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FACTORS GOVERNING THE DEVELOPMENT OF FLUORSPAR OREBODIES IN THE NORTH PENNINE OREFIELD

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE UNIVERSITY OF DURHAM

by

FREDERICK WARDLE SMITH, B.Sc. (DUNELM), VAN MILDERT, MAY 1974

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ABSTRACT

The present knowledge of the structure of the North Pennines is reviewed. Vein orebodies are found to occupy cavities formed by combinations, in varying proportions, of strike and dip displacements on irregular fault planes, the dimensions of the orebodies being determined by those of the cavities. "Bonanza" vein orebodies occur where vein systems intersect major belts of washout channel sandstones within Namurian strata.

Fluid inclusion studies show that the lead-zinc-fluorine ores of the fluorite zone of the orefield were carried in brines of 20.2 to 25.6 equivalent weight per-cent NaCl salinities and were deposited during brine cooling within the temperature range from 211 to 119°C. The published solubility data of fluorite in brines of these characteristics indicate that some 5.05×10^{12} tonnes of brine would have been required in order to deposit the total fluorite content of the orefield. Three main phases in the evolution of the mineralization can be distinguished, an early, possibly higher temperature, quartz-chalcopyrite-pyrite-marcasite phase, a main ore-depositing phase and a late, lower temperature, quartz-carbonate phase.

Consideration of the geometry of orebody systems suggests that feeder conduits must have existed between sub-horizontally-disposed orebody cavities. These were located chiefly at fracture or vein intersections. Detailed fluid inclusion studies of individual orebodies show temperature maxima at such feeder intersections. Trace element analysis of fluorite by X.R.F. shows that the contents of yttrium, cerium and lanthanum are also highly enriched at feeder sites. This has been used as a means of locating intersecting veins within partially developed orebodies. In combination, the fluid inclusion and trace element techniques enable determination of hydrothermal flow directions in vein systems.

Mineralization of the Red Vein of Weardale has been studied in detail using structural interpretation, fluid inclusions and trace element analysis of fluorite. The dimensions of the major orebodies have been delimited, indicating

possible targets for exploration.

Application of the analytical methods to fluorite veins in the Derbyshire and Central Pennine orefields was unsuccessful in locating intersections. Results from the Cornubian orefields, however, appear promising.

Fluid inclusion determinations have been made on minerals from a number of other orefields in Britain and abroad, some of which had not been previously studied. Trace element analysis of 690 fluorites of varying provenance indicates that the yttrium content may be useful in showing the ultimate source of the fluorite-depositing brine. Fluorites carrying more than about 80 - 90 ppm Y are associated with igneous sources. Fluorites carrying much lower concentrations of Y are characteristically, though not inevitably, from deposits of the Mississippi Valley, or telethermal type of deposit. Fluorites from the North Pennine veins carry high concentrations of Y, in the general range 120 to 815 ppm, and the ore brines are thus considered to have had an ultimately magmatic source.

ACKNOWLEDGEMENTS

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I am also most grateful to Drs.D.M Hirst and G.A.L. Johnson for academically stimulating discussions and, with Mr.R. Phillips, for reading sections of the manuscript of this thesis. Dr.J.G. Holland and Mr.R. Hardy advised on X-ray techniques. Mr.G. Randall supported the project throughout by his high skill, speed and workmanship in producing polished discs for fluid inclusion study. Mr.M. Andrews and Mr.J. Forster have been particularly valuable sources of information and assistance in the field. Friends and colleagues, by their advice or criticism, have been responsible for many improvements and advances in this work, but for none of its shortcomings. Among many, I wish to thank Mr.Omer Akinci, Dr.Kevan Ashworth, Dr.Graham Borrodaile, Dr. George Gale, Mr.Les Knight, Dr.Thomas Shepherd and Dr.Win Htein.

My wife, through her patience and encouragement, has helped me greatly during the last three years.

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CHAPTER ONE

INTRODUCTION

The North Pennine orefield covers an area of approximately 1500 km^2 in the counties of Cumberland, Westmoreland, Northumberland, Durham and Yorkshire in Northern England (Fig.1.1). It is treated in this work as a separate entity from the neighbouring mineralized areas of the Lake District orefields, the Central Pennine or Askrigg Block orefields and the mineral districts of the South-East Durham Permian rocks. Lead, zinc, copper, iron, fluorine and barium mineralization occurs in a large number of steeply inclined veins cutting through the Palaeozoic rocks of the area, with occasional strata-bound bodies of mineralization, of limited extent, known locally as 'flats'. Dunham (1948) has described the mineralization in detail and has shown how the orefield can be subdivided into two mineral zones, a central 'fluorite zone' in which the dominant non-metallic ore mineral is fluorite, and a peripheral 'barium zone' in which barite and witherite predominate.

Although during the latter half of the nineteenth century the orefield was an important world source of lead and zinc, production of these ores declined into this century and has been very small since about 1930. The decline in the mining of metallic ores has to an extent been offset by the development of fluorspar and barium mineral resources. At the present time the tonnage of ore broken annually is about half that broken annually during the heyday of the industry in the 1880's,

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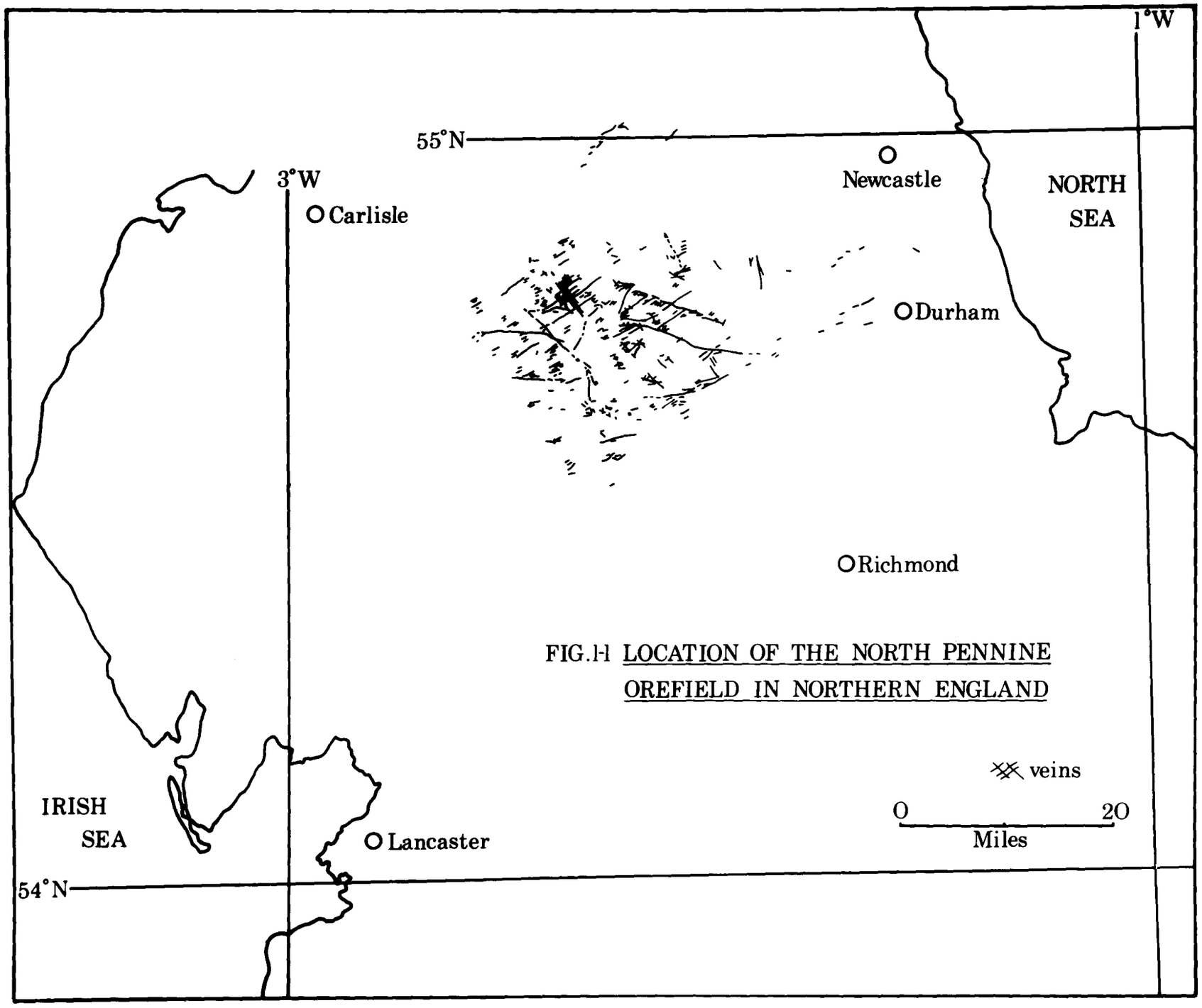


FIG.1 LOCATION OF THE NORTH PENNINE OREFIELD IN NORTHERN ENGLAND

although the number of operations and the number of men employed have been drastically reduced. Fluorspar reserves in the orefield have been estimated at five million tons (No tholt and Highley, 1971), much of which is in untried ground beneath the traditional mining districts such as Weardale. The increasing world demand for fluorspar, from the steel, aluminium and fluorochemical industries in particular, means that world production must continue to increase by about 5-10% p.a. throughout the foreseeable future. Thus, if Britain is to maintain her present position as the world's eighth largest producer, marketing nearly a quarter of a million tons of concentrate p.a., exploration and evaluation of the North Pennine resources form important and urgent tasks.

However, as in most mineralized districts throughout the world, the distribution of ore minerals in the veins, both horizontally and in depth, is far from uniform. Workable concentrations of the useful minerals are found in oreshoots of variable dimensions separated by much ground containing uneconomic concentrations, even though the vein system may still be present. Although some principles have been established that can be used as guides to the location of oreshoots, they are of limited application and poor definition. At present there is no alternative to the costly process of drilling and tunnelling for the discovery of vein oreshoots and the often highly profitable, but less common, flats.

The work to be described in this thesis began in 1970 as an attempt to learn more of the nature of the mineralization and its mode of formation, in the hope that this might throw light upon the more important factors governing the disposition of oreshoots on veins. It might then be possible to suggest improved practical methods that would assist in ore search. At that time in, 1970, there were five active mines in the orefield. Only one of these, Redburn Mine, was a completely new mine, the others being refurbished lead mines. During the following three years another old mine has been brought fully into fluorspar production at Cammock Isle and three more brought to very advanced stages of reopening. Whereas the previous ten or fifteen years had seen the orefield dominated by one or two major companies surrounded by many very small scale local operators engaged in tip removal, opencutting and pillar robbing, a bewildering array of national and international mining and exploration interests have recently been occupied in examining and assessing old properties. Against this background of renewed mining enthusiasm and with the active assistance of three main companies, the Weardale Lead Company, British Steel Corporation and Fergusson Wild Limited, the project was undertaken and completed.

It has been accepted for many years that the various hydrothermal minerals found in the orefield were deposited from aqueous solutions that circulated along vein channels following minor faults. Inspection of the veins shows that there is little evidence of solution of wall-rocks by the hydrothermal fluids. The contacts between wall-rocks and mineral infillings are sharp and often angular. Vein orebodies of the same width occur both in limestone and sandstone. Moreover the form of the crystals within the vein infilling shows that the veins were filled from the walls inwards. Thus we are led to the conclusions that an open conduit system existed prior to mineralization, that the conduit system was not created by solution of the host rocks and that the mineralization was not deposited by replacement of the host rocks.

The very low solubility of vein minerals and the relatively low rate of precipitation caused by change in physical environment, even allowing for the influence of chemical complexing, means that in order to provide the observed thicknesses of minerals filling the veins (up to 10m) large volumes of solution must have flowed through the conduit system.

Dunham's studies of the geographical zonation of the hydrothermal minerals provide a foundation for further studies of vein mineralogy. However, veins of similar thickness, geological environment and geographical situation are not uncommonly found to contain widely varying proportions of different hydrothermal minerals and hence do not readily fit into simplistic regional zonation schemes.

Consideration of these preliminary, but nonetheless important, conclusions indicated that a structural, mineralogical and geochemical study of the orefield was required. In particular, evidence was sought that could reveal the direction of flow of hydrothermal fluids within the complex system of conduits. As will be described later, this aim has been realised and has been incorporated into an apparently successful exploration scheme capable of detecting certain vein intersections and orebody terminations.

The thesis is subdivided into three sections, two of which are text and the third, appendices. Section One formulates, reviews and presents the evidence for concepts of the nature of the hydrothermal mineralization of the North Pennine orefield. It explores firstly the concept of an open conduit 'plumbing system' by considering its mode of formation, geometry and relationship to local stratigraphy. Secondly, the chemistry of hydrothermal solutions is described, paying particular attention to chemical evolution with time. The physical evolution of the solutions, in response to changing pressure and temperature within the conduit system is described in Chapter 5 and then the chemical evolution of the mineralization in relation to conduit geometry is recognized and discussed. The relationship of mineralogically, geothermometrically and geochemically discernible features of the mineralization with conduit geometry provides a scheme by which conduit layout can be recognized and to some extent predicted. Finally, in Section One, other fluorite-bearing deposits are investigated to assess the universal applicability of the scheme.

Section Two is a detailed study of a major Weardale Vein, the Red Vein, presently the scene of most intense fluorspar mining activity in the North Pennines. The structure and mineralogy of orebodies along the vein are examined and those exploration techniques formulated in Section One are applied to real problems.

SECTION ONE.

CHAPTER TWO.

STRUCTURAL CONTROLS OF MINERALIZATION

2.1 The Structure of the North Pennines.

2.1.1 General Introduction

The deep structure of the region is well known from seismic, magnetic and gravity surveys (Bott, 1967), from three deep boreholes at Allenheads, Rookhope and Roddymoor, near Crook, and from basement inliers at Cross Fell and Pencil Mill, Teesdale.

The pre-Carboniferous basement consists of highly-folded slates and volcanic rocks of Ordovician age. These are penetrated by the Weardale Granite, dated radiometrically at 392 ± 6 My (Fitch and Miller, 1965). The relatively low density of the basement granite has caused the region to remain structurally and topographically positive since late Devonian times. The positive region is called the Alston Block and is bounded to the north, west and south by major hinge fault systems separating it from the basinal regions of the Northumberland Trough, Vale of Eden and Stainmore Trough (Fig. 2.1). These fault systems, formed in late Devonian times, were active throughout the Carboniferous period and continue to show signs of activity at the present (Johnson, 1970; Bott and coworkers, 1972). The basement of the block dips eastwards and is believed to terminate, again in a hinge fault system, 24 km of the Durham coast (Bott, 1961).

FIG.2-1 REGIONAL GEOLOGY

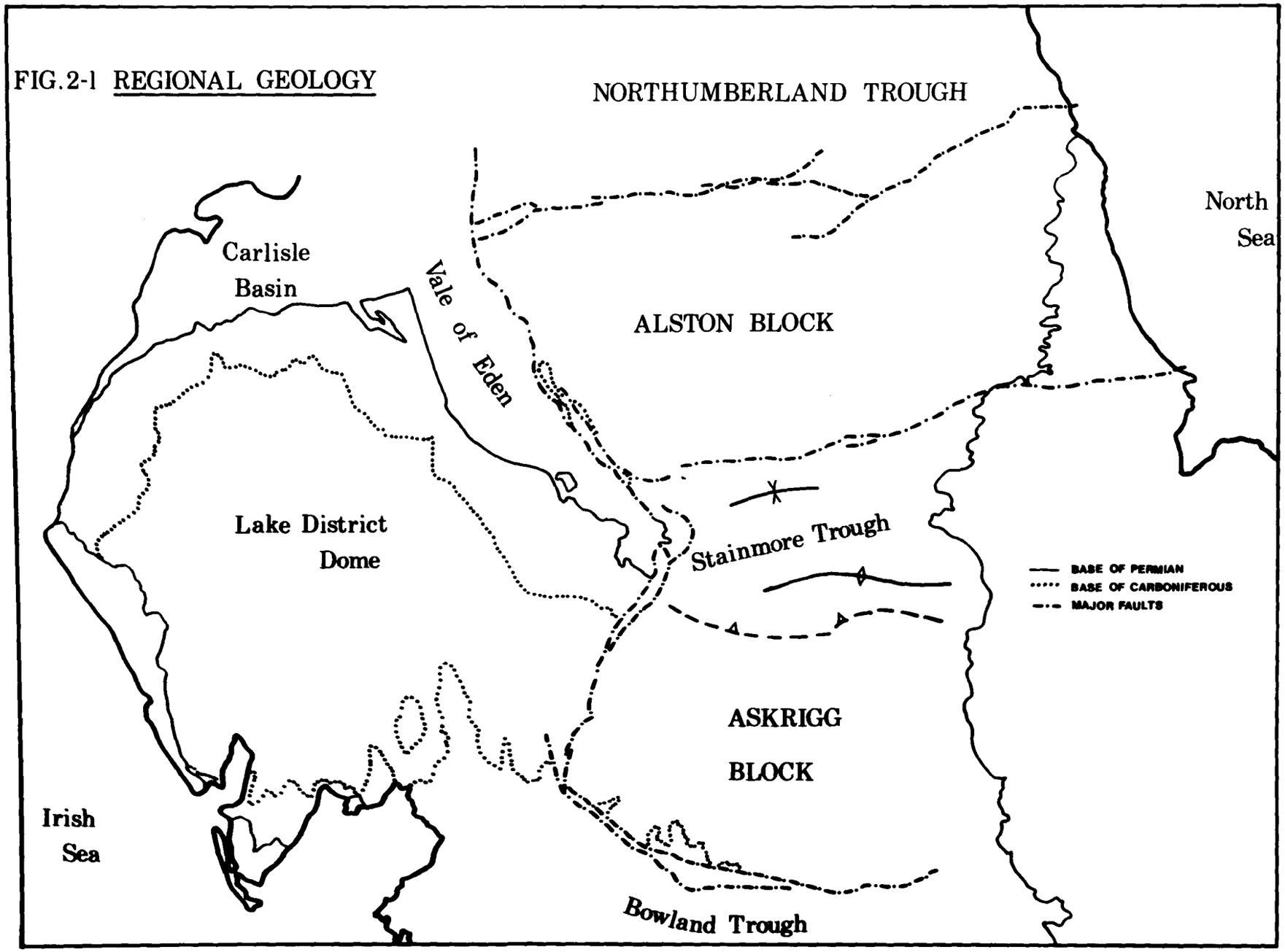
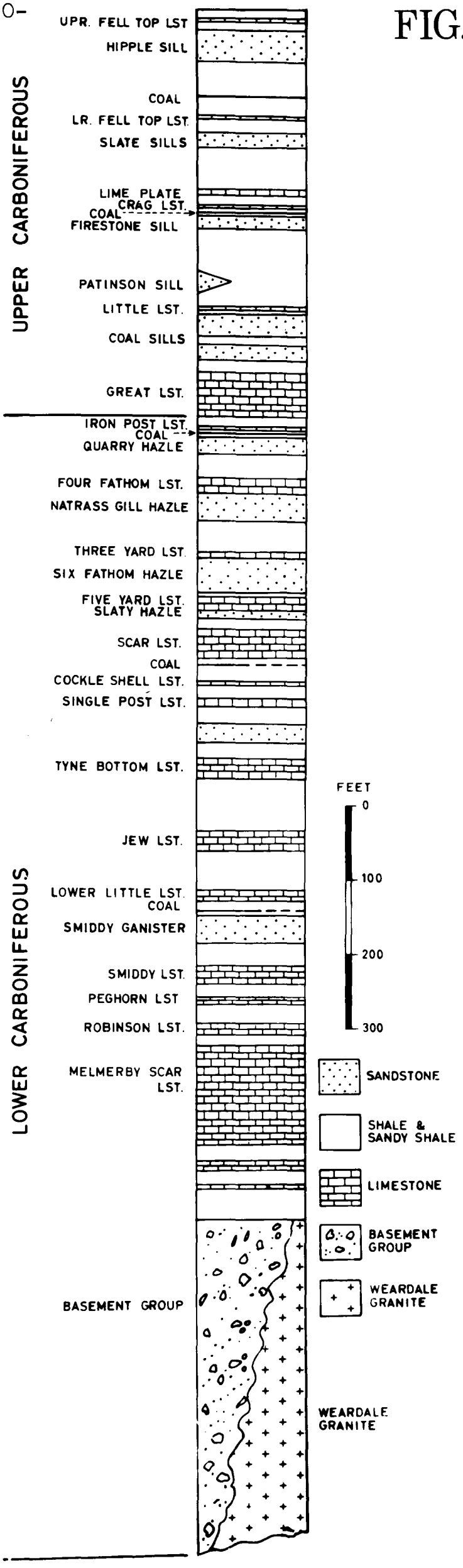


FIG.2-2


UPPER CARBONIFEROUS
UPR. FELL TOP LST
HIPPLE SILL
COAL
LR. FELL TOP LST
SLATE SILLS
LIME PLATE
CRAG LST.
COAL
FIRESTONE SILL
PATINSON SILL
LITTLE LST.
COAL SILLS
GREAT LST.
IRON POST LST.
COAL
QUARRY HAZLE
FOUR FATHOM LST.
NATRASS GILL HAZLE
THREE YARD LST.
SIX FATHOM HAZLE
FIVE YARD LST.
SLATY HAZLE
SCAR LST.
COAL
COCKLE SHELL LST.
SINGLE POST LST.
TYNE BOTTOM LST.
LOWER CARBONIFEROUS
JEW LST.
LOWER LITTLE LST.
COAL
SMIDDY GANISTER
SMIDDY LST.
PEGHORN LST
ROBINSON LST.
MELMERBY SCAR LST.
BASEMENT GROUP
WEARDALE GRANITE
FEET
0
100
200
300
SANDSTONE
SHALE & SANDY SHALE
LIMESTONE
BASEMENT GROUP
WEARDALE GRANITE

Gently-folded Carboniferous strata overlie the Lower Palaeozoic basement with marked unconformity. Viséan and Namurian beds, bearing the bulk of exploitable mineralization, consist of discrete sedimentological cyclothems of alternating limestones, shales, sandstones (and coals). Individual beds are seldom thicker than 20m (Fig. 2.2).

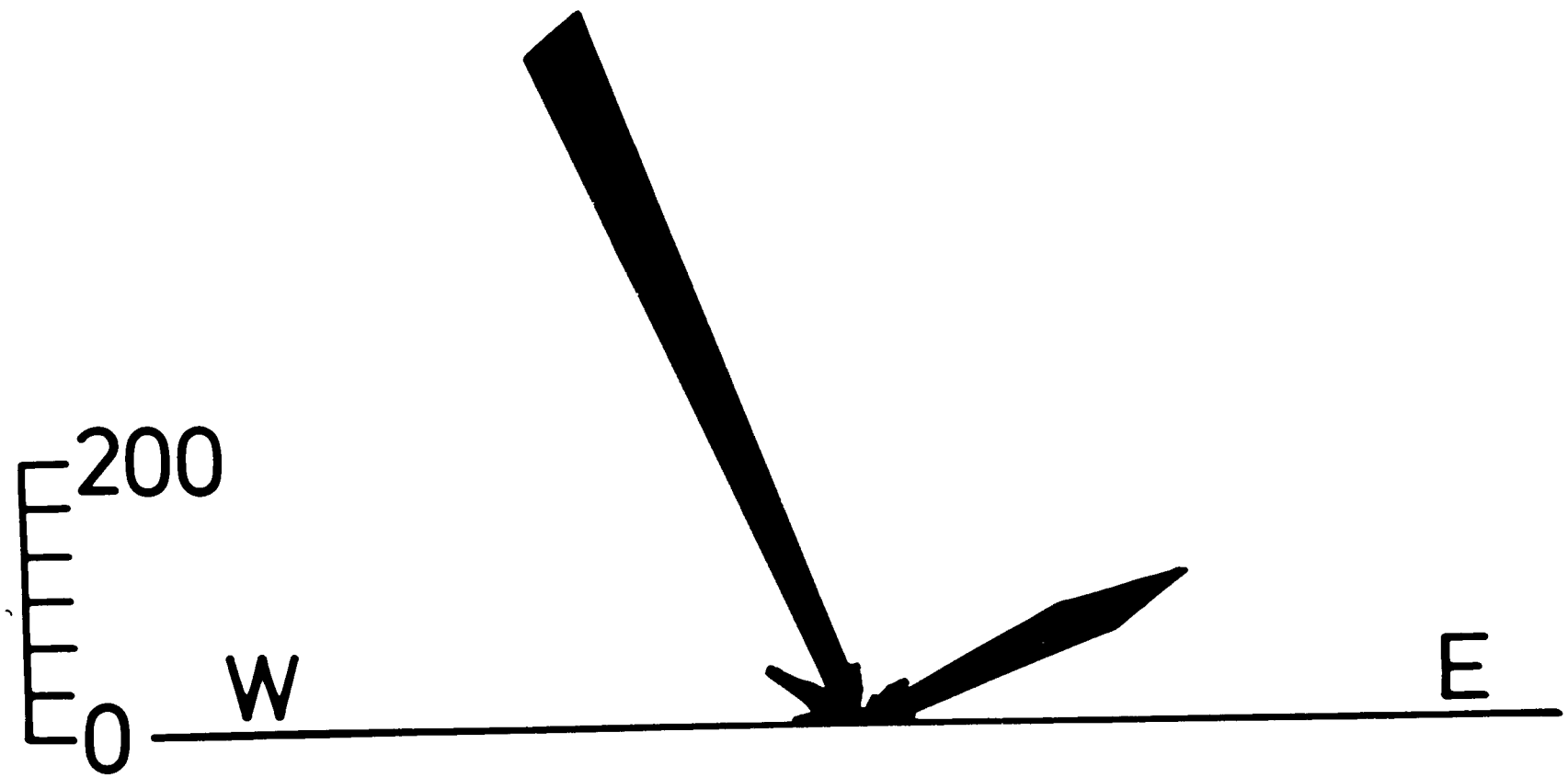
Quartz-dolerite sills, the thickest of which is known as the Great Whin Sill (1.8 to 74 m thick on the Alston Block), occur at various stratigraphic horizons of the Carboniferous sediments. The sills and a series of petrographically similar dykes, the Whin Dykes (trending N.60 - 70°E.), are regarded as cogenetic (Dunham, A.C., 1970) and have been dated radiometrically at 295 ± 6 My (Fitch and Miller, 1967).

2.1.2 Detailed Structural History.

The Carboniferous sediments of the Alston Block are strongly and regularly jointed. The joint system has been studied by Dunham (1933) and by Fairbairn (unpublished work). Approximately 300 joint measurements were made during the present work and, though not worth analysing in detail, were found to support Dunham's published observations. Two persistent joint trends are present. The first, running N.20 - 25°W. is better defined than the second, running N.60 - 70°E. (Fig. 2.3). Since joints in both directions cut one another, Dunham concluded that they originated simultaneously, constituting a conjugate system of shear joints. However, it is now known that shear joints cannot subtend dihedral angles so close to 90°.

FIG 2-3

JOINT TREND FREQUENCY



DUNHAM 1933

Such a situation would imply that the rocks had no internal friction (Borrodaile, pers. comm. 1972). The alternative is to consider the joints as tension joints, which may form at 90° to one another. Price (1966, p.135) states that during uplift " ..... when the tensile stresses equal the tensile strength of the rock, tension joints form which are perpendicular to the axis of least principal stress. The moment the fractures develop in the rock, the tensile stresses are relieved; the erstwhile least principal stress changes and is probably replaced by a compressive stress ..... . The other horizontal principal stress ..... becomes the least principal stress. Further uplift can cause a second set of tension joints to develop." The two sets are at 90° and Price concludes by saying that if the horizontal stresses were initially very similar, then the formation of the two joint sets may be practically simultaneous. All of the surface features of the joints and their total lack of any shear displacement are consistent with this origin. It is possible to suggest at this stage that, of the two joint trends, the N.N.W. set was first formed. The evidence for this, bearing in mind the orientation of Price's principal stresses, is that minor E.N.E.trending folds are known that predate tension fissuring in that direction (Dunham, 1933). This is consistent with an initial maximum principal stress trending N.N.W. - S.S.E.and causing the N.N.W directed tension joints to open. The second, reformed maximum principal stress would then have been E.N.E. - W.S.W. directed and, as will be shown in later paragraphs, remained approximately so throughout the remainder of the Carboniferous period. Dunham fixed the

age of jointing by reference to the Whin quartz-dolerites. The Great Whin Sill shows no jointing comparable with that in the sedimentary rocks, indicating that it was intruded after the initiation of the joint system. Moreover, the Whin Dykes follow exactly the trend of the E.N.E. joints. Hence at the time of intrusion the maximum principal stress must have been E.N.E. - W.S.W. directed. Jointing has been regarded as the first manifestation of Hercynian tectonic activity and the uplift responsible for the formation of the joint system may correlate with intra-Westphalian unconformities recognized in the coalfields of Northern England.

Dunham (1933) also described small monoclinal folds and thrust faults trending N.20 - 25°W. The age of these structures could not be fixed by direct observation. However, the Burtreeford Disturbance, a major, east-facing monocline, is believed to be contemporaneous and has been shown to predate the Whin Sill (Bott and Johnson, 1970). Fitch and Miller (1967) recognize this phase of N.N.W. folding and thrusting as the second phase of the main Hercynian orogeny in Northern England and correlate it with the appearance of 'red beds' close to the Westphalian - Stephanian boundary in the Canonbie Coalfield (dated by implication at around 300 - 295 My).

TABLE 2.1

Structural History (adapted from Dunham, 1948)

Period [1]	Movements	Stress field orientation [2]
Late Devonian	Initiation of marginal hinge fault systems (active intermittently to the present day)	
Westphalian	Formation of N.20-25°W. tension joints and N.60-70° E. folds	Uplift with σ_1 s N.20-25°W
Late Westphalian or early Stephanian	Formation of N.60-70° E. tension joints and N.20-25° W. compression features	Continued uplift. σ_1 towards E.N.E.
300-295 My	Formation of Burtreeford Disturbance (N.N.W. to N.-S.)	σ_1 towards E. -W.
295 My	Intrusion of Whin Sill and Dykes (Dykes trend E.N.E.)	σ_1 E.N.E.
290 ± 5 My	Periclinal doming, elongate approx. E.-W.	σ_1 s E. - W.
290 ± 5 My	Faulting and stratal extension. Chief trends 1,N.50-60°E. 2,N.20-25°W. 3, E.-W. to N.65°W. 4, approx N.-S.	σ_1 s E. - W.

284 ± 40 My	Mineralization, possibly contemporaneous with faulting
225 ± 5 My)	Reheating episodes, marked by argon
180 - 170 My)	loss from clay minerals. Possibly
?80 My)	related to periods of tectonic activity, particularly the formation of post-ore faults with horizontal slickensides.
Tertiary	Intrusion of dykes in linear echelon trending W.N.W.

Footnotes.

1. The chronology is adapted from Dunham, 1948, and Fitch and Miller, 1967.
2. σ_1 is the maximum compressive stress in the notation of Price, 1966.

Northern Pennine Orefield (Mem. Geol. Surv.)

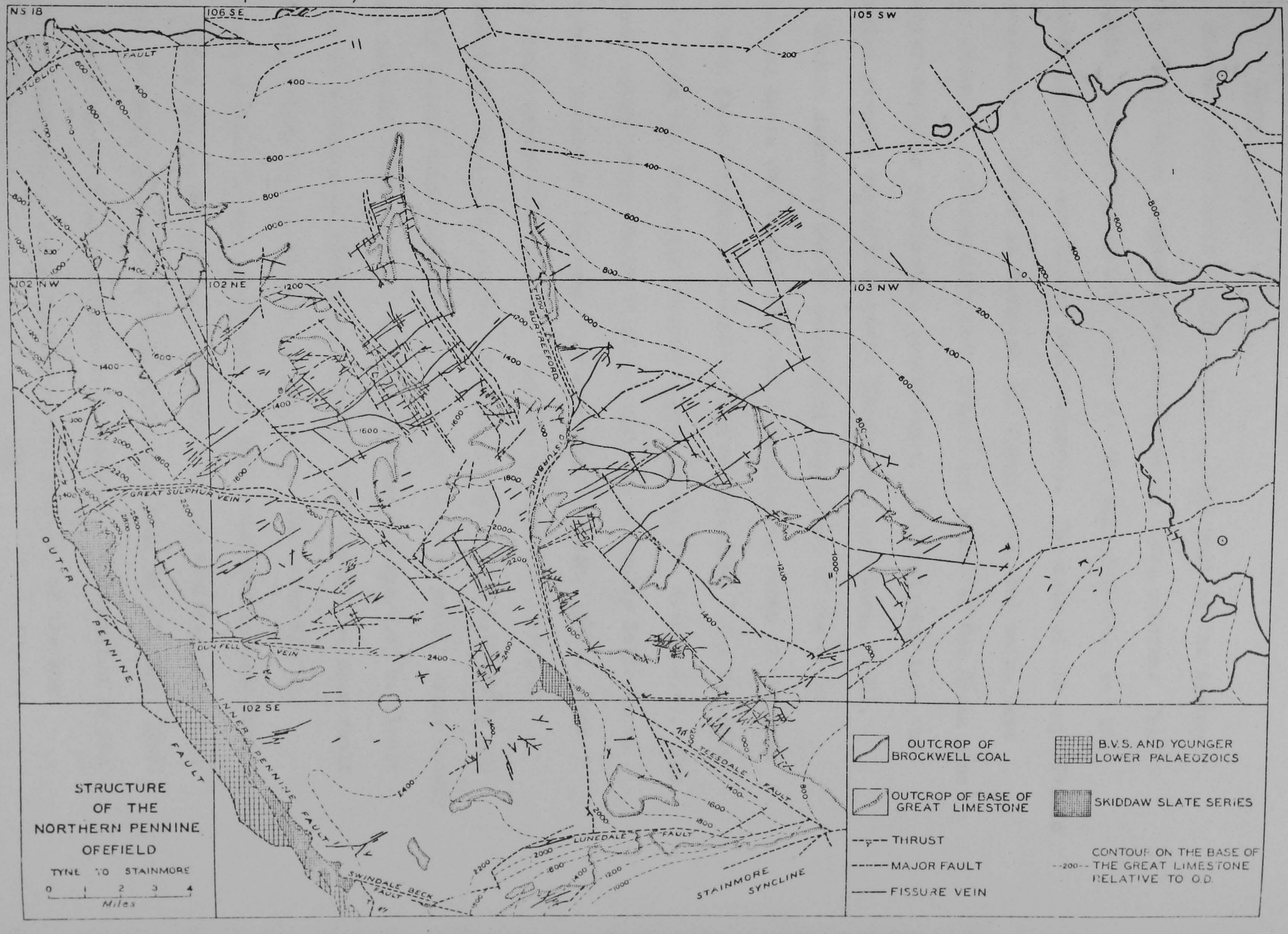


FIG. 2.4

2.1.3 Mineral Veins

Mineral veins occur mainly in the western part of the Alston Block, where Lower Carboniferous and Namurian rocks outcrop. The youngest rocks cut by mineral veins are the Whin dolerites and the youngest sediments are Middle Coal Measures. The bulk of the exploitable mineralization occurs in Namurian and Viséan beds, but veins have been shown to continue down into Ordovician slates at Cow Green Mine (Forster-Smith in discussion, Schnellmann, 1955) and deep into the Devonian granite beneath Rookhope (Dunham and coworkers, 1965).

Dunham demonstrated,by contouring the height of the Great Limestone above sea level, that the Carboniferous rocks of the area have been folded into an elongated dome or pericline ('the Teesdale Dome') with its long axis running approximately E.- W.(Fig 2.4). The mineral veins occupy fault fissures that are generally believed to have been formed at the same time as doming (Dunham, 1948). Four main fault series are present. The best defined and strongest mineralized trend N.50 - 60°E. Another series trends N.20-35°W. and is only poorly mineralized. The important 'quarter point' veins occupy long, sinuous fault fissures trending between E-W. and N.65°W. Least common is a series of almost N-S. faults. Thus two of the main fault vein directions follow the master jointing. The veins are not however, widened joints since they may have considerable hade whereas the joints are quite vertical. Orebodies occupy cavities formed on faults of small displacement (generally less than 3m - Dunham, 1948). That these cavities were mechanically produced, as described in the following section,is shown firstly by the geometry of the host

structures and secondly by the fact that, except very rarely, there is no evidence of solution of the wall-rocks by the hydrothermal fluids. The contact between ore and vein wall is generally sharp and frequently angular in both limestone and sandstone host rocks. Large irregularities on one wall can often be matched up with the opposing wall (and can be used to determine the direction and amount of fault displacement). Orebodies of equal width occur in relatively soluble limestone and insoluble sandstone host rocks. Examination of crystal faces preserved in the vein infilling shows that the vein minerals grew from the walls inwards to fill open cavities.

The processes of rock solution and rock replacement were, however, active in the formation of flat deposits. Though mentioned several times in later chapters, flats have not been studied in this work. They formed alongside some veins, but not others, and were fed with mineralizing solutions from the veins. They may be separated from the parent vein by up to 10m of barren rock. The mode of formation of flats is fairly well understood as a combination of solution, cavity infilling and rock replacement. However, the causes of flat formation, their localized occurrence, their variable size and contents are still problems to be investigated.

Lead isotope abundance studies on four specimens of galena from the North Pennine orefield provided common lead ages ranging from 310 ± 50 My to 260 ± 60 My (Moorbath, 1962). Radiometric measurement on uranium mineralization in the Weardale Granite gives an age of 292 ± 20 My (Bowie in Dunham, 1966). Radiometric dating, using the $^{40}Ar - ^{39}Ar$ method, of wall-rock alteration associated with the veins indicates two further episodes of reheating and argon loss at about 230 and 170 My (Dunham and coworkers, 1968). A refinement of this study has shown the possible presence of a further reheating at about 80 My and has emphasized the importance and widespread occurrence of the 170-180 My event (Gilchrist, pers.comm. July 1973).

Tectonic activity subsequent to ore deposition and possibly correlating with the reheating episodes described above, has produced numerous horizontally slickensided faults both in the ore and in the wall-rocks. Those faults wholly in ore tend to follow the line of the vein and coalesce to form a central, major fault plane, often known as the 'vein leader', because it continues, following the vein trend, through patches of poor ground. The slickensides seen in the vein wall seldom penetrate far into the vein, but intersect it at appreciable angles (20 - 90°). Apart from the possible correlation of movement with the argon loss events mentioned above, the age of this faulting is uncertain. Dunham (1932) records polishing of limonite and cerussite on some slickensides, suggesting that small movements have occurred since the orebodies have been brought within the zone of oxidation.

2.2 Fault Cavity Formation

The belief was expressed in the previous section that orebodies occupy cavities, opened under tension, on faults formed during periclinal doming of the Carboniferous rocks. This statement must be examined very closely to ensure that such an effect is possible.

The widespread opening of tension cavities can only have occurred by stratal extension. The total extension of the Great Limestone (the chief ore-bearing horizon), caused by periclinal doming can be calculated, knowing, from Dunham's Maps, the radius of the dome and the thickness of the sediments between the Limestone and the stable basement. It is reasonable to assume that only the Carboniferous rocks were domed, since the cause of doming is believed to have been isostatic 'uplift' of the underlying basement block (Bott and Johnson, 1970). Total extension of the Great Limestone in a 20 miles (32.2 km), N.- S.section of the pericline encompassing the productive orefield is calculated as 23.6 m ie the aggregate width of tension cavities in the Limestone along that line of section ought to be 23.6 m if fissuring had been caused by doming alone. The numbers of known vein fissures occurring in any similar N.- S.section can be found approximately by counting from the one inch to one mile geological map of the orefield. This figure ranges between 10 and 30 veins. Thus taking all the veins as perpendicular to the line of section, average fissure width would equal between 2.4 and 0.8 m. Alternatively, taking the veins as falling into two groups at 90^{o}, intersecting the section obliquely, then the average fissure width would equal between 1.7 and 0.56 m. In practice, veins intersect the section both obliquely and at 90^{o}, therefore, the average fissure width,

at a conservative estimate, would lie within the range of 2.4 to 0.56 M. If this range of average tension fissure widths computed to have been caused by doming alone, is compared with actual vein widths in the Great Limestone, the correspondence is remarkably good considering the crude methods used. Dunham (1944), for example, estimated that the average width of an orebody fell between 1.2 and 1.5 M. The average width of mineralization averaged out along an entire vein is probably very much less than this. The overall average width of mineralization in the veins of the Rookhope Valley, for example, is probably in the order of $\frac{1}{2}$ to $\frac{3}{4}$ M, despite having local accumulations of up to 10 M.

Dunham recognised that if fissuring was the result of doming then veins must narrow in depth. He attributed the common failure of veins when followed to depth, to this effect and a tabulation of vein widths at successively deeper horizons (Dunham, in discussion Varvill, 1937) supports his conclusion. Varvill (op.cit.) reports a similar narrowing effect in veins on the Craven Anticline. There is actually insufficient evidence, in the light of the fact that many veins in the North Pennines have been profitably worked from very low stratigraphic horizons, to prove an overall average vein width decrease or else a decrease in the number of veins present (caused by convergence of veins in depth).

The statal extension discussed above was accommodated by faulting. In an ideal situation, anticlinal folding may be accompanied by longitudinal tension fissures parallel to the fold crest and by simple oblique-slip faults subtending about 30° with the fold axis (Price, 1966). In many ways, despite their variable strike direction, the W.N.W. to E.- W.trending 'quarter point' veins are analogous to longitudinal tension fissures. They are persistent and deep. They show lesser shear and normal displacements than the other vein types. They are usually wide, yet can often, as in the case of the Great Sulphur Vein (Thompson , 1933), be shown to narrow in depth. The other two main vein trends however cannot be reconciled with the directions predicted by Anderson's classic dynamic analysis. They follow the master-joint trends very closely and this indicates that these directions had become weaknesses in the rock, imparting considerable anisotropy. Thus there was less resistance to failure following these trends that to failure at 30° to the maximum principal stress (the pericline axis). The resulting asymmetric arrangement of the oblique-slip faults had far-reaching consequences. The N. 50-60° E.faults were closer in trend to the contemporary maximum principal stress (approx. E-W.) than were the N.20-35° W. faults and hence were under relative tension, whereas the others were under relative compression. It has been long known that the two vein sets are not equally well mineralized. The E.N.E. set are known as the

'productive lead veins' and the others as 'cross veins'. This difference in degree or width of mineralization is probably a result of their orientation relative to the pericline axis and maximum principal stress, causing the 'productive veins' to be pulled open under tension and the 'cross veins' to be held closed under relative compression. Many of the barren 'cross vein' faults are actually known to be minor thrusts, indicating considerable local compression.

Mechanical formation of cavities along oblique-slip faults occurs by a combination of two effects:

1) normal movement on a fracture of variable hade

2) shear movement on a fracture of variable strike

For the sake of clarity, both effects, though closely interacting, will be dealt with separately. .

Variation of fault hade as it crosses beds of differing competence is known as refraction, The fault stands nearly vertical in hard beds tending to increase in hade up to 40 - 50° as it passes into soft beds (Dunham, 1948). Normal movement on such a refracted fault plane results in the opening of cavities in those regions of least hade i.e. in the more competent beds. This effect has been recognised from the earliest days of study in the orefield. (Forster, 1821; Leithart, 1838; Louis, 1917; Dunham, 1932, 1948; Varvill, 1937). Three vein sections in Fig. 2.5 illustrate the effect and it is important to note that the vertical displacement on all these veins is not great. If the throw exceeds three or four metres

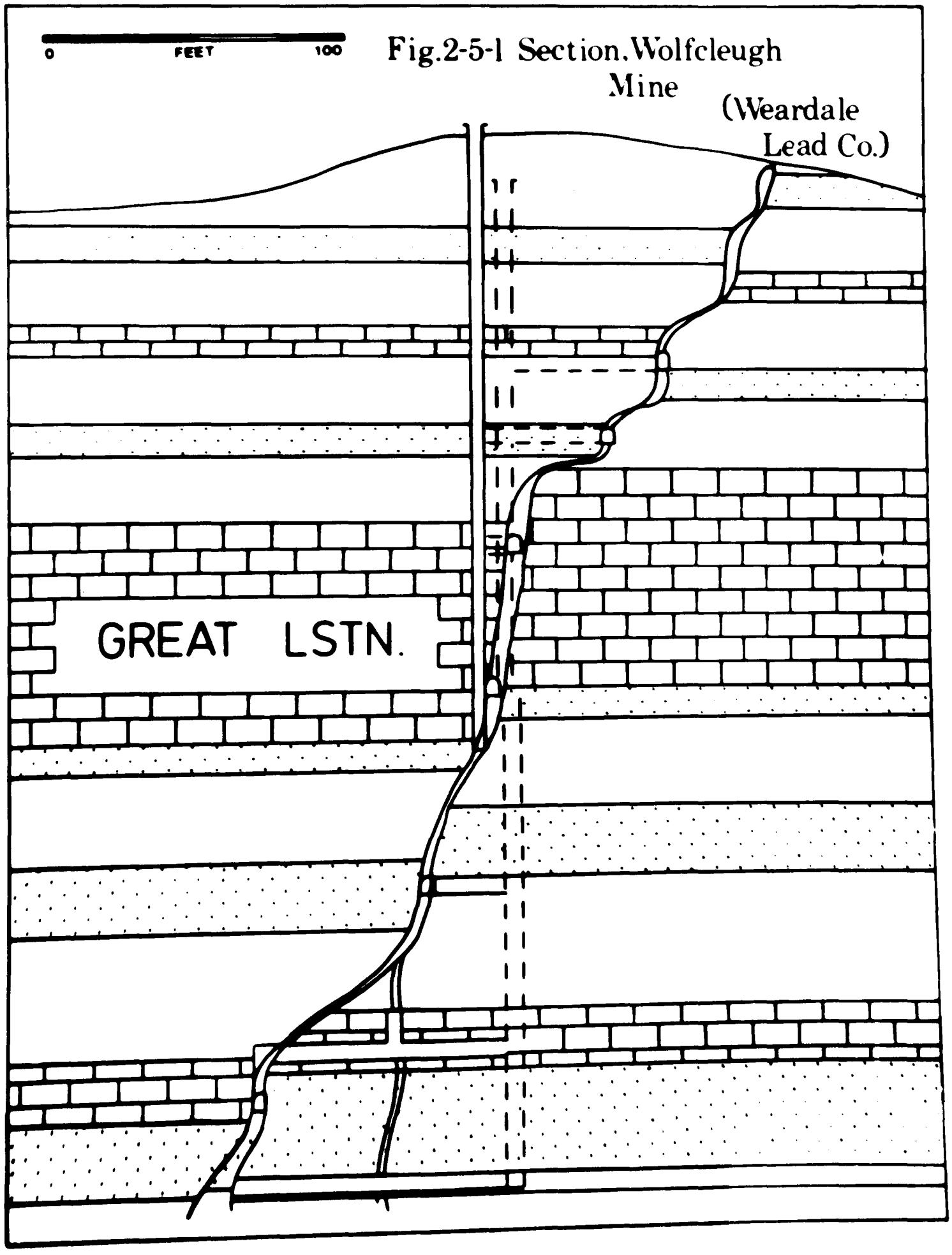
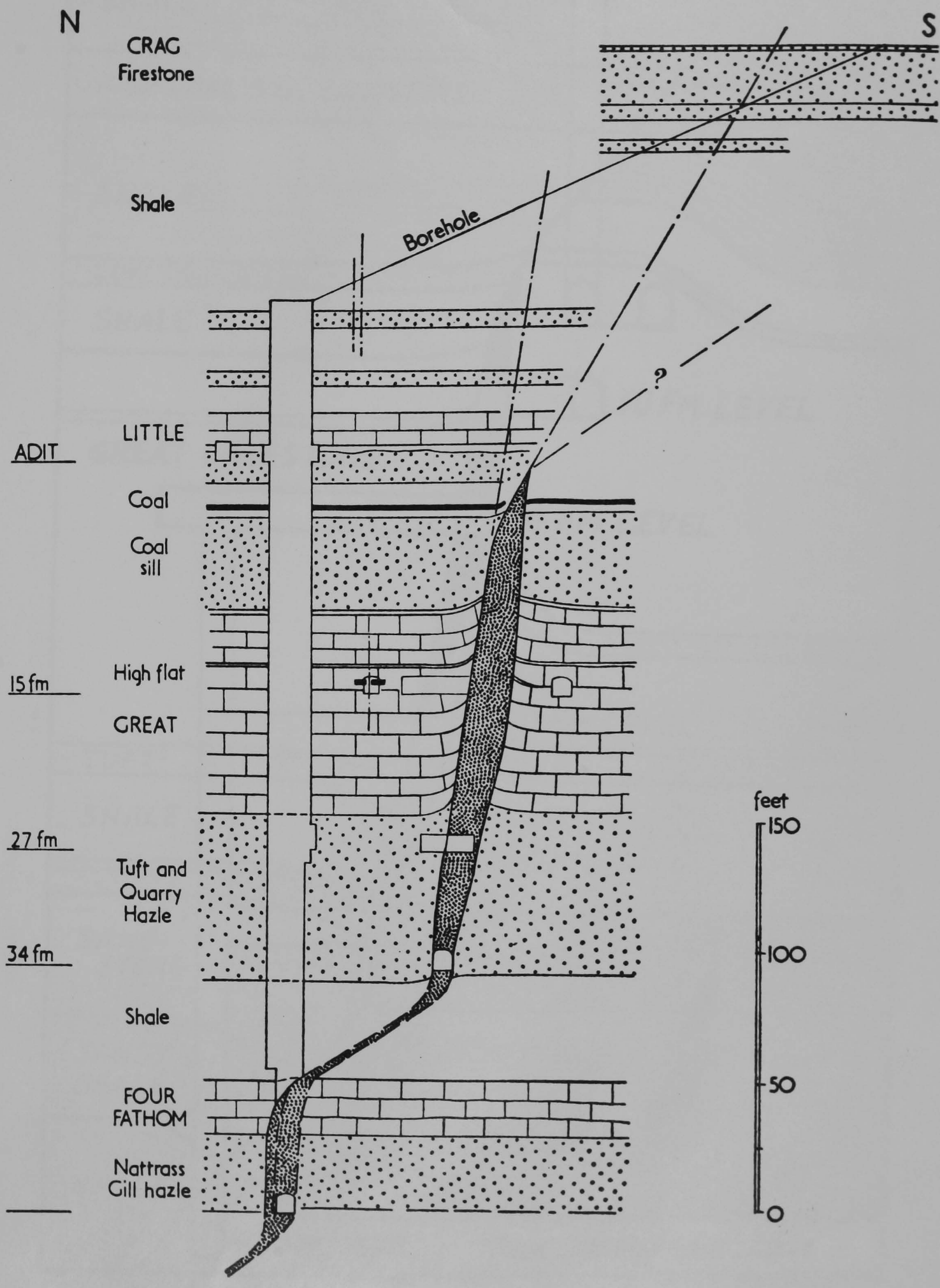


Fig.2-5-1 Section.Wolfcleugh Mine (Weardale Lead Co.)

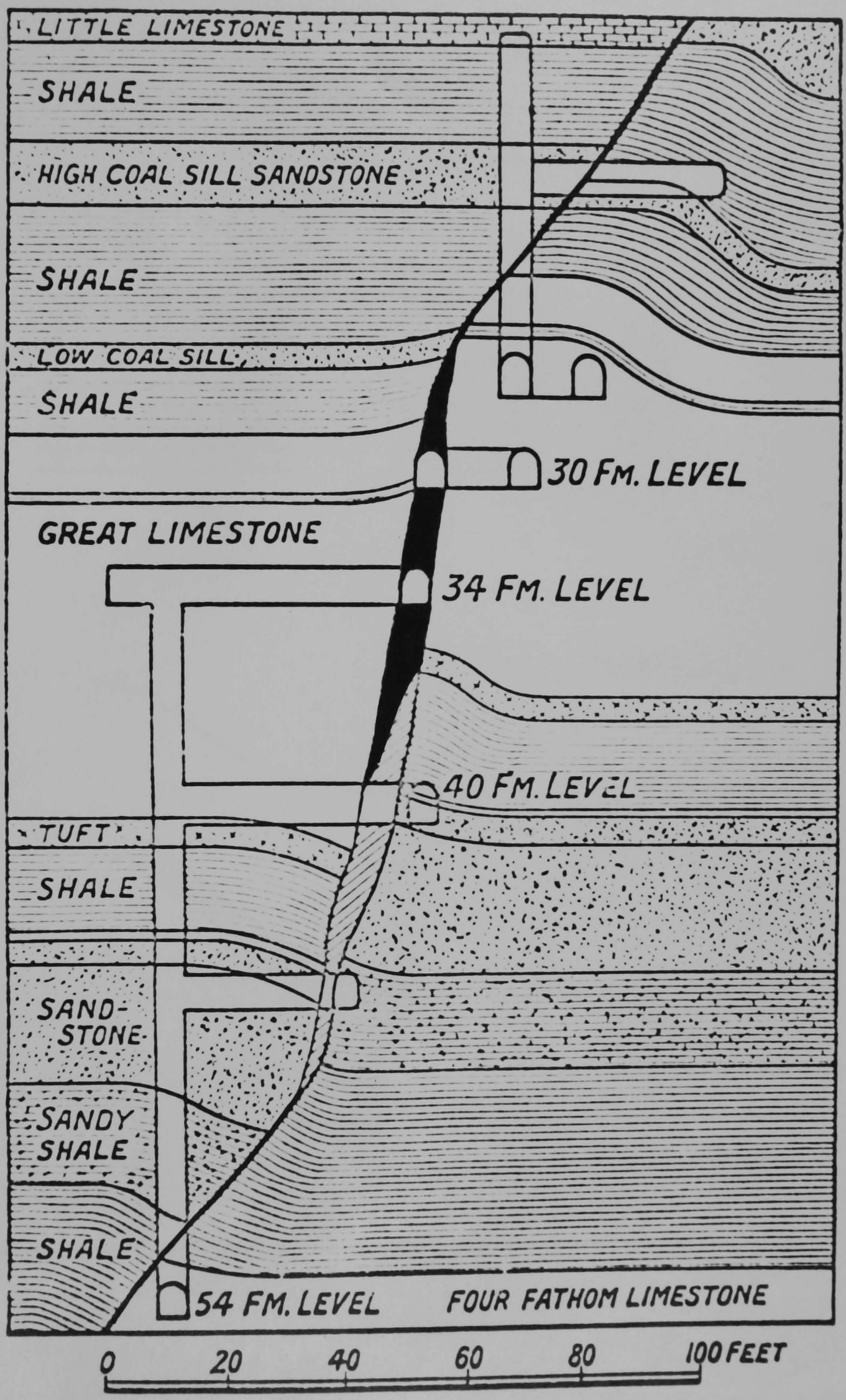
FIG. 2-5-2



RED VEIN, No.4 U/G SHAFT

STOTFIELDBURN MINE - DUNHAM, 1970

FIG. 2-5-3

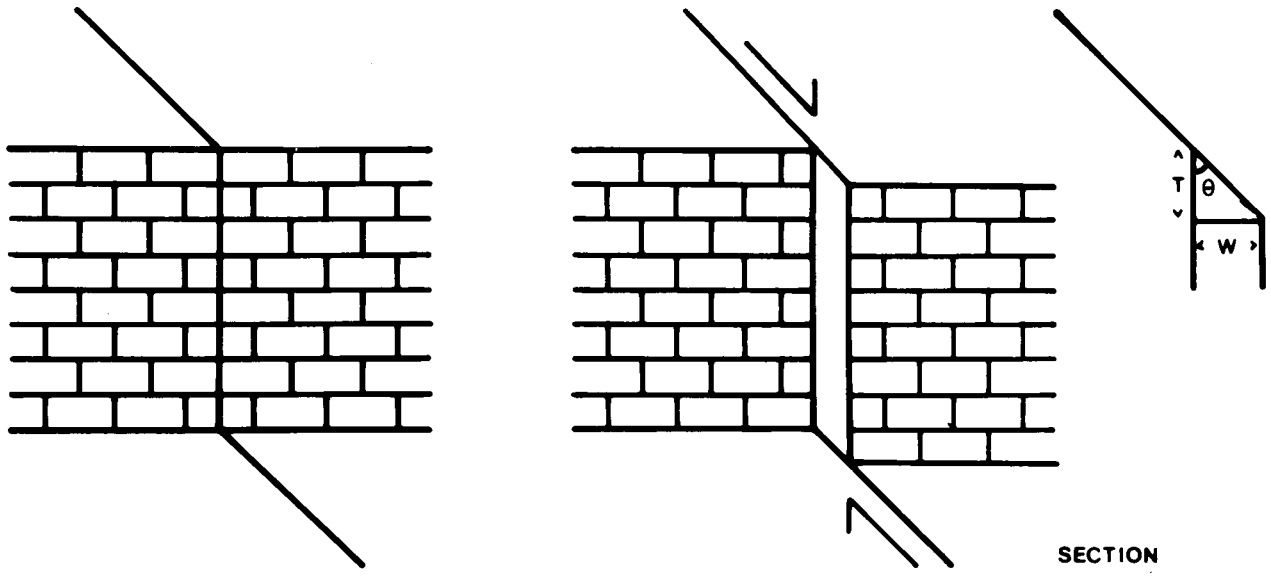


St. PETER'S VEIN - DUNHAM, 1937 b

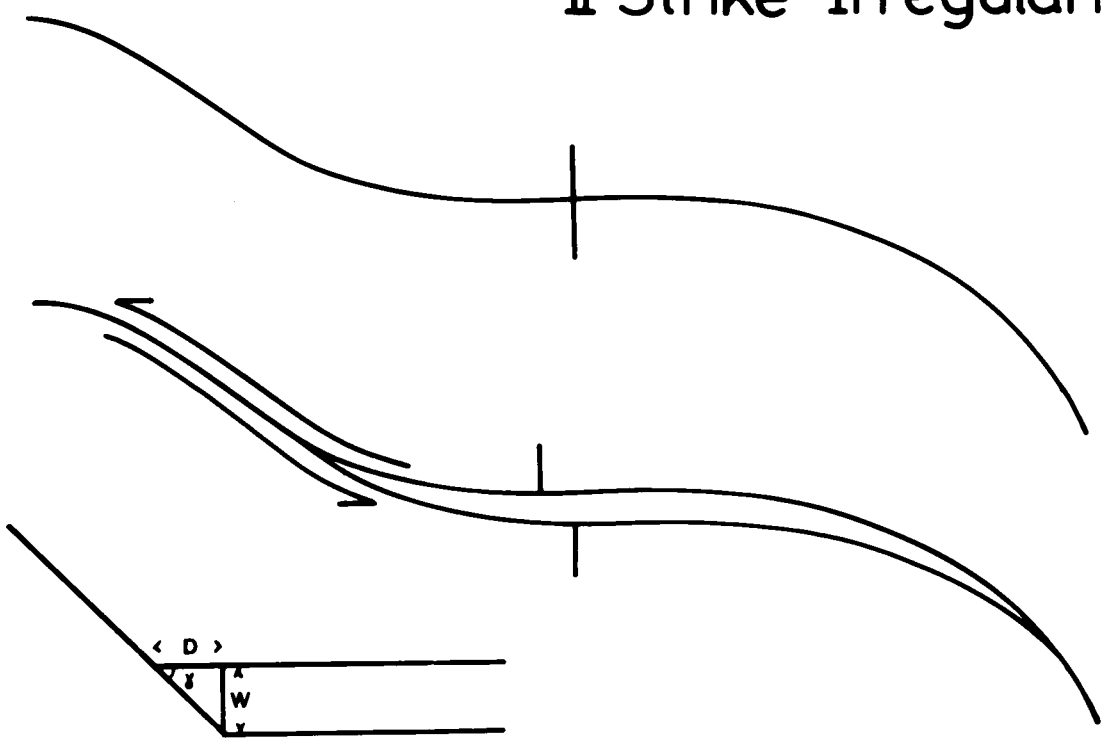
FIG 2-6

CAVITY FORMATION

I Vein Refraction



II Strike Irregularity



then dragging of soft beds against hard may tend to even out the hade of the fault and choke any cavities. As a result of refraction, open cavities capable of carrying ore were formed only in hard beds. Thus the height of the cavities were limited by the thicknesses of the hard beds and since these are thin, the cavities were of much greater length than height. The filling of such cavities with hydrothermal minerals produced 'ribbon oreshoots', so-called after their appearance in longitudinal section (Dunham 1948). Thus the principal control of oreshoot height is wall-rock stratigraphy. The principal control of oreshoot width, however, was the throw of the fault. In an ideal situation on a fault of small throw, (Fig. 2.6) the width of the cavity equals T tan θ where T is the vertical throw of the fault and θ is the difference in fault hade passing from the hard to the soft bed. Thus if, as Dunham states, veins narrow in depth then the hade of the fault must decrease with depth.

Variation in fault strike occurs in response to local perturbations of the regional stress field. These may have been caused by local lithological or sedimentological characteristics, or by pre-existing fractures and other lines of weakness. Shear movement on sinuous fault planes results in the opening of cavities along those sections of the planes that do not oppose the

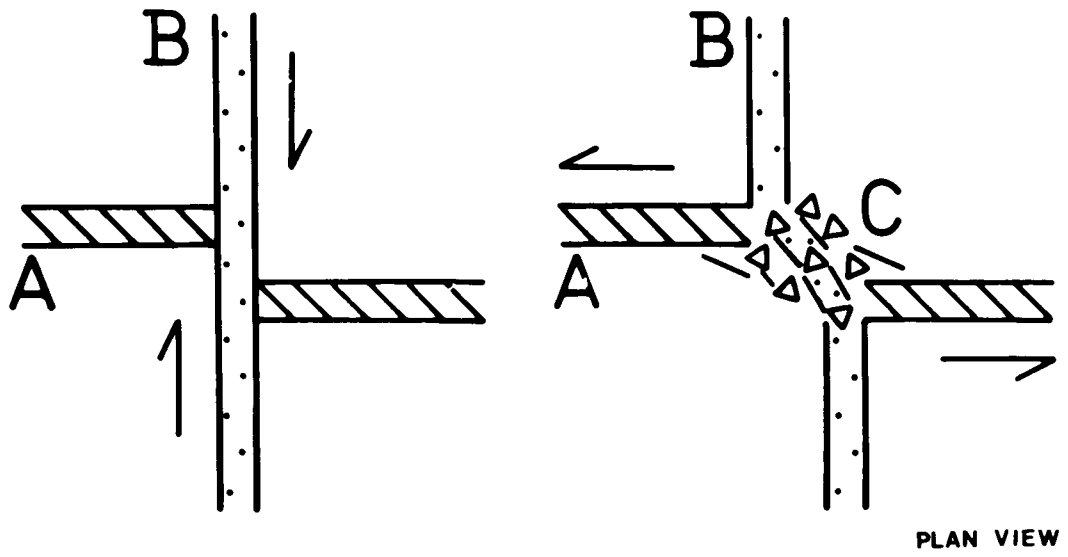
movement (Fig. 2.6). The length of the resultant cavity is thus dependent upon the amplitude of major irregularities of the fault trace. The width of the cavity equals D tan δ where D is the longitudinal fault displacement and δ is the change in fault strike.

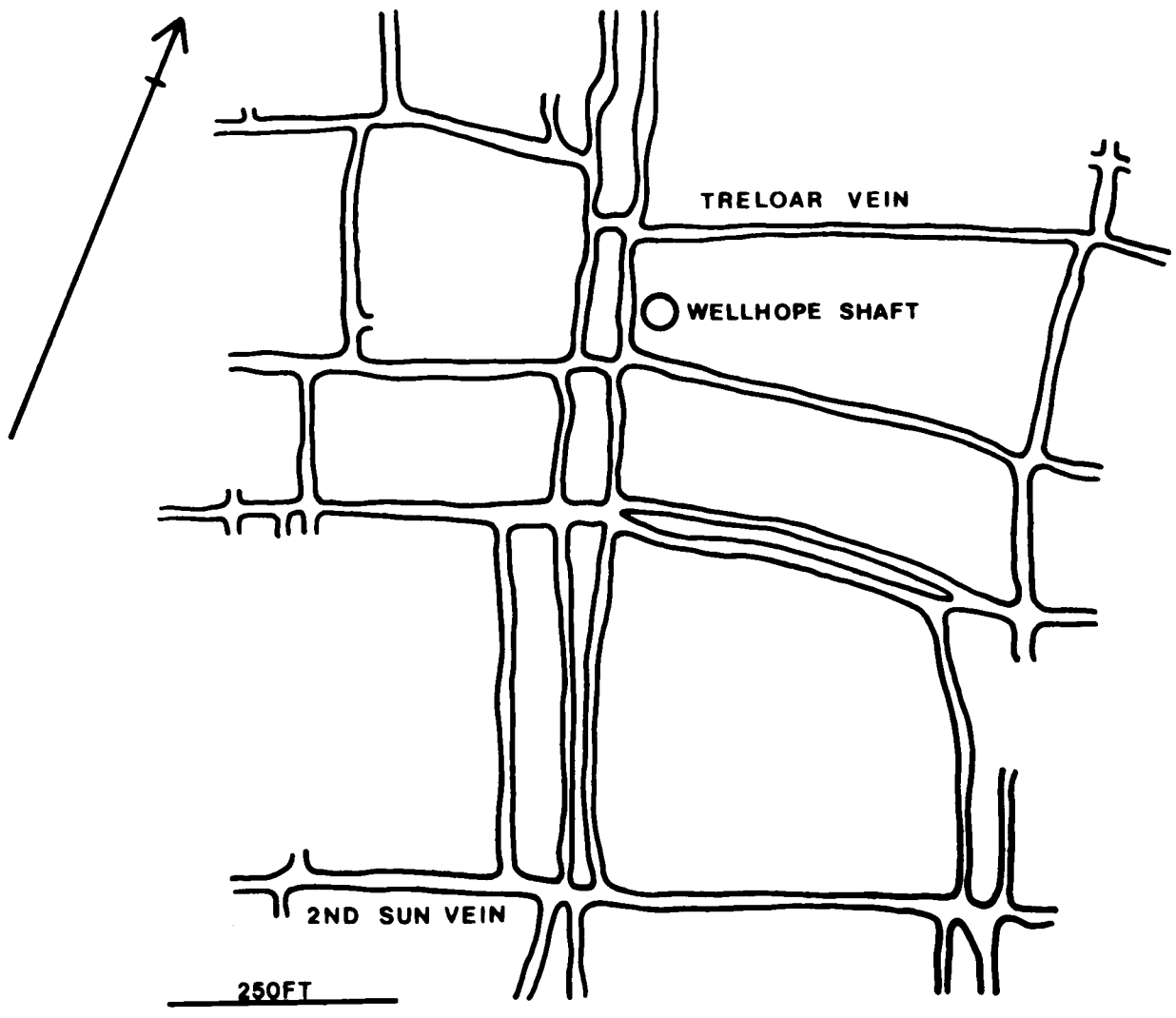
Clearly the two mechanisms just described operate together on oblique-slip faults and form cavities of restricted height and restricted length. Newhouse (1942) analysed in great detail the three-dimensional interaction of the mechanisms and his book provides a large number of other field examples from varied mining districts. Careful measurements, therefore, of changes in vein hade throw or strike can be used to predict the presence of conditions favourable to cavity formation.

2.3 The Geometry of the Hydrothermal System.

At the onset of mineralization, discrete, tectonically-formed cavities of restricted height and length, existed in the harder strata of the Alston Block. Although these cavities lay upon fault planes the interconnecting fractures were tightly closed, effectively sealing off each cavity from others on the same fault plane, at the same or different stratigraphic horizons. Introduction of ascending ore-bearing fluids to the cavities was made possible by the intersection of particular, sub-vertical lithological and structural features with the vein. (Lithological channelways are

FIG 2-7


B
A
B
C
A
PLAN VIEW


TRELOAR VEIN
WELLHOPE SHAFT
2ND SUN VEIN
250FT

discussed in Chapter 3). Sub-vertical structural channelways were formed by fracture intersections. Intersections provided relatively permeable breccia pipes. The probability of continuing movement on the two intersecting structures during mineralization must have acted to maintain permeability (Fig. 2.7) particularly in cases where the initial breccia had been silicified by early phase solutions (Sect. 4.3.1). The regular, orthogonal fracture pattern of the orefield is ideal for the formation of a strong network of intersection feeders. Study of particular lengths of Red Vein suggests that intersection spacings may be as little as 50m, whereas cavity length may reach 300-400 m.

Thus, having formed interconnected vertical and horizontal pipes, through-flow of hydrothermal fluids from their deep source, could take place. Fluid flow within intersection channelways was vertically directed, that within cavities was longitudinally directed. Presumably within any cavity flow would have been from strong input channelways to strong exit channelways, the two not necessarily occupying the same intersection pipe. Thus it is possible that flow directions within cavities were not absolutely stable but varied as particular channelways become choked or were reopened. Nevertheless, the great observed thicknesses of ore and gangue minerals now coating the cavity walls show that very considerable longitudinal flow must have occurred, probably supported by eddying of vertically ascending brines.

CHAPTER THREE

LITHOLOGICAL AND SEDIMENTOLOGICAL CONTROLS OF MINERALIZATION IN NORTHERN WEARDALE.

3.1.1. Introduction

The ore-bearing potential of any particular horizon was shown in Chapter 2 to be dependent, largely through its hardness upon lithology. Thus, by normal movement on a refracted fault plane, orebody cavities were opened in hard rocks permitting hydrothermal circulation and ore deposition.

In the assessment of the potential of a horizon for ore, such properties as lateral persistence, facies variability and sedimentological features must be accounted. For instance, it is possible for normally massive sandstones to thicken, thin or cut out, and adventitious beds of differing lithologies (e.g. washouts) to cut in. Naturally these changes in the host rock character have bearing upon :

1) the height and width of the vein cavity
2) the lateral development and maintenance of an open vein channel.
3) the efficiency of vertical feeder zones, easily stifled by abnormal development of shale
4) mining costs such as timbering, ultimately affecting the orebody cut-off grade.

The vertical dimensions of an orebody may be greatly increased, over limited distance, by the superimposition of favourable variant lithologies and favourable normal beds. Examples of this are discussed later. The possibility of feeders forming between separate orebody cavities at such sites of breakthrough of trangressive sandstone-filled washouts may obviate the need for structural channelways in certain cases.

Strata of the Middle and Lower Limestone Groups are remarkably constant in lithology and thickness over the Alston Block. Notable exceptions in Weardale to this rule include the coal basin developments replacing sandstones at Heights (Lyon and Scott, 1957) and Redburn Mines, and the Tuft washout at Stanhopeburn Mine. The Upper Limestone Group is a much more complex series of sandstones, limestones, shales and ironstones, subject to much rapid lateral facies variation. Erosive washouts are common, ranging in size up to major palaeorivers channels. Our detailed knowledge of the stratigraphy of this Group is derived from the pioneer works of early mine surveyors (Forster, 1821; Sopwith, 1833; Wallace, 1861) and two fairly recent doctoral studies (Pattinson, 1964; Hodge, 1965). The courses of the major washout channels in northern Weardale have, to a large extent, been determined. Generally these channels are sandstone-filled, though minor shale-filled washouts are known and may locally have adverse effects on ore-bearing horizons.

The distribution and character of major facies variations and their effects upon mineralization in the mining areas of Northern Weardale and Hunstanworth are discussed in the following sections. Northern Weardale is described in detail since it was taken as a field area at the beginning of the project. Further field details are described in Section Two of this thesis but it was considered to be more appropriate to introduce and demonstrate the importance of lithological and sedimentological controls at this early stage in the work. The Red Vein of Weardale has been studied in greatest detail.

3.1.2 The Nattrass Gill coal facies, Redburn Mine.

The Nattrass Gill Hazle is a hard, persistent nine metre sandstone known throughout the North Pennines nowadays as a good ore-bearing horizon (Dunham, 1948). However, it has not always had this good reputation and Sopwith (1833, p.94) says of it "in a mining point of view, no stratum is less important, veins in it being generally barren" ! It is usually separated from the overlying Four Fathom Limestone (6m) by a thin band of black marine shale. Locally a minor coal sequence also occurs at this junction. This facies is particularly well-developed at Gilderdale, Alston, where a 46 cm coal seam was once worked. Coal basin facies have been found again, unexpectedly, while driving the 40 Fms Haulage Level beneath Bield Hill from Redburn Mine (Fig. 3.1). The level is at around the top of the sandstone which in the shaft vicinity is a ganister overlain by a reworked seatearth (quartz,

FIG. 3.1 Development of the Nattrass Gill Coal Facies in Redburn Mine

Three selected sections beneath the base of the Four Fathom Limestone showing the lateral facies variation of the Nattrass Gill Hazle.

1) exposed in western forehead of 40 Fms Level, Dec. 1972

2) 640'W. of shaft, 40 Fms Level

3) 1000'E. of shaft, 40 Fms Level

FIG. 3.2. The Iron Post and Four Fathom Cyclothems Near Rookhope

Showing lateral facies variations in the strata beneath the base of the Great Limestone (datum line 0')

1) Stanhopeburn Mine (Durham, 1948)

2) Stotfieldburn Mine

3) Rookhope Borehole

4) Redburn Shaft

5) Redburn Western ore-zone, 17 Fms Level

FIG 3-1 Development of Nattrass Gill Coal Facies, Redburn

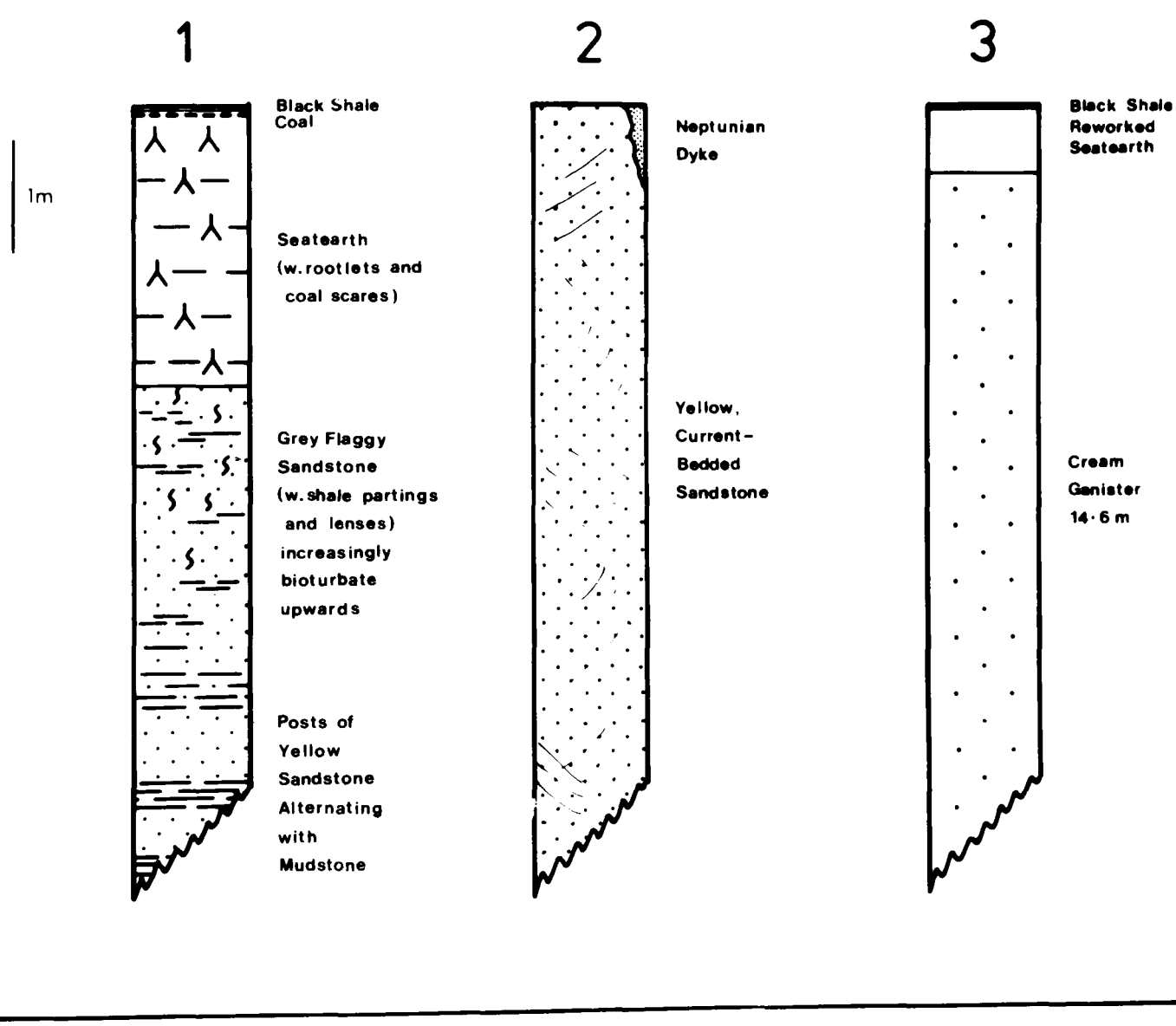
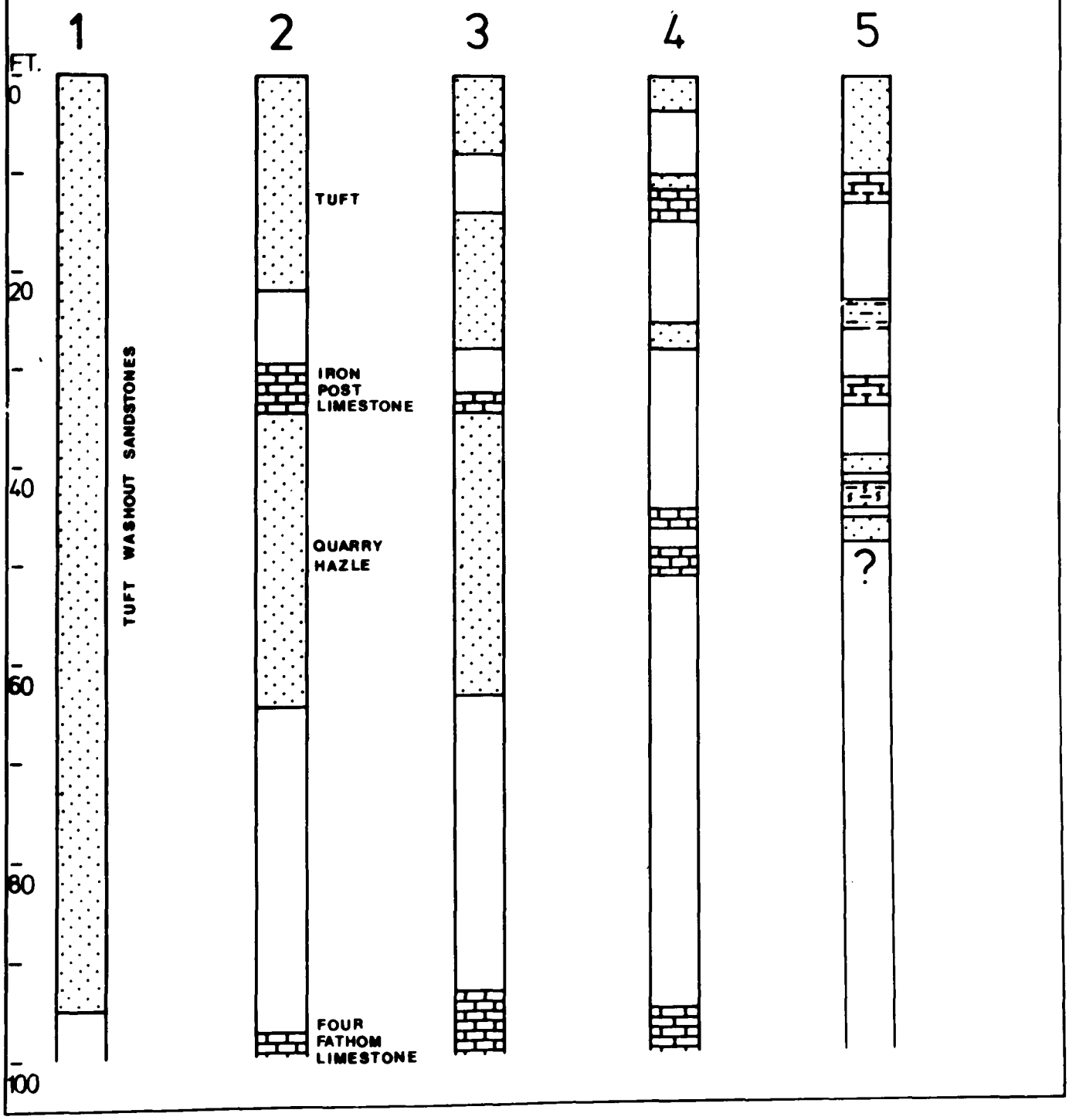


FIG.3.2 THE IRON POST AND FOUR FATHOM CYCLOTHEMS NEAR ROOKHOPE



ankerite, siderite, illite) and minor black shales. Traced westwards the reworked seatearth thins and cuts out as the limestone and sandstone come into contact 194m from the shaft. Further westwards the top of the sandstone becomes increasingly bioturbate and carbonaceous, grading gradually into a 3m seatearth with coal scares, capped by an impersistent 25mm coal seam.

The seatearth development is at the expense of hard sandstone and the change in lithology has an adverse affect upon mineralization.

3.1.3 The Tuft channel, Stanhopeburn.

In the area of Stanhopeburn Mine a thick washout channel in the Tuft sandstone cuts down through underlying shales, penetrating the Quarry Hazle sandstone in places. The total thickness of united ore-bearing strata (including the Great Limestone) where this occurs is 51m and consequently orebodies of remarkable height and strength have developed. The width of the channel is uncertain. At Hope Level the washout sandstone has thinned (Dunham, 1948) and beneath Wolsingham Park Moor it is absent. To the west it is present in No. 4 underground shaft, Stotfieldburn Mine, but terminates a little west of this. A southward continuation is believed to pass through Cornish Hush Mine.

