers	NY911012	403 m (1325')	1011-1016
Cockrake	NY912012	412 m (1350')	1017-1022
Swinnergill Level	NY911012	389 m (1275')	1023-1027

Structure: Several veins cross the gill here and were followed by a level eastwards to the cross vein 'Field Marshal Vein' and then along this until they were again reached. The Sun Vein and Cockrake Vein strike almost 090°: they have modest throw 5 m or less and veer towards the north as they run eastwards. The Middle Vein has a similar throw and strikes 090° west of the gill but nearer 045° east of the gill. The North Vein is parallel to the Middle Vein, but has a throw of around 7 m. The Field Marshal Vein strikes 110° with large throw in the east, but small in the west, because of the intersecting faults.

Stratigraphic Horizon: Workings extend from the Undersett Limestone up to the Crow Limestone, although Bradley (1862) records production only in the Main Limestone and Chert.

Mineralization: Calcite, barite, witherite, sphalerite, galena, pyrite (fluorite?).

Wallrock Alteration: Sphaleritization, galenafication.

Workings: Hushes and levels of similar age to Beldi Hill Mines. Tips are moderate in size with only small amounts of veinstuff. Production figures are complicated by incorporation of Blakethwaite Veins etc. after 1878 and probably all postdate the height of production. Swinnergill Level was active from 1752 to 1880; Parkes Level closed in 1878, but the local smelt mill was closed in 1819 for lack of ore.

Production:

Year	Ore	Lead
1873	13 tons 2 cwt.	9 tons 16 cwt.
1874	36 tons 5 cwt.	27 tons 3 cwt.
1876	86 tons 17 cwt.	54 tons 9 cwt.
1877	48 tons 0 cwt.	30 tons 0 cwt.
1878	700 tons 0 cwt.	455 tons 0 cwt.
1880	954 tons 0 cwt.	715 tons 10 cwt.
1881	629 tons 0 cwt.	440 tons 0 cwt.

Details of Mineralization: Except at Parkes' Level where no veinstuff was found, the localities have similar material in the tips, i.e. calcite with galena, sphalerite and a little barite and pyrite. Limestone breccias are commonly found filled with these minerals. The calcite is generally massive and varies in colour from white to grey to yellowish. Barite tends to be white and massive, and, in at least one case, is intergrown with calcite and ore minerals. Pink barite is found, but only rarely. The sphalerite is pale and as abundant as galena. Caruthers & Strahan (1923) record "The gangue was mainly calcite, with some barytes, and the galena mostly came from the centre of the vein; fluor, cerussite and zinc blende also occurred in small quantity. In pockets in the limestone walls there were occasional bodies of witherite, . . .". No fluorite or witherite were detected in the present survey, but cerrusite is almost always present where there is galena.

Gunnerside Gill Veins, Gunnerside Gill

Locality	Grid Ref.	Altitude	Specimens
1. Silver Hill Level	NY937002	472 m (1550')	1589-1590
2. Harriet Level	NY935004	472 m (1550')	-
3. High Whim	NY928012	564 m (1850')	1591-1595
4. Lownathwaite Hushes (a)	NY932013	533 m (1750')	1596-1599
5. Lownathwaite Hushes (b)	NY936013	472 m (1550')	1604-1608
6. Lownathwaite Hushes (c)	NY936013	457 m (1500')	1609-1613
7. Blind Gill Level	NY935017	457 m (1500')	1614-1616
8. Upper Blakethwaite Level	NY939027	480 m (1575')	1617
9. Water Sikes Level	NY943011	488 m (1600')	0488-0493
10. Barbara Level	NY942006	457 m (1500')	0483-0487

Structure, Workings and Stratigraphic Horizons: These extensive workings were in veins and attendant strings, with no records of any flats. The most important veins are:-

1. Silver Hill Vein, striking 110°, downthrow north 7 m. Worked at Main Limestone and Cherts.

2. Barbara Vein, striking 110°, downthrow north 22 m at Lownathwaite, but only 7 m near Winterings, where ore was obtained from the Main Limestone and Richmond Chert Series.

3. North Vein, Sun Vein, and attendant strings. This complex of veins was worked in the Lownathwaite Hushes, nearby shafts and the Woodward, Priscilla and Sir Francis Levels. The main downthrow is south and veins strike 060°-090°.

4. Watersykes Vein, strikes 110°, downthrow south 8 m near Lownathwaite and 16 m further east. Productive in the Undersett Limestone and Chert and Little Limestone in the west and in the Main Limestone and Chert in the east.

5.   Blind Gill Veins, worked from Blind Gill Level.

6.   Blakethwaite Veins, striking almost 090° with downthrow north.

Worked by Levels and shafts. Worked in the Main Limestone and other

horizons.

Mineralization: Barite, calcite, witherite, galena, sphalerite, hematite,

pyrite.

Wallrock Alteration: Dolomitization, galenafication.

Production: Separate figures for these veins are not available, but

figures are partly included in the Old Gang figures and figures for the

Blakethwaite Company detailed below.

Year	Ore	Lead
1862	94 tons 8 cwt.	58 tons 10 cwt.
1867	171 tons 12 cwt.	128 tons 14 cwt.
1868	155 tons 0 cwt.	114 tons 0 cwt.
1869	95 tons 0 cwt.	70 tons 0 cwt.
1870	148 tons 18 cwt.	111 tons 13 cwt.
1871	99 tons 9 cwt.	74 tons 10 cwt.
1872	16 tons 10 cwt.	12 tons 7 cwt.

The mines may have already passed their heyday before the commence-

ment of these figures.

Details of Mineralization: The veinstuff found at the different tips

varies a little, but generally barite is the dominant gangue mineral with

some calcite, galena, and sphalerite. Witherite is found in places and

indicators of it in others.

Barite occurs massive with pink and white colours common, and plates

of barite with sphalerite or other sulphides are sometimes in more open

structures. Gossan barite is also found on the high ground, for instance

at High Whim. Fan aggregates of toothy barite are present abundantly in places such as the Watersikes level. Tuby barite after witherite is also present at Lownathwaite Hushes and Barbara Level.

At Watersikes level, witherite is abundant as radiating bundles of witherite fibres forming poor pseudohexagonal crystals. No massive barite was found at this locality.

Clear calcite is present in the Lownathwaite area. It is generally massive and not associated with sulphides.

Galena and sphalerite are both fairly abundant, although sphalerite less than galena. Replacement forms, such as good cubes in limestone, are found with the more common massive forms and cavity lining crystals.

Hematitic layers in barite specimens have been found, but it appears to be both secondary hematite after sulphides and barite after witherite.

Little veinstuff was seen in tips at Silver Hill and Upper Blakethwaite Levels, and no minerals could be found at Harriet Level, although all must have produced ore.

Fell End Veins, Booze Moor

Locality	Grid Ref.	Altitude
Great Blackside Vein – Strike 080°. Large downthrow south. Worked from the Main Limestone to the Crow Chert		
Lower Level	NY005031	381 m (1250')
Middle Level	NY006032	411 m (1350')
Tanner Rake Vein – Strike 130°. Small downthrow south. Worked from the Main Limestone to the Crow Chert		
Tanner Rake Hush	NY013032	427 m (1400')
Cockleshell Level	NY015031	381 m (1250')
Doctors Level	NY018028	305 m (1000')

Structure: Many veins of which only two were sampled.

Mineralization: Barite, calcite, witherite, (fluorite), galena.

Wallrock Alteration: Not observed.

Workings: Extensive workings by hush, shaft and level.

Production: Unrepresentative figures only are available

Year	Ore	Lead
1869	0 tons 7 cwt.	0 tons 6 cwt.
1870	8 tons 0 cwt.	5 tons 0 cwt.
1871	9 tons 1 cwt.	6 tons 15 cwt.
1872	9 tons 3 cwt.	6 tons 18 cwt.
1873	2 tons 2 cwt.	1 ton 10 cwt.
1874	0 tons 16 cwt.	0 tons 12 cwt.
1876	1 ton 2 cwt.	0 tons 16 cwt.
1877	0 tons 10 cwt.	0 tons 7 cwt.
1880	2 tons 8 cwt.	1 ton 15 cwt.
1881	3 tons 14 cwt.	2 tons 15 cwt.

Details of Mineralization: Prosperous Level (NY006029) was visited and tips showed no veinstuff, although a trace of galena and barite were found in a joint plane. The tips of Great Blackside Vein have common massive barite, white to pink in colour. Toothy barite is also present, and clear massive calcite is common. Traces of purple fluorite are to be found and galena is common with the massive barite. Tanner Rake Vein has tips which show abundant massive and toothy barite. Massive barite can be white-pink in colour and is frequently accompanied by galena. Calcite is present in the tips and witherite is found at Doctors Level. Goethite bands in barite probably represent original pyrite.

Specimens: Specimens are neither numbered nor studied in detail.

Windegg Veins, Booze Moor

Locality	Grid Ref.	Altitude	Specimens
North Windegg Vein, strike 090° and 120°. Moderate downthrow north. Worked in Main Limestone and Cherts, and Windegg Float.			
North Level	NZ010044	488 m (1600')	1520-1523
Middle Level	NZ010043	488 m (1600')	1524-1528
(a) Shafts	NZ011043	518 m (1700')	1513-1519
(b) Shafts	NZ012043	518 m (1700')	1508-1512
(c) Shafts	NZ013044	518 m (1700')	1477-1481
(d) Fines	NZ015043	503 m (1650')	1482-1486
(e) Fines	NZ018041	472 m (1550')	1487-1491
Windegg Vein, strike 095°. Downthrow south of 55-73 m worked in Main Limestone and Cherts			
(f) Hush	NZ014041	488 m (1600')	1504-1507
(g) Hush	NZ016040	472 m (1550')	1501-1503
(h) Fines	NZ017040	457 m (1500')	1498-1500
(i) Hush	NZ019040	442 m (1450')	1492-1497

Mineralization: Barite, calcite, galena, pyrite, (cerussite, limonite)

Wallrock Alteration: Dolomitization, galenafication.

Workings: A large hush worked the Windegg Vein and shafts and levels from the west and east all entered the vein. The veins to the north were entered by level from the west and also by shafts. Shafts and small hushes worked the Windegg Float or Flats which are between the northern and main veins. The workings are probably of many ages and production statistics may be partly included in the Fell End Mines.

Details of Mineralization: Tips are composed of limestone, chert and occasionally sandstone. Primary massive barite, both pink and white, is common, except at localities (c) and (d). Massive calcite is common both

white and clear. It is occasionally found in other colours, for instance
pinkish. The relationship of the abundant galena to calcite is not clear
since they were not observed together, but galena and pyrite commonly
occur with barite and probably coexisted. Sphalerite was not observed
in hand specimen but limonitic indicators of its presence were seen.
Galena occurs in very good crystals in some pieces of dolomitized lime-
stone and some may have replacement origin. Gossan is found and is
mostly decalcified limonitic limestone and chert with porous barite agg-
regate. Galena from the gossan is strongly rimmed with cerussite.
Disseminated galena is occasionally found in the dolomitic limestone.

Hurst Veins, Hurst

Locality	Grid Ref.	Altitude	Specimens
Racca Vein, strike 110°, strong downthrow to the north. Shafts enter in Richmond Cherts and higher beds			
1. Shafts	NZ032022	465 m (1525')	1529-1533
2. Shafts	NZ035021	457 m (1500')	1534-1538
Hind Rake Vein, strike 075°, moderate downthrow north (20 m). Shafts and Hush into the Richmond Cherts			
3. Shafts	NZ037020	449 m (1475')	1539-1542
4. Shafts	NZo39020	434 m (1425')	1543-1546
Hurst Vein, strike 075°, small downthrow. Shafts and hush into Richmond Cherts.			
5. Whim Shaft	NZ039021	427 m (1400')	1547-1548
6. Shafts	NZ042022	396 m (1300')	1549-1553
7. Shafts	NZ044022	381 m (1250')	1554-1559
Hurst Level	NZ052026	328 m (1075')	0153-0162

Structure: The Hurst Vein complex is composed of many veins of strike approximately 075° which have formed between the ends of two en-echelon veins (the Racca Vein and Wallnook Vein) which strike approximately 110°.

Stratigraphic Horizon: The veins were worked in the upper horizons (the Richmond Cherts etc.) from shafts and at the Main Limestone horizon by levels and the deeper shafts.

Workings: These workings are very extensive and include shafts, levels and hushes. This area has been mined from Roman times until the end of the 19th century. The total production is perhaps suggested by the figures overleaf.

Mineralization: Barite, calcite, witherite, (fluorite), galena, sphalerite, chalcopyrite.

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Year	Lead	Ore	Silver
1853	274 tons 0 cwt.	169 tons 16 cwt.	–
1854	225 tons 0 cwt.	168 tons 0 cwt.	–
1855	129 tons 12 cwt.	96 tons 15 cwt.	–
1856	118 tons 0 cwt.	87 tons 0 cwt.	–
1857	190 tons 8 cwt.	130 tons 0 cwt.	–
1858	149 tons 10 cwt.	102 tons 0 cwt.	–
1859	158 tons 0 cwt.	33 tons 2 cwt.	–
1860	58 tons 0 cwt.	39 tons 0 cwt.	–
1861	60 tons 0 cwt.	41 tons 0 cwt.	–
1862	331 tons 0 cwt.	221 tons 0 cwt.	–
1863	272 tons 0 cwt.	176 tons 0 cwt.	–
1864	272 tons 0 cwt.	176 tons 0 cwt.	–
1865	137 tons 5 cwt.	95 tons 18 cwt.	–
1866	465 tons 16 cwt.	197 tons 9 cwt.	–
1867	1,171 tons 0 cwt.	749 tons 10 cwt.	–
1868	704 tons 18 cwt.	528 tons 13 cwt.	–
1869	652 tons 14 cwt.	501 tons 10 cwt.	–
1870	752 tons 16 cwt.	564 tons 12 cwt.	–
1871	387 tons 4 cwt.	290 tons 8 cwt.	–
1872	357 tons 12 cwt.	268 tons 4 cwt.	–
1873	476 tons 11 cwt.	357 tons 7 cwt.	–
1874	536 tons 17 cwt.	397 tons 0 cwt.	–
1875	351 tons 2 cwt.	263 tons 10 cwt.	789 oz.
1876	342 tons 14 cwt.	247 tons 0 cwt.	741 oz.
1877	407 tons 13 cwt.	307 tons 10 cwt.	875 oz.
1878	241 tons 16 cwt.	180 tons 0 cwt.	513 oz.
1880	55 tons 9 cwt.	42 tons 15 cwt.	120 oz.

Wallrock Alteration: Dolomitization, galenafication

Details of Mineralization: The most abundant vein material is barite which is generally massive and ranging from white through pinks to red and orange.   Calcite is occasionally found and often occurs as clear scalenohedrons coated with platy or toothy barite.   Some calcite crystals are seen to be grown upon earlier massive primary barite.   Massive barite is often accompanied by galena and less frequently with sphalerite. Chalcopyrite occurs in small amounts with barite and galena.   Witherite has been found in the Racca Vein, and at Whim shaft on the Hurst Vein. Large pieces, tens of centimetres across, may be found occasionally although witherite is not especially common on the surface of tips.

Hellwith Veins, Skelton Moor

Locality	Grid Ref.	Altitude	Specimens	Horizon
Munn End Veins 1	NY077026	290 m (950')	1834 to	Crow Limestone and Chert
Munn End Veins 2	NY077023	335 m (1100')	1837	Main Limestone and Chert
Moss Mine Vein 3	NY076018	343 m (1125')	1838-1841	Richmond Cherts

Structure: Munn End Vein 1, strike 110°, downthrow north perhaps 20 m. Munn End Vein 2, strike 080°, downthrow north perhaps 50 m. Moss Mine Vein, strike 050°, downthrow south.

Mineralization: Calcite, barite, galena.

Wallrock Alteration: Dolomitization

Workings: Old shafts along the ; Moss Mire :, and the Munn End Veins. No record of production.

Details of Mineralization: Calcite is the main gangue mineral at each locality although there is a little barite in the Munn End Vein. The calcite varies from colourless to white and pinkish and is massive. In some cases white platy barite is crystallized on top of the calcite. A pink massive barite was seen to be followed by a white barite with open platy structure. Galena is the only ore mineral observed and is found massive or occasionally as well formed crystals in the Moss Mine Vein. The tips are on the whole poor in veinstuff.

Copperthwaite Veins, Marrick Moor

Locality	Grid Ref.	Altitude	Specimens
South Copperthwaite Vein, strike 085° in west veering 060° in east. Bearing from Undersett Limestone to Little Limestone. Throw up to 7 m.			
1. Level	NZ064004	351 m (1150')	1191-1195
2. Opencut	NZ062004	366 m (1200')	1196-1203
3. Shaft	NZ063003	381 m (1250')	1204-1209
4. Shaft	NZ061002	396 m (1300')	1211-1212
5. Shaft	NZ059003	396 m (1300')	1214-1215
6. Shaft	NZ058002	411 m (1350')	1216
7. Shaft	NZ056002	412 m (1375')	1217
8. Shaft	NZ054002	427 m (1400')	1220-1224
North Copperthwaite Vein, strike 060°, throw less than 2 m. Bearing from Main Limestone to Little Limestone.			
9. Shaft	NZ054005	396 m (1300')	1245-1248
10. Shaft	NZ052004	411 m (1350')	1249-1251
11. Shaft	NZ051004	411 m (1350')	1252
12. Shaft	NZ049003	427 m (1400')	1253-1255
Jingle Pot Vein? strike 060°, throw less than 4 m. Bearing from Main Limestone to Little Limestone.			
13. Shaft	NZ040009	442 m (1450')	1263-1266
14. Shaft	NZ042010	442 m (1450')	1267-1271
15. Shaft	NZ043010	442 m (1450')	1272-1279

Mineralization: Barite, calcite, galena. 9 and 10 have fluorite and should be in the F Zone along with some localities already considered on the west end of the South Vein.

Wallrock Alteration: Galenafication

Workings: Fairly extensive, probably old, from 14th century onward.

Details of Mineralization: The tips contain much chert and limestone with veinstuff common in places.   Gossan barite is common and includes much limonite at times and some galena with cerussite skins.   Massive barite, white to pale pink, is also to be found and contains galena at times.   Calcite also occurs and is found interbanded with barite and galena.

Cleaburn Pasture Veins, Marrick Moor

Locality	Grid Ref.	Altitude	Specimens
Cleaburn Pasture Vein, strike 040°, strong downthrow south (perhaps 50 m or more). Productive in Main Limestone and Cherts on upthrown side.			
1. Shaft	NZ080001	305 m (1000')	1113-1120
2. Shaft	NZ081001	305 m (1000')	1121
3. Shaft	NZ081002	312 m (1025')	1122-1127
4. Shaft	NZ082002	312 m (1025')	1128-1130
5. Shaft	NZ082003	312 m (1025')	1131-1134
6. Shaft	NZ083003	320 m (050')	1135-1139
7. Shaft	NZ083004	320 m (1050')	1140-1143
8. "Fine's" tip	NZ085004	320 m (1050')	1144-1150
9. Shaft	NZ084005	312 m (1025')	1141-1154
10. Shaft	NZ085005	312 m (1025')	1155-1159
11. Shaft	NZ086005	305 m (1000')	1160-1166
12. Shaft	NZ086006	305 m (1000')	1167-1172
Wallnook Vein, strike 120°, downthrown north up to 30 m but mostly less here. Productive in Main Limestone and Cherts.			
13. Shaft	NZ087006	305 m (1000')	1173
14. Shaft	NZo86007	312 m (1025')	1174
15. Shaft	NZ085008	320 m (1050')	1175-1178
16. Shaft	NZ083009	320 m (1050')	1179-1182
17. Shaft	NZ082000	327 m (1075')	1183-1184
18. Shaft	NZ080011	335 m (1100')	1185-1187
Marske Fault, strike 125°, strong downthrow north. Productive in Main Limestone?			
19. Shaft	NZ084010	320 m (1050')	1188

Mineralization: Calcite, galena, barite, sphalerite.

Wallrock Alteration: Dolomitization.

Workings: Shaft workings along the line of the veins. Mostly shallow if the tip size is anything to go by. They are probably old workings, i.e. pre-1800 at the latest.