The Iron Post cyclothem, which includes the Tuft Sandstone, is very variable in lithology and thickness in the Rookhope area. Some of this variability is shown in Fig. 3.2

3.1.4. The High Coal Sill Washout (Fig. 3.3).

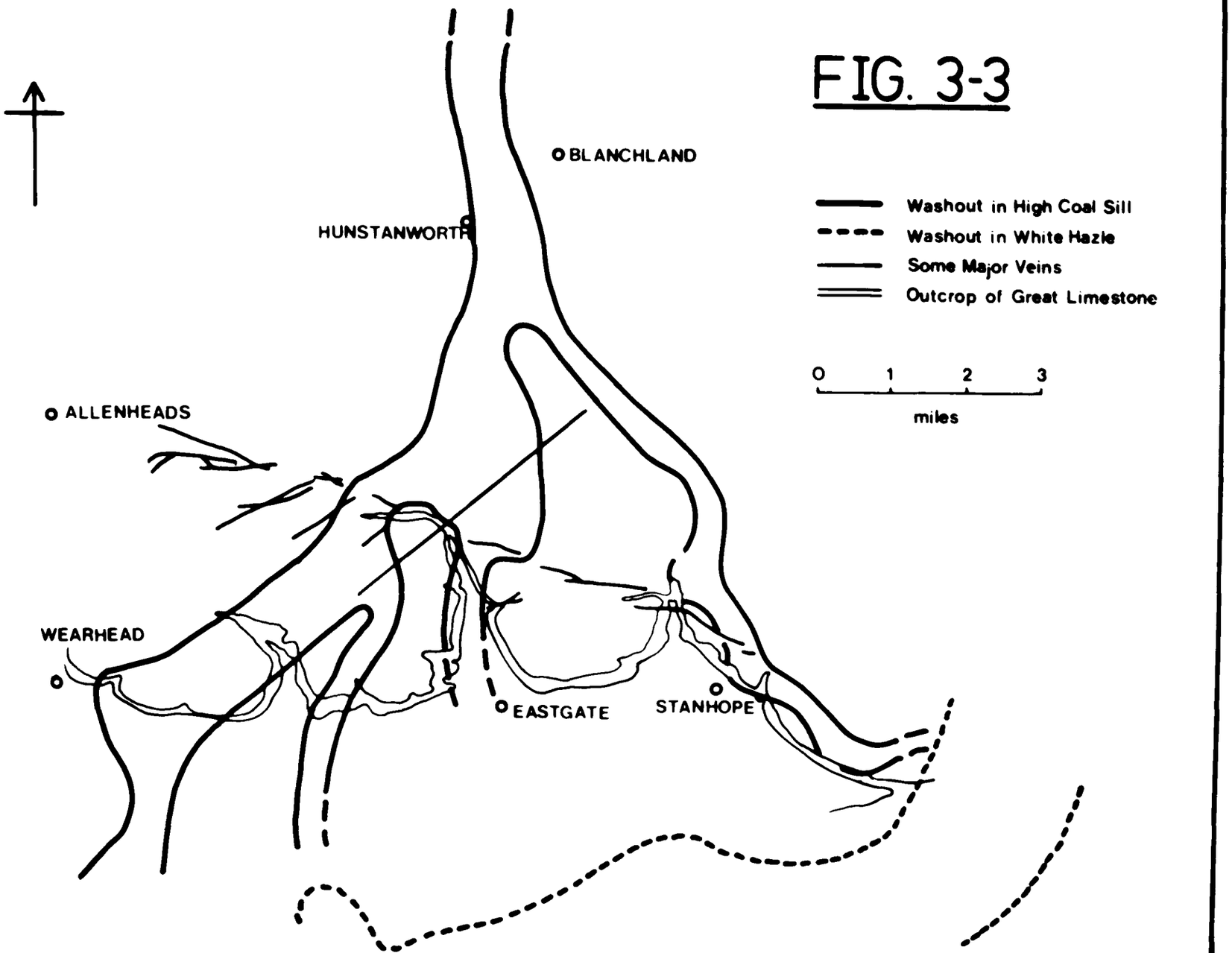
The High Coal Sill is represented in the area by an extensive sheet sandstone averaging 3 to 5m in thickness, and locally by washout channel sandstones.

The main washout channel runs slightly E. of N. through St. John's Chapel and Rookhope, to Hunstanworth and Blanchland. Three subsidiary channels branch off to the east. All the channels cut down to within about a metre of the Great Limestone and in particular instances e.g. No. 3 Shaft

Explanation of Figs. 3.3 to 3.7

These figures show the margins of sandstone - filled washout channels in the northern Weardale - Derwent Valley areas. The information has been taken mainly from Hodge (1965) and Pattinson (1964) with additions arising from the present project. Fig. 3.5, taken from Pattinson (op. cit.) shows the normal and washed out stratigraphical successions in the Slate Sills Formation.

FIG. 3-3

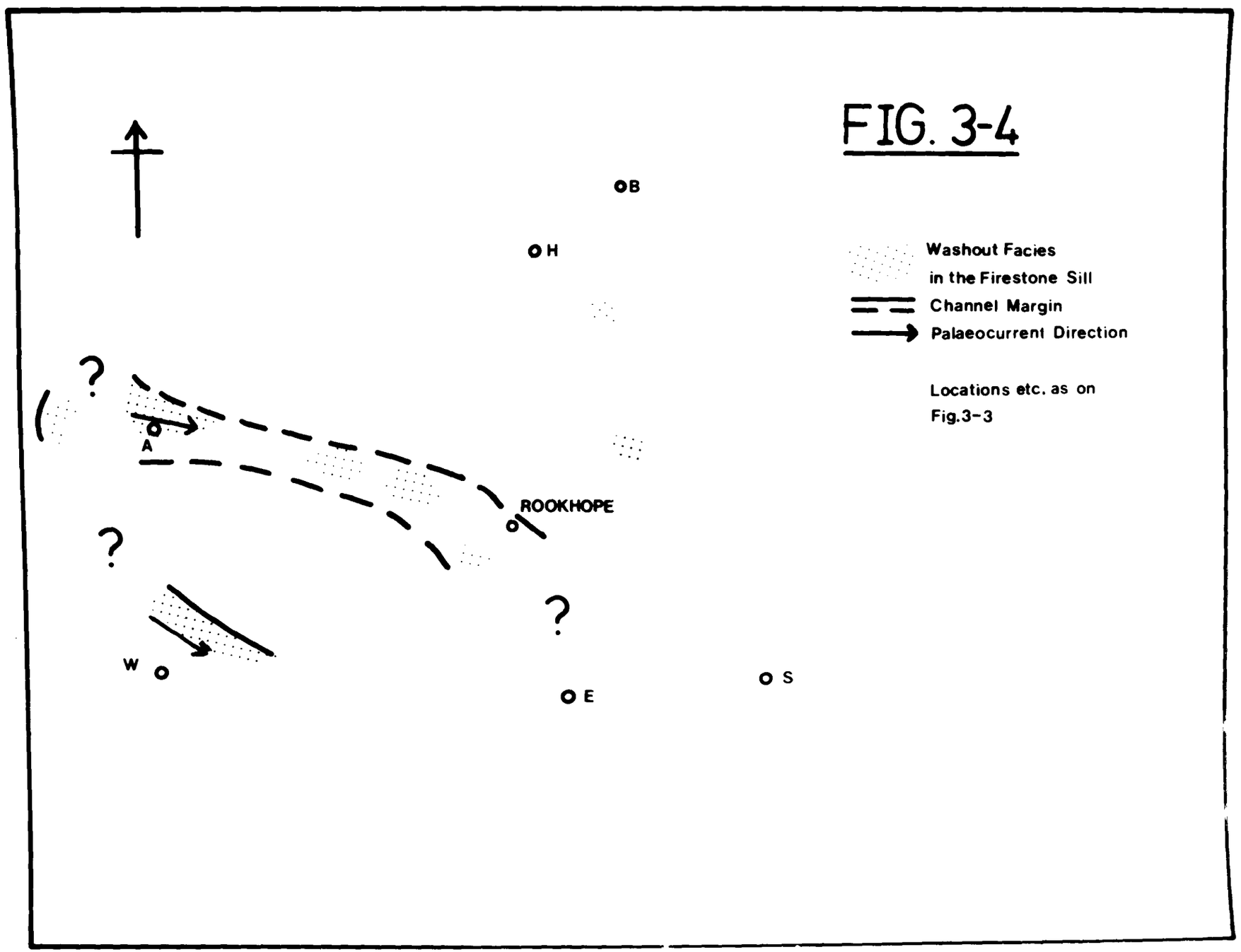

BLANCHLAND
HUNSTANWORTH
ALLENHEADS
WEARHEAD
EASTGATE
STANHOPE
Washout in High Coal Sill
Washout in White Hazle
Some Major Veins
Outcrop of Great Limestone
0 1 2 3
miles

section, Stotfieldburn Mine, may penetrate the top of the Limestone. The main channel is generally about $1\frac{1}{2}$ km wide with an irregular base and contains a maximum thickness of 27m of mainly coarse sand and pebbly channel fill. The subsidiary channels are about $\frac{1}{2}$ km wide containing a maximum of 13 m of fill, again mainly sandstone (Hodge, 1965).

At Hunstanworth, Middlehope and Blackdene the massive main channel sandstones bear large extended orebodies continuing upwards from the Great Limestone. The total heights of orebodies at Hunstanworth, moreover are increased by the coincidence of further washouts in higher strata. The situations of major palaeorivers appear to have remained fairly constant with time in this area. At Middlehope Mine, orebodies in the Scarsike Vein reached 58 m in height within the washout area and at Blackdene, orebodies continue for at least 16 m in sandstone above the Great Limestone. Dunham (1948) suggests that the location of the washout channel margin has exerted strong control over the lateral continuity of mineralization in the Ramshaw Veins within Namurian strata. The distribution of flat deposits at Boltsburn Mine was also affected by channel configuration (Fig. 3.8).

The effect of the washout sandstones on Red Vein orebodies is difficult to assess. Existing plans of Red Vein Level, Crawleyside Mine and Hope Level show no workings at this horizon. Wide stopes continue into the Coal Sills group in Stanhopeburn Mine despite the absence of washout facies. At both Redburn and Stotfieldburn Mines orebodies have been worked from the sandstones, the marginal facies of which also coincide

FIG. 3-4


B
H
Washout Facies
in the Firestone Sill
Channel Margin
Palaeocurrent Direction
Locations etc. as on
Fig.3-3
?
A
ROOKHOPE
?
?
W
E
S

approximately with the limits of payable ore in the west and east of these two mines. Sections exposed by Nos. 3, 4, 5 and 9 Rises in the Western ore-zone at Redburn show quite clearly the westward thinning of the High Coal Sills sandstone and the Great Limestone cyclothem. In these instances, however, though it is agreed that development of orebodies at this horizon was primarily due to the presence of washouts, lateral ore failure is more likely to have been structurally controlled.

3.1.5 The Firestone Sill. (Fig. 3.4)

A massive, persistent, sheet sandstone, the Firestone Sill is prone to wide variation in thickness, ranging from 2 to 17 m in the area. Channel erosion is again a common feature and thick channel facies sandstones occur at Allenheads in a zone trending towards Rookhopehead. Current directions measured from these beds indicate flow in that direction (Pattinson, 1964). Further evidence of the eastward continuity of the channel is found at Groverake and Redburn where the Sill is 13 and 11.5 m thick respectively. In both mines good orebodies are developed. (up to 11 m in total width in the Firestone Drift, Groverake), though at Groverake the presence of further, massive channel sandstones above the Firestone has contributed to the strength of mineralization. The orebody limits at this horizon at Groverake may well be determined by the marginal facies of washout channels. Certainly the existence of the channels close to the main Red Vein intersection has provided an ideal access conduit for brines ascending to the upper orebodies.

FIG.3-5 Namûrian Facies Variation (taken from Pattinson 1964)

SCHEMATIC SECTION OF THE STRATA BETWEEN THE LITTLE LIMESTONE AND THE ROWTON WELL SILL OF THE TYNE-WEAR WATERSHED

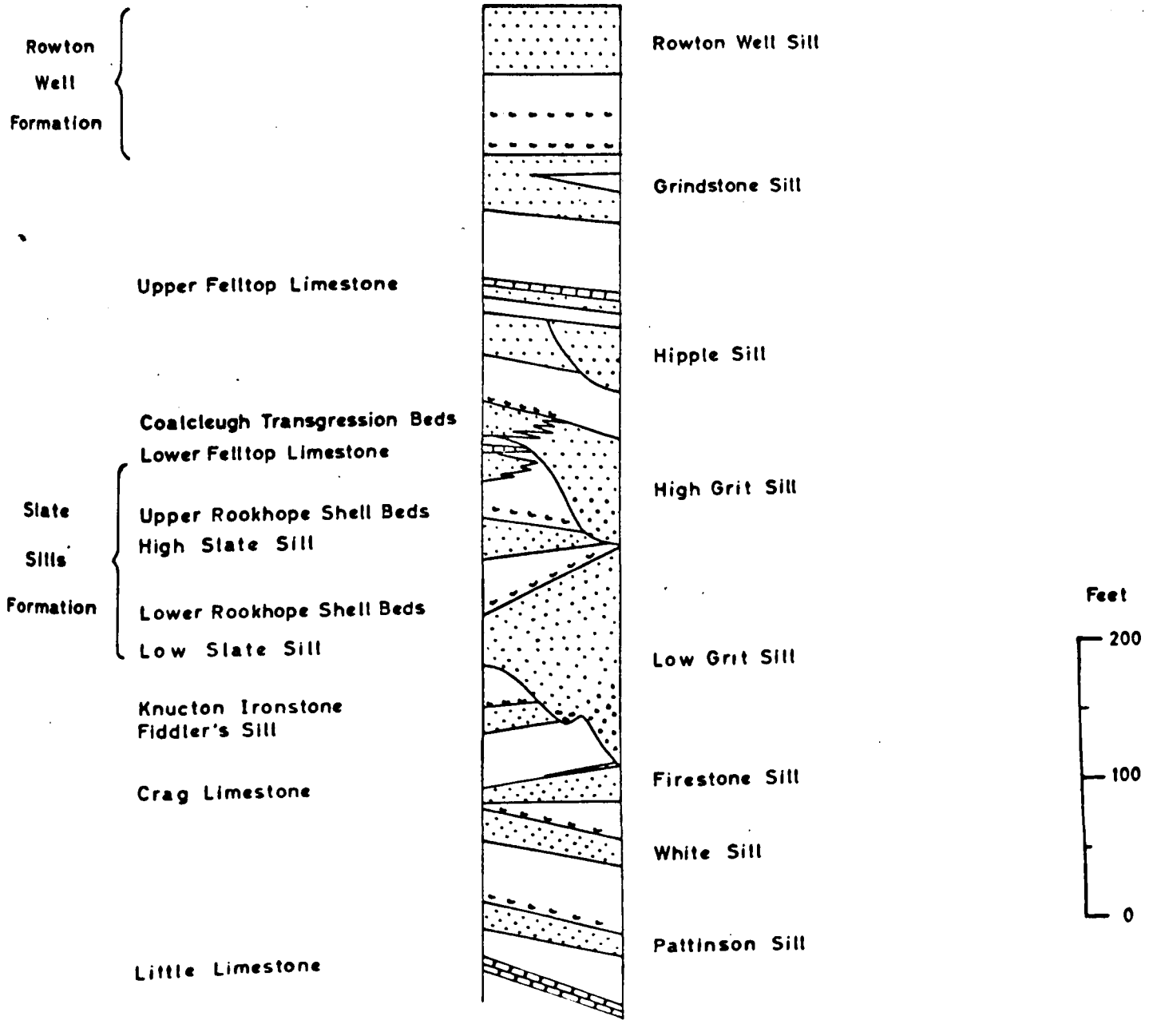


FIG. 3-6

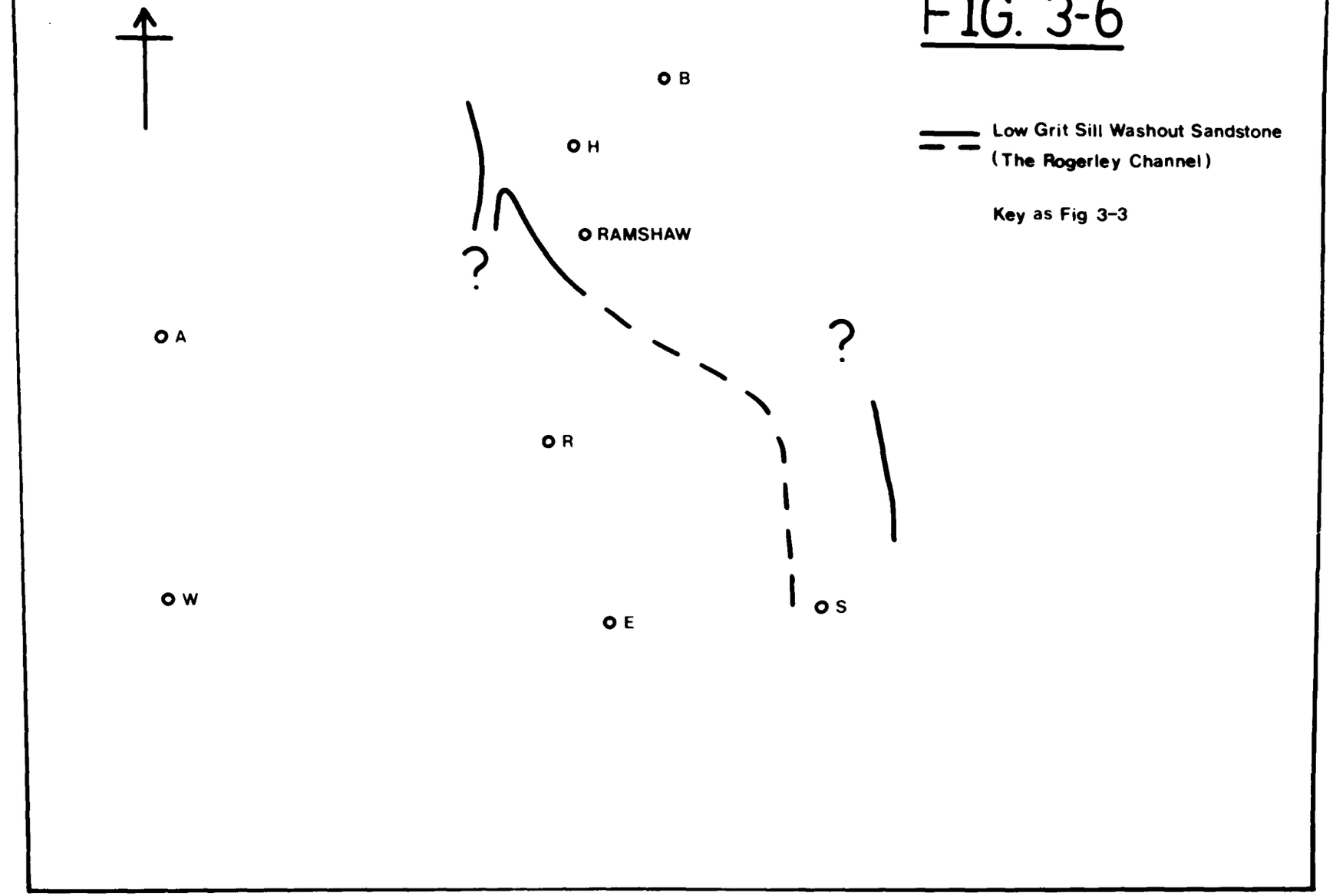
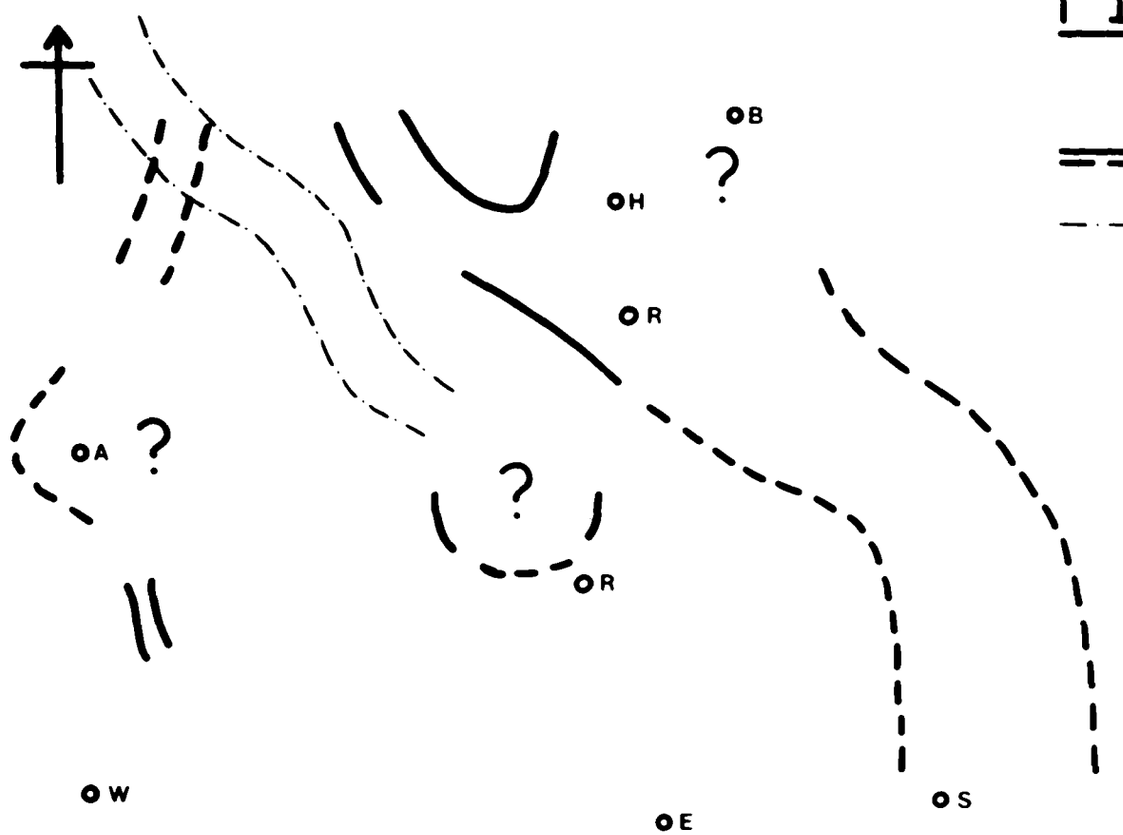

B
H
RAMSHAW
?
?
A
R
W
E
S
Low Grit Sill Washout Sandstone
(The Rogerley Channel)
Key as Fig 3-3

FIG. 3-7



High Grit Sill Washout Sandstone (Coalcleugh Channel)

Washout in Hipple Sill

Key as Fig 3-3

3.1.6 The Grit Sills (Figs. 3.5, 3.6, 3.7)

The Slate Sills formation is subject to considerable disruption and facies variation across the Alston Block. Most important of the irregularities is the development of two very large washout channels known as the Rogerley and Coalcleugh channels - (Pattinson, 1964). The conglomeratic channel-fill sandstones themselves are known as the Low and High Grit Sills respectively. The former is a variant facies of the Low Slate Sill sandstone and the latter is a highly erosive facies of the overlying Coalcleugh Transgressive Beds. Channel facies sandstones are also known to occur in the intervening High Slate Sill, particularly at Groverake.

The channel courses are not well-known but, following previous channels, they trend roughly N. - S. and pass through the Hunstanworth and Crawleyside mining areas. Further areas of High Grit Sill facies occur at Allenheads Mine and at Corbetmea, Rookhopehead. Good widths of mineralization reported from this latter locality have not been seriously exploited. Highly profitable orebodies, however, have been virtually worked out at Allenheads, Whiteheaps and Crawley Mines.

3.2 Discussion.

Mineralization is characteristically distributed along veins in a non-uniform fashion. The location of vein cavities can be shown to have been mainly structurally controlled. The size of vein cavities, however, also depended upon lithological factors.

Dunham (1944) grouped North Pennines lead mines according to output and found the following distribution:

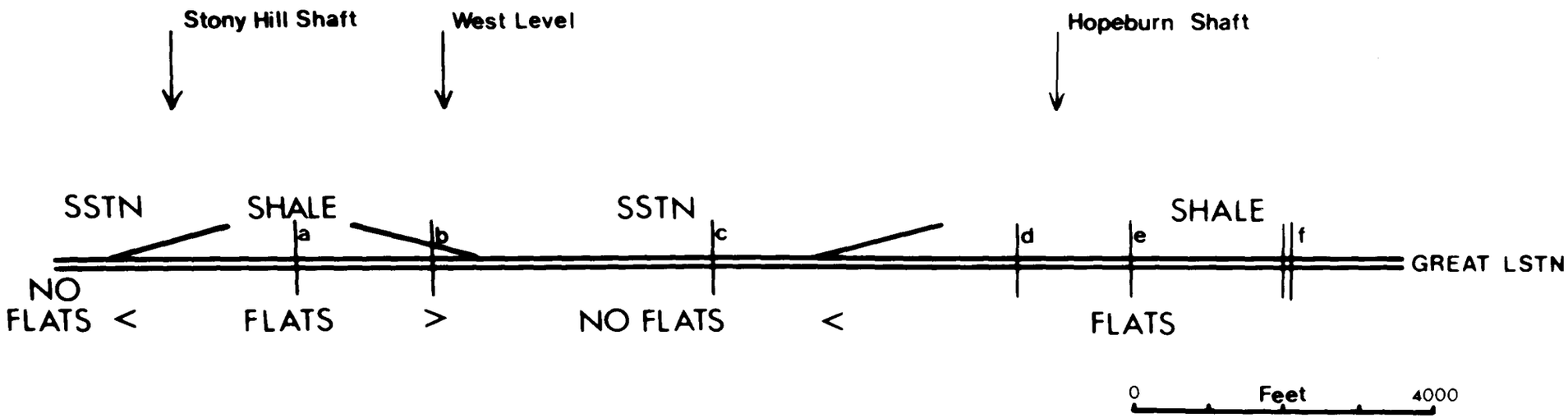
Long tons of lead concentrates :-

over 100,000	50,000- 100,000	20,000- 50,000	10,000- 20,000	5,000- 10,000	1,000- 5,000	under 1,000
Number of mines						
7	4	15	14	15	38	65

(Bozdar and Kitchenham (1972) have recently confirmed that lead productions from North Pennine mines are lognormally distributed with a mean of 25,402 tons of concentrates, 95 per cent confidence limits of 9,762 - 41,042 tons).

Dunham found that in spite of the wide distribution of the veins throughout the area, the bulk of the production, including those mines producing over 10,000 tons of concentrates, has come from restricted belts (Dunham, 1944, Plate 11). Neglecting for the time being those mines that worked flat deposits, the belts of major lead producing orebodies correspond crudely with the courses of major sandstone belts. The most remarkable correspondence is that between the Coal Sills washout channel and the Hunstanworth - Stotfieldburn Boltsburn - Middlehope - Elmford - Blackdene deposits. Another very strong relationship can be demonstrated between the Grit Sills washout, running from Bollihope Fell, south into Teesdale, and the great belt of oreshoots at Sharnberry, Eggleshope, Lodgesike, Coldberry and Skears. The Eggleshope orebody, for example was one of the largest known in the orefield. It was worked for 8,000', and

SECTION ON BOLTSBURN VEIN SHOWING THE DISTRIBUTION OF FLAT MINERALIZATION



a Paterson's Vein ; b Red Vein ; c,d,e Unnamed Cross Veins ; f Burntshieldhaugh Cross Vein?

FIG. 3-8

reached a maximum height of 300' averaging 200' and was continuously mineralized throughout the thick Grit Sills belt (Dunham, 1948). Total lead production from orebodies in this washout belt exceeds 340,000 tons (of concentrates, since 1816, Dunham, 1944).

The distribution of flat deposits in well-defined belts, e.g. the Coalcleugh - Rampgill - Smallcleugh - Middlecleugh belt, may also indicate some lithological - stratigraphical control, since all these flats are largely confined to the Great Limestone and Dunham has shown that the formation of flats is probably related to the restriction of flow of fluids above the host limestones. Where sandstones overlie limestone, flats do not occur (Dunham 1959). This point is brought out particularly well on Fig. 3.8 which shows the distribution of the famous flat deposits at Boltsburn Mines.

There is a very important inference from this discussion. Washout belts are virtually restricted to the Upper Limestone Group. Thus most of the very large ore-zones occur in this Group. These ore-zones were easily accessible to the older miners and still form the loci of modern operations. However, since mineralization within the Upper Limestone Group is said to have been worked out or else to be too dangerous to exploit owing to instability of old workings, present exploration is directed towards prospects at depth in the Middle and Lower Limestone Groups. The uniformity of strata in these Groups makesit unlikely that they contain washout belts. Thus the special lithological conditions required to form orebodies of outstanding dimensions were absent and the size of vein orebodies to be worked in the future from these strata can only be expected to decrease. On the other hand, since large volumes of ore-bearing fluids have passed through these 'root-zones', the presence of strong mineralization, albeit in bodies of smaller dimensions, is

CHAPTER FOUR

THE CHEMISTRY OF THE MINERALIZING SOLUTIONS.

4.1 Introduction.

Until quite recently the estimation of ore solution composition was virtually restricted to interpretation of hydrothermal mineralogy and wall-rock alteration. Such interpretations, however, can seldom provide totally unambiguous information on the composition of a solution before it entered the zone of ore deposition, though they can be very valuable in determining thermodynamic parameters of solution and constituent ions. The study has gained new impetus over the last few decades through the development of micro-chemical and other techniques for the analysis of samples of the solutions trapped as fluid inclusions in growing mineral crystals. Probably the most important discovery has been that of the high concentration of sodium (K.Mg.Ca) chloride in the solutions and of the part played by chloride complexing in ore transport. Mass spectrographic techniques are available to provide complete analyses of fluid inclusions, but have not yet been used on the North Pennine deposits. It is proposed to review in this chapter, the present state of knowledge of the nature and composition of the North Pennine hydrothermal solutions, incorporating additional information and new discoveries arising from this project.

Dunham (1932, 1934), following the pioneer work of Forster (1883) and Smythe (1922), demonstrated that the gangues fluorite

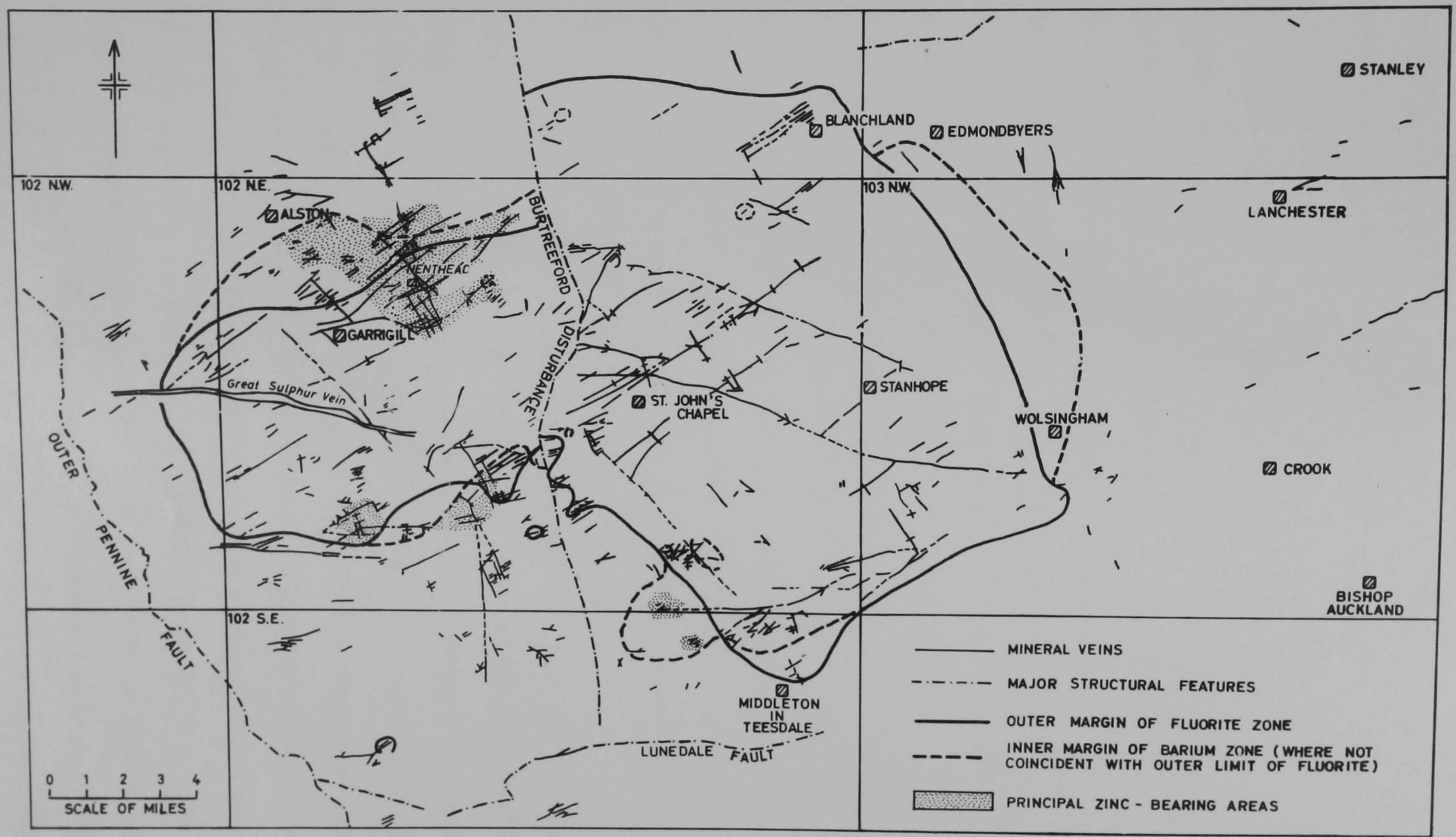


FIG.4-I

THE NORTHERN PENNINE OREFIELD.

(AFTER DUNHAM 1949 PLATE II)

and the barium minerals (barite and witherite) are mutually exclusive, occuring in two separate,concentric zones,an inner fluorite zone and an outer barium zone. There is essentially no mixing of the gangues over the zone boundary, although an intermediate zone in which neither mineral occurs in great quantity is sometimes found (Fig. 4.1). The main part of this chapter is devoted to the chemistry of fluorite zone solutions. The mineralization of the barium zone is poorly exposed at present and is also, at present, of lesser economic importance. The extremely sharp demarcation between the two gangue zones contrasts strikingly with other British lead-zinc-barium-fluorine orefields where both fluorite and the barium minerals can occur together in proportions governed by normal gradational spatial and temporal zonation. Two theories have been presented in the literature to explain this unusual feature and to account for the genesis of the North Pennine ores.

Sawkins (1966) based his theory largely on fluid inclusion data (discussed in detail later). He interpreted the zonation in terms of the mixing of hydrothermal brines with barium chloride-bearing connate brines similar to those found at present in the Durham and Northumberland coalfields (Anderson, 1945) and in other coalfields of northern Europe. The rising juvenile solutions,carrying metals, fluorine and sulphate emanated from cupolas of the Weardale Granite and were ultimately derived from below the crust(Fig. 4.2,reproduced from Sawkins, 1966). Fluorite zone mineralization occurred under conditions of decreasing temperature. Mixing of the two brines occurred near the present fluorite-barium zones boundary, resulting in the inception of barium sulphate precipitation, local formation of rich sulphide bodies by reaction of

the juvenile metals with reduced sulphur in the connate brines, and cessation of fluorite deposition through dilution.

The more recent theory of Solomon, Rafter and Dunham (1971) is based mainly upon sulphur and oxygen isotopic ratio data obtained from sulphides and barite of the orefield. While retaining mixing as the dominant mechanism of zone demarcation, they suggest that both brines were of connate origin. One, which circulated deep in the crust picking up heat, barium, fluorine and ore metals from its surroundings was brought by convection through the fluorite zone (precipitating mineralization during cooling) into contact with the other, a shallow cold, sulphatic brine (Fig. 4.3 reproduced from Solomon and co-workers, 1971). Both brines are interpreted as being of Lower Carboniferous age.

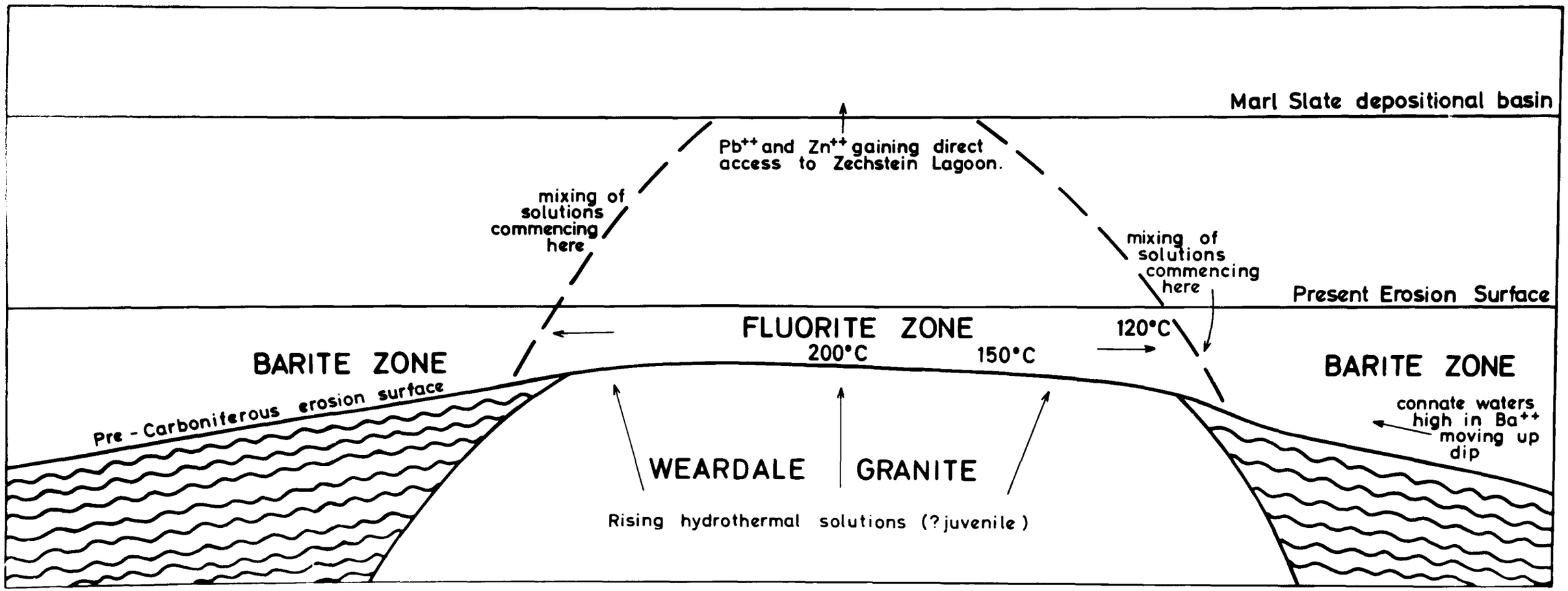
Neither theory is totally successful in explaining the sharpness of the zonal boundary, but it is most important to note that both recognise physicochemical dissimilarities between the dominant solutions of each zone. Hence deductions regarding the composition of the mineralizing solutions are not necessarily applicable to both zones.

4.2 Mineralogical Deductions

Primary hydrothermal minerals in the ore deposits have been introduced in solution or colloidal suspension. The extent to which some of these minerals, such as carbonates and quartz, are derived from the original, primary constituents of the mineralizing solution, or were remobilized within the zone of mineralization, from rock horizons undergoing reaction or ion exchange with the solution, is difficult to estimate. Mineralizing solutions appear to undergo continuous evolution throughout their existence, making definition of primary composition philosophical.

For example, Wager (1929) suggested that the iron carbonate minerals of the North Pennine deposits owe their origin to hydrothermal leaching of iron from the Whin Sill. Dunham (1948)

FIG.4-2


Marl Slate depositional basin
Pb++ and Zn++ gaining direct access to Zechstein Lagoon.
mixing of solutions commencing here
mixing of solutions commencing here
Present Erosion Surface
FLUORITE ZONE
200°C
150°C
120°C
BARITE ZONE
BARITE ZONE
Pre - Carboniferous erosion surface
connate waters high in Ba++ moving up dip
WEARDALE GRANITE
Rising hydrothermal solutions (?juvenile)

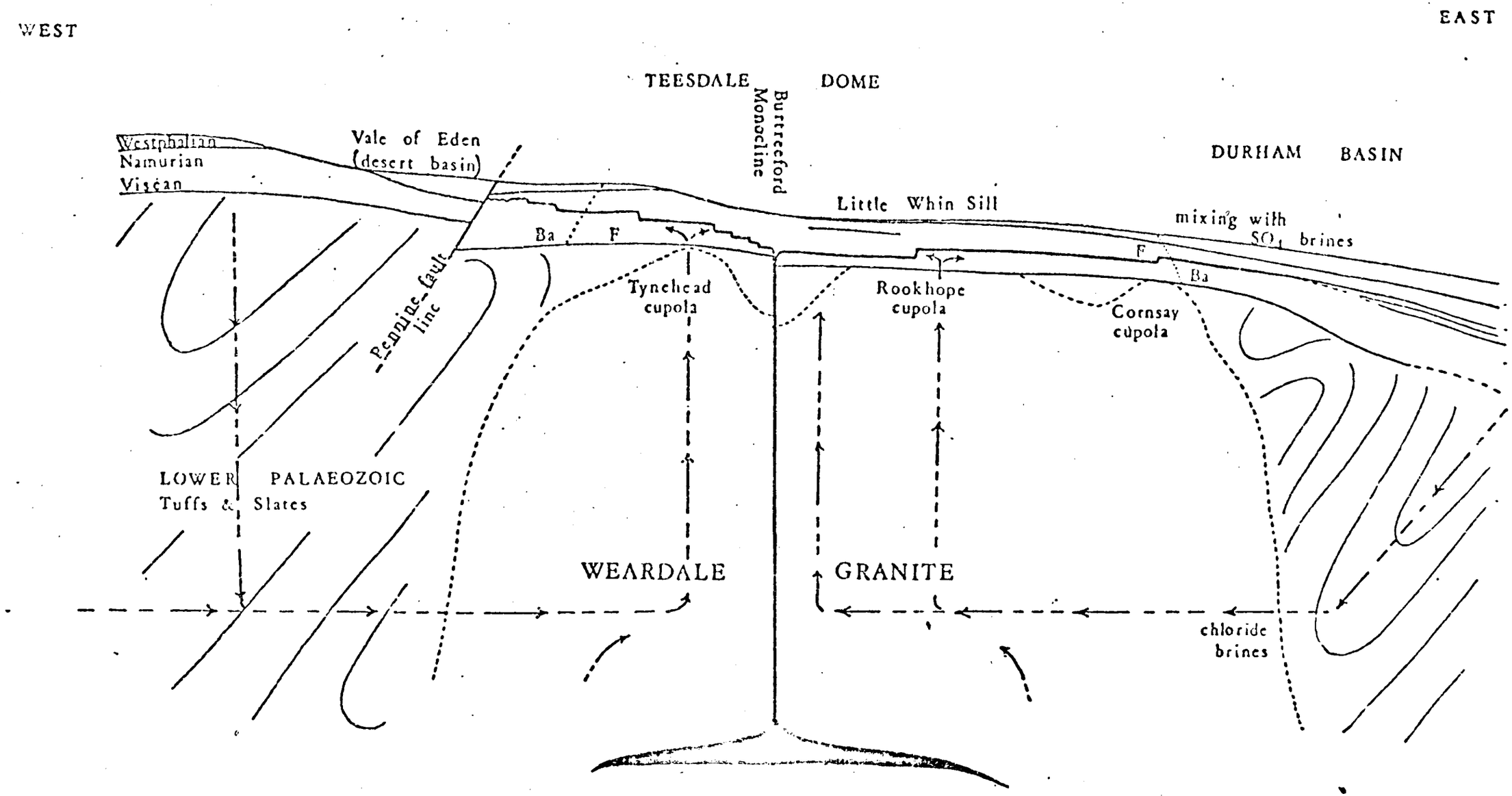


FIG.4-3

after Solomon, Rafter, and Dunham 1971

expanded this concept to embrace silica and magnesium, both of which, with iron, are enriched in the North relative to the Central and South Pennine orefields where the Whin Sill is absent. Wallace (1863, p.136) estimated that during the formation of the Handsome Mea flat deposit at Nenthead some five million cubic feet of limestone had been removed in solution. Finlayson (1910b) noted with interest that the dominant gangue minerals in most British ore deposits seem to bear a relation to the host rock mineralogy. Thus deposits in the Lake District, Central and N.W. Wales and Leadhills/ Wanlockhead, being situated in Lower Palaeozoic siliceous, clastic rocks, carry quartz gangue whereas the Pennine, North Wales and Mendip deposits, situated in carbonate-rich host rocks, carry dominantly soft spar gangues (particularly including carbonates). The inference from this observation was that gangue minerals may, to an extent, be derived from leaching and remobilization of host rock constituents. It is important, incidentally with regard to the conclusion arrived at in an earlier chapter that North Pennine vein cavities were solely mechanically formed, to point out that Wallace's record of mass solution of limestone refers to a flat and not vein deposit and that widespread leaching, of the Whin Sill for example, does not necessarily result in significant enlargement of vein cavities. Thus these records are not incompatable with the earlier-formed conclusions.

TABLE 4.1

Primary Mineralogy and Trace and Minor Element Constituents, North Pennine Deposits. (Tabulation of Elements).

Primary Mineral	Constituent Elements	Minor and trace elements
Oxides and silicates:		
Silica	Si, O	
Harmotome	K,Ba,Al,Si,O	
Halides:		
Fluorite	Ca, F	Ba,Sr,Mg,Rare Earths and Y
Carbonates:		
Calcite Siderite and intermediate compositions Dolomite Ankerite	Ca,Fe,Mg, Mn, C, O	Sr
Strontianite	Sr, C, O	Ca
Aragonite	Ca, C, O	Sr
Witherite	Ba, C, O	
Barytocalcite	Ba, Ca, C, O	
Alstonite	Ba, Ca, C, O	
Sulphates:		
Barite	Ba, S, O	Sr, Ca, Mg, Fe

Sulphides:

Galena	Pb, S	Ag,As,Sb,Bi,Cu,Zn, (Ti,V,Cr,Sn)
Sphalerite	Zn,Fe,S	Cd,Mo,In,Sn,Ga,Se, Sb, Ag,Co,Hg,Mn
Chalcopyrite	Cu,Fe,S	Ge,Mn,Sn,(Ag,Pb,Ti)
Pyrite	Fe,S	
Marcasite	Fe,S	Co
Pyrrhotite	Fe,S	
Ullmannite	Ni,Sb,S	As,Fe
Niccolite	Ni,As	
?Smaltite	Co,As	
Millerite	Ni,S	

Data sources based on:-

Dunham, 1932, 1948; El Shazly, Webb and Williams, 1957;

Smith, F.W. ab intra; Bishara, 1967.

Minor constituents of ore-bearing solutions at the time of ore deposition can sometimes be detected by trace element studies of primary minerals. Thus, for example, the presence of cadmium silver and rare earths is known from analysis of sphalerite, galena and fluorite respectively, though none of these elements were present in sufficient quantity to form their own primary minerals. A number of such determinations of minor and trace element constituents of the solutions are listed in Table 4.1 which also tabulates the primary mineralogy of the North Pennine deposits, indicating the elements transported by the mineralizing solutions.

4.3 Evolution of the Mineralizing Solutions with Space and Time in the North Pennines.

Dunham (1932, 1934, 1948) distinguished five zones of distinctive sulphide mineralogy and two of gangue mineralogy within the orefield. A preceding section described the gangue zonation in terms of the mixing of two separate parent solutions. Zonation of the lead and zinc sulphides is gradational. Sulphide zone boundaries are roughly concentric with gangue zone boundaries, and the boundary between Zones II and III with Zone IV, marking the termination of significant sphalerite deposition, lies close to the mixing interface postulated to explain the gangue zones (Fig. 4.4 reproduced from Dunham, 1948). Thus the fluorite zone contains most of sulphide Zones I, II and III (the definitions of these zones are given in the key to Fig. 4.4). The concentric nature of sulphide variations was compared with other orefields, notably Cornwall, and the conclusion arrived at that the variation reflects chemical and

Fig. 4.4 Sulphide zonation within the North Pennine orefield (from Dunham, 1948)

Zone I — Veins carrying chalcopyrite in notable quantities, with galena and subordinate sphalerite.

Zone II — Galena veins with subordinate sphalerite.

Zone III — Veins with both galena and sphalerite in approximately equal amounts.

Zone IV — Veins with galena alone, sphalerite being absent except for microscopic traces.

Zone V — Veins barren of sulphides except in microscopic amount (chalcopyrite, galena, sphalerite, ullmannite and niccolite)

FIG. 4-4 Dunham's Sulphide Zones

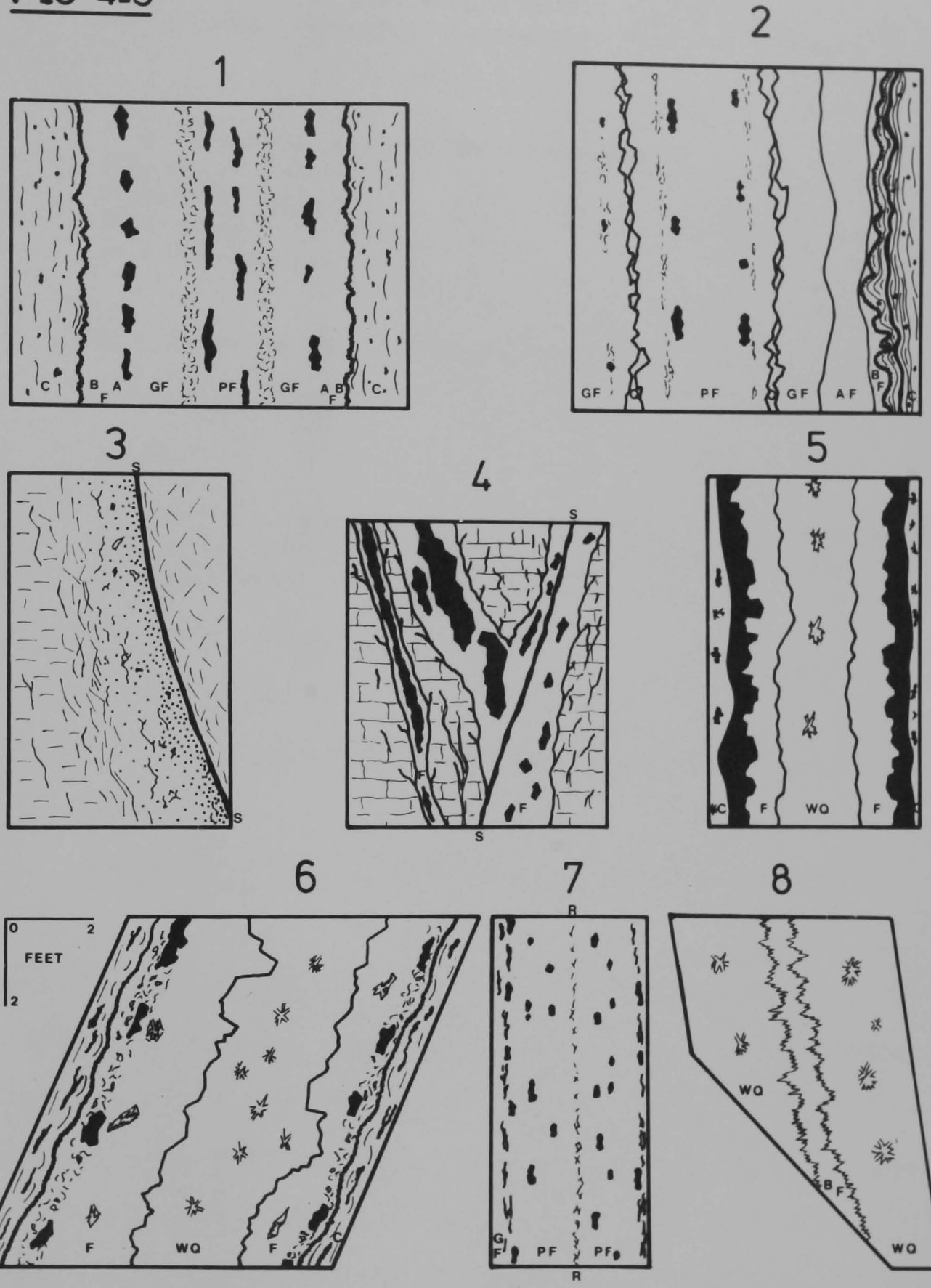
thermal evolution of solutions emanating from a central source (in Zone I).

In some other ore deposits similar mineralogical variations can be traced across a single vein section, often showing, in a vertical sense, onlap relationships (Kutina, 1957). Such variations, at a single geographical locality, reflects evolution of the mineralizing solutions with time. In the North Pennines the normal paragenetic approach that would be adopted to unravel temporal evolution is very much complicated by repetitive, monomineralic alterations in the crustiform veins and vugs. However, broad scale variation is present in so far as early, main and late phase mineral assemblages can be distinguished within the fluorite zone.

4.3.1. Early phase assemblages, fluorite zone.

Careful examination of fluorite-bearing veins in Weardale, Hunstanworth and at Nenthead has revealed that the immediate walls of orebodies have been silicified. The exact thicknesses of the silicified zone is highly variable, ranging from less than a millimetre to several metres. The earliest minerals deposited on the walls of an open orebody cavity frequently comprise cryptocrystalline or recrystallized silica with granular chalcopyrite, marcasite and pyrite, (Fig. 4.5). This assemblage forms the early phase of mineralization, it is restricted in occurrence to vein margins, though it is not always present. The variation in thickness and exact distribution of the assemblage is discussed later (Sect. 5.9). Chalcopyrite and marcasite are seldom found in the following phases.

FIG 4.5


1
C
B
F
A
GF
PF
GF
A
B
F
C
2
GF
PF
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3
S
S
4
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F
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5
C
F
WQ
F
6
0
2
FEET
2
C
F
WQ
F
C
7
R
G
F
PF
PF
R
8
WQ
B
F
WQ

Fig 4.5 Sketch Sections of North Pennine Veins

Key:-

Banded, greyish, chalcedonic quartz. Early phase
Black bodies represent chalcopyrite ribs and granules

F = Fluorite, mottled purple and green
AF = Amber fluorite
BF = Blue fluorite
GF = Green fluorite
PF = Purple fluorite

WQ = White Quartz, coarsely crystalline

Quartz-lined vug

Galena

Sphalerite - generally occurring interstitially to fluorite or else in thin layers with occasional granular crystal agglomerations.

Marcasite - bladed form

Crushed veinstuff

S
S Slickenside faced with 'steelore' - polished galena paste

R
R 'Rider' - altered rock fragments enclosed by veinstuff

Section locations and descriptions

1) Red Vein, Redburn Mine, Great Limestone. Located near a feeder intersection, this section shows typical thick cheeks of early phase, fine, grey silica enclosing granules of pyrite and chalcopyrite. The main phase fluorite carries ribs of galena and parallel zones of disseminated, fine sphalerite.

2) Red Vein, Redburn Mine, about 20m from section 1. very close to the feeder. The thick early phase cheeks carry granules and thick ribs of chalcopyrite, overgrown by botryoidal growths of chalcedony that enclose blue fluorite cubes. The main phase comprises colour-banded fluorite with quartz, sphalerite and galena ribs.

(contd)

3) Red Vein, Redburn Mine, Coal Sills Group. The vein has been crushed by a strong, horizontally slickensided, post-ore fault following the line of the vein. Stippling represents the concentration of veinstuff, assaying about 80% SiO_2, 20% CaF_2, in crushed shale, increasing towards the fault. Wall-rocks - sandy and black shales.

4) Red Vein, Redburn Mine, Little Limestone. Vein here is split by horsts of ankeritized limestone, and cut by a slickensided fault. No early phase is present. The main phase is galena-rich.

5) Groverake Vein, Groverake Mine, Nattrass Gill Hazle. The vein cheeks comprise chalcedony with bladed marcasite, sphalerite (in fine-grained nodules and as coarse crystals)and quartz. A solid rib of galena bounds main phase fluorite. The vein centre is occupied by very vuggy late-stage (?), fine-grained white quartz.

6) Groverake Vein, Groverake Mine, Pattinson Sill (?). A thick cheek of grey banded silica carries discontinuous ribs of chalcopyrite and is followed by green and purple banded fluorite with interstitial white quartz, discontinuous banding in sphalerite and galena. The vein centre is occupied by very vuggy late-stage (?) fine-grained white quartz.

7) Groverake Vein, Groverake Mine, Great Limestone. Early phase silica is absent but discontinuous ribs of chalcopyrite occur at the vein margin enclosed in green (and purple) fluorite, passing into purple fluorite with discontinuous galena bands. The vein centre is occupied by rider -fragments of silicified limestone.

8) Poor Vein, Whiteheaps Mine, Namurian washout sandstones. Malachite-stained, coarse, white quartz vein, very vuggy, with unidentified, tarnished sulphide mineral in some vugs. The vein centre is filled with blue fluorite.

It seems therefore, that the earliest hydrothermal solutions to have entered the system carried silica, iron and copper. The presence of marcasite with pyrite and chalcedony indicates metastable deposition, probably at low pH (Allen and coworkers, 1912; Barton and coworkers, 1963). Anderson (1973) has shown that appreciable deposition of chalcopyrite with pyrite from a slightly acid solution can only take place by addition of reduced sulphur. This is compatible with the probable situation during early phase mineralization in which hydrothermal brines were flushing out and mixing with groundwaters that had previously filled the orebody cavities and that were probably enriched in reduced sulphur from reaction with pyritiferous shales. The solubility of silica appears essentially independent of both pH and the ionic strength of aqueous solutions in the acid and slightly alkaline range (Holland, H. 1967) and deposition must have been largely controlled by cooling. (No complexes, other than hydrated silica monomers $ySiO_2 . nH_2O$ are known to be important in silica transport - Holland, op.cit.). The cryptocrystalline nature of the early phase silica is strongly suggestive of rapid deposition caused by sudden cooling. The process of silicification of wall-rocks (shales and limestones appear to have been replaced by silica, sandstones to have been sealed by silica deposition in intergranular pores) indicates that the early phase solutions were quite reactive in nature. In some veins silicification was preceded by dolomitization and ankeritization of limestones, such as at Boltsburn and Handsome Mea (Dunham, 1948). This has apparently left the wall-rocks more susceptible to silicification

(cf. the Derbyshire orefield and the Mississippi Valley deposits, where ore replacements are largely confined to areas of dolomitized limestone). It is known that beyond the zone of wall-rock replacements in limestone there occasionally occur flat deposits. These represent cavity infillings of main phase ore minerals with lesser amounts of direct ore replacements (Cayzer, 1973; Dunham 1948). It appears that the flat cavities, since they are spatially related to veins with heavily silicified and Mg-Fe metasomatized wall-rocks and since they pre-date main phase mineralization, were most probably dissolved by the early phase solutions, giving further evidence of their reactive, probably rather acidic character.

Comparison of the mineralogy of the early phase assemblage (the distribution of which is described in Section 5.9) with that of Dunhams Zone I mineralogy (quartz, chalcedony, chalcopyrite, pyrite marcasite, pyrrhotite) shows similarities pointing towards consanguinity and thus reinforces Dunham's concept of the central nature of Zone I with respect to solution emanation and evolution.

No information is available on the presence of an early mineral phase in the barium zone, but examination of the outcrops of Rod's, Angle and Winterhush Veins at Cow Green, Teesdale, reveals no visible silicification of wall-rock limestones or marginal vein quartz (though thin limonite patches suggested possible ankeritization). Underground examination of barite lodes and replacements at Closehouse Mine, Lunehead, also failed to produce any evidence of an early phase mineralogy, but did demonstrate widespread ankeritization preceding barium mineralization.

4.3.2. Main Phase.

Main phase mineral assemblages of the North Pennine orefield comprise the ore minerals galena and sphalerite, fluorite, barite and witherite, with quartz, calcite, pyrite and very rare chalcopyrite. In any one place the approximate composition of the assemblage can be predicted from Dunham's zonal studies. In the rare instances that barite and fluorite occur together (in only 17 veins from more than 500 named in the orefield - Dunham, 1934), barite always follows fluorite.

4.3.3 Main phase banding.

Mineral banding, a common feature in many vein deposits (Kutina, 1957), is well-developed in most of the South, Central and North Pennine deposits bearing fluorite, calcite and barium minerals alike. Banding in the North is of two morphological types, named by Dunham 'continuous', in which repetitive alternations of minerals form bands continuous throughout the visible section and 'discontinuous' in which isolated masses of mineral (generally sulphides) occur aligned parallel to banding, in a matrix of another mineral (Fig. 4.5). A discontinuity of matrix deposition links the masses. Thus, deposition was essentially monomineralic and repetitive, alternating from amongst a total possible assemblage of up to six mineral phases. There is still no satisfactory explanation of such a phenomenon in any scheme that continues to accept the monoascendant nature of North Pennine mineralization. Banding in Derbyshire, on the other hand, has been shown to be the

result of polyascendant mineralization, derived from pulsatory introduction of hydrothermal solutions (admittedly of similar composition), interleaved with periods of tectonic activity (Ineson and Al-Kufaishi, 1970).

By analogy with Dunham's sulphide zonation scheme, broad variation in the Pb:Zn ratio of the ores may have occurred with time in accordance with normal monoascendant strike and dip zonation (Korolev cited by Kutina, 1957). This is masked in vein sections, however, by the effects of vein banding, presumably caused by local reversible changes in the environment of deposition or physicochemical parameters of the solutions.

4.3.4. Late phase.

Discordant veinlets of quartz, chalcedony, pyrite and carbonates cutting the main phase bodies are ascribed to a late phase of mineralization. The same assemblage is found as the youngest encrustations in vugs and in cavities in the centre of vein orebodies. This phase is normally quite devoid of ore minerals, although one or two occurrences with minute chalcopyrite grains (identified by X-ray powder photography) were found in Redburn Mine.

Brown ankerites from three late veinlets (cross-cutting calcite) in Redburn Mine were analysed semiquantitatively by Mr. K. Ashworth, using the electron microprobe and were found to contain between 9 and 17% $MnCO_3$. Comparison of this range with

manganese contents of syngenetic ankerites of the Durham coalfield (0-5.6% $MnCO_3$, 14 samples, Smythe and Dunham, 1947) and with bulk analyses of unaltered Pennine limestones (330 - 370 ppm Mn, 30 samples Ineson, 1969) suggests that high manganese carbonates may be diagnostic of hydrothermal activity in the region and that it may be possible, using this criterion, to distinguish between the products of such activity and normal recrystallization carbonate veins commonly occurring in limestones.

In the proximity of orebody terminations in Groverake, Redburn and Stanhopeburn mines, Red and Groverake veins become enriched in late phase assemblage minerals, particularly vuggy, white quartz and brown carbonate. Sulphides become very scarce. Early phase silicification is absent and vuggy replacement of wall-rocks with the late phase minerals has often taken place. The veins tend to run into stringers which are cut by many generations of late siliceous veinlets. The cause of this latter effect is easily explicable since the majority of orebodies can be shown to terminate at changes in vein strike. Wrench fault movement has occurred bearing upon the fault plane in these regions of unfavourable strike in order to assist opening of cavities elsewhere (Sectn.2.2) Continuation of wrench movement during mineralization would tend to have had particularly destructive effects at these sites of strike change, i.e. at orebody terminations. The cause of the concentration of late phase minerals near terminations is unclear. It may be that as the main flow of solutions passed from feeder to exit points along the orebody cavity, the tail-ends of the cavity were rather stagnant, only beginning to receive forced circulation as the main cavity became choked, hence much of the main phase minerals are

absent. The western termination of the west orebody on the 17 Fms. Level at Redburn Mine is typical. It carries some fluorite yielding fluid inclusion formation temperatures (discussed later) in the region of 24°C lower than those obtained from fluorite in the main parts of the orebody. Masses of ankerite, up to 30 cms across, occur, with vugs of quartz, replacing the host limestone. The fluorite is very badly brecciated and is cut by very many veinlets of chalcedony and ankerite. The vein itself is breaking into stringers.

4.4 Wall-Rock Alteration

In addition to the constituents known from minerals introduced during the formation of the deposits, wall-rock alteration studies have been used to demonstrate the existence of elements in solution before and after the alteration reaction. Study in the North Pennines has centred largely upon the Whin Sill. Two types of alteration of the Whin were described by Wager (1929 a and b) as caused by 'juvenile solutions' (auto-alteration) and by the 'lead vein solutions'. The former, which deposited quartz, calcite, chlorite and zeolites and altered the Whin to a quartz-chlorite rock, will not be considered here. "Lead Vein" metasomatism converted the normal quartz-dolerite into a clay-carbonate rock known as "White Whin", which is apparently similar in both fluorite and barium zones. Chemical analysis has shown that CO_2 and K were carried in aqueous solution to the sill and that Na, Fe, Mg and Si were leached from the sill (Finlayson, 1910 b; Wager, 1929a; Smythe, 1930; Dunham, 1932; Ineson, 1972). Comparison of the altered rock with altered dolerites from the Shropshire orefield, an area lacking in carbonate rocks, shows marked enrichment of CO_2 in the White Whin over that in the Shropshire specimens. This led Dunham (1932) to postulate partial derivation of CO_2 in the North Pennine

solutions from solution of local limestones. Alteration of the Whin dolerite results in the formation of new carbonates, muscovite, anatase, kaolinite and a clay mineral aggregate thought by Wager to be paragonite and Dunham to be brammalitic illite. Ineson also identified this component as illite. A sample of White Whin from Breckonsyke Bore 1 (W.L.C. 1971) was analysed in the present study, using glycolation techniques on the X-ray diffractometer. This sample consisted mainly of quartz, carbonates and pyrite with some kaolinite and potassium-rich feldspar. Muscovite was absent. The clay aggregate proved to be a mixture of illite and non-expanding, mixed-layer illite-montmorillonite clays. The overall alteration assemblage then is characteristically sericitic to intermediate argillic (following the classification of Meyer and Henley, 1967) indicating a solution pH within 2.5 units of neutrality.

Wall-rock alteration of the Weardale Granite is sericitic, tending slightly, with the presence of minor kaolinite towards intermediate argillic. The formation of sericite was for many years taken to indicate the presence of alkaline solutions. Recently, however, it has been found to occur over a wide range of pH including weakly acidic conditions (Nakamura, 1961). Kaolinitic alteration is believed to be the result of acidic conditions, though as a rule intermediate argillic alteration may occur up to 2.5 pH units either side of neutrality (Meyer and Henley, op.cit.)

The very limited extent of wall-rock alteration adjacent to mineralization in the granite suggested to Dunham and coworkers (1965) that ore components of the North Pennine veins had not been leached from this source, at least not above a depth of 420 m within the Granite. This contention was later supported by Solomon (1966), who showed an

enrichment of barium in the granite wall-rocks, presumably introduced by the hydrothermal solutions.

Careful study of wall-rock alteration can provide very precise values for pH, Eh and constituent ionic activities in hydrothermal solutions (Korzhinskii, 1970). This has not been pursued during the present project, but the information above has been taken to indicate, along with the mineralogical and geological evidence from the early phase mineralization, that the North Pennine solutions may have been weakly acidic. Reaction of the earliest solutions to pass through orebody cavities resulted in silicification and local solution of limestone to form ramifying voids alongside, but slightly separate from, veins. Later solutions must have been quickly and efficiently isolated from carbonate wall-rocks by the impermeable silicified zone and by marginal chalcedonic deposits. Thus the existance of weakly acidic solutions in a carbonate-bearing sequence was not impossible.

4.4.1 Alteration as an exploration guide.

Wall-rock alteration is commonly used by the mining industry as a guide to ore (Lowell and Guilbert, 1970). Throughout the Pennines occurrences of ankeritized or silicified rock may be considered to indicate the proximity of mineralization and be worthy of further investigation. The occurrence of White Whin in the Northern orefield is a very good indication of mineralization. During an exploration project in Weardale in 1970, deep cores were once presented for logging as the drill rig was being dismantled. The cores showed

the presence, in the very bottom of the hole, over a thousand feet in length, of about 10 m of White Whin. Following this evidence of mineralization, drilling was renewed for a further 10.1 m, in which a major vein channel was penetrated.

In general, however, the extent of Pennine wall-rock metasomatism is less than the size of the associated deposit, limiting its value in ore search because finding the altered rock is almost as difficult as finding the ore.

4.5 Wall-Rock Aureoles

Trace element aureoles surrounding Pennine veins, first described by Finlayson (1910b), have been studied by Ineson (1969, 1970, 1971) to test their value as exploration guides. In general he found that aureoles were too limited in extent to be of great value in this direction. Wilson (1972) also found that at Geevor Mine, Cornwall, the primary dispersion patterns do not extend beyond the zone of visible alteration and are hence of very limited use in prospecting. Application of the method of Blackdene Mine, Weardale, by the British Steel Corporation has similarly provided disappointing results. Fluorine aureoles (detected using a specific ion meter) around fluorite veins at Groverake Mine, Rookhope were found again to be of very limited extent, their size often bearing little relation to the intensity of mineralization (R. Wilmers, pers. comm. 1972).

However, in so far as trace element aureole studies demonstrate the introduction or removal of particular element they provide information on the nature of ore-bearing solutions. Ineson found that apart from the introduction of constituent elements of the hydrothermal minerals (Table 4.1), the elements Zr, V, Cr, Ni and Rb have been enriched in North Pennine wall-rocks and Sr removed. The unexpected discovery of Zr in solution was

taken at the time as evidence of the magmatic nature of the fluorite zone solutions.

4.6 Composition of Fluid Inclusions

This section describes studies of fluid inclusions in transparent minerals from the North Pennine deposits that have revealed that the parent hydrothermal solutions were aqueous, alkali-earth, chloride brines. Thus they are similar to parental solutions of most other lead-zinc-fluorine-barium deposits that have been studied (Roedder, 1973).

Fluid inclusions are pockets of parent solution trapped by irregular growth, etc. of hydrothermal minerals. Trapping mechanisms, definitions and other details of the fluid inclusion apparatus and methods are given in Appendix 2.

Solid particles are not usual within the fluid inclusions. Partially and totally leaked inclusions, however, often contain cubic, isotropic crystals, presumed at present to be halite, that have formed by evaporation of the aqueous solvent. Grains of opaque minerals sometimes occur within perfect inclusions, but their distribution and size is so irregular that it seems most likely that they are captive minerals (ie. nuclei of ore minerals trapped with the fluid) rather than daughter minerals of the fluid.

4.6.1 Leaching experiments

The relative proportions of ions in fluid inclusions can be determined by crushing the mineral specimen to break open the inclusions, leaching it with pure water and analysing the leachate. Naturally, great precautions must be observed to prevent contamination or leaching of ions from the mineral itelf. Sawkins (1966) used this method to determine the Na : K ratios of fluid inclusions in North Pennine minerals

and discovered that the hydrothermal solutionsof the fluorite zone were enriched in potassium relative to those of the barium zone. At that time it was believed that potassium-rich brines were diagnostic of late stage magmatic fluids and that potassium-deficient brines were typical of connate waters. This was taken, then, as valuable evidence supporting his theory that the minerals of the orefield were deposited from two separate brines, one magmatic and the other connate. However, it has since been shown that the Na : K ratio of sub-surface brines is broadly a function of the temperature at which the brines equilibriated with silicate-bearing rocks (Sawkins, 1968; Billings and coworkers, 1969). Thus hot brines are potassium-enriched relative to cold brines. Moreover, the value of a ratio incorporating Na, K and Ca has recently been calibrated and suggested as a geothermometer of natural waters (Fournier and Truesdell, 1973).

Sawkins' results are presented in Table 4.2 with nine further determinations made during this study. These further determinations were made with the intention of checking the constancy of brine composition through a vertical vein section. The results are listed in descending stratigraphical order. The mean corrected fluid inclusion homogenization temperature (discussed in the following chapter) representing the formation temperature of the sample is given if known, otherwise the temperature obtained from an adjacent sample is quoted in brackets. The results show that, as Sawkins pointed out, there are large differences between Na ; K ratios of fluorite and barium zone minerals. The relation with formation temperature within the fluorite zone is not strong. There is no evidence of a systematic change in Na : K with the depth of mineralization, hence there is no evidence of brine dilution or mixing within this particular sequence. All of the samples examined during this study had been collected

TABLE 4.2

Na:K Weight Ratios of Fluid Inclusions in Fluorite

Sample No.	Locality and formation temp.	Concentrations in filtrate Na ppm	K ppm	Na:K
410	North Pennine orefield Red Vn., C Level, Redburn Mine (Firestone horizon) Tcor 146°C	123.1	22.8	5.4
669	Red Vn., Rogerwell Hush, (Firestone horizon) 158.5°C	108.6	9.1	11.9
661	Red Vn., 17 FMS. Sublevel, Redburn Mine, (Great Limestone) 158.2°C.	69.2	5.3	13.1
662	Red Vn., 17 FMS. Level, Redburn Mine, (Great Limestone) 151.7°C	116.5	10.5	11.1
172	Red Vn., 40 FMS. Level, Redburn Mine, (Four Fathom Limestone) 152.6°C	89.6	19.0	4.7
174	Red Vn., 50 FMS. Level, Redburn Mine, (Grey Beds/3 Yd. Lst.) 157.6°C	102.6	8.0	12.9
672	Red Vn., 34 FMS Level, Stanhopeburn Mine, (Three Yard Lst.) 139.6°C.	68.6	6.4	10.7
596	Blackdene Vn., Main Haulage, Blackdene Mine, (Great Whin Sill)	103.9	11.6	9.0
215	Red Vn., 941′, Rookhope B.H., (Lower Little Lst.) 176.5°C	94.8	13.4	7.1
Data from Sawkins (1966):-		1) Fluorite		
63-S-34	Blackdene Vein, 171°-176°C	35	5.8	6.9
64-S-28	Greencleugh Vn., Groverake, 158° - 167°C	50	5.2	9.6
64-S-52	Slitt Vein, 127° - 131°C	7.5	1.1	6.8
		2) Quartz (fluorite zone)		
64-S-46	Great Sulphur Vein	67	5.9	11.4

63-S-34	Blackdene Vein, 143°-153°C	15	1.2	12.4
64-S-25	Whiteheaps Mine, (? Poor Vein) 155° - 177°C	38	4.75	8.0
		3) Barite (Barium zone)		
64-S-50	Closehouse Mine	81	5.3	15.3
64-S-49	Silverband Mine 50°C	15	0.75	20
64-S-49	Silverband Mine 50°C	43	1.4	31
64-S-59	New Brancepeth Vein 50°C	50	1.2	42
64-S-30	Nemtsbury Mine 126° - 129°C	32.5	0.7	46

Footnote

Tcor = Mean corrected fluid inclusion homogenization temperature - see text and Appendix 2. A range of corrected fluid inclusion homogenization temperatures is quoted by Sawkins.

from the earliest part of the main phase vein infilling. A further 27 Na : K ratios were determined on fluorites from other deposits in order to compare them with the North Pennines. These are discussed in Chapter 7. The methods used in leaching and analysis follow those described by Sawkins (1966). They are subject to the same errors as those he discusses. Although laboratory contamination, checked in blank runs, is believed to have been negligible and the analytical method using an E.E.L.flame photometer has been found to be accurate, the samples invariably contain some secondary inclusions. These are not representative of the parent brines and have been trapped by fracturing after the formation of the host crystal (Appendix 2.1). Though much less common in these specimens than primary inclusions, the effect of their presence is probably to increase the Na : K ratio since the most likely fluids to be trapped in secondaries are low temperature spent hydrothermal brines or ground-waters.

In addition to analysing the leachates for Na^+ and K^+, twelve of them were tested, qualitatively, for the presence of chloride by the addition of a drop of dilute silver nitrate solution to about 10 mls of leachate. The twelve samples comprised four from the North Pennines, one from Derbyshire, one from Wensleydale, three from Greenhow and Grassington, two from North Wales and one from Belgium. All yielded positive results. A fine opalescence, caused by an extremely fine precipitate of silver chloride, could be clearly seen in each case, the opacity of which was roughly proportional to the total Na + K content of the analysed leachate. Care had been taken to avoid chloride contamination of the samples from cleaning acids, tapwater or human touch. A blank run using distilled water gave no precipitate. Samples of the same twelve leachates were also tested for the presence of sulphate by the addition of

a drop of dilute barium chloride solution. This test proved negative on all samples. Although it would obviously have been of great interest to determine chloride quantitatively, this was not done because of the length of time that would have been involved in developing a sufficiently accurate method for the minute amounts present in the leachates. It was felt that this was going far beyond the aims of the project. No further elements were sought in the leachates.

4.6.2 Equivalent salinity determinations using the freezing technique

The concentration of dissolved salts in fluid inclusions can be measured by the freezing technique, in which a depression of melting point, due to the lowering of the vapour pressure of a solvent in solution, is measured (Roedder, 1962, 1963). The technique and apparatus are described in Appendix 2.2. Data are usually interpreted from the system NaCl - H_2O, since chemical analyses of hydrothermal fluids from widely differing environments have shown NaCl to be the dominant dissolved salt (Roedder, 1973). The discussion above, in Section 4.6.1, appears to indicate that the North Pennine orefield is no exception to this general statement and indeed the freezing data have been found to be easily interpreted from the NaCl system (neglecting KCl). Salinities are therefore expressed in terms of equivalent weight % NaCl.

The aims of the salinity study were fourfold:

1) To check the original determinations of Sawkins (1966) for the North Pennines, that were made using inferior apparatus, and to obtain new data on this and other British orefields.
2) To look for variation in salinity along a vein and in vertical and transverse sections. The presence of such variation would indicate evolution of the hydrothermal brines with time and with distance from

source and could provide evidence of dilution or brine mixing.

3) To provide values of salinity (X) for correction of fluid inclusion homogenization temperatures (Appendix 2).

4) To provide values of salinity to substitute into theoretical heat flow calculations.

The results are presented in Table A2·2. Measurements made during this project are broadly compatible with those made by Sawkins. A source of bias in Sawkins' work, which he recognized, was introduced by the low efficiency of his freezing stage. The ingenious design, incorporating Peltier Effect thermo-modules, was such that temperatures below - 18°C were unattainable. The new measurements, made on a stage capable of operating down to approximately - 100°C (Smith, F. W., 1973a) show that the usual melting point of primary inclusions is in the range - 19°C to - 23°C (equivalent to 22 to 24 weight % NaCl). Several samples contain fluid inclusions melting below the eutectic temperature of the pure NaCl - H_2O system (-21.1°C - Fig. A2.1) indicating the presence of other ions in solution. The leachate analyses discussed earlier show that potassium is one of these ions. One specimen, no. 410, yields a Na : K ratio of 5.4 while an adjacent specimen yielded a mean melting point of - 22.8°C. If these data are combined (and the possibility of secondary contamination increasing the ratio is noted) then they fall close to the low temperature tertiary eutectic in the NaCl - KCl - H_2O system (-22.9°C, 5.81 wt. % KCl, 20.17 wt. % NaCl, equiv.weight Na : K of 3). Another specimen however, no. R.B.H. 19, contains fluid inclusions melting considerably below this temperature proving that other salts are also present (probably $CaCl_2$ since this is a flat deposit specimen). Since there are insufficient data to be able to recalculate actual compositions from melting points and Na:K ratios, the results have been left as

equivalent NaCl percentages. The effect of other chlorides being broadly additive, this is considered a reasonable approximation to the total chloride content.

Twenty-one fluorites from Weardale were selected to test spatial and temporal variation of salinity. All show remarkable similarity of melting temperature (Table 4.3, Fig 4.6). A slight decrease in this temperature, corresponding with an increase in equivalent salinity, seems to occur towards the surface in the vertical section of Fig. 4.6. This may simply be due to an increase in concentration of calcium in solution by very gradual dissolution of calcareous strata. The addition of calcium to a mixed chloride brine has the effect of dramatically decreasing its melting point. An alternative explanation, the removal of water from the brine and formation of hydrous mineral phases, is less likely since few hydrated minerals, except in alteration assemblages, occur in the deposits. There is, from the results so far obtained, no evidence of dilution of the brines as they approached either the ground surface or the margin of the barium zone. Equivalent salinities measured on sample 174 from Red Vein edge and on sample 175 from mid-vein, 50 Fms. Level, Redburn Mine, are 22.45% and 22.00% respectively, showing that at a fixed position there was no significant change in brine salinity with time throughout the main phase of fluorite deposition.

4.6.3 Gaseous components and hydrocarbons

Heating experiments show that primary fluid inclusions in North Pennine minerals always homogenize into the liquid phase proving that the fluids were entirely liquid and were not boiling.

Crushing of tiny fragments of fluorite and galena, from Redburn Mine, between two glass plates under oil (see Deicha, 1950; Ypma, 1965;

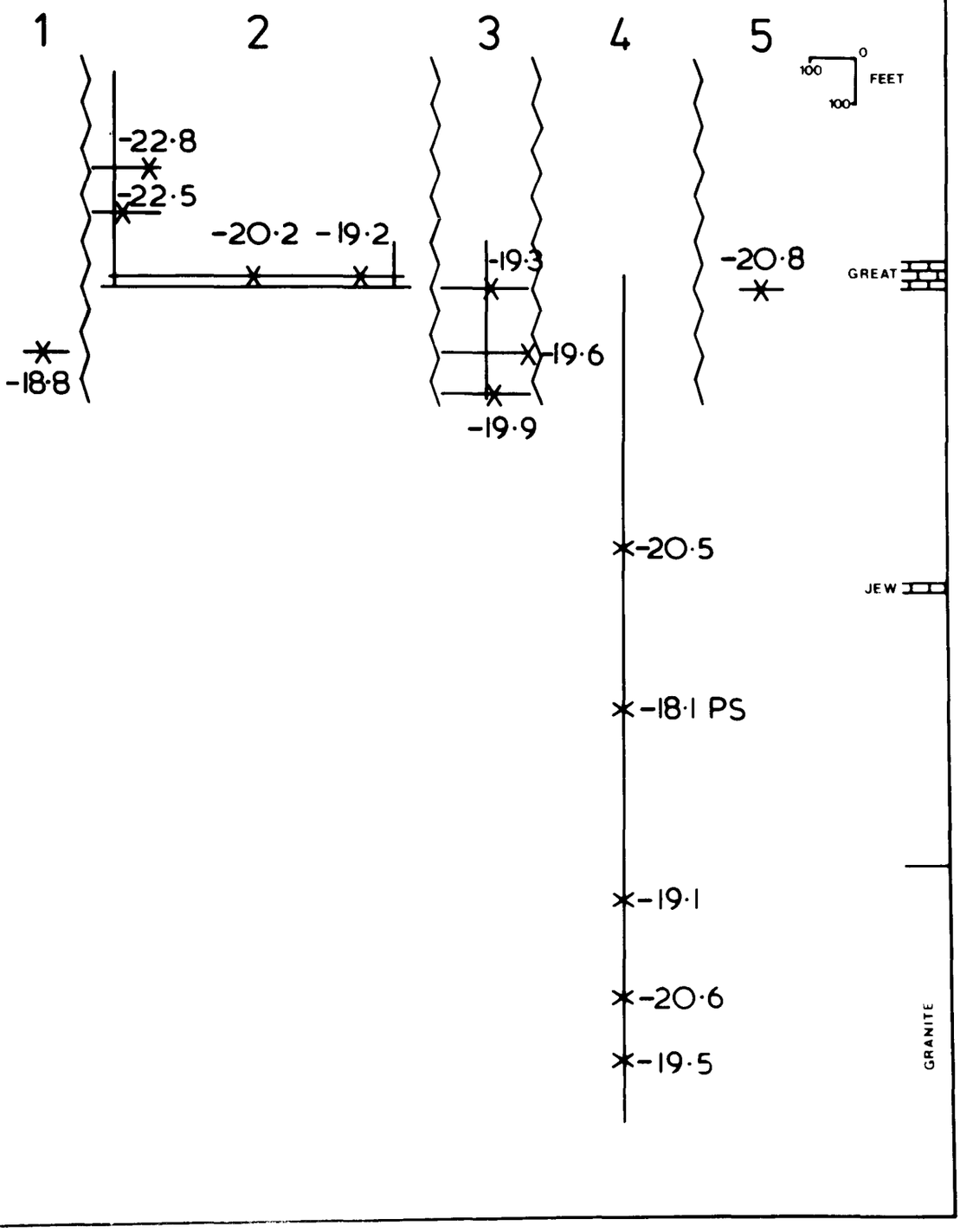
Fig. 4 - 6 Variation of Mean Fluid Inclusion Melting Temperature with Depth of Mineralization

The data (taken from Appendix Table A.2.4) are plotted on vertical sections adjusted to the horizon of the Great Limestone. Only those parts of workings and borehole of relevance are shown.

Key:

1. Groverake Vein. Groverake Mine, 80 Fms. Level.
2. Red Vein. Redburn western ore-zone.
3. Red Vein, Redburn eastern ore-zone.
4. Red and Boltsburn Veins, Rookhope Borehole.
5. Boltsburn Vein, Boltsburn flats, East Mine.

FIG 4.6 Variation of Mean Fluid Inclusion Melting Temperature with Depth of Mineralization



Roedder, 1970) sometimes releases very small gas bubbles, seen under the binocular microscope, apparently released from fluid inclusions. Lack of suitable equipment precluded any attempt to identify this gas, which is completely dissolved in the brine at the homogenization temperature. However Barker (1965) has ingeniously analysed portions of such gas by methods in which samples of fluorite, quartz, sphalerite and galena from the North Pennines were sequentially crushed in a vacuum or else overheated to release volatiles from primary inclusions. Water, determined by the volumetric method, accounted for well over 95% of the volatiles. The remainder, determined by mass spectrometry, was mainly CO_2 with minor amounts of the H_2, N_2, Ar, CH_4 and CO. He considered the CO, found only in samples that had been overheated, to have been formed during the experiments. Barker determined that the H_2O : CO_2 ratio, hence partial pressure of CO_2, in primary inclusions in fluorite from Groverake Mine, Rookhope, decreased with time. This probably reflects the sealing off of wall-rocks and decrease in availability of carbonate strata for reaction with the brines. Values of partial pressure of CO_2 for minerals of the orefield were found to lie in the range 0.2 to 22 atm. Partial pressures of other gases were lower.

The gases found by Barker occur commonly in fluid inclusions from hydrothermal ore deposits as we knew from the prodigious works of Soviet Union geochemists such as Dolgov, Bazaroff and Shugurova, and the French workers Deicha and Touray. They also occur in volcanic emanations, hot springs and meteoric waters. Other materials existing as gases in the first two environments, such as the inorganic acids (HCl, HF, H_2S, SO_2 and H_3BO_3) and inorganic sublimates (SiF_4, $FeCl_3$, NH_4Cl and S) would probably not be detected as gases if trapped in aqueous inclusions. With increasing sensitivity of instrumentation

it is becoming possible to detect ever smaller amounts of noble gases and organic compounds in natural waters. The noble gases, however, occur in both magmatic and connate environments (Mazor and Fournier, 1973) and hence their presence is indicative of neither. The occurrence of hydrocarbon complexes is particularly important both in the part they could have played in metal transport (Krantz, 1968) and in reflection upon the genesis of hydrothermal brines. Connate brines often carry or migrate with hydrocarbons, the commonly quoted example being that of the association of oilfield brines and petroleum minerals. Though occurring in fluid inclusions in some Derbyshire fluorites, petroleum inclusions are not as common in British lead-zinc deposits as in those of the type Mississippi Valley deposits. However, vein hydrocarbons of the bitumen type are frequently found, occuring in the North Wales orefield, Shropshire orefield, Derbyshire orefield, North Pennine orefield (at Settlingstones and South Moor Colliery) and the Avon Gorge, with fluorite (Perceval, 1873), as well as in the Permian dolomitic limestones of the Midlands in association with galena and wulfenite (Deans, 1961), the Magnesian Limestone of S.E. Durham, with fluorite and in the post-magmatic deposits of Cornwall (eg. South Crofty) and the Mount Sorrel Granodiorite. Hydrocarbon impurities were once, but no longer, believed to be responsible for the coloration of intensely purple fluorites (MacKenzie and Green, 1971; Fayziyev and Markov, 1971). Organic geochemists are now in a position to classify hydrothermal hydrocarbons as biogenic or non-biogenic and, as such, can greatly assist in studies of ore genesis (although the ultimate provenance of hydrocarbons in a magmatic environment may still be biogenic by assimilation). Studies of the Windy Knoll (Derbyshire) hydrocarbons, for example, and associated petroleum inclusions in fluorite, suggest that these organic compounds are biogenic, derived from the local sediments

(Pering, 1972)

4.7 Summary and Discussion

The evidence and data presented earlier in this chapter shows that the hydrothermal minerals of the North Pennines were transported by and deposited from approximately 4N sodium (potassium) chloride brines that may have varied up to two pH units towards the acid side of neutrality (neutral point is pH 5.45 at 200°C; 5.75 at 150°C; and 6.14 at 100°C). Sawkins (1966) has shown that the brines were hot and that the transparent gangue minerals were deposited in the approximate temperature range 200° to 120°C.

The solubility of ore minerals and fluorite in brines having these characteristics is known to be greatly increased over that in pure water (e.g. Anderson, 1973). This is believed to be due firstly to complexing of the ore metals with chloride ions and secondly to the partial ionization of fluorite in the presence of other electrolytes. Thus the transport of sufficient quantities of ore metals etc. to form ore deposits is no longer considered such a problem by geochemists studying epithermal Mississippi Valley type deposits (Anderson, op. cit.).

Reduction in solubility, causing ore deposition, may be caused by four main processes:-

1) Cooling

Solubility is temperature dependent. Decrease in temperature generally lowers the solubility of minerals in aqueous solution. (Calcite and dolomite are the main exceptions to this rule and show an opposite effect). Fluid inclusion homogenization temperatures, discussed in the next chapter, demonstrate brine cooling by about 40°C within the restricted vertical section of the orefield known at present.

2) pH change

Anderson (op. cit.) shows that neutralization of a slightly acid ore-bearing brine can be effective in precipitating lead and zinc sulphides. " The stoichiometric solubility of galena in 3N NaCl at 100°C is about 1.47 ppm at pH 5.0, 14.7 ppm at pH 4.0 and 147 ppm at pH 3.0". The effect of neutralization on fluorite solubility is discussed in another context, in Chapter 6, but it too is believed to result in precipitation (c.f. Bandurkin, 1961). Deposition of fluorite under conditions of increasing pH has been recorded by fluid inclusion analyses, from the lead-zinc-fluorine - barium deposits in the limestones of Aurakhmat in the U.S.S.R. (Grushkin, 1958). Neutralization can occur most easily by solution of carbonate wall-rocks or by wall-rock alteration. In discussing evidence against a solution origin of the vein cavities, in Chapter 2, the point was made that there is field evidence of very little solution of vein wall-rocks. Moreover, veins occur with equal widths in sandstones and limestones. In discussing evidence for the possibly weakly acidic nature of the early phase brines, in Sections 4.3.1 and 4.4, this was reconciled with the presence of limestone wall-rocks (comprising approx. 24% of the strata between the Basement Group and Upper Fell Top Limestone - Fig. 2.2) by two facts. Firstly, silicification of the wall-rocks left an early, impermeable and unreactive skin to the walls. Secondly, once an initial crust of minerals had formed upon the vein walls, then this must have sealed the wall-rocks from the possibility of further attack by the brines. The crustiform nature of vein infilling is so disposed as to prove infilling from the margins inward. There is no evidence to suggest attack and dissolution of limestone wall-rocks after precipitation commenced. Hence, neutralization of the North Pennine brines cannot have played a major role in ore deposition but must have occurred very gradually as small areas of limestones were exposed by

shelling off from the vein walls or by additional fault movements. In this way it may have been important in controlling the stabilities of particular minor complexes.

3) Dilution

The salinity and Na:K data presented earlier in this chapter show no sign of dilution of the hydrothermal brines with solutions of differing composition or salinity. Temperature gradients existing in the brines, discussed in the next chapter, show no abrupt changes that might indicate mixing or dilution with colder waters.

4) Increase in reduced sulphur

Sulphide precipitation from a slightly acid brine with fairly low sulphate content may be induced by increase in reduced sulphur. Anderson (op. cit.) states that because of the solubility product relationship, increasing the reduced sulphur content at constant pH reduces the lead or zinc content of a brine as 1:1. The increase may result from:

a) sulphate reduction

b) mixing of two brines

c) reaction with sulphur-rich wall-rocks

Mixing has already been shown to have been unlikely within the fluorite zone of the orefield. Reaction with pyritiferous shales, though probably occurring on a small scale was probably quantitatively insignificant (see para. 2 above) For example, the intrusion of the Great and Little Whin Sill resulted in the formation of nodular pyrite layers in the nearby shales (these are well-exposed beneath the Little Whin at Greenfoot Quarry, Stanhope and beneath the Great Whin, in the River Tees near Wynch Bridge). The origin of the pyrite is uncertain, the nodular

layers are however of wide extent. If significant interaction between the hydrothermal brines and these layers had occurred, then some mention of sulphide enrichment of veins near these horizons should exist in the records of the old miners. In fact most veins appear to have been disappointingly poor in lead ore near, and in, the Great Whin (Dunham, 1948). (Little is known of the Little Whin, but certainly no sulphide enrichment of Red Vein has been noted near this horizon at Stanhopeburn Mine). Sulphate reduction by organic minerals has been shown to be a geologically feasible process in other Mississippi Valley type deposits (Barton, 1967). However there is no evidence, either in the fluid inclusions or in the vein mineralogy, of the presence with the ascending brines, of organic compounds such as petroleum or bitumen. The only major source of organic material could have been black shales and coaly strata. Large scale interaction between brines and such wall-rocks has already been shown improbable. In this connection, however, it is interesting to note that some veins seem to become enriched in galena (and pyrite) on a very local scale alongside dark, shaley horizons, particularly where these have caused the vein to narrow. The effect is of very limited extent and only really apparent because the vein is narrow, thus whether caused by increase in reduced sulphur derived from the shales or by reduction of brine sulphate by organic matter in the shales, it does not seem to relate to the bulk of ore deposition.

5) Decrease in pressure

Barnes (1972) suggests that this has a significant effect upon the stability of chloride complexes in Mississippi Valley type environments. There is, however, very little information upon the effect in the literature, particularly in the case of gas-bearing brines.

Decrease in pressure was inevitable through the vertical range of mineralization and has been quantified in the following chapter.

Thus the evidence at present points towards cooling as having been the chief cause of ore precipitation in the orefield.

The North Pennine deposits consist of large tonnages of minerals that, despite complexing, are very poorly soluble and must have required very large amounts of solvent to transport them. The total amount of solvent brine can be calculated approximately using the crude data available at present and assuming that cooling was the only significant mechanism causing ore deposition.

Sawkins (1966) estimated that a total of 20×10^6 tons of fluorite had been deposited in the orefield. Dunham (1957) estimated that 4×10^6 tons of lead ore (averaging about 70% PbS) have been produced from the region. An equivalent amount probably remains in tailings and low grade and undiscovered deposits. Dunham also records a total production, up to 1947, of 270,000 tons of zinc concentrates. Since, however, this ore has only been intentionally raised on a large scale during the last 100 years and, since sphalerite appears to have been almost as common as galena over vast tracts of the orefield, the total tonnage remaining is probably equal to many times the recorded production.

The data of Strubel (1965) for the solubility of fluorite in a 2N sodium chloride brine, up to 100°C, can be extrapolated to give approximate solubilities in a 4N brine up to 200°C. A temperature decrease of 40°C (from 170° to 130°C) would result in the deposition of approximately 4 mg CaF_2 / Kg H_2O. At this rate some 5×10^{12} tons (5.05×10^{12} tonnes) of brine would have been required to carry and deposit the estimated total tonnage of fluorite in the orefield.

The data of Nriagu(1971) for the solubility of PbS in a 3 N brine indicates a decrease in solubility from 70 ppm to 28 ppm for the 40°C

temperature drop, 160°C to 120°C. At this rate, some 1.4×10^{11} tons (1.41×10^{11} tonnes) of brine would have been required to carry and deposit the estimated quantity of galena once present in the orefield.

Since galena was not continuously deposited, it would appear that PbS was not always in saturated solution. Many fluorite-bearing veins, however, carry up to 70 - 80% CaF_2. Hence the estimate of brine tonnage required to precipitate the total CaF_2 content of the orefield is more appropriate for the total amount of circulating brines.

Consider now a single orebody, 100 m long by 20 m high and 1m wide, part of a vertically-aligned series of orebodies and feeders. Assuming that the orebody is filled with ore grading 70% CaF_2 and that this was precipitated by a cooling brine (taking a cooling gradient of 1°C / 10m see Section 5.4), then 4.4×10^9 tons of brine must have passed through the original cavity to deposit that fluorite.

This implies, if 5×10^{12} tons of brine deposited fluorite throughout the entire orefield and 4.4×10^9 tons of brine must pass through an orebody-feeder system to fill it with ore, that there are in the order of 1000 fluorite-filled orebody-feeder systems within the orefield. Since this is not an unreasonable estimate it provides a useful check on the previous calculations.

CHAPTER 5.

PHYSICAL PROCESSES INVOLVED IN THE MINERALIZATION OF THE NORTH PENNINES

5.1 Introduction

Several points may be summarized from the preceding chapters.

A system of rock cavities existed prior to mineralization in the North Pennines. These cavities were formed by mechanical means and, to an extent, their geometry may be predicted from basic structural observation. The cavities were restricted in height and length, seldom exceeding two or three metres in width. Vertical channelways that acted as brine conduits to and from the cavities were usually located at vein fracture intersections. Circulation of mineralizing brines within the subhorizontal orebody cavities was largely confined to flow between conduits of differing potential flow rate. Ore minerals carried by the brines were deposited within the orebody cavities in response to changes in physicochemical conditions within the system, probably resulting in part from the geometry of the system. Chief among the factors causing precipitation seems to have been cooling. However, other factors may have been locally important.

This chapter examines the physical changes, particularly cooling that the brines underwent as they passed through the hydrothermal system. Methods of measuring these changes and hence determining brine flow directions are discussed. Finally it is suggested that flow directions can be used to work out the geometry of a partially explored system. The field work was based mainly in northern Weardale, but results from specimens collected throughout the orefield suggest that Weardale is typical of the whole area. The work is presented in detail in Section Two.

5.2 A Simple Model

Although cavity evolution probably continued during the period of mineralization, open cavities must have existed at the sites of present orebodies at the onset of brine circulation. Indeed the opening of such cavities may have provided the release mechanism triggering off brine ascent from deep reservoirs.

A simple model then for the hydrothermal system consists of series of vertically aligned, sub-horizontal, ribbon-like cavities interconnected by constricted, sub-vertical breccia channels formed at fracture or vein intersections. Upwelling brines passed vertically through the breccia channels and horizontally along the cavities, proceeding eventually perhaps to surface and the Zechstein Basin (see Sawkins, 1966).

For any given flow rate, brine velocities must have been greater within the constricted breccia pipes than in the open cavities. Thus, entry to a cavity must have been associated with sudden decceleration and loss of head. This could have also caused a change in flow type and consequently a change in rate of heat transfer with the surroundings (Appendix 1). If it were possible to detect these changes from examination of the orebody at the present day then they would provide excellent indications to mining of the proximity of feeders.

Brine cooling is also related to flow rate and to distance from source. If brine cooling occurred within the cavity systems then measurement of cooling gradients must indicate flow directions and hence lead one to feeder conduits.

5.3 Thermal Aspects of Hydrothermal Circulation

Processes that influence the cooling of a hot hydrothermal brine during its ascent to the earth's surface have been analysed and discussed by some American and French geologists (Clark, 1959; Lafitte, 1958, 1962; Barton and Toulmin, 1961; Toulmin and Clark, 1967).

Toulmin and Clark distinguish those processes tending to warm the brine (exothermic precipitation, wall-rock alteration and heat exchange with a warmer environment) from those tending to cool it (decompression, heat exchange with cooler walls, hydrothermal leaching, mixing with cooler fluids and endothermic reactions).

Most of these processes can be shown to have had little influence in the North Pennines. Wall-rock alteration, leaching and mixing with cold solutions may have had significant effects only during early brine phase circulation, while the walls were sealed by silicification and mineral crusts, and pre-existing groundwaters were flushed out of the fault cavities. Heat exchange with a warmer environment may be discounted since the fluid inclusion temperature gradients presented in following sections show that the wall-rocks were cooler than the brines. Regarding precipitation reactions, Toulmin and Clark state that endothermic reactions are geologically unusual and, although in certain circumstances exothermic reactions may be significant in retarding cooling, there are insufficient data on electrolytic solutions to be able to estimate heats of precipitation quantitatively.

Adiabatic expansion, resulting in loss of internal energy and cooling, occurs with decreasing pressure. This may happen gradually as the brine rises along a normal geostatic pressure gradient, in which case the phenomenon is known as reversible adiabatic expansion, or it may happen suddenly and violently (in the case of throttling) as brines pass through

constrictions into lower pressure environments (irreversible adiabatic expansion). Brine pressure may be estimated, given that the maximum overburden on the Great Limestone was 1100m at the time of mineralization (Sawkins, 1966). Thus if the pressure was hydrostatic (i.e. simply due to the weight of a column of brine extending to ground surface) then brine pressures at the top of the Weardale Granite and at the Lower Fell Top Limestone would have been about 150 and 100 bars respectively. If the pressure was lithostatic (i.e. equivalent to the weight of overlying rocks) then brine pressures at the same horizons would have been about 375 and 240 bars. Although the absolute values of these estimates may be in error owing to the uncertainty in the overburden figure, the pressure ranges, 50 bars (hydrostatic) and 135 bars (lithostatic) between the Weardale Granite and one of the highest, extensively mineralized beds, provide accurate reference data. However, it is most unlikely that either purely hydrostatic or lithostatic pressure gradients apply to the case under consideration. The pressure upon the brine at its immediate source beneath the orefield must have been high, probably approaching lithostatic pressure. This applies equally well to Sawkins' theory whereby the brine is released from a cooling magma deep in the earth's crust, and to the theory of Solomon and co-workers (1972) whereby the brine is a migrating pore fluid coming into contact with a cooling igneous body, again deep in the crust. The pressure in the upper reaches of a hydrothermal system, however, must approach hydrostatic if the system becomes open to the earth's surface. Thus a maximum brine pressure gradient, in which an approximately lithostatic pressure gives way upwards to a hydrostatic pressure, can be obtained. If this took place entirely within the narrow stratigraphic range we are considering (it must have occurred across a

series of constrictions or baffles that could easily have been formed by the vertical breccia conduits connecting orebody cavities) then the maximum pressure gradient would have been 275 bars in 520m.

The data of Toulmin and Clark show that adiabatic cooling of water, starting at 200° C, caused by following a pressure gradient of 275 bars in 520m will be very small, probably in the order of 5°C. The estimate is the same for both reversible and irreversible expansion. Thus, unless the behaviour of 4 N sodium chloride brine is very different from that of water, adiabatic expansion was insignificant in cooling the brines.

Heat exchange with cooler wall-rocks was the most important mechanism for cooling the brines, maintaining chemical saturation and precipitating minerals. The initial temperature of brines entering some parts of the orefield was as high as 200°C (Sawkins, 1966). Initial wall-rock temperatures at the same horizons, assuming a geothermal gradient similar to that found at present (Geothermal gradient 32°C/km measured in Rookhope Borehole-Bott and co-workers 1972), would have been about 55° - 60°C.

Heat transfer from brine to rock occurred across the wall interface. The rate of heat transfer is a function of the temperature difference across the interface and this was governed by the efficiency of heat dissipation by the wall-rocks. Heat dissip ation was controlled by four separate processes:

1. Conduction through solid rock.
2. Conduction through pore water.
3. Free convection of pore water.
4. Forced convection of pore water under a pressure gradient, possibly involving brine percolation.

Detailed calculations are presented in Appendix 1 to show that brine flow in most orebody cavities was turbulent. Heat loss from a turbulent fluid is more efficient than from a fluid in laminar flow and the response to any change in physicochemical parameters is transmitted more rapidly throughout the body of the flow.

5.4 Fluid Inclusion Geothermometry

Interface brine temperatures during mineral growth can be measured by fluid inclusion methods (homogenization, audio and visual decrepitation and Yermakov's rapid method - for a general discussion of the background and of the use of these techniques, see Yermakov, 1949).

Each primary fluid inclusion represents an element of the hydrothermal brine participating in mineral formation that has been trapped at the interface between open vein cavity and mineral wall. The temperature at which the inclusion was trapped is recreated and measured in the homogenization technique (used in this work). Since brine flow must have been turbulent (Appendix 1) this interface temperature must approximate to the mean bulk temperature of the brine.

Inclusion geothermometry can be used to measure the changing temperature of the brine as it flowed through the vein system. The following sections describe the results of such measurements on fluorite veins in the North Pennines. Sawkins (1966) had already shown that the hydrothermal brines of this orefield were heated relative to the wall-rocks and had provided preliminary data indicating a general range of temperatures of fluorite formation between 185°C and 120°C.

The methods developed and used during this investigation for observation of homogenization temperatures, for reduction of data and for data presentation are described, along with fluid inclusion descriptions, definitions and temperature data, in Appendix 2.

5.5 Transverse Temperature Gradients

Temperatures determined across the width of a vein orebody record variation of brine temperature with time at any one place. Several sections are illustrated in Fig. 5.1. It is important to note from these that within the main phase of fluorite deposition there was only slight temperature variation, generally less than 10°C. This is particularly clear from the results from specimens 45 a - g, from a ten metres wide vein.

Temperatures of early phase minerals appear to have been greater than those of main phase fluorite, at depth at any rate. In the Weardale Granite, early vein quartz formed at higher temperatures than the main fluorite (Fig. 5.1). Early phase silica from the Viséan rocks is too poorly crystalline to be used for inclusion work. However, if the early phase minerals and the minerals of Dunham's Zone I represent the products of the same brine phase, then temperatures obtained from Zone I quartz can be used in this discussion (see Sect. 4.3.1). Thompson, in 1915, estimated a minimum formation temperature of 200°C for quartz from the Great Sulphur Vein using observations of bubble to fluid inclusion volumetric ratios. This was confirmed by Sawkins who found primary fluid inclusions in quartz from this Zone I vein homogenizing in the range 165° to 200°C (corrected for pressure to over 200°C).

Late phase "barren" quartz provides lower homogenization temperatures than main phase fluorite (see Boltsburn Vein, 1699, R.B.H. Fig. 5.1).

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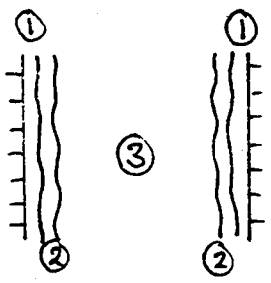
FIG.5-1 TRANSVERSE TEMPERATURE GRADIENTS

A. PHASE VARIATIONS

2·5 cm vein at 1562′ in the Rookhope Borehole

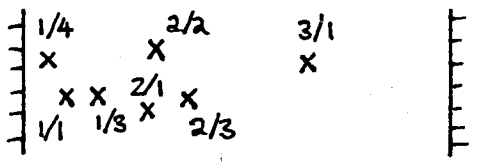


	mean T_{corr}	std. devn. °C
1) Early quartz (2 mm)	211°	11·8
2) Early. green fluorite (2 mm)	189°	7·8
3) Main green fluor. + pyrite	173°	6·4

Minor vein at 1699′ in the Rookhope Borehole

1) Main, massive, green fluorite	180°	9·0
2) Secondary fractures in 1)	152°	8·0
3) Cross-cutting qutz/pyrite	159°	15·7

B. MAIN PHASE - INTERNAL VARIATIONS



Minor vein, 17 Fms Level, Redburn Mine (Fluorite)

1/1	144°	2·2
1/3	144°	5·3
1/4	144°	3·3
2/1	149°	5·6
2/2	146°	2·6
2/3	127°	6·0
3/1	146°	4·1

Groverake Vein, 50 Fms Level Groverake Mine - Approx. 30 feet of fluorite

Dist. of spec. from N. wall (feet) - all fluorites		
45 A	- in early Qtz - Cpt. 0·8′	178° 8·0
45 B	1·2	178° 7·5
45 C	4	177° 8·3
45 D	7·5	167° 2·0
45 E	15	177° 4·7
45 F/G	22·5	176° 5·5
45 F/P	25	173° 8·5
45 G	South wall ~ 30	175° 6·0

Another example of change in temperature with time can be found from vug minerals. Sawkins (op.cit.) used vug minerals widely in his study of the orefield stating that since they gave the same order of temperatures as massive minerals they were valid material for a general or reconnaissance study. Careful examination of fluorite crystals from vugs shows that cooling gradients sometimes exist from the cores to the outer parts of the crystals. For example, a two centimetre crystal from United East Pant Dû Mine, North Wales (Spec. No. 585) yielded a mean formation temperature (uncorrd.) of 104.5°C (std. devn. 6.0) from its core and 96.5°C (std. devn. 4.3) from its outermost layer. The uncertainty as to the reliability of vug mineral temperatures resulted in great care being taken to collect, wherever possible, only massive fluorite during this investigation.

Local variation in temperature may be brought about in several ways. Short term fluctuations in source temperature may be ruled out on the evidence of Lafitte (1962) who showed that heat transfer between vein walls and vein brines would tend to smooth out these fluctuations. Local changes in brine flow rate or pattern, brought about by partial blockage of a part of the vein conduit system could result in greater cooling at any one place.

Precipitation reactions may also have a local effect on cooling. Endothermic reactions at the brine-wall interface would tend to assist cooling and exothermic reactions retard cooling. Most precipitation reactions are exothermic. Several samples of fluorite intergrown with sulphides were taken from a flat in the Rookhope Borehole and the temperatures of fluorite formation compared with those obtained from massive green fluorite from the same flat.

	Tynebottom Flat, 590'	Thom. Mean	Std. Devn.	N.
1.	Massive fluorite	138.6°C	5.1	52
2.	Fluorite intergrown with pyrite	129.5°C	5.3	21
3.	Fluorite intergrown with galena,blende	131.5°C	7.1	47

The differences in homogenization temperature between fluorite 1 and fluorite 2 and 3 were tried using the Student's t test and found both to be highly significant (both values of t falling below the 0.001% probability level). This does not mean that sulphide deposition was necessarily endothermic, however. Cavity infillings in flat deposits such as this must have undergone greater temperature fluctuations than vein infillings because of the lesser stability of brine flow through corroded, ramifying solution cavities. It may simply be that at this point, brine flow in the Tynebottom Flat slowed down for a while, allowing the temperature to drop further than before and to exceed the solubilities of the sulphides in an otherwise slightly under-saturated solution.

5.6 Vertical Temperature Gradients

A number of vertical hydrothermal cooling gradients have been measured from a wide stratigraphic range of mineralized sections in the Rookhope area. The choice of samples in each section was determined by their positions relative to a single feeder intersection. The effects of lateral gradients are assumed to have thus been minimized. Samples of fluorite were always located within 300mm of the vein wall, as described in Appendix 2.

A. Rookhope Borehole

The borehole (NY 938428), sited close to the surface intersection of Red Vein and Boltsburn Vein, penetrated a number of fluorite bearing horizons (Dunham et al., 1965). Flat and vein deposits occur in the Viséan sediments and minor veins in the Devonian granite. Mineralogically, there are two very distinct types of hydrothermal mineralization. The first type, typically Pennine, was found in the sediments and the upper part of the granite. The second type occurs only in the granite, and its range in the borehole overlaps that of the Pennine type veins. The mineralogy of this second, non-Pennine type of vein comprises quartz, intensely purple fluorite, haematite, magnetite, crystalline manganese oxides, chlorite, pyrite, pyrrhotite, garnet and epidote. Chlorite, garnet and epidote also occur in the granite pegmatites and aplites. Fluorite grains can be seen in thin sections of coarse unmineralized granite at 2,200' 4". Primary fluid inclusion temperatures from this mineralization are very much higher than those recorded by the Pennine type veins (Fig. 52). The trace element composition of the fluorite is unusual and quite unlike that of normal Pennine fluorites (Spec. 228; Sr - 524ppm. general range N. Pennine fluor. 20-60ppm.; Y - 14ppm. general range N. Penn. fluor. 120-815ppm.).

Determinations from secondary inclusions fall close to the temperature range and gradient of early brines circulating in complexes of normal Pennine-type veinlets close-by, indicating the greater age of the garnet-bearing veins. Mr. Gilchrist of the School of Physics, Newcastle, kindly dated wallrock alteration of the 2085' veinlet at 260My., using the K-Ar method. This age compares closely with the K-Ar determinations of $255^{+}_{-}10$My. of Fitch and Miller (1965) for the normal Pennine veins in the granite. Thus, although the mineralogy and primary temperatures of the

Fig. 5.2

Corrected mean primary fluid inclusion temperatures from fluorite plotted against depth of mineralization in the Rookhope Borehole. Thermal gradients were calculated by linear regression on mean values. The error bars represent quartiles.

Additional symbols:-

X1 Boltsburn Vein, Boltsburn East Mine, Great Limestone.

X2 Red Vein, Stotfield burn Mine, mean of 3 samples (No. 107) from the Coal Sills opencut.

X3 Recorrected, highest, median primary temperature of Sawkins (1966) for Red Vein, Stotfield burn Mine, plotted at deepest working horizon.

+4,+5 Mean secondary temperatures from the high temperature mineralization, demonstrating the similarity in temperature during the secondary fracturing and the formation temperature of the nearby Pennine type mineralization.

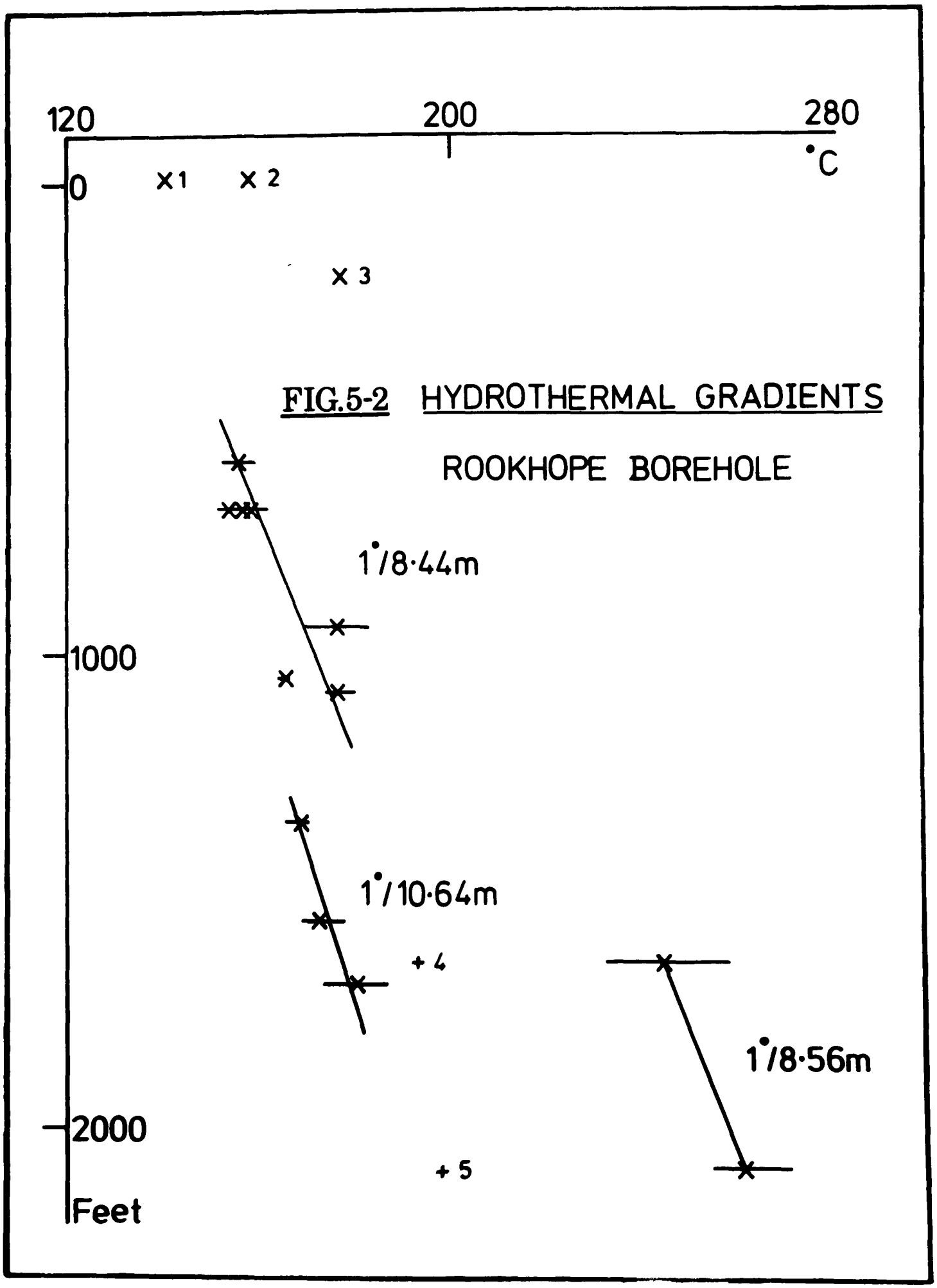
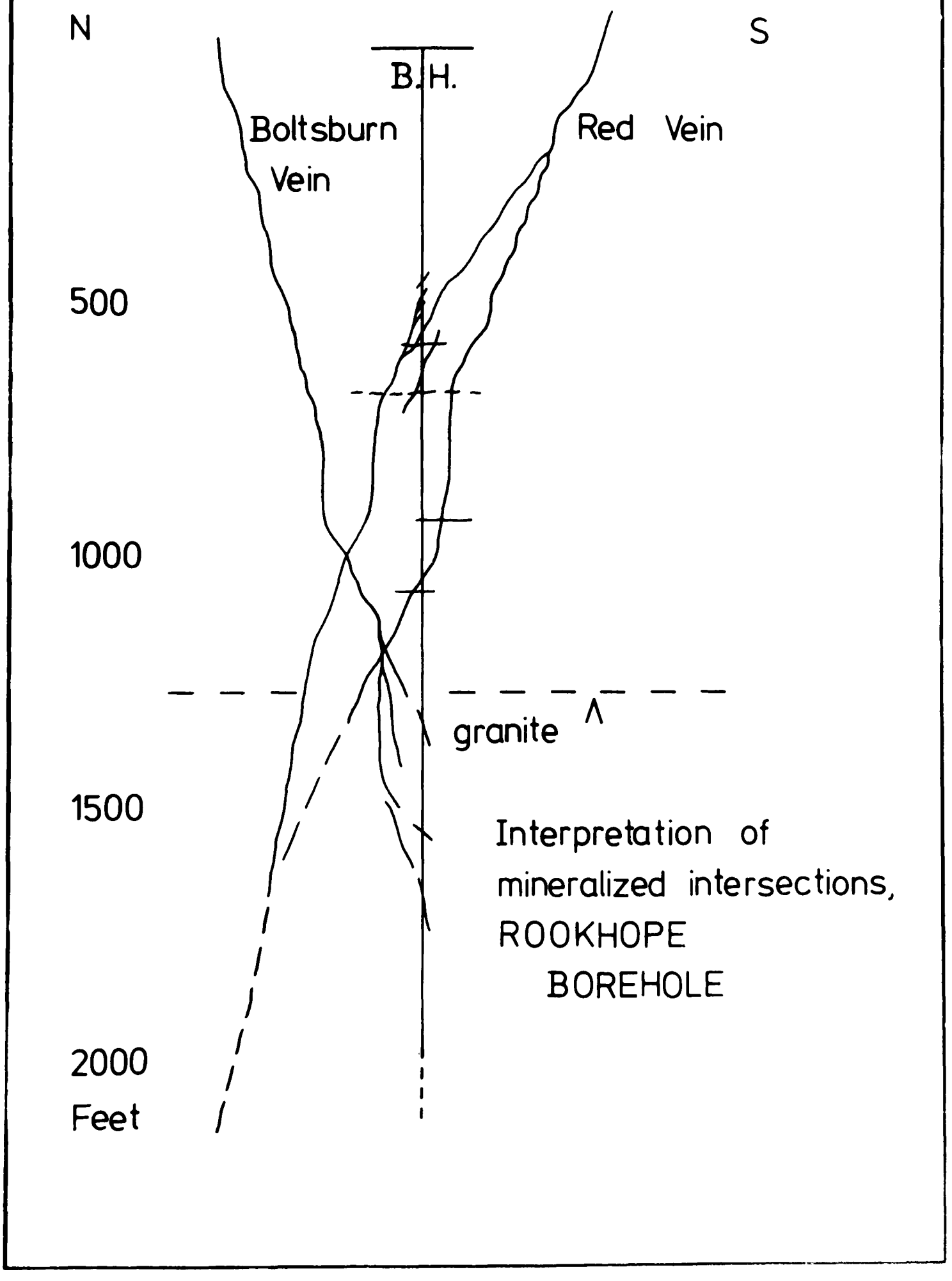


FIG.5-2 HYDROTHERMAL GRADIENTS

ROOKHOPE BOREHOLE

FIG 5_3


N
S
B.H.
Boltsburn Vein
Red Vein
500
1000
granite
1500
2000
Feet
Interpretation of mineralized intersections, ROOKHOPE BOREHOLE

fluorite-haematite-garnet mineralization suggest a postmagmatic origin, perhaps related to the granite itself, the low secondary temperatures and young age record reheating and Ar release during the Pennine phase of mineralization.

Primary temperature determinations enable distinction of the two Pennine type veins. Boltsburn Vein, occurring as a group of en echelon veinlets in the granite, formed at nearly 20°C lower than Red Vein. Findings from studies of the two veins at surface yield a similar result (Fig. 5.2). The difference can be accounted for, by the greater strength, width and depth of Red Vein. Hence, brine ascent would have been more rapid and heat retention more efficient.

Red Vein seems to comprise two distinct vein channels,at depth, which probably coalesce before reaching surface. An interpretation of vein relations in the borehole is shown in Fig. 5.3. The rather low temperatures recorded for the Jew Limestone flat reflect the distance of that mineralization from the nearest vein channel (probably 19m).

B. Redburn Mine

Two gradients have been measured, from the area of the shaft in the main eastern orebody and also by No. 5 rise in the main western orebody, both in the Red Vein system. The gradient in the eastern body, between the Three Yard and Great Limestones, is 1°C/6.3m; that in the western body, measured between the Great Limestone and Firestone Sill, is much steeper at 1°C/2.47m.

C. Groverake Mine

Two general gradients have been taken that represent the vertical cooling of brines not directly within feeder zones. In the centre of the main feeder zones of this mine, vertical cooling rates are very low, in the order of 1°C/19m to 1°C/21m.

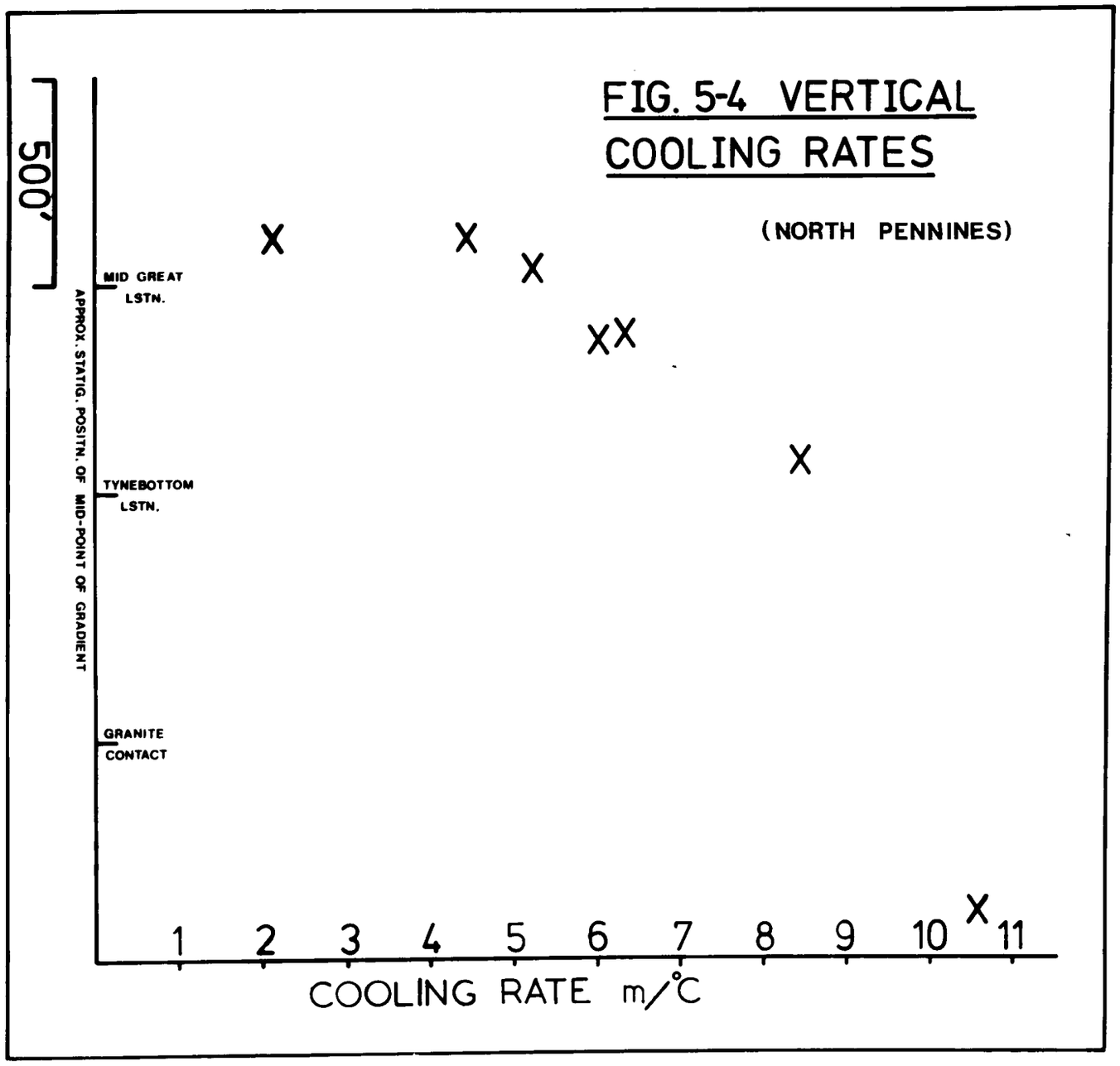


FIG. 5-4 VERTICAL COOLING RATES
(NORTH PENNINES)
500'
APPROX. STATIG. POSITN. OF MID-POINT OF GRADIENT
MID GREAT LSTN.
TYNEBOTTOM LSTN.
GRANITE CONTACT
1
2
3
4
5
6
7
8
9
10
11
COOLING RATE m/°C

TABLE 5.1 Measured Hydrothermal Gradients (Fluid Inclusions)

Gradient °C/metre	Approx. range measurements	Mineralizn.	Locality	Source ref.
		Subvolcanic deposits of Miocene age, Japan		
1°/3.3	300-200	Cu	Showa No. 5 Vn. Osarizawa Mine	1
1°/3.3	-	Cu	'Champion Vn.' Togichi Mine	1
1°/ ≤3.3	200-150	Pb,Zn	'Champion Vn.' Toyoha Mine	1
1°/3.3-2.5	-	Au,Ag	No. 2 Vn. Seigoshi Mine	1
1°/2	-	Cu	Akakura Vn. Yasō Mine	1
1°/2	-	Cu	Kido No. 7 Vn. Yasō Mine	1
1°/1.42	300-200	Cu	Sai Mine	1
1°/ ≤3	350-300	Sn,W,Cu		2
1°/3.3	-	Pb,Zn	Toyoha Mine	3
		Subvolcanic deposits of Cretaceous/Early Tertiary age, Japan		
1°/3.6	320-280	Au	Chosei Vns. Oya Mine	4
1°/4.1	"	Au	" "	4
		'Hydrothermal deposits', Baley orefield, E. Transbaikal		
1°/4.75 to 1°/5.25	280 to 110	Pb, Zn, F		5
		Sub-Neogene volcanic deposits, W. Carpathians		
1°/7	340-270	Cu,Pb,Zn	Muncăceasca West deposit	6
1°/8.5	"	"	" " "	6
1°/10	"	"	" " "	6
1°/10	302-293	Cu,Pb,Zn	Vn. No. 22, Hanes deposit	6
1°/10	297-276	"	Vn. A, Fața Băii	6
1°/12.5	≤ 270	"	Vn. No.1, Brădișor Mine	6

		Sub-Neogene volcanic deposits, Toroiaga-Tiganul Massif		
1°/10	s 350-250	Cu	Sofia Vn.	7
1°/11.6	"	Cu	Orania Vn.	7
1°/11.6	"	Cu	Domnişoara Vn.	7
1°/12.4	"	Cu	Ecaterina Vn.	7
1°/12.4	"	Cu	Emeric Vn.	7
		Postmagmatic, hydrothermal deposits, Cornwall		
1°/10.7	270-250	Sn,Cu	South Crofty Mine	8
		Complex hydrothermal sulphide deposit, Rumania		
1°/15	226-217		"O" Vn. Gerzha, nr. Baia Mare	9
			others nearby have similar gradients	
		North Pennine orefield		
1°/2.1		Pb,F	Red Vein, Redburn Mine	10
1°/4.4		Pb,F	Groverake Vn. Groverake Mine	10
1°/5.2		Pb,F	" "	10
1°/6.0		Pb,F	Red Vein, Stotfieldburn Mine	10
1°/6.0		Pb,F	Red Vein, Redburn Mine	10
1°/8.44		Pb,Zn,F	Red Vein, Rookhope Borehole	10
1°/8.56		Fe,F	Unnamed vein, " "	10
1°/10.64		Pb,F	Boltsburn Vein, " "	10

Source References

1, Miyazawa 1967; 2, Imai 1970; 3, Tokunaga 1970; 4, Imai 1966; 5, Lyakhov 1969; 6, Borços 1966; 7, Borços 1965/1966; 8, Bradshaw and Stoyel 1968; 9, Savul and Pomirleaunu 1958; 10, Smith ab intra.

Cooling rates apparently increased as the brines approached surface (Fig. 5.4). Borços (1966) noted a similar effect from the Muncăceasca-West deposit in the Carpathians. It may be that heat dissipation through wall-rocks was more efficient closer to the surface as the effect of heat loss in the third dimension became significant. It must however be remembered that the highest mineralized horizon used in this study (the Lower Felltop Limestone) may have been as much as 950m beneath the contemporary land surface (Sawkins, 1966). Mixing with cold ground waters has been advocated as a cooling process by some authors, but can be ruled out on lack of evidence of dilution or change in brine composition over vertical distances of 580m of main phase mineralization (Chapter 4).
An intensive literature search provided nine sources of measured vertical cooling gradients from other deposits. These are tabulated in Table 5.1 and fall mainly within a narrow range between $1^{\circ}C/3m$ and $1^{\circ}C/10m$. This range encompasses the Rookhope data. It is very difficult to understand why mineralizing brines from such a variety of environments should bear this similarity.

5.7 Longitudinal Temperature Gradients

It was shown earlier that considerable amounts of brine must have flowed through most orebodies in order to deposit the observed thickness of minerals. This flow was mainly laterally directed between conduits of differing potential. It is possible also to show that the brines cooled during this longitudinal flow and that in fact this cooling was important in precipitation of the vein minerals.

Temperature measurements on contemporaneous phases (generally fluorite from within 300mm of the vein wall-rock) collected in longitudinal traverses of orebodies show brine cooling away from orebody feeder intersections (Figs. in Sect. Two). Feeders are almost always represented by zones of relatively high temperatures, providing proof, incidently, that the vertical hydrothermal gradients just described do not simply conform to abnormal rock geothermal gradients, as had been suggested by Davidson (1966). Major outlet conduits are not marked, in contrast, by low temperatures because, though brines may flow to them from stronger input feeders, the output intersections themselves must form sites of weaker upwelling of hot brines.

The absolute magnitude of longitudinal gradients is variable in the range $1^{\circ}C/7m$ to $1^{\circ}C/25m$ (Weardale mines) and probably depends on a large number of factors, some of which are listed below:

1. The ratio of input to output potential of any given vertical conduit determines the flow rate to or from that conduit.

2. The form and size of the orebody cavity affects the brine cooling rate, as does wall-rock lithology.

3. A high density of vertical conduits to a single orebody, resulting in high vertical flow rates over a restricted section, is liable to simply raise the overall temperature of the central area without producing marked gradients associated with each feeder conduit. A good example of this occurs at Redburn Mine in the Western ore-zone (Sect. 8.6).

Longitudinal temperature gradients determined in several Weardale deposits are described in Section Two where these deposits are described in detail. Measurement of brine flow directions using this method has provided valuable and conclusive information on the location of zones of ascending brine flow, i.e. feeders, during work on several mines. The method can be used, working simply from a traverse along a single mineralized horizon, or with greater effect from a two-dimensional array of samples taken from throughout a mine, in which case the trends of feeders may be extrapolated (e.g. Groverake Mine - Sect. 8.5).

5.8 Regional Temperature Variations

Lateral temperature variation also occurs on a larger scale. Although, contrary to a widely held opinion, it is not possible to construct isotherms that relate to, or are concentric with, orefield mineral zone boundaries, one can distinguish normal and anomalous temperature ranges for deposits within the fluorite zone.

Anomalous areas of occurrence of Dunham's Zone I copper-rich mineralogy were known to exist within his Zone II (galena with subordinate sphalerite) at Groverake, Stotfieldburn and Sedling mines in northern Weardale. Dunham (1934) explained that they are broadly central to Zone II east of the Burtreeford Disturbance. By analogy with mineral zonation in the Cornish deposits, Zone I was interpreted as being of higher temperature origin than surrounding and succeeding zones. Sawkins' (1966) preliminary results again suggested the existance of hot-spots at these and three other localities, Blackdene, Stanhopeburn and Whiteheaps mines. He noted that all these areas are highly mineralized and probably represent regional feeder zones. My own results bear out these conclusions, with the exception of Blackdene Mine, and show in particular that Red Vein and Sedling Vein, as quarter point veins, were formed at generally higher temperatures than the N.E. trending lead veins (including Blackdene Vein).

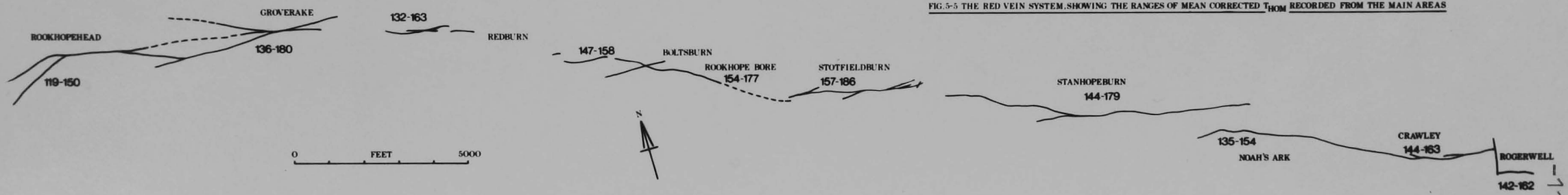


FIG.5-5 THE RED VEIN SYSTEM, SHOWING THE RANGES OF MEAN CORRECTED T_{HOM} RECORDED FROM THE MAIN AREAS

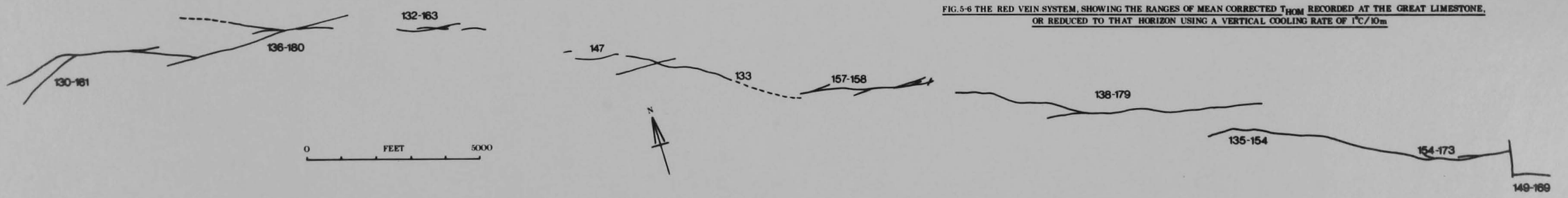


FIG.5-6 THE RED VEIN SYSTEM, SHOWING THE RANGES OF MEAN CORRECTED T_{HOM} RECORDED AT THE GREAT LIMESTONE, OR REDUCED TO THAT HORIZON USING A VERTICAL COOLING RATE OF 1°C/10m

Along Red Vein itself, particular hot centres occur at Groverake, Stotfieldburn, West Stanhopeburn and possibly also beneath Hope Level. This is brought out in Figs. 5.5, 5.6 where the results are represented on a map of the Red Vein system. Obviously, the formation temperatures shown in Fig. 5.5 are of little value for comparisons because they come from stratigraphic horizons spread over a range of about 210m. For this reason all the results have been reduced to a common datum horizon, the Great Limestone, using a vertical hydrothermal gradient of $1^{o}C/10m$, and replotted on Fig. 5.6.

At Whiteheaps Mine a radiating fan of veins forms, at intersection, a high temperature central zone to the Hunstanworth deposits.

Each of these hot-spot deposits coincides with thick washout sandstone bodies in the upper Visean and Namurian strata. Thus the positioning of regional feeders may not be determined by underlying basement structures, it is possible that they were controlled by the situation of large open vein channels which could sustain high flow rates for long periods without choking up. With the exception of Whiteheaps and Groverake, there appear to be no convincing structural intersections that could have controlled the siting of major regional feedersat these locations.

5.9 The distribution of Zone I type mineralogy

In section 4.3.1, the early silica-chalcopyrite-pyrite-marcasite phase of mineralization was compared with Dunham's Zone I mineralogy and the two found to be probably cogenetic. Zone I comprises the old copper-mining district of Tynehead, central to the orefield west of the Burtreeford Disturbance, and also forms pockets east of the Disturbance.

These pockets coincide with the hot-spots mentioned earlier. Taking a closer look at them in Weardale, they are areas in which the early phase is well-developed and its copper content unusually high. They represent areas with strong feeder zones in which the early brines could reach higher stratigraphic horizons than elsewhere. At higher levels, chalcopyrite gradually becomes confined to the immediate feeder area and gives way upwards to pyrite and marcasite. The transition dips eastwards towards the barium zone. Thus, the upper limit of chalcopyrite occurs in the Slate Sills at Groverake, the Coal Sills at Redburn, the Great Limestone at West Stotfieldburn, and the Three Yard Limestone at West Stanhopeburn Mine. Moreover, at any given horizon the copper content of the early phase decreases, as does the extent of early phase mineralization, laterally from hot-spots into regions of 'normal' mineralization, and on a smaller scale laterally from feeder intersections into orebodies.

This distribution can be interpreted from the information we have on the early phase brines. They arose from a fairly central source (viz. central position of Tynehead) and spread radially outwards and upwards (viz. concentric transition of sulphides). Where vertical channelways were strong, e.g. Great Sulphur Vein and intersections on Red Vein, upward penetration of the brines was strongest. The brines flushed out, and reacted with pre-existing groundwaters in the already open cavities, depositing the early phase mineralogy. The greatest thickness of early phase material occurs around the feeders themselves and gradually, depending on the feeder strength thins to a veneer or silicified selvage along orebody cavities.

Thus examination of the early phase can yield information of very great value. The thickening of the phase and appearance of chalcopyrite warns of the proximity of a feeder and the amount of chalcopyrite can indicate the feeder strength (depending on the regional zonation of Cu/Fe sulphides). In all the mineson Red Vein and at Hunstanworth that have been visited during this project (Section Two), feeder inter-sections can be picked out underground using this method.

5.10 Brine flow rates and the duration of mineralization

Knowledge of the value of the vertical hydrothermal gradient and of the thermal characteristics of wall-rocks and brine can provide a relationship between brine flow rate and duration of brine flow, although it is impossible from these data alone to calculate either parameter.

An independent estimate of maximum brine velocity can, however, be made using a very simple method outlined by Barton and co-workers (1970 , p.142). Some specimens of fluorite from the North Pennines contain growth surfaces, typically on one side only of the crystal, outlined by tiny, biterminated, euhedral quartz crystals. These represent nuclei that have grown suspended in the brine flow until they reached a critical maximum size beyond which they could no longer be supported by the flow and settled out onto growing mineral surfaces. At that critical instant, the brine velocity must have been equal to the settling velocity of the same grains in static brine. This can be calculated from knowledge of the size of the grains and of certain thermodynamic parameters of the brine. A modified version of Stokes' Law (Gibbs et al, 1971) was used, (in a specially written computer programme, 'Stokes', F.W. Smith, 1972) which takes into account experimentally-derived correction factors applicable to the settling of very small particles.

The result from measurements of 41 quartz inclusions in fluorite specimen no. 254 from Rispey Vein, Rookhope, at the horizon of the Little Limestone, indicates a maximum vertical component of brine velocity of 1.04cm/sec. Approximate measurements on a number of other fluorites with less regular solid inclusions suggest that they too experienced flow velocities between a half and one cm/sec. Barton and co-workers obtained a value of 0.5cm/sec for the fluid velocity during formation of an epithermal base metal deposit in Colorado.

Other geological evidence supports brine velocity estimates of this magnitude. Dunham (1932) reports observing fragments of shale that has been carried upwards to be enclosed in vein-stuff, implying a strong vertical flow, perhaps caused at a shaley constriction in the vein.

It is also expected that flows of this velocity, or greater, must have been required in order to ensure maintenance of the high temperatures of early phase brines as they rose to relatively high stratigraphic levels in the Tynehead area (e.g. Great Sulphur Vein).

A few attempts to measure asymmetric growth of vein minerals, particularly fluorite which is generally clearly banded with growth lines, were unsuccessful at Redburn due to the very shattered nature of the vein where seen exposed by mining. The asymmetry of growth and the degree of "tilt" of in situ elongate crystals such as quartz could have been used to indicate flow directions and possibly to derive qualitative estimates of relative flow velocity within orebodies (Gross, 1956).

The actual relation between brine flow rate and the time required to set up any given forced convective cooling gradient can be calculated using a formula derived by Toulmin and Clark (1967) and incorporated into the computer program 'Hydrograd' (Smith, F. W., 1972).

The program simulates a vein situation, the conditions of which are shown in Table 5.2, and which approximates to a vein (Boltsburn Vein) penetrated by the Rookhope Borehole, in the Weardale Granite. The measured, corrected, fluid inclusion temperature gradient in this deep mineralization is 13°C/100m. The calculations showed that taking velocities between 0.1 and 1cm/sec, the observed temperature gradient would have been set up very quickly (Table 5.3). They also show that continuing flow under these conditions would tend to rapidly obliterate the cooling gradient (Fig.5.7). This obviously contradicts the evidence produced in Section 5.5 to show that absolute temperatures and cooling gradients stayed virtually constant throughout the period of mineralization. We must assume, then, that the system must, soon, in its history, have entered a steady state in which heat was dissipated through the host rocks at the same rate as it was gained from the brine. This has already been inferred in Section 5.3 and may also afford a key to the puzzle of the uniformity of measured hydrothermal gradients in ore deposits.

It is possible, using absolute solubility data, to explore another approach to find the duration of mineralization. If we take the same example of the vein with a cooling gradient of 13°C/100m, we know the unit volume of the vein cavity, the amount of fluorite required to fill that volume and the percentage CaF_2 precipitation from a 3N NaCl brine over the measured temperature range (Strübel, 1965). From these data we can calculate a relation between brine velocity and time required to fill the vein with fluorite (Table 5.4). Thus, if we settle for a velocity of 1cm/sec, then it would have taken 1,000 years to fill the vein. As long as other conditions are kept unchanged, the same relationship between velocity and duration applies to wider veins.

Table 5.2

Parameters used in vein simulations, (Hydrograd calculations), Model 1 (see Appendix One)

Vein width (w) 5 cm

Rock, thermal diffusivity (Weardale Granite) (A) 0.0130 cm^2 sec^{-1}

Rock, thermal conductivity (Weardale Granite) (K) 0.00703 cal cm^{-1} sec^{-1} $^oC^{-1}$

Rock, heat capacity (CP_b) 0.193 cal gm^{-1} $^oC^{-1}$

Rock, initial temperature varied between 70°C and 170°C T_r

Rock, density (ρ_b) 2.80 gm cm^{-3}

Brine, 20 wt. % NaCl

Brine, thermal diffusivity 0.006403 cm^2 sec^{-1}

Brine, thermal conductivity 0.00133 cal gm^{-1} sec^{-1} $^oC^{-1}$

Brine, heat capacity (CPa) 1.20 cal gm^{-1} $^oC^{-1}$

Brine, initial temperature 200°C T_o

Brine, density 0.915 gm cm^{-3}

Brine, dynamic viscosity (DyVis, μ) 0.003 poises

Brine, coefficient of volumetric expansion (at 150°C) $-\beta$ 0.003 cm^3 $^oC^{-1}$

Brine - wall temperature evaluated at 50, 100, 200, 300, 500, 800, metres (X) from source.

Formula (Toulmin and Clark , 1967): -

$$k = \frac{K}{\rho_a CP_a + \rho_b CP_b}$$

$$v' = \rho_a CP_a v / (\rho_a CP_a + \rho_b CP_b)$$

v = velocity cm sec^{-1}

t = time sec

$$T - T_r = (T_o - T_r)\,\mathrm{erfc}\ \frac{k X / v' (W/2)}{1/2\ (4A(t - X/v'))}$$

Table 5.3 The Brine Velocity - Flow Duration Relationship. Calculated from Hydrograd data. (Duration required to create the observed cooling profile of 13° C /100m in a cm wide vein, background rock temp. constant at 110°C).

Brine velocity, cm/sec	Duration of flow required, years
0 .2	1
0 .07	10
0 .02	100

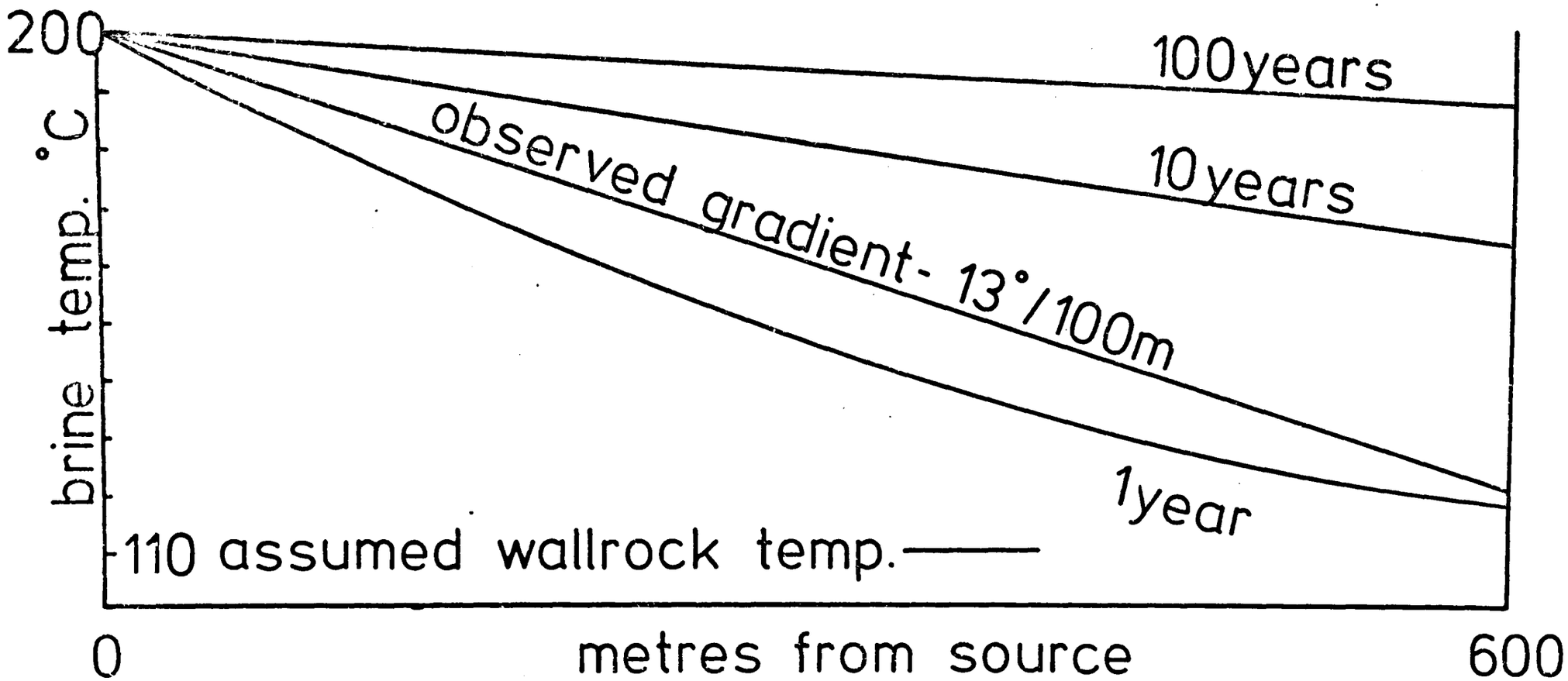
Table 5.4 The Brine Velocity - Flow Duration Relationship

Calculated from absolute solubility data. (Duration required to fill a vein with CaF_2).

Brine velocity, cm/sec	Duration of flow required, years
1.0	1000
0.1	10000
0.01	100000

FIG. 5-7 CALCULATED THERMAL GRADIENTS, SHOWING VARIATION WITH FLOW DURATION

20% NaCl Brine, 0.1cm sec^{-1}, 5cm Fissure in Granite



These calculations have applied only to a simple vein in homogeneous rock but the results are probably of fairly general application. It is important to note, in summary, that there are too many variables to permit unique derivation of either brine velocity or duration of brine flow without estimation of one or the other. Moreover, a steady state situation seems to have existed through most of the flow duration, limiting the value of purely convective heat loss treatment. Velocities measured from geological observations were in the order of 0.5 to 1cm/sec. If these were typical then the observed cooling gradients in the brines could have been created within one year of commencement of brine circulation (neglecting initial brine dilution and mixing with groundwaters) and the duration of brine circulation in any given orebody may have been less than 10,000 years. The nature of the calculations, neglecting many geological factors, is such that these values are most probably underestimates. Yet even underestimation by a power of ten implies that the original circulation period in an individual vein was not unreasonable in comparison with modern, hot, geothermal brine systems, which are, known to be stable for at least 500,000 years (Elder, 1965).

5.11 Comparisons with Modern Day Geothermal Brine Systems

A number of authors have recently suggested comparisons of modern hot brine systems with ancient hydrothermal systems (e.g. Henley, 1973). These are attractive because the modern brines are at temperatures similar to those of ore-forming brines (deduced from fluid inclusions), they offer attractive models for leaching of large volumes of country rock and for the formation of broad alteration zones, moreover they often show signs of base metal precipitates, particularly Pb, Hg, Sb and Zn at brine discharges. However, such systems are not directly comparable with Mississippi Valley type (see Roedder, 1967) deposits, including the North Pennine orefield.

Firstly, the hot brine salinities are always low and do not approach those determined from fluid inclusions from this type of ore deposit. Secondly, physical parameters, such as thermal gradients, of hot brine systems are unlike those observed from ore deposits e.g. vertical thermal gradients in hot brine systems fall within the range $1^{o}C/0.5m$ to $1^{o}C/2.5m$ (Elder, 1965). Although this may simply reflect different periods in the evolution of a hydrothermal system from an early heating and leaching phase to a later cooling and depositing phase. Thirdly and perhaps most important is the fact that the scale of ore metal deposits associated, even loosely, with geothermal systems is inevitably disappointingly small (White, D. C., 1967). Thus the present state of knowledge regarding the connections between geothermal brines and hydrothermal ore deposits is still sufficiently vague and uncertain as to cast doubts over the validity of direct comparisons between the two.

CHAPTER SIX

TRACE ELEMENT COMPOSITION AND VARIATION IN FLUORITE

6.1 Introduction

Preceding chapters describe the changes in pressure, temperature and velocity of the hydrothermal brine as it entered and travelled along an orebody cavity. The fluid inclusion method of determining temperature gradients around feeder intersection was shown to be a potentially useful exploration technique. However, the high degree of shattering caused by modern fluorspar mining (particularly for acid-grade spar) often spoils the ore for inclusion work. Homogenization geothermometry is, moreover, time-consuming, monotonous and requires a fairly skilled operator. For these reasons other indicators of flow direction were sought that are more suitable for industrial application. The most valuable of these was found to be trace element compositional variation in fluorite. This reflects the change in composition and physical state of ore-depositing brines as they travelled away from feeders.

The particular trace elements present in the fluorite and their amount, are functions of :-

i) the environment of fluorite deposition,

ii) the composition, hence source and history, of the parent brine,

iii) the ability of fluorite to accommodate the various elements.

The third factor is unimportant in the cases we will discuss since the elements under study can substitute to form relatively high proportions of fluoride (Sect. 6.2.1). The actual differences in trace element content between fluorites of contrasting mineralogenesis may be far greater than those between fluorites that, though deposited over a wider range of physical environments, were deposited from brines of similar sources. This point is expanded in Chapter 7 to suggest that the mineralogenesis of fluorite may be characterized by trace element suites and concentrations,

but is introduced here to emphasize that the following discussion is limited to the North Pennine deposits.

6.2 Trace Element Composition

6.2.1 General

The most common type of compositional variation in fluorite is the substitution of yttrium, with cerium, for calcium, to limits of Y^{+++} ($+ Ce^{+++}$) : Ca^{++} = 1:6 (yttrofluorite) and Ce (+Y) : Ca = 1:5.2 (yttrocerite) (Palache and co authors, 1951). Other rare earths * , occur in lesser amounts (see Leeder, 1966 and Derré, 1972 for references).

Barium, strontium, magnesium, aluminium and manganese commonly occur in small amounts, again substituting for calcium. Strontium may be present up to 2.1 wt % in fluorites associated with alkali igneous rocks (Yakubovich and Portnov, 1967). Manganese is present in concentrations of up to 0.81wt. %Mn in red fluorite associated with the manganese-rich lead-zinc deposits of Broken Hill, N.S.W. (Appendix 3)

6.2.2 North Pennine fluorites

Analysis by X-ray fluorescence (methods, instrumentation and results are given in Appendix 3) of specimens showed that yttrium concentration ranges from 46 to 812 ppm (only 3 values <120 ppm), cerium ranges from 0 to 971 ppm and lanthanum from 0 to 505 ppm. No other rare earths were sought. Table 6.1 reproduces analyses of previous workers.

Manganese, sought in 12 specimens, was found only in one (No. 404 0.163 wt.% Mn, detection limit about 0.00 1wt.%). Barium ranges from 30 to 116 ppm, strontium from 12 to 122 ppm and magnesium from 0 to 504 ppm. The range of the ratio Ba:Sr is wide (0.5 to 6.0), indicating that the two elements do not vary sympathetically.

Copper, lead, silver, zinc, and iron are often present, probably as contamination.

* Footnote

Yttrium is considered a rare earth for this discussion.

Table 6.1, Analyses of Rare Earths in Fluorite from the North Pennine Orefield

	1	2	3	4	5	6
La	200	< 5	5	87	16.2	
Ce	< 5	5	5	140		
Pr	20	< 20	< 20	19		
Nd	200	< 20	< 20	98		
Sm	20	< 20	< 20	20.5	1.25	
Eu	80	5	8	23		7 to 132
Gd	10	< 1	2	15		
Tb	< 20	< 20	< 20	2.4		
Dy	50	10	10	40		
Ho	10	< 10	< 10	9.2		
Er	20	10	10	22		
Tm	< 10	< 10	< 10	28		
Yb	7	5	5	9.5		
Lu	< 10	< 10	< 10	1.4		

Key (analytical method, author):

1. No. 67/1925 Redburn Mine
2. No. 67/1926 neutron activation,
3. No. 67/1927 Jeffrey, 1967
4. Mean of 8 analyses,'green fluorite, Weardale', emmission spectroscopy, Huber-Schausberger and Schroll, 1967
5. 'Blue fluorite, Durham', neutron activation, Derré, 1972a.
6. Range of Eu in 8 specimens, neutron activation, Jeffrey, 1967.

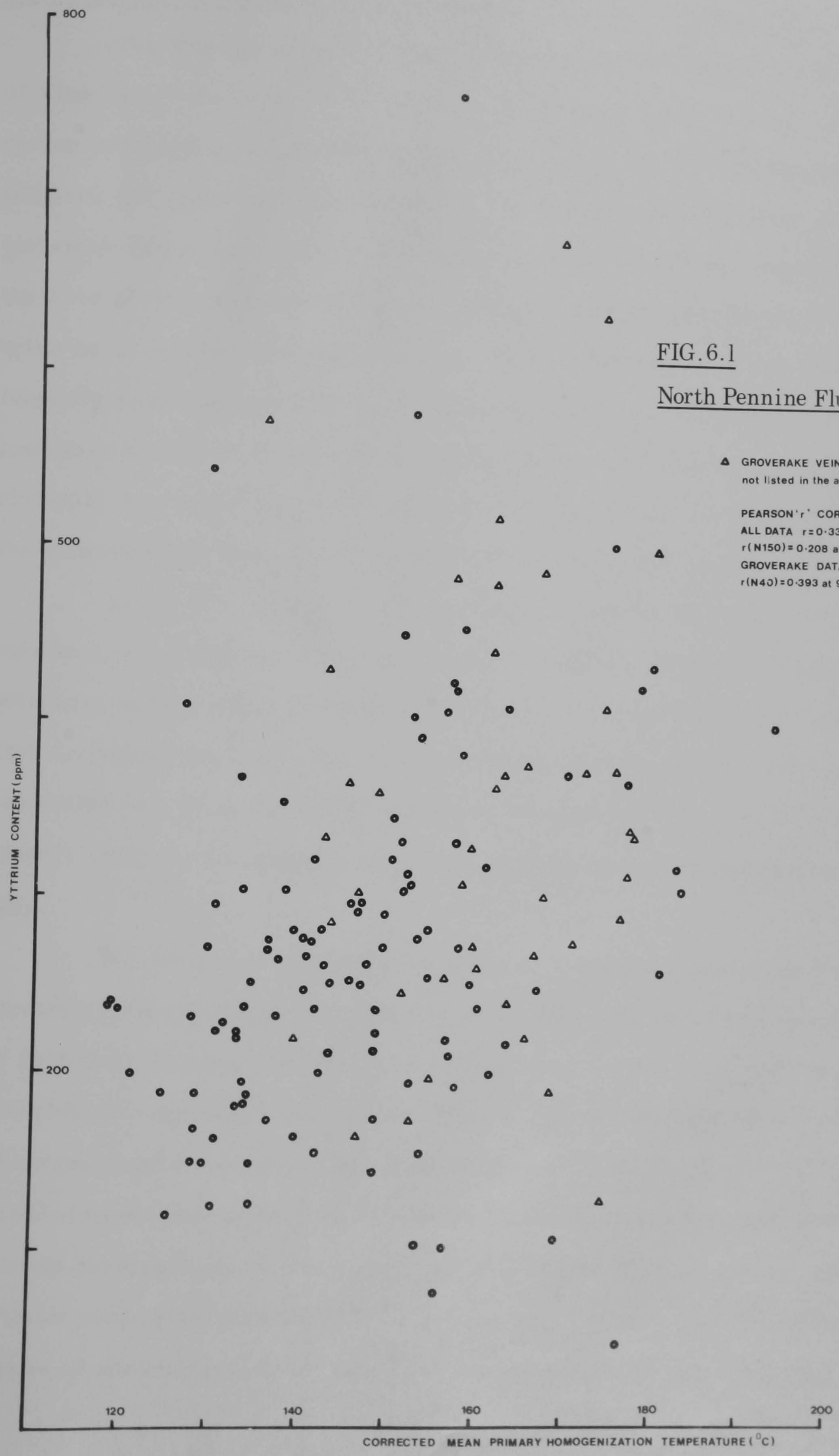


FIG. 6.1

North Pennine Fluorite

6.3 Relation of Trace Element Content of Fluorite to Brine Flow Direction

The yttrium content of fluorite decreases markedly in the direction of flow away from feeder intersection in orebodies (Smith F.W., 1974). Cerium and lanthanum show the same behaviour. Difficulty in obtaining analyses for these two elements however prevented detailed study of their variation (Appendix 3.4). The variation phenomenon appears dependent upon the rate of change of one or several physicochemical parameters of the brine as it entered orebody cavities. It is independent of the absolute temperature and pressure of ore deposition (Figs 6.1, 8.8) and of the cooling gradients measured from fluid inclusions in the host fluorite. Thus virtually the same range of Y values are obtained from orebodies throughout the stratigraphic succession, anywhere in the fluorite zone.

Heavy rare earths generally form more stable complexes than light rare earths and are known to stay longer in certain postmagmatic hydrothermal solutions before being precipitated. There is little evidence at present of such fractionation occurring in the North Pennine solutions. Instead, the concentrations of Y, La and Ce appear to be most probably related to the overall rare earth content, though analysis for Dy is recommended to check this.

The variation of yttrium appears to provide an excellent aid to exploration and development. Vein intersections can be located by three - or four-fold increases in the level of the metal in fluorite over an easily detectable background level in the order of 150 to 200 ppm. (Fig 6.2). A 15 metres sample separation has been found satisfactory to delimit all knownintersections in test sectionsand has successfully detected previously unknown intersectionsin other sections (Smith,op. cit.) . The size of the yttrium anomaly unfortunately does not necessarily give any indication of the degree of mineralization of the intersecting structure but is apparently

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FIG.6-2

related to the importance of the intersection as a feeder (i.e. feeder flow rate). The processes of rare earth transport in hydrothermal brines and deposition, with fluorite, in these concentration gradients are discussed in Sect. 6.5

Variation of the extent of copper contamination gives a rough estimate of the amount and presence of copper in early phase mineralogy and high values often occur at feeder intersections (Sect. 4.3.1). Nickel, detected in the general range 0 to 11 ppm, probably occurs in chalcopyritic and pyritic impurities, and to an extent varies sympathetically with copper. Higher values of nickel, up to 44 ppm, were found in fluorites from the Derbyshire orefield, where bravoite (nickel iron sulphide) occurs commonly as solid inclusions in fluorite. Samples numbered 1 to 439 were analysed for these two metals and for zinc, in order to establish the extent of contamination. This was found to be unimportant.

Barium, strontium and the Ba:Sr ratio show no regular variation. Magnesium values have not been studied in detail.

6.4 Sampling and Analysis

Methods of sample preparation and X.R.F. analysis are described in Appendix 3.

Samples collected for analysis were taken either from within 300mm of the edge of the fluorite- bearing orebody, or from the very middle of the vein. The former were located by reference to wall-rocks and early phase deposits, and the latter using crustiform banding. The assumption has been made that the earliest 300mm of fluorite coating the walls of wide (>1m) orebody cavities are roughly contemporaneous along the length of the cavity. (This is supported by the fact that mineral bands can be seen to have grown from the walls inwards towards the centre of an originally open cavity). Hence any variation in the trace element content of this fluorite reflects

some variation acting on or in the parent brine as it moved along the cavity. Mid-vein samples, though less likely to be contemporaneous in a vein of variable width, show similar trends to those of the vein edge (Fig. 6.2).

Yttrium variation in a transverse sense, i.e. with time, is irregular and so direct comparison of edge and mid-vein samples is not possible. Triplicate samples taken to test variation within a 300mm block of ore yield ranges of yttrium results that are generally within 1% of the mean value, with a maximum range of 7%.

When sampling from opencut and shaft dumps, the original situation of the mineral cannot, of course, be determined. In such cases, large parcels of small fluorite fragments were collected and crushed together to make 'bulk' samples. Specimens from severely brecciated or narrow veins were also sampled in this manner. The trace element variation along veins thus sampled seems roughly comparable with that in more accurately sampled veins, though the background values are more erratic and they are thus less satisfactory.

Contamination of samples with quartz (as chalcedonic veinlets and crystal coatings or as solid inclusions) was found to be unavoidable in most situations. However, since analysis of quartz specimens shows the absence of Y, Ce, La, Ba and Sr, a procedure was adopted whereby all fluorites were analysed (by X.R.F.) for SiO_2 and trace element values were normalized to account for this dilution.

The gradual way in which sampling progressed over nearly three years did not easily fit into the analytical routine of most X.R.F. users in the Durham department. Hence, at the time of writing a number of specimens have not been completely analysed. This deficiency, solely with respect to inessential elements such as Ba, Sr, Cu, Ni and Zn is regretable but nonetheless unimportant. The analyses are presented in Appendix 3 with

coded specimen localities. Accurate locations for those samples mentioned in the text may be found from the appropriate text figures in Section 2.

6.5 Transport and Deposition of Rare Earth Bearing Fluorite

The discussion in Sect. 4. showed that fluorite is very poorly soluble and that 5×10^{12} tons of brine would have been required to transport and deposit the estimated total quantity of calcium fluoride in the orefield. It is believed that the increased solubility of fluorite in sodium chloride brine, over that in water, is due to increased ionization of the fluorite caused by the presence of the other electrolyte (Holland, 1967). If fluorite is transported thus in simple ionic solution, then addition of calcium into solution (by reaction with calcareous wall-rocks for example) would have a large effect on the solubility of fluorite (the common ion effect) tending to decrease the latter. Since it has not been observed that fluorite is any more plentiful in orebodies with calcareous wall-rocks than in those with argillaceous or siliceous wall-rocks, it is worthwhile exploring other means of transport. (At this point it should said that although Strübel, 1965, found the solubility of fluorite to be greater in brine than in water, he did not attempt to identify the species in solution). The large number of highly soluble complex ions formed by fluorine with cations commonly occurring in hydrothermal minerals suggests that this may have been one additional means of transport. The alkali earth metals (Be excepted) form very few soluble complexes and so calcium must have travelled as a simple cation.

The fluorides of yttrium and the rare earths are also highly insoluble. The majority of hydrothermal deposits of these metals are related to alkalic rocks. Mineralogic considerations suggest the necessity for parent solutions

carrying HCO_3, CO_3, F, HSO_4 and SO_4 ions. It is known that the metals can form stable, soluble complexes with the CO_3, F and SO_4 anions (Kosterin, 1959). The fluoride ion is an extremely effective precipitant of rare earths from all their complexes other than fluorides (Bandurkin, 1961). For this reason, coupled with the fact that the North Pennine brines carried an estimated total of 10×10^6 tons of fluorine, it is probable that the rare earths were transported in fluoride complexes. This is supported by the facts that, firstly, the rare earths occur only in association with, and in solid solution within, fluorite and secondly that experiments have shown that YF_3 and ScF_3 (normally insoluble) become readily soluble in fluoride solutions (with the formation of compounds of the $K_3(YF_6)$ type), but <u>not</u> in chloride solutions (Scherbina, 1963).