Details of Mineralization: Tips are composed principally of limestone and chert with veinstuff. Much of the veinstuff has limonite associated, reflecting the shallow depth of working. The main gangue mineral is calcite with barite occurring in small amounts in some localities, especially towards the east where the Cleaburn Pasture and Wallnook Veins intersect. Galena is common as small pieces and is accompanied at times with a little sphalerite. Gossan is mainly limestone and chert of porous decalcified character, with a little galena and cerussite with boxworks of limonite after sphalerite at times. Calcite and barite are found in the gossan and limonite is abundant. The gangue minerals are found massive and calcite may be found in large blocks, .5 m cubes. Occasional crystals of dog tooth calcite may be found. Well formed crystals of galena are more common and have been formed in open veins and as wallrock replacements. Steely galena is found, but rarely.

Other Occurrences Visited

In the western part of the Stainmore Trough there are several occurrences of mineralization which can be placed in the P Zone. The most insignificant of them occurs at Stoneclose Gill, Mallerstang, NY789009, 335 m (1100') where trial shafts at the level of the Main Limestone show minute traces of galena with a little more common calcite. There is at this point a confluence of three faults, one of which is major.

Proceeding northwards, following the Main Limestone outcrops, the Middle Fell Barite Mine is reached. At this point, i.e. NY853114, 457 m (1500') there are open pits working flats of barite along the line of a fault striking 170°, of small downthrow east. The limestone here is dolomitized and in veinlets along joints and replacements, along bedding, etc., there is banded pink and white barite grown into cavities. There are well-formed barite plates and wedges with inclusions of chalcopyrite and even galena. A little galena occurs as grains in the more massive barite. Squat crystals of clear calcite occur in some vugs as the latest phase. Specimens 0914-0928 are from this locality.

Near to Middle Fell at Mousegill Viaduct NY848122, 396 m (1300'), there is some limestone breccia with barite fill which can be found in the bank of the stream where a fault crosses the stream; however, it is not certain whether this is of local origin or from upstream at Middle Fell.

Following the Main Limestone further north is located the Cabbish Barite Mine near North Stainmore. At this location (NY839157, 335 m (1100')) a fault striking 050° of small downthrow south, is followed by a level, the tips of which contain much massive white barite in limestone, a little sandstone and rare coal. Galena is found plentifully in the barite and chalcopyrite inclusions within the crystals of barite. Chalcopyrite crystals are sometimes intergranular with the barite. Some of the limestone, especially in breccias, is dolomitized. Specimen numbers are 0901-0913.

Travelling further north, still in the Main Limestone to the Lunehead Mines (NY850200, 457 m (1500')) there is a complex of faults striking around 060°, with small downthrow south. These have been worked extensively by opencut, level and shaft. Specimens 0240-0250 were collected from the opencuts. They include massive white barite with galena bands from the vein cheek, and massive white barite with chalcopyrite inclusions and malachite staining from the vein a little further from the cheek. Massive barite and galena are abundant in the tips and opencuts.

A visit to the <u>Closehouse Mine</u> (NY850277, 457 m (1300')) which was permitted by George Athol Allen & Co. and guided by the Mine Manager, Mr. Frost, enabled specimens 0531-0548 tobe collected from the veins and replacement which constitute this major barite mine. The dolerite dyke is connected in some way with the Whin Sill. It strikes roughly 080° and is parallel to the faults which constitute the Lunedale Fault system, which throws down into the Stainmore Trough. Specimens of white massive barite with occasional galena are easily collected, but specimens of barite with chalcopyrite are less common. Very well formed clear crystals of barite can be obtained in the underground workings, but are uncommon in the main opencut, which works a replacement up to 6 m wide rather than the irregular vein deposits underground.

At <u>Barras End</u> (NY099011, 396 m (1300')) near Arkengarthdale, there are several levels and some hushes, the tips of which were examined. They had abundant barite and calcite and in one case much witherite. Galena was present, but hard to find. The main vein worked is the Grey Game Vein, strike 140°, downthrow east, although it is possible that the Foregill Veins may have also been worked.

Nearby at <u>Cobbler Hush</u> (NY995018, 411 m (1350')), workings are also in the P Zone with only barite and galena to be found. Barite is found in both massive and toothy forms. The vein worked here strikes 125° and has very small throw.

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To the north west beyond fluorite bearing tips there were workings where fluorite is no longer found. The tips at NY977029 (548 m (1800')) are among these workings. Specimens 1719-1723 from these tips contain massive pink and white barite, massive witherite and crystals of witherite and calcite (prismoidal). Secondary toothy and tuby barite is found here and galena is present in some of the witherite. Chalcopyrite is indicated by malachite staining on some of the barite.

Not far away the tips of Shaw Level (NZ001050, 366 m (1200')) revealed only calcite on the tips of dolomitized limestone, and further east the old shafts of Long Green Vein, Newsham Moor (NZ071064, 381 m (1250')) were examined. Again nothing was revealed other than dolomitized limestone. This vein strikes 165° and throws down to the east.

To the south the shaft tips of Holgate Vein (NZ075041, 335 m (1100')) revealed only a trace of galena in dolomitized limestone. This vein strikes 100° and has downthrow south.

At Richmond Out Moor (NZ130026, 305 m (1000')) a trial shaft revealed a little pink and white massive barite with galena and limonite in the Richmond Chert series rocks.

Occurrences Not Visited

<u>Punchard Gill Mines</u>: Extensive workings in the vicinity of Punchard Gill NY950040 are lead mines with a long history. No reports of fluorite have been found so the veins worked are probably all in the P Zone. The veins worked include Punchard Gill Vein, strike 120°, Wharton String 100°, Cocker Vein 100°, Blakethwaite Vein 100°, Bishop's Vein 090°.

<u>Stonesdale Mine</u>: NY884037. A subsidiary vein of the western extension of the Blakethwaite Vein is reported to have worked barite and galena. It strikes 070° and has a small downthrow south.

<u>Marrick Mines</u>: SD070986. Several old shafts in the area around Marrick village are reported to be lead mines and veins are marked on the one inch map.

Various mineralized localities visited by Dr. A. J. Wells in his survey, and not so far mentioned in this account are:-

<u>North Spanham Fault</u>: Strike 100°, downthrow south in the east and north in the west. This long fault has been worked at Ellerbèck Hush (NY990103), Spanham Hush (NZ010100) and the nearby level and shaft. Another vein nearby (NY990100) on Scargill High Moor (strike 125°) is followed by shafts and is reputedly a lead vein.

<u>Arndale Hill Fault</u>: NZ035069. Strike 100°, downthrow south. In the tips from shaft workings, the Main Limestone blocks are rich in galena, but no barite is mentioned.

<u>Applegarth Vein</u>: NZ013020. Strike 141°. Near Richmond Out Moor and has been worked for galena and barite.

<u>Low Feldom</u>: NZ110038. Extensive workings to the south and "south east" (west?) were for lead ore in flats.

<u>Oregate Vein</u>: NZ097020. Strike 065°. Shaft tips reveal breccia of Main Limestone cemented by barite and galena.

The Moredale Ridge Vein is reported as mineralized at <u>Moresdale</u> <u>Head</u> NZ025050 and <u>Moresdale Ridge</u> NZ048044 with traces of galena and at <u>Holgate Beck</u> NZ063042 where galena and calcite occur in veinlets in the three yard limestone.

C ZONE

Feldom Vein, Feldom Moor

Grid Ref: NZ120042   Altitude: 335 m (1100')

Structure: A long vein striking 070° in the west veering 055° in the east. It has a moderate downthrow to the south. Flats are also present nearby.

Stratigraphic Horizon: Main Limestone.

Mineralization: Barite, calcite, chalcopyrite, galena, goethite, malachite.

Wallrock Alteration: Dolomitization.

Workings: A long line of shallow shafts follow the vein from Grid Ref. NZ117041 to Grid Ref. NZ127046 and similar shafts work the flats nearby to the north, Grid Ref. NZ120045. Feldom Vein may be the Medieval Richmond Copper Mine. No production is recorded.

Details of Mineralization: The material from the many tips examined consists mostly of dolomitized limestone with moderately plentiful barite. The barite occurs in white-pink massive varieties and also as the arborescent aggregates of toothy crystals, so common in other parts of the orefield. Breccias are frequently cemented by a thin layer of chalcopyrite, then much barite.

One good specimen of such a breccia has part of its filling occupied by tree-like cavernous aggregates of toothy barite which definitely post date the platy massive barite; however, the origin of this toothy barite could still be from a replacement of witherite or just a late rapid growth into the vug. In some cases the final filling of breccias is of calcite and this is sometimes accompanied by galena. Occasionally there is a little limestone breccia cemented by calcite and galena.

Some disseminated chalcopyrite can be found in the dolomitized limestone, although much of the chalcopyrite is now replaced by goethite.

Chalcopyrite also occurs as inclusions in the barite.

No tips from the flat workings were examined.

The area is used as an army firing range and some tips have been blown up in demolition tests.

Specimens: 0075-0152, 0839-0851.

Richmond Veins, Richmond

Grid Ref: NZ164006   Altitude: 107 m (350')

Structure: Three veins strike 070° and throw down to the north.

Stratigraphic Horizon: Main Limestone and Richmond Cherts.

Mineralization: Calcite, chalcopyrite, malachite.

Wallrock Alteration: Dolomitization.

Workings: Two levels enter the west bank of the Swale Billy Bank Woods and there are also levels on the east bank of the Swale in Temple Grounds. Plans of the Billy Bank Woods levels have been drawn by L. Beevers, et al of the Moldywarps Speleological Group (1969). Clough (1962) reports a smelt mill being built for copper in 1585, but these workings were active until 1910 according to Caruthers in Dewey and Eastwood (1925)

Details of Mineralization: Small amounts of dolomitized limestone and chert can be found outside the levels and there are small amounts of colourless to white calcite with chalcopyrite, in veinlets. Small amounts of chalcopyrite are also found isolated, or in disseminations, but oxidation to limonite and malachite makes the original nature difficult to determine at times. The proximal workings were entered and the fault breccia examined. Little other than calcite and malachite could be seen in the clay filled breccia, but much had been stoped and so was presumably bearing.

Occasionally small joints and bedding planes had been excavated and calcite bearing chalcopyrite could be found remaining in some of them. Malachite was ubiquitous. Chalcopyrite is found as grains, massive bands, disseminations near joints etc. and as inclusions in calcite crystals. Little other than rare calcite, chalcopyrite and malachite can be seen in the Temple grounds.

Specimens: 0226-0239, 0807-0818

Forcett Quarry Veins, East Leyton

Grid Ref: NZ155105   Altitude: 152 m (500')

Structure: Two veins striking 050°, 055° with throw 6 m, 3 m, down to the north.

Stratigraphic Horizon: The Main Limestone and tuft sandstone beneath.

Mineralization: Barite, witherite, calcite, chalcopyrite, barite, covellite, digenite, malachite, azurite, (chalcanthite), pyrite.

Wallrock Alteration:

Workings: None seen. Trials reported from mid 18th century (Raisbrick, 1936).

Details of Mineralization: Fault breccias of the Main Limestone are cemented with much white platy barite. A little witherite accompanies this and there is much porous fine-grained, sometimes sugary, barite, which may result from its alteration.

Calcite occurs both massive and as squat scalenohedrons. Calcite sometimes occurs later than the large plates of barite, but specimens of well formed calcite crystals are often coated with a thin layer of very delicate barite plates of later origin.

Platy inclusions of chalcopyrite are common in the barite and calcite of these fault zones, and more pure massive chalcopyrite is sometimes found in these zones and in nearby dilated joints. Even massive chalcopyrite sometimes displays the unusual platy habit, which has been shown by etching to be an original grain texture of the mineral rather than cleavage directed weathering. Accompanying these minerals there is a certain amount of black felty covellite which fills cracks, etc. along which weathering has proceeded. Occasional grains of pyrite were seen in a mass of digenite and chalcopyrite. The digenite appears to be a replacement of the platy chalcopyrite and pyrite is only slightly altered to goethite.

In the tuft sandstone and shale beneath the limestone exposed
in the fault zone, there is a strong green colour due to copper minerals
and nodules consisting of diagenetic nodules of pyrite, which has been
replaced in part by bornite and to a small extent by chalcopyrite and
by covellite replacing bornite along its cleavages.

Chalcanthite was reported by Wells (1954), in a temporary exposure
and malachite, azurite and limonite are common in many parts of the
quarry as well as the fault zones.

Specimens: 0001-0050, 0067.

Kneeton Hall Veins, Middleton Tyas (Merrybent Mine)

Grid Ref: NZ210070   Altitude: 137 m (450')

Structure: Several veins, strike 355° – 020°.

Stratigraphic Horizon: Undersett Limestone.

Mineralization: Calcite, galena, chalcopyrite, bornite, digenite, chalcocite, covellite, malachite, limonite.

Wallrock Alteration: Dolomitization.

Workings: There are several shafts and a walled up level in Kneeton Hall quarry. A large tip at Merrybent Farm is overgrown. Mine plans are listed under Merrybent Mine and deposited with the Mines Record Office.

Production:

Year	Copper Ore Tons	Cwt.	Copper Tons	Cwt.	Lead Ore Tons	Cwt.	Lead Tons	Cwt.	Silver oz.
1864	76	0	7	5	150	0	107	0	-
1865	80	0	6	0	345	13	241	10	-
1866	-	-	-	-	205	0	150	0	750
1867	-	-	-	-	178	0	134	18	-
1869	-	-	-	-	135	0	103	0	-
1870	80	13	28	10	-	-	-	-	-
1873	72	6	4	6	131	10	97	16	-
1874	128	10	35	6	9	0	6	15	-

Details of Mineralization: Little of the veinstuff can be found, but that which was collected was very interesting. It is composed mainly of clear calcite crystals and galena grains of similar size. The galena has been partly replaced by chalcopyrite around the rims and that replaced in large part by bornite. This replacement is restricted to the rims, but in many instances further replacement of the core of the

galena grain and replacements of the bornite also occur. Digenite often rims the bornite and chalcocite replaces the main body of the galena. Covellite replaces both chalcocite and other sulphides and on occasion produces interesting sector twinned crystals of covellite with bornite "rims". The covellite itself and other minerals are altered in part to malachite which can be seen clearly as needle like crystals in hand specimen.

Specimens: 0064, 65.

Middleton Tyas Veins, and Black Scar Quarry, Middleton Tyas

Grid Ref: Middleton Tyas Village NZ232058   Altitude: 91 m (300')

              Black Scar Quarry   NZ232051   91 m (300')

Structure: At Middleton Tyas Village there is a vein of little throw, strike 120°, and joints and flats associated with the vein. At Black Scar Quarry mineralization occurs in joints and on bedding planes, with no fault nearby.

Stratigraphic Horizon: Undersett Limestone, perhaps extending into the Main Limestone in the village.

Mineralization: Calcite, chalcopyrite, bornite, chalcocite, covellite, cuprite, copper, malachite, azurite, limonite.

Wallrock Alteration: Dolomitization.

Workings: Many old intricate shaft workings at Middleton Tyas Village, worked in the mid 18th century (Raistrick, 1936). No production figures are available, but a smelt mill was built in the village to process the ore. No workings are present at Black Scar Quarry (Limestone).

Details of Mineralization: Little can be seen at Middleton Tyas except for the occasional trace of malachite amongst the limonite rich soil and limestone which constitute the largely overgrown tips. Occasional clear crystals of calcite can be found. The account of the mines by Jars (1781) gives a contemporary account of the workings and the ores from which one can deduce that there were irregular veins of calcite with malachite, and rounded irregular bodies of copper minerals (grey and peacock ores) in "ferruginous sand" filled cavities (joints?). Native copper and chalcopyrite were also produced from the workings. A flat was also worked (Raistrick 1936).

At Black Scar Quarry, joints filled with brown clay, etc. contain malachite nodules and a chalcocite sheet has been reported from one joint. The malachite nodules are complex and are actually made up of a core of covellite and malachite with a rim of limonite bearing, occasionally,

islands of cuprite with native copper. Malachite and azurite traces
are found all over the quarry. These traces of mineralization reflect
the original deposits in the village.

Specimens: 0062, 0827-0834 from Middleton Tyas Village;

0051-0063, 0826 from Black Scar Quarry.

C Zone Localities Not Visited

Dr. A. J. Wells records many localities where traces of copper minerals were found:

Coalsgarth Vein (trial) NZ147030 – Malachite and azurite

Beacon Hill Quarry NZ146025 – Malachite and azurite

Quarry near Richmond Old Race Course NZ166022 – Malachite and azurite

Bend Hagg Quarry NZ173022 – Malachite and azurite

Gingerfield Quarry NZ161040 – Malachite

Quarry near Richmond Hospital NZ172017 – Chalcopyrite, goethite and

malachite

Sedbury Park NZ204048 – Malachite

Five Hills NZ228066 – Malachite

Melsonby NZ198082 – Chalcopyrite and malachite

Kilmondside Quarry NZ023135 – Chalcopyrite and calcite

SECTION

C

XRF ANALYSIS CONDITIONS

Using Cr tube and flow counters

Line	Crystal	P	B	KV	MA	Mode
Si Kα	PE	108.92	110.00	60	32	100 sec. Abs.
Si Kα	KAP	30.98	32.00	40	16	10^5 cts. Rat.
Ca Kα	PE	44.77	43.00	60	32	100 sec. Abs.
Mg Kα	KAP	43.49	45.00	50	38	3×10 cts. Rat.

Using W. tube and scintilation counter, and LiF crystal

Line	B	P	B	KV	MA	Time (secs.)
Pb Lα	–	48.52	50.0	60	32	40
Ba Lα	15.32	15.54	–	45	20	40
Fe Kα	–	85.61	88.00	80	24	40
Cu Kα	64.83	65.43	66.50	60	32	40
Zn Kα	59.25	60.34	61.42	60	32	40
Mn Kα	94.0	95.11	–	80	24	100
Mo Kα	29.10	29.77	30.70	80	24	100
Co KB	68.52	69.21	29.92	80	24	400
Ni Kα	69.87	71.15	73.07	80	24	100
Sr Lα	34.66	35.60	36.62	80	24	200
Y Lα	32.74	33.63	34.66	80	24	200
Sb Lα	18.40	18.89	19.40	80	24	100
Sn Lα	19.80	19.62	21.05	80	24	100
Cd Lα	21.05	21.44	22.20	80	24	100
Ag Lα	21.05	22.48	24.30	80	24	100
Bi Lα	47.00	47.29	47.55	80	24	400
Hg Lα	50.65	51.45	52.80	80	24	100

P.H.A. was automatic. Spinner was used, and vacuum for the longer wavelengths.

Complicating Factors

Of the elements analysed two were affected by small tungsten peaks. They were Ag Lα and Hg Lα. The size of tungsten peaks (scattered) depends upon the matrix especially the amount of barium so calculations took all of these into account. The peak of Se Lα is also badly affected and could not be analysed for. The Sb Lα peak is interfered with by the Cd LB peak but the effects can be estimated well in galenas when Cd LB is small, and less well in sphalerites where Cd LB is large. Numerous barium peaks some apparently uncharted make it impossible to analyse for In Lα and complicates the positioning of backgrounds for Ag Lα and VKα. Lead peaks make it impossible to analyse for Ni Kα in Galenas, and in lead rich samples interferes with Y Lα determination. Large amounts of iron and copper make Co Kα and KB difficult or impossible to detect in small amounts. The extreme variations of matrix components made calibration and calculation of results difficult at times. As Kα, KB are impossible to measure in the presence of lead, and As Lα has negligible intensity even for high concentrations of As. Tungsten and lead peaks are fairly close to Bi Lα.