Bandurkin (op. cit.) has shown that in a situation comparable with that existing in the North Pennine system, where high valence cations are present in large amounts and rare earths in small amounts. (i.e. $[Me] > [F] \gg [R.E.]$) and also where $[F] > [R.E.F_4]^-$ then the formation of polynuclear and mixed complexes may occur:

Cation complexes -

$$Me\ F^{2+} \qquad (1$$

$$Me_2F^{5+} \qquad (2$$

Anion complexes -

$$R.E.F_4^- \qquad (3$$

Mixed complexes -

$$MeF\ (R.E.F_4)_2 \qquad (4$$

$$Me_2F\ (R.E.F_4)_5 \qquad (5$$

The stability data published by Bandurkin and Scherbina indicate that of the metals present, or probably present, in the North Pennine solutions, the following are capable of forming stable fluoride complexes of the above type:-

Fe, Mn, Al, Zr, (Si?)

Very limited stability data are available on the actual complexes formed by these metals. However, Bandurkin, quoting Soviet Russian literature, makes the point that under conditions of neutralization with increasing alkalinity the mixed fluorides (4 and 5 above), stable only in slightly acid solution, will dissociate. This conclusion was based upon experiments by Alimarin showing that the stability of the mixed complex compound as a whole is directly related to that of the high valence element/fluoride cation complex. Dissociation of the complexes would release rare earths to be captured diadochically by fluorite during precipitation. Experiments have also shown that addition of Ca^{++} to solutions carrying AlF^{++} or AlF_2^{+} causes no precipitation of fluorite. (Ganeev, 1961). Thus fluoride and calcium may travel together in the same solution without being affected by common ion effect precipitation.

The possibility and mechanisms of neutralization of a slightly acidic brine during its ascent in a hydrothermal system were discussed in Chapter 4. The conclusion was drawn that although pH increase probably did occur, it was difficult to see how this could have been of sufficient magnitude to cause significant ore deposition. It may, however, have been sufficient to control degradation of pH sensitive, mixed Me-fluoride-rare earth complexes . Thus the high concentrations of rare earths in fluorite around feeder points to orebodies may have been caused, in part, by pH increase made possible by the decrease in brine velocity enabling increased opportunity for reaction.

There are two observations that support this particular mechanism. Firstly, this precipitation process must have been far more effective during the formation of flat deposits. The high surface area afforded by carbonate grains to the percolating brines could have produced more reaction, greater pH change and thus a greater degree of rare earth prec ipitation. Rare

earth concentration gradients should thus be found in flats, showing decrease in traverses away from feeder veins, as in veins away from orebody feeders. A small replacement flat exposed in a crosscut from Red Vein at the 50 Fms. level, in Groverake Mine, was sampled. The flat occurs about 3 to 4m south of the vein, in the Great Limestone. Yttrium concentrations in fluorite from the centre (spec. no. 19) and south edge (no. 18) of the vein and from the flat (no. 21) are 266, 227 and 505 ppm respectively. Thus fluorite from the flat, close to the feeder vein, is enriched in yttrium over the vein fluorite. Fluorite veins cut by the Rookhope Borehole carry normal concentrations of yttrium for the orefield. Fluorites from the three major flats, in the Borehole, have anomalously low yttrium contents (74, 99 and 44 ppm). The Borehole is thought to have penetrated these flats at considerable (>10m) distances from the feeder veins. Thus these very low yttrium fluorites were deposited from brines effectively gleaned of rare earths by initial, high pH change, precipitation processes operating at the flat margins.

The second supporting observation of possible pH influence upon rare earth contents is found in the rather higher rare earth content of fluorite from limestone wall-rock orebodies over that from sandstone-walled orebodies. The mean Y content of 125 vein fluorites from limestone host rocks is 300 ppm (std. devn. 112) and of 25 fluorites from sandstone host rocks, 238 ppm (std. devn. 76). There is a 99% probability that this is a significant difference. This second observation, however, also shows quite clearly that although it is possible that a pH dependent reaction is responsible for the greater concentration of yttrium in veins with limestone wall-rocks, there is still a lot of yttrium in fluorite from sandstone host rocks. Moreover, the concentrations in these fluorites from sandstone horizons show the same marked gradients away from feeder intersections. Therefore another precipitation mechanism must have also been involved.

It seems most probable that this is associated with the physical changes attendant on brine entry to orebodies from constricted feeders. These, as stated previously, are decrease in temperature, pressure and velocity. The stability and solubility of fluoride complexes are temperature dependent. Moreover, Helgeson (1964, p. 99) states that "irreversible adiabatic expansion of a hydrothermal solution would be expected to result in differentially increased stabilities of complexes in solution", and also that " a large increase in the stability of one complex relative to a small increase in the stability of another is equivalent to a decrease in the stability of the latter as far as solution equilibria are concerned". Thus we have further possible controls of rare earth concentration gradients. Complex stability may be temperature and pressure sensitive and may also be affected by changes in stabilities of other complexes in solution that alter solution equilibria.

In conclusion, it appears that the formation of rare earth concentration gradients, in fluorite, around feeder intersections in orebodies is probably controlled by several processes, each acting simultaneously towards a common end, to decrease the stability of soluble rare earth-bearing fluoride complexes as the hydrothermal brine entered the orebody cavities, slowed, decompressed, cooled, reacted with available, exposed wall-rocks and underwent slight changes in internal chemical equilibria.

6.6 Thermoluminescence (TL) and Electron Spin Resonance (ESR) Studies on fluorite.

All crystalline solids are defective in some respect if described on a sufficiently small scale. Substitution defects are among the most important in fluorite, other types being caused by dislocations, vacant site generation and electron/hole trapping. Rare earth substitution may produce two defect types : simple defects caused by balanced substitution of $RE^{3+} + X^{+}$ for

2 Ca^{2+}; and interstitial anion structures caused by substitution of RE^{3+} for Ca^{2+} with an additional fluorine ion pushed into the lattice.

Since the concentrations and perhaps relative amounts of rare earths in fluorite vary along an orebody it seems probable that the type or magnitude of lattice defects should also show some variation. Other defects, unrelated to rare earth substitution may have also been influenced by the changing physicochemical conditions of fluorite growth.

TL and ESR methods detect defects and afford estimates of type and magnitude. TL is a relatively simple technique and does not require expensive apparatus. ESR on the other hand requires extremely sophisticated instrumentation and highly skilled operators.

6.6.1 Thermoluminescence

TL has several well-known applications in geology. It is commonly used as a tool for dating rocks, minerals, metamorphic and impact events. Recently the method has been applied to derive formation temperatures of fluorite (McDougall, 1970) and in the past has been used to map thermal aureoles around ore deposits.

It was originally intended to apply the technique to fluorites taken in a traverse along the Redburn orebodies, where feeders had already been detected. However, the degree of shattering of these specimens precluded their use. Mechanical stress can drain defect traps, resulting in triboluminescence, and create others. A suite of samples was collected, instead, from Blackdene Mine, a metallurgical grade fluorspar mine in which explosive shattering of the ore is less marked. This choice proved unfortunate in the long run since, though three veins are apparently represented, no feeder occurs in the traverse.

A typical glow curve is shown in Fig. 6.3. The temperature of each peak is a function of the defect trap energy or 'depth', E;

$$E\ (eV) = T\ (^{o}K)/450$$

FIG.6.3 TL Glow Curve of Fluorite No.144, Redburn Mine

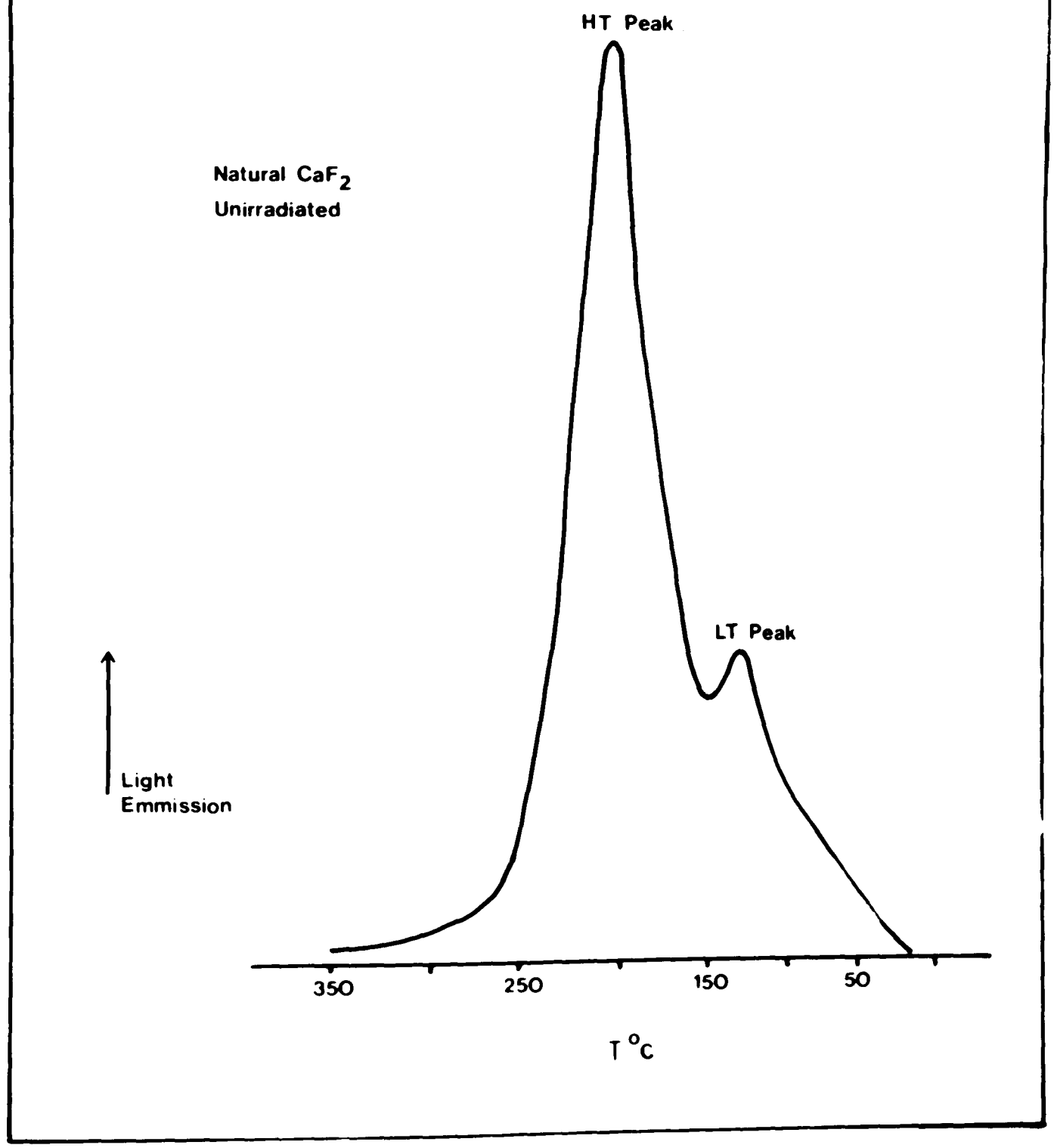


TABLE 6.2

Glow Curve Parameters, Natural Fluorites from the North Pennines (arranged in order of decreasing yttrium content).

Yppm	Spec. No.	L.P.°C	L.P.eV.	H.P.°C	H.P.eV.	P,H/L°C	P,H/L mag.
296	144	129.0	0.895	212	1.079	1.72	3.07
275	602	147.6	0.936	226	1.110	1.53	7.9
253	603	143.0	0.925	215	1.085	1.50	8.1
247	599	143.0	0.925	210	1.072	1.47	7.7
227	600	148.5	0.939	231.5	1.119	1.55	12.2
199	611	159.5	0.960	189	1.025	1.18	11.4
124	604	155.5	0.952	-	-	-	-
104	601	150.4	0.940	202.5	1.055	1.35	9.1

L.P.°C	Low temperature peak position
H.P.°C	High temperature peak position
L.P.eV.	Low temperature peak, defect trap energy
H.P.eV.	High " " " " "
P,H/L°C.	Ratio high to low temp, peak position.
P,H/L mag	Relative peak heights.

and the peak height is proportional to both the degree of trap filling and the area of specimen surface exposed to the photomultiplier. (R.P. Hunt, pers. comm. 1973)

The results of eight determination made using apparatus in the Dept. of Physics, Durham are given in Table 6.2. The determination on specimen no. 604 is incomplete due to thermocouple failure and the low temperature peak data may also be inaccurate. There is some evidence of correlation between defect trap energy and yttrium content. The product moment correlation coefficient, r, between Y ppm and low temperature peak trap energy is 0.567 (critical r, 5% level, 0.497) and between Y ppm and high temp. peak energy is 0.812 (critical r, 1% level, 0.661). Peak energies vary independently of each other (r = 0.339, crit. r 5% = 0.532). Though the data are insufficient to draw any definite conclusions it appears that thermoluminescence may give an indication of the rare earth content of fluorite and is certainly worth further study.

Three important points regarding the collection of specimens and the glow curve determinations may be noted:

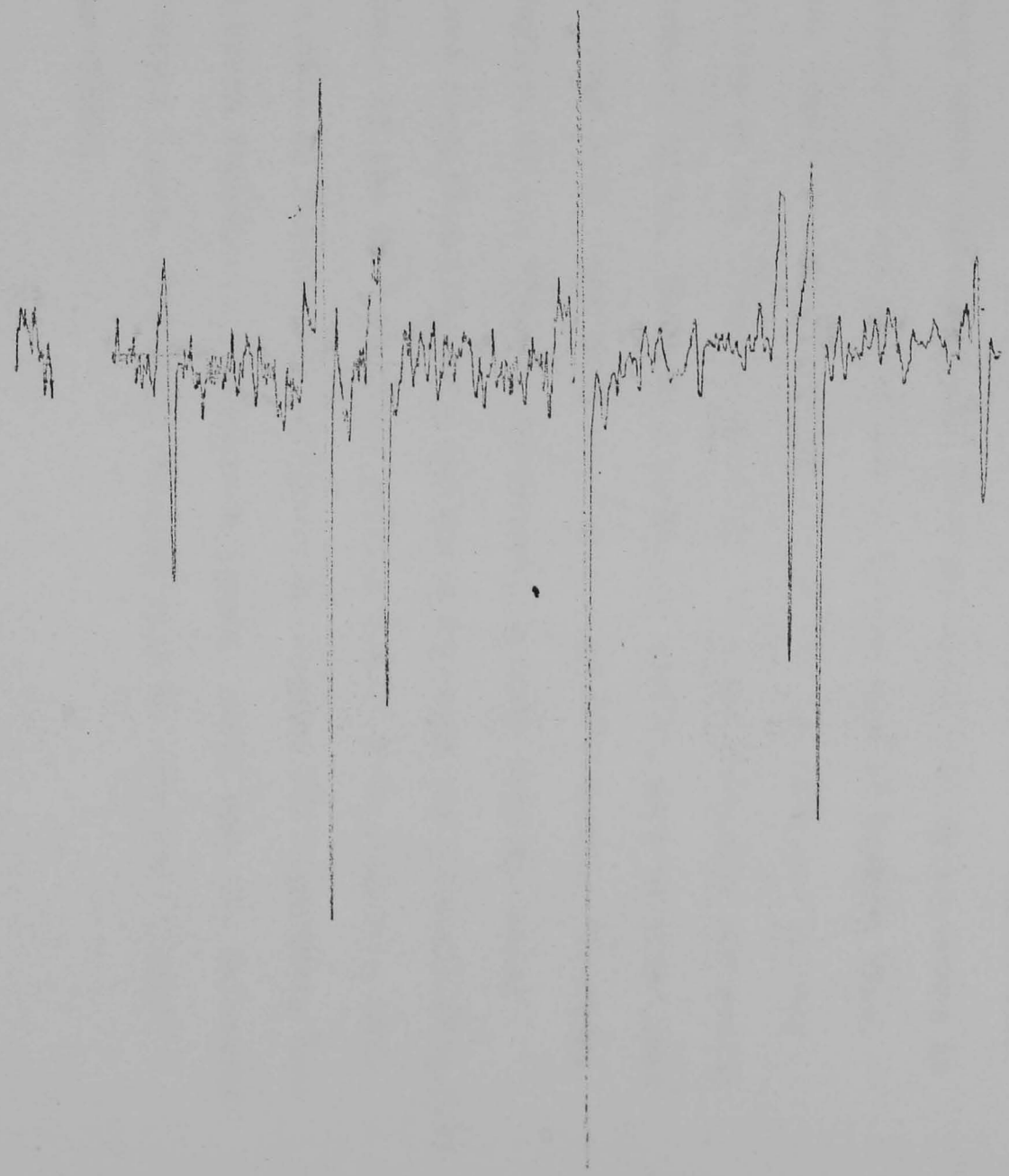
1) Intensely shocked or shattered specimens must be avoided. i.e. specimens should not be taken near post-ore faulting or in areas where heavy explosive shattering is employed in mining.

2) Samples should be kept in the dark and at relatively low temperature before analysis. This will prevent bleaching of low temperature traps. Samples must be collected from underground.

3) Specimens used in each run should be of uniform size, or else an asbestos (matt-surface) cut-out mask used to ensure a uniform surface area exposed to the photomultiplier. Peak heights may then be directly compared.

6.6.2 Electron spin resonance

FIG.6-4 ESR SPECTRUM, FLUORITE 124



Dr. R.P. Hunt of the Department of Physics, University of Durham obtained 89 ESR spectra from 21 fluorite specimens of mixed provenance. The aims of this study were two-fold. Firstly it was felt that some change in spectral parameters should be found to correlate with variation in rare earth content of the fluorite along orebody traverses in the North Pennines. This was proved not to be the case at Redburn Mine. Secondly, it was hoped to obtain information on the location and valency state of impurities in the fluorite lattice. This was partially successful (Hunt and coworkers, 1973). However a number of spectra were obtained that could not be matched with those from synthetic, 'doped', calcium fluoride. Drs Hunt and Taylor, of the Physics Department, believe that the chief spectrum obtained from fluorites from the North Pennines and Cornwall (Fig.6.4) shows the presence of the YH^{2+} ion (see Section 6.6). Fluorites from both these areas are rich in rare earths and yttrium (Chapter 7). Specimens from Derbyshire and South Yorkshire, low in rare earths, yield very low intensity spectra of different types, generally resolved only at very low (liquid nitrogen) temperatures.

6.7 Trace Element Variation in Vein Minerals other than Fluorite

6.7.1 Barite

Several barite specimens were analysed by X.R.F. for the same trace elements as fluorite. Only strontium and the ore metal contaminants were found. Sr seems fairly variable in concentration throughout a number of widely spaced (and genetically separate) localities in North-East England (Table 6.3). It is possible that it may prove of value to exploration. Results obtained by Dr. A.C. Dunham and coworkers (verbal comm., Leicester, 1973) appear to show a regular variation of Ba: Sr in barite from Derbyshire which they relate to the formation temperature (the strontium content decreases with increasing temperature). This should be treated with caution however

TABLE 6.3. STRONTIUM IN BARITE

Spec. No.	Locality	Sr % (weight)
223	Closehouse Mine	0.42
224	Silverband Mine	0.31
221	New Brancepeth Mine	0.12
222	"	0.21
212	Middleton Tyas (Black Scar)	0.40
220	Chilton Quarry, Ferryhill	0.37
211	Secondary bar., Settling stones Mine	0.05
*	Hartside Mine	0.57
*	New Brancepeth Mine	0.23
*	Silverband Mine	0.30
*	Kiersleywell Row Mine	1.72
*	Greenleycleugh Mine	1.01

All specimens except 212 and 220 are from the North Pennines orefield. Numbers 211 to 224 were analysed during this study, by X R.F., those marked * are quoted by Dunham and Dines, 1945.

since low temperature secondary barite (formed by ground water sulphatization of primary witherite) may have a very low Sr content (see spec.211, Table 6.3).

Scott (1967) was unsuccessful in his search for systematic trace element variation in barite from vertical and longitudinal vein traverses at Gasswater Mine, Ayrshire.

6.7.2 Sulphides

Bishara (1967) studied the trace element content of sphalerite and galena collected (largely from dumps) from the orefield. The trace elements are listed in Table 4.1. Multivariate analysis of his data suggested that three factors were responsible for 50.7% of the variation of the 16 trace elements in sphalerite. The first and third most important factors were functions of the original composition of the ore brine and the variation of trace element activity in solution, respectively.

The second factor, accounting for 18.8 % of variation shows strong negative correlation with Fe and Ge, and strong positive correlation with Hg, Cd and the crude measurement 'miles! 'Miles' represents the distance separating sample location from the nearest Zone I 'hot-spot' described by Dunham (1934). Bishara suggested that this factor reflects decrease in temperature of ore formation away from regional 'hot-spot' feeders. The same factor accounted for 9.5% of variation of trace elements in galena (and was third in importance).

Thus there is some indication that brine flow directions could be detected using trace element variation in sphalerite. However, the difficulty in obtaining a suite of contemporaneous specimens, the difficulty in sample purification and the problems of trace element partition between coexisting sulphides, render this prospect impractical.

CHAPTER SEVEN

REGIONAL VARIATIONS IN FLUID INCLUSION AND TRACE ELEMENT DATA FROM FLUORITE

7.1 Introduction

Fluorite occurs as a primary mineral throughout an immense range of geological environments, being found as an accessory mineral in some igneous rock, as a common hydrothermal mineral formed at temperatures ranging from 500°C to less than 50°C (Tugarinov and Naumov, 1972), and as an uncommon constituent of evaporite sequences. Economically valuable concentrations, however, occur almost solely in hydrothermal deposits.

In the United Kingdom, fluorite is a relatively common mineral in post-Carboniferous ore deposits and silicic igneous rocks. It is thus related to the Hercynian metallotect of northern Europe (Gabelman and Krusiewski, 1972) The major Caledonian orefields of Central and North Wales Leadhills/Wanlockhead, The Isle of Man, the Lake District and Combe Martin have provided very few records of fluorite occurrence. The paucity of fluorite in aplites, pegmatites and granites of Caledonian age contrasts with the abundance of the mineral in the late stages of the Hercynian granites of Devon and Cornwall, and relatively common occurrence in Tertiary silicic intrusions (eg. Lundy and Skye). To an extent this implies a time-dependent, sub-crustal control to fluorite mineralization, as postulated by various authors for the fluorite provinces in Eastern Mongolia, Mexico and Thailand. This control is clearly localized and probably sharply defined since, although minor veins occur in the Carboniferous Limestone at Lisdoonvarna, Co. Clare, and Ballymote, Co. Sligo, the extensive Irish Hercynian base metal deposits carry no fluorite. The locations of fluorite orefields and occurrences in the United Kingdom are shown on Fig. 7.1.

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FIG. 7-1

Fig. 7.1. The Occurrence of Fluorite in Britain

Key :-

1 North Pennine orefield;

2 Scordale;

3 Hartley;

4 Clouds;

5 Northern Swaledale;

6 Lover Gill - Stag Fell;

7 Askrigg - Wet Grooves;

8 Keld Heads;

9 Grassington;

10 Nidderdale;

11 Greenhow Hill;

12 Skeleron and Clitheroe Mines;

13 Ferryhill;

14 Boreholes in Permian, S.E. Durham;

15 Boreholes in Triassic evaporites;

16 Shap Granite;

17 Brandlehow;

18 Force Crag;

19 West Cumberland orefield;

20 Furness orefield;

21 Derbyshire orefield;

22 Ecton Dome;

23 Ashover Dome;

24 Crich Dome;

25 North Wales orefield;

26 Tockington;

27 Blaize Castle;

28 Avon Gorge;

29 Central Mendip orefield;

30 Beacon Hill Pericline;

31 Teign Valley;

32 Tamar Valley - Menheniot;

33 St. Agnes;

34 Camborne - Redruth - St. Day;

35 St. Just;

B Ballater; E Elgin; G Grudie Granite; M Maisley Quarries;

N Na Tri Chaochain; O Ousedale, Ord; S Strath, Skye;

W Wanlockhead.

7.2 Fluid Inclusion Data

The only significant fluorspar production in the United Kingdom has come from four orefields. Three of these, The North Pennine, Central Pennine and Derbyshire orefields, occur within the Pennines, a N.-S. trending range of gentle anticlines and anticlinoria exposing Carboniferous rocks that carry lead-zinc-fluorine-barium ores in the lower, limestone - rich beds. The fourth region of fluorite mineralization is in Devon and Cornwall, where the ores are genetically related to the Cornubian Granites and occur in the Granites, in Lower Palaeozoic slates and in Carboniferous pelites. Fluid inclusions in various minerals from these and other occurrences have been examined, the data are given in Table 7.1. This table also summarizes data from other published sources.

These data show that fluorite and accompanying minerals that are clearly related to igneous activity, such as those from Shap and those from Devon and Cornwall, formed from brines that were at times highly saline (up to 50 equiv. wt. % NaCl). The formation temperature range is wide (440° to 115°C, fluorite, uncorrected) as a result of brine cooling during migration from the hot source intrusions. With the exception of the North Pennines, fluorite deposits of telethermal type, with no obvious igneous source for the ore fluids, formed from brines of moderate to high salinity (10.8 to 26.6 equiv. wt. % NaCl) over a narrower range of lower temperatures (145 to 70°C, uncorrected). They are in many ways typical of the Mississippi Valley Type of deposit (Roedder, 1967; Smith, 1973; Hirst and Smith, 1974; Smith and Hirst, 1974). Fluorite from the North Pennine orefield formed from brines of moderately high salinity (20.7 to 25.6 equiv. wt. % NaCl) over an intermediate temperature range of 195° to 115°C (corrected)

Table 7.1 Regional Summary of Primary Fluid Inclusion Data

Ore Locality:	Mineral	Range Temp.	N	Range eq. sal.	N	Range Na/K	N	Source
Cornubian orefield	Qtz.(w.Sn)	653*	1	-	-	-	-	1
	Qtz.	440 to 176	15	4.2.to 50	8	2.8 to 17.9	8	2
	Fluor.	270 to 115	4	13	1	6.7 to 9.5	4	2
	Sphal	170 to 150	1	-	-	-	-	2
	Cassit.	380 to 275	?	-	-	-	-	3
	Qtz.	380 to 165	?	-	-	-	-	3
	Sphal.	240 to 180	?	-	-	-	-	3
	Fluor.	280 to 255	?	-	-	-	-	3
	Fluor.	350 to 117	6	-	-	-	-	4
	Qtz.	348 to 224	2	-	-	-	-	5
	Fluor.	300 to 220	4	-	-	-	-	5
Shap Granite	Fluor. vūg	>440	1	-	-	-	-	5
	Fluor. vein	108	1	-	-	-	-	5
	Calc. vein	73	1	20.2 to 23.5	1	-	-	5
Lake District	Qtz.	122	1	-	-	-	-	5
	Fluor.	130	1	26.3	1	-	-	5
North Pennine orefield	Qtz.	216 to 143*	12	22.5	1	8.0 to 12.4	3	6
	Fluor.	190 to 115*	44	20.7 to 23	5	6.8 to 9.0	3	6
	Calc	84 to 78*	1	-	-	-	-	6
	Qtz.	211 to 139*	3	-	-	-	-	5
	Fluor.	195 to 119*	244	20.2 to 25.6	20	4.7 to 13.1	9	5
Central Pennine orefields	Fluor.	102 to 91	9	19.9 to 26.6	6	-	-	5
	Fluor.	77 to 73	2	-	-	-	-	4
Derbyshire orefield	Fluor.	140 to 70	2	17.5 to 30	2	-	-	7
	Fluor.	127 to 70	3	-	-	-	-	5
Ribblesdale Fold Belt	Fluor.	143	1	-	-	-	-	5
North Wales	Fluor.	114 to 97	6	24.0 to 24.8	3	7.5 to 21.8	3	8
Mendip orefield	Fluor.	85	1	-	-	-	-	5
Shropshire orefield	Qtz.	124	1	-	-	-	-	5
	Bar.	91	1	-	-	-	-	5
S.E. Durham Mag. Lstn.	Fluor.	108 to 104	3	22.4	1	-	-	9
	Bar.	<70	3	21.0	1	-	-	9
West Cumberland orefield	Fluor.	123	1	-	-	-	-	5
Irish Carbonif. Lstn.	Fluor.	137	1	-	-	-	-	5
Belgian Ardennes	Fluor.	149 to <70	4	10.8 to 18.2	3	2.0 to 5.5	2	9

Temp range - Range of mean homogenization temperatures ^{o}C

* - Range of mean corrected temperatures.

Range eq. sal. - Range of mean salinity determination, equivalent wt. % NaCl.

Range Na/k - Range of sodium/Potassium ratios (weight) in leachates.

N - Number of specimens

Sources:-

1 Coveney and Kelly, 1970, Michigan Academician, 3 , 45 - 56

2 Sawkins, 1966, Trans. Inst. Min. Metall. Lond., 75, B109-112

3 Bradshaw and Stoyel, 1968, Trans. Inst. Min Metall. Lond., 77, B144-152

4 Harker, R. Unpublished PhD thesis, Leicester, 1971

5 Smith, ab intra

6 Sawkins, 1966, Econ. Geol., 61, 385-401

7 Roedder in Ford, 1969, Proc. 15th. Interuniversity Geol. Cong., Leicester, 73 - 96.

8 Smith, 1973, Trans. Inst Min. Metall. Lond., 82, B174-176

9 Hirst and Smith, 1974, Trans. Inst. Min. Metall. Lond., in press

10 Smith and Hirst, 1974, Ann. Geol. Soc. Belg., in press

Note - Quartz and fluorite from the Cornubian orefield occur in a number of paragenetic associations. These, where given in the original reference, have not been reproduced here.

7.3 Regional Yttrium Surveys

7.3.1 Central Pennine orefields

The Askrigg Block exposes a region of Carboniferous sediments underlain by isostatically buoyant basement material, including the buried,older, Wensleydale Granite which was predicted from geophysical data by Bott (1967) and cored by a recent deep borehole. The Block is bounded by major hinge fault systems that are partly adjacent or continuous with those bounding the Alston Block to the north (Chapter 2). Limestones make up a greater proportion of the Lower Carboniferous cyclothems than on the Alston Block.

Mineralization is generally scattered and small-scale but with a number of strongly mineralized areas that may contain fluorite as well as the usual calcite-barite-galena-sphalerite assemblage. Their distribution is indicated on Fig. 7.2, taken from Dunham (1952, Plate III). The ores occur as alternating, monomineralic, crustiform infillings of fissure veins and solution cavities.

The yttrium content of fluorite of various generations within Gillheads Vein at Appletreewick, near Pateley Bridge, Yorkshire, does not vary greatly (Table 7.2). According to P. Rogers (pers. comm. 1974) primary fluid inclusion homogenization temperatures also remain fairly constant. Five fluorites from two stockworks, one vein and one replacement deposit at Nateby and Hartley Birkett, near Kirkby Stephen, Westmoreland lying by the Dent Fault Line (a block margin structure) also show little variation of Y contents (20 to 27 ppm.)

The Northern Swaledale centre (Fig. 7.3), containing the Lownathwaite Old Gang - Hungry Hushes vein complexes, has been studied in detail. Fluorite samples taken from shallow shaft tips and opencuts were probably derived from within 50 m of vein strike and dip from the collection sites. Large dumps from the main, ramifying workings were ignored. The Y contents

Table 7.2 Analyses of Fluorite Samples from Gillhead Vein, Appletreewick, Yorks.

		Yppm	Ceppm	Lappm
514	Vein margin	19	9	0
511	Vein margin, vug.	15	4	0
509	Main vein in-filling	23	9	0
508	With galena, near vein centre	25	24	0
507	Vein centre	21	0	0
226	Vug lining, main vein	20	20	0
515	Vug in cross-cutting vein	21	4	0

Fig. 7.2 Distribution of fluorite in the Central Pennine orefields of the Askrigg Block. Plate III of Dunham (1952).

Fig. 7.3 Veins, specimen locations and yttrium contents (ppm) of fluorites in the Swaledale centre of mineralization, Yorkshire (about 5km west of Reeth in Fig. 7.2). This is the northernmost major mining area of the Askrigg Block, contains the well-known districts of Lownathwaite, Old Gang and Hungry Hushes, and is related to the E. - W. trending Stockdale Monocline. The outer margin of the fluorite zone is marked by the broken line.

Fig. 7.4 Map of the mineral veins and hydrothermal zones of Derbyshire. Fig. 4 of Ford and Ineson (1971).

Fig. 7.5 Veins, specimen locations and yttrium contents (ppm) of fluorites in the Ashover mining district of Derbyshire. This district (about 10 km S.S.W. of Chesterfield) is set on a dome in which limestones and volcanic rocks are overlain by thick shales. Erosion has exposed the core of the dome showing it to be intensely mineralized. The bulk of the mineralized area falls within Fig. 7.5, redrawn from Ford and Ineson (1971). Stratigraphical boundaries are shown by broken lines. Samples were collected from shallow bell-pits and opencuts.

Fig. 7.6 Veins, specimen locations and yttrium contents (ppm) of fluorites in the Crich mining district of Derbyshire (16 km S.S.W. of Chesterfield). Veins are exposed in the limestone core of the Crich Dome, flanked by thick shales. Key and attribution as for Fig. 7.5.

FIG 7.2

THE CENTRAL PENNINE OREFIELDS

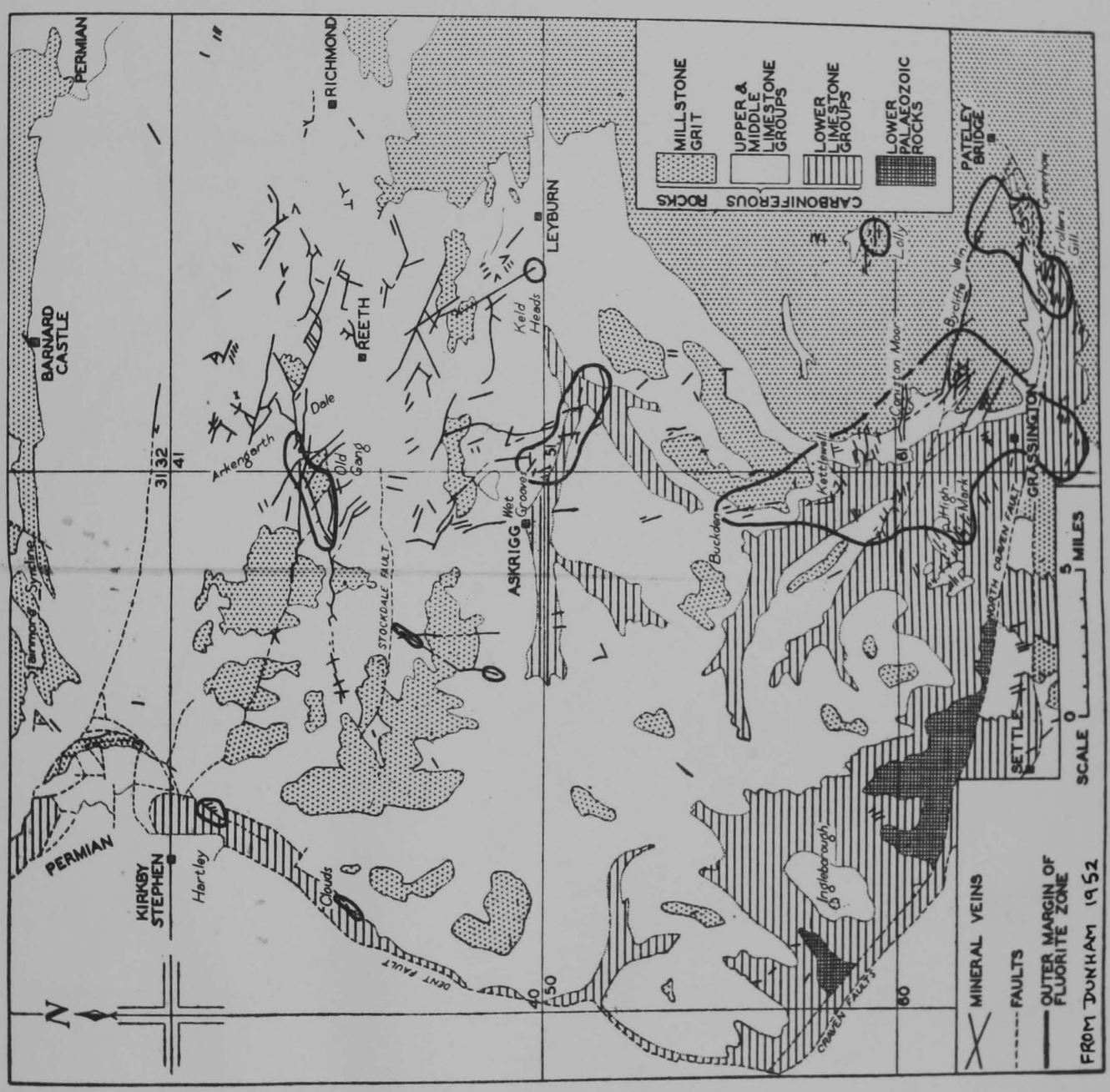
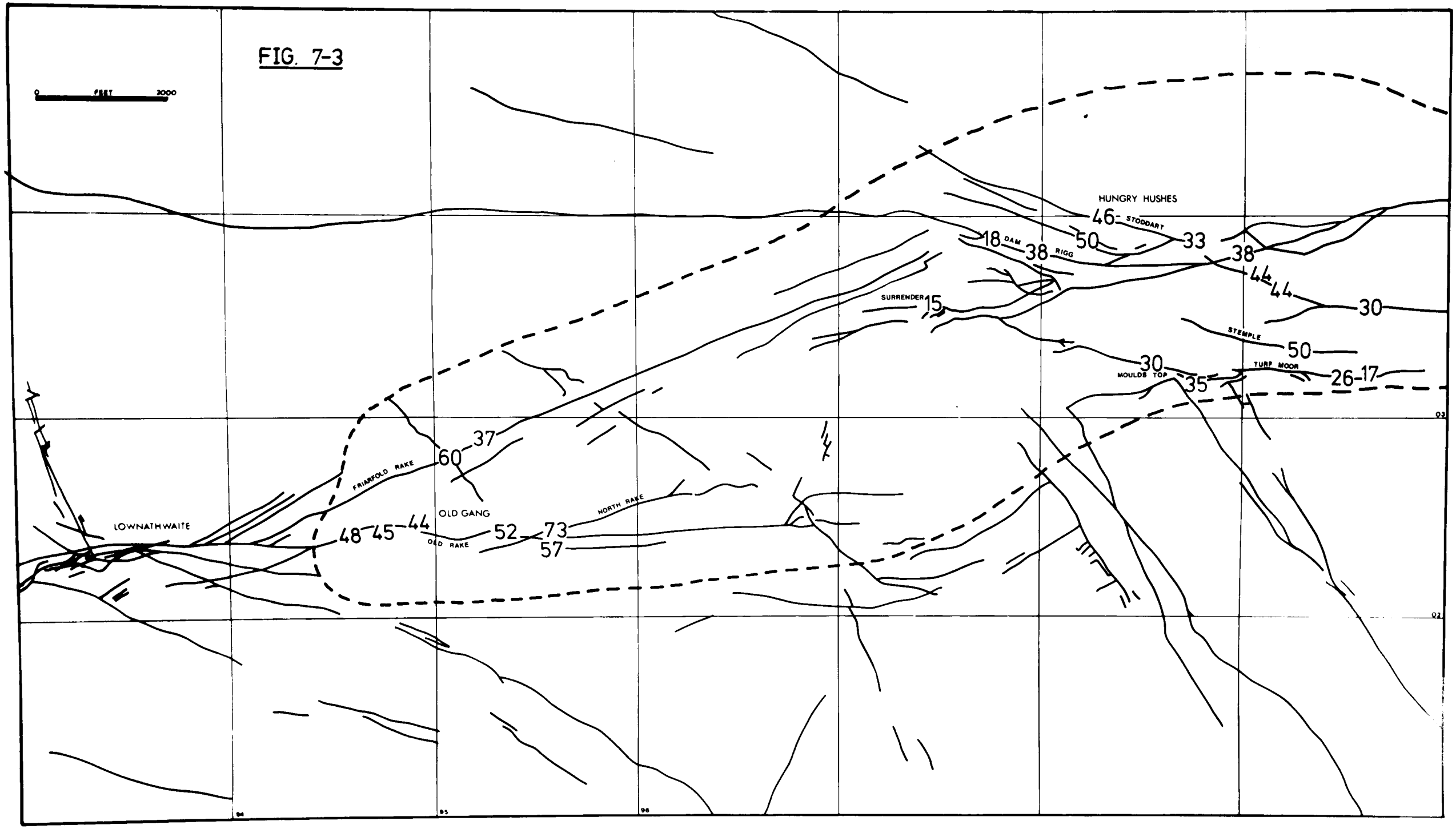


FIG. 7-3


0 FEET 2000
HUNGRY HUSHES
46
STODDART
18
DAM
38
RIGG
50
33
38
44
44
30
SURRENDER
15
STEMPLE
50
30
MOULDS TOP
35
TURF MOOR
26-17
03
37
60
FRIARFOLD RAKE
NORTH RAKE
OLD GANG
LOWNATHWAITE
48
45
44
OLD RAKE
52
73
57
02
94
95
96

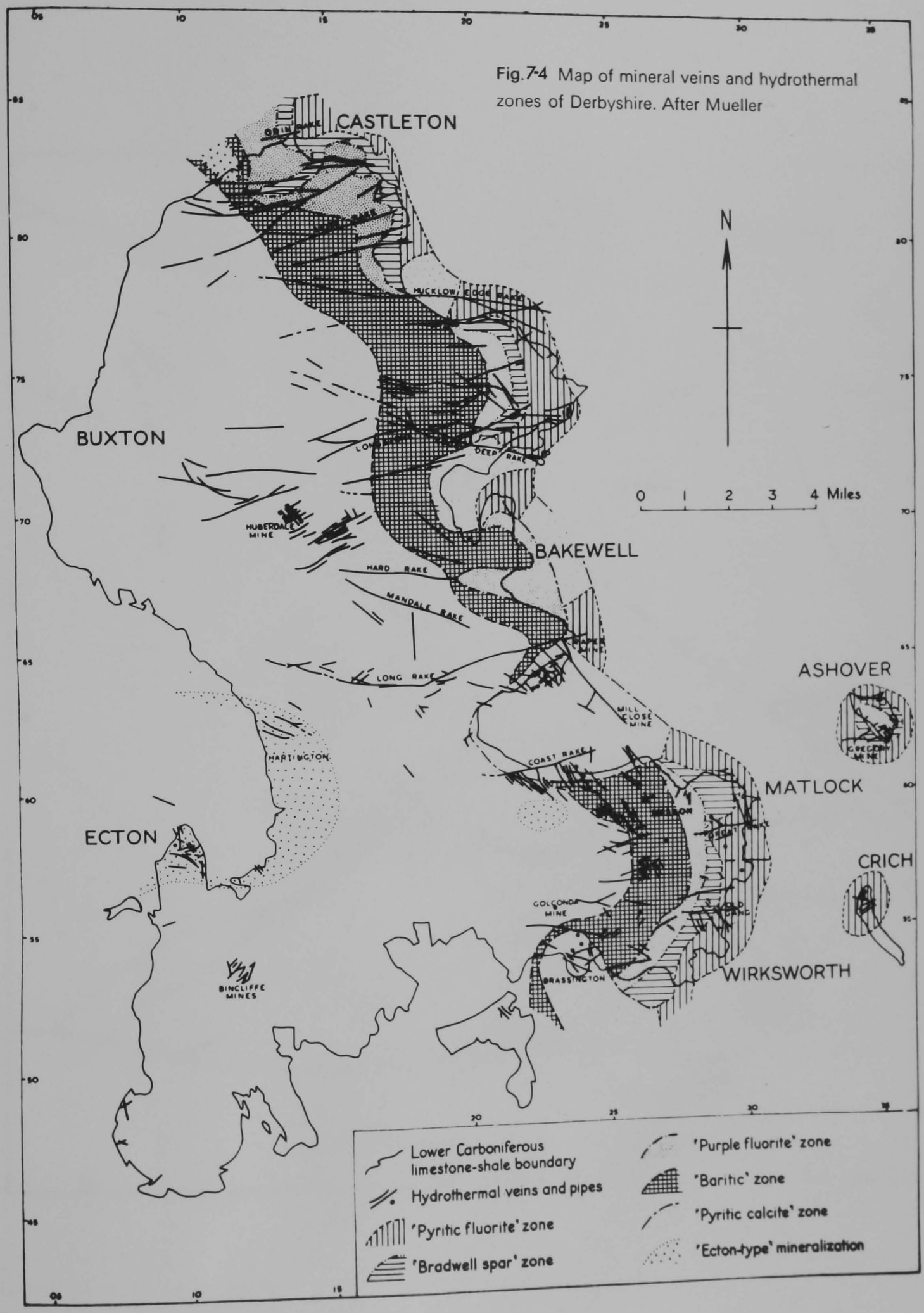


Fig. 7-4 Map of mineral veins and hydrothermal zones of Derbyshire. After Mueller

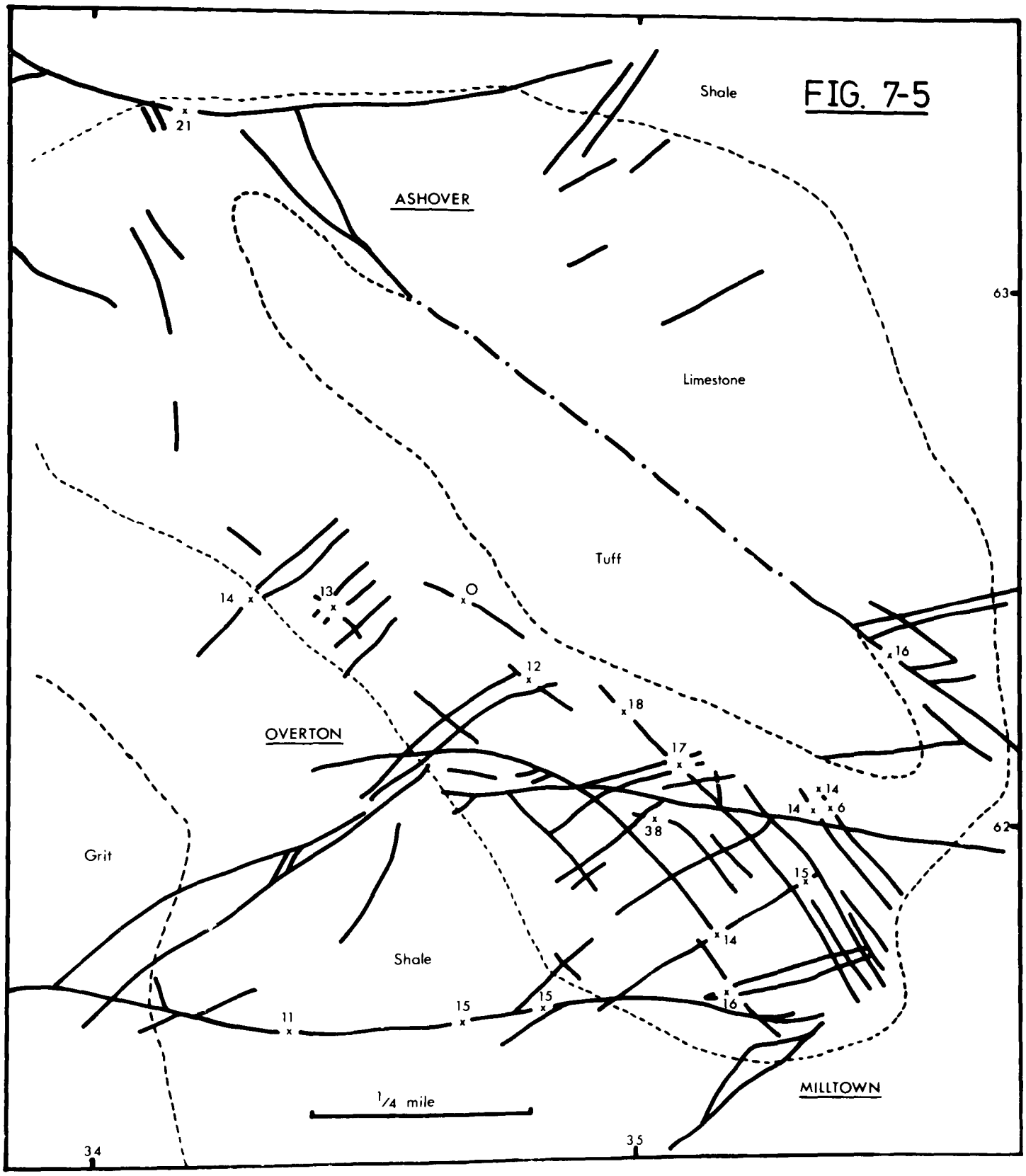
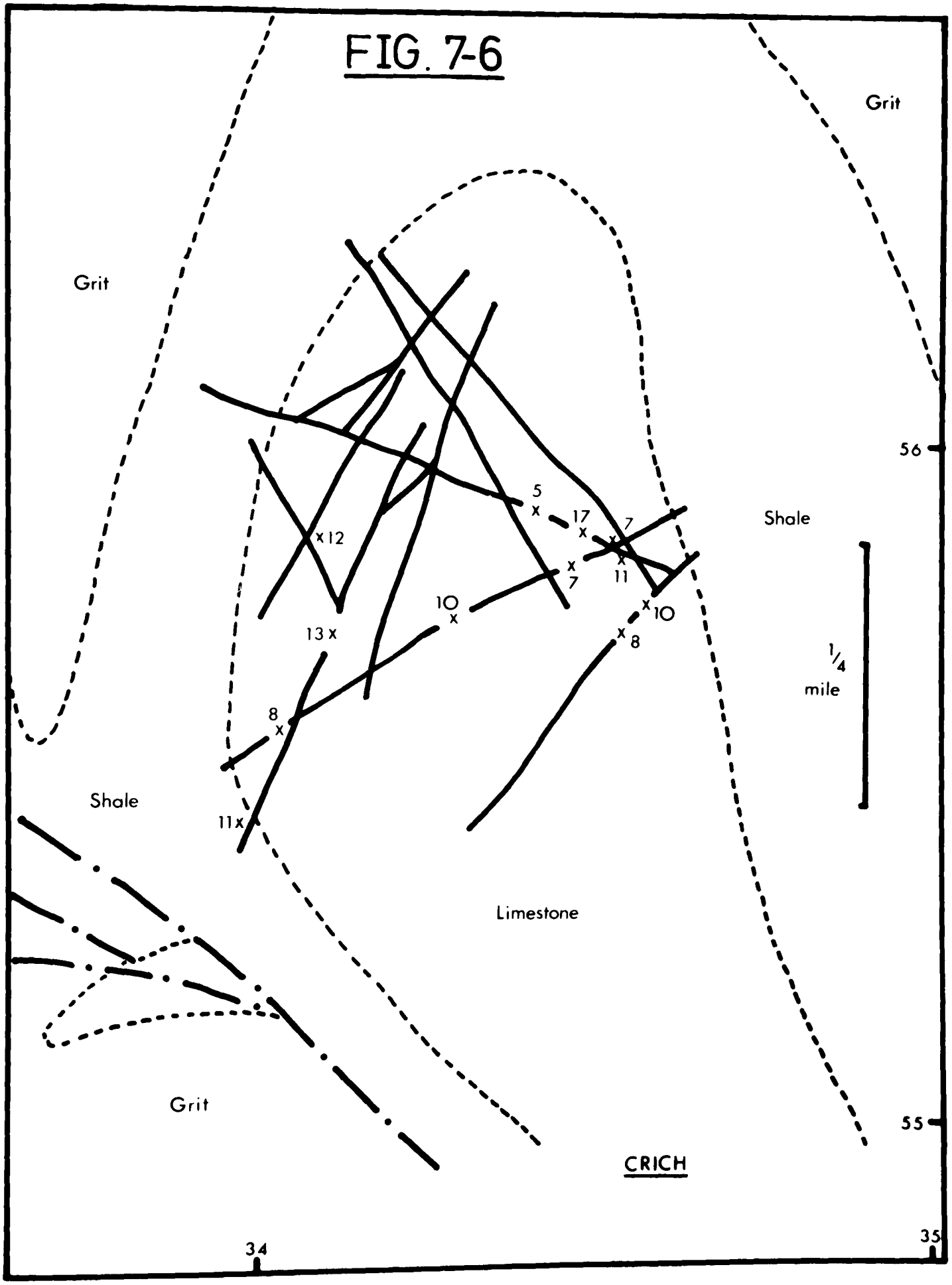


FIG. 7-5
Shale
21
ASHOVER
63
Limestone
Tuff
14
13
O
16
12
18
OVERTON
17
14
14
6
38
62
Grit
15
14
Shale
11
15
15
16
MILLTOWN
1/4 mile
34
35

FIG. 7-6


Grit
Grit
56
Shale
5
17
7
12
7
11
10
10
13
8
8
11
1/4
mile
Shale
Limestone
Grit
55
CRICH
34
35

plotted on Fig. 7.3 show a tendency toward areal zonation, with relative enrichment occurring in the centres of the Hungry Hushes and Old Gang districts. These were the most important mining sites in the zone, with waste dumps carrying up to 20 wt.% fluorite (Dunham, 1952)

The overall range of Y analyses from the Askrigg Block is 3 to 60 ppm, with the highest values occuring in the northern areas. Variation within individual fluorite-bearing zones is, however, with the exception of the Swaledale centre, of the order of $\pm$ 30 per cent of the mean value for the particular zone. The variation conforms to no recognisable pattern.

7.3.2 Derbyshire orefield

The Derbyshire orefield (Fig. 7.4) is situated in a gentle anticlinorium of massive, Lower Carboniferous limestones and interbedded lavas and tuffs. These ore-bearing strata are overlain by thick basal shales of the barren, local Millstone Grit series. Two small domes, at Ashover and Crich, S.E. of the main orefield, are also strongly mineralized. A further mineralized dome has been discovered during oil exploration boring deep beneath Eakring. Fluorite occurs in decreasing amounts westwards across the orefield, being successively replaced by barite, then calcite, gangues (though it reappears in the copper deposits of the Ecton Dome, on the S.W. margin of the orefield). The ores infill fissure veins and also cavities related to palaeokarst developments of intra-Carboniferous and Permo-Triassic ages that are chiefly located in areas of dolomitized limestone (Ford, 1969).

Nine fluorites from Great Rake, a fissure vein, and Masson Pipe, a palaeokarst infilling, at Masson Hill, Matlock Bath, show a random variation of Y contents in the range 12 to 20 ppm. Similarly, no systematic variation could be detected in the Y contents of 17 fluorites from the Ashover Dome (Fig. 7.5) or 14 fluorites from the Crich Dome (Fig. 7.6).

A number of other analysed specimens from the centre and north of the orefield are included in an overall Derbyshire range of Y contents from 0 to 38 ppm. The highest values again occur in the north of the orefield.

7.3.3 Cornubian orefields

The Cornubian orefields comprise those mineralized districts of Devon and Cornwall that carry ores spatially, temporally, and by implication genetically, related to the Hercynian Cornubian Granites. Tin, tungsten, copper, arsenic, zinc, lead, iron, fluorite and barite ores have all been raised on a large scale from vein lodes and disseminations marginal to, and within, the granite intrusions. The lodes contain evidence of polyascendant infilling in which fluorite may be present in a number of stages. Bradshaw and Stoyel (1968) demonstrated fluid inclusion temperature zonation about emanative sources centred within granite stocks.

A total of 38 fluorites, collected from mine dumps in the Tamar Valley, Menheniot, St. Agnes, Carn Brea, Carn Marth and St. Just districts, have been analysed. Y contents range from 15 to 322 ppm. Only three values however, fall below 95 ppm and these (Coronation Lode, Geevor Mine; Wheal Gorland and Wheal Devonshire) are from mines located within the deeper zones of tin mineralization. The remaining specimens were associated with relatively lower temperature copper, zinc and lead mineralization. Regional variation is obscure among these specimens. Local variations, such as might be caused at feeders, are impossible to detect owing to the scale and style of sampling.

7.4 The Source of Yttrium and Rare Earths in Fluorite.

The analytical results presented in this, and an earlier chapter have proved that fluorite-depositing hydrothermal brines can contain appreciable amounts of Y and R.E. The exact amount of these rare elements incorporated into the fluorite depends firstly upon their concentrations in

the brine and secondly upon the conditions of mineral growth. Variation in local conditions is important in producing the ranges of Y contents observed in fluorites from individual orefields. The absolute values of the ranges, however must reflect fundamental differences in composition of the ore-forming brines.

The ultimate source of Y and R.E. must depend upon the origin and life history of the brines. The origins may be generally classified as follows:-

1) juvenile brines, resulting from magmatic exhalation, or mantle degassing,
2) metamorphic brines, resulting from dehydration reactions during increase of metamorphic grade,
3) connate brines, representing trapped interstitial seawater in sediments,
4) meteoric brines, resulting from deeply circulating ground waters.

Only juvenile brines can have contained ore and trace components from inception. The remainder must have evolved into ore-bearing solutions by processes involving large scale leaching of rocks and selective concentration of particular elements.

Hydrothermal ore deposits of Y and R.E. are associated with the late stages of alkaline,and sometimes silicic, magmatism alone, thus confirming that the processes of igneous differentiation and segregation tend to concentrate the rare elements into residual fluxes. Thus it could be predicted that minerals such as fluorite, that are capable of taking up these elements, precipitating from such late-stage fluid, should contain Y and R.E. Yttrofluorite (up to 11% YF_3 and cerfluorite or yttrocerite, up to 6% YF_3) seem to occur exclusively in alkaline pegmatit es and carbonatites. Two coarse-grained foyaites from SN5, the most highly differentiated unit, of the North Qûrog centre, Igaliko Complex, S.W. Greenland, contain primary fluorite and calcite. Whole rock analysis shows enrichment, in particular of Ce and La, of rare

elements produced by the differentiation process. Y, Ce, La, and Sr of G.G.U. samples numbered 155160 and 155187 are 182, 1134, 818 and 219 ppm, and 262, 1145, 845 and 283 ppm respectively. Analyses of two fluorites associated with pegmatites in syenites of the Igaliko Complex, are given in Table 7.3 together with eight analyses of fluorites from carbonatites at Okorusu, S.W. Africa, and Amba Dongar, India (Deans and coworkers, 1973). Yttrium in these samples ranges from 60 to 690 ppm. The high strontium contents of all these fluorites (from 80 to 3318 ppm) is said to be characteristic of fluorites associated with alkaline igneous rocks (Yakubovich and Portnov, 1967).

Fluorite is a common mineral in granitic late-stage differentiates and hydrothermal mineralization. Clearly the amount of Y and R.E. present in these residual fluxes is dependent partly on the crystallization processes and partly upon the amount originally present in the parent magma, and hence on the source of the granite. The presence of mineralization by late-stage alkali earth - chloride - fluoride brines implies differentiation of some degree, during crystallization, that could lead to concentration of incompatible elements. With regard to petrogenesis, there is a major geochemical distinction between granite magmas that have formed by crustal anatexis producing partial melts of the eutectic composition in the albite-orthoclase - quartz - water system. In the first instance the rare elements may have reached high concentrations by exclusion from the main rock-forming minerals, whereas in the second instance, very small amounts of rare elements are mobilized into the magma at its inception. Thus, two fluorites from the very highly-differentiated leptites of the Bushveld Complex contain 1672 and 5193 ppm of Y (Table 7.3). Another fluorite from the Layered Granites of Pyramidefjeld, S.W. Greenland, again highly differentiated, yielded a low Y value of 44 ppm, but was preceded by intense allanite mineralization that presumably

took up the rare earth elements. Fluorite from the cryolite deposit at Ivigtut, S. Greenland, associated with a differentiated alkaline granite, contains only 87 ppm Y, but is associated with hydrothermal topaz, another Y acceptor mineral. Cryolite ($NaAlF_6$) from Ivigtut contains no detectable Y or R.E. Other alkali-aluminium fluorides such as ralstonite, pachnolite and gearksutite from the same locality have not been analysed. Fluorites associated with granites generally believed to be derived by anatexis, the Banffshire intrusions, the Julianehaab Granite - Migmatite Complex and a Swedish migmatite, contain small amounts of Y ranging between 11 and 31 ppm (Table 7.3). The majority of granitic intrusions cannot be so clearly assigned. Moreover it is becoming apparent that a number of major granitic plutons have formed during complex partial melting processes, involving the upper mantle and subduction slabs, at active, consuming, continental plate margins (eg. Andes and Western N.America). Ore deposits associated with such granitic batholiths form the Cordilleran type of Sawkins (1972). The Hercynian granite batholith of Devon and Cornwall, and the Caledonian batholith of Northern England have been emplaced in similar environments. It seems probable that the degree of melting of downgoing oceanic crust and of the upper mantle, combined with the degree of differentiation required to produce calc-alkaline plutons (granites, monzonites, quartz porphyrys, granodiorites) could result in late stage concentrations of Y and R.E. intermediate between those of the eutectic melts of continental crust, discussed above, and those of highly differentiated silicic residua of mafic plutons. Fluorites from the Cornubian orefields, from the Shap Granite and from British Columbia, for example, contain Y in the range 15 to 322 ppm. (Table 7.3). Fluorites of postmagmatic origin, but related to igneous rocks of indeterminate parentage, are included in Table 7.3 and show a broad range of Y contents from 10 to 3663 ppm.

Consider now the other types of ore-forming brines, particularly those of connate origin since information on metamorphic and meteoric brines

Table 7.3 Analyses of Fluorites from Probable Magmatic Sources

	Y	Ce	La
Fluorite Source:-			
Alkaline pegmatites, S.W. Greenland			
748 Peg. in syenite, Igäliko	533	558	582
749 Dyke in syenite, Igäliko	701	177	74
Carbonatites (Deans and coworkers, 1973)			
1 Okorusu, S.W. Africa	100	80	15
8B " "	150	160	60
3B " "	200	60	<10
9 " "	60	30	<10
4442H Amba Dongar, India	330	45	45
4473B " " "	300	45	45
4473A " " "	80	50	50
4474F " " "	120	60	60
Differentiate granites			
686 Buffalo, Bushveld	1673	245	102
687 Vernogoeg, Bushveld	5193	490	260
752 Pyramidefjeld, Greenland *	44	1	0
724 Ivigtüt deposit, Greenland *	88	0	2
(988 Cryolite from Ivigtüt*)	0	0	0
* Associated with R.E. minerals			
Anatectic granites			
194 Na Tri Chaochain, Banffshire	14	39	2
195 "	11	26	0
239 Yxsjöberg, Sweden	25	0	0
675 Julianehaab, Greenland	31	29	0

		Y	Ce	La
Cordilleran type, oredeposits (Sawkins, 1972)				
720	Adam's Plateau, Brit. Columbia	105	14	0
723	Shap, Westmoreland	90	0	0
328a	Brandlehow, Lake District	202	34	1
328b	" " "	227	25	10
228	Weardale Granite, Rookhope B.H.	14	0	0
Average of 38 fluorites from the Devon and Cornwall deposits		220	27.6	5.2
range 15 to 322 ppm Y, 0 to 116 ppm Ce, 0 to 28 ppm La				
Associated with granitic rocks				
707	Pikes Peak, Colorado	270	113	53
713 - 717, Telemark area, Norway				
713	Fyresdalsvannet	66	21	2
714	Brissevann	135	10	16
715	Borkevann	99	0	0
716	Haukås	10	34	0
717	Tveitstå	143	37	11
683	Silius Mine, Sardinia	95	18	0
691 - 743	Australia			
691	Carboona, N.S.W.	198	13	7
692	Gulf, I, N.S.W.	3663	565	260
693	Gulf II, N.S.W.	877	122	45
695	Plumbago Station, S. Aus.	156	17	0
696	Plumbago Main, S. Aus.	110	13	19
697	Sandy Creek, Vic.	51	0	11
698	Pine Mountain, Vic.	313	24	5
700	Mistake, Qnld.	74	25	0
701	True Blue, Qnld.	152	21	0
708	Almaden, Qnld.	174	20	0
973	Mount Garnet, Aus.	17	0	0
743	Speewah Valley, W. Aus.	197	35	25

		Y	Ce	La
227	Ballater, Aberdeenshire	144	11	0
709	Tomnakeist, Aberdeenshire	121	0	3
678	Maisley, Banffshire	55	13	1
Associated with shield gneissic terrain				
318	Madoc, Ontario	144	18	1
689 - 972	Australia			
689	Thackaringa, N.S.W.	127	0	0
690	Mayflower, N.S.W.	102	1	0
694	Mount Eltie, N.S.W.	247	0	0
699	Relief and Midway, Qnld.	42	8	0
702	Meentheena, W. Aus.	49	13	1
972	Alice Springs, N.T. Aus.	127	0	0

is sparse. They must extract fluorine and the ore metals from reservoir and passage rocks during their migration from source to site of deposition. They have been presumably heated by deep burial or local high heat flow (e.g. the Salton Sea geothermal system). Any Y and R.E. contained in fluorite deposited from such brines must also have been derived by leaching en route.

The average Y, Ce and La contents of a number of analysed igneous rocks are given in Table 7.4 (from Herrmann, 1970). The average Y content varies from 32 to 38 ppm. It is noteworthy that those igneous minerals with highest concentration of Y (Herrmann, op. cit.) are those most resistant to weathering and leaching (e.g. garnet, sphene, apatite, zircon, monazite, epidote, and muscovite). Clinopyroxenes and feldspars, on the other hand, contain very little Y (Lambert and Holland, 1974). Analysis of weathered granite and soils above the buried Wensleydale Granite, Yorkshire, shows a 50% increase in total Y content (Holland, pers. comm. 1974), presumably due to concentration of the detrital minerals. These facts tend to indicate that leaching of normal igneous rocks will not release very much Y and R.E. into solution. A recent study by Shepherd (1973) of the West Cumbrian haematite orefield showed that the ores of the district had been deposited from connate brines. Deep circulation had permitted leaching of iron and other elements from the Lake District granitic batholith. Fluorite occurs in very small amounts in the orefield and contains 30 to 47 ppm Y, presumably also derived by leaching of the granitic rocks.

The average Y, Ce and La contents of a number of analysed sedimentary rocks are given in Table 7.4 (from Herrmann, op. cit.). The average Y content varies from 3.8 ppm (in limestones) to 38.4 ppm (in Palaeozoic shales). The chief host minerals for Y and R.E. are probably the detrital minerals apatite, sphene, epidote etc., accounting for the 15 ppm in sandstones.

Table 7.4 Average Y, Ce and La Contents of Some Analysed Rocks (from Herrmann, 1970)

	Y	Ce	La	≤ Y,La-Lu
Basalts	32	16	6.1	≤ 99
Intermediate rocks	35	60	31	≤ 196
Granitic rocks	38	104	55	≤ 290
Weighted av. ig. rocks	35	81	42	≤ 245
Recent marine clays	32	56	31	≤ 194
8,616 Russian shales (Pal. and Mesoz.)	30	67	34	≤ 200
36 Palaeozoic shales	38.4	91	45	258
17 Greywackes	31	62	33	≤ 190
6,051 Sandstones	15	33	17	≤ 100
11,205 Limestones	3.8	6.5	4.1	≤ 25
Average sedim. successn. (77% Sh. 15% Sst. 8% Lstn.)	26	57	29	≤ 170

The elements are also taken into clay minerals where they will occupy the stable octahedral lattice sites. This fact accounts for the higher contents of the elements in shales. Thus sedimentary rocks should again be quite resistant to leaching of Y and R.E. This is supported by the fact that the analysed Palaeozoic shales of Table 7.4 show no depletion of the relevant elements when compared with more recent sediments. The figures actually suggest fixation of Y and R.E. from groundwaters, by shales. Herrman (op. cit.) states that Y and R.E. contents of metamorphosed shales are not different from those of undeformed shales. Lambert and Holland (op. cit.) reach a similar conclusion that Y is inert throughout metamorphic processes. It seems therefore that leaching of Y and R.E. from igneous and sedimentary rocks by relatively low temperature (connate brines probably do not normally exceed 150°C) brines is an inefficient process, very unlikely to result in high concentrations of these elements being deposited with fluorite ores or substituting in the fluorite lattice.

Within recent years it has become widely accepted that the most probable source brines of most of the so-called Mississippi Valley Type telethermal, lead - zinc - barium - fluorine deposits are connate. Brine temperatures were elevated by deep burial or by abnormal heat flow above deep intrusions or intersections of major fracture zones. Leaching during migration provided the ore elements. Depositional mechanisms involve purely convective cooling or mixing with colder, shallow brines. Analyses of fluorites from Mississippi Valley Type deposits, given in Table 7.5, show low concentrations of Y and R.E. (0 to 55 ppm Y). If the telethermal deposits of the Central Pennines are included then the range of Y becomes 0 to 60 ppm.

Mixing of different brine types may account for a number of deposits of disputed type, providing trace element concentrations between the relatively high Y and R.E. fluorites of some magmatic sources, and the inevitably low Y and R.E. fluorites of purely connate sources.

Table 7.5 Analyses of Fluorites from Mississippi Valley Type telethermal deposits

	Y	Ce	La
Belgian Ardennes			
744 Seilles	9	0	0
745 Foisches, Givet	15	31	0
746 Ave, Wellin	25	0	0
747 Engihoul, Liege	16	9	0
Asturias, Spain			
706 Ribadasella	4	20	0
Illinois/Kentucky			
231 Minerva, Ill.	3	0	0
232 Alcoa, Ill.	12	7	0
704 Sheridan, Ky.	1	0	0
Permian deposits, N. E. England			
219 Chilton Q.Durham.	42	0	0
977/1 Rough Furze Q. Durham.	53	0	0
977/2 "	22	0	0
Co. Clare, Eire			
238 Doolin, Lisdoonvarna	0	3	0
Lancs. England			
679 Clitheroe reef knolls	5	0	0
North Wales orefield			
584 East Pant Dû	34	9	0
585 United East Pant Dû	22	14	0

	Y	Ce	La
586 Pant-y-gwlanod	7	0	0
587/1 Bryn Gwiog	9	12	0
587/2 Bryn Gwiog	10	0	0
588 East Halkyn	3	0	0
644 Ffrith Quarry	30	18	0
West Cumberland orefield			
643 Florence Pit	47	6	0
989 Beckermet Mine	30	0	0
Derbyshire orefield, average of			
51 fluorites -	14	5.4	0.8
range 0 - 38 ppmY; 0 - 38 ppm Ce; 0 - 18 ppm La			
Central Pennine orefield, average of			
65 fluorites -	27	4.6	0.8
range 3 - 60 ppm Y; 0 - 53 ppm Ce; 0-34 ppm La			

7.5 The Origin of the Mineralizing Brines of the North Pennine Fluorite Zone

The earliest known scientific exposition on the genesis of the North Pennine ores suggested meteoric waters as an agency of transport and lateral secretion as the means of ore concentration (Wallace, 1861). This was finally abandoned in favour of Dunham's writings, from 1932 until the late 1960's, that supported a magmatic source for the ore solutions. Dunham predicted the existence of the Weardale Granite beneath the orefield and was strongly supported by Bott's geophysical researches in the area. The discovery that the Weardale Granite was in fact very much older than the host rocks to the mineralization did not discourage the proponents of the magmatic theory. The fluid inclusion work of Sawkins (1966) was taken to support the emanation of hot juvenile brines, from a source beneath the Weardale Granite. Sawkins suggests that the fluorite zone ores were deposited under conditions of decreasing temperature but pointed out that some process of mixing with cold, barium chloride, connate brines must be invoked to explain the barium zone mineralization. Ineson's discovery of zirconium aureoles about the fluorite veins was again taken as evidence of the magmatic origin of the brines. In 1971, however, a major reversal of opinions occurred when Solomon, Rafter and Dunham published δS^{34} isotopic ratio data from sulphides of the fluorite zone. These ratios were atypical of magmatic sulphides and Solomon and his coworkers suggested that the fluorite zone minerals had been deposited from a cooling connate brine, of Lower Carboniferous derivation, that had been heated and had leached ore components from reservoir and passage rocks during deep circulation. The heat source, they proposed, was the cooling Whin Sill dolerite magma chamber. A problem with this model, however, is the inherent improbability of large volumes of formation waters descending, from Lower Carboniferous rocks alone, through the suggested 6km of folded Lower Palaeozoic states and through several kilometres of fresh granite, then returning to surface and depositing

sulphide ores that have preserved the original sulphur isotopic ratios of Lower Carboniferous seawater. Moreover, the very existence of a Whin magma chamber is in some doubt since many authorities believe that the Whin dolerites arose directly from the upper mantle (Dunham, A.C. and Kaye, 1965; Bott, pers. comm. 1974). Although the δS^{34} values are relatively high and their wide range, from +15.0 to -5.9 per mille, contrasts with the near zero values and narrow range of δS^{34} from well-established magmatic hydrothermal ares, similar values have been recorded from deposits in northern Sardinia and Zeehan,Tasmania, where granitic sources seem probable (Solomon and coworkers, 1971).

The yttrium contents of North Pennine vein fluorites (361 specimens) vary from 102 to 813 ppm (mean, 290), cerium from 0 to 971 (mean, 78) and lanthanum from 0 to 505 (mean, 41). Comparison of these values with those of fluorites from deposits of known origins in Tables 7.3 and 7.5 shows a clear affinity with those derived from juvenile brines. Indeed the most similar material occuring in the British Isles (in terms of trace element content, formation temperature, colour,susceptibility to radiation colouration, E.S.R. spectrum and TL emmission) is from the orefields related to the Cornubian granite plutons. It is clear from the considerations in Section 7.3 that the high concentrations of Y and R.E in the North Pennine fluorite could not have been derived by normal leaching of rocks by connate brines. Could the North Pennine brines, being hotter than most normal connate brines, have been more efficient at leaching? Table 7.6 lists analyses of the Weardale Granite from the Rookhope Borehole. Samples DH 20 and 783 are altered granite adjacent to Pennine-type fluorite-galena veins. Sample 784 is altered granite adjacent to the ? Caledonian (Section 5.6) vein at 2085' that contains low Y fluorite (no. 228). DH11 is an aplite vein. The remaining DH samples are unaltered, fresh granite. The Y and R.E. values are considerably lower than those of the buried Wensleydale Granite (prefix WN). The elements show

Table 7.6 Y, Ce and La Analyses of the Weardale and Wensleydale Granites

Weardale Granite Analyses (ppm)

Spec. No.	Y	Ce	La	Spec. No.	Y	Ce	La
DH 1	12	94	55	DH 12	10	81	118
DH 2	10	121	86	DH 13	2	143	91
DH 3	10	96	72	DH 14	NA	127	80
DH 4	11	96	70	DH 15	NA	114	82
DH 5	NA	72	84	DH 16	NA	97	97
DH 6	NA	98	72	DH 17	NA	105	88
DH 7	NA	112	63	DH 18	NA	134	92
DH 8	NA	110	77	DH 19	4	142	103
DH 9	NA	132	93	DH 20	61	220	132
DH 10	NA	109	73	783	60	112	NA
DH 11	6	88	46	784	52	112	NA

Wensleydale Granite Analyses (ppm)

WN 1630	132	88	69	WN 1851	72	204	137
WN 1703	79	155	128	WN 1882	84	205	130
WN 1722	79	170	107	WN 1967	12	210	143
APLITE	143	NA	NA				

no particular enrichment in either the late stage Weardale aplite (contrast the Wensleydale Granite) or the post-magmatic fluorite mineralization. The two Pennine-type vein wall-rocks, however, show appreciable addition of Y, Ce and La, presumably from the hydrothermal brines. This indicates, of course, that no leaching of these elements from the granite has taken place within its upper 200 m.

Holland (1967) showed that the Weardale Granite was emplaced by a process of 'underplating' or cauldron subsidence, in which increasingly differentiated sill-like intrusions were forced up beneath previous sills. The upper most intrusions, penetrated by the Rookhope Borehole, were emplaced during the Middle Devonian, but the underplating process must have continued long after this in order to produce the batholithic dimensions indicated by geophysics. Although this magmatic activity cannot reasonably be related with the North Pennine mineralization, it is important to note its scale and possible duration. Further deep-seated activity during late Carboniferous times resulted in the intrusion of more thatn 1,550 km^3 of primitive basic magma, and provides clear indication of instability at about the base of the crust in this region, possibly reactivated by the beginning of the Hercynian earth-movements. The close spatial coincidence of this long term, deep, magmatic activity with the ascent, a little later, of hot, mineralizing brines enriched in F, Y, R.E. and Zr, must surely imply a considerable contribution, if not total involvement, of juvenile brines in the fluorite zone mineralization of this orefield.

SECTION TWO

THE RED VEIN, WEARDALE

This second part of the thesis contains a detailed description of the occurrence and controls of mineralization on a particular vein, the Red Vein, and its neighbouring veins, in the North Pennine orefield. The methods of study and aids to exploration, described in Section One, were developed and applied in this area. Summaries of the applications and results are given.

CHAPTER EIGHT

THE RED VEIN OF WEARDALE, COUNTY DURHAM

8.1 Introduction

Red Vein is one of the more important fluorspar-producing 'quarter point' veins of the orefield. It is known over about $14\frac{1}{2}$ Km E.S.E. from Rookhopehead although, as Dunham (1948, p.243) states, "the extent of mineralized ground on the vein has proved to be but a fraction of its total length". The vein is not a single continuous fault structure but consists of several en echelon structures, each of which is complicated with branch and loop veins. Ore-zones are generally of considerable width (attaining maximum reported vein widths of over 15m) and extend over a wide vertical range of strata. In common with the other Weardale 'quarter point' veins, Red Vein contains mainly fluorite.

The vein was thoroughly explored during the eighteenth and nineteenth centuries by the Beaumont Co., London Lead Co. and the Weardale Iron Co. Although lead values are not high (Pb metal content ranges between 0.05 and 20 metre per cent, averaging in the order of 2 to 3 metre %), the first two of these companies were able to win profitable returns from Groverake and Stanhopeburn Mines. The Weardale Iron Co., often exploring jointly with the Beaumonts, worked extensive ironstone replacement flats associated with the vein (total iron ore production from the vein was in excess of 500,000 tons Dunham, 1948). Towards the end of the nineteenth century, lead mining fell steadily into decline following the collapse of the lead market and the remaining production centred upon a few of the richer mines. However, at around the turn of the century a mining revival began, that has continued to the present day. This was stimulated by the need for fluorite as a steelmaker's flux and more recently intensified by the demands of the aluminium smelting and chemical industries. Fluorspar mining, begun by the Weardale Iron Co. and by the

Weardale Lead Co. (successor to the Weardale leases of the Beaumont Co. in 1883), now markets in the region of 42,000 to 45,000 tons of metallurgical and acid grade concentrates per annum from the orefield. More than half of this is derived from Red Vein which has probably, to date, yielded in the order of 750,000 tons of fluorspar concentrates.

Three companies hold leases to work the vein. Fergusson Wild and Company (a member of the William Baird Group) hold leases from the eastern extremity of the vein to the western end of Stanhopeburn Mine and is at present developing ground in that mine. The Weardale Lead Co. (a subsidiary of I.C.I.) holds the lease from Stanhopeburn Mine to the western known extremity of the vein, except for a smaller lease area around Groverake Mine, owned and operated by the British Steel Corporation. Weardale Lead Co. operate Redburn Mine which is the only successful mine opened up in new ground during this century.

8.2. Structural Controls of Mineralization

The Red Vein system is structurally dissected into a number of E.-W. trending mineralized sections, disposed en echelon. Each section generally contains a unit of payable ground with definite lateral limits, usually worked by a single mining enterprise. Each has its own feeder system that provided channelways for ascending mineralizing brines. The tendency for the vein to break up and reconstitute off-set has been examined and various structural mechanisms will be discussed. The simplest rule of thumb however, regarding these orebody terminations, can be found by observation and is that en echelon continuations of an orebody will be found to the N.W. if working westwards and to the S.E. if working eastwards. Orebodies are formed where the vein trend is closest to E. - W. When the trend changes becoming North of West then there is a tendency for orebodies to narrow and terminate.

8.2.1 Strike irregularity control

The principle of strike irregularity control on a wrench fault of

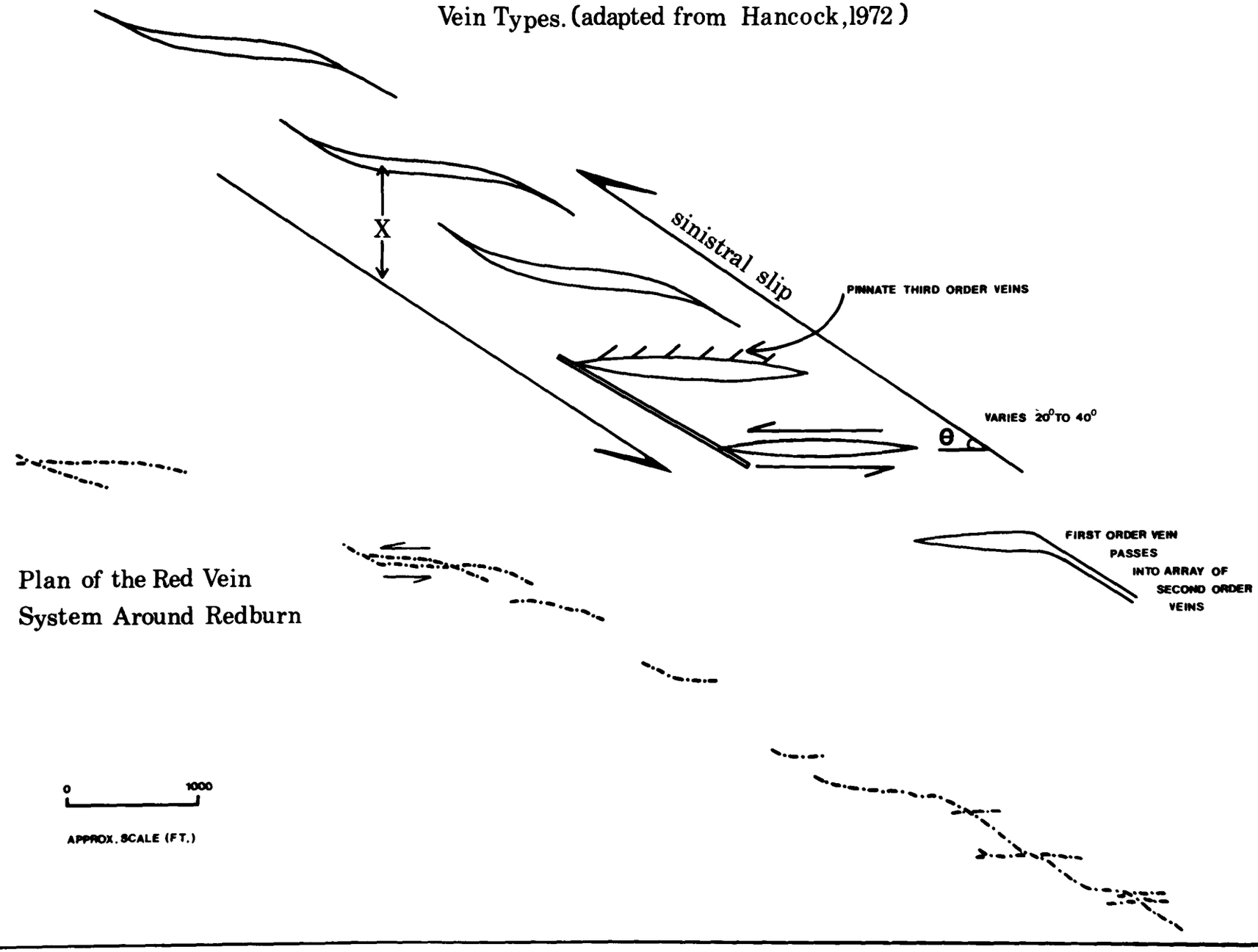
sinuous trace was discussed in Sect. 2.2. Detailed examination of Red Vein underground and from plans, shows that sinistral wrench movement would have tended to open tension cavities at exactly those places now occupied by orebodies. Detailed examination of Slitt Vein in Blackdene Mine (east of its intersection with Blackdene Vein) shows that this other 'quarter point' vein must also have slipped in a sinistral fashion. The degree of strike change required to open a particular width of orebody cavity can be calculated from the longitudinal displacement of the veins. Thus, a 10m displacement would open a 1.5m wide cavity on a vein showing a strike change of only 8^{o}. This is a fairly normal situation on 'quarter point' veins, noted for their degree of longitudinal displacement. Exact underground measurement of actual displacement is, however, of little value at the present day, due to the confusing effect of post-ore wrench faulting (of unknown sense). The sense of primary displacement can be predicted as sinistral on all 'quarter point' veins since these vein systems as a whole, make angles of about 30^{o} to the axis of the Teesdale Dome, (the maximum principal stress direction at the time of faulting).

The control over vein width exercised by this process was very great and it has been found possible to explain most observed vein width variations in terms of it (by measuring vein strike changes).

8.2.2 En echelon tension gash zones

Strike control cannot explain orebody staggering when the ends of neighbouring bodies overlap, or where no connection at all can be found between them. This is probably the case between Crawley and Stanhopeburn Red Veins, individual Redburn orebodies and the Redburn and Groverake Red Veins. In these instances, particularly in the Redburn area, there is a very strong resemblance between the staggered orebodies and typical en echelon tension gash veins (Fig. 8.1). In such gash vein systems, zones of lensoid to sigmoidal cavities form at angles of 15^{o} to 40^{o} to the primary shear couple

FIG. 8-1 Schematic Diagram of Second Order, en échelon, Vein Types. (adapted from Hancock, 1972)



Plan of the Red Vein System Around Redburn

(Hancock,1972). The angle of propogation, sense of curvature and sense of shear of the known vein bodies are compatible with the proposed sense of the sinistral, N.N.W. directed regional shear couple discussed in Sect. 2.2. Although arrays of tension gashes of this length are rare, individual gashes up to 0.8 km in length have been mapped from parts of Africa by M.P. Coward (pers. comm., 1972).

Working from this hypothesis as a mechanism of cavity formation, it seemed that some regular geometric relationship might exist that could predict gash length and separation. However, this can only be found from observation. The perpendicular distances separating known orebodies in the Redburn - Boltsburn section of Red Vein (including branch veins) can be expressed as multiples of x (see Fig. 8.1), where x was found to be 51 to 65m. This suggested the presence of potential tension gash cavities, approximately 50 - 65m apart, in a long stretch of unworked ground between the east and west orebodies at Redburn Mine. The predicted locations of cavities correspond well with at least two actual zones of rubble-filled, tectonic cavities, unmineralized except by late phase carbonates, quartz, pyrite and a very little chalcopyrite. These cavities, seen in the Great Limestone in the 17 Fms. Haulage Level, trend within 20° of E.-W. One zone may be traced in the Nattrass Gill Hazle, at 900m in the 40 Fms. Haulage Level, again as a series of calcite and ankerite veins trending between 45° and 80° W. of N.

It therefore seems that this hypothesis may be capable of predicting cavity location, but that in this particular example the lack of feeder intersection (no cross-cutting veins occur in this part of the mine) meant that the cavities remained cut off from the main flow of mineralizing brines. The hypothesis of en echelon gash arrays, though interesting, is by no means proven. Much of the information regarding the so-called terminations and en echelon continuations of Red Vein comes from old records, partly perhaps based upon hearsay. Although some exploration of apparent ore termination is going on at present it seems very unlikely that anyone could be induced to prove the

FIG. 8-2 VEIN TERMINATION BY CROSS-FRACTURE SLIP (VARVILL 1937)

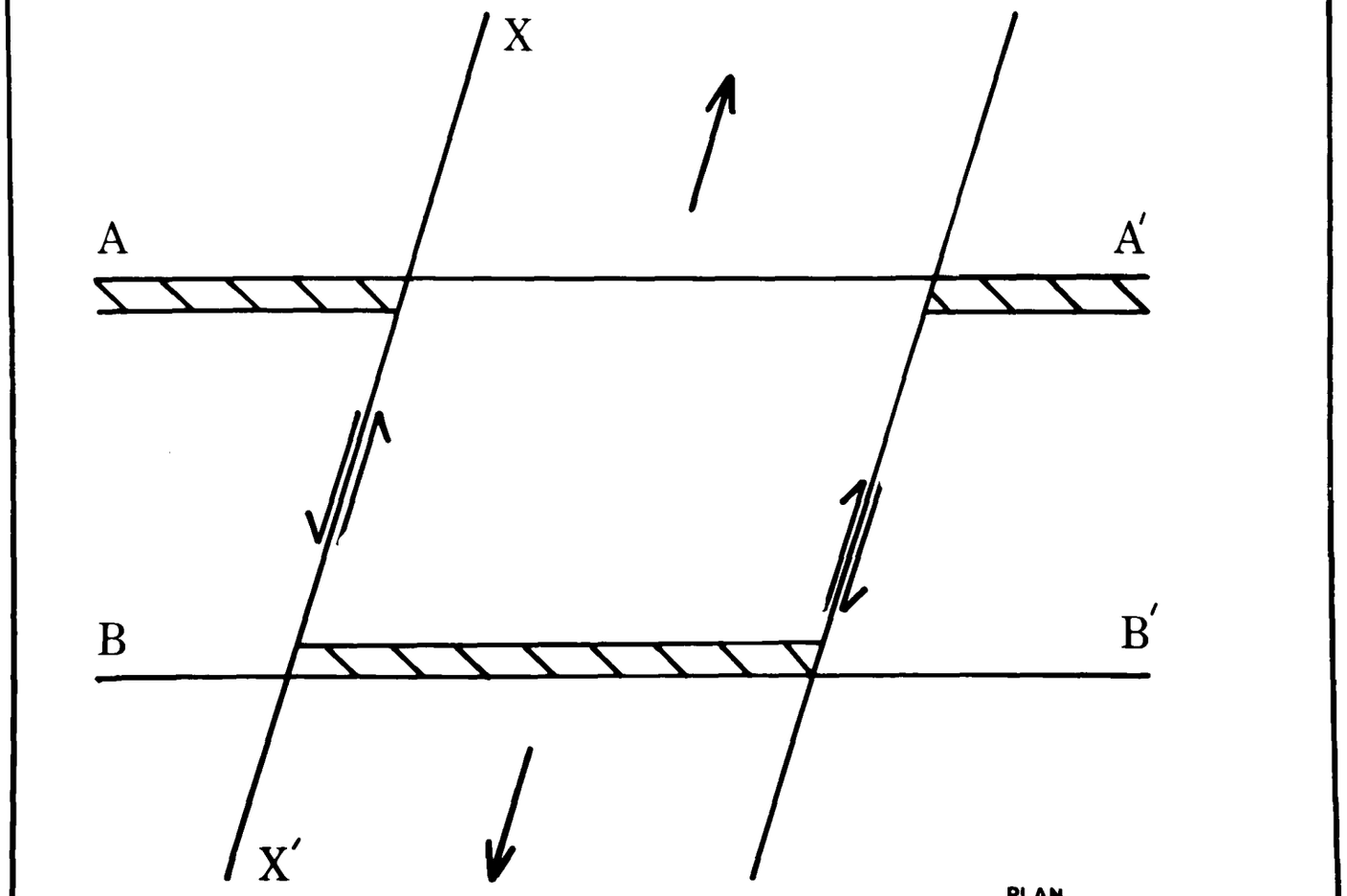
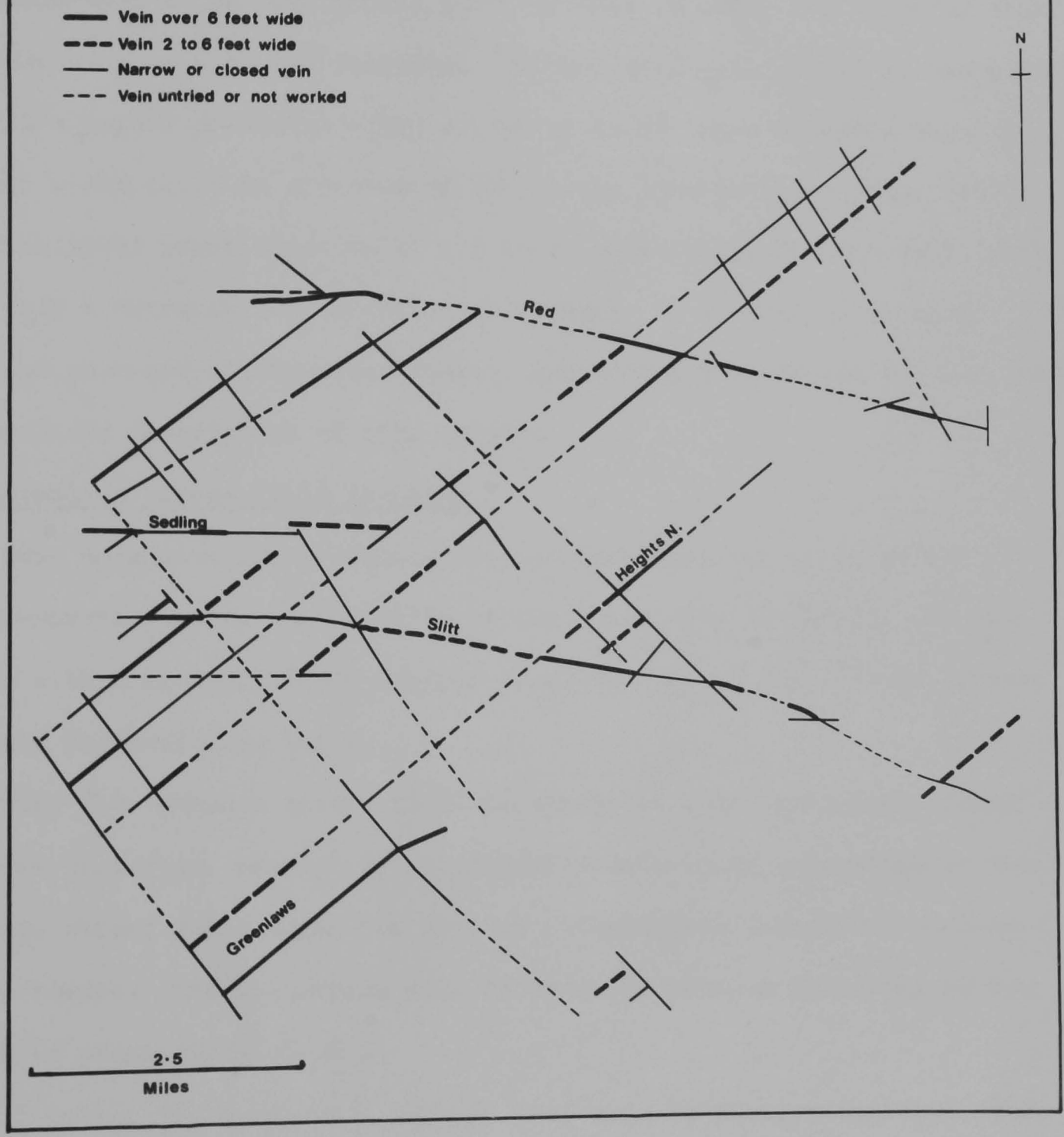


FIG. 8-3 VEINS AND CROSS VEINS OF UPPER WEARDALE, AFTER DUNHAM (1937)



structures occurring in known barren ground separating parallel orebodies.

8.2.3 Cross vein terminations

Fracture intersections may occasionally be associated with the abrupt termination of an ore-bearing zone. This phenomenon has been analysed in detail by Varvill (1937). His explanatory diagram was reproduced as Fig. 8.2 from which it is evident that slight strike slip on cross fracture X - X' would open a new cavity on a parallel Vein (B -B'), the original vein A-A', continuing as a closed fracture. Dunham, with J.A. Hill, (in discussion of Varvill's paper) presented a map of the veins of Upper Weardale showing that their width could be affected by cross vein intersections (Fig. 8.3). The difficulty of identification of a closed, unmineralized cross fault with perhaps only a metre or two lateral displacement, in an area of abundant unimportant, post-ore, slickensided faults, has probably prevented further, more detailed, field description of this effect.

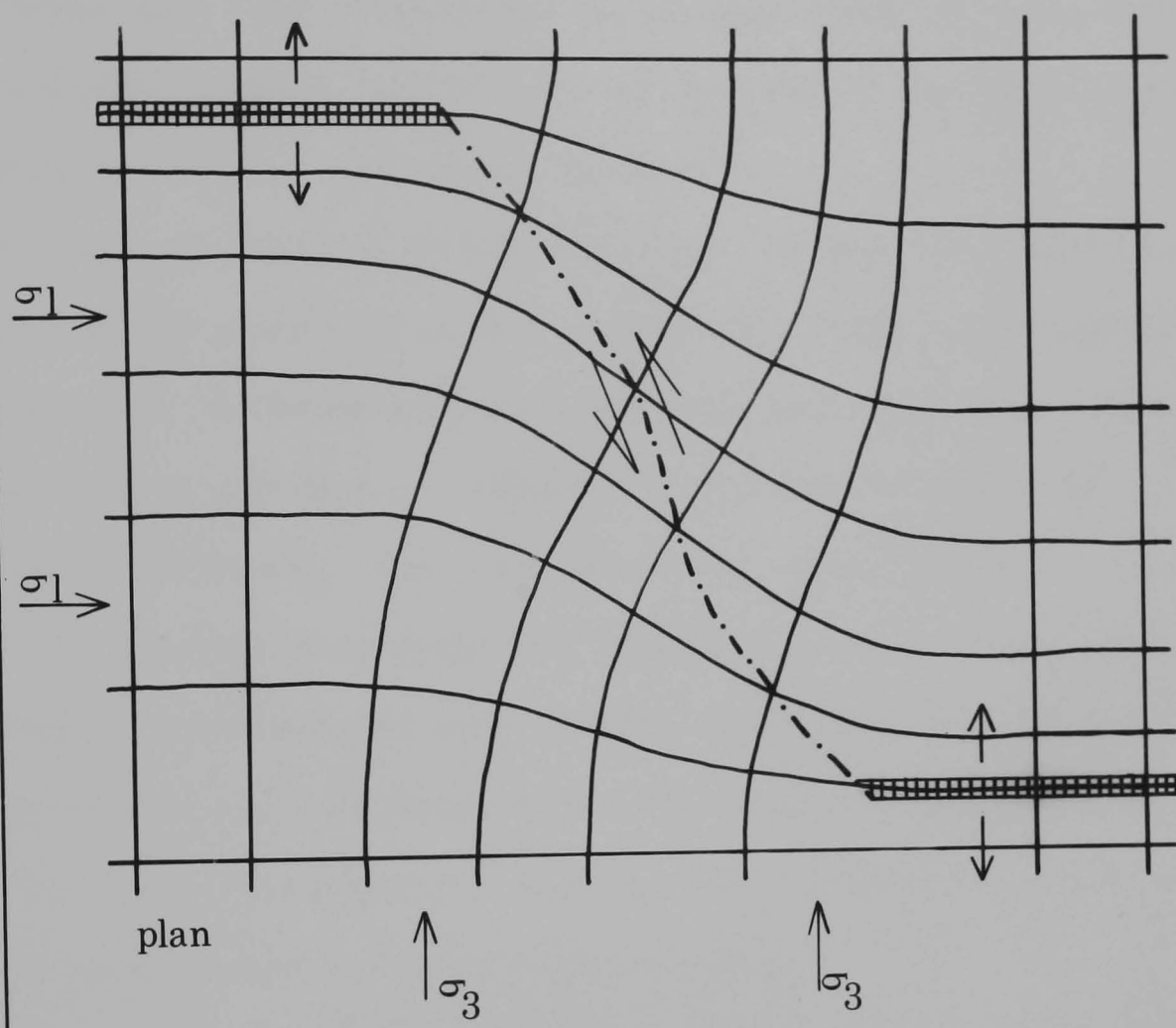
8.2.4 Anomalous stress field faulting

This mechanism for producing off-set orebodies was proposed by Dr. G. Borrodaile (pers. comm., 1973) of the University of Durham. It was suggested with a specific field example in mind, that of the off-set between Crawley and Rogerwell Red Veins.

Fig. 8.4 shows a stress field in which the least principal stress σ_3 has been distorted, perhaps by structurally determined weaknesses in the rocks (e.g. strong joint zones) or else by lithological variations such as washout presence. The distortion also affects the maximum principal stress σ_1, which is perpendicual to σ_3.

If cavity formation on a vein in this area is purely tensional, then these cavities, will open perpendicual to σ_3 except in the zone of stress distortion where slight shear faulting must occur, simultaneously, subtending approximately 30° to σ_1. Thus it is possible to find off-set orebodies narrowing towards a connecting shear fault, itself mineralized and of small lateral displacement.

FIG. 8-4 GENERAL MECHANISM FOR TRANSFORMATION OF TENSIONAL OPENINGS INTO A SHEAR FAULT



—— STRESS TRAJECTORIES ▭▭ TENSION CAVITY
—·— SHEAR FAULT

This is represented on Fig. 8.4.

8.3 Methods of Examination

Red Vein and its neighbouring veins have been, as far as possible, examined at their surface and underground exposures.

Observations have been made on the vein strike and particular notice taken of prolonged changes in strike. These have proved useful in interpreting changes in vein width (Sects. 2 and 8.2.1.) The presence of branch, loop and cross-cutting veins were also noted since the intersections of these with the main vein are believed to have provided feeder channelways for ascending mineralizing brines reaching the orebody (Sect.2.)

Observations were made on vein mineralogy. It was found (Sect 5.9) that the marginal early phase rib of grey quartz with mixed copper and iron sulphides increases in thickness approaching feeder intersections. The copper content of the rib also increases, although the presence of copper is influenced by the stratigraphic and areal location. (Sect. 5.9.)

Samples of fluorite were taken, at regular intervals if possible, along ore bodies. Some of these samples were examined for fluid inclusions so that brine cooling gradients could be drawn from the inclusion homogenization temperatures (Sect 5.4). The gradients indicate the direction of brine flow and hence can be used to detect feeder intersections.

All of the samples were analysed for the trace elements Y, La and Ce. Concentration gradients of these elements in fluorite were found and, again, these indicate brine flow directions, pinpointing orebody feeders (Sect. 6.3)

Other methods were devised in attempts to predict orebody terminations or improve brine flow direction determination. Though described in Section One of this thesis they proved either unsuitable or else could not be perfected in the time available.

Much emphasis has been placed upon locating orebody feeder (and exit) conduits in order to build up a better picture of the geometry of hydrotherical systems. This enables certain predictions regarding extensions or terminations

of known mineralization. To a certain extent surface observations of vein strike variations etc. can show that in this or that part of a vein there were structures favourable for mineralization i.e. cavities existed, and perhaps that cross veins existed, capable of providing feeders for the mineralizing brines. However, by tracing brine flow directions in a nearby section of known mineralization it should be possible to say with confidence whether or not mineralizing brines did enter and pass through the projected structural openings. Moreover, the presence of a vertical feeder conduit implies continuity of mineralization in depth and above, hence provides a reference point for further exploration at other stratigraphic horizons.

Feeders are most frequently found as fault intersections. The intersecting fault may be mineralized and may present an exploration target or opportunity in itself, particularly if it is of favourable trend. Often when working wide ore bodies, such as are characteristic of 'quarter point' veins, the vein walls are seldom exposed. Sometimes a mine may rework for fluorspar a vein that has been 'slit' for the ribs of sulphide ores that it contains. Thus the conditions underground are seldom favourable for the identifiaction of intersecting veins, unless they shift the main vein (and this is very rare). In these situations, rapid mineralogical and geochemical techniques have places in assisting exploration and development in the mines of the North Pennines.

8.4. Rookhopehead and the Greencleugh Veins

Westwards from Groverake the Red Vein system comprises three main veins named, from north to south, Red, Greencleugh and Groverake (Fig 8.5.) Little is known of the so-called Red Vein here except that it continues as a fault structure, is probably poorly mineralized at surface and has never been considered worthy of trial at depth. Minor ironstone flats in the Lower Fell Top Limestone that must be related to the vein and associated faults have been worked from Hole Heads opencut and a quarry just south of the road, at North Grain. Groverake Vein becomes impoverished west of Groverake Mine and stoping in the Great Limestone followed a N.W. branch vein. This probably intersects Greencleugh Vein in the region of Frazar's Hushes (a series of ancient, surface lead workings). A small flier may continue to the N.W. of the intersection but apparently does

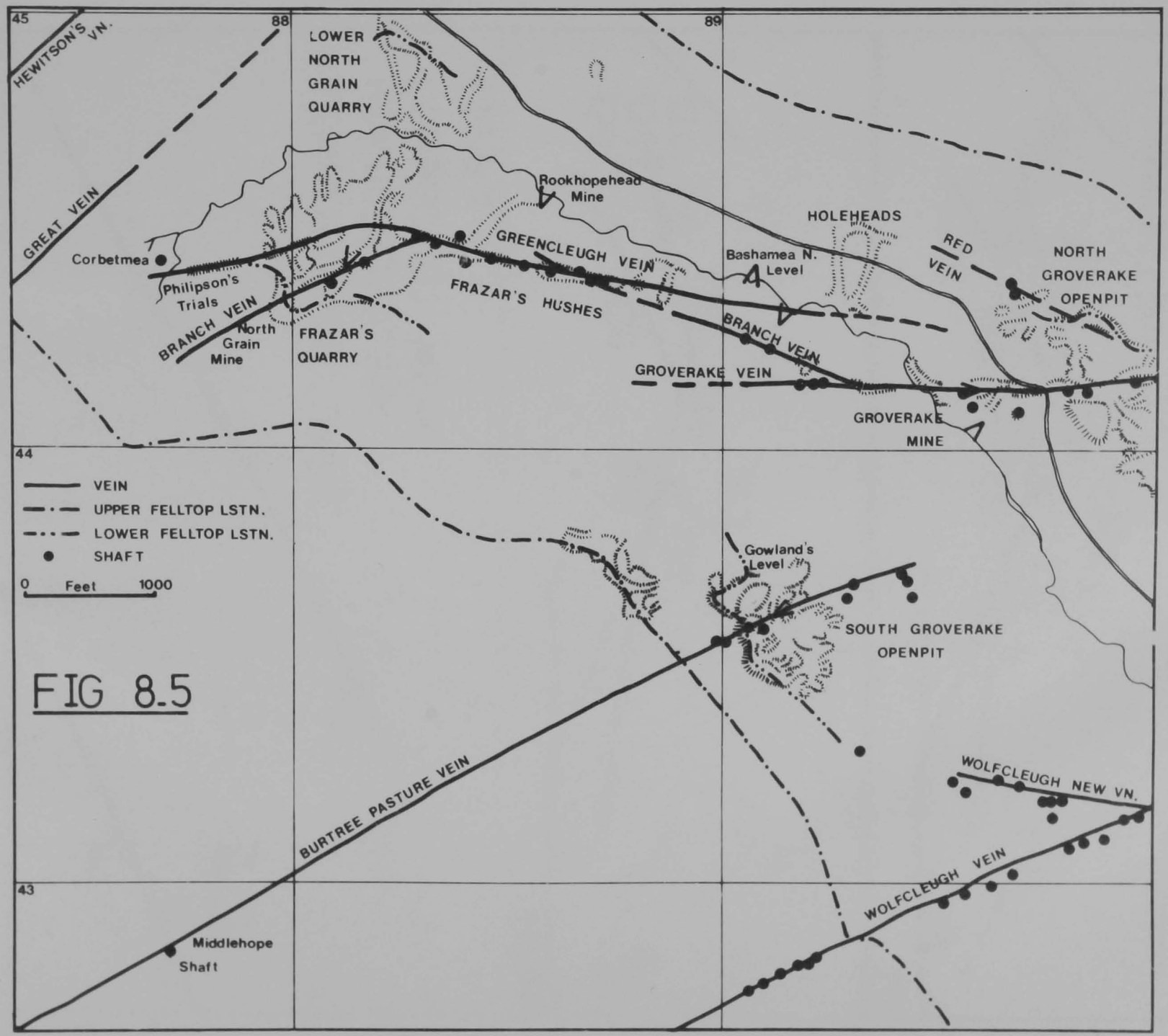

45
88
89
44
43
HEWITSON'S VN.
LOWER NORTH GRAIN QUARRY
GREAT VEIN
Rookhopehead Mine
HOLEHEADS
RED VEIN
NORTH GROVERAKE OPENPIT
Corbetmea
Philipson's Trials
BRANCH VEIN
North Grain Mine
FRAZAR'S QUARRY
GREENCLEUGH VEIN
FRAZAR'S HUSHES
Bashamea N. Level
BRANCH VEIN
GROVERAKE VEIN
GROVERAKE MINE
VEIN
UPPER FELLTOP LSTN.
LOWER FELLTOP LSTN.
SHAFT
0 Feet 1000
Gowland's Level
SOUTH GROVERAKE OPENPIT
BURTREE PASTURE VEIN
WOLFCLEUGH NEW VN.
WOLFCLEUGH VEIN
Middlehope Shaft

FIG 8.5

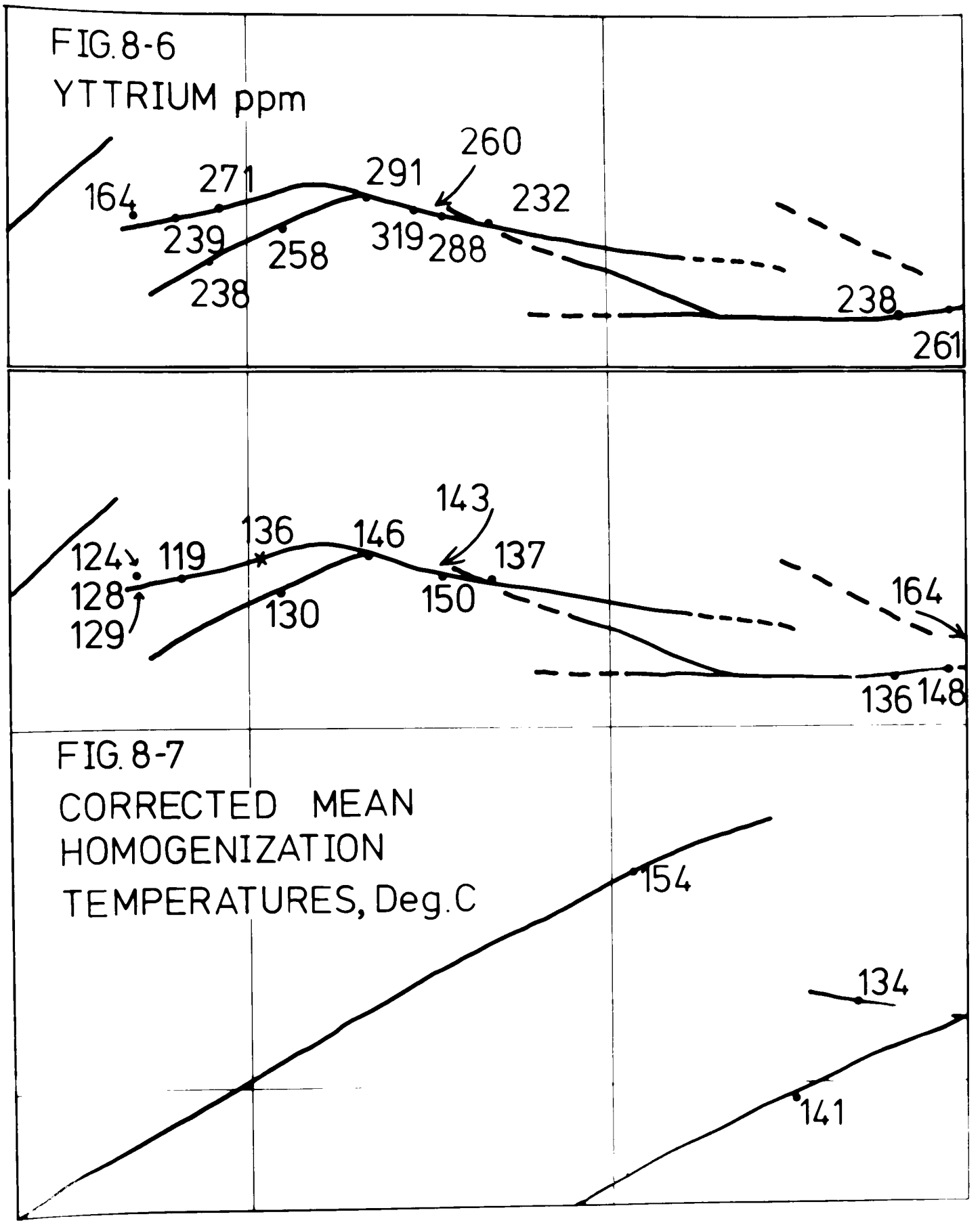


FIG. 8-6
YTTRIUM ppm
164
271
291
260
232
239
258
319
288
238
238
261
124
119
136
146
143
137
128
129
130
150
164
136
148
FIG. 8-7
CORRECTED MEAN
HOMOGENIZATION
TEMPERATURES, Deg. C
154
134
141

not reach the adit level of Rookhopehead Mine where no mineralization north of Greencleugh Vein is recorded on a rough plan held by W.L.C. A S.W. trending branch vein leaves Greencleugh Vein at the western end of the Hushes and is probably largely responsible for extensive metasomatic ironstone deposits in the Lower Fell Top Limestone, worked by Frazar's Quarry and North Grain Mine. Galena, sphalerite and fluorite occur sporadically in the sideritic ironstone. Chalcopyrite has not been found west of Groverake. Fluorite samples from the Greencleugh veins were collected from shallow opencuts, run-through stopes and small shaft tips. Specimen 111 was obtained on dumps from North Grain Mine and specimens 119 (1, 2 and 3) from Corbetmea Shaft, presumably derived from trail workings on Greencleugh vein in the Firestone Sill.

Fluid inclusion results (Fig. 8.6) show a marked cooling of ore brines west of Frazar's Hushes, which appear to be located on feeder zones associated with the two branch vein intersections. Yttrium results (Fig. 8.7), too, show a clear maximum at the Hushes, confirming the presence of feeders. Interestingly the Hushes are the only lead workings of any size in the area. Fluorite ore potential for the area as a whole seems reasonably good, though a number of trials have been made for this mineral in recent years, without great success (Philipson's workings, 1940: Rookhopehead Mine, 1944; Ridley's Shaft, 1957) Good ore widths have been reported (Durham. 1952), but are not continuous. It must be remembered that the strata at this horizon are very irregular, and this may have had an adverse effect on open vein channels. Washout sandstones may occur at depth, however, at around the Firestone Sill (Sect. 3.1.5). The best location for a trail to depth is Frazar's Hushes, in the feeder area. Fluorite formation temperatures, corrected and reduced to the level of the Great Limestone using a vertical cooling gradient of $1^{o}C/10m$, are up to $161^{o}C$ and are thus comparable with feeder temperatures at that horizon elsewhere on the Red Vein system, but are somewhat cooler than feeder temperatures in Groverake Mine. Progressive westward cooling of ore brines from Groverake Mine is further

illustrated by the relatively low temperatures (recorrecte 130-149°C at Great Limestone, Sawkins, 1966; corrected 137°C No. 807, Old Vein, 128°C. No. 808. Diana Vein, this study) recorded for fluorite from Allenheads Mine (now called Beaumont Mine). Although the Red Vein system, as such, has not been followed beyond Rookhopehead, its structural continuation is probably represented by strong, en echelon, E.W. veins at Allenheads.

8.5 Groverake Mine

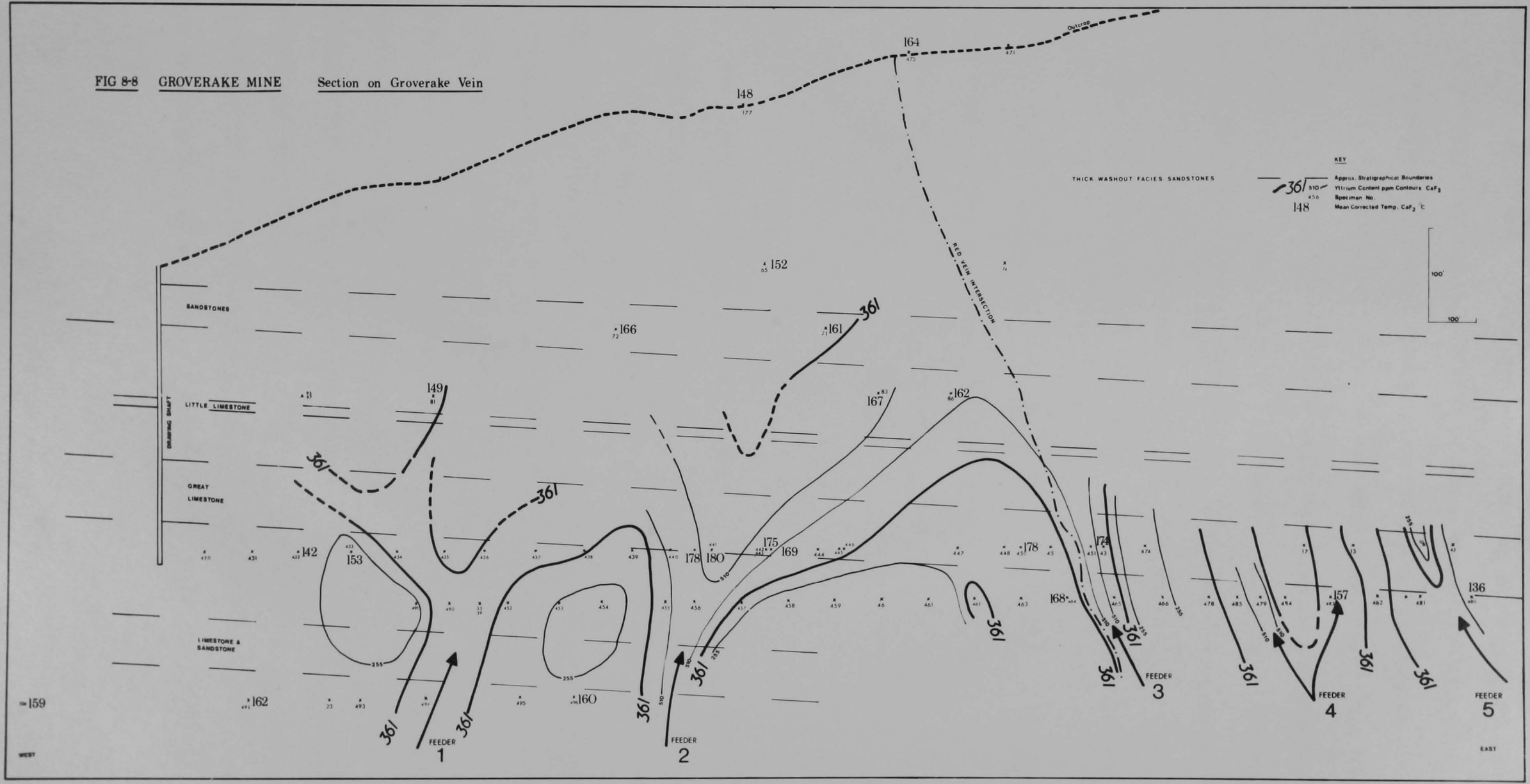
Old lead and fluorspar workings around the intersections of Red, Greencleugh and Groverake Veins now form Groverake Mine. Burtree Pasture Vein is believed to join the other veins but has not been positively identified. A number of other branch and loop veins may be distinguished underground. The interrelations of all the veins are far from clear. Massive orebodies in the Upper Limestone Group occur mainly on Groverake Vein, which is the most nearly E.-W. of the group. The extent of the massive deposits is governed chiefly by the location of washout channel sandstone. Normal ribbon-type ore shoots occur in the Middle Limestone Group.

Fluorite samples were collected mainly from the lower workings on Groverake Vein. They were taken in a systematic fashion on a sample separation of 100'. Details noted at each locality (where possible) included: i. exact position of sample in vein; ii. approximate vein width; iii. presence and scale of early phase mineralization; iv. presence and amount of chalcopyrite; v. disposition of nearby mineralization, i.e. proximity of branch veins, flats etc.

It had been expected that results would simply verify that the main intersection, with Red Vein, had acted as feeder to the orebodies. Thus it was surprising that in fact five feeders were found at the horizon of about the Four Fathom Limestone, three of which could be seen to bifurcate upwards. Two feeders, including Red Vein intersection, were shown by temperature results to have been of greates importance.

Results are plotted on Fig. 8.8., a schematic vein section. Yttrium values, in ppm, are contoured using a root two scale. Mean formation temperatures, corrected for pressure, are represented individually. Certain intersections

FIG 8-8 GROVERAKE MINE Section on Groverake Vein



were observed during sample collection, and were shown up clearly by yttrium and temperature maxima. Following inspection of these maxima, values of Y greater than 360 ppm were accepted as having significance in indicating feeder proximity. This enabled demarcation of the main feeders and flow direction. The flow rates in each feeder may be compared using the temperature results. (The feeders are numbers 1 to 5 on Fig. 8.8.) Feeders 2 and 3 sustained high flow rates, maintaining high brine temperatures and slight cooling gradients. Geothermometric work can show more detailed cooling gradients, hence flow directions, in individual oreshoots but these are not clear from the few results presented here.

Feeder 1 bifurcates between the 60 and 50 Fms Levels. In the 50 Fms Level the western channel coincides with a section of abnormally wide vein (approx 6 m in old stopes), the eastern channel is associated with a minor vein intersection. This intersection is somewhat more important on the 60 level.

Feeder 2 coincides with a loop vein complex bearing strong mineralization. In the 50 Fms Level there are only two leads to the loop, which is about 30-40m in length here. The Firestone Drift has proved three leads, all strongly mineralized, for more than 200 m and thus demonstrates the opening out or funnelling upwards of the loop complex. The form of the structure in depth is difficult to predict. Certainly, on the 60 Fms Level there is a minor vein intersection corresponding with the eastern loop join, but exploration on the 80 Fms. Level has not proceded far enough to prove the structure beneath the loop disappearance, in its 'root zone'. This funnelling feature seems common to all the feeders here, indicating a shortening and narrowing of oreshoots in depth. The broader, more open nature of feeders in the upper strata is explicable in terms of the general widening of orebody cavities higher in the sequence (Sect. 2.2.) and the presence of washout sandstones, particularly in the east. Feeder 3 follows the main intersection of Red Vein with Groverake Vein. Feeder 4 is

represented by two channels in the 60 Fms Level, probably coalescing in depth. The Western channel coincides with the intersection of Groverake Vein with a small vein from the north. Feeder, 5, just penetrated at the time of sample collection has been proved, by mine development, to coincide with a branch in the vein. Thickening of the early phase cheek occurs at each feeder, particularly at numbers 2, 3 and perhaps 5. These three are also associated with high concentrations of early phase chalcopyrite.

The identification of these feeders enables certain predictions regarding future prospects at the mine.Feeders 2 and 3, with their high brine temperature (in the region of 180°C) are clearly central to the main mineralized zone seen at present. Eastwards the brine temperature was much lower, (136°C), indicating lower flow rates, probably poorer mineralization and possibly the termination of the ore-zone. The lower flow rates may be a natural consequence of orebody narrowing in this direction. In depth, feeder zones are contracting into presumably well-mineralized pipes, rich in chalcopyrite, providing exploration targets. One clear example of the usefulness of the information may be taken from the 80 Fms Level. Driven inthe Natrass Gill Hazle, the level opened out orebodies from the Whimsey Shaft to a point about 875' E. of the Drawing Shaft where it was stopped in a much impoverished vein. Temperature results from this horizon show that brine flow from feeder 1 was stronger to the west than the east. The yttrium contours on Fig.8.8 show that the abandoned forehead was about halfway between two feeders. The cause of the impoverished vein in this area is probably related to vein strike changes, but these have not been measured. Further trials at this horizon should be made beyond this stretch of constricted ground, towards feeders 2, 3 and 4, all of which seem to have supported higher and hotter brine flow than feeder 1.

8.6. Redburn Mine

Redburn is an entirely new mine, begun by the Weardale Lead Co. in 1964 and working fluorspar from a previously untouched section of Red Vein. Neither Mill Level nor the Weardale Iron Co's Redburn Level are believed to have reached Red Vein, though this had been their objective. Current fluorspar production is in the region of 20,000 tonnes of concentrates (mainly acid grade) per year. Two ore-bearing zones have been discovered, separated by a length of ground in which no obvious vein channel can be seen. The disposition, of orebodies within the ore-zones of the mine shows a striking resemblence to a partial array of en echelon tension gashes (Section 8.2.2.)

Geological plans (1:500) of the 17 Fms Level and sublevel and of No. 5 Rise (to surface) were made covering the western ore-zone during 1970 and 1971. The 40 Fms Level was geologically surveyed in December, 1972. Plans of the central part of the 17 Fms Level and the eastern ore-zone had been made previously by Dr. A. Hall.

Mining operations during the last three years have, apart from the driving of the 40 Fms Haulage Level, been confined to the western ore-zone.

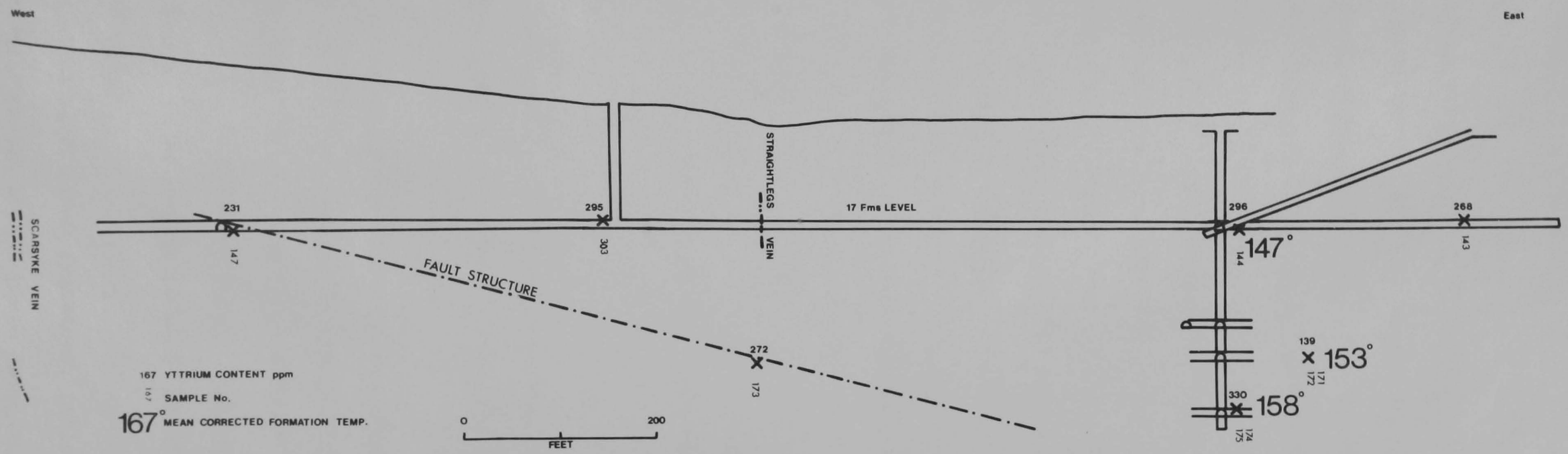
8.6.1. Eastern ore-zone

The earliest mine workings were founded in this zone, penetrated to a depth of 98 m by Redburn Shaft. Orebodies have been worked out from the Coal Sills to the shales above the Three Yard Limestone. Boreholes have proved mineralization down to at least the Tynebottom Limestone. Orebodies have well-defined lateral limits. They have the form, in plan, of sigmoidal lenses up to 5.5m in width around the midpoint, narrowing at either end. The eastward terminations have not been fully explored owing to the proximity, in this direction, of water-filled workings on Red Vein and Mary's Vein from Boltsburn Low West Level. The Great Limestone orebody, however, can be seen to narrow and break up in a region of strong ironstone flats. This is taken as an indication of termination. The Nattrass Gill orebody, too, appears to narrow

and is split by horsts of country rock in this direction. The western terminations are problematical and appear to be associated with an unusual fault. This is well exposed in the 40 Fms Level (143.4 m West of the shaft) as a thrust, trending N.23°W., dipping 60° to 80° E.N.E. and displacing the top of the Nattrass Gill Hazle 1.8 m down to the W.S.W. It predates mineralization since the Nattrass Gill sandstone shows intense hydrothermal rotting approaching the fault plane, and the plane itself carries mineralized breccia with some uncrushed quartz and fluorite crystals. This particular exposure is some 6.1 m from the main vein. The intersection of this thrust with Red Vein is no longer visible, the relevant stopes being in states of collapse, however it is reported that the vein narrowed and pinched out beyond the thrust. Borehole records verify that vein widths decrease by 3 m across the thrust. The projected line of the thrust to the 17 Fms level, in the Great Limestone, corresponds with a normal fault, trending N.40°W. and throwing more than 1 m to the N.E. (shown on Hall's geological survey, 1968-1970). Again the orebody narrows considerably (in the order of 1-2m) across the fault and was followed for only eight further metres. Where the fault is cut again in the 17 Fms Level, further to the N.W. it has broken into a series of minor fractures, near a complex intersection of small faults of 1600' from the shaft.* Until this fault and its mechanics are better understood it is impossible to suggest an explanation. to the orebody terminations, with confidence. It appears, however, that the 17 Fms orebody, judging from its sigmoidal form, was approaching termination anyway when intersected by the fault. The orebodies in lower beds are prematurely terminated. The action of the fault is probably best described at present in terms of Varvill's cross vein theory (Section 8.2.3.) in which the tensional movement required to open an orebody cavity was taken up in wrench movement

*Footnote: Footages along the 17 Fms Level were taken from 1:500 mine plans

FIG.8-9 Section, Redburn Eastern Ore-zone



on this pre-mineralization structure.

The line of Straightlegs Vein can be projected from shafts south of Rookhope Burn to intersect Red Vein approximately 76m west of Redburn Shaft. In fact a strong, vertical fracture zone, trending N. 64°E. and mineralized with ankerite, fluorite and quartz, cuts Red Vein 137 m west of the shaft and almost certainly represents the other lead vein.

A total of nine samples were collected from this ore-zone, four of which were used for fluid inclusion study, providing a vertical temperature gradient of 1°C/6.3m between the 50 and 17 Fms Levels (Sect. 5.6.). The yttrium concentration data are insufficient to use for feeder detection. They do show, however, rather lower values at each end of the orebodies than in the central portions (Fig. 8.9.), verifying that these ends are some distance from feeders. The analyses also show a considerable increase in quartz contamination in the end samples. This is partly due to the increased brecciation of these narrower veins and hence to the difficulty in collecting pure samples, but it is also a real effect noticed along the whole length of Red Vein occuring with orebody termination. The quartz is generally milky, fairly coarsely crystalline and associated with brown carbonates and calcite.

8.6.2. Central Zone

The 17 Fms Level, turning approximately N.W. from the eastern ore-zones, pursues a sinuous course for a further 1,060 m before intersecting the western ore-zone.

Four veins can be projected to intersect the course of the level. Scarsyke Vein and Little Scarsyke Vein may be represented by groups of very minor quartz and ankerite stringers at about 1225' - 1250' and 1800' - 1900' respectively, both in line with shafts south of Rookhope Burn. Scarsyke Vein can be seen in old stopes from Tailrace Level to average about 50 cm of limonitic iron ore, fluorite and quartz.

Rispey Vein comprises a complex of mineralized fractures, filled with quartz, ankerite, siderite and pyrite (indicating a late phase infilling) in limonitized and silicified limestone at 2420'. West of this, at 2450' is a

narrow stringer of vuggy quartz and blue fluorite, the formation temperature of which is 129.5°C (no.667). The high yttrium content of the fluorite (542 ppm) indicates the close proximity of a feeder point, though the low formations temperature suggests that the feeder was relatively weak. Rispey Vein in the 40 Fms Level occurs between 700 and 750m, similarly composed of a complex of fine quartz and ankerite stringers trending from N.45°E. to N.75° E. (throwing a little S.S.E. down) with, to the west, two close, parallel veinlets of vuggy quartz veined by ankerite (no fluorite), trending N.74°W., throwing S.S.E. side down. Rispey Vein has been worked extensively from Rookhope Valley, originally for galena, but more recently for siderite (and ankerite) iron ore. Tips and bell-shafts around Rispey Syke Levels demonstrate the presence of mineralization (massive fluorite with galena and quartz) in the Firestone Sill up to about 500m of Red Vein, beyond which trial pits appear to have been barren.

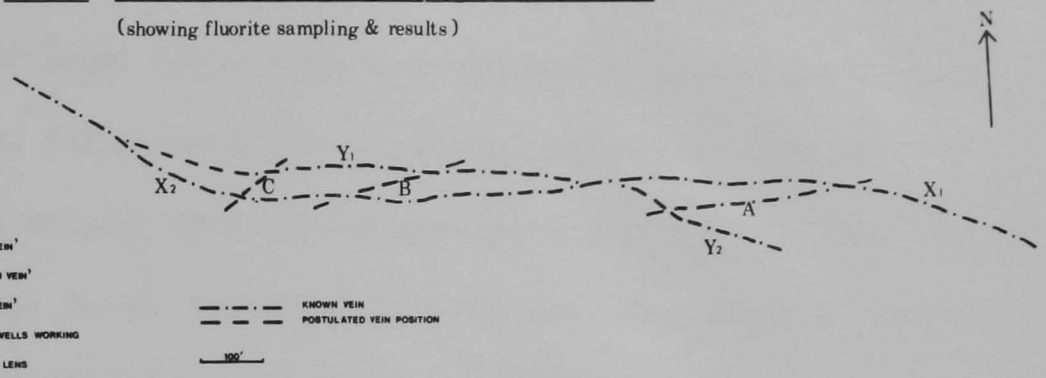
An unnamed vein (or veins) trending N60.°E, cut by Tailrace Level and marked by old shafts by the Rookhope-Allenheads road does not appear to reach Red Vein.

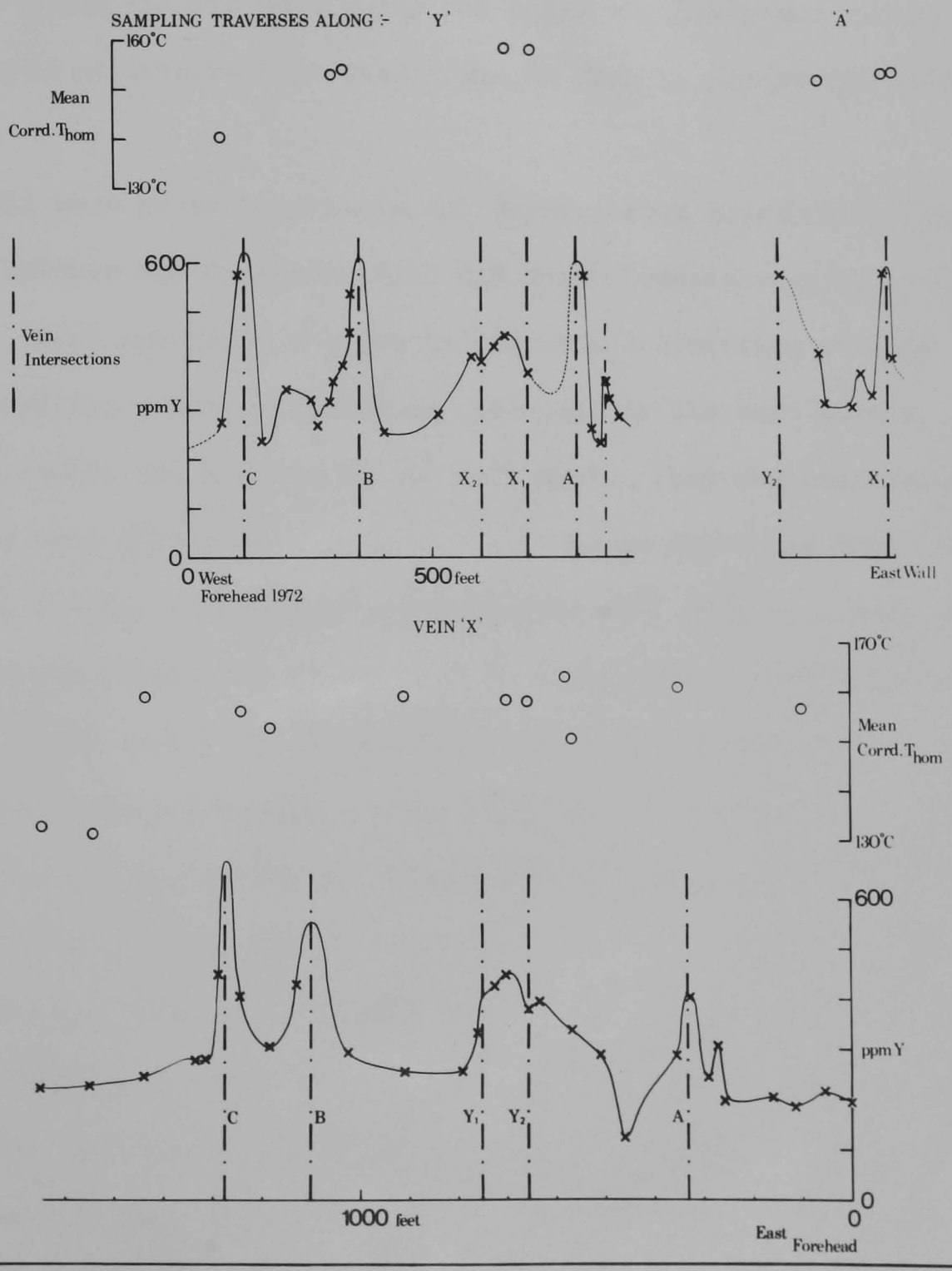
8.6.3. Western ore-zone

The 17 Fms Level first struck vein mineralization of this zone at 3920'. This proved to be another lensoid (seen in plan) body, containing very siliceous fluorspar ore (in places 30% SiO_2), severely brecciated by post-ore slickensiding. The level was driven along this for 200m in the Great Limestone until it had narrowed in the west, to about $\frac{1}{3}$m of crushed veinstuff (14% SiO_2 - spec. 302). Turning N.W. again the level cut the main productive orebodies of the ore-zone, off-set by about 61m. The nomenclature of veins in the western ore-zone, adopted in this work, is shown on Fig. 8.10, with the corresponding names used by the miners. Two main veins, X and Y, each trending very approximately E.-W. intersect at an angle of 15°. This main vein intersection forms the widest part of the ore-zone since not only do both veins trend most favourably here for orebody cavity formation (assuming sinistral movement) but they seem to run alongside for a short distance at the intersection itself. Beyond this intersection both

FIG. 8-10 WESTERN ORE-ZONE, 17 Fms LEVEL, REDBURN MINE

(showing fluorite sampling & results)





veins show a tendency, at differing distances, to turn from E.-W. to a maximum of N.55°W. This change to a structurally unfavourable trend caused orebody narrowing and impoverishment. Orebodies above the Great Limestone become shorter approaching the surface. It is difficult to be sure of this, though, since the orebody 'terminations' have not been fully explored yet and may simply be caused by local pinching. On the other hand the sigmoidal aspect of the vein (the high mine levels are driven mainly upon X) becomes more pronounced, the central, structurally favourable, E.-W. trending portion becoming shorter towards surface. The distance over which the two main veins run together, increases markedly in C level and the area of intersection itself can be seen to plunge westwards through the mine.

The overall hade of both veins is not great, being measured at about $3\frac{1}{2}^{o}$ to the north between the Firestone Sill and Great Limestone by No. 4 Rise. Locally, however, there are rapid changes in degree and direction of hade. The orebodies themselves stand approximately vertical in the hard strata, but, wherever the vein faults are seen in thick, soft shales they hade considerably. For example, where vein Y(1) passes up into black shales above the Great Limestone in stopes from No. 9 Rise, it hades at approximately 30°- 40°S. in a mass of minor slides and crush zones, yet at the same general horizon at No. 6 Rise (further east) it hades only 8°S. This difference is accounted for by the presence of a washout channel margin, in the High Coal Sill sandstone, thickening eastwards and increasing the competence of these strata (Secn. 3.1.4.). The influence of lithology upon hade is emphasized in a Conolly Contour diagram, Fig.8.11. An arbitrary, vertical reference plane has been selected (corresponding with grid line N543800). The distance, in feet, between the plane and the southern wall of the vein has been determined at regular intervals and contoured to provide a picture of the vein structure. At the margins of the ore-zone the contours are vertical and closely-spaced indicating that the vein fracture is essentially vertical here and that the strike is rapidly changing. In the central, productive part of the ore-zone there is very slow strike change, but important hade variation takes place. A geological section transposed on to Fig. 8.11

FIG 8.11 Connolly Contour Diagram, Western Orebody, Redburn Mine

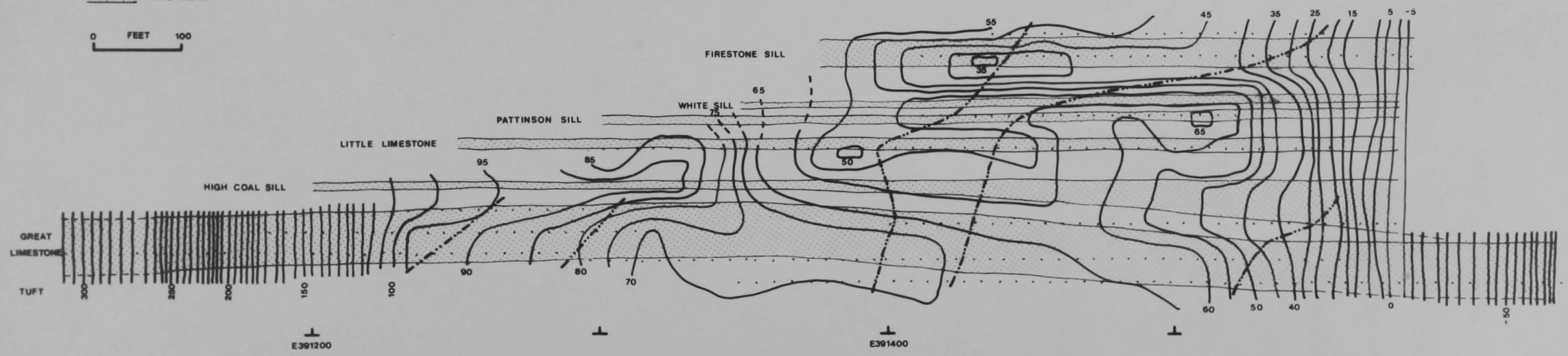
PROJECTION OF SOUTHERN WALL, VEIN X, TO THE VERTICAL PLANE N 543800. DISTANCE CONTOURED AT 5' INTERVALS

DATA POINT (20' INTERVALS)

VEIN INTERSECTION

HARD STRATA MAPPED DURING THIS WORK

0 FEET 100



demonstrates the close relationship of hade and lithology. Areas of rapid hade change, indicated by closer vertical spacing of contours, tend to correspond with shale beds. Moreover, the dip of contours frequently reflects the dip of the hard strata, picking out the minor faulted anticline in the Great Limestone, towards the west of the zone, and the High Coal Sill washout margin in the east of the zone. There is insufficient data to indicate the hade change occurring beneath the Great Limestone in the variable sandstones, silts and shales of the Tuft, although underground measurements show that vein X(2) hades at 30°N.,narrowing downwards in the 17 Fms. Haulage Level. If the 3m orebody above here had been opened by vertical movement alone, then a displacement of 5m would have been required (Sectn. 2.2.). In fact, the vertical displacement here is ca.40 cm. Considerable longitudinal displacements, in the order of 15m (sinistral on X(2) in 'branch vein' stopes), can be demonstrated by mapping wall-rock features. The complication of post-ore wrench faulting of course makes it impossible to ascribe all the present day displacement to the original fault movement. However, it can be calculated, given that the strike changes by 35° west of the ore-zone, that a sinistral displacement of 3m is all that would have been required to open up a 2m wide cavity on the original fault.

Two productive E.N.E.trending lead veins, Greenwell's and Wolfcleugh, can be traced from Rookhope Valley towards Red Vein and the Weardale Lead Co was anxious to locate them in Redburn with a view to testing them at their intersection with Red Vein. One of them,Greenwell's,has now been located, after more than three years, during a recent exploration programme of diamond drilling and cross-cutting. It lies south of the ore-zone at a position implying an overall hade of 29° S.E. from surface to the Great Limestone, and though rich in galena, does not carry sufficient fluorite to be economically worked. In the meantime an interconnecting cross vein, A, trending N.86°E,° dipping 80°to the west, was found (fig. 8.10) carrying up to 2.5m of vuggy quartz and fluorite.

Approaching the projected intersection of A with Y(2) both veins become filled with vuggy silica minerals carrying chalcopyrite, pyrite and marcasite. This concentration of early phase minerals indicates the proximity of a feeder i.e. at the intersection. Analyses show that this intersection and the other known vein intersections in the ore-zone are marked by maxima in the yttrium content of the vein fluorite (Smith, F.W., 1974) Examination of the main veins to the west showed up four further areas of copper-rich early phase minerals, two on each vein, X and Y. These again correspond closely in location with maxima of yttrium concentrations in fluorite and have been taken as indicating the intersections of two more interconnecting veins, B and C, with the main veins. Sampling in E, D and C levels, above, provided a three dimensional picture of these and the other vein intersections in the ore-zone. Vein B trends approximately N.72°E.and Vein C approximately N. 45°E. The true dips, found from these trends and the apparent dips (from Y maxima), are 70°and 52° to the N.W. respectively (found by stereographic projection). No exposures of B and C are accessible although a strong, sub-vertical fracture zone occurs in the vein wall about 3m N.W. of the intersection of B with Y(1) in the 17 Fms Haulage Level.

Fluid inclusion temperatures, Fig. 8.10 are fairly constant at about 155-160°C within the productive area. This is probably due to the high number (7) of feeders in such a small area permitting high, bulk, vertical, brine flow and simply heating the whole area to a uniform temperature. The vertical cooling gradient is high, measured at 1°/2.5 m from the Great Limestone to the Firestone Sill. Beyond the central productive area, with its feeders, the temperature falls to 133°and 130°C (specimens 140 and 396) near the western forehead. The background values of yttrium in fluorite also decrease in this direction and indicate the termination of the orebody. This isstrongly supported by the occurrence, near the forehead, of a large amount of vuggy quartz (with no chalcopyrite) in the vein, associated with extensive ankerite-siderite metasomatism of the host limestone. Two possible ways of locating further orebodies west of this point are as follows:

Firstly, if the tension gash theory (Sect 8.2.2.) is correct then a potential en echelon continuation body should exist to the N.W. offset by about 50m. Although still not in line with the highly productive Groverake Vein, this potential body would be in line with Red Vein in its easternmost workings in the Great Limestone at Groverake Mine. Alternatively, if it is considered more likely that the present vein fracture continues (the western forehead is still in mineralization) then this could be followed again to the N.W. in the hope of finding another zone in which the vein trend changes towards E.-W.,opening an orebody. The change of this occuring is not good, considering the behaviour of Red Vein elsewhere in Redburn, but there is certainly a sufficient distance between Redburn and Groverake to accommodate such an ore-zone, (again offset by about 50m) up to about 210 m in length, without resorting to very abrupt changes in trend. Discussion of continuation of the ore-zone in depth is unnecessary since the high density of strong feeders in this ore-zone indicates a strong source of mineralizing brines beneath the presently known orebodies. The 40 Fms. Level is being driven at present to intersect the ore-zone in the Nattrass Gill Hazle at about the feeder locations.

8.7 Red Vein in Boltsburn Mine and Mary's Vein

Between Redburn and Stotfieldburn Mines is a stretch of scarcely worked ground totalling 1.8 km in length. The central and western part of this was explored by the Low West Level from Boltsburn Mine, following Red Vein in the Great Limestone. Five E.N.E. trending, intersecting veins were proved between and including Boltsburn and Fulwood Veins. Dunham (1948) reports, however, that mineralization was nowhere strong and that only iron ores were worked from this level. Red Vein strike (Fig.8.12), though variable, is often considerably off E.-W., sometimes reaching N. 45°W. Presumably, under the influence of the dominant sinistral, N.W. directed shear couple the vein remained mainly closed, except for a few E.-W. trending lenses. Mary's Vein, trending exactly E.-W. is cut and displaced (including post-ore displacement) by Red Vein at about Rookhope Burn. It has been stoped out, for lead ore in the Great Limestone for 160m. Later trials for the vein from Lintzgarth Shaft, in the west, found it closed.

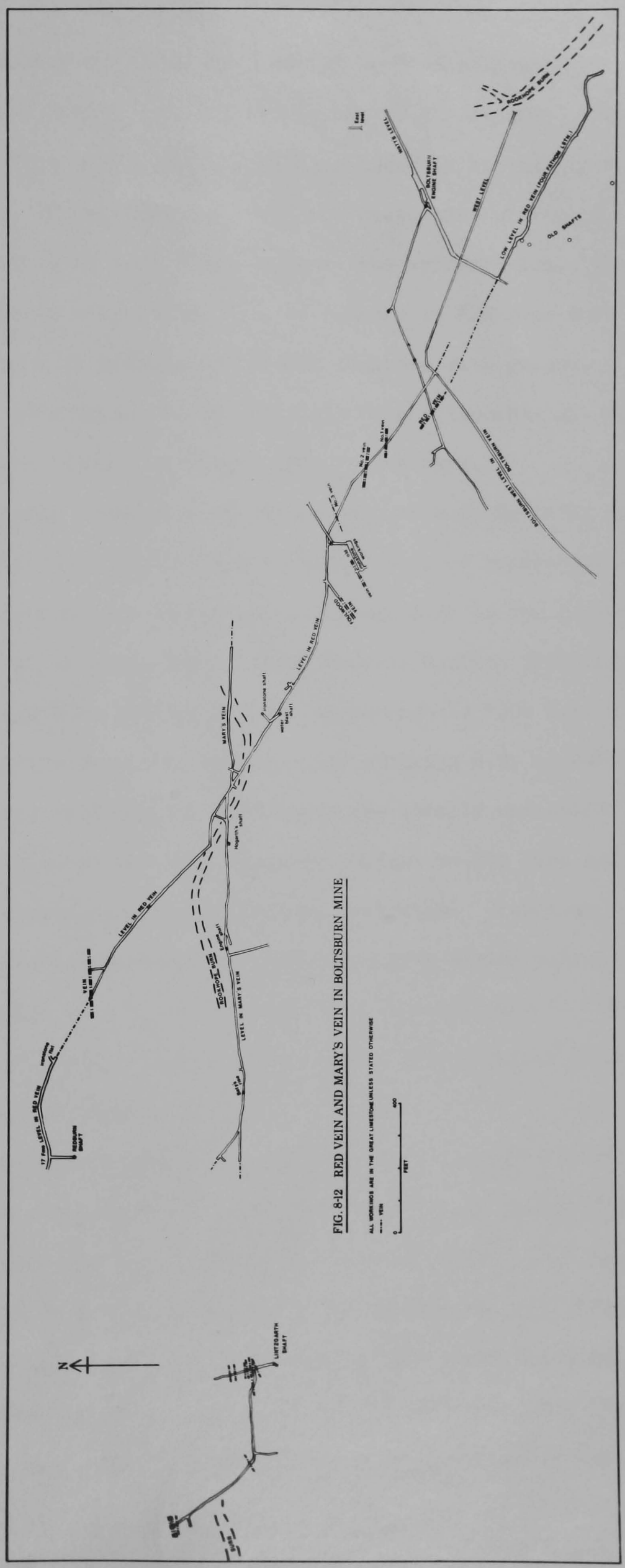


FIG. 8-12 RED VEIN AND MARY'S VEIN IN BOLTSBURN MINE

Judging from this information and from the scale of surface collapses following the vein between Baty's Rise and Engine Shaft, the orebody seems to have been lensoid. Red Vein itself, having changed trend favourably to N.60°W. is shown on a plan (no. B.O. 46 Weardale Lead Co.) as containing widths of 3' to 4' of 'Spar with spots of ore' for 150m about the intersection. This situation continues to surface where Red Vein is exposed in Rookhope Burn carrying approximately $1\frac{1}{2}$ m of somewhat siliceous fluorite with galena. These reserves have not been exploited and may well be inaccessible due to the proximity of collapsed and flooded workings, open to the burn.

Mary's Vein probably forms part of the en echelon orebody array at Redburn (Fig.8.1.). So too does another E.-W. trending vein, of unrecorded width, bearing fluorite and ironstone and marked as occurring close to the forehead of Low West Level (i.e. it is about 46m south of Redburn Eastern Orebody). Though called Straightlegs Vein on Plan B.O.46, it intersects 150m S.E. of the projected line of that vein, moreover, Straightlegs workings S.W. of Rookhope Burn trend N. 50°E., showing that the two structures are totally unrelated.

The Mary's Vein orebody was thus probably subject to the same structural constraints on lateral development as the Redburn orebodies. Orebodies on Red Vein in Low West Level are probably controlled by vein strike variation (Sect. 8.2.1.). East of Low West Level, Red Vein has been followed in the Four Fathom Limestone by a trial ("Low Level") from Boltsburn Engine Shaft. It was found to be "gouge-filled".

Between Boltsburn and Stotfieldburn Mine the vein is poorly known from borehole data. Evidence from the Rookhope Borehole (discussed in Sec. 5.6.) shows that the vein splits into two, narrow, but strongly mineralized veins at depth, associated with rich flat deposits in the Tynebottom, Jew, Lower Little and Lower Smiddy Limestones. Inclusion temperatures from these deposits however are relatively low compared with nearby hot-spots, indicating that this was not a major feeder area. The trend of the vein between Boltsburn and

Stotfieldburn is so far from E.-W. that no orebody cavities could be expected. Indeed, inclined exploratory boreholes in this region have failed to find strong vein mineralization despite the presence of promising flat deposits. This, to an extent, confirms Dunham's observation that flats tend to form where the parent vein is constricted and blocked.

8.8. Stotfieldburn Mine

This mine, now abandoned and inaccessible, worked lead and fluorspar ores during the periods 1863-1884 and 1914 to 1964. Total fluorspar production is estimated in the region of 200,000 tonnes. A length of about 1.3 km of Red Vein was explored, in which two major ore-zones were discovered.

The main vein trends approximately N.80°W. Three branch veins, trending between E.-W. and N.82°E. have been worked. The two main ore-zones coincide with the intersections of these branch veins with Red Vein (Fig. 8.13). Further minor orebodies occur where Thorny Brow Vein (here two parallel veins about 0.5m wide, some 5.3 m apart) intersects the main vein.

Both ore-zones fall within the margins of a Coal Sills washout sandstone belt (Section 3.1.4.) which roughly coincides with the mine limits. The eastern ore-zone is also within the western margin of the Tuft washout (Sect. 3.1.3.). Hence orebodies of unusual height were formed.

8.8.1. The Western ore-zone

Orebodies in this zone (Fig. 8.13) were first worked for galena by the Rookhope Valley Mining Co., 1863 - 1884. They were by-passed by the Weardale Lead Co. when the mine was reopened in 1914, but were later to provide a significant part of the new company's fluorspar production.

The ore-zone, between Low Shaft and Small Shaft, has been developed to the 65 Fms level in the shale beneath the Six Fathom Hazle. Boreholes have proved deeper mineralization in the Cockleshell Limestone. This was believed to be too siliceous to be worked economically for fluorspar. Gowland's vein, trending almost due E.-W. intersects the central portion of the zone from the east.

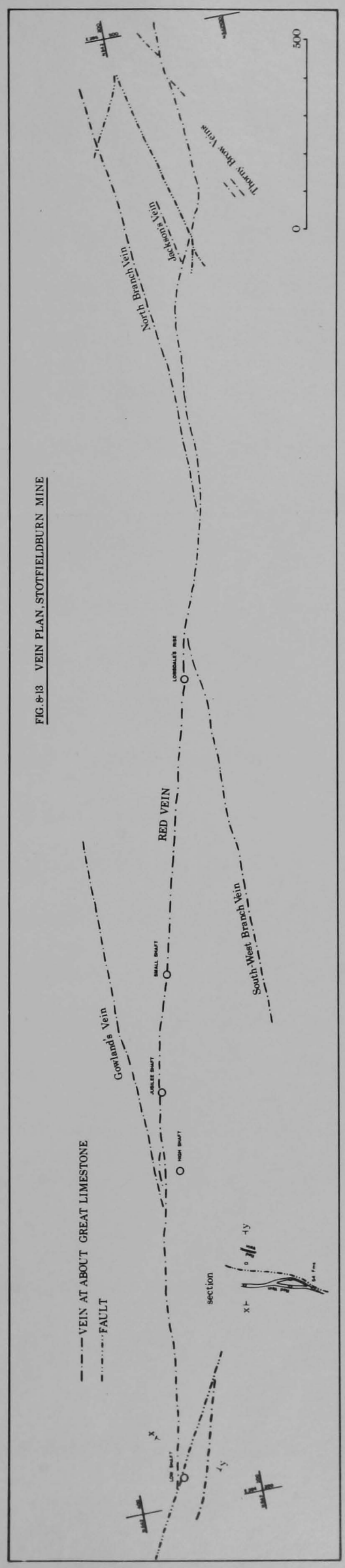


FIG. 8-13 VEIN PLAN, STOTFIELDBURN MINE

It is not known to continue beyond Red Vein to the west, although Mr. H. Green has pointed out that an ancient shaft at about 1200'O.D. on Snailsburn Common, is on the line of the vein. Geological plans of the western orebody, surveyed by Freeman and Hallett in 1959, show widths of up to 11.5m of siliceous fluorspar ore. Chalcopyrite is recorded close to Gowland's Vein intersection in the 15 and 25 Fms Levels,becoming generally abundant in deeper levels. This intersection, then, appears to have acted as main feeder to the ore-zone.

The ore-zone terminates to the west against a post-ore wrench fault with approximatly 100 m sinistral displacement. The vein has been located by drilling beyond this fault, but was not worth working. The fault coincides with a sharp change in vein strike and the new vein trend (N.56°W.) had resulted in conditions quite unfavourable for orebody cavity formation. This situation may not persist in depth, however, since mineralization does occur in boreholes between Boltsburn and Stotfieldburn (e.g. Rookhope Borehole and boreholes to the Jew Limestone put down for W.L.C - B/H's A and B).

Orebodies narrow eastwards between Jubilee and Small Shafts, breaking up into stringers. The Great Limestone - Coal Sills orebody alone continues, much diminished in width (2m maximum), to the eastern ore-zone. The cause of this impoverishment is structural since the vein trend alters, becoming further S. of E. Associated with orebody narrowing is an increase in silica content. The Coal Sills orebody was worked opencast during 1963 and 1964. Mr. Green states that ore from the main part of this working was of very high grade, about 78 to 80% CaF_2, and the silica content rose accordingly. The whole of the central 'barren' zone was found to be very siliceous.

8.8.2. The Eastern ore-zone

The E.-W. trending 'South-West Branch Vein' intersects Red Vein in the

15 Fms Level near Lonsdale's Rise. The intersection is accompanied by a return in strike of the latter vein towards E.-W. and a corresponding increase in width (up to 6.5m). North Branch Vein and Jackson's Vein, both trending N.82°E., intersect 150m and 345m further east (Fig.8.13). The two main 'branch' veins are well-mineralized near the intersections. A geological plan by E.F. Croft, dated 1954, records chalcopyrite close to the North Branch Vein intersection with Red Vein deep in the 34 Fms Level. This is the only written record of chalcopyrite in the eastern ore-zone. Mr. Green confirms this, statin g that there were very few visible signs of copper mineralization in this zone, contrasting sharply with the relatively copper-rich western zone. The ore in this zone was found to become very siliceous in depth, in the same way as the western zone except for the differing copper content. The Quarry Hazle orebody, for example, contained extremely pure fluorspar averaging about 85% CaF_2, 7-8% SiO_2, 3-4% PbS, whereas the underlying Nattrass Gill Hazle orebody carried 40-50% SiO_2.

The eastern termination of this ore-zone coincides with a complex post-ore fault zone which intersects the vein obliquely. This probably represents a continuation of the north-dipping fault in the Great Limestone, some 50m N.W. of Thorny Brow Vein, at Thorny Brow. In the 27 Fms Level the fault zone is 40m N.W. of Thorny Brow Vein in the Great Limestone. The fault zone coincides with a change in vein strike to one less favourable for orebody cavity formation. The 34 Fms orebody, however, terminates before reaching this structure. A shale lens within the Tuft washout channel thickens eastwards and chokes the orebody with soft, contorted shale gouge.

Beyond the fault zone, vein width was reducted to 0.6m of quartz, fluorite and galena strings in jasperoid. Exploration continued eastwards in the hope of finding more ore at the intersection with Thorny Brow Vein. In fact, though short orebodies up to 3-4 m wide occurred at the intersection, it was found that production was insufficient to offlay the cost of development (in about 1952-1954).

8.8.3. Discussion

It appears then, from records, plans and the reports of the mine manager, Mr. Green, that the Stotfieldburn ore-zones were located where the vein strike trended most nearly to east-west. Ore-zones terminated where an abrupt change away from this trend occurred. The coincidence of two major post-ore faults with ore-zone termination is important in having made exploration work difficult and expensive. However, it is clear that the faults themselves were not responsible for the terminations but presumably reflect the same rock weaknesses that caused the destructive changes in vein trend. Feeder channelways between orebodies were provided by vein intersections and possibly by washout channels (e.g. No.3. U/G Shaft area, see Section 3.1.4.) Two of the branch veins bore significant orebodies themselves. Prospects of further orebodies in depth are tempered by the known high silica content of such bodies.

No accurately located samples were obtained from this mine for analysis. Five specimens from the waste of opencast workings on the western ore-zone probably all originated from the Coal Sills orebody. Three temperature determinations (nos. 107.1,2,3) of 157°C, 158°C and 158°C (corrected) are similar to those obtained from fluorite from the nearest accessible orebodies in Redburn and Stanhope-burn Mines at the same horizon. The range of yttrium in the five specimens is 181 to 756 ppmY.

Sawkins (1966) records ranges of primary fluid inclusion determinations on six fluorite specimens, probably collected from the current workings at that time beneath the 44 Fms Level in the western ore-zone. Predictably these temperatures are higher than those from the open-cast samples and range from 163° to 186°C.

8.9 Stanhopeburn Mine.

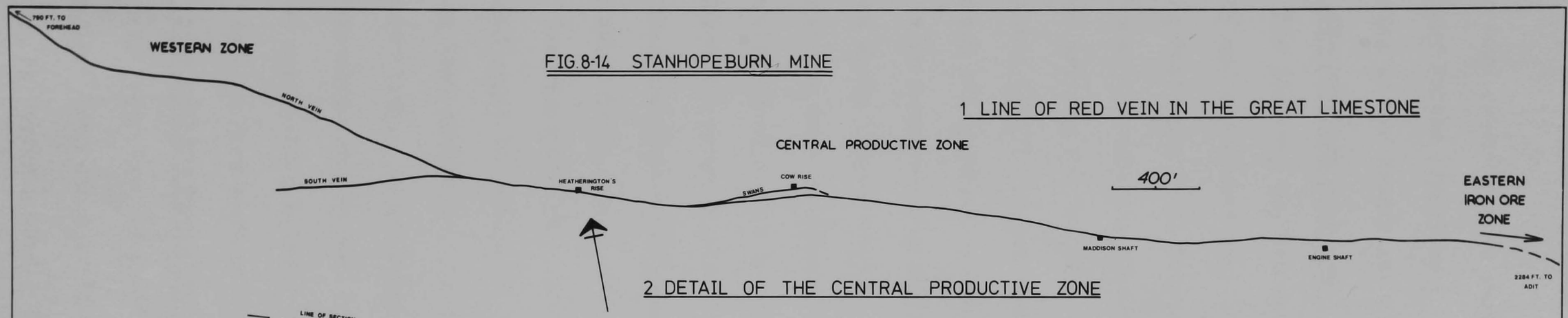
Stanhopeburn Red Vein is generally regarded as the continuation of Red Vein from Stotfieldburn Mine. The relationship between these two lengths of worked vein are, however, far from clear. A very sharp change in vein trend would be required to join the veins as seen in the foreheads of the two mines. Such a change is unlikely because, if it were the case, an orebody cavity should have been opened on Stanhopeburn North Branch Red Vein (Fig. 8.14), (assuming sinistral movement) and this has not occurred. Alternative explanations, e.g. that the two veins are separate en echelon structures, cannot be tested since the area is now inaccessible.

Stanhopeburn Mine may be conveniently subdivided into three areas. Work commenced in the east, near Stanhopeburn, probably in the early eighteenth century, though poor records of mining around here date much older. At first a series of lead and iron ore bearing flats were worked. Eventually the main vein was discovered and this lead the miners, in around 1820, to the highly productive central part of the mine (Fig. 8.14). Two rich vein ore-zones occur here and have been worked intermittantly for lead and fluorspar ores by successive companies until the present day. The vein was followed beyond these ore-zones for 1,140m to the west without finding further orebodies. This western part of the mine is no longer accessible.

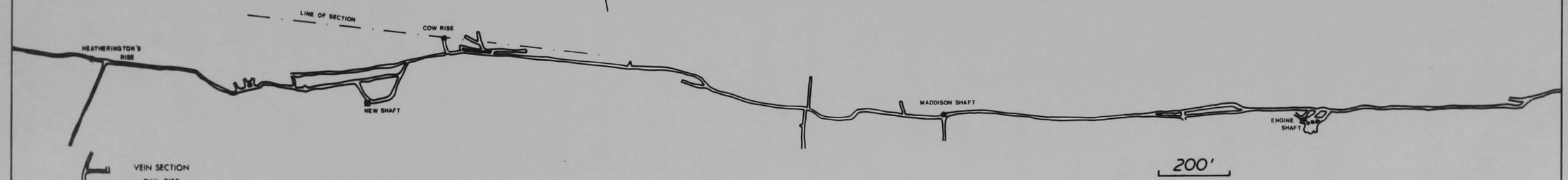
The most productive orebodies of Stanhopeburn have been worked from between the Nattrass Gill Hazle and the Coal Sills. Throughout the mine there is a thick washout channel in the Tuft sandstone, replacing the normal shales that separate the Great Limestone from the Quarry Hazle (Fig. 3.2). The result of this was the formation of a virtually continuous vertical section of hard, potentially ore-bearing strata between the base of the Nattrass Gill Hazle and the Coal Sills, a total height of 80m.