XRF STANDARDS

'Galena' majors – made from Analar grade chemicals

	Si	Ca	Ba	Pb	O	S	F
'MIP'	0	0	0	86.53	6.69	6.78	0
'M2P'	0	0	0	69.25	5.34	25.41	0
'M3P'	0	0	11.65	69.40	10.79	8.16	0
'M4P'	0	0	23.55	51.85	14.88	9.72	0
'M5P'	0	0	35.28	34.49	19.10	11.13	0
'M6P'	0	0	47.04	17.36	23.27	12.33	0
'M7P'	0	13.57	0	68.97	5.34	5.69	6.43
'M8P'	0	20.36	5.94	51.77	6.76	5.52	9.65
'M9P'	4.70	33.87	0	34.62	8.01	2.74	16.06
'M1OP'	9.31	13.51	17.49	17.67	20.13	15.48	6.41

'Chalcopyrite' majors – made from Analar grade chemicals

	Si	Ca	Fe	Cu	Ba	O	S	F
'M1C'	0	0	30.39	34.59	0	21.79	13.23	0
'M2C'	0	0	12.31	13.88	35.10	25.15	13.56	0
'M3C'	0	0	18.29	20.80	23.49	24.04	13.38	0
'M4C'	0	0	24.31	27.67	11.77	23.02	13.23	0
'M5C'	0	0	24.33	27.67	0	17.80	30.20	0
'M6C'	21.06	23.70	6.08	6.92	0	28.37	2.64	11.23
'M7C'	16.34	16.95	12.30	13.70	0	27.35	5.33	8.03
'M8C'	14.11	6.82	17.82	20.91	0	29.01	8.10	3.23
'M9C'	9.45	0	24.15	27.65	0	28.13	10.62	0

'Galena' traces - made from spec. pure chemicals

	Mn	Co	Ni	Zn	As	Ag	Cd	Sb	Pb	O
'T1P'	.0028	.0117	.0078	.0031	.0161	.0203	.0083	.0064	92.80	7.17
'T2P'	.0224	.0059	.0039	.0253	.0081	.0102	.0042	.0032	92.80	7.17
'T3P'	.0112	.0030	.0312	.0127	.0041	.0051	.0332	.0256	92.80	7.17
'T4P'	.0056	.0236	.0156	.0063	.0323	.0026	.0166	.0128	92.80	7.17
'T5P'	.0016	.0017	.0022	.0018	.0023	.0014	.0024	.0018	92.80	7.17
'T6P'	.0405	.0417	.0545	.0457	.0572	.0356	.0582	.0448	92.40	7.13

'Galena' with bismuth - made from spec. pure chemicals

	'BI1'	'BI2'	'BI3'
Pb	91.68	92.83	92.83
Bi	.9750	.0882	.0082
O	7.17	7.17	7.17

'Chalcopyrite' traces – made from spec. pure chemicals

	Mn	Fe	Co	Ni	Cu	Zn	As	Ag	Cd	Sb	O
'T1C'	.0029	34.90	.0117	.0079	39.90	.0033	.0161	.0209	.0085	.0065	25.00
'T2C'	.0231	34.90	.0058	.0040	39.90	.0260	.0080	.0105	.0042	.0033	25.00
'T3C'	.0116	34.90	.0029	.0317	39.90	.0130	.0040	.0052	.0338	.0260	25.00
'T4C'	.0058	34.90	.0234	.0158	39.90	.0065	.0321	.0026	.0169	.0130	25.00
'T5C'	.0016	34.90	.0016	.0022	39.90	.0018	.0022	.0014	.0023	.0018	25.00
'T6C'	.0488	34.90	.0435	.0619	39.90	.0551	.0597	.0384	.0661	.0510	25.00

'Chalcopyrite' with tin – made from spec. pure chemicals

	'SN1'	'SN2'	'SN3'
Sn	.3225	.1805	.0873

Fe $\simeq$ 34.9   Cu $\simeq$ 39.9   O $\simeq$ 25.0

'Gangue' majors — made from Analar grade chemicals

	Mg	Ca	Mn	Co	Zn	Ba	Hg	O	S	F	Cl
'S7'	0	13.55	0	0	0	47.09	0	21.94	11.10	6.42	0
'S8'	0	27.11	0	0	0	35.32	0	16.46	8.25	12.85	0
'S9'	0	40.69	0	0	0	24.04	0	11.20	5.61	19.29	0
'S10'	0	54.24	0	0	0	11.79	0	5.49	2.75	25.72	0
'S11'	2.05	60.95	0	0	0	0	0	5.40	2.71	28.89	0
'S12'	4.05	53.55	0.657	0	0	0	0	11.63	5.34	25.38	0
'S13'	0	0	0	0	64.24	11.79	0	21.21	2.75	0	0
'S14'	0	20.42	1.92	0	56.15	0	0	13.74	0	9.68	0
'S15'	5.87	6.63	0	0	23.31	17.11	0	30.23	11.73	3.16	0
'S16'	20.20	0	0	0	0	0	0	53.16	26.62	0	0
'S17'	0	0	0	0	80.34	0	0	19.66	0	0	0
'S18'	0	0	0	0.115	78.51	0	1.34	19.40	0	0	0.613

Strontium Spiked Barite - made from Analar grade chemicals

	'S19'	'S20'	'S21'	'S22'	'S23'
Sr	1.97	2.13	2.80	3.55	5.49 (corrected for initial strontium)

Fluorite with Yttrium (made by F. W. Smith)

	'S1'	'S2'	'S3'	'S4'	'S5'	'S6'
Ba	0	.0271	.0136	.0096	.0064	.0053
Y	0	.0819	.0359	.0177	.0087	.0043

Calcite with Yttrium (made by K. Ashworth)

	'10000'	'5000'	'2500'	'1250'	'630'	'310'	'160'	'80'	'40'
Y	.0956	.0478	.0239	.0119	.0058	.0029	.0019	.0009	.0004

Spiked Pyrite, Series A (in departmental collection)

	Fe	S	
'2500PA'	46.00	53.00	2500 ppm of Mn, Ni, Ag, Cd, Sb
'1800PA'	46.20	53.2	1800 ppm of Mn, Ni, Ag, Cd, Sb
'1000PA'	46.30	53.3	1000 ppm of Mn, Ni, Ag, Cd, Sb
'500PA'	46.40	53.4	500 ppm of Mn, Ni, Ag, Cd, Sb
'250PA'	46.42	53.42	250 ppm of Mn, Ni, Ag, Cd, Sb
'125PA'	46.45	53.45	125 ppm of Mn, Ni, Ag, Cd, Sb
'60PA'	46.45	53.45	60 ppm of Mn, Ni, Ag, Cd, Sb
'30PA'	46.48	53.48	30 ppm of Mn, Ni, Ag, Cd, Sb
'15PA'	46.52	53.50	15 ppm of Mn, Ni, Ag, Cd, Sb

Spiked Pyrite, Series B (in departmental collection)

As above except that traces are of Co, Ni, As, Cd, Sb

ELECTRON PROBE DATA

Conditions of Analysis

Line	Crystal	B	P	B	Standard	Counter
Pb Mα	Qtz	102° 00'	104° 25'	107° 00'	PBM2	Flow
As Lα	KAP	38° 00'	42° 37'	45° 00'	AS L1	Flow
Ca Kα	Qtz	59° 00'	60° 20'	64° 00'	CAK2	Scint.
P Kα	Mica	32° 00'	35° 45'	38° 00'	PⳢK2	Flow
Cl Kα	Qtz	87° 00'	90° 03'	93° 00'	CLK2	Flow
Ba Lα	LiF	85° 00'	87° 12'	90° 00'	BAL2	Scint.
Sr Lα	PET	101° 00'	103° 23'	106° 00'	SRL2	Flow
S Kα	PET	74° 00'	75° 42'	77° 00'	SⳢK3	Flow
Sb Lα	LiF	115° 00'	117° 18'	120° 00'	SBL1	Flow
Fe Kα	LiF	55° 00'	57° 32'	59° 00'	FED4	Scint.
Cu Kα	LiF	44° 00'	45° 02'	47° 00'	CUK1	Scint.
Zn Kα	LiF	40° 00'	41° 48'	41° 46'	ZNK1	Scint.
Ag Lα	PET	55° 00'	56° 35'	59° 00'	AGL1	Flow
Pb Mα	PET	68° 00'	76° 52'	72° 00'	PBM2	Flow
Sn Lα	PET	47° 50'	48° 27'	49° 10'	SNL1	Flow

All analysis at 40 nA probe current

Program: SMOOTH (in PL1)

Purpose: To smooth fault and vein density data

Method: Data is entered into a rectangular array. Each datum represents

the magnitude of a variable such as density in a known area on a map.

For example each datum may represent fault length measured for each

kilometre square. The data is smoothed by taking larger squares or rec-

tangles within the main array and calculating the average for the area.

This average is then assigned to the central position of the corresponding

square or rectangle of a new array. There is an edge effect so a border

of zero's appears around the edge of the new array. The smoothing process

is rather like the "moving mean" frequently used in statistical studies

to remove seasonal effects.

Input: B = Title of 40 characters or less

   X = Integer dimension of array

   Y = Integer dimension of array

   D1 = Integer variable determing size of area to be averaged

   D2 = Integer variable determing size of area to be averaged

   If D1 & D2 = 1 area averaged = 3X3. If D1, D2 = 2, then area = 5X5 etc.

   A(X,Y) = Array (fixed binery) of data to be smoothed

   Enter in order A(1,1), A(1,2), A(1,3) . . . A(2,1), A(2,2) . . .

            A(X,Y)

Output: 'Map' of the new array (ARES) which has been smoothed.

Comment: Although vein density, fault density, and fault intersection

data were all measured (entailing many weeks of tedious work) only the

fault density was actually processed. The results of one set of con-

ditions are the basis of Fig. 2
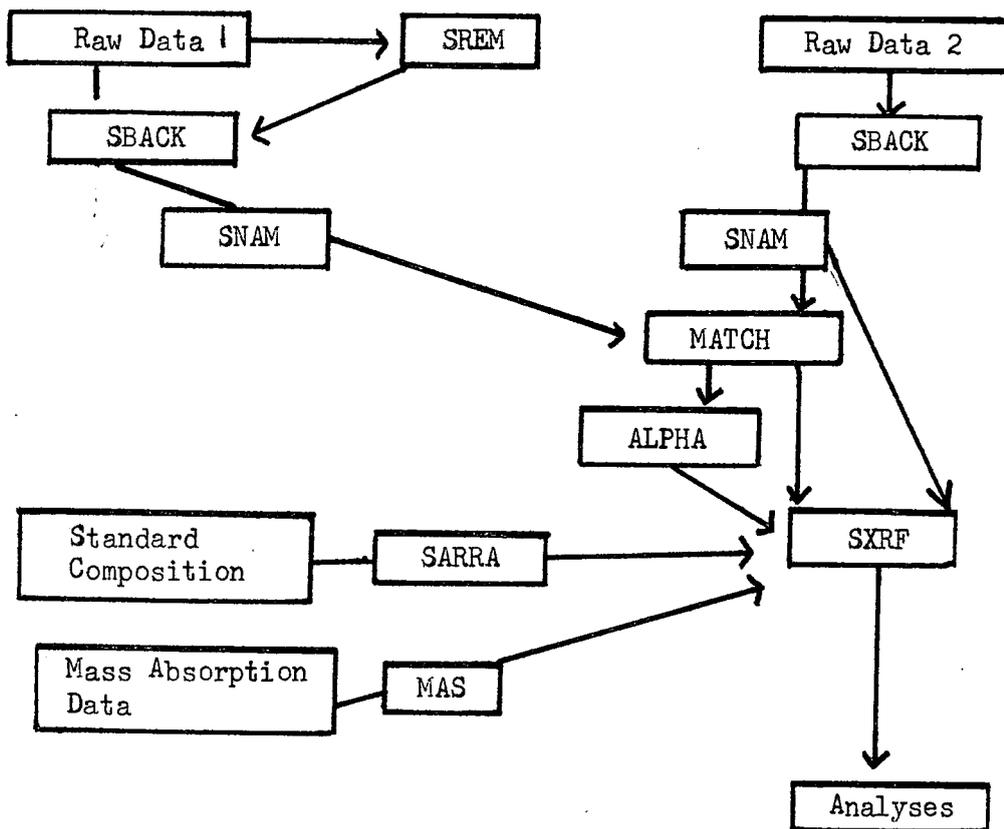
```
 1.000    SMOOTH:PROC OPTIONS(MAIN);
 2.000        ON ENDPAGE(SPRINT);
 3.000        DCL B CHAR(40),
 4.000            A(X,Y) FIXED BIN CONTROLLED,
 5.000            ARES(X,Y) FLOAT CONTROLLED,
 6.000            (AREA,X,Y,I1,I2,J1,J2,I,J,D1,D2) FIXED BIN;
 7.000        GET LIST(B,X,Y,D1,D2);
 8.000        ALLOCATE A,ARES;
 9.000        GET LIST(A);
10.000        ARES=0;
11.000        AREA=(1+2*D1)*(1+2*D2);
12.000        DO I1=(1+D1) TO (X-D1);
13.000          DO J1=(1+D2) TO (Y-D2);
14.000            DO I2=I1-D1 TO I1+D1;
15.000              DO J2=J1-D2 TO J1+D2;
16.000                ARES(I1,J1)=ARES(I1,J1)+A(I2,J2);
17.000              END;
18.000            END;
19.000            ARES(I1,J1)=ARES(I1,J1)/AREA;
20.000          END;
21.000        END;
22.000        PUT PAGE EDIT(B)(A(40));
23.000        DO I=1 TO 60 WHILE (I-1<X);
24.000          PUT SKIP;
25.000          DO J=1 TO 40 WHILE (J-1<Y);
26.000            PUT EDIT(ARES(I,J))(F(3));
27.000          END;
28.000        END;
29.000        PUT PAGE EDIT(B,'CONTD EASTRDS')(A(40),A(13));
30.000        DO I=1 TO 60 WHILE (I-1<X);
31.000          PUT SKIP;
32.000          DO J=41 TO 80 WHILE (J-1<Y);
33.000            PUT EDIT(ARES(I,J))(F(3));
34.000          END;
35.000        END;
36.000        PUT PAGE EDIT(B,'CONTD SOUTHRDS')(A(40),A(14));
37.000        DO I=61 TO 120 WHILE (I-1<X);
38.000          PUT SKIP;
39.000          DO J=1 TO 40 WHILE (J-1<Y);
40.000            PUT EDIT(ARES(I,J))(F(3));
41.000          END;
42.000        END;
43.000        PUT PAGE EDIT(B,'CONTD SEASTRDS')(A(40),A(14));
44.000        DO I=61 TO 120 WHILE (I-1<X);
45.000          PUT SKIP;
46.000          DO J=41 TO 80 WHILE (J-1<Y);
47.000            PUT EDIT(ARES(I,J))(F(3));
48.000          END;
49.000        END;
50.000        END SMOOTH;
```

XRF Programs

A series of programs were written to process raw XRF data and calculate the analyses. They can be used in the following manner:

```
┌──────────────┐      ┌──────────┐              ┌──────────────┐
│  Raw Data 1  │─────▶│  SREM    │              │  Raw Data 2  │
└──────────────┘      └──────────┘              └──────────────┘
       │                                               │
       ▼                                               ▼
  ┌──────────┐                                   ┌──────────┐
  │  SBACK   │◀──                                │  SBACK   │
  └──────────┘                                   └──────────┘
       │                                               │
       ▼                                               ▼
   ┌──────────┐                                  ┌──────────┐
   │  SNAM    │                                  │  SNAM    │
   └──────────┘                                  └──────────┘
         │                                          │
         ▼                                          ▼
                          ┌──────────┐
                          │  MATCH   │
                          └──────────┘
                               │
                               ▼
                          ┌──────────┐
                          │  ALPHA   │
                          └──────────┘
  ┌──────────────┐
  │  Standard    │    ┌──────────┐              ┌──────────┐
  │  Composition │────│  SARRA   │─────────────▶│  SXRF    │
  └──────────────┘    └──────────┘              └──────────┘
                                                     │
  ┌──────────────┐    ┌──────────┐                   ▼
  │ Mass Absorption│──│  MAS     │              ┌──────────┐
  │  Data        │    └──────────┘              │ Analyses │
  └──────────────┘                              └──────────┘
```

SXRF is the Main Program and SBACK is the main preparatory program, but all the others can be of value. The job control language has not been included as this changes occasionally and can be easily obtained from the N.U.M.A.C. instruction guides.

Examples of data and output are not included as they are voluminous, but all information required for preparing data has been included.

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Program: SREM (in PL1)

Purpose: To remove unwanted data from 'fixed binery' data with repetitive "format". Principally designed for removing monitor values from raw X.R.F. data, or for removing unwanted estimates from the same data, as would occur if a background value was considered misleading, or if an element had also been measured in another run, or by another method or was no longer required.

Method: Trivial

Program:

```
SREM:PROC OPTIONS (MAIN);
        DCL (A(N), B(N)) FIXED BIN(31) CONTROLLED;
        ON ENDFILE (SCARDS) BEGIN;
           PUT SKIP(2);
           M = 0;
           END;
        GET LIST (N);
        ALLOCATE A, B;
        M = 1;
        GET LIST (B);
        DO WHILE (M = 1);
        GET LIST (A);
        PUT SKIP;
        DO I = 1 TO N;
           IF B(I) = 1 THEN
              PUT LIST (A(I));
        END;
        END;
        END SREM;
```

Input: (In 'free format')

　　　　(a) N = Total number of intensities per group of samples (Integer)

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(b) B (N) = Array of 0's and I's indicating those which should
occur in the output. (0's correspond to the values to be
removed)

(c) A (N) = Intensities for first group of samples.

(d) (c) repeated for the remaining group of samples.

Program: SBACK (in PL1)

Purpose: To take X.R.F. intensity data and remove background estimates from peak values. It was written because the program in common use TAPE is written only for "major element" data of common rocks e.g. basalts and has a strict format, which is not at all suitable for the traces and majors required in studying mineralization. The output from SBACK can be treated to feed program SXRF the principal program of this series.

Method: The program requires information regarding the number and names of elements determined, the angular positions of peaks and backgrounds, and the number of samples in each group of intensities (normally 3 or 4). This data is used to decide how to estimate the background in the following ways:-

1. If only the peak is measured then background is assumed to be zero.

2. If only one background is measured with the peak then that is assumed to be the true background.

3. If two backgrounds are measured then the angular positions are used to calculate two factors which when multiplied by the corresponding intensity values give an estimate of the background at the peak position.

The backgrounds are subtracted from peaks and the results printed out with a new line or card for each sample.

Input: (In 'free format')

1. TB 'fixed binery' or 'float' with value = 1 if peaks and estimates of background are to be printed

   = 0 if peaks only are to be printed.

2. E 'fixed binery' or 'float' = Number of elements determined.

3. A(E) 'character string' array = E strings of two character element symbols.

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4. P(E,3) 'Fixed binery' array filled by entering unit character string = 3 x E strings of one character 'B', 'P' or 'M' representing the position or absence of peaks and backgrounds. 'B' = background position measured, 'P' = peak position measured, 'M' = background position absent. Hence the format should be 'B' or 'M' followed by 'P' followed by 'B' or 'M' repeated E times.

5. WANG1, WANG2, ANGLE. 'Float' can be entered as decimals = Angular positions of the 'P's and 'B's in order of occurrence in the data.

6. L 'Fixed binery' = number of samples in a group of intensity (counts) data. Normally 1, 3 or 4.

7. DATA (E,3,L) 'Fixed binery' (whole numbers only) = the intensity (counts) data. It can be in free format, but numbers must be in the following sequence:-

   L intensities for first L samples in angular position 1
   L intensities for first L samples in angular position 2

   L intensities for first L samples in angular position n
   L intensities for next L samples in angular position 1

If the intensity data is from "ratio" operation of the X.R.F. machine then the counts data for the monitor (only measured on peaks) must be removed before data is fed into this program. Program SREM can be used for this job.

Output: Print output consists of values of the array P (presence and absence of backgrounds and peaks) followed by the values of the two factors for each element. Then the main output of peak values with or without background estimates is printed one line per sample. Finally the number of samples processed is printed.

Card or stored output is fed into file SMOCK and consists only of peak values with or without background estimates. Element symbols are printed at the top of each new page.

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```pli
1.000    SPACK:PROC OPTICNS(MAIN);
2.000    DCL SMOCK FILE,
3.000        A(E) CHAR(2) CONTROLLED,
4.000        B CHAR(1),
5.000        FACTOR(E,2) FLOAT CONTROLLED,
6.000        (DATA(E,3,L),PUTUT(E,4,2),P(E,3)) FIXED BIN(31) CONTROLLED;
7.000    GET LIST(TB);
8.000    GET LIST(E);
9.000    ALLOCATE A,FACTOR,P;
10.000   GET LIST(A);
11.000   ON ENDPAGE(SPRINT) BEGIN;
12.000   PUT PAGE LIST('A.T.SMALL BACKGROUND CORRECTION');
13.000   PUT SKIP LIST(A);
14.000   PUT SKIP(2);
15.000   END;
16.000   P=0;
17.000   DO I=1 TO E;
18.000   DO J=1 TO 3;
19.000   GET LIST(B);
20.000   IF B='B' | B='P' THEN P(I,J)=1;
21.000   END;
22.000   END;
23.000   PUT SKIP LIST(P);
24.000   FACTCR=0;
25.000   DO I=1 TO E;
26.000   DO J=1 TO 3;
27.000   IF P(I,J)=0 THEN DO;
28.000   IF J=1 THEN
29.000   FACTCR(I,1)=0;
30.000   IF J=3 THEN

31.000       FACTOR(I,2)=0;
32.000   END;
33.000   IF P(I,J)=1 THEN DO;
34.000   IF J=1 THEN DO;
35.000       GET LIST(WANG1);
36.000       FACTOR(I,1)=1;
37.000       END;
38.000   IF J=2 THEN GET LIST(ANGLE);
```

```
41.000          IF J=3 THEN DO;
42.000             GET LIST(WANG2);
43.000             IF P(I,1)=0 THEN DO;
44.000                FACTOR(I,1)=0;
45.000                FACTOR(I,2)=1;
46.000             END;
47.000             ELSE DO;
48.000                FACTOR(I,2)=(ANGLE-WANG1)/(WANG2-WANG1);
49.000                FACTOR(I,1)=(WANG2-ANGLE)/(WANG2-WANG1);
50.000             END;
51.000          END;
52.000       END;
53.000       PUT SKIP LIST('FACTORS');
54.000       PUT SKIP LIST(FACTOR);
55.000
56.000
57.000    GET LIST(L);
58.000    ALLOCATE DATA,PUTUT;
59.000    DATA,PUTUT=0;
60.000    NMN=0;
61.000    ON ENDFILE(SCARDS) BEGIN;
62.000       PUT SKIP LIST('NUMBER OF SAMPLES',NMN);
63.000       STOP;
64.000    END;
65.000    START:DO I=1 TO E;
66.000       DO J=1 TO 3;
67.000          IF P(I,J)=0 THEN
68.000          DO K=1 TO L;
69.000             GET LIST(DATA(I,J,K));
70.000             IF J=3 THEN DO;
71.000                IF FACTOR(I,1)=0 THEN
72.000                IF FACTOR(I,2)=0 THEN DO;
73.000                   PUTUT(I,K,1)=DATA(I,2,K);
74.000                   PUTUT(I,K,2)=0;
75.000                END;
76.000                ELSE DO;
77.000                   PUTUT(I,K,1)=DATA(I,2,K)-DATA(I,3,K);
78.000                   PUTUT(I,K,2)=DATA(I,3,K);
79.000                END;
```

```
80.000        IF FACTOR(I,1)=1  THEN
81.000        IF FACTOR(I,2)=0 THEN DO;
82.000           PUTUT(I,K,1)=DATA(I,2,K)-DATA(I,1,K);
83.000           PUTUT(I,K,2)=DATA(I,1,K);
84.000        END;
85.000        IF FACTOR(I,1)¬=1 & FACTOR(I,1)¬=0 THEN DO;
86.000           FACT=DATA(I,1,K)*FACTOR(I,1)+DATA(I,3,K)*FACTOR(I,2);
87.000           PUTUT(I,K,1)=DATA(I,2,K)-FACT;
88.000           PUTUT(I,K,2)=FACT;
89.000        END;
90.000        END;
91.000        END;
92.000        END;
93.000        END;
94.000        IF TB=1 THEN
95.000        DO K=1 TO L;
96.000           PUT SKIP LIST(PUTUT(*,K,*));
97.000           PUT FILE(SMOCK) LIST(PUTUT(*,K,*));
98.000        END;
99.000        IF TB=0 THEN
100.000       DO K=1 TO L;
101.000          PUT SKIP LIST(PUTUT(*,K,1));
102.000          PUT FILE(SMOCK) LIST(PUTUT(*,K,1));
103.000       END;
104.000    NMN=NMN+1;
105.000    GO TO START;
106.000    END SBACK;
```

Program: SNAM (PL1)

Purpose: To link sample names with the intensity data from program SBACK.

Method: Trivial

Program: SNAM: PROC OPTIONS (MAIN);

```
            DCL NAME CHAR (6),
                A(N) FIXED BIN (31) CONTROLLED,
                (COUNTS, OUTP) FILE;
            GET LIST (N);
            ALLOCATE A;
            ON ENDFILE (SCARDS) BEGIN;
                PUT SKIP (2);
                M = 0;
            END;
            ON ENDFILE (COUNTS) BEGIN;
                PUT SKIP (2);
                M = 0;
            END;
            M = 1;
            DO WHILE (M = 1);
            PUT SKIP;
            PUT FILE (OUTP) SKIP;
            GET LIST (NAME);
            GET FILE (COUNTS) LIST (A);
            PUT FILE (OUTP) LIST (NAME, A);
            PUT LIST (NAME, A);
            END;
            END SNAM;
```

Input: Sample names are entered in order through the standard input file (SCARDS). The intensity data are entered through the file COUNTS from cards or storage.

Output: Print from the standard output file (SPRINT) and cards or
storage etc. from the file OUTP.

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Program: MATCH (in PL1)

Purpose: To combine output from different runs of the XRF machine for use in program SXRF.

Method: Sample names from 2 PL1 structures are compared and the results for the same samples are combined and given as output.

Input: From the standard input file SCARDS read in

SA = Number of samples in run one (file one). Integer

SB = Number of samples in run two (file two). Integer

EA = Number of elements in run one (file one). Integer

EB = Number of elements in run two (file two). Integer

From file ONE read in structure A

1, A(SA). 2,AN sample name up to six characters

2,AC(EA) EAX Intensities (fixed binery)

From file TWO read in structure B

1, B(SB). 2,BN sample name up to six characters

2,BC(EB). EBX Intensities (fixed binery)

Output: Into standard print file SPRINT all out put

Into file THREE all out put except value of total number of samples.

Notes: If no corresponding name can be found in structure B then the nul values of -1010 are entered into file THREE to indicate those elements have not been analysed. This is utilized in program SXRF. When a sample has been "taken" from structure B into file THREE then it can not be used again. Any not taken from structure B when structure A has been used are printed into file THREE with nul values for the elements analysed in run one (structure A).

```
4.000    MATCH:PROC OPTIONS(MAIN);
5.000         DCL 1 A(SA) CONTROLLED,
6.000              2 AN CHAR(6),
7.000              2 AC(EA) FIXED BIN(31),
8.000            1 B(SB) CONTROLLED,
9.000              2 BN CHAR(6),
0.000              2 BC(EB) FIXED BIN(31),
1.000            (SA,SB,EA,EB) FIXED BIN,
2.000            (ONE,TWO,THREE)FILE,
3.000            ELEM(JI) CHAR(2) CONTROLLED,
4.000            (NUL1(EB),NUL2(EA))FIXED BIN CONTROLLED;
5.000       ON ENDFILE(ONE) PUT SKIP LIST('ENDFILE ONE ERROR');
6.000        ON ENDFILE(TWO) PUT SKIP LIST('ENDFILE TWO ERROR');
7.000       GET LIST(SA,SB,EA,EB);
8.000       /*NOSAMPLESINONE,NOSAMPLESINTWO,NOELEMENTSONE,NOELEMENTSTWO*/
9.000       JI=EA+EB;
0.000       ALLOCATE A,B,ELEM,NUL1,NUL2;
1.000       L=0;    NUL1=-1010  ; NUL2=-1010;
2.000       GET FILE(ONE) LIST(A);
3.000       GET FILE(TWO) LIST(B);
4.000       DO I=1 TO SA;
5.000         NUT=1;
6.000         DO J=1 TO SB WHILE(NUT=1);
7.000           IF AN(I)=BN(J) THEN DO;
8.000            PUT FILE(THREE) LIST(AN(I),AC(I,*),BC(J,*));
9.000            PUT FILE(THREE) SKIP;
0.000            PUT LIST(AN(I),AC(I,*),BC(J,*));
1.000         PUT SKIP;
2.000            BN(J)='USED';
3.000            NUT=-1;
4.000            L=L+1;
5.000                              END;
6.000       IF J=SB & AN(I)]=BN(J) THEN DO;
7.000            PUT FILE(THREE) LIST(AN(I),AC(I,*),NUL1);
8.000            PUT FILE(THREE) SKIP;
9.000            PUT LIST(AN(I),AC(I,*),NUL1);
0.000            PUT SKIP;
1.000            L=L+1;
2.000                                       END;
3.000         END;
4.000       END;
5.000       DO J=1 TO SB;
6.000         IF BN(J)]='USED' THEN DO;
7.000            PUT FILE(THREE) LIST(BN(J),NUL2,BC(J,*));
8.000            PUT FILE(THREE) SKIP;
9.000            PUT LIST(BN(J),NUL2,BC(J,*));
0.000            PUT SKIP;
1.000            L=L+1;
2.000                              END;
3.000       END;
4.000       PUT SKIP LIST(L);
5.000       END MATCH;
```

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Program: Alpha

Purpose: This program was written to remove the effects of interfering peaks. It only works for the situation where a subsidiary peak of element B interferes with the main peak of element A.

Method: The coefficient which expresses the relationship between the main peak and subsidiary peak of the interfering element is calculated from a single standard of pure B or a pair of standards of A & B mixtures. The height of the subsidiary peak for each sample is calculated using the main peak of B and the coefficient. This is subtracted from the main peak of element A and printed.

Program:

```
4.000   ALPHA:PROC OPTIONS(MAIN);
5.000       DCL (ONE, TWO) FILE,
6.000           N(NN) FIXED BIN(31) CONTROLLED, A CHAR(6);
7.000       GET LIST (NN, NZ, C, LN1, LN2);
8.000       /*NO ELEMENTS, NO SAMPLES, COEFFICIENT,
             DTO CORRECT WITH DTO CORRECT*/
9.000       ALLOCATE N;
10.000      DO I=1 TO NZ;
11.000          GET FILE(ONE) LIST (A,N);
12.000          N(LN2) = N(LN2) - C*N(LN1);
13.000          PUT FILE(TWO) LIST (A,N);
14.000          PUT FILE(TWO) SKIP;
15.000          PUT SKIP LIST (A,N);
16.000      END;
17.000      END ALPHA;
```

Input: All from file ONE

   NN = Number of elements

   NZ = Number of samples

   C = Coefficient for multiplying with main peak of element B

LN1 = Position in data array of peak B

LN2 = Position in data array of peak A and subsidiary peak B

A = Sample name

N(NN) = Intensity data for sample   repeated

Output: Corrected data into file TWO

Program: SARRA

Purpose: To create a data block of standard names and compositions from a more comprehensive data set. The standard composition data block is needed for calibration in program SXRF.

Input: IOPT1 = 1 if main data block is to be printed out, otherwise 0

IOPT2 = 1 if new data block is to be created.

E = Number of elements

NS = Number of standards

ELEMEN = Element symbols. E strings of two characters.

NAMES = Standard names. NS strings of up to six characters.

IND1 = Position equivalent to Standard names. Integer

IND2 = Position equivalent to Element name. Integer

COMPS(IND1,IND2) = Concentration of element INDR in standard IND1

repeated until IND1 = -11

Next variable are optional i.e. required when IOPT2 = 1

J = Number of elements in new data block.

NELEM(J) = Element symbols for new data block. Two characters

Output: Into file OUT. Everything if IOPT1 & IOPT2 both = 1 or else just the main block (IOPT1 = 1) or the subsidiary block (IOPT2 = 1)

```
5.000    SARRA:PROC OPTIONS(MAIN);
6.000         DCL E FIXED BIN;
7.000         DCL 1 STAND CONTROLLED,
8.000              2 ELEMEN(E) CHAR(2),
9.000              2 NAMES(NS) CHAR(6),
10.000             2 COMPS(NS,E) FLOAT;
11.000         GET LIST(IOPT1,IOPT2);
12.000         GET LIST(E,NS);
13.000         ALLOCATE STAND;
14.000         GET LIST(ELEMEN,NAMES);
15.000         COMPS=0;
16.000         DO WHILE(IND1¬=-11);
17.000           GET LIST(IND1,IND2);
18.000         IF IND1¬=-11 THEN DO;
19.000           GET LIST(COMPS(IND1,IND2));
20.000         END;
21.000           END;
22.000         IF IOPT1=1 THEN DO;
23.000         PUT FILE(OUT) LIST(E,NS,ELEMEN);
24.000         PUT FILE(OUT) SKIP;
25.000         DO I=1 TO NS;
26.000       PUT FILE(OUT) LIST(NAMES(I),(COMPS(I,N)DO N=1 TO E));
27.000         PUT FILE(OUT)SKIP;
28.000         END;
29.000         END;
30.000         IF IOPT2=1 THEN DO;
31.000         GET LIST(J);
32.000         BEGIN;
33.000         DCL 1 NSTAND,
34.000              2 NELEM(J) CHAR(2),
35.000              2 NNAMES(NS) CHAR(6),
36.000              2 NCOMP(NS,J) FLOAT;
37.000         NNAMES=NAMES;
38.000         GET LIST(NELEM);
39.000         DO I=1 TO J;
40.000           DO I1=1 TO E;
41.000             IF (ELEMEN(I1)=NELEM(I)) THEN
42.000             DO I2=1 TO NS;
43.000           NCOMP(I2,I)=COMPS(I2,I1);
44.000             END;
45.000           END;
46.000         END;
47.000         DO N=1 TO NS;
48.000       PUT FILE(OUT) LIST(NNAMES(N),NCOMP(N,*));
49.000         END;
50.000         END;
51.000         END;
52.000         STOP;
53.000       END SARRA;
```

Program: MAS (in PL1)

Purpose: To create mass absorption data block for use in program SXRF,
and to select a smaller data block for SXRF from a large data block.

Method: Program requires to be fed with the main data block and the
names of the elements and wavelength names required. The method is a
simple sifting.

Input: NEP = Number of elements possible (large block)

NEA = Number of elements analysable (large block)

NEAP = Number of elements actually present (small block)

NEAA = Number of elements actually analysed (small block)

EL1(NEP) = Element symbols. Two characters (large block)

NAME1 = Wavelength name, e.g. FEKA   repeated

MAB1(NEP) = Mass Absorption coefficients (NEP of them)   NEA times

EL2 (NEAP) = Element symbols (small block)

NAME2 (NEAA) = Wavelength names (small block)

Output: Into standard print file SPRINT: large block and small block

Into file CAR for storage or cards: small block only