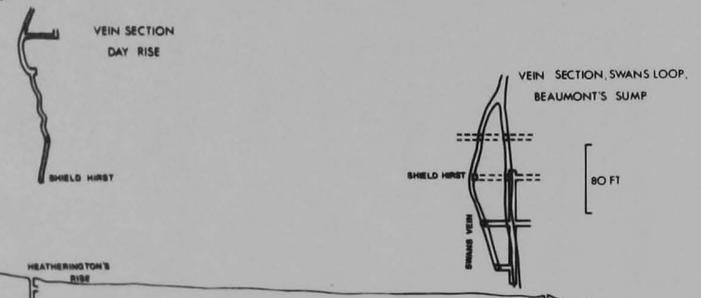
FIG.8-14 STANHOPE BURN MINE

1 LINE OF RED VEIN IN THE GREAT LIMESTONE



2 DETAIL OF THE CENTRAL PRODUCTIVE ZONE

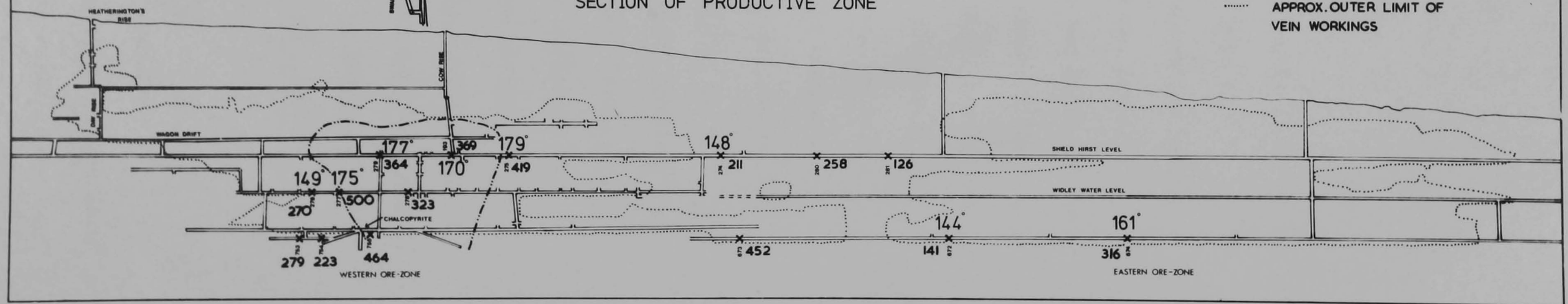




PLAN OF SHIELD HIRST LEVEL

699 SAMPLE NO.
444 YTTRIUM CONTENT PPM
150° FLUORITE FORMATION TEMP.°C
SWANS LOOP INTERSECTION
APPROX. OUTER LIMIT OF VEIN WORKINGS

SECTION OF PRODUCTIVE ZONE



There is some evidence from stope plans that beneath the washout beds, in the Four Fathom Limestone, the ore-zones are shortening in length, contracting around feeder structures (c.f. Groverake Vein, Fig. 8.8).

8.9.1. Stanhopeburn Mine, west of Heatherington's Rise.

The Beaumont Co. commenced exploration in this area in about 1870-1875 and discovered that Red Vein splits westwards into the diverging North and South Branch Veins (Fig. 8.14). Exploration ceased in 1875 when the mine was abandoned. The Weardale Lead Co. eventually continued driving the Beaumont Levels, concentrating on the North Branch Vein. Louis (1917) stated that the foreheads in 1916 showed a 'little ore, though not payable' in the 'Quarry Hazle' (Shield Hirst Level) and a vein 'also comparatively narrow and poor in lead ' in the Great Limestone above (Wagon Drift). The levels were continued, he says, 'less with the hope of getting good lead ore in this vein than with the expectation of a rich strike where it is intersected by some of the veins which are known to cross it further to the westward'. In fact though fracture zones, including presumably the main E.N.E. trending Brandon Walls Vein, were cut, the expected strike was not found.

The disappointing condition of the vein here is difficult to understand since it undergoes, at its divergence, marked strike variation that should have resulted in the opening of good potential orebody cavities. It is probable, however, that when the main vein split, the strike-slip displacement that had opened orebodies in the main ore-zones was divided between the two branch veins and then became insufficient to open such good cavities on either vein.

8.9.2 Stanhopeburn Mine, the Central productive area.

The productive ground is concentrated into two ore-zones (Fig. 8.14), both extensively stoped and separated, above the Three Yard Limestone, by barren ground. The present owners believe that these two

ore-zones may coalesce in depth, though this is by no means proven. In fact, although stoping from the ore-zones has continued beneath the barren zone, in the Three Yard Limestone and Little Whin Sill, it seems that this is only a temporary improvement connected in some way with beneficial effects, such as recrystallization and hardening, related to the intrusion of the sill. The barren zone (about 230m long in the Great Limestone) coincides with a small change in vein strike to a less favourable direction. The vein in the eastern ore-zone trends N.81°W., in the barren zone N.70°W. and in the western ore-zone, approximately E. - W. This change was sufficient to narrow the orebody cavities producing an impoverished vein.

The western ore-zone is strongly mineralized carrying widths of up to 10m of fluorspar. A major loop vein, Swan's Loop Vein, occurs to the north of Red Vein and is similarly well-mineralized. The intersections of loop and main veins appear to have provided the feeder channelways for the whole ore-zone. Although a number of samples have been taken and analysed from this and the eastern ore-zone they are not sufficient to enable any but the most general of conclusions to be drawn regarding feeder positions. Formation temperatures for example are higher in the centres of the ore-zones than the margins. The same may be said about the yttrium results (with the exception of sample no. 673 which carries an unusually high amount of yttrium, 452 ppm, and occurs in an ore pocket beneath the barren zone, coinciding with the intersection of a N. - S. vein with the main vein). In a very broad way both temperature and yttrium concentrations pick out two areas in the western ore-zone that may correspond with the intersections of Swan's Loop Vein with Red Vein. These intersections are not clearly located within the old workings in the loop area. It is interesting that chalcopyrite occurs in the vein, beneath the Whin Sill in the 34 Fms Level (Johnson, pers.comm. 1973), at around the position of the indicated western feeder

intersection of Swan's Loop. This is the only record of the mineral within the mine and moreover, apart from a few problematical showings of malachite in joint face mineralization within Lanehead Quarry, copper mineralization is absent in exposed parts of Red Vein and nearby veins east of here.

The eastern ore-zone, again strongly mineralized was worked at an earlier date than the other and consequently is now less well known. No intersecting structures are shown on existing plans.

Since this mine has only recently been re-entered and is still at present being made safely accessible, very little field work could be undertaken. However, the results of this limited survey have shown that the mine is well-suited to the methods of development exploration outlined in this thesis. The first task of any further, more comprehensive, survey would be to define the intersecting feeder structures on the Shield Hirst Level and to follow the structures to depth, particularly in Swan's Loop, in order to predict the nature and trend of mineralization beneath the present workings.

8.9.3 Stanhopeburn Mine, the eastern area.

This part of the mine has not been worked for very many years and workings are only poorly accessible through partly backfilled ironstone stopes. No plans or records exist. One sample, from a vug with quartz, taken from an ironstone working near Vipond's Shaft, yielded a corrected formation temperature of 151.4°C (Spec.No. 285). This is sufficiently high as to suggest the neighbourhood of an area of high brine flow, such as a vein oreshoot, and may be worth exploring at depth, beneath the old workings.

8.10 The Crawley Red Vein.

Crawley Red Vein is an en echelon structural continuation of the vein worked in Stanhopeburn Mine. No connection has ever been shown

between them.

8.10.1 West of Stanhope Burn.

The vein is not exposed in Stanhope Burn, but flats of fluorite, quartz and siderite associated with it occur in limestone pillars enclosing Red Vein Quarry (Fig. 8.15), just above the east bank. Westwards from the burn it is followed by Low Level, believed to have been driven by the Earl of Carlisle and Company in the seventeenth century. No plans or records of this level remain. It commences at the base of the Great Limestone and has tips carrying highly siliceous veinstone, but little fluorite. Its course may be traced, following shafts with tips carrying fluorite and quartz, to Noah's Ark Quarry. This is in fact an ironstone opencast mine, in flats within the Great Limestone, last worked by the Weardale Iron Co. in the early nineteenth century. The ground north of Noahs' Ark is peppered with small shafts and pits. The old (1875) Six inch to one mile geological map, sheet XXlV, marks this area as "intersected by a network of veins". Undoubtedly it has been very strongly mineralized due to the close proximity of Stanhopeburn and Crawley Red Veins and West Pasture Vein.

Red Vein may be traced further westwards following a line of whimsey shafts to the south bank of Reahope Burn. The shafts represent sizeable excavations with large tips carrying much fluorite. Approaching the burn the vein must have died out, since there are few signs of workings further west except for three ancient, N. - S. aligned shafts near Stoneby Syke. These appear to have been trials, probably connected by cross-cutting. The tips are devoid of vein minerals.

Widley Level, commencing by Stanhope Burn in the Four Fathom Limestone, serves as a water level to Stanhopeburn Mine. Part of its course is driven on Crawley Red Vein, providing access to possibly extensive underground workings. Entry cannot be gained to these at the present time and no plans or records are extant. The only visible mineralization in the water level is a flat with vuggy quartz and fluorite, near Lister's Shaft (Fig. 8.15).

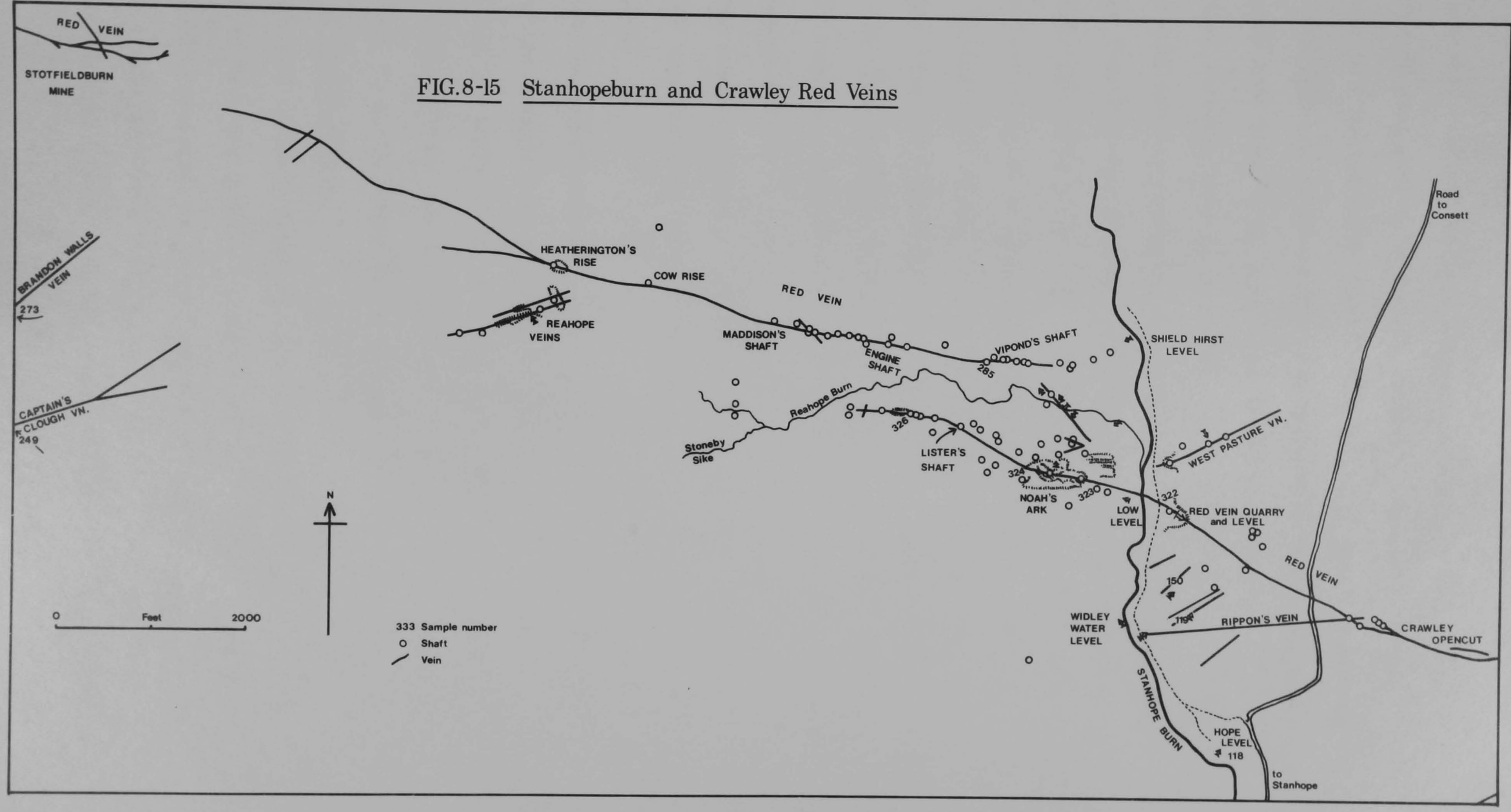
FIG. 8.15 Plan of Stanhopeburn and Crawley Red Veins

Except for Stanhopeburn Red Vein west of about Maddison's Shaft and for Stotfieldburn Red Vein, the veins are shown at outcrop. The ground between Noah's Ark ironstone quarry and mine, and Vipond's Shaft of Stanhopeburn Mine, is apparently strongly mineralized with ironstone flats and small veins in the Great Limestone. Old maps call this area Groove Pasture, where the word groove is medieval, derived from the old Norse verb 'grafa', 'to dig', reflecting the great antiquity of workings here. The word is found again in Groverake (originally Grooveheads or Groove Rake) Mine, Rookhope, and Groove Rakes - an old name for the Crawley workings on Red Vein. A barite vein of unrecorded width was found in about 1945 , by Mr. O. Lee, mine manager of Stanhopeburn, during construction work on the east bank of Stanhope Burn opposite Shield Hirst adit. The exact position (in the Great Limestone) and trend has not been recorded.

The data from fluorite samples collected from the east end of Stanhopeburn Red Vein, the western portion of Crawley Red Vein and others on the figure are as follows:-

Sample no.	Yppm	Corrected mean $T^{o}C$
285 (ironstone flats, Shield Hirst Level)	330	151.4
322 (Red Vein Quarry)	279	154.4
323/1 (Low Level)	280	-
323/2 (Low Level)	263	-
324 (Noah's Ark)	194	134.7
283 (Widley Level)	400	(Qtz. 139.1)
326 (Clint's Plantation)	181	134.9
150 Lanehead Quarry Vein	398	-
119 Lanehead Vein	296	-
249 Captain's Clough Vein	-	141.2
273/1 Brandon Walls Vein	191	-
273/2 "	137	-

FIG. 8-15 Stanhopeburn and Crawley Red Veins



The general trend of the vein around Noah's Ark is unfavourable for the opening of good potential orebody cavities. However, further westwards there is a marked swing towards E. - W. and, though remaining sinuous, the vein appears to have taken up a favourable trend. In this respect it seems more than coincidence that the only substantial underground vein workings were in this area.

Fluid inclusion temperatures show a general decrease westwards along the vein from Red Vein Quarry. The temperature of vein fluorite from Noah's Ark (134.73°C, corrected) is considerably less than that obtained from flat fluorite at approximately the same horizon and longitude in Shield Hirst Level, Stanhopeburn Mine (151.4°C, corrected). A quartz sample from the Widley Level yielded only very poor primary inclusions, the corrected mean formation temperature of which, 139.1°C, indicates the increasing temperature of mineralization beneath Noah's Ark with depth (approximately 1°/9.5m).

Yttrium concentrations in the fluorite also decrease gradually westwards. The high value of 400 ppm from Widley Level is exceptional and inexplicable.

Despite the temperature and trace element results that indicate a vein termination towards Reahope Burn, the favourable structural configuration and the scale of old workings here suggest that economic deposits may remain, within the old workings, or deeper, perhaps at the Little Whin Sill, in a relatively low temperature ore-zone.

8.10.2 East of Stanhope Burn.

As mentioned earlier, flats associated with Red Vein are exposed on either side of Red Vein Quarry. Although the vein itself in the Great Limestone is concealed, a barren fault structure is evident in the contorted beds of the overlying Coal Sills. A throw of 5.1m has been recorded underground near here. Red Vein Level follows the vein from this

quarry to Hope Mine, beneath Crawleyside. The main level runs N.70°W. in the Great Limestone, from which ironstone flats have been worked, at intervals, for 1070m (Dun ham 1941). These are most extensive S.E. of the intersection with Rippon's Vein, 670m from the level mouth. An old plan (53, A 12 of the Weardale Lead Co.) shows the workings of Red Vein Mine and Rippon's Level merging here. A shaft from the north side of Red Vein Quarry was put down to the Four Fathom Limestone and iron ore worked for 122m to the S.E.

The vein within Red Vein Level has not been considered worth mining by either lead or fluorspar producing companies that have held this lease. The level-mouth is now collapsed but may be re-opened in future exploitation of Crawleyside reserves.

An old level, charted on the plan mentioned above, runs N.46°E. from Crawleyside Village, starting in the Pattinson Sill. Surveyed in 1824 and possibly much older than this, the level worked a short length (240m) of Red Vein presumably for lead ore. Above it lie the spectacular opencuts of Crawley Mine (Fig. 8.16). The vein here, in Grit Sills washout beds, averaged 4 - 5m wide over a length of 420m. The position of the levels on old plans indicate that the vein was vertical within the washout beds but began to hade northwards in depth. The vein narrows rapidly west of the opencut to Blue Heap Shaft (barren-tips) and can be seen to narrow down to 0.2m in the east of the opencut. A small vein, approximately 0.4m wide, diverges north of Red Vein, trending N.52°W. some 122m east of Blue Heap Shaft (the vein is marked A on Fig. 8.16). Another branch vein (B on Fig. 8.16) runs almost parallel with, and has been opencut up to 30m north of, the main vein. It seems to intersect the main vein in the west end of the opencut and may loop around to intersect it again just west of the intersection with A. It was found that in the Great and Four Fathom Limestones in Hope Mine, Red Vein is joined by a looped branch vein named Loop Vein. If this structure continues to surface then it may be represented by this sub-parallel, rather feeble, branch vein, B.

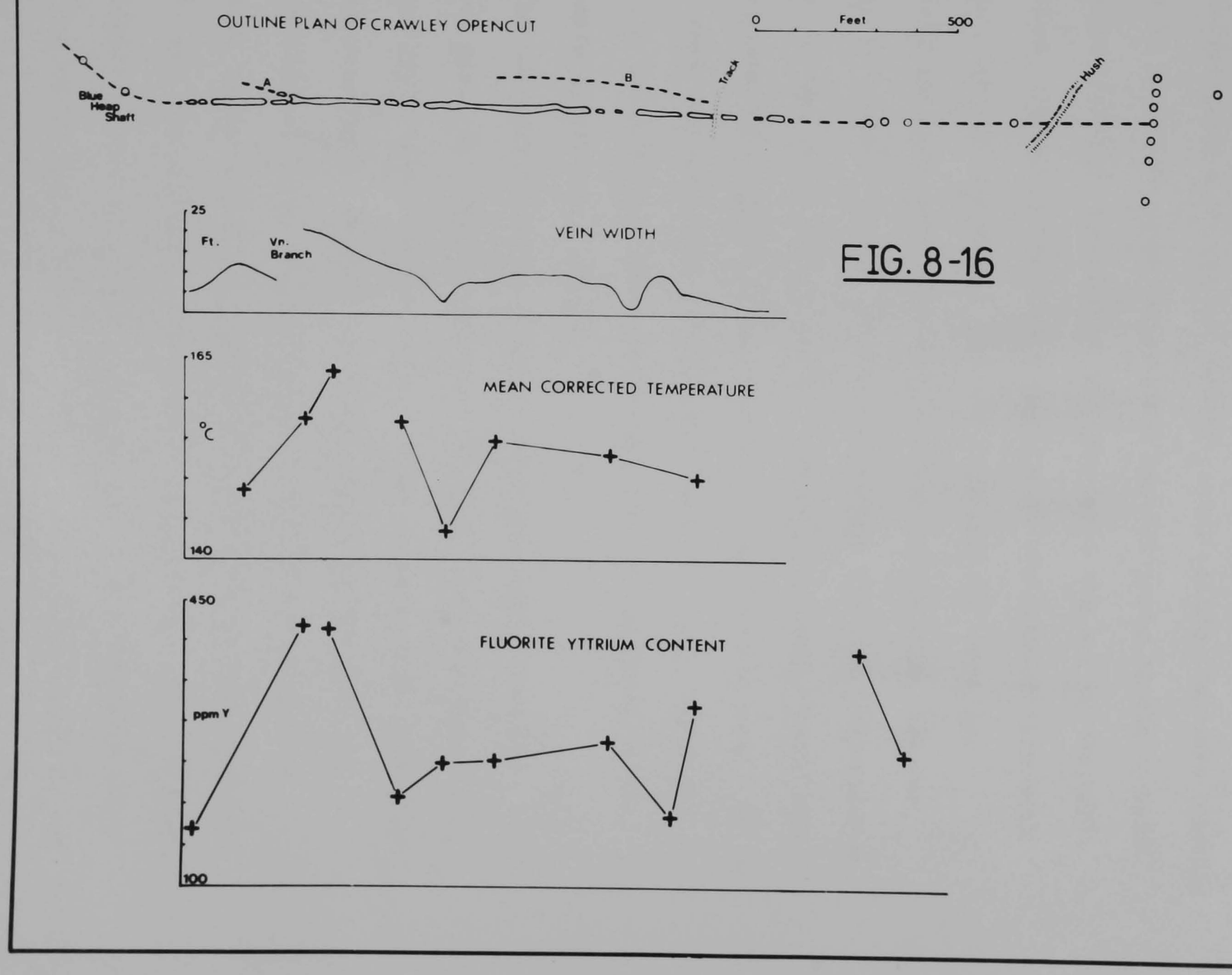

OUTLINE PLAN OF CRAWLEY OPENCUT
0 Feet 500
Blue Heap Shaft
A
B
Track
Hush
25
Ft.
Vn. Branch
VEIN WIDTH
165
°C
140
MEAN CORRECTED TEMPERATURE
450
ppm Y
100
FLUORITE YTTRIUM CONTENT

FIG. 8-16

A rough, taped survey, plan of the opencut stopes is shown in Fig. 8.16 with sample locations, approximate vein widths, fluid inclusion and yttrium results. It can be seen that the yttrium concentrations pick out two clearly anomalous areas and that these both correspond with the known intersections with the two branch veins. Fluid inclusion studies were confined to specimens from western and central parts of the opencut since post-mineralization brecciation has shattered the ore to the east. The temperatures, however, also form a maximum at the intersection with branch vein A. This is the widest part of the opencut. Thus two feeder intersections have been detected, neither branch vein, however, seeming worthy of further trial. It is interesting that the temperatures recorded here (in the range 144 to 163°C) are not noticeably lower than those measured from areas right in the centre of the fluorite zone, $9\frac{1}{2}$ km away, at the same horizon, thus indicating a lack of clear, regional, thermal zonation (such as has often been, incorrectly, supposed to be shown by the data of Sawkins, 1966).

Yttrium concentrations in fluorite from Hope Level tips are 230,242 and 345 ppm. No temperatures were obtained from this material.

Dunham (1952) records that Loop and Red Veins in Hope Level Mine varied in width from 0.6 to 3.6m. An average grade of 64% CaF_2 and 26% SiO_2 was calculated to be representative of the veins throughout the Mine. Galena is rare (a single ore assay, quoted by Dunham, showed only 0.14% Pb) and the original mine, opened for lead ore, was a failure. A little sphalerite occurs in Crawley opencut, with much manganese oxide staining, but no chalcopyrite has been found. Early phase quartz is not common, even at the intersection with branch vein A, however the opencut walls are too badly weathered to permit a really detailed examination. Total production from Hope and Crawley Mines is given as 75,000 tons of fluorspar concentrates (Dunham, op.cit.).

The main Crawleyside orebodies occur where Red Vein lies approximately N.80°W. West of this, by Blue Heap Shaft, the strike changes to a less favourable situation, N.65°W. It can be seen that sinistral movement would tend to open cavities at the site of the present opencut orebody and close the vein, under compression, in the region of poor vein with ironstone flats in Red Vein Level. Thus the localization of orebodies was structural. The great vertical height (nearly 61m) of the orebodies is due primarily to the presence of very thick washout sandstones in the Grit Sills (Chap.3). The presence of the Tuft washout sandstone, though diminished in thickness from Stanhopeburn, has aided the development of further orebodies at this horizon in Hope Mine. From the mine sections it can be seen that stoping was virtually restricted to strata about washout beds. Further prospects are unlikely to be very good outside these lithologies.

8.10.3 Rogerwell Hush.

Crawley Red Vein thins to about 0.1m of crushed fluorite in the east end of Crawley opencut. Its further course is marked by some very old shafts, with tips carrying fluorite, until intersected by a N. - S. line of shafts just west of Shittlehope Burn. These are said to be workings upon a cross vein, although no evidence of mineralization remains on the shaft tips. Red Vein is next encountered some 213m to the south, on the east side of the 'cross vein' in Rogerwell Hush, (Fig. 8.17). The top of the hush is marked by the old dam and a shaft in conglomeratic grits carrying fluorite mineralization. The vein in this opencut seems to be the structural continuation of the vein in Crawley Mine, yet the exact relationship between the two and with the N. - S. 'cross vein' is problematical. A straight-forward strike-slip displacement of 213m along the 'cross vein' is impossible since the 'vein' cannot be found a few hundred metres further south and has apparently died out.

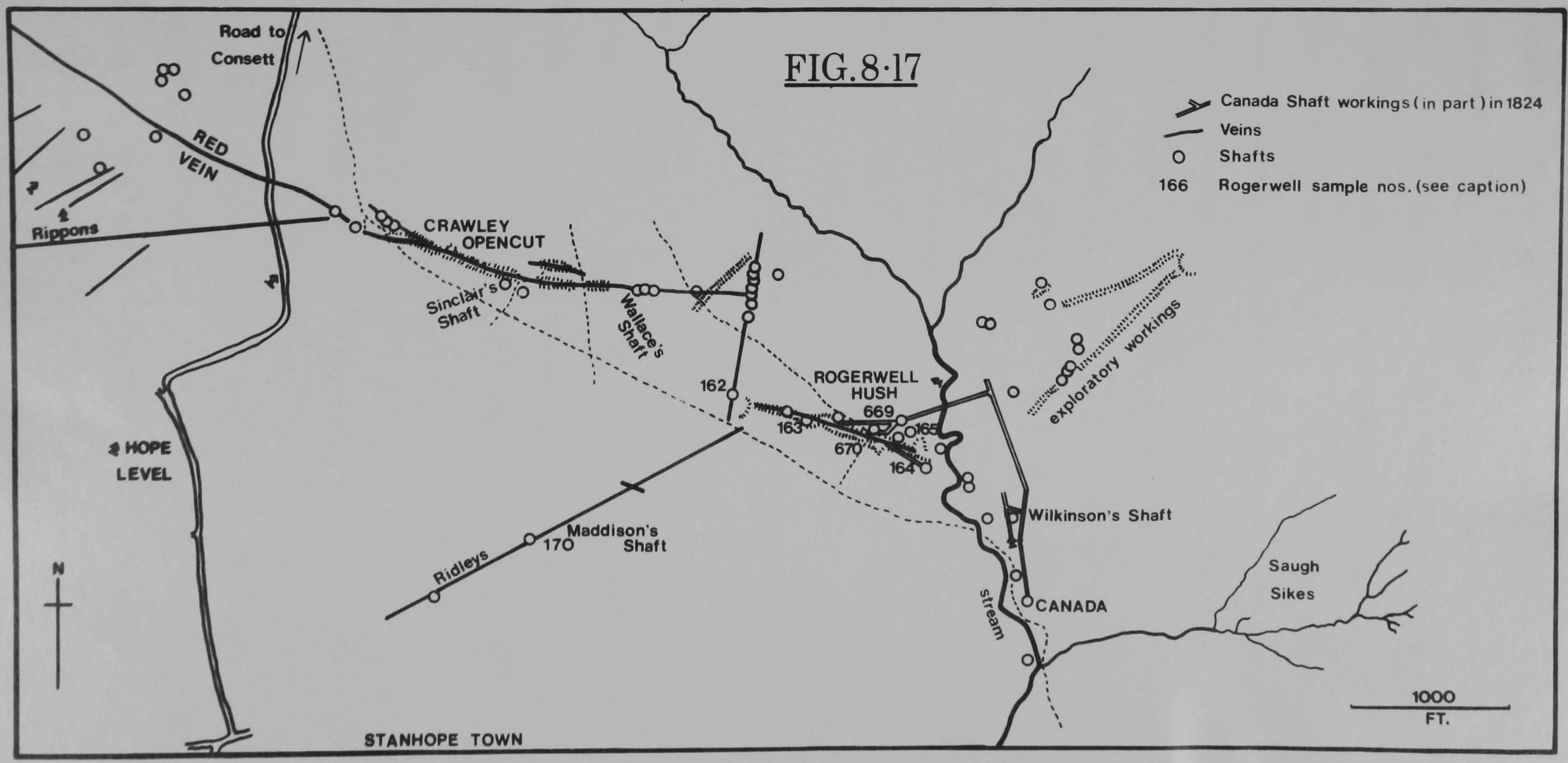
FIG. 8.17 Location Map of the Eastern End of Red Vein, at Crawley Opencut and Rogerwell Hush

Rippon's and Ridley's Veins are shown at their positions in the Great Limestone (taken from the original mine plans). Other veins are shown approximately at outcrop. Old trial shafts, prospecting hushes and underground workings east of Shittlehope Burn show the degree of exploratory activity beyond the apparent termination of Red Vein. It is reputed that, apart from the discovery of ironstone flats, these workings were unsuccessful.

The data from fluorite samples collected from about Rogerwell Hush are as follows:-

Sample no.	Y ppm	Corrected mean temp. °C.
162 (loose)	192	-
163 "	172	148.6
164 "	214	-
165/1 "	198	161.9
165/2 "	245	-
669 "	198	-
670 (in site)	182	-
170/1 Ridley's Vn.	210	-
170/2o " "	230	142.2
170/2i " "	198	143.1

FIG.8·17


Canada Shaft workings (in part) in 1824
Veins
Shafts
166 Rogerwell sample nos. (see caption)
Road to Consett
RED VEIN
Rippons
CRAWLEY OPENCUT
Sinclair's Shaft
Wallace's Shaft
HOPE LEVEL
162
ROGERWELL HUSH
669
163
165
670
164
exploratory workings
Wilkinson's Shaft
Ridleys
170
Maddison's Shaft
stream
CANADA
Saugh
Sikes
N
1000 FT.
STANHOPE TOWN

Varvill's cross vein termination scheme (Sect. 8.2.3, Fig. 8.2) could be successfully invoked with the implication that both Crawley and Rogerwell Veins continue as closed fractures beyond the 'cross vein'. Borrodaile's example of anomalous stress field faulting (Sect. 8.2.4.) is also particularly well suited to this problem and it was in fact formulated with this area in mind. Stress field distortion (Fig. 8.4) could have been caused by the near proximity of washout channel margins both to the east and west of the 'cross vein' area (the area falls between washouts at two different horizons).

The workings in Rogerwell Hush are as obscure as are the shafts on the N. - S. 'cross vein'. The tips were long ago picked over for fluorite, yet, though little of this remains in the hush now, the peat and topsoil of the area are rich in the mineral. Some small veins 20 - 30 cm in width, were exposed by digging in 1972 and sampled (No. 670). They occur in grits on the south side of the hush just west of the path crossing and carry galena in green fluorite. A trend of N. 80°E. was measured.

Yttrium results for six fluorite specimens are fairly constant and low, in the range 171 to 213 ppm. Temperatures determined on a sample (No. 163) from the opencut, 149°C, and another from a tip (No. 165), 162°C, are as high as those obtained from fluorite from Crawley opencut.

The large whimsey shafts by the hush show vein-stuff on their tips. However, a level from Canada Shaft, driven north to penetrate the vein in the Great Limestone, is said to have found only ironstone flats. The vein channel was not located (Dunham, 1948) despite driving some 146m beyond the expected intersection. This is in fact the easternmost known limit of Red Vein. However the evidence of final termination here is difficult to reconcile with the relatively high temperatures of

Rogerwell fluorite. The possibility of vein extension should be considered. West of Rogerwell there is a marked coincidence of ironstone flats with orebody terminations caused by change of vein strike. If this were also the case at Rogerwell, and assuming that a closed vein fracture could have been cut unnoticed in Canada Level if it were much south of the expected position, then Rogerwell Red Vein could continue east of Shittlehope somewhere just north of Saugh Sikes. This is a matter of considerable interest to mining companies in the area. Red Vein has yielded in the order of 750,000 tons of fluorspar concentrates, over 500,000 tons of iron ore and approximately 60,000 tons of lead concentrates (70% PbS) worth somewhere in the region of £17,500,000 at todays prices. The ground east of Rogerwell contains the very favourable lithologies of Rogerley washout channel, extends approximately 5 km to the margin of the fluorite zone and has been completely unexplored. Clearly the possibility of mineralization continuing beyond such a poorly documented termination should be explored and it is indeed fortunate that the area may soon be penetrated by the Northumberland River Authority's proposed aqueduct tunnel.

Mr. M. Sarginson, a geophysics postgraduate of the University of Durham, accompanied the writer to Crawleyside to evaluate the Swedish-made A.B.E.M. gun (a portable instrument for measuring the distortions, caused by buried sulphide bodies, in an induced electromagnetic field). However, several traverses over the line of Crawley Red Vein just west of the opencut failed to demonstrate a sufficiently good anomaly profile to permit usage on the unknown ground east of Shittlehope. This failure was attributed to the low sulphide content of the vein and to the low sensitivity of this particular instrument. Another traverse over the relatively richer Rippon's Vein in Lanehead Quarry proved more satisfactory. The development of E.M. instruments such as the Geonics E.M.17, with much

greater sensitivity, prevents ruling out such methods of exploration in the area.

8.11 The 'productive' lead veins.

Since the tensional opening of orebody cavities was caused by periclinal doming then those fractures closest in trend and position to the pericline crest should have the greatest potential width (the 'quarter-point' veins) and those perpendicular to the fold axis, the least potential width (the N.N.W. 'cross'veins). The E.N.E. trending 'productive' veins are of intermediate width, up to a maximum of about $3\frac{1}{2}$m and were the main lead-yielding veins of the orefield. Burtree Pasture Vein (N.55°-65°E.), for example, averaged between 0.45 and 1.85m in width throughout the stopes of Burtree Pasture Mine and yielded more than 175,000 tons of lead concentrates making this the richest lead mine in Weardale (Dunham, 1948). The reason for the concentration of galena in veins of this trend is not known.

Exploration for the lead veins was very intensive in bygone days. They were most easily discovered, though, in the valley-sides and dales, where displacements of the 'basset', or outcrop, of bearing strata could be seen and where the old 'hushing' (hydraulic opencutting) methods of prospecting and extraction could be employed. Examination of maps and plans shows that veins found to be worth mining from valley-sides were seldom followed far beneath a watershed, implying that they became impoverished and that further exploration (if it took place) was not carried far enough to locate other ore-shoots. At one time it was considered that veins naturally became impoverished beneath watersheds and Wallace (1861) explained the phenomenon in his famous treatise. He took the watersheds to represent anticlinal areas and believed that the source of ore minerals lay in the vein wall-rocks. His laws regulating the deposition of ores require that all meteoric water seeping into the hillsides drains down towards the valleys

following the natural inclination of strata flanking his supposed anticlinal axes. Circulation was diverted into vein cavities formed on faults and it was here that the meteoric waters, having become saturated with ore constituents dissolved from the rock, deposited their loads. Thus, he says, since the depth of percolation of meteoric waters is not great, mineralization tends to occur best at the valley-sides and does not continue deeply beneath hills. We now know that Wallace's views on this topic were wrong. The anticlinal axes do not exist, the ore solution source lies beneath the Pennines and mineralization continues to very great depths. However, attempts to prove the continuity of mineralization beneath the major watersheds are still unsuccessful. In Northern Weardale, the Wear-Middlehope-Rookhope watersheds have been penetrated only by workings on the strong Burtree Pasture and Boltsburn Veins. The Rookhope-Derwent watershed has never been penetrated. Each of these valleys, however, is occupied by very many mines, some of which have been highly successful. New Consolidated Goldfields Ltd. drove a long prospecting tunnel, in 1955-1959, for $2\frac{1}{2}$ km S.E. from Swinhope Mine in the East Allen Valley. This was to test, beneath a watershed, the continuation of two groups of veins, the Allenheads veins and the Killhope-Barneycraig Veins, the total production from which (in neighbouring valleys) had been around 515,000 tons of lead concentrates. The trial proved a failure, few mineralized fractures were found and none would repay working. The recent experience of Redburn Mine, driven parallel to the Rookhope Valley, following Red Vein for $2\frac{1}{2}$ km beneath the fell-side, also proved disappointing. Eight E.N.E. veins have been worked in the valley over that distance but only four of these have been identified in Redburn and are valueless (compare this with Tailrace Level, driven 2.8 km beneath and along the

valley, that struck six veins not including the Red Vein system). Similarly, the penetration of the Rookhope-Stanhopeburn watershed in search of Brandon Walls Vein (Sect. 8.9.1) proved fruitless. The problems are not confined to the fluorite zone and Closehouse Mine, at Lunehead has found progressive weakenings of barite oreshoots beneath the Arngill-Long Grain watershed. These oreshoots are up to 20m in width at outcrop in the respective valleys. There seems to be no satisfactory geological explanation of this apparent distribution of known orebodies on the veins and this implies that future experience may prove it to have been caused more by difficulties in mining and exploration techniques.

E.N.E. veins were sampled, at surface and underground in old workings wherever possible, along the course of Red Vein in order to see whether Red Vein had acted as a regional feeder structure to them. This has been shown to be untrue. The veins possess their own systems of cross vein intersections that appear to have been no less efficient as feeders than intersections with the 'quarter point' veins. Fig. 8. 18 shows the veins of the Rookhope Valley indicating specimen locations, corrected fluid inclusion temperatures and yttrium concentrations. The main points shown by these data are:-

A) 'Lead vein' formation temperatures are generally lower than those measured from Red Vein, even when the two groups are reduced to the same horizon, the Great Limestone (using a vertical cooling gradient of $1^{o}C/10m$, the maximum correction would be $+12^{o}C$ to those samples from the Lower Felltop Limestone).

B) There is a broad areal temperature and yttrium zonation in which the ranges of each increase in value towards the Groverake and Stotfieldburn areas. These have been discussed already as 'hot spots' (Section 5.8) presumably indicating zones of high vertical flow rates with correspondingly greater temperatures

Fig. 8.18 The Veins of the Rookhope Valley

x - Sample location

377 - Yttrium content (ppm) of fluorite sample

157 - Mean fluid inclusion homogenization temperature (^{o}C) after correction for pressure.

-·- - Approximate outcrop of the Upper Fell Top Limestone

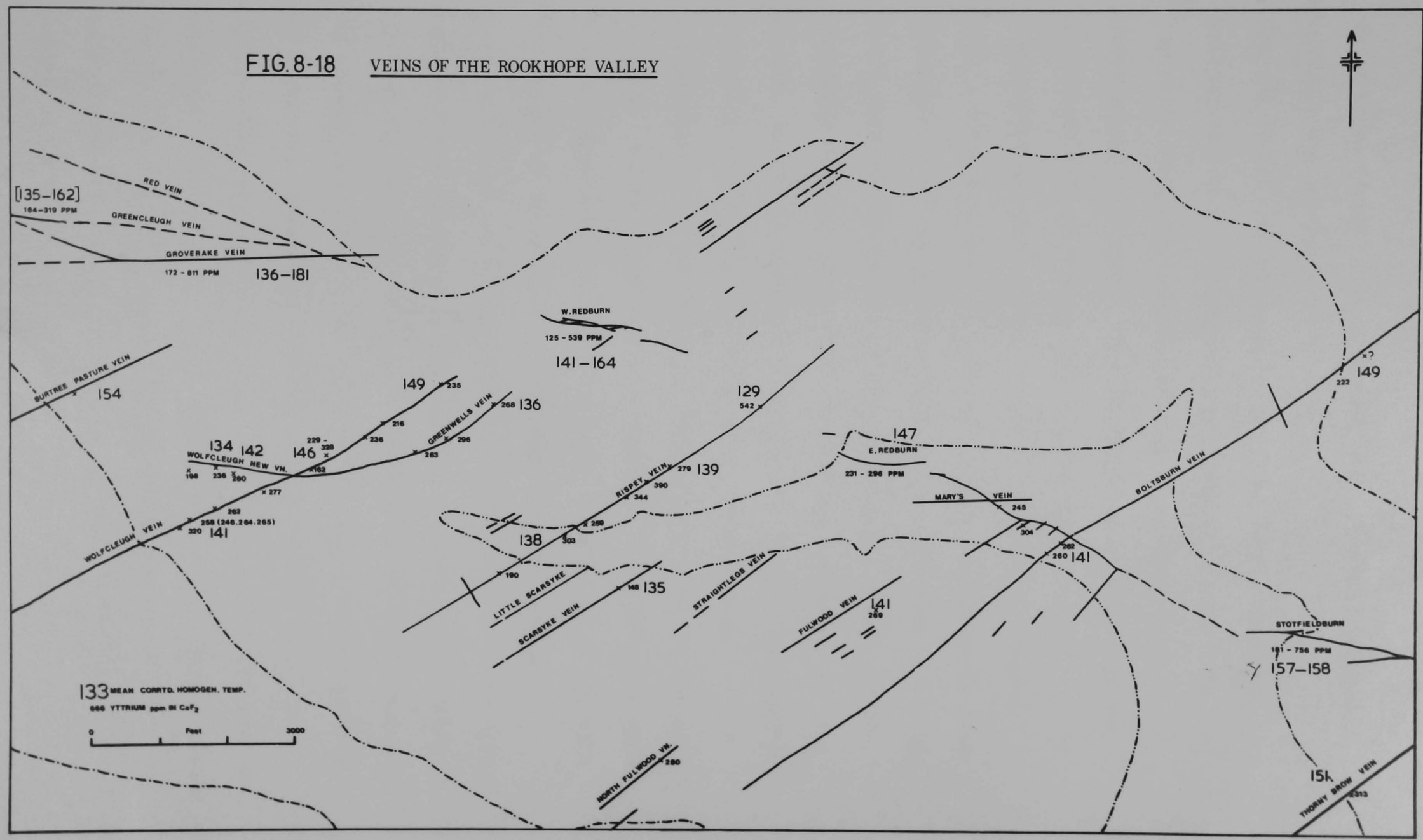
-··- - Approximate top of Little Limestone.

Yttrium and temperature data from the Red Vein system at Stotfield, Redburn and Groverake are taken from around the Great Limestone. Greencleugh Vein samples from Frazar's Hushes (furthest west of map) are located at around the Lower Fell Top Limestone but the mean inclusion temperatures have, after correction for pressure, been reduced to the level of the Great Limestone using a cooling gradient of $1^{o}C/10$ m.

The Red Vein system is shown approximately at the horizon of the Great Limestone. The other veins are shown approximately at out crop. Fluorite samples from Redburn and Groverake,and Scarsyke, West Boltsburn, Fulwood (by intersection with Red Vein) and Rispey (in Redburn) Veins were collected underground. The others were taken from vein outcrops, opencuts or tips from shallow shafts.

It should be noted that the veins shown to the N.E. of W. Redburn were cut in the Hawksike prospecting level (in shale beneath the Firestone Sill) or else exposed by ironstone trials in the Upper Fell Top Limestone. No records of their contents remain but none were considered worthy of further exploration.

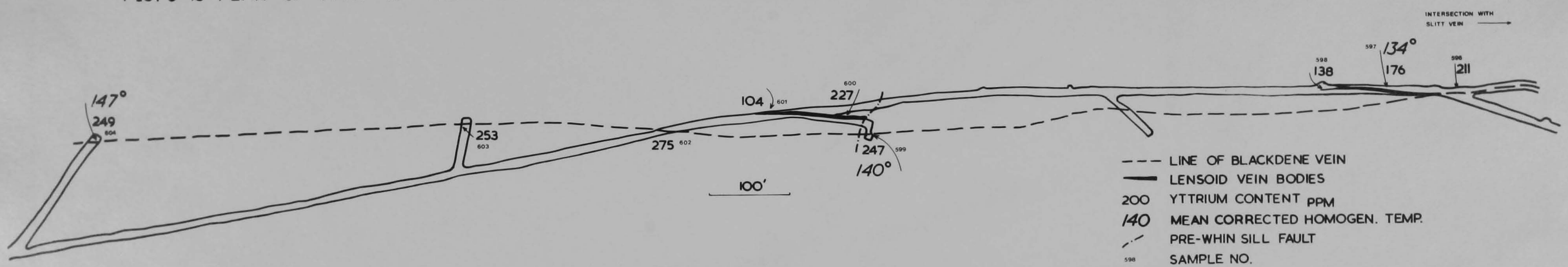
FIG. 8-18 VEINS OF THE ROOKHOPE VALLEY



and greater thermal, pH, pressure, etc. gradients (causing yttrium enrichment - Sectn. 6.5).

C) The maintenance of high temperatures and fairly constant yttrium values in surface workings along Wolfcleugh Vein indicates that this vein is strongly mineralized to high stratigraphic horizons. This is reflected by the frequency of ancient bell-shafts marking out the vein, south of Rookhopeburn in particular. Dunham (1948) states, however, that a "recent attempt to work the vein in the Firestone from a surface level was unsuccessful". Wolfcleugh Mine itself has had a somewhat chequered history, having been abandoned as unpayable at least three times in the last century. The vein system, including Greenwell's Vein, seems to have considerable potential considering the distance it can be traced, northeastwards to the ironstone flats explored by the Weardale Iron Co. in the Upper Fell Top Limestone, southwestwards about 5 km to Coptcleugh Vein, Sedling Burn, which is $1\frac{1}{3}$ to $1\frac{2}{3}$m wide ("composed of fluorspar") and regarded as the simple continuation of Wolfcleugh Vein (Dunham, op.cit.). It is also believed that Greenwell's Vein may be represented by Florence Vein on the Hunstanworth side of the Rookhope-Derwent watershed. Wolfcleugh New Vein, on the other hand, shows a clear decrease in formation temperature and yttrium content away from its intersection with Wolfcleugh Vein, correlating with decrease in evidence of veinstuff on shaft tips in that direction. Otherwise the data on Fig. 8.18 show no signs of termination of mineralization, despite its apparently uneconomic, pocket y nature on the Wolfcleugh system in Rookhope Valley.

FIG. 8-19 PLAN OF PART OF THE MAIN HAULAGE LEVEL, BLACKDENE MINE



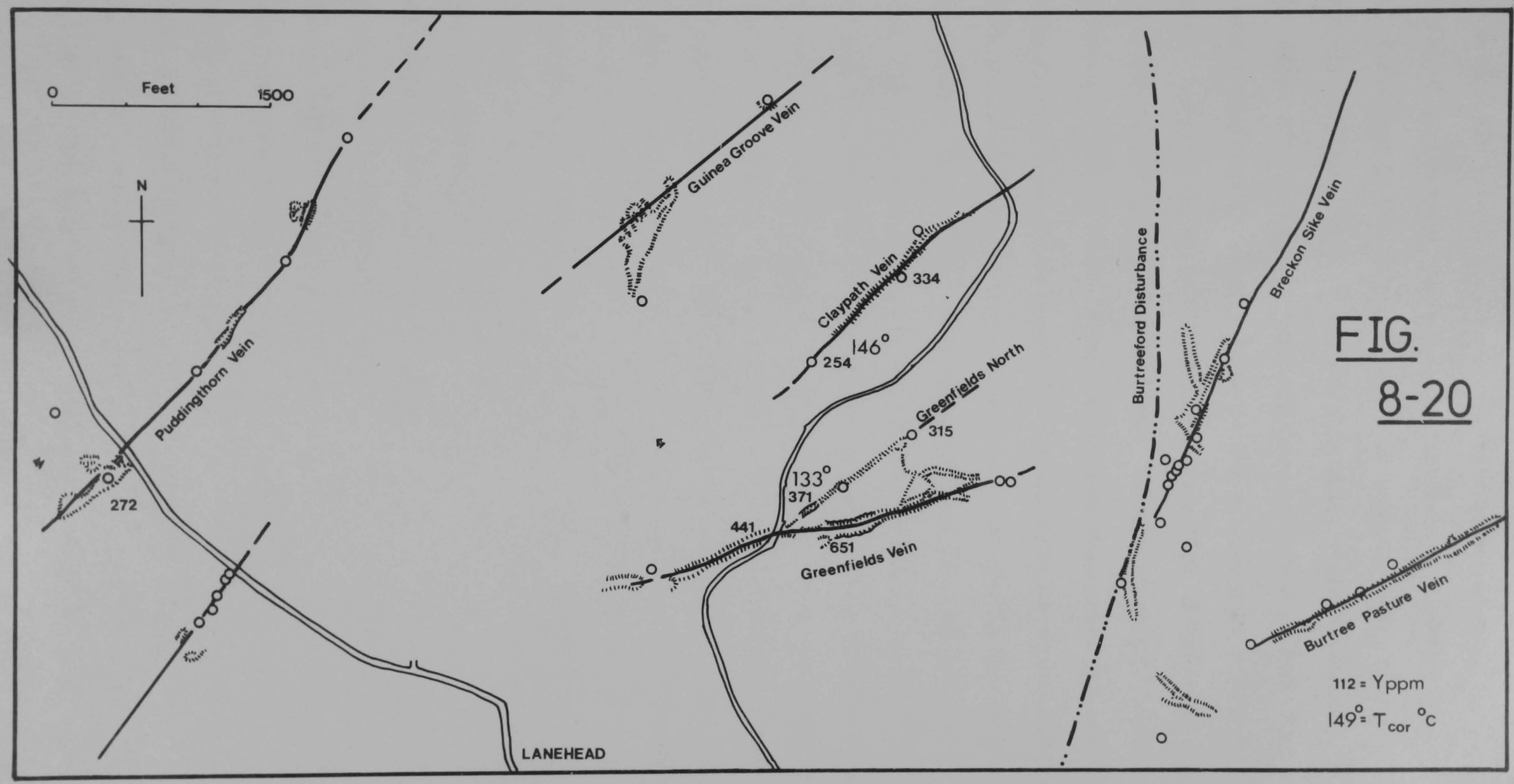

0 Feet 1500
N
Guinea Groove Vein
Claypath Vein
334
254
146°
Puddingthorn Vein
272
Greenfields North
315
133°
371
441
651
Greenfields Vein
Burtreeford Disturbance
Breckon Sike Vein
Burtree Pasture Vein
LANEHEAD
112 = Yppm
149° = T cor °C

FIG. 8-20

Sixteen accurately located samples of fluorite were collected (by J. Forster and R. Wilmers) from Blackdene and Slitt Veins, Blackdene Mine. for analysis. Corrected formation temperatures of some of these, from Blackdene Vein at about the top of the Great Whin Sill, yield the range 134° - 147°C. This, considering the depth, is low and indicates that this area cannot have contained the chief feeders to the massive vein orebodies some 100m above. Contrary to expectations the intersection of Blackdene and Slitt Veins was not marked by high temperatures. Further structural work, however, has revealed that in fact neither vein trends favourably for cavity opening at this point. Some lensoid bodies of strong fluorite mineralization are associated with Blackdene Vein and two of these were included in the sampling along the Main Haulage Level. Fig. 8.19 shows the locations and yttrium concentrations. It should be noted that the precise relationships of the lenses to the main Blackdene Vein fault structure are unclear. Yttrium values from the main vein are fairly constant at about 245 ppm. Values from the two lensoid bodies show gradients. In the southern lens yttrium decreases away from a small, pre-mineralization, cross fracture. In the northern lens yttrium decreases away from its extrapolated intersection with the main vein and South Slitt Vein. In each case the bodies are known to die out in the direction of decreasing Y content. The direction of shear movement of Blackdene Vein can be shown, from the disposition of oreshoots on the sinuous plane, to have been sinistral.

Several samples taken around the intersection of two further, typical 'lead veins' at Greenfield Hush, Wearhead, (Fig. 8.20) again show high yttrium values at the intersection.

The data from some 13 samples from Whiteheaps Mine could not be interpreted without a plan of the workings.

A control selection of fluorite specimens, widely spaced throughout the orefield, were analysed to ensure that the Weardale area is not unusual within the orefield. The range of sample locations are indicated by Fig. 8.21 and

the results tabulated separately (Table 8.1). Although the range of yttrium concentrations is perhaps not so great as that found from Red Vein, the Weardale samples discussed in detail earlier in this work seem to be in no way unusual.

TABLE 8.1 Fluid Inclusion Temperature and Rare Earth Concentrations in Fluorite from Localities indicated on Fig. 8.21, North Pennine orefield

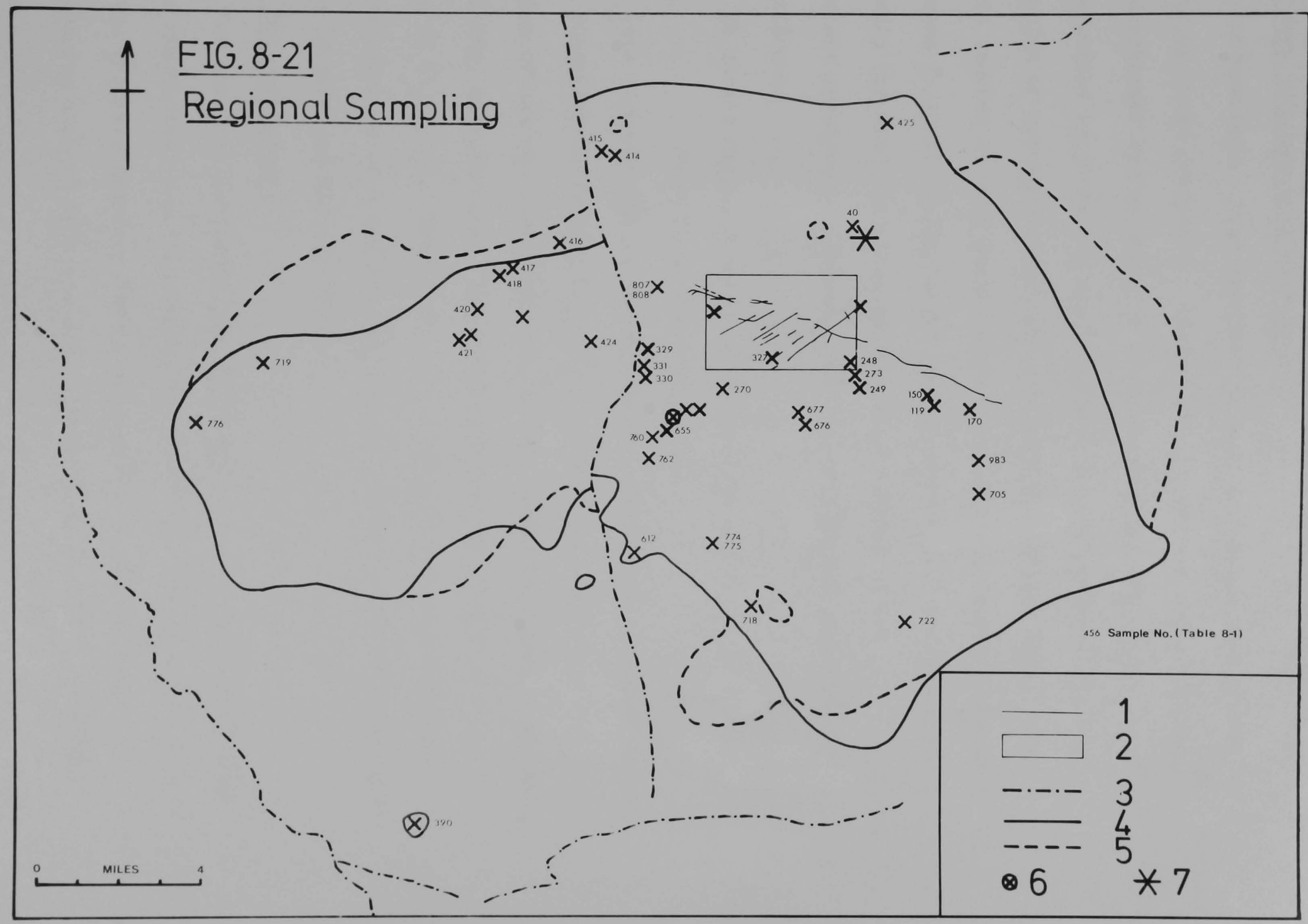
Vein, Spec. No. and Locality	T_{corr} °C	ppm Y	ppm Ce	ppm La
Brandon Walls, 273, Brandon Walls Mine		191	32	40
Breckonsyke, 331, Queensberry Ironstone Mine		273	74	35
Caple Clough, 421, Caple Clough Level		294	60	23
Captain's Cleugh, 249, Captain's Cleugh Mine	141.2	NA	NA	NA
Company's, 426, Whiteheaps Mine		351	54	37
" ,427, " "		163	0	23
Coptcleugh, 329, Coptcleugh Level		263	127	74
Coves, 983, Coves Mine		267	84	54
Diana, 807, Allenheads Mine	137.5	266	49	47
Esps, 414, Siptonhead Level		243	64	20
" 415, Sipton Mine		295	58	25
Great Sulphur, 776, Smittergill Head Mine	194.7	401	30	35
Harrowbank, 842, Harrowbank Quarry	119.5	235	0	0
Heights South, 676, Heights Quarry		247	54	36
Heights North, 677, Heights North Mine		202	151	77
Ireshopeburn, 655, Barbary Mine		216	53	35
Ireshopeburn, 760, Barbary Incline		238	72	66
Lanehead Q.2, 150, Lanehead Quarry		398	50	9
Langdon Beck Mines, 612		300	41	21
Little Eggleshope, 722, Eggleshope		273	58	22
Longsike, 270, Middlehope Old Mine		327	204	121
Low Coalcleugh, 417, Whetstonemea		327	72	28
Low Coalcleugh, 418, Black Hill		330	90	35
Low Groveheads, 762, Surface pits		251	126	71
Markiel, 705, Howden Burn Level		357	59	24
North Foulwood, 327, opencut in Coalcleugh Beds		280	46	17
North Slitt, 606, Blackdene Mine		222	0	5
" " , 607, " "	133.5	296	50	21
" " ,608, " "	130.5	110	41	18
Old, 808, Allenheads Mine	128.2	189	0	15
Pike Law Mines, 718		440	30	4
Poor, 52, Whiteheaps Mine		359	53	0
" , 54, " "		337	19	5
" , 55, Whiteheaps Mine		321	42	5

	T_{corr} °C	Y	Ce	La
Puddinthorn, 424, Puddingthorn Low Level		272	58	39
Rampgill, 420, Firestone Level		310	78	23
Ramshaw, 40, Plantation shafts	160.2	236	29	0
" 40, " "		243	30	3
Red (Hunstanworth), 50, Whiteheaps Mine		364	88	30
" " , 51, " "		529	110	37
" " , 58, " "		531	108	27
" " ,59, " "		438	52	17
" " , 60, " "		310	18	0
Ridley's 170, Crawleyside Level		210	43	17
" , 170(2)o "	142.2	230	38	7
" , 170(2)i, "	143.1	198	34	1
Rippon's, 119, Lanehead Quarry		296	74	16
Rotherhope, 719, Rotherhope Fell Mine		427	58	29
Scordale Mines, 390		169	7	0
Sedling, 330, Sedling Mine		325	174	96
" , 330, "		362	162	92
Shildon, 425, Shildon Farm Shaft	128.0	149	0	0
South Slitt, 609, Blackdene Mine	118.6	222	69	33
" " ,610, "	125.6	114	0	8
" " ,611, "		189	95	59
Swinhope Cross, 774, Swinhopehead Mine	130.6	164	6	0
" " ,775, "		171	100	49
Thorny Brow, 248, Thorny Brow Mine	150.7	313	247	147
White, 100, Sikehead Mine		283	100	34
" 98, Whiteheaps Mine		361	97	21
William's, 416, Swinhope Mine		262	72	28

Fig. 8.21 Showing Sample Distribution within the North Pennine Orefield in Relation to Dunham's Gangue Zone Boundaries.

1. Mineral veins of the Red Vein System and of the Rookhope Valley within the area of Fig 8.18 - These have been extensively sampled, individual localities are hence not marked.
2. Approximate area of Fig. 8.18.
3. Major structural features.
4. Outer margin of fluorite zone - after Dunham, 1948.
5. Inner margin of barium zone (where not coincident with outer limit of fluorite)
6. Blackdene Vein, see Fig 8.19 and text.
7. Whiteheaps/Sikehead Mine, see Table 8.1 and text.

FIG. 8-21
Regional Sampling



APPENDIX 1.

HEAT TRANSFER

A1.1 Heat Exchange with Wall Rocks.

Fundamentally, heat transfer between two phases in a system can occur by three processes: conduction, convection and radiation. In a hydrothermal system there is fluid motion, and energy and mass are transported by potential gradients and by the movement itself. This complex of transport processes is convection (Kays, 1966). Since motion is induced by some means other than internal density gradients, the process is specifically called forced convection. Convection is undoubtedly the most important mechanism of cooling of hot hydrothermal solutions, although radiative cooling may occasionally be significant.

In simple terms, a convective heat flux can be defined thus:

$$\text{Heat Flux, } Q = h\,(t_1 - t_2)$$

where h (the conductance) is an essentially hydrodynamic property and the thermal potential difference $(t_1 - t_2)$, a thermodynamic property. h is a function of all the parameters that affect heat flow, such as thermal conductivity, specific heat, viscosity etc. and may itself be a function of $(t_1 - t_2)$. The problem of finding Q is largely confined to the calculation of h and the solution of corresponding fluid dynamic problems (Rogers and Mayhew, 1957).

A1.2 Boundary Layers.

For most applications, the influence of viscosity in a flowing fluid is restricted to a thin region very close to the wall. This is called the velocity boundary layer, defined as the region in which fluid velocity changes from its free stream value to zero at the wall surface.

Major temperature and concentration gradients are also located in regions very close to wall surfaces, giving rise to thermal and concentration boundary layer concepts.

During precipitation and crystal growth, assumed to occur within the thermal boundary layer, concentration gradients obeying Fick's law of diffusion are created. The rate of diffusion of a component ion along the concentration potential gradient is a function not only of that gradient but also of the other potential gradients within the system.

Boundary layers are generally regarded as very thin relative to other flow dimensions. However, in the case of steady laminar flow through a tube, the boundary layer may grow until it meets itself in the tube centre and establishes a fixed velocity or thermal etc. profile. Boundary layer profiles from orebody cavities may have approximated to those of tube flow.

A1.3 Flow types.

There are two basic types of fluid flow :

1) Laminar flow, in which elements of fluid move in smooth steady paths, forming velocity layers parallel to the wall. Heat transfer is by conduction across the fluid layers to the wall.

2) Turbulent flow, in which individual elements of fluid move in random paths super-imposed on a steady, mean bulk flow. Heat transfer is generally more effective since the velocity and thermal boundary layers are very thin and the thermal potential $(t_1 - t_2)$ occurs over a shorter distance than in laminar flow.

Reynolds discovered that evaluation of the ratio:

$$Re = \frac{2 r \rho V}{\mu} .$$

The Reynolds Number (dimensionless)

gives a criterion of flow type. When Re exceeds a critical value, Re_{Cr}, flow becomes turbulent. The value of Re_{Cr} for smooth walled tubes of circular cross-section (Kays, 1966) is about 2,300. By analogy, this figure is probably broadly applicable to orebody cavity models of finite rectangular etc. cross-section. Re_{Cr} for flow over a flat plate, a situation possibly analogous to deep fissure veins of the type occurring in the Weardale Granite where both height and length are effectively infinite, varies from a few thousand to 10^7, generally taken as 5×10^5 (Rogers and Mayhew, 1957).

Stable flow regimes can be expected to develop at distances of 30 to 40 times the equivalent hydraulic cavity diameter from the cavity entry point. In the intermediate zone, known as the hydrodynamic entry length, flow is generally violently turbulent when the feeder is constricted. In this same zone, the effects of throttling or irreversible adiabatic expansion aid in cooling the hydrothermal brine.

(The equivalent hydraulic diameter Deq is calculated from $^{4A}/_{S}$ and, for our purposes, if the ratio of height to orebody cavity width is large, is effectively 2 x the wall separation or cavity width. The equivalent hydraulic radius Req = $^{A}/_{S}$).

Brine flow characteristics have been calculated for two orebody types. The first type, a model cavity of rectangular cross-section 20m by 1 to 2m simulates an orebody cavity in the Great Limestone. The second model, a cavity 5 cm wide, of infinite height and length, approximates to the open fissure veinlets penetrated in Weardale Granite by the Rookhope Borehole.

Calculations have been made for brine velocities ranging from 1 cm/sec to 0.001 cm/sec which probably encompass the actual values at

mineralization (Section 5.10). The effects on flow type of surface irregularities from 1 to 4 cm high are also considered. Brine properties where necessary, have been calculated for a 20% NaCl solution at 150°C.

Flow characteristics 1 — Brine in rectangular cavity

Dimensions 2,000cm, 100 cm.

$D_{eq} = 200$ cm, $R_{eq} = 50$ cm

$$Re = \frac{2 R_{eq} \rho V}{\mu}$$

The Reynolds Number can be considered a function of brine velocity.

Vcm/sec.	Re
1.0	31700
0.1	3170
0.01	317
0.001	31.7

The transition from laminar to turbulent flow in a smooth pipe occurs at Re 2300. However, this estimate is lowered in a normal situation by consideration of:

1) Contact resistance. When the ratio of roughness height (crystal terminations and wall rock impurities) to boundary layer thickness is significant, drag becomes proportional to the square of the velocity and may produce enforced turbulence.

2) Buoyancy effects. Defined in part by the dimensionless Grashof Number, buoyancy effects are proportional to the difference between free stream brine temperature and interface wall temperature. In the high Grashof region, buoyancy effects are large and free convective overturns may be superimposed on the bulk forced flow system.

3) Pulsatory flow.

The effect of contact resistance can be evaluated using the Relative Roughness factor (R.R.) (Streeter, 1962).

$R.R. = \varepsilon / 4\ Req$ $\quad$ ε = effective dimension of surface irregularity.

Thus, for projections of :

1 cm	R.R. = 0.005
2 "	R.R. = 0.01
3 "	R.R. = 0.015
4 "	R.R. = 0.02

Referring to Moody's Stanton diagram (Moody, 1944) which relates R.R., Re and flow type, a modified estimate of the critical Reynolds Number can be obtained which is a function of the size of cavity wall irregularities.

	Relative Roughness			
	0.005	0.01	0.015	0.02
31700	Transition Zone	Upper Transition	Upper Transition	Completely Turbulent
Reynolds 3170	Critical	Critical	Critical	Critical
317	Laminar	Laminar	Laminar	Laminar
Number 31.7	Laminar	Laminar	Laminar	Laminar

Thus, as the value of ε is increased, so the value of Re_{Cr} is reduced, and hence the probability of turbulence at a given brine velocity is increased.

In a wider model cavity (2m), the relative roughness effect decreases considerably and is not fully compensated by the corresponding increase in Re.

Projection height (Cavity 2m in width)	1 cm	R.R. - 0.0025
	2 "	R.R. - 0.005
	3 "	R.R. - 0.0075
	4 "	R.R. - 0.01

Relative Roughness

V	Re	0.0025	0.005	0.0075	0.01
1cm/sec.	63300	Transition Zone	Transition Zone	Transition Zone	Upper Transition
0.1	6330	Transition	Transition	Transition	Transition
0.01	633	Laminar	Laminar	Laminar	Laminar
0.001	63.3	Laminar	Laminar	Laminar	Laminar

Thus, other properties constant, change in cavity width can affect flow stability by altering the Reynolds Number and relative roughness factor. Since crystal growths on orebody walls may attain projecting dimensions in excess of 4cm (the maximum discussed here), relative roughness may be an important factor to consider.

Buoyancy effects

The Grashof Number, Gr, is a measure of the interaction between the forces of buoyancy (tending to create free convective walls) and inertia, the viscous forces tending to maintain steady flow.

Approximate calculations of Gr for the Great Limestone model (1m width) yield a value of $2 \times 10^{10} \times (t_1 - t_2)$. The temperature difference is an unknown variable, but unlikely to alter Gr by more than one order of magnitude.

The critical Grashof number for convective instability can be calculated for the system from the relation:

$$Pr \times Gr_{Crit} = 5 \times 10^5$$ (Kutateladze and Borishanskii, 1966)

where Pr, the Prandtl Number $\frac{CP_a \times DyVis}{K} = 0.5$

Thus, Gr_{Crit} is 1 x 10^6 and, quite clearly, convective instability was inevitable in an orebody cavity of large dimensions. Despite the possibility of sub-critical Reynolds Numbers, enforced turbulence probably occurred.

Flow characteristics 2 — Brine in 5cm wide fissure of infinite extent

Deq = 10 cm, Req = 2.5cm

V cm/sec.	Re	Reynolds Number
1.0	1580	
0.1	158	
0.01	15.8	
0.001	1.58	
1cm projection	R.R = 0.1	Relative Roughness
2" "	R.R. =0.2	
3" "	R.R. =0.3	
4" "	R.R. =0.4	

Although the Reynolds Number is well below Re_{Cr} for smooth well conditions, the effect of any surface roughness greater than $R.R_{Crit.}$, calculated as 0.5 cm, would produce turbulence.

Calculation of Gr yields the value of 3 x 10^6x $(t_1 - t_2)$, the same order of magnitude as $Gr_{Crit.}$

It is apparent, then, that superimposition of free convective cells, hence enforced turbulence, upon the bulk flow system of the larger orebody cavities was inevitable. Although the buoyancy effect is very much reduced in narrow fissures, the effect of wall surface roughness

increases drastically to ensure turbulence over any but the smoothest fissure walls. Heat exchange between the ore-bearing brine and wall-rocks was therefore an efficent process. The thorough mixing of the brine through turbulence was probably significant in producing rapid response to any change in the environment.

APPENDIX 2.

FLUID INCLUSION COMPOSITION STUDIES AND GEOTHERMOMETRY.

A2.1 Definitions.

One, two and three phase inclusions (excluding wholly solid inclusions) within mineral crystals are classified according to their mode of formation, using a system devised by Yermakov (1950).

A) Primary fluid inclusions

Primary fluid inclusions comprise fluid trapped within a crystal by primary growth (as opposed to recrystallization or redistribution of material) of the crystal. The fluid is representative of that part of the nutrient fluid participating in crystal growth. Thus the determined composition of primary inclusions can be said to be that of the mother fluid (Yermakov, op.cit. and Roedder, 1960, 1967, review the evidence for this statement). The determined temperature and pressure of primary inclusion trapping pertain to the actual conditions of crystal growth (Roedder and Skinner, 1968). These inclusions are syngenetic, according to Yermakov's classification.

The various mechanisms of fluid enclosure in growing crystals have been discussed by Yermakov (op.cit.), Smith (1953) and many others. Experiments with laboratory - grown crystals are reported by Leray (1970). Some of the trapping mechanisms active in the fluorite deposits studied during this project are,listed below:

i) Incomplete junction of growth steps, crystal imperfections. Gross imperfections caused by hopper growth, overlapping growth planes and episodic change in crystal growth rates provide trapping sites. The last two processes are particularly commonly found in fluorite.

ii) Infilling of dendrites (Knight, 1967)

iii) Gas adherence to growth planes

iv) Solid adherence to growth planes
Settled solids can be overgrown, often simultaneously trapping

some fluid, or can be pushed along by growth faces (Roedder, 1967). In both cases, trails of imperfections provide trap sites. This again is very common in hydrothermal fluorites.

v) Multinucleate growth and twin plane interference

vi) Mutual interference between adjacent crystals (forming the inductional inclusions of Grigor'ev, 1948).

B) Epigenetic, secondary fluid inclusions.

Epigenetic, secondary inclusions comprise fluid trapped in healed and sealed fractures. They have formed after that part of the crystal in which they are found. Fracture healing porcesses have been intensely studied by Russian workers (Lemmlein and Kliya, 1952; Lemmlein, 1956).

The broad class of epigenetic, secondary inclusions can be subdivided into the pseudosecondary inclusions, trapped in fractures occuring during growth of the host crystal *; syn-ore secondary inclusions, trapped in fractures formed during mineralization, but after completion of growth of the host crystal; and secondary inclusions (sensu stricto), trapped in fractures known to definitely postdate the parent mineralization of the host crystal. In a broad sense, all three of these types are referred to as secondary (particularly since type diagnostics are frequently very difficult to observe), though it is quite apparent that if an inclusion can be critically assigned to any particular type, then the value of the information derived from the inclusion is greatly increased.

Footnote.

* Yermakov notes that such inclusions are secondary only with respect to the certain portions of the crystal where they occur. Since they were contemporaneous with outer parts of the same crystal, they could be said to be syngenetic with respect to the whole crystal.

The diagnostic feature of pseudosecondary inclusions, stated by Yermakov, is that healing of the pseudosecondary fracture coincided with further outward growth which effectively sealed the fracture at its open end. Temperature obtained from these inclusions are the same as thos from contemporaneous primary inclusions in the same crystal.

Syn-ore secondary inclusions may be recognised from salinity or other compositional data, as the same mineralizing brine that formed the host crystal. Temperatures, however, are generally lower than the temperature of the brine in the open brine cavity. This is the result of thermal gradients existing in the vein margin and provides evidence that the mineralizing brines were hotter than the wall rocks. The difference in temperature is proportional to the thickness of mineral fill separating the crystal and open vein cavity at the time of fracturing.

The usefulness and validity of data from these types of inclusion (with the exception of syn-ore secondaries) has been discussed at great length by foreign workers and the reader is referred to the literature for summaries of the various points of view (see refs. in Roedder, 1960; Roedder and Skinner, 1968). The consensus of opinion among geochemists today is that as long as the investigator maintains a clear idea of the genetic implications of inclusion classification, the technique is a relatively simple, yet invaluable, source of information on the nature of ore-forming fluids and on the process of ore deposition. However, the onus is very much on the instrument operator to use his common sense in what is obviously a very selective study.

A2.2 Freezing Technique and Apparatus.

Hydrothermal solutions are known to be largely NaCl brines. The salinity in terms of equivalent NaCl, of fluid inclusion can be found

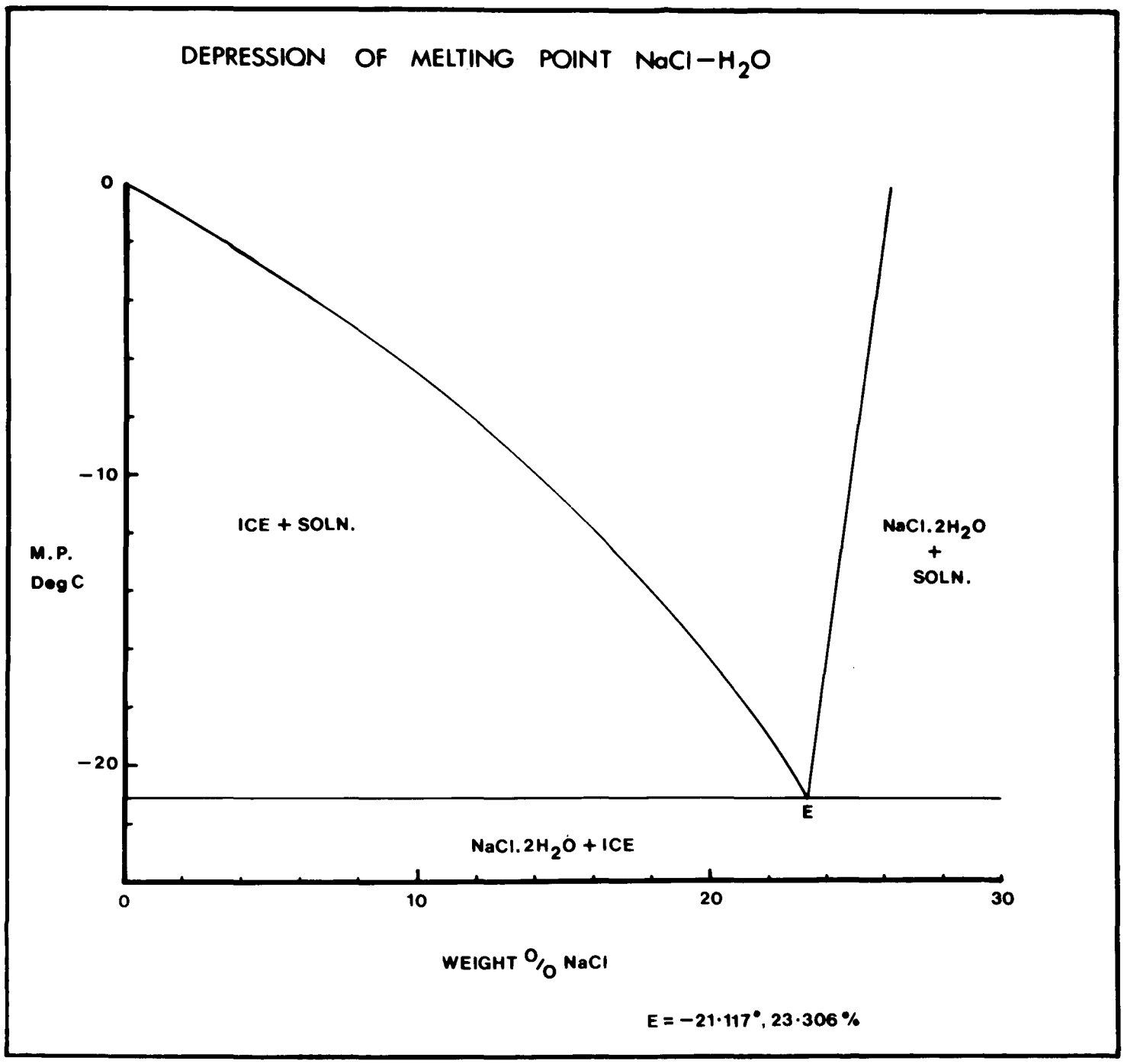

DEPRESSION OF MELTING POINT NaCl–H_2O
0
−10
−20
M.P.
Deg C
ICE + SOLN.
$NaCl.2H_2O$
+
SOLN.
E
$NaCl.2H_2O$ + ICE
0
10
20
30
WEIGHT % NaCl
E = −21·117°, 23·306 %

FIG. A2-1

FIG. A2-2

FREEZING STAGE OPERATING ARRANGEMENT

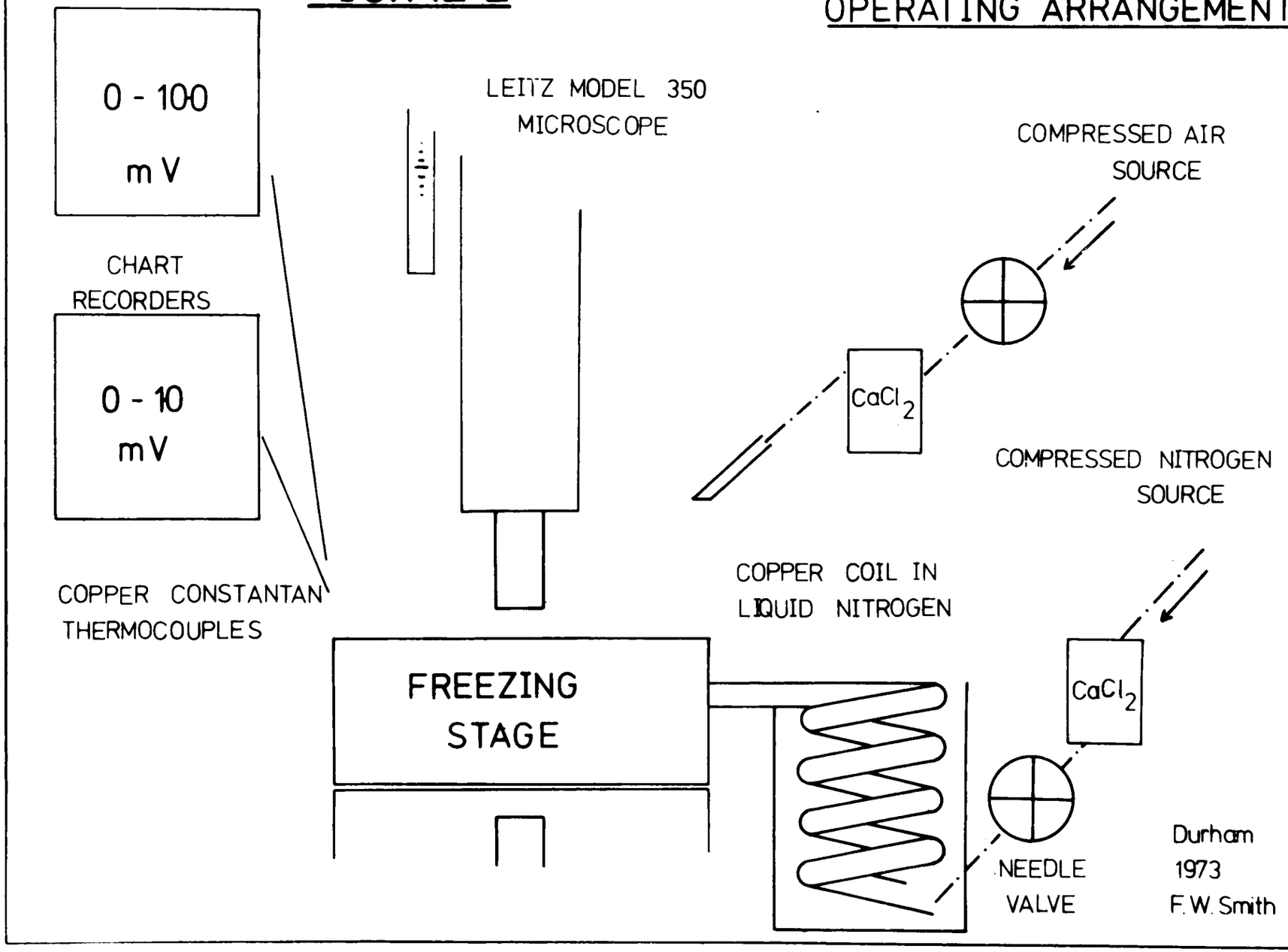


TABLE A2.1

STANDARDS USED FOR THERMOCOUPLE CALIBRATION

Compound	Melting point, °C
n - Decane *	- 29.7
Quinoline *	- 15.9
Benzonitrile	- 13.0
Methyl Benzoate *	- 12.3
Bromine *	- 7.2
Butyric Acid	- 6.5
Benzene	5
Stannous chloride	37.7
1 Chloro 2-4 Dinitrobenzene	48 - 52
Acetoxime *	61 - 62
8 - Hydroxyquinoline *	73 - 75
Sucose β acetate *	82 - 84
M Nitrophenol *	95 - 98
Resourcinol *	110 - 111
Benzoic acid *	122 - 123
Urea *	132 - 133
o Nitroaniline *	147.5
∝ Benzoin oxime *	152 - 154
Succinic acid *	186 - 188
Anthracene *	216
Hexachlorobenzene	228
Gallic acid	263
Benzene hexachloride	310

* Standards most frequently used

The standard compounds are enclosed in normal melting point capillary tubes, sealed at both ends.

by measuring the depression of freezing point (Fig. A2.1). The presence of other ions can effect the results and potassium and calcium in particular lead to spuriously high results. A check on these ions was made by analysing mineral leachates for Na:K ratios.

At low temperature, some components of inclusions may form cryohydrates. $NaCl.2H_2O$ (cryhalite) and $CO_2.5\frac{3}{4}H_2O$ are formed fairly commonly. Gaseous components may liquify and this is the standard method of detecting and measuring the concentration of CO_2. Liquid CH_4 and H_2S have been observed in inclusions. Melting point determinations on trapped liquid hydrocarbons often assist their identification.

Thus, low temperature studies can provide information on both the composition and concentration of hydrothermal brines in fluid inclusions (Roedder, 1963; Bazarov and Motorina, 1968).

A description of the freezing stage built for, and used during the present study has been published (Smith, F.W., 1973 a). The layout of stage with auxiliary apparatus is shown in Fig. A2.2. The thermocouple (copper-constantan) was calibrated against the known melting temperature of standard compounds (Table A2.1).

A2.3 Freezing Stage Results.

(data from the literature are included, for comparison).

North Pennine Fluorites.

Primary and pseudosecondary inclusions freeze very easily, supercooling by less than 10°C, indicating the presence of suspended solid particles in the brine. This observation supports the previous suggestion of relatively high brine flow rates in vein cavities.

No cryohydrates or liquid gases were observed during melting, therefore results have been interpreted from the low NaCl side of the

eutectic in the $NaCl-H_2O$ system. Unfortunately, this interpretation is not strictly correct since Na:K ratio analyses indicate the presence of up to 20 weight percent K^+. This is reflected in the melting points of the most concentrated brines, which are lower than the eutectic in the pure $NaCl-H_2O$ system. Data on mixed chloride systems are, however, lacking.

The inclusions generally measure less than 0.1mm in diameter.

North Wales Fluorites.

These results are fully discussed by Smith (1973b). $NaCl\ 2H_2O$ was observed in all primary and pseudosecondary inclusions, all of which froze easily. The observed eutectic is close to that of the pure $NaCl-H_2O$ system, reflecting the low potassium content of the brines indicated by Na:K ratios.

Deposits in the Permian of East Durham.

Inclusions in fluorite and clear barite were examined. The results are fully discussed in Smith (1972) and Hirst and Smith (inprep.). Freezing was very slow and a high degree of supercooling occurred. Inclusions in some barite from Raisby Hill Quarry did not freeze even after immersion in liquid nitrogen ($-196^{o}C.$) for 16 hours. Clearly, the minerals formed from very clean, slow-moving brines.

Lake District Fluorite.

Primary and secondary inclusions froze easily. Both yielded eutectics close to the pure $NaCl-H_2O$ value and both formed cryohalite. Primary inclusions also developed halite which dissolved at temperature less than ambient. The eutectic figure is of great interest in showing the absence of significant amounts of $Ca\ Cl_2$ in solution. Postlethwaite (1889) records the presence in the vein workings at Brandlehow, of brines bearing 1.0wt. % $CaCl_2$ and 1.2wt. % NaCl, and it

TABLE A 2.2 EQUIVALENT SALINITY DETERMINATIONS

SPECIMEN NO	LOCN	FI TYPE	N	ICE MELTING POINT RANGE	MEAN	NACL EQUIV.WT.%
	N.PENNINES					
144	REDBURN	P	12	-18.65 TO -19.55	-19.13	22.00
		S/PS	9	-15.70 TO -18.1	-17.36	20.80
172	REDBURN	P	6	-19.25 TO -20.5	-19.64	22.40
		S/PS	17	-12.25 TO -18.65	-16.52	20.20
174	REDBURN	P	7	-18.7 TO -20.5	-19.86	22.45
175	REDBURN	P	12	-18.3 TO -20.5	-19.11	22.00
201	REDBURN	P/PS	17	-17.6 TO -23.0	-20.2	22.7
300	REDBURN	PS	11	-20.5 TO -22.8	-22.5	24.0
402	REDBURN	P	6	-18.5 TO -19.75	-19.22	22.05
411	REDBURN	P	6	-22.8	-22.8	24.2
32A	GROVERAKE	P	13	-17.7 TO -19.3	-18.8	21.8
		S/PS	2	-5.5	-5.5	7.2
		S/PS	4	-16.25 TO -16.75		20.25
155A	CRAWLEY	P	4	-17.25 TO -18.3	-17.8	21.1
155B	CRAWLEY	P	4	-16.25 TO -16.7	-16.5	20.2
163	ROGERLEY	P	6	-16.4 TO -17.7	-17.0	20.6
165	ROGERLEY	P	19	-16.4 TO -20.2	-18.05	21.35
233	EAST BOLTSBURN	P	1	-20.2 TO -21.5		22.75 TO 23.5
		S	3	-4.72	-4.72	7.55
RBH4	ROOKHOPE BH.	P	10	-19.45 TO -22.25	-20.52	22.9
RBH9	ROOKHOPE BH.	PS	6	-16.0 TO -19.2	-18.1	21.35
		S	9	-8.3 TO -13.4	-11.04	15.1
RBH12	ROOKHOPE BH.	P	7	-19.50 TO -20.15	-19.91	22.60
RBH22	ROOKHOPE BH.	P	7	-19.50 TO -20.15	-20.64	23.0
		S	1	-9.0	-9.0	12.95
RBH13	ROOKHOPE BH	P	2	-19.20 TO -19.74	-19.47	22.35
		PS/S	10	-17.5 TO -20.5		20.9 TO 22.9

SPECIMEN NO	LOCN	FI	TYPE	N	ICE MELTING POINT RANGE			MEAN	NACL EQUIV.WT.%
RBH19	ROOKHOPE BH		P	19	-23.5	TO -30.2		-25.9	
			S	2	-17.3	TO -18.5		-17.9	21.2
			S	2	-9.30	TO -9.75		-9.53	13.5
	CENTRAL PENNINE OREFIELDS								
356	KELD HEADS		P	10	-18.25	TO -18.75		-18.5	21.65
503	GREENHOW RAKE		P	8	-18.25	TO -18.8		-18.4	21.60
751	CARDEN HILL		P	8	-20.2			-20.2	22.75
766	OLD GANG		P	6	-15.75	TO -16.4		-16.1	19.9
			S	5	-5.0	TO -7.5		-6.25	9.5
828	HARTLEY BIRKETT		P	10	-16.1	TO -17.5		-16.75	20.35
	LAKE DISTRICT								
517	CALCITE, SHAP		P		-16.5	TO -21.5			20.2 TO 23.5
	EAST DURHAM								
219	CHILTON		P	10	-19.15	TO -20.30		-19.57	22.35
			S		0.0			0.0	0
627	BARITE FERRYHILL GAP		P/PS	20	-12.6	TO -25.9		-17.55	16.6 TO 25.6 (20.95)

SPECIMEN NO	LOCN	FI	EUTECTIC TEMPERATURE N	RANGE		MEAN	HYDRATE/SALT MELTING PT. N	RANGE		MEAN	SAL EQWT%
	N.WALES										
585	PANT DU	P	7	-17.4	TO -19.75	-18.95	7	-12.3	TO -17.1	-15.0	24.10
587	BRYN GWIOG	P	13	-18.3	TO -20.30	-19.5	22	-6.8	TO -12.05	-9.4	24.78
	BRYN GWIOG	PS	5	-20.25		-20.25	7	-14.95	TO -16.5	-15.6	24.15
588	EAST HALKYN	P	-	-21.4	TO -21.9		30	-14.3	TO -18.0	-16.4	24.00
	LAKE DISTRICT										
328	BRANDLEHOW	P	12	-20.3	TO -24.1	-22.3	13	+1.75	TO +11.4	+7.25	26.3
		PS/S	8	-20.3	TO -20.9	-20.6	8	-14.99	TO -16.40	-15.9	24.1
	CENTRAL PENNINE OREFIELDS										
617	SEATA MINE	P	2	-22.7		-22.7	4	0.0	TO +10.0		26.6

seemed possible, at first, that this was a remnant of the mineralizing fluid. However, the contrasting calcium contents of the fluid inclusions and brine seepages indicates that they are not related.

A2.4 Homogenization Geothermometry, Technique and Apparatus.

Fluid inclusions trapped at temperatures greater than 70°C. generally contain vapour bubbles at room temperature. These form, during cooling, through differences between the coefficients of contraction of the trapped brine and host mineral. The homogenization technique simply entails reheating the inclusion and host until the bubble just disappears and the inclusion reverts to a single fluid phase (Sorby, 1858). During this study all of the inclusions homogenized into the liquid phase, indicating that the parent brines too were liquids.

It is essential to note, however, that T_h is generally not the same as the true trapping temperature of the inclusion, but an underestimate, subject to an additive correction ΔT. The significance and derivation of ΔT, which is pressure dependent, is discussed in a following section. For purposes of comparison of specimens obtained within a relatively small pressure domain, T_h alone is quite satisfactory.

It is not necessary to find T_h, and very accurate measurement of the filling ratio (F% = degree of filling of inclusion by liquid phase) can provide the same information required to find T. This forms the basis of Yermakov's 'rapid method'.

Results of investigations and modern developments in fluid inclusion geothermometry are reported in the Proceedings of C.O.F.F.I. (an international compilation of abstracts, translations and papers).

The apparatus used in the study comprised a micro-furnace (∿30 ohms) stage, Leitz 350 microscope and Rotary Regavolt - rheostat. Temperatures were read on a Philips PR 2210 U/21 chart recorder operating from an ice-cold junction, chromel-alumel thermocouple. The furnace used during most of the study had been constructed by Sawkins, who was also responsible for setting up the rest of the apparatus in 1965. Another furnace, incorporating air-cooling to shorten the waiting period between determinations, was built during the summer of 1973. Identical results can be obtained from both furnaces. A description of the detailed layout, usage and calibration of the apparatus was compiled by Gale (1971). The form of the present study exactly followed the lines set out by Gale, to whom the author is extremely grateful for instruction and introduction to the technique. It is only necessary to place on record the fact that heating rates over the point of homogenization varied from $5^{o}C$/min. to, $1^{o}C$/min during experimental and calibration runs. Reasonable precautions were taken against thermal gradients and overshooting and a number of duplicate runs made to check instrumental and operational stability. The thermocouple calibration (Table A2.1) was regularly checked and found to be quite stable.

Specimens comprised cleavage fragments and doubly polished mineral wafers varying from 0.5 mm. to 2 mm. in thickness.

The effect of specimen thickness on T_h has been shown by Harker (1971) to be important at "fast" heating rates using the commercial Leitz stage (7% difference in T_h was found after grinding discs from 2 to 1 mm.). I have not been able to test this effect , but suspect that the Durham stage permits much better all-round heat construction than the other, and hence thermal gradients within the specimen are slight.

The thickness of the disc used in the study depended upon

mineral transparency (blasted or weathered material is finely shattered, tending towards opacity), the optimum being 1.5 to 2 mm.

A2.5 The Pressure Corre ction, $\triangle T$.

The homogenization temperature, T_h , is a minimum value for the true trapping temperature, T. In order to find T, it is necessary to know, or be able to estimate, two further parameters:

1) The salinity, X, of the brine

2) The pressure, P, on the brine when trapped.

It is not necessary to measure T_h if the filling ratio F, and salinity can be measured accurately.

At T_h, when the vapour bubble completely disappears, the internal pressure of the inclusion is equal to the vapour pressure of the solution. (Actually, surface tension effects cause premature collaps and slight liquid stretching, but this is considered quantitatively insignificant in inclusions with diameters greater than about 2μ). Thus, for any given salinity and brine density, T_h is constant, regardless of T and P. This point is best illustrated with reference to the P-T-F diagram for a 20% NaCl brine (Fig. A2.3). The curve A-B-C is the two-phase equilibrium curve or vapour pressure curve (Sourirajan and Kennedy, 1962). The line B-G is the isochor of 20% NaCl brine with a density of 1.06081gm/cc, equivalent to a filling ratio, F = 92.5. This is representative of primary fluid inclusion in North Pennine fluorites. Since all the inclusions studied during this work homogenize into the liquid phase, i.e. T $<$ the critical temperature, indicating the liquid nature of the parent brine, this type of behaviour alone will be discussed.

Inclusions trapped at C, E and G lies upon the same isochor. They have the same density. Since they remain at constant volume during cooling (crystal shrinkage is assumed negligible), they must follow the isochor (the slope of which is essentially a function of compressibility of the brine) to its inter-section with the vapour pressure curve at B. B is the homogenization temperature. The internal pressure of the inclusion is equal to the vapour pressure of the brine at that temperature, and a bubble nucleates. Thereafter, the pressure decreases slowly with fall in temperature along the line B-A as the vapour bubble gradually expands.

The temperature difference between T_h and the trapping temperature at D, E and F is the pressure correction, which can only be found if an estimate of the trapping pressure is available. Values for $\triangle T$ under varying physical and chemical conditions can be ontained from the Russian literature (Lemmlein 1956; Lemmlein and Klevtsov, 1956a, 1956b, 1961; Klevtsov and Lemmlein, 1959; Samoylovich and Khetchikov, 1968, 1969; Samoylovich et al., 1970).

A2.6 Temperature Data, Reduction and Presentation.

Homogenization temperatures may be determined with good precision and apparent accuracy. Duplicate measurements were made quite frequently in the first stages of the project and reproducibility found to be better than $\pm$ 1.5°C on normal runs. Precision can be improved at the expense of time, eyestrain and boredom by lowering the heating rate to less than 1°C/min. A compromise rate of about 2°C/min at T_h was aimed for throughout the main study and found quite satisfactory. Calibration determinations rarely vary beyond $\pm$ 1.5°C from the mean of previous determinations.

FIG. A2.3

P. - T - F diagram illustrating the derivation of Δ T. Drawn from the data of Lemmlein and Klevtsov (1961) and Sourirajan and Kennedy (1962). See text for explanation.

FIG. A2.4

Fluid inclusion pressure correction curve (ΔT. int). Data drawn or calculated from Lemmlein and Klevtsov (1961) for a 20% NaCl brine, F = 92.5 ($\equiv \rho$ 1.06181).

ΔT_{Lith} - Correction from a lithostatic pressure gradient, 1 bar/3.78m

$\Delta T_{Hy.}$ - Correction from a hydrostatic pressure gradient, 1 bar/10m.

ΔT_{Int} - Correction from a mean gradient.

Key to horizons: 1 Lower Fell Top Limestope at Boltsburn; 2 Rogerley Hush; 3 Little Limestone; 4 Great Limestone; 5 Base Four Fathom Limestone; 6 Tynebottom Limestone; 7 Jew Limestone; 8 Lower Little Limestone; 9 Lower Smiddy Sandstone; 10 Lower Leaf, Lower Smiddy Limestone; 11 2080' in Rookhope Borehole.

TRAPPING TEMPERATURES AND PRESSURES FOR A 20% NACL BRINE, F = 92.5; T HOM = 158.0°C (V.P. 25 ATM.) CALCULATED FROM THE DATA OF LEMMLEIN AND KLEVTSOV, 1961, USING A MONOCUBIC SPLINE FUNCTION PROGRAM (WRITTEN BY P.GUNN)

TEMPERATURE °C

PRESSURE ATM.	00	10	20	30	40	50	60	70	80	90
0000				158.5	159.4	160.3	161.2	162.1	163.0	163.9
0100	164.8	165.7	166.6	167.5	168.4	169.2	170.1	171.0	171.9	172.8
0200	173.7	174.5	175.4	176.3	177.1	178.0	178.9	179.7	180.6	181.4
0300	182.2	183.1	183.9	184.8	185.6	186.4	187.3	188.1	188.9	189.8
0400	190.6	191.4	192.3	193.1	193.9	194.8	195.6	196.5	197.3	198.1
0500	199.0	199.9	200.7	201.6	202.4	203.3	204.2	205.1	205.9	206.8
0600	207.7	208.6	209.5	210.3	211.2	212.1	213.0	213.9	214.8	215.7
0700	216.6	217.4	218.3	219.2	220.1	221.0	221.9	222.8	223.7	224.5
0800	225.4	226.3	227.2	228.1	229.0	229.8	230.7	231.6	232.5	233.4
0900	234.2	235.1	236.0	236.9	237.7	238.6	239.5	240.4	241.2	242.1
1000	243.0	243.9	244.8	245.6	246.5	247.4	248.3	249.1	250.0	250.9
1100	251.8	252.7	253.5	254.4	255.3	256.2	257.1	257.9	258.8	259.7
1200	260.6	261.5	262.3	263.2	264.1	265.0	265.9	266.8	267.7	268.5
1300	269.4	270.3	271.2	272.1	273.0	273.9	274.7	275.6	276.5	277.4
1400	278.3	279.2	280.0	280.9	281.8	282.7	283.5	284.4	285.3	286.1
1500	287.0	287.9	288.7	289.6	290.4	291.3	292.1	293.0	293.8	294.7
1600	295.5	296.3	297.2	298.0	298.9	299.7	300.5	301.4	302.2	303.0
1700	303.9	304.7	305.5	306.3	307.2	308.0				

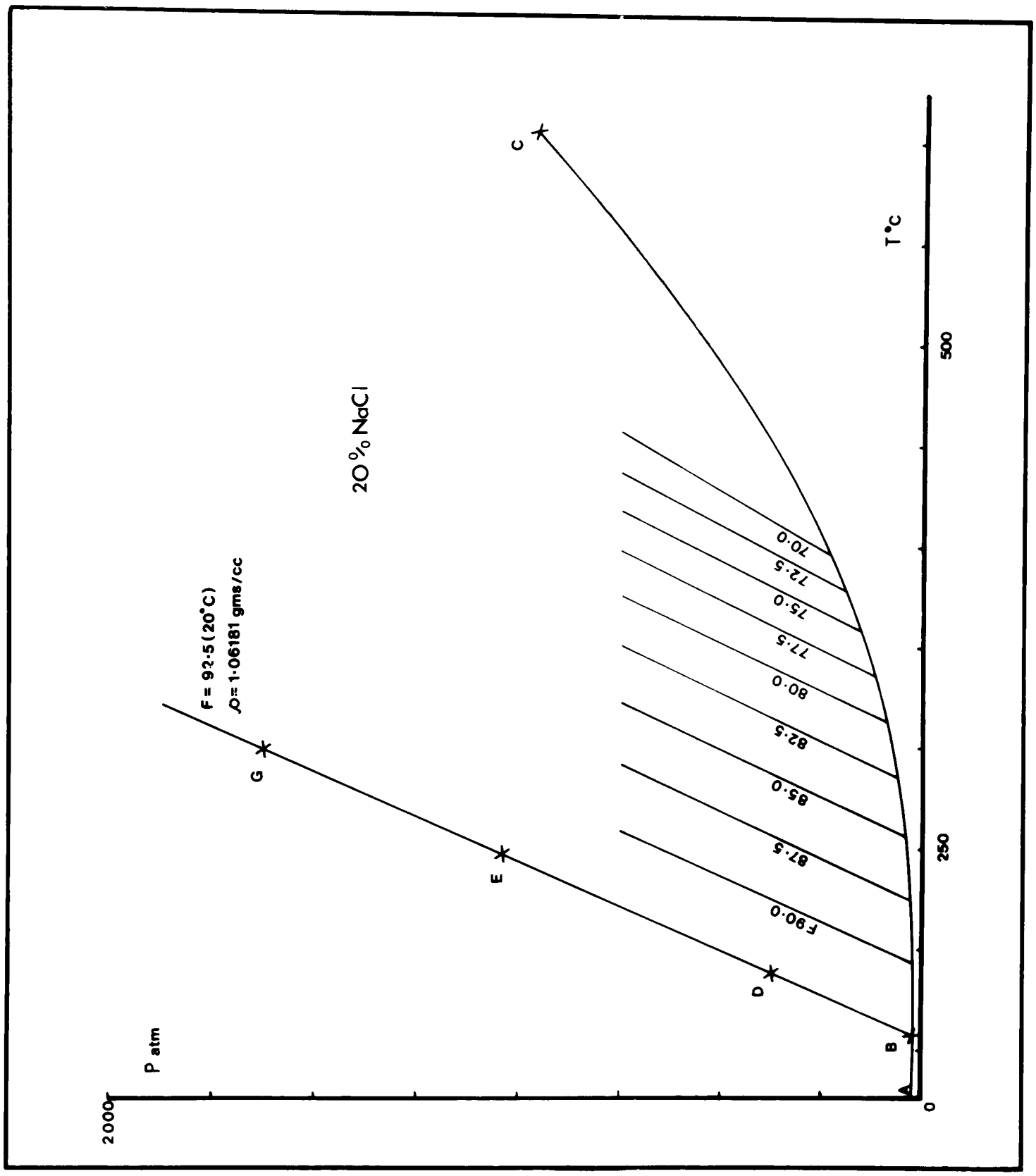
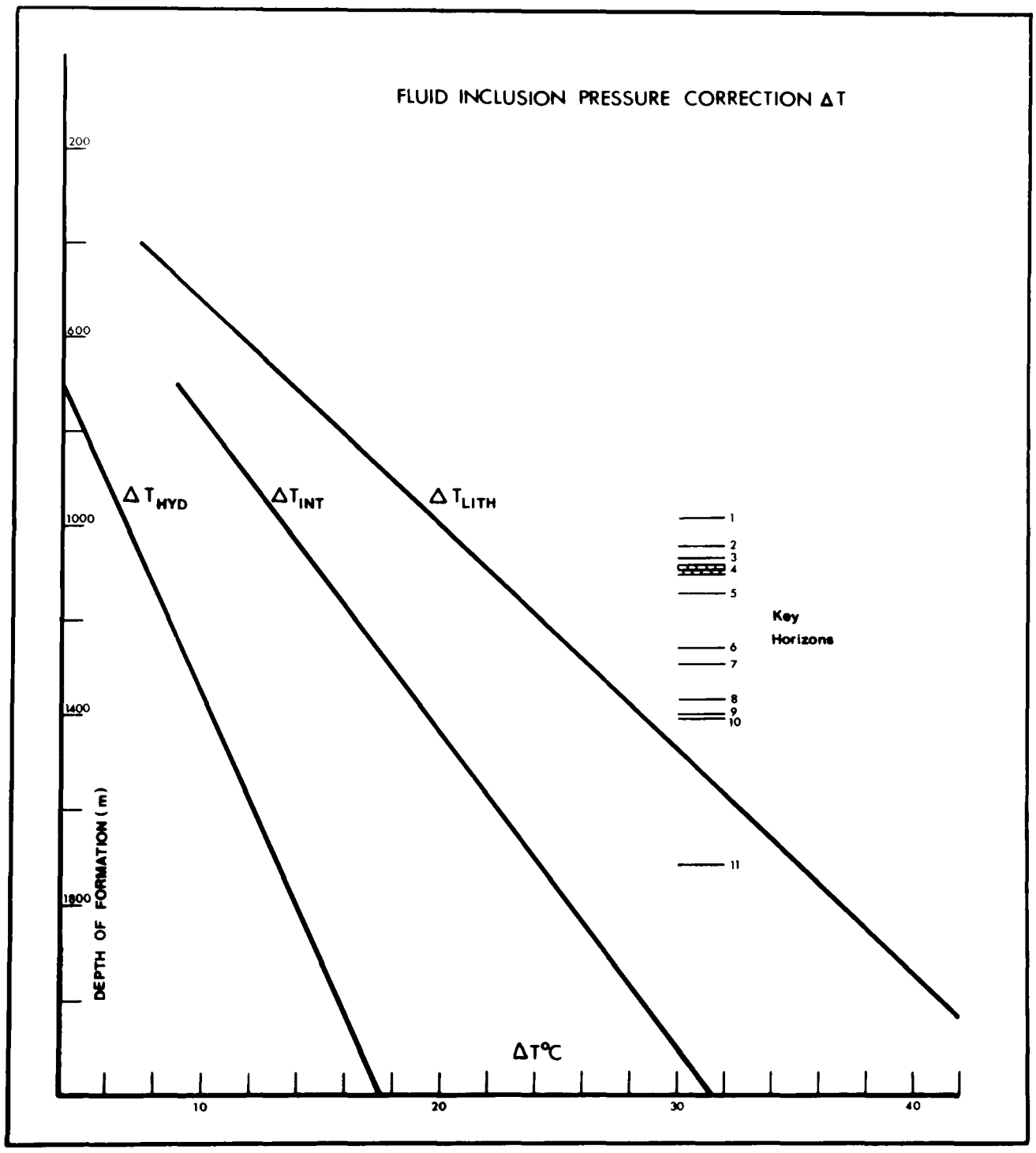

20% NaCl
F = 92·5 (20°C)
ρ = 1·06181 gms/cc
P atm
2000
T°C
500
250
0
C
G
E
D
B
A
70·0
72·5
75·0
77·5
80·0
82·5
85·0
87·5
F90·0

FIG. A2-3

FIG. A2-4


FLUID INCLUSION PRESSURE CORRECTION ΔT
200
600
1000
1400
1800
DEPTH OF FORMATION (m)
ΔT HYD
ΔT INT
ΔT LITH
1
2
3
4
5
Key
Horizons
6
7
8
9
10
11
ΔT°C
10
20
30
40

In contrast, the corrected trapping temperature, T, may be a most inaccurate and imprecise figure. This is the inevitable result of incorporating a large factor, Δ T, which is very pressure dependent, when such a high degree of uncertainty surrounds most pressure estimates.

Pressure estimation generally involves calculation of lithostatic and hydrostatic pressures for the likely maximum overburden at the time of mineralization. Sawkins took a value for the North Pennines of 1100m of overburden upon the base of the Great Limestone. True trapping pressures must lie between the extremes of lithostatic (2.5 bars/10m) and hydrostatic (1 bar/10m) pressures. In fact, as stated earlier, it is quite possible that mineralization occupies a vertical transition zone between these two pressure regimes, triggered by the sudden additional cooling and pressure decrease. Since such a transitional gradient cannot be quantified, a compromise median value between the pressure extremes has been taken to find ΔT Int (Fig. A2.4).

All inclusion temperatures quoted in the text are stated as mean homogenization or corrected mean homogenization temperatures.

Primary T_h determinations on any specimen generally fell within a narrow range. The distribution of results within the range varies between normal and lognormal. The spread of results is a function of several factors:

1) Observational errors - random errors. (Calibration errors may lead to systematic error or inaccuracy, but do not affect spread)

2) Necking down. This phenomenon, the "budding" of daughters inclusions, is very common in all of the specimens studied. Where it could be identified, the inclusions were generally not used. However, in badly broken material, where inclusions can be very difficult to see, necking criteria were not always recognized.

Three necking down stages are important:

(a) Necking occuring soon after trapping, before bubble nucleation, results in exactly the same T_h from each budded inclusion.

(b) Necking down, shortly after bubble nucleation, is very difficult to identify since the resultant inclusions have similar filling ratios, but T_h is slightly different, tending to produce spread.

(c) Necking after considerable cooling produces budded inclusions of grossly different filling ratios, generally quite obvious unless the two inclusions are very differen t in size.

3) Brine temperature fluctuation. This is very unlikely to reflect source variations (Lafitte, 1962), but could represent local perturbations in flow path and may include heat exchange from precipitation reactions. None the less, it is unlikely to have been on a greater scale than ± 3-4°C.

4) Inclusion size. Surface tension effects may cause premature bubble collapse in very small inclusions.

5) Permanent inclusion dilation resulting from accidental overheating (Larson et al., 1973)

6) Mistaken identification of secondary inclusions

Samples from the localities listed in Table A2.3 were also examined for fluid inclusions. Only gasless inclusions were present and if, as was believed, many of these were primary, then this implies that the minerals were formed at temperatures less than about 60 - 70°C (see Roedder, 1967, for example). Inclusions trapped at about these temperatures, and less, often fail to

nucleate bubbles since surface tension forces counteract thecontraction forces during cooling, resulting in metastable or stretched liquids. This tendency towards metastability is affected by the presence of fine solid particles that normally act as nuclei for bubble formation. It may be possible, under conditions of extremely slow and pure flow, to trap particle-free inclusions that may maintain a metastable single-phase despite formation at temperatures greater than 70°C.

Experience has shown that of the many modes of data representation, the statistical format adopted in this work is the most useful. Data are recorded in such a way that others may use them or recorrect them. This is in marked contrast with formats adopted by other workers, which very seldom permit useful quantitative comparison or collation of results. Typically, ranges, histograms or "bulk" temperatures are published with little or no indication of derivation, precision or numbers of samples involved.

A2.7 Note on the Decrepitation Technique

This technique involves heating a specimen of uniform grain-size, crushed mineral until the increase in internal pressure, after homogenization, bursts inclusions, shattering grains. The explosions, or decrepitation, can be monitored visually or by sound measurement (Yermakov, 1950). The resultant data can provide, to the experienced operator, a 'decrepitation temperature'. Naturally, this is higher than T_h, the exact overshoot depending upon the ratio of grain size to inclusion size, material (strength), trapping pressure and heating rate. Checks made against homogenization runs on identical material enable optimization of the first and last factors aiding peak resolution and providing a correction factor (for further work on that particular material) to find T_h (Naumov et al., 1967). The method holds great promise in

that it is very rapid and it can be used with opaque minerals (Ryabov, 1969). Portable field instruments have been produced in the U.S.S.R. for many years and the technique is much used in prospecting.

During 1971, I conducted, with Dr. K. Ashworth, a number of experiments in the construction of a thermosonic instrument A record of some of these experiments is kept with the files of the fluid inclusion laboratory, Durham. The experiments were largely unsuccessful owing to lack of suitable heat resistant microphones. Two charts, representing both sonic and visual decrepitation records compared with respective homogenization results (Fig. A2.5), demonstrate the overshoot effect and are among the best obtained during the experiments.

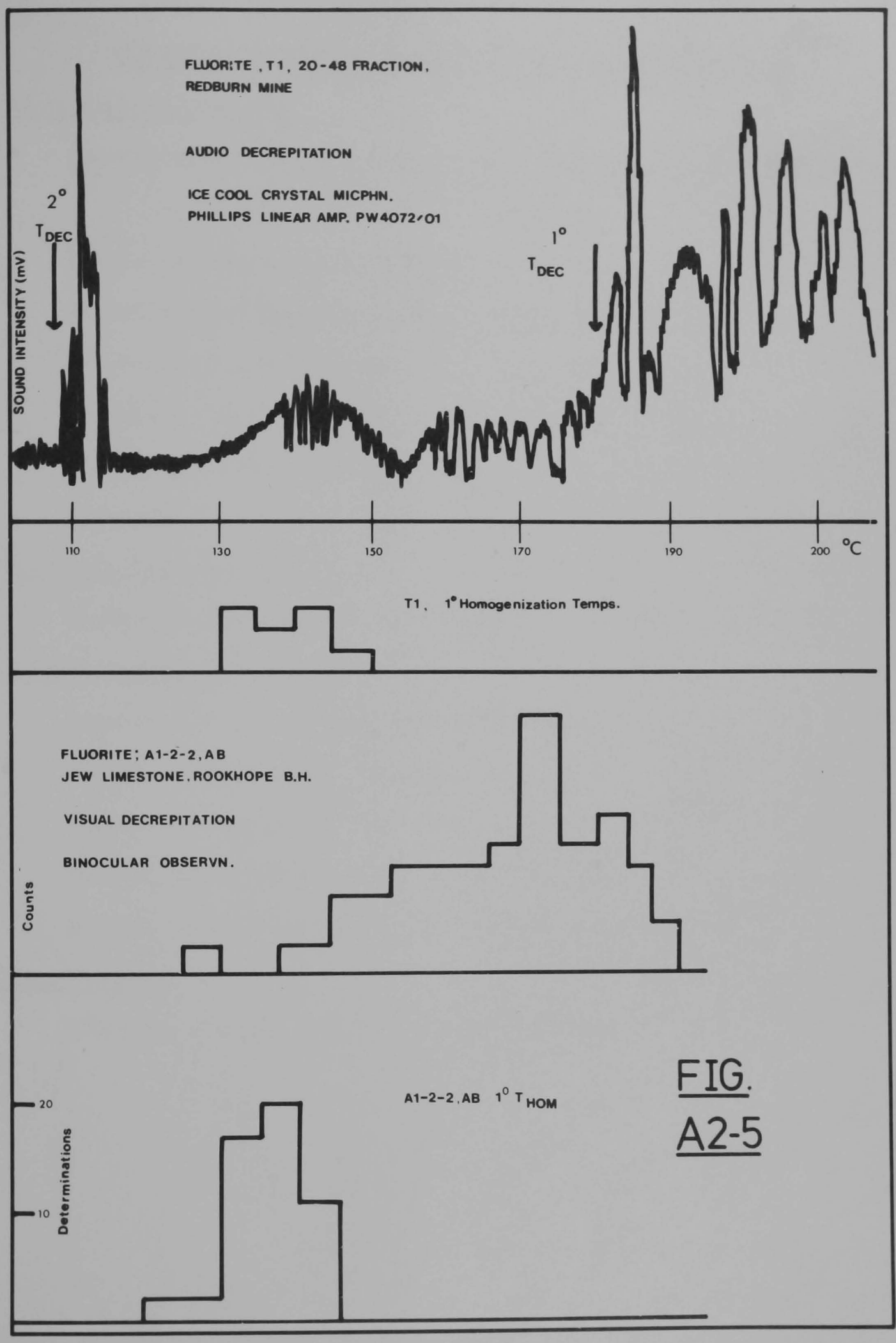

FLUORITE , T1, 20-48 FRACTION,
REDBURN MINE
AUDIO DECREPITATION
ICE COOL CRYSTAL MICPHN.
PHILLIPS LINEAR AMP. PW4072/01
2°
T DEC
1°
T DEC
SOUND INTENSITY (mV)
110
130
150
170
190
200 °C
T1, 1° Homogenization Temps.
FLUORITE; A1-2-2, AB
JEW LIMESTONE, ROOKHOPE B.H.
VISUAL DECREPITATION
BINOCULAR OBSERVN.
Counts
20
10
Determinations
A1-2-2, AB 1° T HOM

FIG. A2-5

TABLE A2.3

SPECIMENS CONTAINING GASLESS PRIMARY FLUID INCLUSIONS.

North Pennine Orefield

RBH 3	Calcite from Calcite, ankerite vein in Rookhope B.H, 450'
RBH 5	" 471'
-	Barite, Ellergill, Moor House Reserve
223	Barite, Closehouse Mine, 5 Fms. Level, Lunedale
211	Barite, Settlingstones Mine
-	Witherite, Settlingstones Mine
6477	Barite, New Brancepeth Colliery
-	Witherite " " "

Middleton Tyas District

6702	Barite, Forcett Quarry, East Layton

Permian rocks, S.E. Durham

8370	Calcite, Chilton Quarry, Ferryhill Station
627	Barite, Ferryhill Gap (in vein)
629	Barite, Ferryhill Gap (in vein)
-	Barite, Raisby Hill Quarry, Coxhoe (in vug)
-	Barite, Running Waters Quarry, Shadforth (in vug)

Miscellaneous

746	Fluorite, Ave,nr. Wellin, Belgian Ardennes.

INDEX TO SPECIMENS FROM LOCALITIES OUTSIDE THE NORTH PENNINES

ASKRIGG BLOCK

356 KELD HEADS VEIN,WENSLEY STATION,ASKRIGG BLOCK
503 GREENHOW RAKE,GREENHOW HILL Q.ASKRIGG BLOCK
617 SEATA MINE,AYSGARTH,WENSLEYDALE,ASKRIGG BLOCK
645 CLOUDS FELL END,DENT LINE AREA,ASKRIGG BLOCK
751 CARDON HILL,CRAVEN FAULT AREA,YORKS.
766 OLD RAKE,OLD GANG MINES,SWALEDALE,ASKRIGG BLOCK
823 LADTHWAITE ADIT,NATEBY,KIRKBY STEPHEN,DENT LINE AREA,ASKRIGG BLOCK
828 HARTLEY BIRKETT HILL,KIRKBY STEPHEN,DENT LINE AREA,ASKRIGG BLOCK

CORNUBIAN OREFIELD

376-1 WHEAL BUNGAY,ST.AGNES,CORNWALL
383 MAIN LODE,COPPER HILL MINE,CAMBOURNE,CORNWALL
386 WEST WHEAL DAMSEL,ST.DAY,CORNWALL
387 WHEAL GORLAND,ST.DAY,CORNWALL
DA2 QUARTZ,WITH CASSITERITE,PENDARVES,CAMBOURNE,CORNWALL

DERBYSHIRE OREFIELD

130 OLD FALL VN.LADYWASH MINE,EYAM,DERBYSHIRE O/F.
575 LONG RAKE,SHANKDALE OPENCAST,YOULGREAVE,DERBYSHIRE O/F.
581 ODIN VEIN,ODIN MINE,CASTLETON,DERBYSHIRE O/F.

LAKE DISTRICT

328 BRANDLEHOW VEIN,CAT BELLS,LAKE DISTRICT O/F.
CQ1 QTZ.CALEBRACK TRIALS,SANDBEDS BARYTES VN.CALDBECK FELLS O/F.
1527B SHAP GRANITE Q.WESTMORELAND
1527B CALCITE,SHAP GRANITE Q.WESTMORELAND

MENDIP HILLS

X22 HALECOMBE Q.LEIGH UPON MENDIP,EAST MENDIPS

NORTH WALES OREFIELD

585 UNITED EAST PANT DU MINE,N.WALES O/F.
586 PANT-Y-GWLANOD VEIN,ERRYRIS,N.WALES O/F.
587 BRYN GWIOG MINE,N.WALES O/F.
588 EAST HALKYN MINE,RHOSESMOR,N.WALES O/F.
644 FFRITH Q.FFRITH,CAERGWRLE,N.WALES O/F.

PERMIAN DEPOSITS,CO.DURHAM

240 CHILTON Q.FERRYHILL,DURHAM
8371 CHILTON Q.FERRYHILL,DURHAM
8372 CHILTON Q.FERRYHILL,DURHAM

SHROPSHIRE OREFIELD

595BA BARITE,SNAILBEACH MINE,SHROPSHIRE O/F.
595B QTZ.SNAILBEACH MINE,SHROPSHIRE O/F.

WEST CUMBERLAND OREFIELD

643 FLORENCE PIT,EGREMONT,WEST CUMBERLAND O/F.

MISCELLANEOUS

194 NA TRI CHAOCHAN,BANFFSHIRE
235 MAIN LODE,NORTH BROKEN HILL,N.S.W.
238 FITZGERALD'S,DOOLIN,LISDOONVARNA,CLARE
318 MADOC,ONTARIO
678 MAISLEY,BANFFSHIRE,SCOTLAND
679 WITHGILL,CLITHEROE,LANCS.
744 SEIELLES,BELGIUM
745 FOISCHES,GIVET,FRANCE
747 ENGIHOUL,LIEGE,BELGIUM
6444 BALLATER PASS,ABERDEENSHIRE
6445 BALLATER PASS,ABERDEENSHIRE
RPQ QTZ.NR.SPEAN BRIDGE,INVERNESSHIRE

23 GROVERAKE VEIN,GROVERAKE MINE,80 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 156.00 STD.DEVN.= 6.29 NO.MEAS.= 49

MEDIAN= 156.00 1ST QUARTILE= 150.00 3RD QUARTILE= 161.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 15.40 CORRECTED HOMOGENIZATION TEMP.= 171.40

32 GROVERAKE VEIN,GROVERAKE MINE,80 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 144.22 STD.DEVN.= 7.04 NO.MEAS.= 44

MEDIAN= 145.00 1ST QUARTILE= 140.12 3RD QUARTILE= 149.00 QUARTILE DEVIATION= 4.44

PRESSURE CORRECTION= 15.40 CORRECTED HOMOGENIZATION TEMP.= 159.62

40 RAMSHAW VEINS,HUNSTANWORTH,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 146.16 STD.DEVN.= 7.46 NO.MEAS.= 25

MEDIAN= 148.50 1ST QUARTILE= 141.25 3RD QUARTILE= 151.00 QUARTILE DEVIATION= 4.87

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 160.16

40 RAMSHAW VEINS,HUNSTANWORTH,FLUOR.PSEC

MEAN HOMOGEN.TEMP.= 142.67 STD.DEVN.= 8.27 NO.MEAS.= 26

MEDIAN= 145.50 1ST QUARTILE= 137.37 3RD QUARTILE= 148.62 QUARTILE DEVIATION= 5.62

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 156.67

40 RAMSHAW VEINS,HUNSTANWORTH,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 118.71 STD.DEVN.= 2.76 NO.MEAS.= 7

MEDIAN= 119.00 1ST QUARTILE= 118.00 3RD QUARTILE= 120.00 QUARTILE DEVIATION= 1.00

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 132.71

45A GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY,A1

MEAN HOMOGEN.TEMP.= 163.56 STD.DEVN.= 8.03 NO.MEAS.= 26

MEDIAN= 162.00 1ST QUARTILE= 158.00 3RD QUARTILE= 171.75 QUARTILE DEVIATION= 6.87

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 178.31

45B GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY,A2

MEAN HOMOGEN.TEMP.= 163.08 STD.DEVN.= 7.52 NO.MEAS.= 49

MEDIAN= 163.00 1ST QUARTILE= 157.00 3RD QUARTILE= 168.25 QUARTILE DEVIATION= 5.62

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 177.83

45C GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY.

MEAN HOMOGEN.TEMP.= 162.09 STD.DEVN.= 8.26 NO.MEAS.= 41

MEDIAN= 162.00 1ST QUARTILE= 155.50 3RD QUARTILE= 169.00 QUARTILE DEVIATION= 6.75

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 176.84

45D GROVERAKE VEIN,GROVERAKE MINE,50 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 153.80 STD.DEVN.= 1.98 NO.MEAS.= 10

MEDIAN= 153.25 1ST QUARTILE= 152.00 3RD QUARTILE= 155.12 QUARTILE DEVIATION= 1.56

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 168.55

45E GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY.

MEAN HOMOGEN.TEMP.= 162.57 STD.DEVN.= 4.65 NO.MEAS.= 14

MEDIAN= 163.50 1ST QUARTILE= 158.62 3RD QUARTILE= 166.50 QUARTILE DEVIATION= 3.94

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 177.32

45F GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY,GN.

MEAN HOMOGEN.TEMP.= 161.00 STD.DEVN.= 5.46 NO.MEAS.= 32

MEDIAN= 159.50 1ST QUARTILE= 157.00 3RD QUARTILE= 164.00 QUARTILE DEVIATION= 3.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 175.75

45F GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY,PURP

MEAN HOMOGEN.TEMP.= 157.75 STD.DEVN.= 8.49 NO.MEAS.= 6

MEDIAN= 155.50 1ST QUARTILE= 150.00 3RD QUARTILE= 162.12 QUARTILE DEVIATION= 6.06

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 172.50

45G GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 159.81 STD.DEVN.= 5.99 NO.MEAS.= 10

MEDIAN= 160.25 1ST QUARTILE= 153.95 3RD QUARTILE= 165.25 QUARTILE DEVIATION= 5.65

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 174.56

45G GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 130.56 STD.DEVN.= 3.05 NO.MEAS.= 5

MEDIAN= 130.80 1ST QUARTILE= 127.75 3RD QUARTILE= 133.25 QUARTILE DEVIATION= 2.75

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 145.31

65 GROVERAKE VEIN,GROVERAKE MINE,RAKE LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 137.71 STD.DEVN.= 2.33 NO.MEAS.= 9

MEDIAN= 137.00 1ST QUARTILE= 135.50 3RD QUARTILE= 139.50 QUARTILE DEVIATION= 2.00

PRESSURE CORRECTION= 13.80 CORRECTED HOMOGENIZATION TEMP.= 151.51

71 GROVERAKE VN.GROVERAKE MINE,FIRESTONE LEVEL,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 147.10 STD.DEVN.= 5.57 NO.MEAS.= 21

MEDIAN= 148.00 1ST QUARTILE= 142.00 3RD QUARTILE= 151.25 QUARTILE DEVIATION= 4.62

PRESSURE CORRECTION= 13.65 CORRECTED HOMOGENIZATION TEMP.= 160.75

72 GROVERAKE VN.MIDDLE LD.FIRESTONE DRIFT,GROVERAKE MINE,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 151.76 STD.DEVN.= 4.64 NO.MEAS.= 28

MEDIAN= 151.50 1ST QUARTILE= 148.50 3RD QUARTILE= 155.50 QUARTILE DEVIATION= 3.50

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 165.76

81 GROVERAKE VEIN,GROVERAKE MINE,30 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 127.02 STD.DEVN.= 6.22 NO.MEAS.= 9

MEDIAN= 130.00 1ST QUARTILE= 121.75 3RD QUARTILE= 131.50 QUARTILE DEVIATION= 4.87

PRESSURE CORRECTION= 14.40 CORRECTED HOMOGENIZATION TEMP.= 141.42

83 GROVERAKE VN.GROVERAKE MINE,30 LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 153.34 STD.DEVN.= 5.80 NO.MEAS.= 27

MEDIAN= 153.50 1ST QUARTILE= 150.80 3RD QUARTILE= 157.60 QUARTILE DEVIATION= 3.40

PRESSURE CORRECTION= 14.10 CORRECTED HOMOGENIZATION TEMP.= 167.44

86 GROVERAKE VN.GROVERAKE MINE,30 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 147.96 STD.DEVN.= 1.69 NO.MEAS.= 14

MEDIAN= 147.75 1ST QUARTILE= 146.50 3RD QUARTILE= 148.50 QUARTILE DEVIATION= 1.00

PRESSURE CORRECTION= 14.10 CORRECTED HOMOGENIZATION TEMP.= 162.06

86 GROVERAKE VN.GROVERAKE MINE,30 LEVEL,SECNY,FLUOR

MEAN HOMOGEN.TEMP.= 133.48 STD.DEVN.= 6.00 NO.MEAS.= 9

MEDIAN= 134.50 1ST QUARTILE= 128.50 3RD QUARTILE= 137.50 QUARTILE DEVIATION= 4.50

PRESSURE CORRECTION= 14.25 CORRECTED HOMOGENIZATION TEMP.= 147.73

96 GROVERAKE VEIN,GROVERAKE MINE,30 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 128.77 STD.DEVN.= 5.26 NO.MEAS.= 8

MEDIAN= 125.85 1ST QUARTILE= 124.30 3RD QUARTILE= 135.50 QUARTILE DEVIATION= 5.60

PRESSURE CORRECTION= 14.25 CORRECTED HOMOGENIZATION TEMP.= 143.02

107 STOTSFIELDBURN MINE,LOOSE ORE AT SURFACE,GREEN FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 143.18 STD.DEVN.= 8.26 NO.MEAS.= 22

MEDIAN= 141.50 1ST QUARTILE= 137.37 3RD QUARTILE= 148.50 QUARTILE DEVIATION= 5.56

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 157.68

107 STOTSFIELDBURN MINE,LOOSE ORE AT SURFACE,PURPLE FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 142.67 STD.DEVN.= 5.27 NO.MEAS.= 20

MEDIAN= 142.00 1ST QUARTILE= 138.62 3RD QUARTILE= 146.75 QUARTILE DEVIATION= 4.06

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 157.17

107 STOTSFIELDBURN MINE,LOOSE ORE AT SURFACE,PURPLE(BLEACHED)FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 143.12 STD.DEVN.= 4.63 NO.MEAS.= 20

MEDIAN= 142.75 1ST QUARTILE= 138.50 3RD QUARTILE= 147.00 QUARTILE DEVIATION= 4.25

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 157.62

109 GREENCLEUGH VN.ROOKHOPEHEAD MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 129.75 STD.DEVN.= 6.07 NO.MEAS.= 16

MEDIAN= 129.35 1ST QUARTILE= 125.05 3RD QUARTILE= 136.02 QUARTILE DEVIATION= 5.49

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 142.75

112 (WO.1) WOLFCLEUGH MINE,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 131.12 STD.DEVN.= 6.18 NO.MEAS.= 28

MEDIAN= 133.00 1ST QUARTILE= 128.62 3RD QUARTILE= 133.00 QUARTILE DEVIATION= 2.19

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 145.87

112 (WO.1) WOLFCLEUGH MINE,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 106.00 STD.DEVN.= 11.31 NO.MEAS.= 3

MEDIAN= 114.00 1ST QUARTILE= 90.00 3RD QUARTILE= 114.00 QUARTILE DEVIATION= 12.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 120.75

116 WOLFCLEUGH VEIN,WOLFCLEUGH MINE,FLUOR,?SECNY

MEAN HOMOGEN.TEMP.= 115.06 STD.DEVN.= 6.00 NO.MEAS.= 13

MEDIAN= 114.00 1ST QUARTILE= 111.00 3RD QUARTILE= 122.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 129.81

121 SCARSYKE VEIN,TAILRACE LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 120.18 STD.DEVN.= 7.52 NO.MEAS.= 17

MEDIAN= 119.00 1ST QUARTILE= 114.00 3RD QUARTILE= 127.75 QUARTILE DEVIATION= 6.87

PRESSURE CORRECTION= 14.40 CORRECTED HOMOGENIZATION TEMP.= 134.58

125 BOLTSBURN VEIN,BOLTSBURN WEST LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 126.17 STD.DEVN.= 4.20 NO.MEAS.= 18

MEDIAN= 127.50 1ST QUARTILE= 122.00 3RD QUARTILE= 130.00 QUARTILE DEVIATION= 4.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 140.92

130 OLD FALL VN.LADYWASH MINE,EYAM,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 73.79 STD.DEVN.= 4.87 NO.MEAS.= 11

MEDIAN= 76.00 1ST QUARTILE= 68.00 3RD QUARTILE= 78.00 QUARTILE DEVIATION= 5.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 73.79

140 RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 118.20 STD.DEVN.= 0.0 NO.MEAS.= 1

MEDIAN=******* 1ST QUARTILE=******* 3RD QUARTILE=******* QUARTILE DEVIATION= 0.0

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 132.95

144 RED VEIN,REDBURN MINE,17 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 132.38 STD.DEVN.= 6.20 NO.MEAS.= 26

MEDIAN= 132.00 1ST QUARTILE= 128.00 3RD QUARTILE= 137.00 QUARTILE DEVIATION= 4.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 147.13

155 RED VN.CRAWLEY OPENCUT,FLUOR.PRMY.WHITE

MEAN HOMOGEN.TEMP.= 138.28 STD.DEVN.= 4.92 NO.MEAS.= 16

MEDIAN= 137.50 1ST QUARTILE= 134.00 3RD QUARTILE= 142.75 QUARTILE DEVIATION= 4.37

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 151.88

155 RED VN.CRAWLEY OPENCUT,FLUOR.PRMY.PURPLE

MEAN HOMOGEN.TEMP.= 149.75 STD.DEVN.= 7.52 NO.MEAS.= 12

MEDIAN= 150.50 1ST QUARTILE= 143.00 3RD QUARTILE= 158.00 QUARTILE DEVIATION= 7.50

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 163.35

163 RED VN.ROGERLEY HUSH,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 134.58 STD.DEVN.= 8.62 NO.MEAS.= 31

MEDIAN= 135.00 1ST QUARTILE= 128.00 3RD QUARTILE= 139.50 QUARTILE DEVIATION= 5.75

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 148.58

163 RED VN.ROGERLEY HUSH,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 112.41 STD.DEVN.= 5.22 NO.MEAS.= 16

MEDIAN= 113.50 1ST QUARTILE= 106.37 3RD QUARTILE= 116.00 QUARTILE DEVIATION= 4.81

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 126.41

165 RED VN.ROGERLEY HUSH,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 147.93 STD.DEVN.= 5.55 NO.MEAS.= 14

MEDIAN= 149.00 1ST QUARTILE= 144.50 3RD QUARTILE= 151.25 QUARTILE DEVIATION= 3.37

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 161.93

165 RED VN.ROGERLEY HUSH,FLUOR.SECY.

MEAN HOMOGEN.TEMP.= 123.12 STD.DEVN.= 8.32 NO.MEAS.= 28

MEDIAN= 126.00 1ST QUARTILE= 119.25 3RD QUARTILE= 129.50 QUARTILE DEVIATION= 5.12

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 137.12

168 RED VN.CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 129.91 STD.DEVN.= 7.31 NO.MEAS.= 38

MEDIAN= 131.00 1ST QUARTILE= 123.87 3RD QUARTILE= 136.75 QUARTILE DEVIATION= 6.44

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 143.51

170(2) RIDLEY'S VEIN,FLUOR,INNER LAYER OF XTAL.PRMY

MEAN HOMOGEN.TEMP.= 128.30 STD.DEVN.= 6.37 NO.MEAS.= 10

MEDIAN= 128.00 1ST QUARTILE= 124.00 3RD QUARTILE= 132.25 QUARTILE DEVIATION= 4.12

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 143.05

170(2) RIDLEY'S VEIN,FLUOR.CORE OF XTAL.FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 113.03 STD.DEVN.= 3.99 NO.MEAS.= 19

MEDIAN= 113.00 1ST QUARTILE= 109.00 3RD QUARTILE= 117.50 QUARTILE DEVIATION= 4.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 127.78

170(2) RIDLEY'S VEIN,FLUOR,OUTER LAYER OF XTAL.PRMY

MEAN HOMOGEN.TEMP.= 127.45 STD.DEVN.= 7.91 NO.MEAS.= 39

MEDIAN= 126.00 1ST QUARTILE= 121.00 3RD QUARTILE= 135.00 QUARTILE DEVIATION= 7.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 142.20

170(2) RIDLEY'S VEIN,FLUOR.OUTER XTAL.LAYER.SECNY

MEAN HOMOGEN.TEMP.= 105.58 STD.DEVN.= 6.86 NO.MEAS.= 18

MEDIAN= 104.50 1ST QUARTILE= 100.37 3RD QUARTILE= 107.25 QUARTILE DEVIATION= 3.44

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 120.33

172 RED VEIN,REDBURN MINE,40 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 137.24 STD.DEVN.= 11.13 NO.MEAS.= 29

MEDIAN= 136.00 1ST QUARTILE= 129.00 3RD QUARTILE= 148.50 QUARTILE DEVIATION= 9.75

PRESSURE CORRECTION= 15.40 CORRECTED HOMOGENIZATION TEMP.= 152.64

174 RED VEIN,REDBURN MINE,50 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 142.00 STD.DEVN.= 4.81 NO.MEAS.= 11

MEDIAN= 143.00 1ST QUARTILE= 137.50 3RD QUARTILE= 147.00 QUARTILE DEVIATION= 4.75

PRESSURE CORRECTION= 15.60 CORRECTED HOMOGENIZATION TEMP.= 157.60

175 RED VEIN,REDBURN MINE,50 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 126.16 STD.DEVN.= 2.66 NO.MEAS.= 16

MEDIAN= 126.50 1ST QUARTILE= 125.00 3RD QUARTILE= 127.75 QUARTILE DEVIATION= 1.37

PRESSURE CORRECTION= 15.60 CORRECTED HOMOGENIZATION TEMP.= 141.76

177 GROVERAKE VEIN,NORTH GROVERAKE OPENPIT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 134.52 STD.DEVN.= 7.75 NO.MEAS.= 34

MEDIAN= 136.95 1ST QUARTILE= 127.60 3RD QUARTILE= 140.77 QUARTILE DEVIATION= 6.59

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 147.52

191(1) GREENCLEUGH VN.CORBETMEA SHAFT,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 114.21 STD.DEVN.= 6.72 NO.MEAS.= 31

MEDIAN= 115.00 1ST QUARTILE= 108.00 3RD QUARTILE= 119.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 128.21

191(2) GREENCLEUGH VN.CORBETMEA SHAFT,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 115.27 STD.DEVN.= 7.39 NO.MEAS.= 22

MEDIAN= 114.00 1ST QUARTILE= 109.00 3RD QUARTILE= 118.75 QUARTILE DEVIATION= 4.87

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 129.27

191(3) GREENCLEUGH VN.CORBETMEA SHAFT,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 110.18 STD.DEVN.= 9.15 NO.MEAS.= 11

MEDIAN= 110.00 1ST QUARTILE= 106.00 3RD QUARTILE= 117.50 QUARTILE DEVIATION= 5.75

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 124.18

192 GREENCLEUGH VEIN,NR.PHILIPSON'S SHAFT,FLUOR.SECNY?PRMY?

MEAN HOMOGEN.TEMP.= 105.79 STD.DEVN.= 5.52 NO.MEAS.= 12

MEDIAN= 106.00 1ST QUARTILE= 100.37 3RD QUARTILE= 109.00 QUARTILE DEVIATION= 4.31

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 118.79

193 RED VEIN,STANHOPEBURN MINE,SHIELD HIRST LEVEL,FLUOR.?PRMY

MEAN HOMOGEN.TEMP.= 155.50 STD.DEVN.= 6.87 NO.MEAS.= 4

MEDIAN= 154.50 1ST QUARTILE= 148.50 3RD QUARTILE= 163.50 QUARTILE DEVIATION= 7.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 170.25

194 GREEN FLUOR.NA TRI CHAOCHAN,BANFFSHIRE,(RUSSELL,MIN.MAG.1937)POSS.PRMY

MEAN HOMOGEN.TEMP.= 63.67 STD.DEVN.= 3.35 NO.MEAS.= 6

MEDIAN= 64.00 1ST QUARTILE= 60.00 3RD QUARTILE= 67.00 QUARTILE DEVIATION= 3.50

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 63.67

194 PURPLE FLUOR.NA TRI CHAOCHAN,INCLUSIONS TYPE?

MEAN HOMOGEN.TEMP.= 109.33 STD.DEVN.= 12.92 NO.MEAS.= 3

MEDIAN= 113.00 1ST QUARTILE= 92.00 3RD QUARTILE= 123.00 QUARTILE DEVIATION= 15.50

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 109.33

201 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 142.14 STD.DEVN.= 9.74 NO.MEAS.= 11

MEDIAN= 142.50 1ST QUARTILE= 131.00 3RD QUARTILE= 151.50 QUARTILE DEVIATION= 10.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 156.89

206 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 149.00 STD.DEVN.= 4.12 NO.MEAS.= 11

MEDIAN= 148.00 1ST QUARTILE= 145.00 3RD QUARTILE= 153.50 QUARTILE DEVIATION= 4.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 163.75

233 BOLTSBURN VEIN,BOLTSBURN EAST MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 133.90 STD.DEVN.= 6.02 NO.MEAS.= 23

MEDIAN= 137.00 1ST QUARTILE= 128.00 3RD QUARTILE= 139.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 148.65

235 MAIN LODE,NORTH BROKEN HILL,N.S.W.ORANGE FLUOR.SECNY.TYPE

MEAN HOMOGEN.TEMP.= 163.20 STD.DEVN.= 5.55 NO.MEAS.= 10

MEDIAN= 163.00 1ST QUARTILE= 158.75 3RD QUARTILE= 166.75 QUARTILE DEVIATION= 4.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 163.20

238 VEIN,FITZGERALD'S FARM,DOOLIN,LISDOONVARNA,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 136.57 STD.DEVN.= 2.94 NO.MEAS.= 12

MEDIAN= 135.75 1ST QUARTILE= 134.12 3RD QUARTILE= 139.22 QUARTILE DEVIATION= 2.55

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 136.57

240 CHILTON QUARRY,FERRYHILL,YELLOW FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 107.68 STD.DEVN.= 4.47 NO.MEAS.= 11

MEDIAN= 109.20 1ST QUARTILE= 104.00 3RD QUARTILE= 111.50 QUARTILE DEVIATION= 3.75

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 107.68

8372 CHILTON QUARRY,FERRYHILL,YELLOW FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 103.89 STD.DEVN.= 10.34 NO.MEAS.= 9

MEDIAN= 101.00 1ST QUARTILE= 97.50 3RD QUARTILE= 111.50 QUARTILE DEVIATION= 7.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 103.89

8371 CHILTON QUARRY,FERRYHILL,YELLOW FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 107.27 STD.DEVN.= 10.12 NO.MEAS.= 28

MEDIAN= 108.50 1ST QUARTILE= 101.00 3RD QUARTILE= 115.12 QUARTILE DEVIATION= 7.06

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 107.27

243 WOLFCLEUGH NEW VN.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 128.28 STD.DEVN.= 5.08 NO.MEAS.= 33

MEDIAN= 126.00 1ST QUARTILE= 123.80 3RD QUARTILE= 133.50 QUARTILE DEVIATION= 4.85

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 142.28

244 WOLFCLEUGH NEW VEIN,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 119.67 STD.DEVN.= 4.91 NO.MEAS.= 11

MEDIAN= 119.00 1ST QUARTILE= 116.50 3RD QUARTILE= 122.50 QUARTILE DEVIATION= 3.00

PRESSURE CORRECTION= 14.20 CORRECTED HOMOGENIZATION TEMP.= 133.87

247 BURTREE PASTURE VEIN,GOWLANDS LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 140.93 STD.DEVN.= 6.06 NO.MEAS.= 42

MEDIAN= 140.00 1ST QUARTILE= 136.00 3RD QUARTILE= 146.37 QUARTILE DEVIATION= 5.19

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 153.93

248 THORNY BROW VEIN,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 137.61 STD.DEVN.= 7.43 NO.MEAS.= 20

MEDIAN= 136.75 1ST QUARTILE= 133.12 3RD QUARTILE= 144.50 QUARTILE DEVIATION= 5.69

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 152.11

248 THORNY BROW VEIN,FLUOR.PRMY+PSEC

MEAN HOMOGEN.TEMP.= 135.91 STD.DEVN.= 5.74 NO.MEAS.= 42

MEDIAN= 136.50 1ST QUARTILE= 132.00 3RD QUARTILE= 138.00 QUARTILE DEVIATION= 3.00

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 150.41

249 CAPTAINS CLEUGH VEIN,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 126.40 STD.DEVN.= 4.92 NO.MEAS.= 21

MEDIAN= 127.50 1ST QUARTILE= 122.50 3RD QUARTILE= 128.75 QUARTILE DEVIATION= 3.12

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 141.15

252 RISPEY VEIN,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 125.23 STD.DEVN.= 5.55 NO.MEAS.= 25

MEDIAN= 125.00 1ST QUARTILE= 122.00 3RD QUARTILE= 128.00 QUARTILE DEVIATION= 3.00

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 139.23

254 RISPEY VEIN,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 123.86 STD.DEVN.= 5.67 NO.MEAS.= 21

MEDIAN= 124.00 1ST QUARTILE= 119.25 3RD QUARTILE= 128.50 QUARTILE DEVIATION= 4.62

PRESSURE CORRECTION= 14.40 CORRECTED HOMOGENIZATION TEMP.= 138.26

258 GREENWELLS VN.FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 123.34 STD.DEVN.= 5.14 NO.MEAS.= 48

MEDIAN= 122.25 1ST QUARTILE= 121.00 3RD QUARTILE= 125.00 QUARTILE DEVIATION= 2.00

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 136.34

259 WOLFCLEUGH OLD VN.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 135.93 STD.DEVN.= 5.92 NO.MEAS.= 42

MEDIAN= 135.25 1ST QUARTILE= 131.00 3RD QUARTILE= 141.12 QUARTILE DEVIATION= 5.06

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 148.93

264 WOLFCLEUGH OLD VN.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 126.84 STD.DEVN.= 5.35 NO.MEAS.= 16

MEDIAN= 126.00 1ST QUARTILE= 125.00 3RD QUARTILE= 131.75 QUARTILE DEVIATION= 3.37

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 140.84

274 RED VN.STANHOPEBURN MINE,SHIELD HURST LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 133.61 STD.DEVN.= 6.87 NO.MEAS.= 16

MEDIAN= 135.15 1ST QUARTILE= 125.85 3RD QUARTILE= 140.90 QUARTILE DEVIATION= 7.52

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 148.36

275 RED VN. STANHOPEBURN MINE, SHIELD HURST LEVEL, FLUOR. PRMY

MEAN HOMOGEN. TEMP. = 164.14 STD. DEVN. = 9.93 NO. MEAS. = 28

MEDIAN= 165.00 1ST QUARTILE= 156.32 3RD QUARTILE= 175.75 QUARTILE DEVIATION= 9.71

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP. = 178.89

276 RED VN. STANHOPEBURN MINE 17 LEVEL, FLUOR, PRMY

MEAN HOMOGEN. TEMP. = 133.66 STD. DEVN. = 2.52 NO. MEAS. = 12

MEDIAN= 133.25 1ST QUARTILE= 132.00 3RD QUARTILE= 135.55 QUARTILE DEVIATION= 1.77

PRESSURE CORRECTION= 15.50 CORRECTED HOMOGENIZATION TEMP. = 149.16

277 RED VN. STANHOPEBURN MINE, 17 LEVEL, FLUOR, PRMY

MEAN HOMOGEN. TEMP. = 160.30 STD. DEVN. = 9.82 NO. MEAS. = 35

MEDIAN= 157.50 1ST QUARTILE= 154.00 3RD QUARTILE= 165.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 15.50 CORRECTED HOMOGENIZATION TEMP. = 175.80

279 RED VN. STANHOPEBURN MINE, SHIELD HURST LEVEL, PRMY, FLUOR

MEAN HOMOGEN. TEMP. = 162.71 STD. DEVN. = 12.33 NO. MEAS. = 9

MEDIAN= 162.50 1ST QUARTILE= 154.00 3RD QUARTILE= 171.75 QUARTILE DEVIATION= 8.87

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP. = 177.46

279 RED VN.STANHOPEBURN MINE,SHIELD HURST LEVEL,SECNY,FLUOR

MEAN HOMOGEN.TEMP.= 129.40 STD.DEVN.= 10.06 NO.MEAS.= 6

MEDIAN= 133.95 1ST QUARTILE= 122.70 3RD QUARTILE= 135.00 QUARTILE DEVIATION= 6.15

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 144.15

283 RED VEIN,WIDLEY LEVEL,QUARTZ,PRMY.

MEAN HOMOGEN.TEMP.= 123.67 STD.DEVN.= 16.80 NO.MEAS.= 6

MEDIAN= 120.00 1ST QUARTILE= 107.62 3RD QUARTILE= 146.87 QUARTILE DEVIATION= 19.62

PRESSURE CORRECTION= 15.40 CORRECTED HOMOGENIZATION TEMP.= 139.07

285 RED VN.STANHOPEBURN MINE,SHIELD HURST LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 136.66 STD.DEVN.= 3.79 NO.MEAS.= 9

MEDIAN= 139.00 1ST QUARTILE= 132.75 3RD QUARTILE= 139.50 QUARTILE DEVIATION= 3.37

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 151.41

289 RED VN.REDBURN MINE,E LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 144.50 STD.DEVN.= 7.04 NO.MEAS.= 20

MEDIAN= 146.25 1ST QUARTILE= 138.62 3RD QUARTILE= 150.00 QUARTILE DEVIATION= 5.69

PRESSURE CORRECTION= 14.70 CORRECTED HOMOGENIZATION TEMP.= 159.20

290 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 168.39 STD.DEVN.= 5.76 NO.MEAS.= 10

MEDIAN= 167.45 1ST QUARTILE= 166.67 3RD QUARTILE= 170.62 QUARTILE DEVIATION= 1.98

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 183.14

293 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 169.12 STD.DEVN.= 16.48 NO.MEAS.= 37

MEDIAN= 169.00 1ST QUARTILE= 157.75 3RD QUARTILE= 175.00 QUARTILE DEVIATION= 8.62

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 183.87

295 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 137.60 STD.DEVN.= 7.83 NO.MEAS.= 31

MEDIAN= 140.50 1ST QUARTILE= 133.00 3RD QUARTILE= 143.00 QUARTILE DEVIATION= 5.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 152.35

297 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 166.60 STD.DEVN.= 12.86 NO.MEAS.= 10

MEDIAN= 169.00 1ST QUARTILE= 157.62 3RD QUARTILE= 176.37 QUARTILE DEVIATION= 9.37

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 181.35

300 RED VN.REDBURN MINE,D LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 143.51 STD.DEVN.= 5.06 NO.MEAS.= 13

MEDIAN= 144.00 1ST QUARTILE= 140.75 3RD QUARTILE= 145.00 QUARTILE DEVIATION= 2.12

PRESSURE CORRECTION= 14.40 CORRECTED HOMOGENIZATION TEMP.= 157.91

310 GREENCLEUGH VEIN,FRAZARS HUSHES,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 124.37 STD.DEVN.= 3.55 NO.MEAS.= 12

MEDIAN= 124.70 1ST QUARTILE= 121.50 3RD QUARTILE= 127.12 QUARTILE DEVIATION= 2.81

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 137.37

310 GREENCLEUGH VEIN,FRAZARS HUSHES,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 114.20 STD.DEVN.= 1.91 NO.MEAS.= 5

MEDIAN= 114.00 1ST QUARTILE= 112.75 3RD QUARTILE= 115.75 QUARTILE DEVIATION= 1.50

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 127.20

311 GREENCLEUGH VN.FRAZARS HUSH,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 136.78 STD.DEVN.= 7.21 NO.MEAS.= 17

MEDIAN= 136.50 1ST QUARTILE= 131.00 3RD QUARTILE= 142.35 QUARTILE DEVIATION= 5.67

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 149.78

314 GREENCLEUGH VN.FRAZARS HUSH,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 133.47 STD.DEVN.= 7.57 NO.MEAS.= 25

MEDIAN= 133.30 1ST QUARTILE= 127.45 3RD QUARTILE= 141.55 QUARTILE DEVIATION= 7.05

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 146.47

316 GREENCLEUGH S.W.VN.FRAZARS QUARRY,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 117.09 STD.DEVN.= 4.92 NO.MEAS.= 15

MEDIAN= 118.30 1ST QUARTILE= 111.50 3RD QUARTILE= 120.50 QUARTILE DEVIATION= 4.50

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 130.09

318 MADOC,ONTARIO,GREEN FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 127.59 STD.DEVN.= 4.71 NO.MEAS.= 20

MEDIAN= 127.00 1ST QUARTILE= 124.00 3RD QUARTILE= 132.50 QUARTILE DEVIATION= 4.25

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 127.59

322 RED VN.RED VEIN QUARRY,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 139.69 STD.DEVN.= 4.65 NO.MEAS.= 16

MEDIAN= 141.50 1ST QUARTILE= 135.20 3RD QUARTILE= 143.90 QUARTILE DEVIATION= 4.35

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 154.44

324 RED VN.NOAHS ARK QUARRY,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 119.98 STD.DEVN.= 2.01 NO.MEAS.= 9

MEDIAN= 118.80 1ST QUARTILE= 118.40 3RD QUARTILE= 122.40 QUARTILE DEVIATION= 2.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 134.73

326 RED VEIN,CLINTS PLANTATION,STANHOPEBURN,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 120.36 STD.DEVN.= 5.30 NO.MEAS.= 14

MEDIAN= 121.50 1ST QUARTILE= 118.62 3RD QUARTILE= 125.87 QUARTILE DEVIATION= 3.62

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 134.86

328 BRANDLEHOW VEIN,CAT BELLS,LAKE DISTRICT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 130.04 STD.DEVN.= 9.98 NO.MEAS.= 9

MEDIAN= 127.50 1ST QUARTILE= 119.35 3RD QUARTILE= 141.00 QUARTILE DEVIATION= 10.82

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 130.04

328 BRANDLEHOW VEIN,CAT BELLS,LAKE DISTRICT,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 108.92 STD.DEVN.= 3.62 NO.MEAS.= 5

MEDIAN= 107.00 1ST QUARTILE= 105.65 3RD QUARTILE= 113.15 QUARTILE DEVIATION= 3.75

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 108.92

356 KELD HEAD LEVEL,WENSLEY,PINK FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 102.03 STD.DEVN.= 4.50 NO.MEAS.= 9

MEDIAN= 102.00 1ST QUARTILE= 98.05 3RD QUARTILE= 103.95 QUARTILE DEVIATION= 2.95

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 115.03

356 KELD HEAD LEVEL,WENSLEY,PINK FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 86.19 STD.DEVN.= 3.93 NO.MEAS.= 12

MEDIAN= 86.80 1ST QUARTILE= 85.33 3RD QUARTILE= 89.25 QUARTILE DEVIATION= 1.96

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 99.19

376-1 WHEAL BUNGAY,ST.AGNES,PURP.FLUOR.PSEC

MEAN HOMOGEN.TEMP.= 219.68 STD.DEVN.= 2.51 NO.MEAS.= 5

MEDIAN= 219.60 1ST QUARTILE= 217.00 3RD QUARTILE= 222.40 QUARTILE DEVIATION= 2.70

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 219.68

383 MAIN LODE,COPPER HILL MINE,GREEN FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 251.60 STD.DEVN.= 10.58 NO.MEAS.= 5

MEDIAN= 250.20 1ST QUARTILE= 243.00 3RD QUARTILE= 260.90 QUARTILE DEVIATION= 8.95

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 251.60

383 MAIN LODE,COPPER HILL MINE,GREEN FLUOR,PSEC

MEAN HOMOGEN.TEMP.= 242.80 STD.DEVN.= 10.35 NO.MEAS.= 19

MEDIAN= 245.00 1ST QUARTILE= 235.00 3RD QUARTILE= 253.00 QUARTILE DEVIATION= 9.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 242.80

383 MAIN LODE,COPPER HILL MINE,GREEN FLUOR,SECNY

MEAN HOMOGEN.TEMP.= 225.00 STD.DEVN.= 6.07 NO.MEAS.= 5

MEDIAN= 223.00 1ST QUARTILE= 220.00 3RD QUARTILE= 231.00 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 225.00

386 WEST WHEAL DAMSEL,FLUOR,GREEN,PRMY

MEAN HOMOGEN.TEMP.= 220.00 STD.DEVN.= 2.38 NO.MEAS.= 6

MEDIAN= 220.00 1ST QUARTILE= 218.25 3RD QUARTILE= 221.25 QUARTILE DEVIATION= 1.50

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 220.00

386 WEST WHEAL DAMSEL,FLUOR,GREEN,SECNY

MEAN HOMOGEN.TEMP.= 237.56 STD.DEVN.= 10.67 NO.MEAS.= 8

MEDIAN= 236.60 1ST QUARTILE= 234.60 3RD QUARTILE= 239.77 QUARTILE DEVIATION= 2.59

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 237.56

387 WHEAL GORLAND,ST.DAY,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 299.53 STD.DEVN.= 2.34 NO.MEAS.= 10

MEDIAN= 298.75 1ST QUARTILE= 297.70 3RD QUARTILE= 302.45 QUARTILE DEVIATION= 2.37

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 299.53

387 WHEAL GORLAND,ST.DAY,FLUOR,SECNY

MEAN HOMOGEN.TEMP.= 276.37 STD.DEVN.= 3.36 NO.MEAS.= 8

MEDIAN= 276.00 1ST QUARTILE= 274.00 3RD QUARTILE= 278.15 QUARTILE DEVIATION= 2.07

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 276.37

395 RED VN.REDBURN MINE,17 SUBLEVEL FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 125.46 STD.DEVN.= 2.20 NO.MEAS.= 11

MEDIAN= 126.50 1ST QUARTILE= 123.00 3RD QUARTILE= 127.60 QUARTILE DEVIATION= 2.30

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 140.21

396A/B RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 116.70 STD.DEVN.= 2.70 NO.MEAS.= 2

MEDIAN= 116.70 1ST QUARTILE=******* 3RD QUARTILE= 120.75 QUARTILE DEVIATION=*******

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 131.45

396A/B RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.TOTAL INCLUSIONS

MEAN HOMOGEN.TEMP.= 96.64 STD.DEVN.= 14.72 NO.MEAS.= 7

MEDIAN= 93.00 1ST QUARTILE= 81.60 3RD QUARTILE= 114.00 QUARTILE DEVIATION= 16.20

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 111.39

397 RED VN.REDBURN MINE,17 SUBLEVEL FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 141.76 STD.DEVN.= 5.93 NO.MEAS.= 25

MEDIAN= 144.00 1ST QUARTILE= 137.50 3RD QUARTILE= 146.50 QUARTILE DEVIATION= 4.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 156.51

398 RED VN.REDBURN MINE,17 LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 138.97 STD.DEVN.= 4.77 NO.MEAS.= 26

MEDIAN= 139.95 1ST QUARTILE= 135.00 3RD QUARTILE= 143.02 QUARTILE DEVIATION= 4.01

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 153.72

401 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 138.12 STD.DEVN.= 5.61 NO.MEAS.= 28

MEDIAN= 136.95 1ST QUARTILE= 134.60 3RD QUARTILE= 141.50 QUARTILE DEVIATION= 3.45

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 152.87

402 RED VN.REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 137.85 STD.DEVN.= 5.71 NO.MEAS.= 19

MEDIAN= 137.00 1ST QUARTILE= 133.30 3RD QUARTILE= 144.00 QUARTILE DEVIATION= 5.35

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 152.60

403 RED VN.REDBURN MINE,17 SUBLEVEL FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 146.45 STD.DEVN.= 7.59 NO.MEAS.= 29

MEDIAN= 147.50 1ST QUARTILE= 142.00 3RD QUARTILE= 150.95 QUARTILE DEVIATION= 4.47

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 161.20

403 RED VN.REDBURN MINE,17 SUBLEVEL FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 117.23 STD.DEVN.= 4.41 NO.MEAS.= 10

MEDIAN= 115.75 1ST QUARTILE= 112.70 3RD QUARTILE= 124.00 QUARTILE DEVIATION= 5.65

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 131.98

406 RED VN.REDBURN MINE,17 SUBLEVEL FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 143.35 STD.DEVN.= 8.19 NO.MEAS.= 20

MEDIAN= 142.40 1ST QUARTILE= 136.25 3RD QUARTILE= 148.32 QUARTILE DEVIATION= 6.04

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 158.10

411 RED VN.REDBURN MINE,C LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 112.94 STD.DEVN.= 2.77 NO.MEAS.= 27

MEDIAN= 112.60 1ST QUARTILE= 110.50 3RD QUARTILE= 114.00 QUARTILE DEVIATION= 1.75

PRESSURE CORRECTION= 14.00 CORRECTED HOMOGENIZATION TEMP.= 126.94

425 SHILDON VEIN,SHILDON MINE,FLUOR.PRMY,PSEC.

MEAN HOMOGEN.TEMP.= 113.50 STD.DEVN.= 2.96 NO.MEAS.= 14

MEDIAN= 113.25 1ST QUARTILE= 111.00 3RD QUARTILE= 115.00 QUARTILE DEVIATION= 2.00

PRESSURE CORRECTION= 14.50 CORRECTED HOMOGENIZATION TEMP.= 128.00

433 GROVERAKE VN.GROVERAKE MINE,50 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 137.85 STD.DEVN.= 4.79 NO.MEAS.= 13

MEDIAN= 140.40 1ST QUARTILE= 135.20 3RD QUARTILE= 141.50 QUARTILE DEVIATION= 3.15

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 152.60

441 GROVERAKE VN.GROVERAKE MINE,50 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 165.56 STD.DEVN.= 5.74 NO.MEAS.= 21

MEDIAN= 165.60 1ST QUARTILE= 163.00 3RD QUARTILE= 170.00 QUARTILE DEVIATION= 3.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 180.31

442 GROVERAKE VN.GROVERAKE MINE,50 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 154.61 STD.DEVN.= 6.72 NO.MEAS.= 22

MEDIAN= 158.25 1ST QUARTILE= 148.47 3RD QUARTILE= 160.00 QUARTILE DEVIATION= 5.76

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 169.36

443 GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY,PSEC.

MEAN HOMOGEN.TEMP.= 160.05 STD.DEVN.= 2.50 NO.MEAS.= 21

MEDIAN= 160.00 1ST QUARTILE= 159.00 3RD QUARTILE= 161.85 QUARTILE DEVIATION= 1.42

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 174.80

449 RED VN.GROVERAKE MINE,50 LEVEL,PRMY?,FLUOR

MEAN HOMOGEN.TEMP.= 151.07 STD.DEVN.= 5.06 NO.MEAS.= 6

MEDIAN= 151.40 1ST QUARTILE= 146.95 3RD QUARTILE= 156.17 QUARTILE DEVIATION= 4.61

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 165.82

449 RED VN.GROVERAKE MINE,50 LEVEL,PRMY?,FLUOR

MEAN HOMOGEN.TEMP.= 124.41 STD.DEVN.= 4.28 NO.MEAS.= 10

MEDIAN= 124.25 1ST QUARTILE= 119.50 3RD QUARTILE= 127.62 QUARTILE DEVIATION= 4.06

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 139.16

451 GROVERAKE VN.GROVERAKE MINE,50 LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 159.54 STD.DEVN.= 5.96 NO.MEAS.= 26

MEDIAN= 162.15 1ST QUARTILE= 154.70 3RD QUARTILE= 164.55 QUARTILE DEVIATION= 4.93

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 174.29

464 GROVERAKE VN.GROVERAKE MINE,60 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 152.87 STD.DEVN.= 3.59 NO.MEAS.= 22

MEDIAN= 152.50 1ST QUARTILE= 150.87 3RD QUARTILE= 155.87 QUARTILE DEVIATION= 2.50

PRESSURE CORRECTION= 15.00 CORRECTED HOMOGENIZATION TEMP.= 167.87

467 NORTH FULWOOD VEIN,HIGH FULWOOD MINE,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 126.49 STD.DEVN.= 2.58 NO.MEAS.= 15

MEDIAN= 126.00 1ST QUARTILE= 123.70 3RD QUARTILE= 128.00 QUARTILE DEVIATION= 2.15

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 141.24

475 ?GROVERAKE VEIN,NORTH GROVERAKE OPENCUTS,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 150.74 STD.DEVN.= 5.92 NO.MEAS.= 26

MEDIAN= 148.50 1ST QUARTILE= 145.07 3RD QUARTILE= 156.07 QUARTILE DEVIATION= 5.50

PRESSURE CORRECTION= 12.80 CORRECTED HOMOGENIZATION TEMP.= 163.54

475 ?GROVERAKE VEIN,NORTH GROVERAKE OPENCUTS,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 134.50 STD.DEVN.= 2.33 NO.MEAS.= 5

MEDIAN= 135.90 1ST QUARTILE= 132.25 3RD QUARTILE= 136.05 QUARTILE DEVIATION= 1.90

PRESSURE CORRECTION= 12.80 CORRECTED HOMOGENIZATION TEMP.= 147.30

480 GROVERAKE VN.GROVERAKE MINE,60 LEVEL,PRMY,FLUOR

MEAN HOMOGEN.TEMP.= 120.59 STD.DEVN.= 4.52 NO.MEAS.= 16

MEDIAN= 120.50 1ST QUARTILE= 117.30 3RD QUARTILE= 124.00 QUARTILE DEVIATION= 3.35

PRESSURE CORRECTION= 15.00 CORRECTED HOMOGENIZATION TEMP.= 135.59

483 GROVERAKE VN.GROVERAKE MINE,60 LEVEL,FLUOR,PRMY.

MEAN HOMOGEN.TEMP.= 142.44 STD.DEVN.= 5.69 NO.MEAS.= 11

MEDIAN= 142.80 1ST QUARTILE= 137.00 3RD QUARTILE= 146.40 QUARTILE DEVIATION= 4.70

PRESSURE CORRECTION= 15.00 CORRECTED HOMOGENIZATION TEMP.= 157.44

496 GROVERAKE VN.GROVERAKE MINE,80 LEVEL,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 144.59 STD.DEVN.= 5.25 NO.MEAS.= 18

MEDIAN= 145.60 1ST QUARTILE= 139.30 3RD QUARTILE= 148.15 QUARTILE DEVIATION= 4.43

PRESSURE CORRECTION= 15.40 CORRECTED HOMOGENIZATION TEMP.= 159.99

503 GREENHOW RAKE,GREENHOW Q.FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 91.83 STD.DEVN.= 6.83 NO.MEAS.= 18

MEDIAN= 93.25 1ST QUARTILE= 89.25 3RD QUARTILE= 97.50 QUARTILE DEVIATION= 4.12

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 104.83

575 LONG RAKE,SHANKDALE OPENCAST MINE,ALPORT/YOULGREAVE,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 70.27 STD.DEVN.= 4.36 NO.MEAS.= 10