```
MAS:PROC OPTIONS(MAIN);
   DCL (FL1(NEP),FL2(NFAP)) CHAR(2) CONTROLLED,
       (NAME1(NEA),NAME2(NEAA)) CHAR(4) CONTROLLED,
       (MAB1(NEA,NEP),MAB2(NEA,NEAP)) FLOAT CONTROLLED,
       CAR FILE OUTPUT;
   GET LIST(NEP,NEA,NEAP,NFAA);
   ALLOCATE FL1,FL2,NAME1,NAME2,MAB1,MAB2;
   GET LIST(FL1);
   DO I=1 TO NEA;
      GET LIST(NAME1(I),MAB1(I,*));
   END;
   GET LIST(EL2);
   PUT SKIP EDIT('        ')(A(4));
   DO I=1 TO NEAP;
      PUT EDIT(EL2(I))(X(7),A(2));
      IF I=12 | I=24 THEN PUT SKIP EDIT('    ')(A(4));
   END;
   PUT SKIP;
   DO I=1 TO NEAA;
      GET LIST(NAME2(I));
      PUT EDIT(NAME2(I))(A(4));
      DO J=1 TO NFA;
         IF NAME1(J)=NAME2(I) THEN
            DO K=1 TO NEAP;
               DO L=1 TO NEP;
                  IF FL1(L)=EL2(K) THEN DC;
                     MAB2(I,K)=MAB1(J,L);
                     PUT FILE(CAR) LIST(MAB2(I,K));
                     PUT EDIT(MAB2(I,K))(F(9,2));
                     IF K=12 | K=24 THEN PUT SKIP EDIT('____')(A(4));
                  END;
               END;
            END;
      PUT FILE(CAR) SKIP;
      PUT SKIP;
   END;
END MAS;
```

Program: SXRF

Purpose: This program is designed to calibrate sets of composition – intensity data of standard materials, and to then determine the composition of unknown materials whose intensity data has been determined under the same conditions as the standards. It has been written to link with programs SBACK, SNAM etc., and to thereby process X-Ray Fluorescence data. Many of the features of this program are specific to XRF calculations. The program was needed, because the program used in Durham i.e. XRFPL1 by M. J. Reeves, is "oxide based" and not suitable for the materials studied.

Language: PL1 with Fortran subrontines EO2ABF(NAG), and Plotter routines (DURPLOT).

Method: The experimentally determined intensity data for samples (both standards and unknowns) and the sample names are entered into storage, along with a data block containing the compositions and names of the standards.

The program then selects the experimental data for standards and calibrates this against the compositional data. The NAG (Nottingham Algorithem Group) sub routine EO2ABF which incorporates Forsythes Method fits least mean square polynomials to two input arrays of the corresponding values of experimental parameter in the F array and known parameter in the X array. The subroutine attempts to fit polynomials of order rising from 0 to the specified maximum and gives an answer corresponding to the first good fit of lower order than the specified maximum. An estimate of the error of each fit is also returned by the subroutine.

Having calibrated the experimental and compositional data for the standards the experimental data is all processed with the aid of subroutine ROOT written in the program to give the composition of unknowns and standards, which can be printed out and stored. The composition calculation can be simple or itterative.

Details: The experimental data (measured counts or counts-background, and sample names) are read into the program from an input file COUNTS which must have data stored in the following form:-

'NAME' 12345 12674 15432 . . .

with a name of length less than or equal to 6 characters with enclosing apostrophes, followed by m numbers which will be the measured counts for each of the m elements for that sample. m can be any known number and one can have any known number of samples (limited only by computer space limits). The numbers are read as fixed binary numbers so that if fractional data for other techniques is used it should firstly be scaled up. If any of the numbers are -1010 then the program recognizes them as no experimental result and acts accordingly in removing that sample from any calibration with that element, and also later gives the concentration as 0 or not determined.

The standard compositions are read in through the input file DAT in the following format:-

'NAME' 0.25 25.20 . . . where 'NAME' is less than or equal to 6 characters and is followed by n numbers (the known concentrations) in per cent, which are read as floating point numbers and so can be entered as decimal numbers, whole numbers, or in scientific notation (1.0E0 = 1). If a matrix correction is to be applied the numbers must be as per cent, but if not required any numbers can be used. If any numbers are negative the program will attempt to calculate their values from the other elements using a calculation routine. n must be at least as large as m. The calculation routine uses the known or analysed concentrations (C_1 - C_m) and a coefficient matrix (X_{11} - X_{mn}) to generate the concentrations of all elements (C_1 - C_n) using the expression

$$\sum_{i=1}^{m} C_i X_{ij} = C_j$$

where j has values 1 to n., or m + 1 to n to save time. A more complicated

calculation could be used instead of this, such as a sort of normative distribution of elements in a specified order.

The program scans the two blocks of data above mentioned for identical names and then builds up an internal calibration data block (a PL1 structure) SSS which is composed of the following elements:-

(a) the sample name,

(b) the $\underline{m}$ experimental parameters (counts)

(c) an optional $\underline{m}$ matrix corrected experimental parameter

(d) the known parameters (compositions)

This data block is printed out through the output file OUT and can be modified by reading in appropriate data if required. The calibration data is then read into suitably sized arrays D, F and SF which contain M1 values of the known parameter (F) and M1 values of the corrected parameter (SF) if required. Values of -1010 cause concentrations (X) and intensity (F) to be ignored in filling the arrays.

The arrays are then checked to ensure there are sufficient different values in X to allow the fitting of the maximum specified polynomial. If there are not the maximum order is lowered. The arrays are then slightly rearranged to put the lowest X value first and the highest last, making the same elements move in other arrays. This ensures correct functioning of EO2ABF. If the first and last elements are the same after this the program prints out a message advising that there is no standard for that element, and then misses it out of the proceedings except to print zero for its "determined" concentrations later on. The lack of checks in EO2ABF makes such preliminaries necessary. The need for their incorporation was only discovered after many hours trying to unravel execution errors with real data. The problem was complicated by the PL1-Fortran inter-action.

Control data is read in through input file DAT and includes the maximum order of polynomial for each experimentally measured element.

$(\text{POLYD}(*))$, and also a logical variable L which if given the value 1 causes EO2ABF to return the maximum polynomial, and if 0 the first good fit. With the control and calibration data EO2ABF calculates least mean square fits to each chemical element in turn. The coefficients can be printed out, and the option 'graph' allows a graph of each calibration to be printed on the graph plotter.

The program next solves the polynomial for each element, for the experimental values of each sample. The polynomials are solved using subroutine ROOT which uses the following methods:-

1. For 1st order polynomials $x = (y - c)/m$

2. For 2nd order polynomials with no x terms $x = {}^+\sqrt{\dfrac{y - c}{m}}$

3. For 2nd order polynomials with x terms

$$x = \frac{-b \pm \sqrt{b^2 - fa\ (c - y)}}{2a} \text{ in range } X_0^{100} \text{ (or less)}$$

4. For 3rd order or higher polynomials

Newtons approximation

$$x = x_0 - \left(\frac{dy}{dx}\ f(0)/f(0)\right) \text{ in range } X_0^{100} \text{ (or less)}$$

The concentrations calculated directly from the intensity measurement and the coefficients for uncorrected counts against concentration are printed out and an itterative calculation of a matrix corrected concentration may be carried out as follows:-

(a) To correct for the absorbing effects of a matrix it is necessary to correct the measured intensity to an intensity at constant matrix absorption, usually the mass absorption of the pure element being measured. A calibration is carried out at constant absorption by correcting the standard intensities thus

$$I_{corrected} = I_{measured} \times \frac{\underline{\text{Mass Absorption Coefficient}}}{\text{MAC Element}} \text{Matrix}$$

$$MAC_{Matrix} = \sum_{i = 1}^{m} MAC_i \times Concentration_i$$

(b)   Then the unknown sample intensities are corrected

$$I_j = \frac{I_j{}^0 \; (\mu_j{}^*) \; est}{jj}$$

Where $(\mu_i{}^*)$ est is an estimate of the mass absorption of the matrix for the element j being corrected. It is best calculated from the concentrations (corrected to sum to 100%), because the sum of concentrations may not be very close to 100%.

(c)   The composition of the unknowns is then determined using the procedure ROOT and the correction carried out again using the new normalized concentrations in the $(\mu_i{}^*)$ est.

(d)   The process is repeated until a fairly consistent answer is produced.

This itterative method requires that all concentrations of elements be known, subject to analysis or calculable from the other elements (e.g. oxygen). The concentrations resulting will not necessarily sum to 100% especially if the calibration has been poor or if some elements have not been determined, or if the calculation is based on an incorrect chemical structure (e.g. if calcite is present instead of fluorite). This itterative method is closely allied to that employed in XRFPL1 (Reeves) and both arrive at systematically incorrect total concentrations with some sorts of mixtures. This is partly due to the inadequacy of the mass absorption correction especially with mixtures of elements of very different atomic numbers. Such mixtures also produce inaccurate calibrations which contribute to the errors.

The final analysis is printed and also put into the output file STAD which can be copied to * PUNCH * as a permanent record of the analysis.

Options: The program can be run in several different ways:-

1.   No matrix correction and no calibration. 'NOMAC', 'NOCAL'. The calibration data must be supplied by the user then the program will calculate from the experimental data "uncorrected" concentrations.

2.   No matrix correction. 'NOMAC' 'CAL' 'GRAPH' or 'NOGRA'. The composition of standards is supplied and the program calculates the concentrations of unknowns.

3.   Matrix correction etc. The composition of standards and the mass absorption block (or empirical factors block) are all supplied and unknowns are calculated.

Some options not mentioned so far are:-

1.   Standards can be ignored for some elements during running by specifying the standard names and elements at the correct time.

2.   The concentrations of some elements analysed by a different technique can be fed into the program to be used in matrix corrections. Their values remain unchanged by the program.

3.   If a normalized solution is required the 'NORM' option arranges for the last result to be normalized.

Problems: Calibration using polynomials of order greater than 1 can produce difficulties especially if the standard range is not much greater than the range of unknowns. The problem is most accentuated in analysing for heavy elements in light matrices since a maximum can be introduced just inside the range of standards. This could be especially important in the uncorrected intensity versus concentration calibration. When a maximum or minimum occurs within the range -5 to 100% finding the correct root becomes more difficult. Using linear equations, however, can cause inaccuracy because at least in the uncorrected calibration values can be under or over estimated.

These problems and perhaps others not yet understood have meant that the calculated analysis has not been all that could be desired. The use of mineral concentrates has, however, meant that the problems were not intractable.

Input: Source file, variable, description.

DAT, CARD Title of work, up to 80 characters

DAT, NUMBER M.T.S. user number

DAT, OPT Calibration option. 'CAL', 'EXT'

DAT, COPT Mass Absorpiton Correction. 'MAC', 'NOMAC'

DAT, GRAPH Graph option. 'GRAPH', 'NOGRA'

DAT, ADJ Option to alter YYY during running 0 = not required

1 = required

DAT, NOR Normalized last answer 'NORM' = required 'NOTR' = not

required

DAT, N Number of elements present. Integer

DAT, M Number of elements analysed. Integer

DAT, NS Number of standards. Integer

DAT, CO Number of samples. Integer

DAT, SSS Number of standards, including repeats. Integer

DAT, LIM Number of itteration required in calibration. Integer

DAT, POLYD Maximum order of polynomial + 1. Integer

DAT, NOM 0 = First good fit polynomial. 1 = Order specified

DAT, SLIM 'Precision' of Newton's approximation

DAT, RANG (4,M) Range of values

DAT, TEST Print option 1 = Prints out input data 0 = not printed

DAT, VEST Print option 1 = Prints out calibration data

0 = not printed

DAT, JEST Print option 1 = Prints out YYY 0 = not printed

DAT, STAND Optional only with OPT = 'CAL' = Block of standard

compositions. In format N5X ('ST0001', N x concentration)

COUNTS, COUNTO   Counts data. Format CO x ('SA0001', M x intensity)

DAT, X(N, N-M)   Calculation data for unanalysed N-M elements

DAT, ELT(N)   Element symbols N x strings of 2 characters

DAT, MAB(M,N)   Optional only with COPT = 'MAC'. Mass absorption
        coefficients of N elements present for each of the
        M analysed elements in turn

DAT, ZZ   First row of analysed values (i.e. First element analysed
        by different technique)

DAT, ZZZ   Last row of analysed values (i.e. Last element analysed
        by different technique)

DAT, KJI   Number of samples with analyses

DAT, CHEN (KJI)   Names of samples with analysed values 6 characters

DAT, CHEM (KJI, NTZ)   Analysed values (NTZ = ZZZ-ZZ+1)

DAT, CN (M)   M values of orders of polynomials

DAT, CCN (M)   As above for absorption corrected
        results   Optional, required

DAT, COEF (M,POL)   Coefficients for each of the   if
        M polynomials   OPT = 'EXT'

DAT, CCOEF (M,POL)   As above for absorption
        corrected results

INP, AME   Standard name 'ST0001'   Values to be removed

INP, AEL   Element name   from calibration

        AME & AEL   can be repeated in pairs with the last AME = 'X'.

Output: Print into files   OUT = YYY printed if ADJ = 1

                        PRINT = roll data

        Cards or storage into file   STAD = Sample names and final
                                calculated composition

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 2.000    SXRF:PROC OPTIONS(MAIN);
 3.000    ON CONVERSION BEGIN:
 4.???       PUT SKIP LIST(ONSOURCE,'HAS NOT THE CORRECT ATTRIBUTES');
 5.000       STOP;
 6.000       END;
 7.???       DCL PCL FIXED BIN(31);
 8.000    DCL(CM(M),CCN(M),POLYD(M))FIXED BIN(31) CONTROLLED,
 9.000       (SSS,TOTAL,NOM,CO,N,M,NS,ZZ,ZZZ,KJI)FIXED BIN(31),
10.000       (X(N,N),COMP(N),CAMP(N),MAF(M,N),CCEF(M,POL),CCOEF(M,POL),
11.000       CRCI(4),SE(M),CSF(M),CHEM(KJI,NTZ))FLOAT(16) CONTROLLED,
12.???       (MAC,FOUAT,SCOUNT,SLIM,ADJ)FLOAT(16),
13.000       FLT(N)CHAR(2)CONTROLLED,
14.000       CHEM(KJI) CHAR(6)CONTROLLED,
16.???       CAPD CHAR(80)VARYING,
16.000       (OPT,COPT,GRAP)CHAR(6),
17.000       TITLE CHAR(74),
18.000       HEAD CHAR(17);
19.000    DCL (VM(2,M),RAMC(4,M)) FLOAT(16) CONTROLLED,
21.???       GUFS FLOAT(16);
21.000    DCL V(2) FLOAT(16);
22.000    DCL NCR CHAR(6);
23.???       DCL ALI CHAR(3) INITIAL('ALL');
24.000    DCL(COUNTS,DAT,INP)FILE INPUT,
25.000       (OUT,PRIN)FILE PRINT,
26.000       STAD FILE OUTPUT;
27.000    DCL 1 TS,
28.000       2 NUMBER CHAR(6),
29.000       2 BLANK CHAR(2) INITIAL('   '),
30.000       2 CORRT CHAR(9) INITIAL('       '),
31.???       2 CLANK CHAR(15) INITIAL('COUNTS AGAINST'),
32.000       2 ELEMEN CHAR(2),
33.000       ST CHAR(34),
34.???       1 YYY(SSS) CONTROLLED,
35.000       2 NAME CHAR(6),
36.000       2 CQINT(M) FLOAT(16),
37.000       2 CCOUN(M) FLOAT(16),
38.000       2 PCOM(N) FLOAT(16),
39.000       1 COUNTG(CC) CONTROLLED,
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40.000          2 TTL CHAR(6),
41.000          2 KOUNT(M) FLOAT(16),
42.000        1 FX CHAR(74)DEFINED TITLE,
43.000        1 STAND(NS) CONTROLLED,
44.000          2 PTL CHAR(6),
45.000          2 CMP(N) FLOAT(16);
46.000    LCL ROOT ENTRY(FLOAT(16),FIXED BIN(31),(*)FLOAT(16),FLOAT(16),
47.000          FLOAT(16),FLOAT(16),FLOAT(16),(*)RETURNS(FLOAT(16)),
48.000    GRAPH ENTRY((*)FLOAT(16),FIXED BIN(31),(*)FLOAT(16),(*)FLOAT(16),
49.000                            FIXED BIN(31),CHAR(34));
5 .            TITLE='THIS PROGRAM WAS WRITTEN BY A.T.SMALL FOR THE CALCULATION O
51.000    F X.R.F RESULTS';
52.000    HEAD='SXRF BY A.T.SMALL';
53.   .    GET FILE(DAT) LIST(CARD);
54.000         /*TITLE OF WORK*/
55.000    GET FILE(DAT) LIST(NUMBER);
56.   .        /*X.T.S. USER NUMBER*/

57.000    GET FILE(DAT) LIST(OPT,COPT,GRAP,ADJ);
58.   .        /*CALIBRATION,MASSABSCORRCTN,GRAPH,AMENDYYY*/
59.000    GET FILE(DAT) LIST(NOE);
6 . .     /* NORMALIZED END ANSWER */
61.000    GET FILE(DAT) LIST(N,M,NS,CO,SSS);
62.000         /*NOELS,NOELSANI ZD,NOSTDS,NOSAMPS,NOSTDRUNS*/
63.   .    ALLOCATE X,CCMP,CAMP,MAR,CN,CCN,ELT,YYY,COUNTO,POLYD,SF,CSE;
64.000    IF OPT='CAL' THEN ALLOCATE STAND;
65.   .    IF INDEX(FX,'A.T.S')¬=29 THEN STOP;
66.000    GET FILE(DAT) LIST(LIM,POLYD,ACM,SLIM);
67.000        /*NO.ITERATIONS,ORDERPOLY+1,LOGICAL,PRECISION*/
68.000    POL=5;
69.000    ALLOCATE RANG,VM;
70.000        GET FILE(DAT) LIST(RANG);
71.   .    ALLOCATE CCEF,CCCEF;
72.000    GET FILE(DAT) LIST(TEST,VEST,JEST);
73.000        /*INPUTDATA,CALIBRATIONDATA,PRINTOUTYYY*/
74.CCO    IF OPT= 'CAL' THEN
75.000    GET FILE(DAT) LIST(STAND);
76.   .       /*STANDARD COMPOSITIONS*/
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GET FILE(COUNTS) LIST(COUNTO);
/*COUNTS DATA*/
X=0;
    DO I=1 TO N;
    X(I,I)=1;
    END;
    IF N>M THEN
    DO J=1 TO N;
    DO I=M+1 TO N;
    GET FILE(DAT) LIST(X(J,I));
    /*    CALCULATION DATA    */
    END;
END;
    GET FILE(DAT) LIST(ELT);
    /* ELEMENT SYMBOLS    */
IF COPT='MAC' THEN
GET FILE(DAT) LIST(MAR);
/*MASS ABSORPTION BLOCK*/
GET FILE(DAT) LIST(ZZ,ZZZ,KJI);
NTZ=ZZZ-ZZ+1;
IF KJI>3 THEN DO;
ALLOCATE CHEN,CHEM;
GET FILE(DAT) LIST(CHEN,CHEM);
                END;
/*STARTROWANAL,ENDRANAL,NOANALS,ANALNAMES,ANALYSES*/
PUT FILE(PRIN) EDIT(TITLE)(A(74))PAGE;
PUT SKIP FILE(PRIN) EDIT(CARD)(A(80));
IF TEST=1 THEN
PUT FILE(PRIN) DATA(N,M,NS,CO,SSS,LTM,POLYD,NOM,ELT,X);
IF COPT='MAC' & TEST=1 THEN
PUT FILE(PRIN) DATA(MAR);
IF OPT='CAL' THEN DO;
/*SELECTION OF STANDARD RUNS */
TOTAL=0;
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111.000          CCOUN=0;
112.000          DO I=1 TO CO;
113.000          DO J=1 TO NS;
114.000          IF TTL(I)=PTL(J) THEN
115.000          DO;
116.000            TOTAL=TOTAL+1;
117.000            NAME(TOTAL)=TTL(I);
118.000            PRO=;
119.000            DO K1=1 TO N WHILE(PRO=0);
120.000            IF OMP(J,K1)<0 THEN
121.000            PRO=1;
122.000            END;
123.000            IF PRO=1 THEN
124.000            DO K2=1 TO N;
125.000            IF OMP(J,K2)>0 THEN
126.000            DO K3=1 TO N;
127.000            IF OMP(J,K3)<0 THEN
128.000            PCOM(TOTAL,K3)=PCOM(TOTAL,K3)+OMP(J,K2)*X(K2,K3);
129.000            END;
130.000            DO K4=1 TO N;
131.000            IF OMP(J,K4)=0 THEN
132.000            PCOM(TOTAL,K4)=0;
133.000            IF OMP(J,K4)>0 THEN
134.000            PCOM(TOTAL,K4)=OMP(J,K4);
135.000            IF OMP(J,K4)<0 THEN
136.000            OMP(J,K4)=PCOM(TOTAL,K4);
137.000            END;
138.000            DO K5=1 TO M;
139.000            IF COPT='MAC' THEN DO;
140.000            MAC=0;
141.000            DO K6=1 TO N;
142.000            MAC=MAC+PCCM(TOTAL,K6)*MAB(K5,K6)/100;
143.000            END;
144.000            END;
145.000            COUNT(TOTAL,K5)=KOUNT(I,K5);
146.000            IF COPT='MAC' THEN
147.000            IF KOUNT(I,K5)-=-1010 THEN
148.000 _____
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149.000        CCOUN(TOTAL,K5)=KOUNT(I,K5)*MAC/MAB(K5,K5);
150.000        IF COPT='MAC' & KOUNT(I,K5)=-1010 THEN
151.000        CCOUN(TOTAL,K5)=-1010;
152.000        END;
153.000        END;
154.000        END;
155.000        IF JEST=1 THEN
156.000        IF JEST=1 THEN
157.000    PUT FILE(PPIN) PAGE EDIT(YY)(SKIP,A(6),(M)(F(8,0),SKIP,X(6),
158.000        (M)(F(8,0)),SKIP,X(6),(M)(F(8,4)));
159.000        IF ADJ=1 THEN DO;
160.000    PUT FILE(OUT) EDIT(YY)(SKIP,A(6),(M)(F(8,0),SKIP,X(6),
161.000        (M)(F(8,0)),SKIP,X(6),(N)(F(8,4)));
162.000        DCL AME CHAR(6),
163.000        AEL CHAR(2) INITIAL('Z');
164.000        ISIG=1;
165.000        ON ENDFILE(INP) BEGIN;
166.000        ISIG=0;
167.000        GO TO T;
168.000        END;
169.000        DO WHILE(ISIG=1);
170.000        GET FILE(INP) LIST(AME);
171.000        DO WHILE(AEL¬='X');
172.000        GET FILE(INP) LIST(AFL);
173.000        IF AFL¬='X' THEN
174.000        DO I=1 TO SSS;
175.000        IF NAME(I)=AME THEN
176.000        DO J=1 TO M;
177.000        IF ELT(J)=AFL THEN
178.000        CCOUN(I,J),CCUNT(I,J)=-1010;
179.000        END;
180.000        END;
181.000        END;
182.000        AFL='Z';
183.000        T:END;
184.000        END;
185.000        COFF,CCOFF=0;
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```
PR:BEGIN;
   DCL (L,K1,M1,N,VAR)FIXED BIN(31),
       (F(VAR),SF(VAR),X(VAR),W(VAR),P(NTIT),
       ST(NTIT))FLOAT(16) CONTROLLED;
   VAR=0;
   VNN=0.00001;
   L=ACR;
   DO I=1 TO M;
   ELEMEN=FLT(I);
   N=2;
   DO J=1 TO TOTAL;
   IF COUNT(J,I)¬=-1010 THEN
   VAR=VAR+1;
   END;
   M1=VAR;
   ALLOCATE F,SF,X,W;
   F=0;  SF=0;  X=0;
   NNN=0;
   W=1;
   DO J=1 TO TOTAL;
   IF COUNT(J,I)¬=-1010 THEN
   DO;
   NNN=NNN+1;
   F(NNN)=COUNT(J,I);
   IF COPT='MAC' THEN
   SF(NNN)=CCOUN(J,I);
   X(NNN)=PCOM(J,I);
   END;
   END;
   NTIT=1;
   DO K=2 TO NNN;
   NIT=0;
   DO K2=K-1 BY -1 TO 1;
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219.000          IF X(K)=X(K2) THEN NIT=1;
220.000            END;
221.000          IF NIT=0 THEN NIT=NTIT+1;
222.000        END;
223.000      IF NTIT>POLYD(I)-1 THEN DO;
224.            K1=POLYD(I);
225.000          NTIT=POLYD(I);
226.000        END;
227.          ELSE K1=NTIT;
228.000      ALLOCATE P,SI;
229.000      P=0;      SI=0;
230.000    FT=X(1);
231.000    NXX=1;
232.030    FM=X(1);
233.000    NMX=1;
234.000    DO NX=2 TO M1;
245.          IF X(NX)>FT THEN DO;
237.000        FT=X(NX);
237.000        NXX=NX;
238.000      END;
239.000      IF X(NX)<FM THEN DO;
240.135        FM=X(NX);
241.000        NMX=NX;
242.000      END;
243.         END;
244.000    IF NXX-=M1 THEN DO;
245.000      X(NXX)=X(M1);
246.000      X(M1)=FT;
247.000      FT=F(NXX);
248.          F(NXX)=F(M1);
249.000      F(M1)=FT;
250.000      FT=SF(NXX);
251.033      SF(NXX)=SF(M1);
252.000      SF(M1)=FT;
253.000    END;
254.000    IF NMX-=1 THEN DO;
255.000      X(NMX)=X(1);
256.          X(1)=FM;
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257.000        FM=F(NMX);
258.000        F(NMX)=F(1);
259.???        F(1)=FM;
260.000        FM=SF(NMX);
261.000        SF(NMX)=SF(1);
262.000        SF(1)=FM;
263.000        END;
264.000        IF X(1)-=X(M1) THEN DO;
265.000        IF VEST=2 THEN
266.000 PUT FILE(PRIN) DATA(M1,X,F,W,K1,SI,P,1);
267.000        PUT FILE(PRIN) SKIP;
268.???        PUT FILE(PRIN) SKIP;
269.000        CALL EQ2ABF(M1,X(1),F(1),W(1),K1,N,SI(1),P(1),L);
270.000        DO J=1 TO N+1;
271.???        COEF(I,J)=P(J);
272.000        END;
273.???        CN(I)=N;
274.000        SE(I)=SI(N+1);
275.000        ST=NUMBER||BLANK||CORRT||CLANK||ELEMEN;
276.CCC        IF GRAP='GRAPH' THEN
277.000        CALL GRAPH(P,N,F,X,K1,ST);
278.???        SI= ;  P=?;
279.000        N=0;
280.000        IF COPT='IMAG' THEN
281.???        DO;
282.000        F=SF;
283.000        IF VEST=2 THEN
284.000 PUT FILE(PRIN) DATA(M1,X,F,W,K1,SI,P,L);
285.000        PUT FILE(PRIN) SKIP;
286.000        CALL EQ2ABF(M1,X(1),F(1),W(1),K1,N,SI(1),P(1),L);
287.000        CO J=1 TO N+1;
288.000        CCOFF(I,J)=P(J);
289.000        END;
290.000        CORRT='CORRECTED' ;
291.???        ST=NUMBER||BLANK||CORRT||CLANK||ELEMEN;
292.000        IF GRAP='GRAPH' THEN
293.000        CALL GRAPH(P,N,F,X,K1,ST);
294.???
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CCN(I)=N;
CSE(I)=SI(N+1);
SI=0; P=0;
END;
END;
IF X(J)=X(M1) THEN PUT FILE(PRIN) SKIP LIST('NO STANDARD FOR',
    FLT(J));
VAP=0;
PEEE F,SF,X,M,SI,P;
END;
END BB;
END;
IF OPT='EXT' THEN
GET FILE(DAT) LIST(CN,CCN,COEF,CCOEF);
    IF VEST=1 | VEST=2 THEN DO;
PUT FILE(PRIN) EDIT('CALIBRATION RESULTS')(X(20),A(19))PAGE;
PUT FILE(PRIN) EDIT('ELEMENT','CROEP','COEFFICIENTS','ERROR')
    (A(7),X(1),A(5),X(1),A(12),X(1),A(5))SKIP;
DO I=1 TO M;
PUT FILE(PRIN) SKIP;
PUT FILE(PRIN) EDIT(ELT(I),CN(I))(A(2),X(2),F(2))
    (COEF(I,*))(X(2),F(12,2));
PUT FILE(PRIN) SKIP;
    (SE(I))(X(2),F(16));
PUT FILE(PRIN) EDIT(FLT(I),CCN(I))(A(2),X(2),F(2))
    (CCOEF(I,*))(X(2),F(12,2));
    (CSE(I))(X(2),F(16));
END;
END;
IF INDEX(HEAD,ALL)=15 THEN STOP;
ON ENDPAGE(PRIN) BEGIN;
PUT FILE(PRIN)PAGE;
```

```
327.000        PUT FILE(PRIN) EDIT(HEAD)(A(17));
328.              PUT FILE(PRIN) SKIP EDIT('SAMPLE')(A(6));
329.000          DO NMO=1 TO N;
330.000          PUT FILE(PRIN) EDIT(ELT(NMO))(X(5),A(2));
331.              IF NMO=11 | NMO=22 THEN
332.000          PUT FILE(PRIN) EDIT(' ')(A(6));
333.000          END;
334.              PUT FILE(PRIN) EDIT('TOTAL')(X(7),A(5));
335.000          PUT FILE(PRIN) SKIP;
336.000      PAG:
337.         VR=0;
338.000      DO I=1 TO M;
339.000      APL,NPM=1;
340.000      IF CN(I)>1 | CCN(I)>1 THEN
341.000      DO VX=0.1 BY 0.5 TO 100.1;
342.         V(1)=COEFF(I,1);
343.000      V(2)=COEFF(I,1);
344.000          DO J=2 TO CN(I)+1;
345.             V(1)=V(1)+COEFF(I,J)*XX**J-1;
346.000          DO J=2 TO CCN(I)+1;
347.000          V(2)=V(2)+CCOEFF(I,J)*XX**J-1;
348.000      END;
349.000      END;
350.             IF APL=1 THEN DO;
351.000          IF V(1)>VM(1,I) THEN
352.000          VM(1,I)=V(1);
353.000          VM(1,I)=V(2);
354.         IF V(1)<VM(1,I) THEN DO;
355.000          RANG(2,I)=XX-0.5;
356.000          NPL=0;
357.000          END;
358.000          END;
359.000          IF NPM=1 THEN DO;
360.000          IF V(2)>VM(2,I) THEN
361.000          VM(2,I)=V(2);
362.             IF V(2)<VM(2,I) THEN DO;
363.000          RANG(4,I)=XX-0.5;
                 NPM=0;
```

```
364.000          END:
365.000          END:
366.000   END:
367.???   END:
368.500          PUT FILE(PRIN) SKIP LIST(RANG,VM):
369.000          SIGNAL ENDPAGE(PRIN);
370.???          DO I=1 TO CC;
371.000             COMP=0;
372.000             JKI=1;
373.000             DO J=1 TO M;
374.000             QUES=(RANG(1,J)+RANG(2,J))/2;
375.???             SCOUNT=KOUNT(I,J);
376.000             IF COPT='CRCTN' THEN SCOUNT=SCOUNT*CRCT(J);
377.000                IF SUM(COEF(J,*))-=0 THEN
378.???             IF KOUNT(I,J)-=-1010 THEN
379.000                COMP(J)=ROOT(SCOUNT,CN(J),COEF(J,*),SLIM,RANG(1,J),
381.???                RANG(2,J),       QUES,VM(1,J));
382.???             ELSE COMP(J)=0;
383.???          IF COMP(J)=-99 THEN DO;                                              (5)
384.000             PUT FILE(PRIN) SKIP LIST('TWO ROOTS IN RANGE');
385.???             PUT FILE(PRIN) SKIP DATA(FLT(J),RANG(*,J));
386.000             PUT FILE(PRIN) SKIP;
387.000             PUT FILE(PRIN) SKIP;
388.???          STOP;
389.000          END;
390.000          IF COMP(J)<0 THEN COMP(J)=0;
391.???          END;
392.000          IF JEST=1 THEN DO;
393.000             PUT FILE(PRIN) EDIT(TTL(I))(A(6)) SKIP;
394.000          DO NMO=1 TO M;
395.000          PUT FILE(PRIN) EDIT(KOUNT(I,NMO))(X(2),F(8));
396.???             IF NMO=11 | NMO=22 THEN
397.000             PUT FILE(PRIN) SKIP EDIT('                     ')(A(6));
398.000          END;
399.???       IF KJI> THEN
400.000          DO IJK=1 TO KJI WHILE(JKI=1);
```

```
401.000       IF TTL(I)=CHEM(IJK) THEN
402.000       LMN=IJK;
403.000              JKI=0;
404.000       END:
405.000           DO K=1 TO LIM;
406.000           IF N>K THEN
407.000           DO K1=M+1 TO N;
408.000           DO K2=1 TO M;
409.000               COMP(K1)=COMP(K1)+COMP(K2)*X(K2,K1);
410.000           END;
411.000           END;
412.000       IF KJI>0 THEN DO:
413.000           NXX=0;
414.000           DO IJ=ZZ TO ZZZ;
415.000           COMP(IJ)=CHEM(LMN,NXX);
416.000           NXX=NXX+1;
417.000           END;
418.000       END:
419.000           TOT=SUM(COMP);
420.000           IF NOR='NORM' THEN
421.000       IF K=LIM & TOT=0 THEN DO;
422.000           COMP=COMP*100/TOT;
423.000           TOT=100;
424.000           END;
425.000       PUT FILE(PRIN) EDIT(TTL(I))(A(6))SKIP;
426.000       DO NMO=1 TO N;
427.000       PUT FILF(PRIN) EDIT(COMP(NMO))(X(2),F(8,4));
428.000           IF NMO=11 | NMO=22 THEN
429.000       PUT FILF(PRIN) EDIT(' ')(A(6))SKIP;
430.000       END;
431.000       PUT FILF(PRIN) EDIT(TOT)(X(2),F(8,4));
432.000       IF TOT-= ' THEN
433.000           IF K-=LIM THEN DO:
434.000           IF COPT='MAC' THEN DO;
```

```
          CANP=0;
          COMP=COMP*100/TOT;
          DO K1=1 TO N;
             MAC=0;
             GUES=COMP(K1);
             IF GUES-30-<RANG(3,K1) THEN
             RANG(3,K1)=GUES-30;
             IF GUES+30->RANG(4,K1) THEN
             RANG(4,K1)=GUES+30;
             IF COMP(K1)-=0 THEN
             DO K2=1 TO N;
                MAC=MAC+WAB(K1,K2)*COMP(K2)/100;
             END;
   IF (KOUNT(I,K1)-=-1110) & (SUM(CCOEF(K1,*))-=0) THEN
          IF KOUNT(I,K1)-=0 THEN DO
          FCUNT=KOUNT(I,K1)*MAC/WAB(K1,K1);
          CAMP(K1)=ROOT(FCOUNT,CCN(K1),CCOEF(K1,*),SLIM,RANG(3,K1),
          RANG(4,K1),GUES,VM(2,K1));
   IF CAMP(K1)=-99 THEN DO;
          PUT FILE(PRIN) SKIP LIST('TWO ROOTS INRANGE');
          PUT FILE(PRIN) SKIP DATA(ELIT(K1),RANG(*,K1));
          PUT FILE(PRIN) SKIP;
          PUT FILE(PRIN) SKIP;
   STOP;
          END;
   IF CAMP(K1)<0 THEN CAMP(K1)=0;
             END;
          END;
          COMP=CAMP;
          END;
PUT FILE(STAD) SKIP LIST(TTL(I));
          DO NMO=1 TO N;
PUT FILE(STAD) EDIT(COMP(NMO))(X(2),F(8,4));
   IF NMO=9 | NMO=19 | NMO=27 THEN
PUT FILE(STAD) EDIT(' ')(A(6))SKIP;
          END;
PUT FILE(STAD) EDIT(TOT)(X(2),F(8,4))SKIP;
```

```
END;
    END;
    ROOT:PROCEDURE(Y,N,A,SLIM,L1,L2,G,V)RETURNS(FLOAT(16));
       DCL(X,Y,A(*),DPOLY,POLY,DTA,SLIM)FLOAT(16),
          (L2,L1,G,V)FLOAT(16),
          (N,INX,I)FIXED BIN(31);
       DCL(X1,X2) FLOAT(16);
       IF N=1 THEN DO;
          X=(Y-A(1))/A(2);
       END;
       IF N>1 THEN DO;
          IF Y>V | Y=V THEN X=L2;
          IF Y<A(1) | Y=A(1) THEN X=L1;
          IF Y<V & Y>A(1) THEN DO;
          :
          IF A=2 THEN DO;
          IF A(2)<0.000001 THEN DO;
          X=SQRT(ABS(Y-A(1)));
          END;
    ELSE IF (0<A(2)**2-4*A(3)*(A(1)-Y)) THEN DO;
          X1=-A(2)+SQRT(A(2)**2-4*A(3)*(A(1)-Y));
          X1=X1/(2*A(3));
          X2=-4*A(2)-SQRT(A(2)**2-4*A(2)*(A(1)-Y));
          X2=X2/(2*A(3));
       X=0;
          IF X1>L1 & X1<L2 THEN
             X=X1;
          IF X2>L1 & X2<L2 THEN
             X=X2;
          IF X1>L1 & X1<L2 & X2>L1 & X2<L2 THEN
             X=-99;
          END;
       END;
       IF N>2 THEN DO;
          X=0;
          DTA=1.0000;
          DO INX=1 TO 100 WHILE(DTA>SLIM);
             POLY=A(1)-Y;
```

```
510.000     DO I=2 TO N+1;
511.000       POLY=POLY+A(I)*X**(I-1);
512.000     END;
513.000     DPOLY=A(2);
514.000     DO I=2 TO N+1;
515.000       DPOLY=DPOLY+(I-1)*A(I)*X**(I-2);
516.000     END;
517.000     DTA=POLY/DPOLY;
518.000     X=X-DTA;
519.000     END;
520.000     END;
521.000   END;
522.000   RETURN(X);
523.000   END RCOT;
524.000   GRAPH:PROCEDURE(P,N,F,X,K1,ST);
525.000   DCL (P(*),F(*),Y(*))FLOAT(16),
526.000   (A(100),R(100),NF(K1),NX(K1))FLOAT,
527.000   (N,K1,I,J,L)FIXED BIN(31),
528.000   (XHIGH,XLOW,XSTEP,XFACT,FHIGH,FLOW,FSTEP,FFACT)FLOAT,
529.000   M FIXED BIN(31)INITIAL(0),
530.000   1 DUM, 2(IJ FIXED BIN(31),CHPAR  CHAR(34)),
531.000     FPAR DEFINED CHPAR,
532.000     ST CHAR(34);
533.000   XHIGH=HBOUND(X,K1);
534.000   XLOW=LBOUND(X,K1);
535.000   XSTEP=(XHIGH-XLOW)/100;
536.000   XFACT=1/XSTEP*10;
537.000   FHIGH=HBOUND(F,K1);
538.000   FLOW=LBOUND(F,K1);
539.000   FSTEP=(FHIGH-FLOW)/100;
540.000   FFACT=1/FSTEP*10;
541.000   CALL PLTOFS(XLOW,XFACT,FLOW,FFACT,0.5E0,0.5E0);
542.000
```

```
CHPAR='ELEMENT CONCENTRATION';
I=-1; J=1;
CALL PAXIS(0.5E0,0.5E0,FPAR,J,1.0E1,1,0.0E0,XLOW,XFACT,0.5E0);
CHPAR='COUNTS';
I=1;
CALL PAXIS(0.5E0,0.5E0,FPAR,J,1.0E1,1,0.0E0,FLOW,FFACT,0.5E0);
DO I=XLOW BY XSTEP TO XHIGH;
  M=M+1;
  H(M)=0;
  DO J=1 TO N+1;
    B(M)=P(J)*L**J-1;
  END;
  A(M)=L;
END;
L,J=/;
CALL PLINE(A(1),B(1),M,1.0E0,J,1,1.0E0);
J=-1;L=4;
CALL PLINE(X(1),F(1),K1,1.0E0,J,1,1.0E0);
CHPAR=ST; J=1;
CALL PSYMR(1.0E1,0.0E0,0.5E0,FPAR,0.5E0,J);
CALL PLTEND;
RETURN;
END GRAPH;
END SXRF;
```

Zonation of Pb-Zn-Cu-F-Ba mineralization in part of

the North Yorkshire Pennines

Abstract

An investigation of mine tips and surface evidence of mineralization in N. Yorkshire is reported. A crude overt geographical mineral zonation exists with a core of chalcopyrite-quartz mineralization. Laboratory study has shown similar cryptic zonation of some trace element contents of minerals, notably yttrium in fluorite and silver and antimony in galena. Leaching experiments demonstrate a similar crude zonation of sodium/potassium ratios. Mechanisms and significance of zonation are discussed in the light of these results.

Introduction

The origin and occurrence of Pb-Zn-Cu-F-Ba mineralization in the Carboniferous strata of the Pennines of England has attracted a lot of recent attention,[1-8] but mostly in the Alston and Derbyshire orefields which are still being exploited. The importance of basement highs has been stressed in past work[9], but with the discovery of large deposits in Eire associated with the downthrown side of large faults [10] an investigation of the controls of Pennine mineralization, with special reference to the Carboniferous hinge lines [11] was considered desirable and was started in 1972.

This study centred on the North Yorkshire Orefield along the Stockdale Line since this orefield sits astride a hinge line rather than to one side of it and it had been somewhat neglected. The main reason for recent neglect is the inaccessibility of underground workings most of which ceased operation before 1900, and are now in a dangerous condition. The restriction on collecting places a limitation on the type of work which can be readily attempted. This study therefore involves properties which vary significantly from one locality to another, and which can be investigated

from mine tip material. This emphasis on regional rather than local study suits both the material collected and the aim of finding large scale controls, but can create difficulties in interpretation.

The generalised structure and geography of the area studied is shown on Fig. 1. It lies in the Pennines, west of Darlington, between National Grid Lines, East 370-430 and North 480-525. The most important areas of past exploitation are in Swaledale, Arkengarthdale and parts of Wensleydale, but small workings are scattered thinly over a larger area. The mineralization of the orefield occurs principally in veins, and to a lesser extent in flats, in limestone and chert beds of the Carboniferous Yoredale Cyclothems. The association of workable deposits with faults of small throw and against "bearing beds" was demonstrated in 1860 by Lonsdale Bradley,[12] who compiled much information from (then) working mines. The importance of the availability of suitable fractures explains in part the concentration of most known orebodies near the Stockdale Line, a basement feature with probable long history.

Dunham (in Raynor and Hemingway[5]) gives a full review and synthesis of previous work on the area and relevant related work. He describes briefly a zonation of minerals in the North Yorkshire Orefield with a suggested feeder between Gunnerside and Langthwaite, to the north of the Stockdale Line. The feeder area has abundant fluorite, whilst surrounding areas are considered to have insignificant fluorite, although its presence is noted, e.g. in Wensleydale and along the Dent Line. A vertical zonation is described and has greatest fluorite concentrations at depth. Copper mineralization (sporadically worked) is considered to be a peripheral recrudescence of copper minerals as has been observed in the Alston Orefield.

Overt zonation of mineral occurrence.

Many records of mineral occurrences can be found, for instance in the Geological Survey Memoirs [13-17]. These records were collated and a field sampling programme was started. When results of sampling were compared with past records, broad agreement was found, although difference in detail did occur and was found to be significant in interpretation.

The assemblage of minerals occurring at each of 63 collecting areas was investigated. The assemblage is composed of primary minerals deposited in the veins of the collecting area. It does not signify the coexistence of all these minerals. If only ten primary minerals are considered when the assemblage of an area is determined, it is mathematically possible to produce 1023 different assemblages. With a sample size of 63 collecting areas, 41 assemblages were present when quartz, fluorite, barite, witherite, calcite, chalcopyrite, galena, sphalerite, pyrite and marcasite were considered. The number of assemblages found reflects the large number possible, but is much lower than the expected number ($m = 60$ $5 = 1.3$) and the assemblages occurring are far from randomly distributed in the composition space. This can be shown by examining assemblages when fewer minerals are considered. When five "gangue" minerals are considered 50 collecting areas fall into only 7 assemblages, and all 63 areas fall into 16 out of the mathmatically possible 31. The most common assemblages contain the most widely distributed minerals (calcite, barite, fluorite) and assemblages with no representatives have one or both of the most restricted minerals (quartz, witherite). Similar results occur for the five sulphides. 48 areas fall into only 4 assemblages, and all 63 areas fall into 13 out of the 31 possible. Pyrite and marcasite are the most restricted minerals.

The assemblages have been simplified further so that the sulphide – "gangue" occurrence relationships can be demonstrated in the histograms (Fig. 2). The relative abundances of minerals can be seen in the histograms but are distorted in some (a, b, c) where there are widely varying numbers of areas with each assemblage.

Examination of the geographical distribution of much simplified assemblages revealed a zonal pattern (Fig. 3). The minerals commonly or essentially occurring in each zone are shown in Fig. 4. The zonal map is drawn taking account of vertical and lateral variations. Traces of minerals are ignored and the presence or absence of known vein connections is not taken into account. The occurrences of sphalerite, pyrite and marcasite are not used in constructing zones because their presence is significantly affected by oxidation, which affects many deposits on the watersheds.

The zonal pattern is supported to some extent by orders of crystallisation, although these are not everywhere simple. There is a similarity between the zones here described and those of the Alston Orefield [18]. Secondary enrichment is considered to have significantly affected parts of the C zone, and it is hoped to present evidence regarding the origin of the C zone in a future contribution.

Cryptic zonation of trace elements in minerals.

Partial analyses of various minerals were undertaken in the search for indicators of zonation. Difficulties in analysis or interpretation limit the use of this technique to minerals which: a) are easy to find and separate; b) can be found over a wide area, and c) have widely varying trace element content which can be easily measured. Two minerals are well suited to this approach:- fluorite (42 samples) and galena (199 samples). Both were prepared as mineral concentrates by manual separation methods.

The content of yttrium in fluorite determined by X.R.F. spectrometry shows a marked variation from about 200 ppm down towards the detection limits ($\simeq$ 10 ppm). Yttrium values for the 42 samples are shown on Fig. 5 as average values for collecting areas. High values are concentrated near the inner edge of the F zone and fall off rapidly away from this centre. This confirms a similar pattern of zonation to that of mineral occurrence. A cryptic spatial zonation demonstrates that local variations due to position in the vein are not as great as the district variations.

The antimony content of galena concentrates was also determined by X.R.F. spectrometry. Values are widely variant from 2800 downwards and average values for localities have been plotted (Fig. 5). High values are conspicuously zoned about the core region of the orefield where galena is not found, and topographic-horizon effects are also present.

The silver content of galena concentrates determined by X.R.F. spectrometry have also been plotted (Fig. 5). The core is also indicated although not as clearly as with antimony. This is probably due to the less favourable

analysing conditions for silver and the smaller range of values observed.
Two anomolously high values are probably the result of trace silver minerals
although they could not be found microscopically. The anomolous values are
both from localities with only two analysed samples each. Very low values
occur in the Stainmore Trough area, and the generally low silver content of
the orefield agree with poor silver yields shown in production statistics[19].

The cryptic zonation observed in galena is again evidence of
large scale control of mineralization with local variations less than regional.
The widespread occurrence of galena is of great value in determining cryptic
zonation over such a large area.

Evidence of cryptic zoning from mineral leachates.

A series of rapid leaching experiments similar to those described
by Sawkins[20] were carried out using hand separated mineral concentrates.
Cation determination was carried out by flame photometer on leachates from
fluorite, quartz, barite and sphalerite. Sodium/potassium weight
ratios were determined for these mineral leachates.

The fluorite leachates largely originate from primary fluid
inclusions, which can be seen in thick section under the microscope.
Large numbers of inclusions can often be observed with low power
objective and are commonly complexly intergrown and developed in growth
zones in the crystals. Analyses of sodium and potassium combine to give
high total concentrations in the leachates; these depend on the volume and
concentration of the inclusions leached, and the volume of water used for
leaching. The ratio of sodium/potassium is generally low (below 15, sea water
= c. 29), ranging from 1.0 to 23. Most high values are in the north and east of the
area, towards the edge of the fluorite zone (Fig. 5).

The barite leachates were more difficult to interpret.
Most of the specimens did not have large inclusions and those present were
damaged during sectioning; however, they are often so numerous as to give the
mineral a milky appearance. The sum of sodium and potassium in the leachates
was found to vary greatly. Low totals are thought to be due to the incorporation

of secondary inclusions and/or leaking of primary inclusions prior to crushing

Low totals were therefore thought likely to confuse interpretation; their

sodium/potassium ratios have not been incorporated in Fig. 5. Most of the

remaining sodium/potassium ratios are high (>15), although a few very low

values are recorded, mostly in the south (Askrigg Block). Some of the high

values exceed the value for sea water (c. 29) and lie in the range

commonly observed in oilfield brines. The values for barite correspond well

with those of fluorite in the localities where they were both determined and

show the same trend of increasing values in the north and east.

Two samples of quartz (3 determinations) from the inner Q

zone (Fig. 5) both gave low values consistent with fluorite and barite.

Samples of sphalerite (Fig. 5) gave answers generally consistent with those

from fluorite and barite samples from the same or neighbouring localities.

Zoning mechanisms

Zoning is a common feature of all kinds of mineral deposits[21]

although there must be different mechanisms, since there are many origins

of ore deposits.

The principal implications of zoning are:

a) an overall control responsible for the pattern of zoning,

b) a connected origin for the mineralization of the different zones for

example a common source of elements or common concentration mechanism

Zonation of low temperature Pb-Zn-F-Ba mineralisation is well

known in the Alston Orefield[18], the Derbyshire Orefield [6], and the

Mississippi Valley Deposits of the central U.S.A.[22] From the presence of

primary fluid inclusions it may be inferred that the mechanism of zoning is tied in

to the hydrochemical origin of these deposits. Four mechanisms compatible with

a hydrochemical origin are:-

1. The proximity of a mineral location to the source of an initially uniform

   mineralising solution.

2. The spatial variation of initial mineralising solutions.

3. The mixing of two or more solutions.

4. The spatial variation of environment of deposition.

1.　　　　The first mechanism is the most commonly proposed mechanism,
although it has not previously been stated in exactly this form. It is
described in Park's review of the zonal theory of ore deposits, which outlines the
development of ideas on zoning up to 1955.[23] It is argued that minerals are
deposited in a well defined order during progressive crystallization of the
mineralizing solution. Since solutions move away from the source some minerals
are deposited close to the source and others further away. Sulphides
are deposited in a characteristic order which depends principally upon
complex ion stability and to a lesser extent the activity of metal ions
in solution.[24] Non-sulphides are deposited in a variable order, which depends
upon the activity of ions in solution and also the solubility product of the
minerals concerned.[25] Complexing may have some part to play[25] and the
relative importance of different causes of deposition (change of T, P, eH, pH)
may significantly affect the order of crystallization and hence the zonal scheme.

2. The second mechanism is only in accord with the implications of zoning if there is
an overall control of the spatial variation of initial solutions. It has not been
proposed for any well known zoned ore deposits or orefields, although Emmons[26]
suggested that irregularities and reversals of zonal arrangements may have been
caused by: a) two or more sources, b) retreat or advance of the source,
c) deposition of minerals in more than one period of mineralization. In the
role (a) above it is not a zonal mechanism so much as a complicating factor.
Perhaps the principal role of this mechanism is in the interpretation of large
scale zoning where different sources can be reasonably suggested, and
relationships between them understood in terms of large scale features such as tectonic
setting.

3.　　　　The third mechanism is a slightly more complex version of the second,
in that zones correspond to the different extent of mixing of two (or more)
solutions. Since zones are produced by mixing and not principally due to a
differing composition in each zone, this is a different mechanism to the second.
It has been proposed for instance by Sawkins for the Alston Orefield[20]
It has been argued that this mechanism would cause dumping of minerals at the
solution interface rather than a separation or zoning of mineralization.[24]
It is possible, however, that if the mixing process could be carried out slowly
in a turbulent environment, that the progressive deposition of minerals (by
mixing reactions, diluting or change of T, P, eH, pH) could cause a zoning
especially if the dynamic solution interface moved progressively from close

to one source towards the other because of changing flow rates of the solutions. If the causes of deposition are slow reactions this mechanism is attractive, but if not then the possible mixing conditions must be very restricted which implies that it is less likely to be a widespread mechanism.

4. The spatial variation of deposition environment, the fourth mechanism has not been considered important in the zoning of hydrothermal vein deposits, but is relevent to the zoning of some others such as stratiform deposits.[21,23] Where reaction with wall rock is a significant control of mineralization, the spatial variations of wallrock could cause zoning. If mineralization is carried out at host rock temperature, then spatial variation of temperature of host rock could cause zoning and would need explaining. If, however, host rock temperature is determined by the temperature of the solutions then spatial variation of temperature is largely due to variation of proximity to the source of solutions and hence mechanism one.

Zonation of mineral occurrence in the North Yorkshire Orefield can be easily explained with the proximity mechanism providing that the initial solution had an appropriate composition. The exact precipitation methods would probably affect the composition required, but are not important in this discussion providing that they would accomplish progressive crystallization. The zonation of the trace elements can also be accomplished easily by this mechanism. If the ratio of trace element to major element for which it substitutes is greater in the mineral than the solution, then during progressive crystallization the ratio in solution will fall, and in consequence so will that of the mineral. Thus a depletion trend will occur, which is reflected in the high values of yttrium, antimony and silver close to the Q zone and low values further away. If the ratio in the mineral is less than in solution then an enrichment trend will occur. These relations most probably apply even when substitution is not the method of trace element capture. They conform to the belief that trace element content depends principally upon availability of the elements and not on the temperature of formation.[27] Smith has demonstrated that yttrium content of fluorite is related to the proximity to feeders, but not directly to temperature variations.[7,28]

The zonation of sodium/potassium ratios in fluid inclusions is explainable by allowing a low ratio brine to progressively equilibrate with wallrock silicates (clays, micas, feldspars) as the solution moves away from the source. Adequate wallrock silicates in this case shales and sandstone are present in the upper mineralized sequence, but less common deeper in the sequence. Thus, it is possible that a wallrock effect after the environment mechanism must be combined to adequately explain the sodium/potassium ratios which are only high in the deposits from high stratigraphic levels. It should be noted that most workings of this orefield are in limestones and cherts so the effect of wallrock is not certain and depends upon the flow paths of solutions. Once precipitation has isolated wallrock from the system, reaction with it to cause zoning (or mineralization) are not so likely and would depend upon fresh fracturing of the host rock. Thus zonation of sodium/potassium ratios by the proximity mechanism is possible but not entirely satisfactory. In this orefield it is unnecessary to call on a different solution source for each zone or subzone of mineral occurrence. It can not, however, be disproved as a mechanism on the evidence here presented. The possibility of minor spatial variation of an approximately uniform initial solution can be considered with some favour, since uniformity is an ideal seldom achieved in geology. The causes of variation would rest with the source, and therefore perhaps basement composition or a similar factor.

The mixing mechanism could easily explain the variation of sodium/potassium ratios observed in this orefield. Similar variations of ratio were perhaps the principal argument in favour of two solutions and mixing in the Alston Orefield.[20] Unlike the Alston Orefield the North Yorkshire Orefield has common barite in the fluorite zone, which would require modification of the Sawkins mixing hypothesis.[20] The approximate correspondence of relatively small grain size with barite having low ratios, and coarser grain size for those with high ratios, argues in favour of the mixing mechanism but no grain size effect was noticeable on the sodium/potassium ratios of fluorite. Sawkins proposed that dilution by mixing prevented the precipitation of

fluorite outside the zone of unmixed low ratio solutions[20] but in this orefield high ratio fluorite is found, and does not support such a mechanism.

In parts of the fluorite zone interbanding of fluorite and barite is common, and perhaps suggests fluctuating conditions which could result from mixing. There is no noticeable difference of sodium/potassium ratio between the Q zone and most of the F zone, which argues against mixing as the cause of this part of the zonation. Sawkins did not consider mixing to have affected the fluorite zone or presumably the inner quartz-chalcopyrite zones associated with feeders in the Alston Orefield. One explanation of trace element zoning[20] by mixing requires either the progressive enrichment or depletion of trace element in solution by mixing of solutions rich and poor in the trace element, and roughly similar in the major element for which the trace substitutes in the mineral. The other requires progressive crystallization due to mixing and works asdoes the proximity mechanism. It is thus apparent that the mixing mechanism can not account for all zoning and if accepted at all must be considered in conjunction with the proximity mechanism.

There is little evidence for environmental control of zoning of the orefield and it would be difficult in particular to explain the trace element zonation by this method. The only potential contribution of this mechanism is the wallrock interaction effect combined with the proximity mechanism to explain sodium/potassium ratios.

The evidence, therefore, suggests that the proximity mechanism is the most likely and important cause of zoning, and that it must probably be combined with environmental control to explain sodium/potassium ratios. If mixing was active then it must have been combined with the proximity mechanism to produce all the features of zoning. The contribution of a spatial variation of source mechanism is not required by the major evidence, but cannot be disproved. It probably had a small part to play in zoning and may have been the cause of the difference between the Stainmore Q zone and the remaining Q zones.

Large Scale Control

Unlike the Alston Orefield, the zones do not focus over a subsurface granite cupola or even the structural high of the area. Zonation appears to be focussed upon the north west of the Semerwater subsurface cupola (Fig. 1) of Wensleydale Granite.[29] It is also south east of the intersection of the Dent and Stockdale Lines, but is closer to this than the granite. If the tilt of the sub-permian unconformity is allowed for the focus of the zonation perhaps constitutes the lowest part of the Askrigg Block, but there are many parts of the Stainmore Trough (largely unmineralized) which were structurally lower in the Permian.

If the mineralizing solutions flowed principally through the known veins, (Fig. 5a), then it would seem impossible to produce the observed zonations by dominantly horizontal movements, which would perhaps be suggested likely by the ribbon shape of the fissures. The discontinuous nature of the fracture system, would suggest that vertical feeding along fracture intersections and fault planes were important in solution movements. If, however, flow was not restricted to the known veins, then the sandstone beds in the mineralized succession, open joints and perhaps bedding planes in limestones could enable dominantly horizontal (up dip) movements which might account for the zonation. Mineralized joints are often found beside veins, but the relative abundance and extent of such occurrences are not known.

Whether the motive force of the solutions is a hydrological overpressure due to tectonic or sedimentary loading, or a thermal convective system, vertical escape of solutions must have been of prime importance in determining solution paths. Thus the impermeability of shales would be the principal cause of spreading solutions horizontally and therefore important in causing lateral zoning.

Origins of solutions

From the observed lateral zonation, a mineralizing solution originated in the west of the orefield. This solution must have ascended somewhere in the Q zone, and if the apparent separation of the Q zone from the Dent Line is real, then it rose in an area with apparently stable basement, i.e. on the Askrigg Block. As far as is known, however, it did not rise over the Semerwater Granite Cupola. The Q zone does extend to the Stockdale Line and it is possible that solutions could have risen up this structural weakness and then spread to the south because of the very gentle northward dip of the mineralized succession on the Askrigg Block, present at least since the Namurian.[30] The basement under the Q zone may be more variable than has been suggested since there is a possibility of a buried valley system filled with Devonian or Dinantian Sandstones, conglomerates and shales, as found at Sedbergh, west of the Dent Line. There may also be fracturing because of the close proximity of both Dent and Stockdale Lines. Either of these two features could make it easier for solutions to enter the area in the "basement" and then to rise in the Q zone.

It is possible that the western solution was derived deep in the Stainmore Trough (in the Tournasian rocks), and transferred to the higher levels via the Stockdale Line or other structural weakness. The solution was at least initially very rich in potassium, thus the most plausible source for mineralizing solutions in the Stainmore Trough would be residual sea water in contact with halite bearing evaporites. Such brines have been found in Central Mississippi and associated brines contain much lead and zinc.[31] The occurrence of evaporites in the Stainmore Trough has not been proved, but halite pseudomorphs have been found in the lower Dinantian sediments of Ravenstonedale and suggest that evaporites may be present further east.[32]

A different source of a high potassium solution is a brine that was once in equilibrium with alkali silicates; this could occur if a connate water was circulated through the Wensleydale Granite. If the observed Na/K ratios of the North Yorkshire Orefield are compared with White's data[33] their production could only be accomplished at very high temperatures. A ratio of 10 requires a temperature of about $250^{o}C$, which is equivalent to a

source depth of around 8 km assuming a geothermal gradient of around 30°C/km. The very low ratios require even greater depths. Such an origin is perhaps acceptable in the Alston Orefield, where zonation is around granite cupolas,[34] and the highest temperatures are more than 200°C,[20,28] but in the North Yorkshire Orefield such an origin is not as likely because the maximum temperature so far discovered by the author is 120°C with a possible pressure correction of 30°C, and finally the zoning centre does not correspond with the Semerwater granite cupola. A deep origin in the Stockdale Line cannot be ruled out by the zonation pattern, but this will still require high temperatures and a source of potassium silicates.

A magmatic source could explain the low Na/K ratios, but the high salinities of the fluid inclusions in fluorite from the North Yorkshire[35] and Alston orefields[20,28] argue against such an origin, since fluid inclusions from lead-zinc deposits of believed magmatic affinity show low salinities. The Weardale[37] and Wensleydale[29] Granites are both older than the Carboniferous in which the mineralisation occurs and the only igneous activity of comparable though older age than the mineralization is the intrusion of the Whin Sill at 295 m.y.[38]

The less probable mixing mechanism requires at least a second solution. This could be supplied by meteoric water, or connate waters. If meteoric waters are involved they must have dissolved halite or mixed with connate waters to produce the high Na/K ratios observed in barite. Connate or formation waters normally have high Na/K ratios and could originate in the Stainmore Trough or Askrigg Block Carboniferous sediments. A high barium brine is present in the Westephalian of Durham[39] and may be similar to the solutions which deposited the high Na/K barites.

If both solutions for the mixing mechanism are of connate type they could still have evolved in the Stainmore Trough, so that the deep brine from Tournasian rocks was an evaporitic brine rich in potassium and the shallower brine from Namurian-Westephalian rocks was a normal connate brine with a high Na/K ratio.

Sulphur and oxygen isotopes of the barite from the Alston Orefield correspond to the values from lower Carboniferous evaporites and connate waters[2], whilst lead isotopes for the Alston, Derbyshire and Craven Orefields

are all J type and fairly homogeneous, supporting a sedimentary origin for the lead and a Mississippi Valley type classification.[8]   No evidence has yet established a definite magmatic contribution, but since the hydrothermal versus formation water debate continues for the Mississippi Valley deposits[40,41] it will probably continue for the Pennine Orefields as well.

Conclusions

In the past centres of most intensive mining activity have received most geological attention and as a result a large scale zonation of mineral occurrence was not recognised. Investigation of the whole orefield has revealed large scale zonation which focusses on an almost unworked area. The zonation of mineral occurrence was confirmed by trace element distribution. Along with a zonation of sodium/ potassium ratio of fluid inclusions, these zonations and felated features can be most readily explained by a homogeneous source; proximity mechanism. The north west corner of the Askrigg Block is the focus of the zonations, and must have been closer to the source of high potassium brine than the rest of the orefield. Since this part of the Askrigg Block was structurally lower than most of the Orefield at the time of mineralization, solutions probably moved up dip where vertical escape was restricted and thereby produced the zonation pattern.
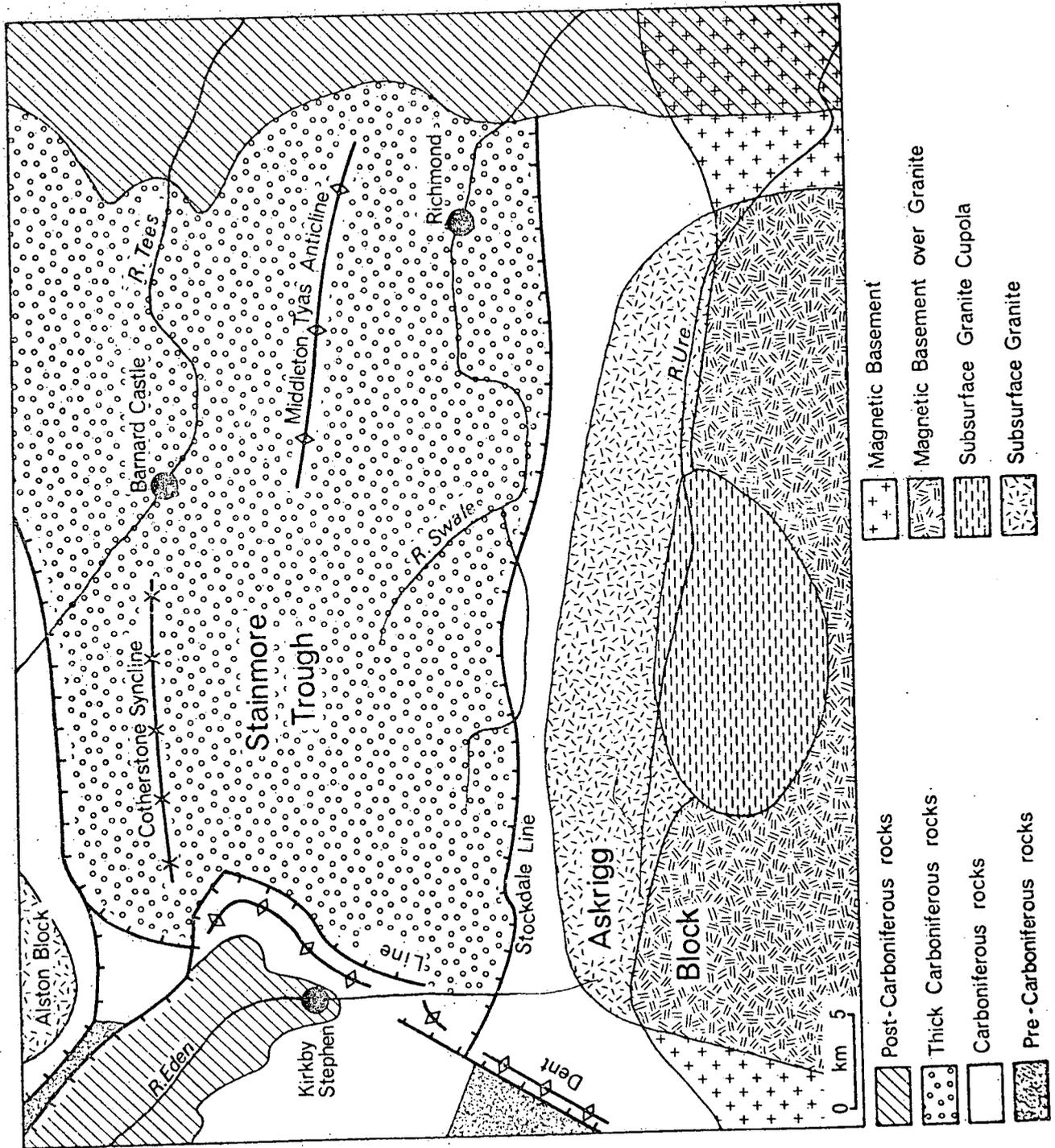
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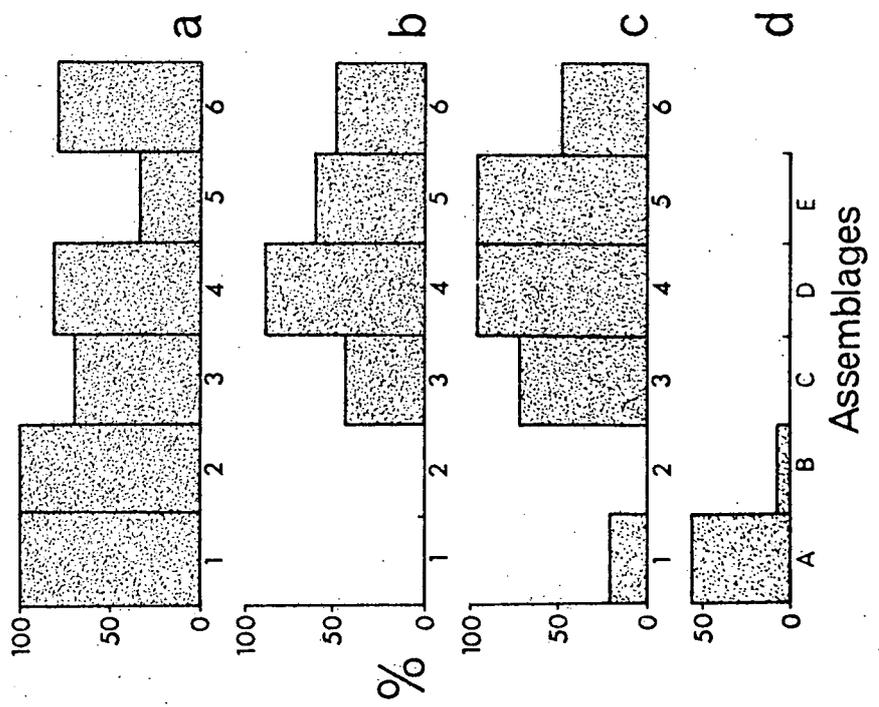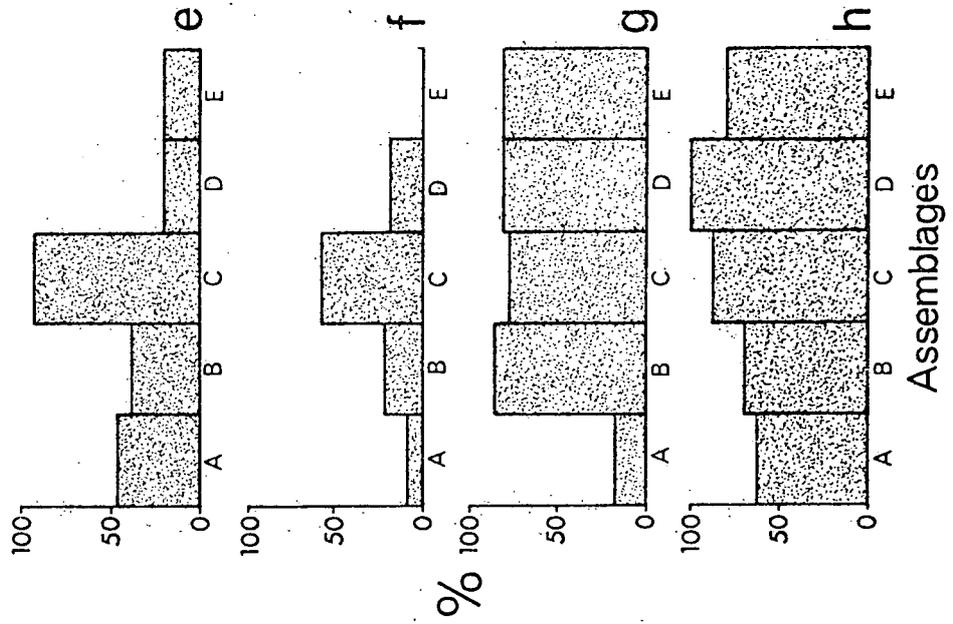
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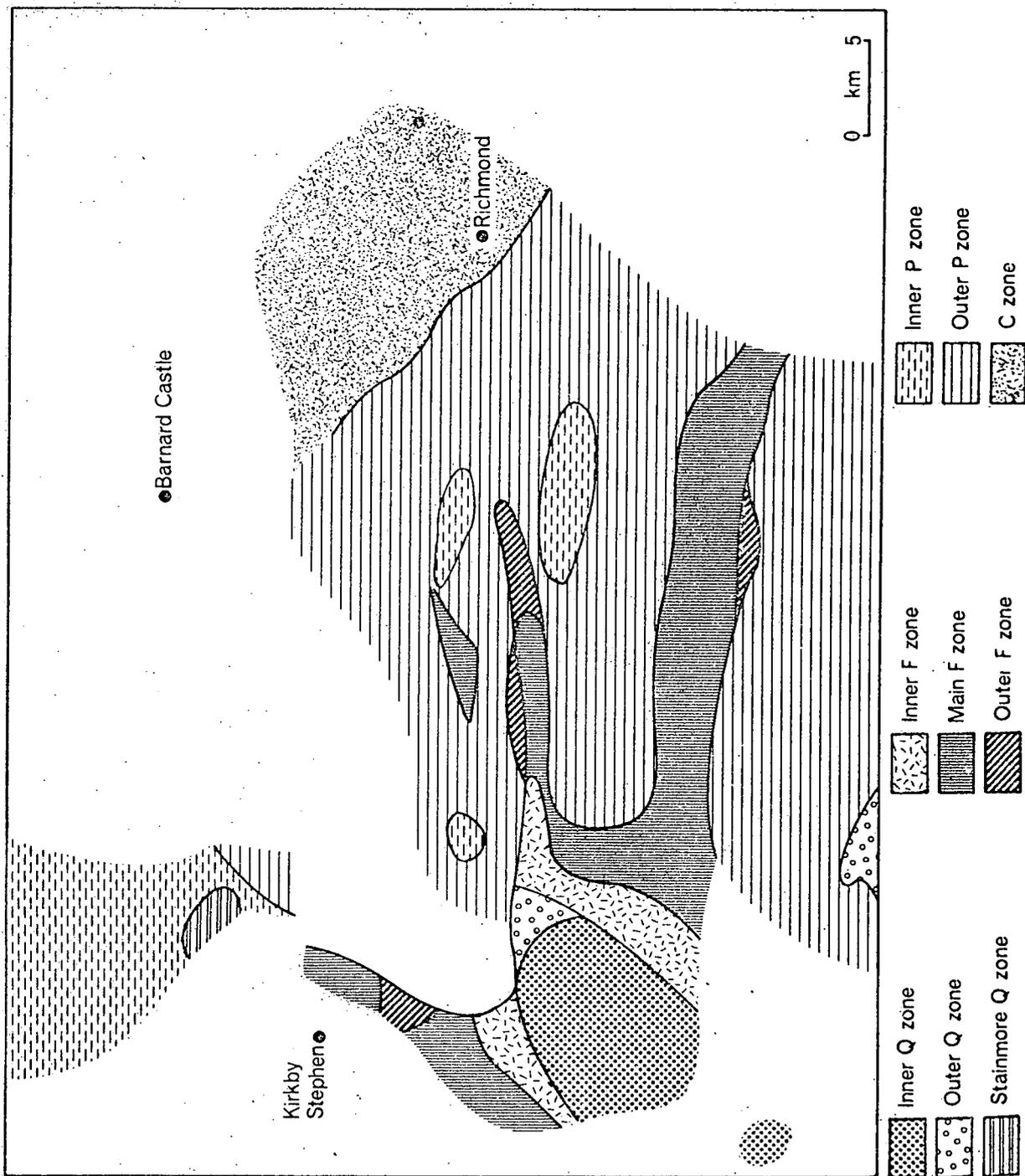
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Fig. 1   Map showing general geology subsurface features and geography of the area studied. Partly based on Bott[34] (Fig. 4).

Fig. 2   Histograms of mineral relationships.

a-c Proportion of areas of each gangue assemblage occurring with each sulphide mineral.

a, chalcopyrite; b, sphalerite; c, galena.

1 = quartz-fluorite; 2 = quartz + fluorite; 3 = fluorite - quartz - barite; 4 = fluorite + barite - quartz; 5 = barite - fluorite - quartz; 6 = calcite - barite - fluorite - quartz.

d-h Proportion of areas of each sulphide assemblage occurring with each gangue mineral.

d, quartz; e, fluorite; f, witherite; g, barite; h, calcite.

A = chalcopyrite; B = chalcopyrite + galena; C = chalcopyrite + galena + sphalerite; D = galena + sphalerite; E = galena.

Fig. 3   Map showing mineral zones.

Fig. 4   Table showing composition of mineral zones.

Fig. 5   a, Map of known mineral veins.

b, Yttrium content of fluorite (ppm)

c, Antimony content of galena (ppm)

d, Silver content of galena (ppm)

     Shaded circles are anomolously high, out of scale and with written values.

e, Na/K (weight) ratios of fluorite and quartz,

     Empty circles and +'s are fluorite, x's are quartz.

f, Na/K (weight) ratios of barite and sphalerite

     Empty circles and +'s are barite, shaded circles and x's are sphalerite.

b-d plot average values of localities (where more than one analysis has been made).

Magnetic Basement

Magnetic Basement over Granite

Subsurface Granite Cupola

Subsurface Granite

Post-Carboniferous rocks

Thick Carboniferous rocks

Carboniferous rocks

Pre-Carboniferous rocks

Alston Block

R. Eden

Kirkby Stephen

Dent

Stockdale Line

Cotherstone Syncline

Stainmore Trough

Barnard Castle

R. Tees

Middleton Tyas Anticline

Richmond

R. Swale

R. Ure

Askrigg Block

0   1   5 km

Barnard Castle

Richmond

Kirkby Stephen

0   km   5

Inner Q zone

Outer Q zone

Stainmore Q zone

Inner F zone

Main F zone

Outer F zone

Inner P zone

Outer P zone

C zone

	Quartz	Fluorite	Barite	Witherite	Calcite	Chalcopyrite	Sphalerite	Galena
Inner Q Zone	+	-	-		o	o		o
Outer Q	+	+	o			o		-
Stainmore Q	+	-	+			o		+
Inner F	-	+	o		o	+		+
Main F	-	+	o	o	o	+	o	o
Outer F	-	+	o		o	-	o	o
Inner P	-	-	o	o	o	+	o	o
Outer P	-	-	o	o	o	-	o	o
C	-	-	o	o	o	x		o

+ Presence diagnostic, - Absence diagnostic, o Presence observed, x Copper rich deposits.
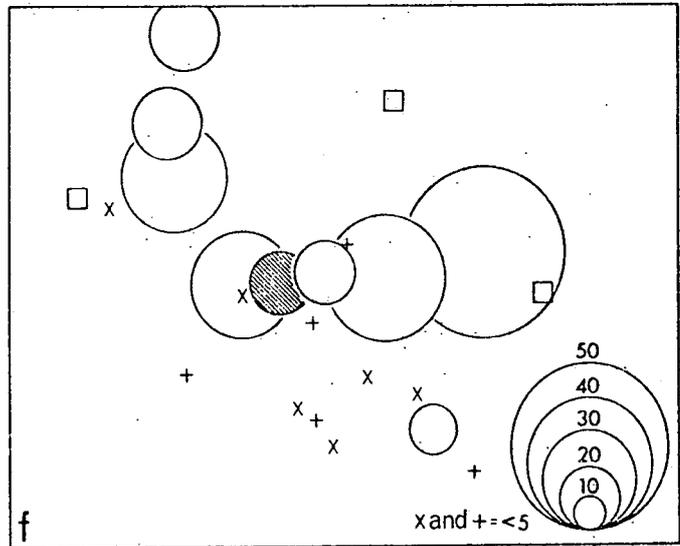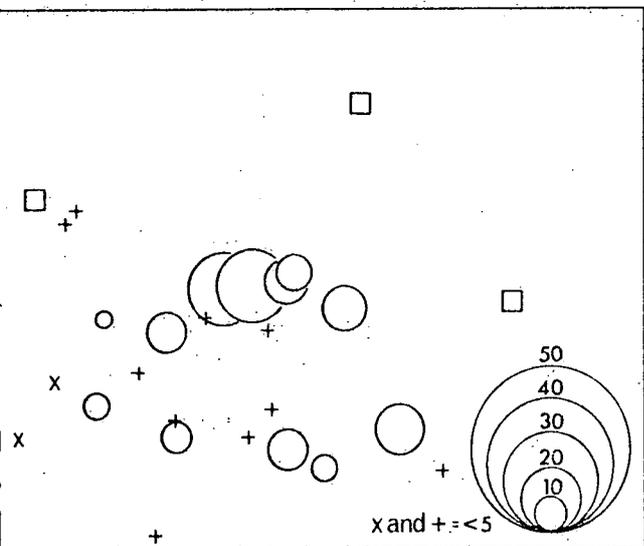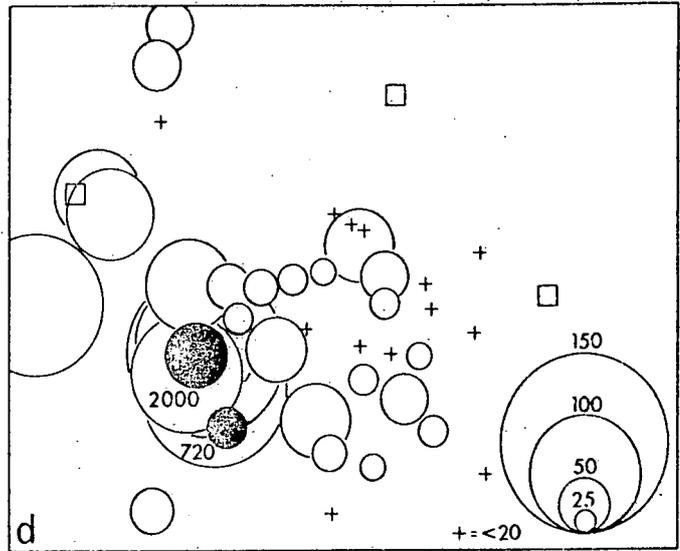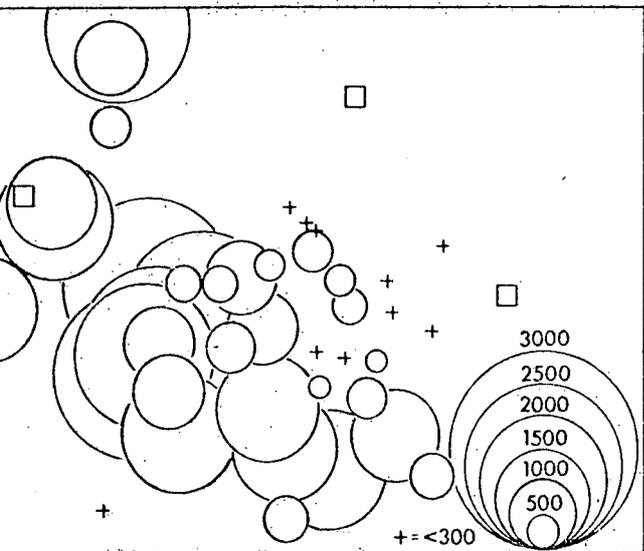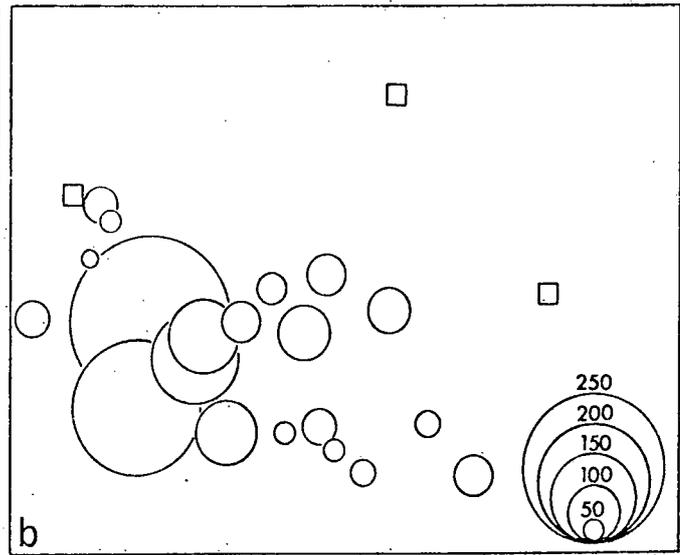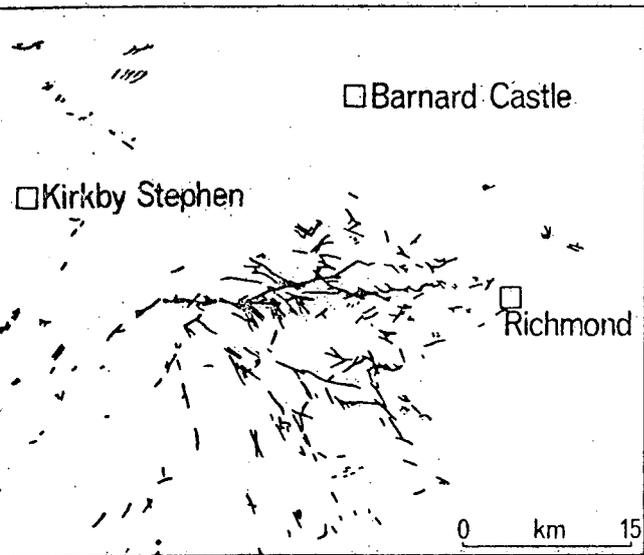
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