MEDIAN= 71.20 1ST QUARTILE= 66.92 3RD QUARTILE= 73.90 QUARTILE DEVIATION= 3.49

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 70.27

581 ODIN MINE,CASTLETON,PURP.FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 127.43 STD.DEVN.= 4.55 NO.MEAS.= 17

MEDIAN= 126.50 1ST QUARTILE= 123.95 3RD QUARTILE= 129.95 QUARTILE DEVIATION= 3.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 127.43

585 UNITED EAST PANT DU MINE,N.WALES,FLUOR.CORE XTAL.PRMY

MEAN HOMOGEN.TEMP.= 104.51 STD.DEVN.= 6.03 NO.MEAS.= 16

MEDIAN= 104.95 1ST QUARTILE= 102.00 3RD QUARTILE= 108.62 QUARTILE DEVIATION= 3.31

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 121.51

585 UNITED EAST PANT DU MINE,N.WALES,FLUOR.OUTER PART OF XTAL.PRMY

MEAN HOMOGEN.TEMP.= 96.54 STD.DEVN.= 4.33 NO.MEAS.= 12

MEDIAN= 94.30 1ST QUARTILE= 93.00 3RD QUARTILE= 101.47 QUARTILE DEVIATION= 4.24

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 113.54

585 UNITED EAST PANT DU MINE,N.WALES,FLUOR.TOTAL PRMY

MEAN HOMOGEN.TEMP.= 101.10 STD.DEVN.= 6.66 NO.MEAS.= 28

MEDIAN= 102.00 1ST QUARTILE= 93.13 3RD QUARTILE= 106.65 QUARTILE DEVIATION= 6.76

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 118.10

586 PANT-Y-GWLANOD VEIN,ERRYRIS,N.WALES,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 105.10 STD.DEVN.= 0.0 NO.MEAS.= 1

MEDIAN=******* 1ST QUARTILE=******* 3RD QUARTILE=******* QUARTILE DEVIATION= 0.0

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 122.10

587 BRYN GWIOG MINE,NORTH WALES,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 107.64 STD.DEVN.= 5.19 NO.MEAS.= 19

MEDIAN= 107.00 1ST QUARTILE= 103.10 3RD QUARTILE= 112.90 QUARTILE DEVIATION= 4.90

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 124.64

588 EAST HALKYN MINE,RHOSESMOR,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 107.11 STD.DEVN.= 2.17 NO.MEAS.= 31

MEDIAN= 106.90 1ST QUARTILE= 106.90 3RD QUARTILE= 108.00 QUARTILE DEVIATION= 0.55

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 124.11

595BA SNAILBEACH MINE,SHROPSHIRE,BARITE,PRMY

MEAN HOMOGEN.TEMP.= 90.70 STD.DEVN.= 11.50 NO.MEAS.= 2

MEDIAN= 90.70 1ST QUARTILE=******* 3RD QUARTILE= 107.95 QUARTILE DEVIATION=*******

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 90.70

595B SNAILBEACH MINE,SHROPS.QUARTZ.PRMY

MEAN HOMOGEN.TEMP.= 124.18 STD.DEVN.= 7.82 NO.MEAS.= 6

MEDIAN= 126.35 1ST QUARTILE= 115.12 3RD QUARTILE= 128.15 QUARTILE DEVIATION= 6.51

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 124.18

595B SNAILBEACH MINE,SHROPS.QUARTZ.SECNY

MEAN HOMOGEN.TEMP.= 72.18 STD.DEVN.= 9.59 NO.MEAS.= 17

MEDIAN= 72.50 1ST QUARTILE= 62.50 3RD QUARTILE= 81.60 QUARTILE DEVIATION= 9.55

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 72.18

617 SEATA MINE,AYSGARTH,YELLOW FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 95.21 STD.DEVN.= 4.67 NO.MEAS.= 21

MEDIAN= 93.00 1ST QUARTILE= 90.60 3RD QUARTILE= 100.00 QUARTILE DEVIATION= 4.70

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 108.21

643 FLORENCE PIT,EGREMONT,BLUE FLUOR,PRMY.

MEAN HOMOGEN.TEMP.= 123.25 STD.DEVN.= 3.79 NO.MEAS.= 16

MEDIAN= 123.00 1ST QUARTILE= 118.75 3RD QUARTILE= 127.35 QUARTILE DEVIATION= 4.30

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 123.25

643 FLORENCE PIT,EGREMONT,BLUE FLUOR,SECNY

MEAN HOMOGEN.TEMP.= 100.10 STD.DEVN.= 0.57 NO.MEAS.= 4

MEDIAN= 100.00 1ST QUARTILE= 99.55 3RD QUARTILE= 100.75 QUARTILE DEVIATION= 0.60

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 100.10

644 FFRITH QUARRY,CAERGWRLE,PURP.FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 113.91 STD.DEVN.= 4.24 NO.MEAS.= 15

MEDIAN= 115.00 1ST QUARTILE= 110.20 3RD QUARTILE= 118.40 QUARTILE DEVIATION= 4.10

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 130.91

644 FFRITH QUARRY,CAERGWRLE,PURP.FLUOR,SECNY

MEAN HOMOGEN.TEMP.= 89.80 STD.DEVN.= 4.92 NO.MEAS.= 8

MEDIAN= 87.50 1ST QUARTILE= 85.25 3RD QUARTILE= 96.00 QUARTILE DEVIATION= 5.37

PRESSURE CORRECTION= 17.00 CORRECTED HOMOGENIZATION TEMP.= 106.80

645 CLOUDS FELL END,DENT,CLLSS.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 93.84 STD.DEVN.= 0.92 NO.MEAS.= 8

MEDIAN= 93.50 1ST QUARTILE= 93.00 3RD QUARTILE= 94.97 QUARTILE DEVIATION= 0.99

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 106.84

645 CLOUDS FELL END,DENT,CLLSS.FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 77.52 STD.DEVN.= 2.18 NO.MEAS.= 11

MEDIAN= 78.00 1ST QUARTILE= 76.00 3RD QUARTILE= 79.20 QUARTILE DEVIATION= 1.60

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 90.52

647 GREENCLEUGH VN.S.GROVERAKE OPENPIT,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 123.49 STD.DEVN.= 4.09 NO.MEAS.= 15

MEDIAN= 125.10 1ST QUARTILE= 119.40 3RD QUARTILE= 126.50 QUARTILE DEVIATION= 3.55

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 136.49

649 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 135.00 STD.DEVN.= 5.05 NO.MEAS.= 4

MEDIAN= 134.50 1ST QUARTILE= 130.00 3RD QUARTILE= 140.50 QUARTILE DEVIATION= 5.25

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 148.60

649 RED VEIN,CRAWLEY OPENCUT,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 105.55 STD.DEVN.= 10.65 NO.MEAS.= 4

MEDIAN= 104.50 1ST QUARTILE= 95.00 3RD QUARTILE= 117.15 QUARTILE DEVIATION= 11.07

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 119.15

650 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 143.86 STD.DEVN.= 2.96 NO.MEAS.= 5

MEDIAN= 142.70 1ST QUARTILE= 141.95 3RD QUARTILE= 147.25 QUARTILE DEVIATION= 3.10

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 157.46

650 RED VEIN,CRAWLEY OPENCUT,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 116.80 STD.DEVN.= 12.90 NO.MEAS.= 5

MEDIAN= 120.50 1ST QUARTILE= 102.00 3RD QUARTILE= 129.75 QUARTILE DEVIATION= 13.87

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 130.40

651 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 136.47 STD.DEVN.= 0.53 NO.MEAS.= 4

MEDIAN= 136.50 1ST QUARTILE= 135.92 3RD QUARTILE= 137.00 QUARTILE DEVIATION= 0.54

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 150.07

652 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 139.60 STD.DEVN.= 4.75 NO.MEAS.= 5

MEDIAN= 139.00 1ST QUARTILE= 134.50 3RD QUARTILE= 145.00 QUARTILE DEVIATION= 5.25

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 153.20

653 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 141.17 STD.DEVN.= 3.46 NO.MEAS.= 9

MEDIAN= 139.00 1ST QUARTILE= 138.00 3RD QUARTILE= 143.50 QUARTILE DEVIATION= 2.75

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 154.77

653 RED VEIN,CRAWLEY OPENCUT,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 124.94 STD.DEVN.= 3.28 NO.MEAS.= 8

MEDIAN= 126.25 1ST QUARTILE= 122.37 3RD QUARTILE= 127.50 QUARTILE DEVIATION= 2.56

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 138.54

661 RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 143.53 STD.DEVN.= 5.93 NO.MEAS.= 10

MEDIAN= 144.00 1ST QUARTILE= 141.42 3RD QUARTILE= 146.00 QUARTILE DEVIATION= 2.29

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 158.28

663 RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 136.78 STD.DEVN.= 2.39 NO.MEAS.= 18

MEDIAN= 136.70 1ST QUARTILE= 136.00 3RD QUARTILE= 136.90 QUARTILE DEVIATION= 0.45

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 151.53

664 RED VEIN,REDBURN MINE,17 SUBLEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 135.64 STD.DEVN.= 10.05 NO.MEAS.= 9

MEDIAN= 137.50 1ST QUARTILE= 123.25 3RD QUARTILE= 143.90 QUARTILE DEVIATION= 10.32

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 150.39

667 RISPEY VEIN,REDBURN MINE,17 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 114.76 STD.DEVN.= 6.29 NO.MEAS.= 35

MEDIAN= 116.00 1ST QUARTILE= 109.00 3RD QUARTILE= 120.60 QUARTILE DEVIATION= 5.80

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 129.51

671 RED VEIN,CRAWLEY OPENCUT,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 143.41 STD.DEVN.= 4.00 NO.MEAS.= 11

MEDIAN= 144.00 1ST QUARTILE= 140.00 3RD QUARTILE= 145.00 QUARTILE DEVIATION= 2.50

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 157.01

671 RED VEIN,CRAWLEY OPENCUT,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 136.77 STD.DEVN.= 4.48 NO.MEAS.= 11

MEDIAN= 139.00 1ST QUARTILE= 132.00 3RD QUARTILE= 141.50 QUARTILE DEVIATION= 4.75

PRESSURE CORRECTION= 13.60 CORRECTED HOMOGENIZATION TEMP.= 150.37

672 RED VEIN,STANHOPEBURN MINE,34 LEVEL,FLUOR.SECNY?

MEAN HOMOGEN.TEMP.= 124.33 STD.DEVN.= 3.12 NO.MEAS.= 6

MEDIAN= 126.00 1ST QUARTILE= 120.00 3RD QUARTILE= 126.50 QUARTILE DEVIATION= 3.25

PRESSURE CORRECTION= 16.60 CORRECTED HOMOGENIZATION TEMP.= 140.93

674 RED VEIN,STANHOPEBURN MINE,34 LEVEL,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 144.41 STD.DEVN.= 3.83 NO.MEAS.= 7

MEDIAN= 146.10 1ST QUARTILE= 139.00 3RD QUARTILE= 147.20 QUARTILE DEVIATION= 4.10

PRESSURE CORRECTION= 16.60 CORRECTED HOMOGENIZATION TEMP.= 161.01

674 RED VEIN,STANHOPEBURN MINE,34 LEVEL,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 127.17 STD.DEVN.= 4.02 NO.MEAS.= 6

MEDIAN= 130.00 1ST QUARTILE= 121.75 3RD QUARTILE= 130.00 QUARTILE DEVIATION= 4.12

PRESSURE CORRECTION= 16.60 CORRECTED HOMOGENIZATION TEMP.= 143.77

678 MAISLEY,SCOTLAND,GN.FLUOR.(W.ANTIM.GAL.)PRMY?

MEAN HOMOGEN.TEMP.= 144.68 STD.DEVN.= 7.38 NO.MEAS.= 11

MEDIAN= 148.50 1ST QUARTILE= 142.50 3RD QUARTILE= 148.50 QUARTILE DEVIATION= 3.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 144.68

679 WITHGILL,CLITHEROE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 143.32 STD.DEVN.= 3.07 NO.MEAS.= 23

MEDIAN= 143.90 1ST QUARTILE= 141.50 3RD QUARTILE= 146.20 QUARTILE DEVIATION= 2.35

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 143.32

679 WITHGILL,CLITHEROE,FLUOR,SECNY

MEAN HOMOGEN.TEMP.= 132.47 STD.DEVN.= 3.53 NO.MEAS.= 8

MEDIAN= 134.50 1ST QUARTILE= 128.37 3RD QUARTILE= 134.50 QUARTILE DEVIATION= 3.06

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 132.47

744 SEILLES,BELGIUM,CLLSS,BLUE,PURP,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 148.88 STD.DEVN.= 3.25 NO.MEAS.= 25

MEDIAN= 148.50 1ST QUARTILE= 145.55 3RD QUARTILE= 152.45 QUARTILE DEVIATION= 3.45

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 148.88

745 FOISCHES,GIVET,FRANCE,PURP.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 124.99 STD.DEVN.= 3.38 NO.MEAS.= 19

MEDIAN= 125.20 1ST QUARTILE= 123.00 3RD QUARTILE= 127.50 QUARTILE DEVIATION= 2.25

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 124.99

747 ENGIHOUL,LIEGE,BELGIUM,ASSOC.W.CALC.PURP.FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 108.79 STD.DEVN.= 10.80 NO.MEAS.= 17

MEDIAN= 106.90 1ST QUARTILE= 101.05 3RD QUARTILE= 117.85 QUARTILE DEVIATION= 8.40

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 108.79

751 CARDON HILL,REEF KNOLL PURP.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 91.03 STD.DEVN.= 1.62 NO.MEAS.= 15

MEDIAN= 91.00 1ST QUARTILE= 89.50 3RD QUARTILE= 92.00 QUARTILE DEVIATION= 1.25

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 91.03

766 OLD RAKE,OLD GANG MINES,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 97.52 STD.DEVN.= 5.21 NO.MEAS.= 13

MEDIAN= 95.50 1ST QUARTILE= 95.00 3RD QUARTILE= 100.75 QUARTILE DEVIATION= 2.87

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 110.52

774 SWINHOPE CROSS VEIN,SWINHOPEHEAD MINE,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 115.86 STD.DEVN.= 5.81 NO.MEAS.= 22

MEDIAN= 114.00 1ST QUARTILE= 111.62 3RD QUARTILE= 122.75 QUARTILE DEVIATION= 5.56

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 130.61

776 GREAT SULPHUR VEIN,SMITTERGILL HEAD MINE,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 177.06 STD.DEVN.= 4.69 NO.MEAS.= 12

MEDIAN= 176.95 1ST QUARTILE= 173.50 3RD QUARTILE= 182.10 QUARTILE DEVIATION= 4.30

PRESSURE CORRECTION= 17.60 CORRECTED HOMOGENIZATION TEMP.= 194.66

776 GREAT SULPHUR VEIN,SMITTERGILL HEAD MINE,FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 153.70 STD.DEVN.= 7.59 NO.MEAS.= 5

MEDIAN= 155.50 1ST QUARTILE= 146.00 3RD QUARTILE= 160.50 QUARTILE DEVIATION= 7.25

PRESSURE CORRECTION= 17.60 CORRECTED HOMOGENIZATION TEMP.= 171.30

805 GREENFIELD NORTH STRING,GREENFIELD HUSHES,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 118.33 STD.DEVN.= 1.29 NO.MEAS.= 9

MEDIAN= 119.00 1ST QUARTILE= 117.00 3RD QUARTILE= 119.50 QUARTILE DEVIATION= 1.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 133.08

806 CLAYPATH VEIN,HEATHERY CLEUGH,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 130.89 STD.DEVN.= 7.10 NO.MEAS.= 14

MEDIAN= 132.85 1ST QUARTILE= 122.25 3RD QUARTILE= 137.20 QUARTILE DEVIATION= 7.47

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 145.64

807 1120'FLATS,OLD VEIN?,ALLENHEADS MINE,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 122.72 STD.DEVN.= 5.85 NO.MEAS.= 16

MEDIAN= 119.50 1ST QUARTILE= 117.50 3RD QUARTILE= 129.37 QUARTILE DEVIATION= 5.94

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 137.47

808 OLD VEIN,ALLENHEADS MINE,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 113.41 STD.DEVN.= 2.39 NO.MEAS.= 9

MEDIAN= 112.80 1ST QUARTILE= 112.30 3RD QUARTILE= 114.00 QUARTILE DEVIATION= 0.85

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 128.16

823 LADTHWAITE ADIT DUMPS,NATEBY,KIRBY STEPHEN,FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 92.50 STD.DEVN.= 2.83 NO.MEAS.= 10

MEDIAN= 91.50 1ST QUARTILE= 90.50 3RD QUARTILE= 95.25 QUARTILE DEVIATION= 2.37

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 105.50

828 FLUORITE DEPOSIT,HARTLEY BIRKETT HILL,KIRBY STEPHEN,FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 93.38 STD.DEVN.= 1.47 NO.MEAS.= 17

MEDIAN= 93.40 1ST QUARTILE= 92.50 3RD QUARTILE= 94.50 QUARTILE DEVIATION= 1.00

PRESSURE CORRECTION= 13.00 CORRECTED HOMOGENIZATION TEMP.= 106.38

842 HARROWBANK VEIN,HARROWBANK Q.,EASTGATE.FLUOR.PRMY.

MEAN HOMOGEN.TEMP.= 104.77 STD.DEVN.= 2.15 NO.MEAS.= 8

MEDIAN= 105.10 1ST QUARTILE= 102.75 3RD QUARTILE= 107.00 QUARTILE DEVIATION= 2.12

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 119.52

TIP1 RED VN. REDBURN MINE,TIPS,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 136.21 STD.DEVN.= 4.45 NO.MEAS.= 7

MEDIAN= 137.50 1ST QUARTILE= 131.50 3RD QUARTILE= 140.00 QUARTILE DEVIATION= 4.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 150.96

1/1 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 128.84 STD.DEVN.= 2.15 NO.MEAS.= 16

MEDIAN= 129.00 1ST QUARTILE= 128.00 3RD QUARTILE= 131.12 QUARTILE DEVIATION= 1.56

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 143.59

1/3 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 129.67 STD.DEVN.= 5.31 NO.MEAS.= 3

MEDIAN= 130.00 1ST QUARTILE= 123.00 3RD QUARTILE= 136.00 QUARTILE DEVIATION= 6.50

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 144.42

1/4 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 129.25 STD.DEVN.= 3.31 NO.MEAS.= 8

MEDIAN= 128.00 1ST QUARTILE= 128.00 3RD QUARTILE= 130.50 QUARTILE DEVIATION= 1.25

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 144.00

2/1 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 134.62 STD.DEVN.= 5.61 NO.MEAS.= 4

MEDIAN= 137.25 1ST QUARTILE= 128.00 3RD QUARTILE= 138.62 QUARTILE DEVIATION= 5.31

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 149.37

2/2 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 131.60 STD.DEVN.= 2.63 NO.MEAS.= 5

MEDIAN= 132.50 1ST QUARTILE= 129.00 3RD QUARTILE= 133.75 QUARTILE DEVIATION= 2.37

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 146.35

2/3 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 112.00 STD.DEVN.= 6.00 NO.MEAS.= 4

MEDIAN= 112.00 1ST QUARTILE= 106.00 3RD QUARTILE= 118.00 QUARTILE DEVIATION= 6.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 126.75

3/1 RED VN.REDBURN MINE,FLUOR,PRMY

MEAN HOMOGEN.TEMP.= 131.10 STD.DEVN.= 4.14 NO.MEAS.= 5

MEDIAN= 129.50 1ST QUARTILE= 127.50 3RD QUARTILE= 135.50 QUARTILE DEVIATION= 4.00

PRESSURE CORRECTION= 14.75 CORRECTED HOMOGENIZATION TEMP.= 145.85

RBH4 590'ROOKHOPE BOREHOLE,TYNEBOTTOM LST.MASSIVE GN.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 138.61 STD.DEVN.= 5.11 NO.MEAS.= 52

MEDIAN= 138.50 1ST QUARTILE= 135.12 3RD QUARTILE= 142.00 QUARTILE DEVIATION= 3.44

PRESSURE CORRECTION= 17.20 CORRECTED HOMOGENIZATION TEMP.= 155.81

RBH4 590'ROOKHOPE BOREHOLE,TYNEBOTTOM LST.GN.FLUOR. 4MM.FROM PYRITE PRIMARY

MEAN HOMOGEN.TEMP.= 129.48 STD.DEVN.= 5.34 NO.MEAS.= 21

MEDIAN= 130.00 1ST QUARTILE= 124.50 3RD QUARTILE= 134.00 QUARTILE DEVIATION= 4.75

PRESSURE CORRECTION= 17.20 CORRECTED HOMOGENIZATION TEMP.= 146.68

RBH4 590'ROOKHOPE BOREHOLE,TYNEBOTTOM LST.GN.FLUOR.INTERSTIT.PB/ZN PRIMARY

MEAN HOMOGEN.TEMP.= 131.53 STD.DEVN.= 7.18 NO.MEAS.= 47

MEDIAN= 132.50 1ST QUARTILE= 127.50 3RD QUARTILE= 137.50 QUARTILE DEVIATION= 5.00

PRESSURE CORRECTION= 17.20 CORRECTED HOMOGENIZATION TEMP.= 148.73

RBH5RBH23 ROOKHOPE BOREHOLE,JEW LST.,690',MASSIVE GN.FLUOR.P/PS

MEAN HOMOGEN.TEMP.= 136.17 STD.DEVN.= 3.78 NO.MEAS.= 51

MEDIAN= 135.00 1ST QUARTILE= 133.00 3RD QUARTILE= 139.50 QUARTILE DEVIATION= 3.25

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 153.87

RASC JEW LIMESTONE,ROOKHOPE B.H. FLUOR.PRMY

MEAN HOMOGEN.TEMP.= 138.81 STD.DEVN.= 3.64 NO.MEAS.= 36

MEDIAN= 140.00 1ST QUARTILE= 137.00 3RD QUARTILE= 142.00 QUARTILE DEVIATION= 2.50

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 156.51

RBH5 690'ROOKHOPE BOREHOLE,JEW LST.GN.FLUOR.BELOW VUG 1,PRMY

MEAN HOMOGEN.TEMP.= 136.90 STD.DEVN.= 15.45 NO.MEAS.= 46

MEDIAN= 130.75 1ST QUARTILE= 123.00 3RD QUARTILE= 154.62 QUARTILE DEVIATION= 15.81

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 154.60

RBH7 689'ROOKHOPE BOREHOLE,JEW LST.QTZ.IN VUG 1,PRIMARY

MEAN HOMOGEN.TEMP.= 135.20 STD.DEVN.= 10.67 NO.MEAS.= 15

MEDIAN= 132.00 1ST QUARTILE= 128.00 3RD QUARTILE= 141.00 QUARTILE DEVIATION= 6.50

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 152.90

RBH5 690'ROOKHOPE BOREHOLE,JEW LST.QTZ.IN VUG 2,PRIMARY

MEAN HOMOGEN.TEMP.= 141.27 STD.DEVN.= 7.69 NO.MEAS.= 20

MEDIAN= 143.50 1ST QUARTILE= 135.25 3RD QUARTILE= 147.00 QUARTILE DEVIATION= 5.87

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 158.97

RBH8 690'ROOKHOPE BOREHOLE,JEW LST.QTZ.WITH SPHAL./GN.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 138.92 STD.DEVN.= 5.95 NO.MEAS.= 6

MEDIAN= 141.00 1ST QUARTILE= 131.50 3RD QUARTILE= 143.25 QUARTILE DEVIATION= 5.87

PRESSURE CORRECTION= 17.70 CORRECTED HOMOGENIZATION TEMP.= 156.62

RBH9 941'ROOKHOPE B.H.LOWER LITTLE LST.MASSIVE GN.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 157.71 STD.DEVN.= 7.79 NO.MEAS.= 55

MEDIAN= 157.00 1ST QUARTILE= 150.00 3RD QUARTILE= 165.00 QUARTILE DEVIATION= 7.50

PRESSURE CORRECTION= 18.80 CORRECTED HOMOGENIZATION TEMP.= 176.51

RBH9 941'ROOKHOPE B.H.LOWER LITTLE LST.MASSIVE GN.FLUOR.SECONDARY

MEAN HOMOGEN.TEMP.= 137.78 STD.DEVN.= 5.19 NO.MEAS.= 23

MEDIAN= 139.00 1ST QUARTILE= 132.50 3RD QUARTILE= 140.20 QUARTILE DEVIATION= 3.85

PRESSURE CORRECTION= 18.80 CORRECTED HOMOGENIZATION TEMP.= 156.58

RBH10 1053'ROOKHOPE B.H.SST.ABOVE LOWER SMIDDY,MASSIVE GN.FLUOR.PRIMARY/PS

MEAN HOMOGEN.TEMP.= 147.75 STD.DEVN.= 6.05 NO.MEAS.= 20

MEDIAN= 146.00 1ST QUARTILE= 144.62 3RD QUARTILE= 148.00 QUARTILE DEVIATION= 1.69

PRESSURE CORRECTION= 19.30 CORRECTED HOMOGENIZATION TEMP.= 167.05

RBH10 1053'SECNY

MEAN HOMOGEN.TEMP.= 135.83 STD.DEVN.= 3.73 NO.MEAS.= 23

MEDIAN= 136.00 1ST QUARTILE= 132.50 3RD QUARTILE= 139.00 QUARTILE DEVIATION= 3.25

PRESSURE CORRECTION= 19.30 CORRECTED HOMOGENIZATION TEMP.= 155.13

RBH24 1079'ROOKHOPE B.H.LOWER LEAF,LOWER SMIDDY LST.MASSIVE GN.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 157.10 STD.DEVN.= 4.96 NO.MEAS.= 31

MEDIAN= 158.00 1ST QUARTILE= 154.50 3RD QUARTILE= 161.00 QUARTILE DEVIATION= 3.25

PRESSURE CORRECTION= 19.50 CORRECTED HOMOGENIZATION TEMP.= 176.60

RBH12RBH20A 1353',1351',ROOKHOPE B.H.GRANITE,MAIN GN.FLUOR.W.PY.PO.PRIMARY

MEAN HOMOGEN.TEMP.= 148.31 STD.DEVN.= 6.23 NO.MEAS.= 27

MEDIAN= 147.50 1ST QUARTILE= 145.00 3RD QUARTILE= 150.00 QUARTILE DEVIATION= 2.50

PRESSURE CORRECTION= 20.80 CORRECTED HOMOGENIZATION TEMP.= 169.11

RBH20B 1351'ROOKHOPE B.H.GRANITE,GN.FLUOR.IN EARLY QTZ.PRIMARY

MEAN HOMOGEN.TEMP.= 135.04 STD.DEVN.= 6.47 NO.MEAS.= 13

MEDIAN= 135.00 1ST QUARTILE= 129.50 3RD QUARTILE= 140.00 QUARTILE DEVIATION= 5.25

PRESSURE CORRECTION= 20.80 CORRECTED HOMOGENIZATION TEMP.= 155.84

RBH22 1562'ROOKHOPE B.H.,GRANITE,QTZ.AT VEINLET MARGIN,PRIMARY

MEAN HOMOGEN.TEMP.= 189.60 STD.DEVN.= 11.77 NO.MEAS.= 5

MEDIAN= 197.00 1ST QUARTILE= 176.00 3RD QUARTILE= 199.50 QUARTILE DEVIATION= 11.75

PRESSURE CORRECTION= 21.70 CORRECTED HOMOGENIZATION TEMP.= 211.30

RBH22 1562'ROOKHOPE B.H.,GRANITE,GN.FLUOR.2-3MM.FROM MARGIN,ON QTZ.PRIMARY

MEAN HOMOGEN.TEMP.= 167.45 STD.DEVN.= 7.78 NO.MEAS.= 10

MEDIAN= 165.50 1ST QUARTILE= 160.37 3RD QUARTILE= 175.50 QUARTILE DEVIATION= 7.56

PRESSURE CORRECTION= 21.70 CORRECTED HOMOGENIZATION TEMP.= 189.15

RBH22 1562'ROOKHOPE B.H.,GRANITE,GN.FLUOR.WITH PY.(MAIN).PRIMARY

MEAN HOMOGEN.TEMP.= 150.92 STD.DEVN.= 6.37 NO.MEAS.= 33

MEDIAN= 150.00 1ST QUARTILE= 147.00 3RD QUARTILE= 156.50 QUARTILE DEVIATION= 4.75

PRESSURE CORRECTION= 21.70 CORRECTED HOMOGENIZATION TEMP.= 172.62

RBH26 1649'ROOKHOPE B.H.,GRANITE,QTZ.VUG.PRIMARY

MEAN HOMOGEN.TEMP.= 222.04 STD.DEVN.= 15.78 NO.MEAS.= 13

MEDIAN= 225.00 1ST QUARTILE= 209.50 3RD QUARTILE= 236.00 QUARTILE DEVIATION= 13.25

PRESSURE CORRECTION= 22.10 CORRECTED HOMOGENIZATION TEMP.= 244.14

RBH26 1649'ROOKHOPE B.H.,GRANITE,QTZ.VUG.SECONDARY

MEAN HOMOGEN.TEMP.= 170.57 STD.DEVN.= 10.99 NO.MEAS.= 7

MEDIAN= 172.00 1ST QUARTILE= 157.00 3RD QUARTILE= 181.00 QUARTILE DEVIATION= 12.00

PRESSURE CORRECTION= 22.10 CORRECTED HOMOGENIZATION TEMP.= 192.67

RBH13 1699'ROOKHOPE B.H.GRANITE,MASSIVE GN.FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 157.89 STD.DEVN.= 9.04 NO.MEAS.= 14

MEDIAN= 156.00 1ST QUARTILE= 149.87 3RD QUARTILE= 165.25 QUARTILE DEVIATION= 7.69

PRESSURE CORRECTION= 22.30 CORRECTED HOMOGENIZATION TEMP.= 180.19

RBH13 1699'ROOKHOPE B.H.GRANITE,MASSIVE GN.FLUOR.SECONDARY

MEAN HOMOGEN.TEMP.= 130.03 STD.DEVN.= 7.94 NO.MEAS.= 27

MEDIAN= 131.50 1ST QUARTILE= 123.00 3RD QUARTILE= 135.00 QUARTILE DEVIATION= 6.00

PRESSURE CORRECTION= 22.30 CORRECTED HOMOGENIZATION TEMP.= 152.33

RBH13 1699'ROOKHOPE B.H.GRANITE,QTZ.VEIN(LATE) WITH PY.PRIMARY

MEAN HOMOGEN.TEMP.= 136.41 STD.DEVN.= 15.71 NO.MEAS.= 11

MEDIAN= 132.00 1ST QUARTILE= 124.50 3RD QUARTILE= 152.00 QUARTILE DEVIATION= 13.75

PRESSURE CORRECTION= 22.30 CORRECTED HOMOGENIZATION TEMP.= 158.71

RBH19 2085'ROOKHOPE BOREHOLE,GRANITE,INT.PURPLE FLUOR.PRIMARY

MEAN HOMOGEN.TEMP.= 236.68 STD.DEVN.= 12.05 NO.MEAS.= 14

MEDIAN= 237.00 1ST QUARTILE= 230.00 3RD QUARTILE= 246.50 QUARTILE DEVIATION= 8.25

PRESSURE CORRECTION= 24.10 CORRECTED HOMOGENIZATION TEMP.= 260.78

RBH19 2085'ROOKHOPE B.H.,GRANITE,INT.PURPLE FLUOR.HIGH SECDY.

MEAN HOMOGEN.TEMP.= 173.81 STD.DEVN.= 12.70 NO.MEAS.= 13

MEDIAN= 170.00 1ST QUARTILE= 163.50 3RD QUARTILE= 185.50 QUARTILE DEVIATION= 11.00

PRESSURE CORRECTION= 24.10 CORRECTED HOMOGENIZATION TEMP.= 197.91

RBH19 2085'ROOKHOPE B.H.,GRANITE,INT.PURPLE FLUOR.LOW SECDY.

MEAN HOMOGEN.TEMP.= 128.44 STD.DEVN.= 9.45 NO.MEAS.= 8

MEDIAN= 126.50 1ST QUARTILE= 121.12 3RD QUARTILE= 137.87 QUARTILE DEVIATION= 8.37

PRESSURE CORRECTION= 24.10 CORRECTED HOMOGENIZATION TEMP.= 152.54

DA2 EARLY QUARTZ WITH CASSITERITE,PENDARVES MINE,CAMBOURNE,CORNWALL,PRMY.

MEAN HOMOGEN.TEMP.= 348.40 STD.DEVN.= 14.61 NO.MEAS.= 5

MEDIAN= 350.00 1ST QUARTILE= 336.00 3RD QUARTILE= 360.00 QUARTILE DEVIATION= 12.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 348.40

DA2 COCKSCOMB QUARTZ,PENDARVES MINE,CORNWALL,PRMY.

MEAN HOMOGEN.TEMP.= 224.00 STD.DEVN.= 9.93 NO.MEAS.= 3

MEDIAN= 230.00 1ST QUARTILE= 210.00 3RD QUARTILE= 232.00 QUARTILE DEVIATION= 11.00

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 224.00

X22 HALECOMBE QUARRY,E.MENDIPS,PURP.FLUOR.,PRIMARY

MEAN HOMOGEN.TEMP.= 84.76 STD.DEVN.= 10.30 NO.MEAS.= 17

MEDIAN= 86.00 1ST QUARTILE= 75.25 3RD QUARTILE= 94.00 QUARTILE DEVIATION= 9.37

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 84.76

CQ1 SANDBEDS BARYTES VN.CALEBRACK TRIAL,QTZ,PRMY

MEAN HOMOGEN.TEMP.= 122.32 STD.DEVN.= 8.13 NO.MEAS.= 14

MEDIAN= 119.40 1ST QUARTILE= 114.50 3RD QUARTILE= 130.47 QUARTILE DEVIATION= 7.99

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 122.32

R.P.Q. DALRADIAN QUARTZ,POWELL & SMITH,NATURE,244,1973,P.70,PRMY

MEAN HOMOGEN.TEMP.= 349.68 STD.DEVN.= 19.66 NO.MEAS.= 25

MEDIAN= 349.00 1ST QUARTILE= 340.00 3RD QUARTILE= 360.00 QUARTILE DEVIATION= 10.00

PRESSURE CORRECTION= 145.00 CORRECTED HOMOGENIZATION TEMP.= 494.68

1527-B SHAP GRANITE QUARRY,APLITE VEIN,AMBER FLUOR.?PRMY

MEAN HOMOGEN.TEMP.= 107.90 STD.DEVN.= 0.0 NO.MEAS.= 1

MEDIAN=******* 1ST QUARTILE=******* 3RD QUARTILE=******* QUARTILE DEVIATION= 0.0

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 107.90

1527-B SHAP GRANITE QUARRY,APLITE VEIN,AMBER FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 97.40 STD.DEVN.= 0.20 NO.MEAS.= 5

MEDIAN= 97.50 1ST QUARTILE= 97.25 3RD QUARTILE= 97.50 QUARTILE DEVIATION= 0.13

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 97.40

1527-B SHAP GRANITE QUARRY,APLITE VEIN,AMBER FLUOR.SECNY

MEAN HOMOGEN.TEMP.= 84.89 STD.DEVN.= 5.23 NO.MEAS.= 8

MEDIAN= 83.95 1ST QUARTILE= 79.65 3RD QUARTILE= 91.25 QUARTILE DEVIATION= 5.80

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 84.89

1527-B SHAP GRANITE QUARRY,APLITE VEIN,CALCITE,PRMY

MEAN HOMOGEN.TEMP.= 73.30 STD.DEVN.= 3.22 NO.MEAS.= 5

MEDIAN= 72.50 1ST QUARTILE= 70.00 3RD QUARTILE= 77.00 QUARTILE DEVIATION= 3.50

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 73.30

6444 BALLATER PASS,SCOTLAND,FLUOR.SECNY.

MEAN HOMOGEN.TEMP.= 138.81 STD.DEVN.= 1.11 NO.MEAS.= 7

MEDIAN= 138.50 1ST QUARTILE= 137.50 3RD QUARTILE= 140.00 QUARTILE DEVIATION= 1.25

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 138.81

6445 BALLATER PASS,SCOTLAND,FLUOR.SECNY.

MEAN HOMOGEN.TEMP.= 131.25 STD.DEVN.= 1.89 NO.MEAS.= 4

MEDIAN= 132.25 1ST QUARTILE= 129.00 3RD QUARTILE= 132.50 QUARTILE DEVIATION= 1.75

PRESSURE CORRECTION= 0.0 CORRECTED HOMOGENIZATION TEMP.= 131.25

MINATED

APPENDIX 3.

FLUORITE ANALYSIS BY X-RAY FLUORESCENCE.

A3.1 Sample Preparation.

Samples collected in the field were kept in sealed, labelled polythene bags until required for analysis. They were then washed in tapwater to remove surface dirt, scrubbed if necessary, and dried in air for a day or two before crushing. Specimens with serious contamination from vegetation, unwanted minerals or rock were dressed with a hammer, if possible. Occasionally fluorite was found intimately mixed with sulphides or rock. If it was impossible to chip sufficient pure fluorite, as fragments, from such specimens for an analysis, the samples were then washed in dilute HCI, to assist disaggregation. This was done very rarely, probably no more than ten times. Mechanical separation was prefered because of the possibility, albeit slight, of leaching trace elements from the solid sample. Naturally since the possibility increased as the sample grain size decreased, no powdered fluorites were ever treated with acid.

Depending upon the type of sample it was further prepared for crushing in one of three ways:

1) If the sample had been accurately located within a vein and was to be taken as representative of that location, then the whole sample (500 gms - 1 kg) was broken down by hammer, split and about 100 - 200 gms taken to be crushed.

2) If the sample comprised small fragments picked from a tip these were crushed together if possible.

3) If the sample comprised a number of large lumps of ore from a tip, one or each of these was broken down and used. Thus there are sometimes several analyses of fluorite described by a single specimen collection number.

The selected samples were crushed and ground to a fine powder using a Tema Laboratory Disc Mill, Model T - 100 with a tungsten carbide Widia grinding barrel. A uniform powder grain size was aimed for in which no roughness could be detected by rolling the powder between the fingers. This was largely achieved.

The powders, again stored in sealed polythene bags, were compressed into bricquettes under a hydraulic ram operated at 8 tons/ sq. in. Five to eight drops of an inert organic binding agent, Mowiol, were added to the powder prior to compression. Each bricquette was made to an approximately uniform thickness (about 7-8 mm), matching that of the standard bricquettes. If the sample powder was insufficient then borax powder was used to back and support the bricquette.

A3.2 Analysis.

The bricquette samples were analysed on a Philips PW 1212 automatic X - ray fluorescence spectrometer. The instrument was set to optimise counting statistics for each particular element studied. Two procedures were used, the absolute ratio method of major element analysis and the absolute method, with fixed time, for trace element analysis. Spectrometer operating conditions are given in Table A3.1.

Standards (Table A3.2) were made by spiking 'extrapure' calcium fluoride (B.D.H.) with the following compounds:

Standards I to $\overline{V1}$: $BaCl_2$, SrO, CeO_2, Y_2O_3

LA1 to LA5 : La_2O_3, Sc_2O_3, LiF, MgF_2

S1 to S6 : SiO_2

Although scanning by the spectrometer had shown the 'extrapure' compound to be free of these cations, subsequent cross-checking of the standards against 'specpure' calcium carbonate spikes and a set of synthetic spiked glass standards showed that in fact the blank mixture

TABLE A3.1

OPERATING CONDITIONS FOR THE SPECTROMETER.

Element	Ba	Sr	Y	Ce	La	Zn	Cu	Ni	Mg	Si	Mn
Line	Kα	Kα	Kα	LB_1	$L\alpha_1$	Kα	Kα	Kα	Kα	Kα	
Tube	W	W	W	W	W	W	W	W	Cr	Cr	W
Peak $^{o}2\theta$	15.58	35.81	33.88	111.7	139.03	60.55	65.51	71.24	43.53	109.1	95.25
Low background	-	34.78	32.93	110.0	137.0	59.33	64.72	69.92	-	-	-
High background	16.55	36.78	34.78	114.3	141.04	61.53	66.43	73.13	45.5	-	97.00
Generator kV	60	60	60	60	60	60	60	60	50	60	60
Ma	32	32	32	32	32	32	32	32	40	24	24
Crystal	LiF110	LiF110	LiF110	LiF110	LiF110	LiF110	LiF110	LiF110	KAP	PE	LiF110
Path	Vac	Vac	Vac	Vac	Vac	Vac	Vac	Vac	Vac	Vac	Air
Collimator	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse	Coarse
Fixed time secs.	40	40	40	200	200	100	100	100	100	-	-
Pump down time secs.	30	30	30	30	30	30	30	30	30	30	30
Spinner	On	On	On	On	On	On	On	On	On	On	On
Method	Abs	Abs	Abs	Abs	Abs	Abs	Abs	Abs	Abs	AbsRa	AbsRa
Fixed Count Secs	-	-	-	-	-	-	-	-	-	$3x10^5$	$3x10^4$
Monitor %										28	
Detection Limit ppm	10	2	2	7	4	5	7	7	10	-	-
Counter	Scint	Scint	Scint	Flow	Flow	Scint	Scint	Scint	Flow	Flow	Flo+Sci

TABLE A3.2

FLUORITE TRACE ELEMENT STANDARDS.

No.	Ba ppm	Sr ppm	Ce ppm	Y ppm
I	271	624	281	819
II	136	536	123	359
III	96	510	61	177
IV	64	500	30	87
V	53	486	15	43
VI	51	484	7.6	22

No.	La ppm	Sc ppm	Li ppm	Mg ppm
LA1	1333	1694	940	1219
LA2	640	814	452	724
LA3	293	372	206	480
LA4	158	201	112	386
LA5	96	123	68	343

No.	S1	S2	S3	S4	S5	S6
% SiO_2	49.8	28.0	12.2	8.0	4.3	1.85

Blank - 42.5 ppm Ba, 478 ppm Sr, 275 ppm Mg, Oppm Ce, Y, La

No.	BSC1	BSC2	BSC3	BSC4	BSC5
CaF_2%	69.6	61.6	83.8	97.4	95.3
Pb%	1.69	1.19	0.40	0.00	n.a.
SiO_2%	12.4	23.2	2.00	0.10	0.17

contained some barium, strontium and magnesium. The exact amount of contamination could be easily determined in the case of barium by back-extrapolation of the calibration curve. The validity of this technique, though yielding close agreement with other standards, is more doubtful in the cases of magnesium and particularly strontium, where the range of element content is quite small and exceeds the maximum concentration in the samples. Strontium analyses therefore may be subject to systematic error of up to 5 ppm. The limited number of zinc, copper, nickel and manganese analyses were calibrated using spiked synthetic glass standards. Five further standards (BSC 1 - 5) were made using wet chemically analysed fluorspar ores (analyst - F. Roache) donated by the British Steel Corporation.

Calibration curves were constructed by plotting counts vs content, percent (Si, Mn) or peak to background counts ratio vs. content, ppm (traces). SiO_2 and Mn percentages and Mg ppm were found directly from the calibration curves by hand, trace element contents were calculated using the computer programme Tratio (R.C.O. Gill). Detection limits, estimated for the former and calculated from accumulated background values for the latter, are given in Table A3.1.

Tests, devised to determine the effects (if any) of variable bricquette thickness and the presence of borax backing, showed that despite varying powder thickness between 2 and 14 mm, Y analyses remained within 4% of the mean value, showing no systematic variation. This precision was found using several sets of bricquettes made from the same samples and from sets including borax backed bricquettes. Since replicate analyses of the same bricquette provide agreement to within 1% of the mean analysis, at the levels of 300 - 400 ppm Y, the variation between

different bricquettes from the same powder must arise from powder inhomogeneity, although it is not easy to see how this could have persisted.

A3.3 Colour.

Fluorite colour was noted before the sample was crushed. All known natural coloured varieties were encountered during the project. All but the most intensely purple or green specimens give white powders. Exposure to the X-ray beam, however, results in some of the fluorite powders becoming very strongly coloured in shades of purple and blue. Bright turquoise hues may be produced in polished discs of Cornish fluorites. Although the intensity of colouration is partly, directly related to the period of exposure, this becomes unimportant after about 200 to 300 secs. The colouration has not faded in specimens kept, in the dark, for three years after the original exposure. Five bricquettes were chosen to form an arbitrary range of colouration standards (Plate A3.1). The remaining bricquettes were then compared, after analysis, with these standards and a value of 'Radam' (radiation damage colouration) estimated.

Two major divisions of British coloured fluorites have become apparent. Fluorites from the North Pennine orefield and the Cornubian orefields are predominantly green or purple. The exact shade of purple in the former is variable, tending at times towards blue, whereas Cornish purple fluorites are generally intensely palatine. Some colourless, white and yellow specimens occur, but, although eye-catching, these are usually quite uncommon. Radiation colouration of all these specimens, shown in Chapter 7 to contain relatively high amounts of rare earths, is slight, regardless of actual colouration or intensity. Mean values of Radam for green and purple Cornubian specimens are 2.3 (33 samples) and 1.96 (4 samples) respectively, and

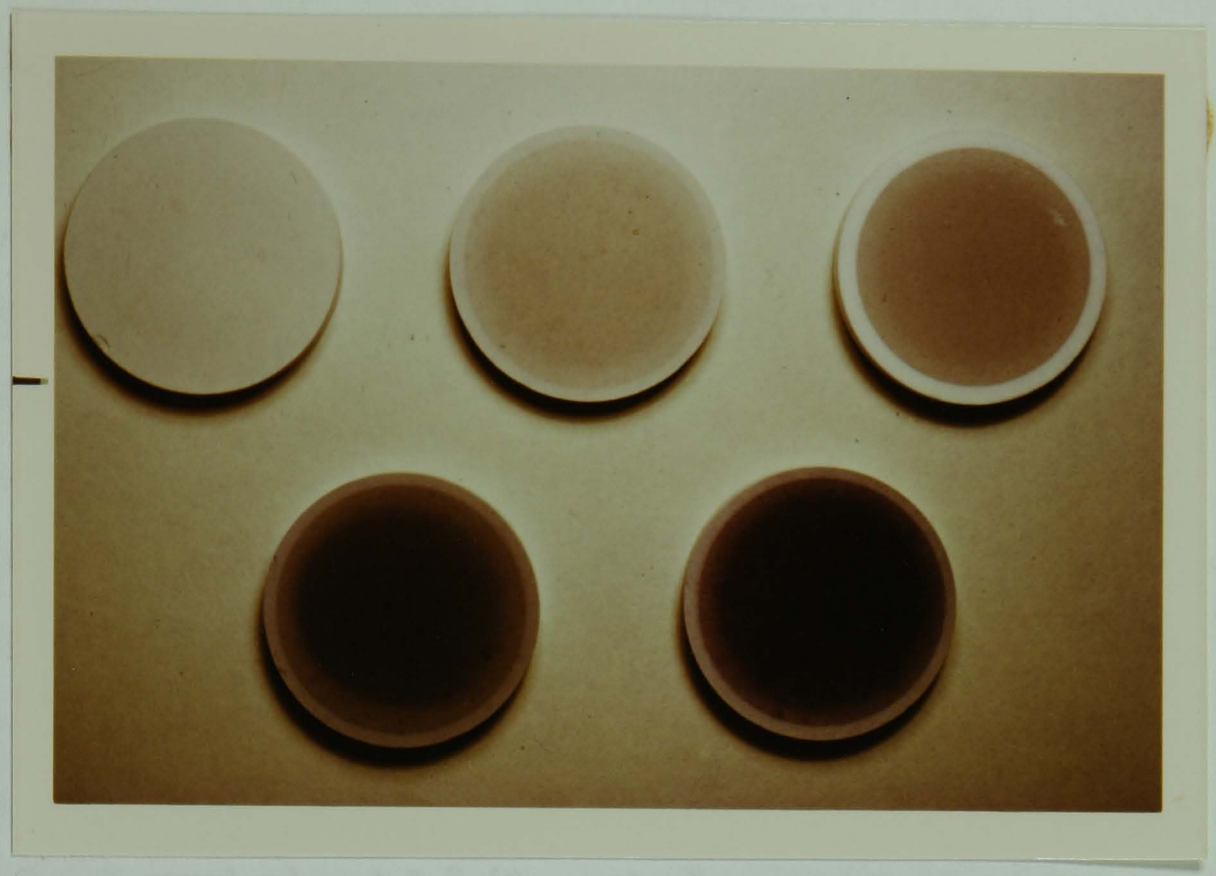


Plate A 3.1 Bricquettes of powdered fluorite after exposure to X - radiation for a similar length of time. These bricquettes were chosen as arbitrary standards for estimation of radiation colouration of fluorite and were numbered 1 (colouration unnoticeable) to 5 (most intense)

and for green, purple and yellow North Pennine specimens are 2.2 (122 samples), 2.4 (61 samples) and 1.85 (10 samples) respectively.

Fluorites from the Askrigg Block and Derbyshire orefields are predominantly yellow or colourless. Intense purple varieties, 'antozonite', such as Blue John, are again eye-catching but uncommon, particularly in the Yorkshire orefields. Frequently the purple colouration may be found as zones parallel to (100) or (111) faces in colourless cubes. Green varieties are unknown. Radiation colouration of all these fluorites, known to contain only small amounts of rare earths, is intense. Mean Radam values for colourless/yellow and purple Askrigg Block specimens are 4.0 (45 samples) and 3.8 (2 samples) respectively, and for colourless/yellow and purple Derbyshire specimens are 3.8 (46 samples) and 3.1 (4 samples) respectively.

Fluoritesfrom the North Wales orefield are usually dark purple or colourless and show intense radiation damage (Radam 4.5, mean 6 samples). Other fluorites, from typical Mississippi Valley style deposits (Asturias, Illinois, Kentucky, Belgian Ardennes) with low rare earth contents show similarly intense radiation colouration.

Dunham (1937a) postulated that yellow fluorites, in the North Pennines, occur chiefly around the margin of the fluorite zone and were deposited at lower temperatures than the other coloured varieties. Fluid inclusion temperatures, however, have shown that yellow varieties formed from solutions no cooler than many other purple and green fluorites. Moreover the greater number of underground vein exposures at the present day tends to modify Dunham's geographical concept. Yellow fluorites occur, though in small amounts in most large vein orebodies in Weardale. There is no evidence whatsoever that purple, green and yellow

colouration is connected with formation temperature.

Mean yttrium contents of variously coloured fluorites have been calculated for the North Pennines. The range and mean for green fluorites are - 102 to 812, 296 ppm Y (124 obsvns.) respectively; for banded or mottled, green and purple fluorites - 126 to 602, 332 ppm Y (88 obsvns.); for purple fluorites - 126 to 673, 338 ppm Y (44 obsvns.); for yellow and white fluorites - 166 to 405, 228 ppm Y (12 obsvns.) and for purple fluorites collected from surface exposed dumps - 172 to 756, 270 ppm Y (63 obsvns.) These indicate that the Yttrium content of fluorite is of no importance in controlling colour variation.

A3.4 Analysis List.

Analyses are listed in Table A3.3 in the order of the specimen number. The specimen number is followed by a coded locality description. The code comprises five numbers. The first refers broadly to the affinity of the deposit, magmatic or connate if known, or disputed. The second refers to the orefield, if known, or some other major geographic location (often country of origin). The third refers to mineral or mining district, thus the North Pennines orefield is subdivided into the Weardale, Teesdale etc. districts. The fourth and fifth numbers refer to the mine (or quarry) and vein respectively, from which the specimen was taken. A zero in any of these places implies that the information is not known.

Colour and radiation damage colouration (Radam) are noted. Colour is abbreviated to PURP or GREE etc., prefixed by I if particularly intense. GPMT and GPBD mean green and purple, mottled and banded respectively. PU/V is used if the sample, though purple, had been exposed to sunlight since it is known that some green fluorite will turn purple on exposure to U/V light. The scale used for Radam assessment was described in Sect. A3.3

Following the X.R.F. number, identifying each bricquette, are the analyses. Trace element content is quoted in ppm, corrected by normalization for the appropriate degree of silica contamination indicated by the SiO_2 percentage, also quoted.

Since it was found, at an early stage, that there was little value in analysing for the contaminating metals Zn,Cu and Ni, only the first 300 or so analyses are complete in this respect, the ommission for the remainder being intentional. It is necessary, however, to remark upon the cerium and lanthanum data. The strict rota of Durham X.R.F. users and their requirements meant that the first opportunity to analyse the fluorites for Ce and La (not commonly of interest to petrologists) did not arise until February, 1973. This was an unfortunate period during which a series of machine and auxiliary failures persisted for two months, in which time only about 400 samples were analysed. Machine instability was so marked, however, that eventually even these were discarded. The Ce and La data shown in the following tables were obtained in December, 1973 and hence are not discussed at length in the main text of this work.

INDEX TO LOCALITY CODE HIERARCHY,TABLE A 3*3

1 MAGMATIC AFFINITY
1 1 S.W.ENGLAND
1 1 1 TAMAR VALLEY
1 NEW TAMAR VALLEY MINE
2 SOUTH TAMAR CONSOLS
3 EAST TAMAR CONSOLS
4 NORTH HOCE MINE
5 BEDFORD UNITED MINE
1 1 2 LISKEARD DISTRICT
1 WHEAL HONY
2 WHEAL TREHANE
3 WHEAL MARY ANN
1 1 3 ST.AGNES DISTRICT
1 WHEAL BUNGAY
2 WHEAL DEVONSHIRE
1 1 4 CAMBORNE,REDRUTH,ST.DAY DISTRICT
1 WHEAL GORLAND
2 WEST WHEAL DANSEL
3 ST.AUBYN UNITED
4 WHEAL CUPID
5 COPPER HILL MINE,MAIN ENGINE SHAFT
1 MAIN LODE
6 WHEAL BULLER,PRAY'S SHAFT
1 NORTH LODE
7 TAYLORS SHAFT,EAST POOL
8 WEST WHEAL SETON
9 WHEAL SETON
10 NORTH ROSKEAR
11 NORTH CROFTY
12 SOUTH CROFTY
1 TINCROFT SOUTH LODE
2 NO.9 FAULT LODE
3 NO.2 LODE,COOKS KITCHEN
13 WHEAL DANSEL
14 WHEAL GRAMBLER ST.AUBYN SETT
15 NORTH WHEAL GRAMBLER
1 NORTH GRAMBLER LODE
16 TREGELLAS SHAFT,WHEAL GRAMBLER
1 MITCHELLS LODE
17 MURRAYS SHAFT,WHEAL GRAMBLER

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                        1 MITCHELLS LODE
                   18 ENGINE HOUSE SHAFT,WHEAL GRAMBLER
                   19 WHEAL GRAMBER,SHAFT
                   20 COLONELS SHAFT,CATHEDRAL MINE
                   21 WHEAL JEWELL
                   22 PENDARVES MINE,CAMBOURNE (PROB.CONSOLS)
                        1 303 HARRIET DRIVE EAST
                   23 WHEAL JANE
                   24 RAME,NR.HELSTON
                        1 CARNMENELLIS GRANITE
1          1     5 ST.JUST DISTRICT
                    1 GEEVOR MINE
                        1 CORONATION LODE
                        2 NORTH LODE
1          1     6 ST.AUSTELL DISTRICT
                    1 ST.STEPHEN IN BRANNEL
                        1 TREGARGUS CHINASTONE QUARRY
1          2 LAKE DISTRICT
               1 SHAP
                    1 SHAP GRANITE QUARRY
1          3 WEARDALE GRANITE
               1 ROCKHOPE BOREHOLE
1          4 GREENLAND
1          4     1 SOUTH-WEST GREENLAND
                        1 JULIANEHAAB GRANITE
                        2 IGALIKO COMPLEX
                             1 IGDLERFIGSSALIG CENTRE
                        3 IVIGTUT REGION
                        4 PYRAMIDEFJELD GRANITE
1          5 AUSTRALIA
1          5     1 VICTORIA
                        1 PINE MOUNTAIN DEPOSIT
                        2 SANDY CREEK DEPOSIT(PINE MOUNTAIN)
1          6 AUSTRALIAN SHIELD-DEPOSITS IN GRANITIC METAMORPHIC TERRAIN
1          6     1 NEW SOUTH WALES
                        1 MOUNT ROSE DEPOSIT
                        2 THACKARINGA DEPOSIT
                        3 MAYFLOWER MINE,PURNAMOOTA
                        4 CARBOONA DEPOSIT
                        5 GULF FLUORITE DEPOSIT
                        6 GULF DEPOSIT
                        7 MOUNT ELTIE DEPOSIT
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1          6     2 SOUTH AUSTRALIA
                     1 PLUMBAGO STATION
                     2 MAIN PLUMBAGO DEPOSIT
1          6     3 QUEENSLAND
                     1 RELIEF AND MIDWAY MINE,MUNGANA
                     2 MISTAKE MINE,EMUFORD
                     3 TRUE BLUE MINE,TATE RIVER
                     4 ALMADEN,CHILLAGOE DISTRICT
                     5 MOUNT GARNET
1          6     4 WEST AUSTRALIA
                     1 MEENTHEENA DEPOSIT
                     2 SPEEWAH VALLEY
1          6     5 NORTHERN TERRITORY
                     1 CENTRAL PACIFIC MINERALS,ALICE SPRINGS
1          7 SOUTH AFRICA
1          7     1 BUSHVELDT COMPLEX
                     1 BUFFALO MINE,N.TRANSVAAL
                     2 VERNOOEG MINE,N.TRANSVAAL
1          8 SARDINIA
                     1 SILIUS MINE
1          9 COLORADO
                     1 SALIDA
                     1 PIKES PEAK
1         10 TELEMARK REGION,NORWAY
                     1 FYRESDALSVANNET
                     2 BRISSVANN
                     3 BORKEVANN
                     4 HAUKAS
                     5 TVEITSTA
1         11 MEXICO
1         11     1 COAHUILA
                     1 EL TULE DEPOSIT
                     2 BUENAVISTA DEPOSIT
                     3 CUATRO PALMAS DEPOSIT
                     4 AGUACHILE DEPOSIT
                     5 MAL ABRIGO DEPOSIT
                     6 DONA NINO DEPOSIT
1         11     2 CHIHUAHUA
                     1 ROSARIO
                     2 MINERA SAN FRANCISCO DEL ORO
                          1 SAN ANDREAS VEIN
1         11     3 GUANAJUATO
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                        1 EL REALITO MINE
                        2 EL REFUGIO MINE
1          11       4 SAN LUIS POTOSI
                        1 CIA MINERA LAS CLEVAS

2 FORMATION WATER DEPOSITS
2             1 EAST DURHAM PERMIAN
                  1 CHILTON,FERRYHILL
                        1 CHILTON QUARRY
                        2 ROUGH FURZE QUARRY

3 HYDROTHERMAL DEPOSITS OF DISPUTED,OR UNKNOWN AFFINITY
3             1 NORTHERN PENNINE OREFIELD.SEPARATE VEIN LISTINGS WHERE
3             1   * 1 WEARDALE *                                    MARKED *
                        1 CORBETMEA
                        2 SOUTH GRAIN MINES
                        3 FRAZARS/ROCKHOPEHEAD MINE
                        4 GROVERAKE MINE
                        5 SOUTH GROVERAKE MINE AND PIT,GOWLANDS LEVEL
                        6 NORTH GROVERAKE MINE AND PIT
                        7 WOLFCLEUGH MINE
                        8 THORNY SLITT
                        9 WHIMSEY CLEUGH MINES
                       10 RISPEY MINE
                       11 RISPEY-SIKE LEVELS
                       12 GREENWELLS LEVEL AND HUSH
                       13 TAILRACE LEVEL
                       14 REDBURN MINE
                       15 LOW FULWOOD MINE
                       16 HIGH FULWOOD MINE,LINTZGARTH CLEUGH,AND OPENCUTS
                       17 BOLTSBURN WEST LEVEL
                       18 BOLTSBURN EAST MINE
                       19 STOTSFIELDBURN MINE
                       20 STANHOPEBURN MINE
                       21 NOAHS ARK OPENPIT
                       22 WIDLEY LEVEL
                       23 RED VEIN LEVEL
                       24 HOPE LEVEL
                       25 LANEHEAD QUARRY,STANHOPE
                       26 CRAWLEYSIDE OPENCUT
                       27 ROGERLEY HUSH
                       28 ASHES QUARRY
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29 MIDDLEHOPE CLD MINE
30 COPTCLEUGH MINE
31 BURTREE PASTURE MINE
32 SEDLING MINE
33 ROCKHOPE PORE HOLE
34 THORNY BROW MINE
35 CAPTAINS CLEUGH LEVEL
36 BRANDON WALLS MINE
37 LANEHEAD VILLAGE
38 BLACKDENE MINE
39 KILLHOPE-BURN WHIMSEYS
40 BARBARY MINE
41 HEIGHTS QUARRY
42 HEIGHTS MINE NORTH
43 WHITFIELD BROW MINE,HOWDEN LEVEL
44 GROVEHEADS OPENCAST
45 LOW GROVEHEADS CROP WORKINGS
46 SWINHOPEHEAD MINE
47 SILVERDIKES LEVEL
48 GREENFIELDS HUSHES
49 CLAYPATH GROOVE
50 COVES MINE
51 YEWTREE MINE
52 HARROWBANK QUARRY

* VEIN LISTING,WEARDALE MINES *

1 GREENCLEUGH S.W.BRANCH
2 GREENCLEUGH VEIN
3 GROVERAKE VEIN
4 RED VEIN (ROOKHOPE TO STANHOPE)
5 RED VEIN (CRAWLEY)
6 RED VEIN (ROGERLEY)
7 BURTREE PASTURE VEIN
8 WOLFCLEUGH OLD VEIN
9 WOLFCLEUGH NEW VEIN
10 GREENWELLS VEIN
11 RISPEY VEIN
12 LITTLE SCARSYKE VEIN
13 SCARSYKE VEIN
14 MARYS VEIN
15 NORTH FULWOOD VEIN
16 FULWOOD VEIN
17 BOLTSBURN VEIN

18 THORNY BROW VEIN
19 BRANDON WALLS VEIN
20 CAPTAINS CLEUGH VEIN
21 RIPPONS VEIN
22 UNNAMED 1 VEIN LANEHEAD(W)
23 UNNAMED 2 VEIN LANEHEAD
24 RIDLEYS VEIN
25 CRAWLEY CROSS VEIN
26 LONGSYKE VEIN
27 PUDDINGTHORN VEIN
28 KILLHOPE-HEAD VEIN
29 BLACKDENE VEIN
30 BLACKDENE BRANCH VEIN
31 NORTH SLITT VEIN
32 SOUTH SLITT VEIN
33 COPTCLEUGH VEIN
34 SEDLING VEIN
35 MIDGEPITS VEIN
36 HEIGHTS SOUTH VEIN
37 HEIGHTS NORTH VEIN
38 MERKIEL VEIN
39 IRESHOPEBURN VEIN
40 GROVEHEADS VEIN
41 LOW GROVEHEADS VEIN
42 SWINHOPE CROSS VEIN
43 SLITT VEIN
44 GREENFIELD VEIN
45 GREENFIELD NORTH STRING
46 CLAYPATH VEIN
47 COVES VEIN
48 YEWTREE VEIN
49 HARROWBANK VEIN

3 1 2 HUNSTANWORTH-BLANCHLAND
1 WHITEHEAPS MINE
1 RED VEIN
2 WHITE VEIN
3 COMPANYS VEIN
4 POOR VEIN
2 SIKEHEAD MINE
1 WHITE VEIN
3 RAMSHAW PLANTATION
1 RAMSHAW VEINS

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                    4 SHILDON MINE
3         1      3 TEESDALE
                    1 LANGDON BECK MINES
                    2 PIKE LAW MINES
                    3 GREAT EGGLESHOPE LEVEL NY971305
                              1 WIRECILL VEIN
3         1      4 ALSTON-NENTHEAD AREA
                    1 COALCLEUGH
                              1 LOW COALCLEUGH VEIN
                    2 WHETSTONEMEA
                    3 BLACK HILL MINES
                              1 RAMPGILL VEIN
                    4 FIRESTONE LEVEL
                              1 RAMPGILL VEIN
                    5 CAPELCLEUGH LEVEL
                    6 SMALLCLEUGH LEVEL
                    7 ROTHERHOPE FELL MINE
3         1      5 ALLENDALE
                    1 ALLENHEADS MINE
                              1 OLD VEIN
                              2 DIANA VEIN
                    2 SIPTONHEAD LEVEL
                              1 ESPS VEIN
                    3 SIPTON MINE
                              1 ESPS VEIN
                    4 SWINHOPE MINE
                              1 WILLIAMS VEIN
3         1      6 SCORDALE
                    1 HILTON MINES
3         1      7 ESCARPMENT
                    1 SMITTERGILL HEAD MINE
                              1 GREAT SULPHUR VEIN
3         2 ASKRIGG BLOCK MINERALIZATION
3         2      1 SWALEDALE-ARKENGARTHDALE CENTRE
                    1 DODGESON HUSH
                    2 TURF MOOR HUSH
                    3 STEMPLE HUSH
                    4 UNNAMED LEVEL
                    5 HIGH LEVEL,BAND HUSH
                    6 MAIN HUSHES
                              1 GREAT BLACKSIDE VEIN
                    7 STODDART HUSH
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8 MARTINS VEIN HUSH
9 DAN RIGG MINES
1 DAN RIGG VEIN
10 SURRENDER MINES
1 FRIARFOLD VEIN
11 UNNAMED LEVEL
12 MOLLOS TOP MINE
13 SNUFF HORN SHAFTS
14 WATERSYKE LEVEL
1 WATERSYKES VEIN
15 OLD GANG MINES
1 OLD RAKE
2 NORTH RAKE
16 FRIARFOLD
1 FRIARFOLD RAKE
17 BUNTON LEVEL

3 2 2 WENSLEYDALE(ASKRIGG)CENTRE
1 THACKTHWAITE GILL LEVELS
2 SPATA MINE

3 2 3 WENSLEYDALE(WENSLEY)CENTRE
1 KELD HEADS LEVEL
1 KELD HEADS VEIN

3 2 4 DENT FAULT LINE AREA
1 CLOUDS
1 FELL END VEIN
2 LADTHWAITE ACIT,NATEBY
3 HARTLEY BIRKETT MINES

3 2 5 UPPER WHARFEDALE
1 STARBOTTON MINES

3 3 GRASSINGTON-GREENHOW-SKYREHOLME OREFIELD

3 3 1 GRASSINGTON MOOR CENTRE
1 YARNBURY MINE
2 CAVENDISH MINE
1 CAVENDISH VEIN
3 PERU MINE
1 BYCLIFFE VEIN
4 LOW PERU SHAFT
1 PALFREY VEIN

3 3 2 GREENHOW HILL CENTRE
1 GREENHOW QUARRY
1 GREENHOW RAKE
2 GALLOWAY PASTURE OPENCUT

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                                    1 GALLOWAY VEIN
                               3 CIC SHAFTS
                                    1 FOREST VEIN
3          3        3 SKYREHOLME-APPLETREEWICK CENTRE
                               1 GILLHEADS
                                    1 GILLHEADS VEIN
                               2 BURHILL MINES
                                    1 FISSURE VN.ABOVE MINES
3          3        4 CRAVEN FAULT AREA
                               1 CARDEN REEF KNOLL
3          4  NORTH WALES COEFIELDS
3          4        1 HALKYN DISTRICT
                               1 EAST HALKYN MINE
                               2 BRYN GWICG MINE
3          4        2 MAESHAFN COEFIELD
                               1 EAST PANT DU MINE,ENGINE SHAFT
                                    1 PANT DU VEIN
                               2 UNITED EAST PANT DU MINE
                                    1 PANT DU VEIN
                               3 PANT Y GWLANDD MINE,ENGINE SHAFT
3          4        3 MINERA COEFIELD
                               1 QUARRY,FFRITH VILLAGE
3          5  MENDIP COEFIELD
3          5        1 BEACON HILL PERICLINE
                               1 HALECOMBE QUARRY,LEIGH-UPON-MENDIP
3          6  DERBYSHIRE COEFIELD
3          6        1 NORTHERN AREA-EYAM,CASTLETON
                               1 LADYWASH MINE
                                    1 OLD EDGE VEIN
                               2 COIN MINE
                                    1 COIN VEIN
                               3 BLUE JOHN MINE
                               4 TREAK CLIFF MINE
                               5 WATERHOLE MINE
                               6 WHITE COE MINE
                               7 BRIGHTSIDE MINE
3          6        2 CENTRAL AREA-BAKEWELL,ALPORT
                               1 KIRKDALE OPENCUT
                                    1 DIRTLOW RAKE
                               2 SHONKHILL OPENCUT
                                    1 LONG RAKE
                               3 RAPER OPENCUT
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1 LONG RAKE

3 6 3 SOUTHERN AREA-MATLOCK,BONSALL
1 MASSON HILL OPENCAST QUARRY
2 KNOWLES MINE WORKINGS
3 CRICHMAN MINE
4 HIGH LOFT MINE
5 MASSON OPENCUT
1 GREAT RAKE
6 LOW MINE,OPENCUT
1 GREAT RAKE
7 KING SHAFT,MASSON HILL
8 OPENCUT BY KING SHAFT

3 6 4 CRICH INLIER
1 CAMBROS QUARRY
1 CHURCH RAKE
2 JINGLER MINE
3 FOUNDER SHAFT
1 BACCHUS PIPE
4 GLORY MINE
5 SURFACE WORKINGS BY OLD END MINE
1 GREAT RAKE
2 WHITE RAKE
3 CHURCH RAKE
6 OLD SHAFT
1 CROOKED RAKE

3 6 5 ASHOVER INLIER
1 GREGORY MINE
1 GREGORY VEIN
2 MILLTOWN QUARRY
1 MILL VEIN
2 SPENCERS RAKE
3 BLACKWELLS VEIN
3 FALL HILL OPENCUT
1 FALL VEIN
4 STARS WOOD MINES
1 SPENCERS RAKE
2 SAWLANDS RAKE
3 UNNAMED VN.NR.SAWLANDS
4 BLACKLAND RAKE
5 BRIMSTONE RAKE
6 GARDEN RAKE
7 UNNAMED VEINS NR.MINERS ARMS

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                    5 WEST ASHCVER CPENCUTS
                              1 TCWNHEAD RAKE
                              2 NEW PUTTS VEIN
3            7 LAKE DISTRICT CREFIELD
3            7     1 KESWICK MINING DISTRICT
                        1 CATBELLS LEVELS
                              1 BRANDLEHCW BRANCH VEIN
3            8 WEST CUMBERLAND CREFIELD
                        1 FLCRENCE PIT
                        2 BECKERMET MINE
3            9 SHRCPSHIRE CREFIELD
3           10 LANCASHIRE REEF KNCLLS
3           10     1 CLITHERCE
                        1 WITHGILL DEPCSIT
3           12 ABERDEENSHIRE
                  1 BALLATER
                        1 ABERGAIRN LEVEL
                  2 CAMBUS C'MAY
                        1 TCMNAKEIST CLARRY
3           13 BANFFSHIRE
                  1 NA TRI CHACCHAIN
                  2 'PCRTSCY'PROBABLY MAISLEY NR.KEITH
3           14 MCRAYSHIRE
3           19 EIRE
                  1 CCUNTY CLARE
                        1 LISDCCNVARNA(DCOLIN)
                              1 FITZGERALDS FARM
3           20 MISSISSIPPI VALLEY
                  1 ILLINCIS-KENTUCKY CREFIELD
                        1 MINERVA MINE,ELIZABETHTCWN
                        2 ALCCA MINE,RCSICLARE
                        3 SHERIDAN,KENTUCKY
                  2 CCLCRADC
                        1 CZARK-MAHCNING,NCRTHGATE
3           21 PENNSYLVANIA
                        1 WHEATLEY MINES
3           23 CNTARIC
                  1 MADOC
            24 BRITISH CCLUMBIA
                  1 ADAMS PLATEAU,NR.PISIMA MTN.W.CF REVELSTCKE
3           25 BELGIUM
3           25     1 SEILLES
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3        25     2 ARDENNES
                    1 AVE,NR.WELLIN
3        25     3 GIVET
                    1 FOISCHES DEPOSIT
3        25     4 LIEGE
                    1 ENGIHOUL
3        26 SCANDINAVIA
              1 LUDVIKA,DELARNE,SWEDEN
                    1 YXSJOBERG MINE,HORKEN
3        27 GERMANY(WEST),BAVARIA
              1 NABBURG,BAYERN
                    1 CAECILIA MINE
              2 WELSENDORF,BAYERN
                    1 HERMINE MINE
              3 HARTZ
                    1 STOLBERG
3        28 FRANCE
              1 MASSIF CENTRAL
                    1 VOLTENNES MINE,MASSIF CENTRAL
              2 SOUTHERN 'SCHIST BELT'
                    1 LORGUES,R.ARGENS
3        29 SPAIN
                 1 ASTURIAS
                       1 RIBADASELLA QUARRY
3        31 TRANSVAAL
                       1 OTTASHOOP 7/2E
                       2 MALMANI,WEST TRANSVAAL
                       3 SWARTS QUARRY,BUFFELSFONTEIN
                    2 ZULULAND
3        33 THAILAND
                       1 DOI THAI NO.19
                       2 KAMNAN MAN,DOI THAI
                       3 NIYOM
                       4 THEPNITHI,FANG
                       5 SP MINING
                       6 THAI RESOURCES DEV.,TOHO SANG YO
                       7 VIM
3        34 COMMUNIST CHINA
3        35 BURMA
3        35    SHAN STATES
                       1 BAWNINGONE MINE,KALAW
3        37 SIBERIA
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		1 LAKE BAIKAL	
		1 CHITA AREA	
3	40	NEW SOUTH WALES	
		1 BROKEN HILL	
			1 NO.3 LENS
		2 NORTH BROKEN HILL	
			1 MAIN LODE

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
1.0	3 1 1 4 3	GPMT	3.00	148	244	50	7	43	23	368	57	27	6.60	1.87
4.0	3 1 1 4 3	GPBD	3.00	166	187	81	5	44	22	236	32	5	6.58	2.00
5.3	3 1 1 4 3	GPBD	3.00	199	90	7	6	44	30	316	106	49	5.00	1.47
10.0	3 1 1 4 3		2.80	316	51	238	11	49	34	183	13	9	4.70	1.44
10.1	3 1 1 4 3	GPMT	0.0	694	-1	-1	-1	0	33	225	55	24	2.80	-1.00
12.0	3 1 1 4 3	GPMT	2.50	167	0	0	2	39	37	238	59	9	2.08	1.05
13.0	3 1 1 4 3	GPBD	4.00	168	47	211	2	44	18	357	69	17	4.59	2.44
14.0	3 1 1 4 3	GREE	3.00	124	0	2	4	43	34	812	141	57	0.20	1.26
15.0	3 1 1 4 3	GPBD	2.00	129	3	173	5	46	25	359	41	2	2.58	1.84
17.0	3 1 1 4 3	PURP	2.00	123	2	5	3	49	32	259	40	2	1.25	1.53
18.0	3 1 1 4 4	BLPU	2.50	149	52	27	4	43	23	240	22	0	5.60	1.87
19.0	3 1 1 4 4	BLPU	1.50	169	3955	19	5	38	38	317	32	29	16.30	1.00
21.0	3 1 1 4 4	IPUR	3.00	150	0	12	5	43	21	505	37	9	0.0	2.05
23.0	3 1 1 4 3	GREE	2.50	151	49	0	5	50	31	273	93	41	10.30	1.61
25.0	3 1 1 4 3	GREE	3.00	152	43	160	1	48	26	270	59	12	4.20	1.85
32.0	3 1 1 4 3	GREE	2.00	137	3	21	4	48	33	271	187	99	3.50	1.45
33.0	3 1 1 4 3	PURP	4.50	138	18	17	4	40	22	387	39	13	2.68	1.82
36.0	3 1 1 4 4	GPBD	1.50	139	29	31	4	51	25	203	1	0	11.10	2.04
38.0	3 1 1 4 4	GPMT	2.00	140	0	17	5	40	19	273	48	10	3.10	2.11
39.0	3 1 1 4 3	GREE	3.00	141	4	24	4	48	32	320	30	7	4.30	1.50
40.1	3 1 3 1 1	GREE	3.00	102	0	0	3	47	51	236	29	0	0.0	0.92
40.2	3 1 3 1 1	GREE	2.50	103	0	4	2	51	49	243	30	3	0.0	1.04
42.0	3 1 1 4 3	GPBD	2.50	142	30	118	5	53	25	521	80	66	14.80	2.12
43.0	3 1 1 4 3	GPBD	2.00	146	9	0	5	40	49	451	120	76	2.65	0.82
45.2	3 1 1 4 3	GREE	3.00	107	1	74	1	45	30	334	68	3	0.90	1.50
45.2	3 1 1 4 3	GREE	3.00	170	8	65	4	48	30	337	66	14	1.44	1.60
45.3	3 1 1 4 3	PURP	3.00	108	20	63	4	40	36	281	39	7	3.32	1.11
45.4	3 1 1 4 3	PURP	3.00	200	2	0	0	50	31	186	40	12	1.30	1.61
45.5	3 1 1 4 3	PURP	3.00	201	23	12	5	48	31	310	35	6	3.80	1.55
45.6	3 1 1 4 3	GPBD	3.00	202	1	15	5	35	32	371	86	33	8.00	1.09
45.7	3 1 1 4 3	GPBD	1.50	451	124	239	1	73	12	126	0	50	28.30	6.08
50.3	3 1 2 1 1	GPMT	3.00	153	0	1	4	44	41	364	88	30	1.60	1.07
51.0	3 1 2 1 1	PURP	2.50	154	31	3	3	40	39	529	110	37	1.45	1.03

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
52.0	3 1 2 1 4	BLUE	3.00	143	1	5	3	47	49	359	53	0	1.50	0.96
54.0	3 1 2 1 4	BLUE	3.00	144	11	1217	3	37	30	337	19	5	6.00	1.23
55.0	3 1 2 1 4	BLUE	3.00	145	6	39	4	49	45	321	42	5	0.55	1.09
57.0	3 1 2 1 1	GPBD	3.00	171	682	6	4	53	37	228	36	4	4.27	1.43
58.0	3 1 2 1 1	GPBD	2.70	172	0	0	5	48	39	531	108	27	3.00	1.23
59.0	3 1 2 1 1	GPBD	2.50	130	0	0	4	36	28	438	52	17	0.70	1.29
60.0	3 1 2 1 1	GREE	3.00	116	19	10	4	42	28	310	18	0	1.10	1.50
61.1	3 1 1 4 2	GREE	2.50	132	0	10	8	41	25	340	49	15	0.0	1.64
61.2	3 1 1 4 2	GPMT	3.00	134	0	6	8	46	23	346	51	14	0.30	2.00
62.0	3 1 1 4 2	GREE	2.00	117	13	13	4	54	35	187	70	19	3.80	1.54
63.0	3 1 1 4 2	GREE	2.50	118	0	5	5	43	30	233	77	16	0.10	1.43
65.0	3 1 1 4 3	GREE	3.00	119	4	48	3	37	37	244	48	0	1.30	1.00
67.0	3 1 1 4 3	GPBD	2.50	179	1	0	4	47	66	405	103	38	4.00	0.71
69.0	3 1 1 4 4	GPMT	2.00	173	511	12	2	54	29	195	42	17	8.44	1.86
70.0	3 1 1 4 3	GREE	2.00	120	4	13	4	47	56	177	72	30	1.70	0.84
71.0	3 1 1 4 3	IGRE	2.50	131	79	85	6	42	40	265	97	34	2.10	1.05
72.0	3 1 1 4 3	GPBD	2.50	128	0	5	5	47	24	374	57	21	2.25	1.96
74.0	3 1 1 4 3	GPBD	2.00	125	2	3	4	54	42	249	114	69	0.60	1.29
79.0	3 1 1 4 3	GPMT	3.00	127	8	0	3	45	34	247	54	6	3.20	1.32
81.0	3 1 1 4 3	GREE	3.00	133	7	35	5	40	23	359	57	27	0.15	1.74
82.0	3 1 1 4 3	GPBD	2.00	122	7	6	3	39	50	452	111	48	1.20	0.78
83.0	3 1 1 4 3	GPBD	3.00	126	0	55	3	49	31	485	71	27	4.15	1.58
86.0	3 1 1 4 3	IGRE	2.00	121	39	533	3	50	31	516	211	124	3.25	1.61
95.0	3 1 1 4 3	GPMT	3.00	174	1	0	2	48	22	269	123	58	0.0	2.18
96.0	3 1 1 4 3	GPBD	3.00	175	489	7	5	43	17	428	72	31	6.70	2.53
98.0	3 1 2 2 2	GPMT	3.00	176	584	26	3	36	37	361	97	21	3.10	0.97
100.0	3 1 2 2 1	GPMT	3.00	177	50	0	5	56	62	283	100	34	1.90	0.90
107.1	3 1 1 19 4	PL/V	3.00	100	61	19	4	48	24	181	15	0	2.55	2.00
107.2	3 1 1 19 4	GREE	2.00	101	0	7	6	51	57	422	161	87	1.10	0.89
107.3	3 1 1 19 4	PL/V	3.00	263	5	8	3	54	25	756	90	35	2.30	2.16
107.4	3 1 1 19 4	PL/V	3.00	264	85	0	6	50	24	232	55	27	3.40	2.08
107.5	3 1 1 19 4	PU/V	3.00	265	227	17	4	44	19	314	43	23	6.50	2.32
108.0	3 6 1 1 1	CLSS	5.00	104	0	18	44	377	71	11	1	0	0.0	5.31

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	CCLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
109.0	3 1 1 3 2	GPBD	2.00	156	337	5	6	41	43	260	132	78	5.20	0.95
111.0	3 1 1 3 2	PU/V	2.50	157	0	4	4	50	66	238	126	56	0.0	0.76
112.0	3 1 1 7 0	PU/V	2.50	158	0	0	6	45	52	296	46	19	0.0	0.87
113.0	3 1 1 7 0	PU/V	3.00	159	1	2	3	45	38	328	64	22	0.0	1.18
114.0	3 1 1 7 0	PU/V	2.50	160	0	16	3	31	24	229	23	4	1.38	1.29
115.0	3 1 1 7 0	PU/V	3.00	161	0	0	7	42	39	302	54	29	0.0	1.08
116.0	3 1 1 7 0	PU/V	2.50	162	13	0	4	46	54	269	62	10	0.0	0.85
118.1	3 1 1 24 5	PU/V	2.50	164	19	0	6	37	57	345	116	52	0.52	0.65
118.2	3 1 1 24 5	GPMT	2.50	221	48	18	5	27	44	242	127	56	3.20	0.61
118.3	3 1 1 24 5	GPMT	2.50	222	179	6	5	39	33	230	50	10	1.00	1.18
119.0	3 1 1 2521	PU/V	2.50	163	47	23	4	42	57	296	74	16	3.18	0.74
121.0	3 1 1 1313	RED.	3.00	195	1	3	3	41	23	148	25	2	2.50	1.78
122.0	3 1 1 1516	RED.	2.50	178	64	7	6	52	41	304	80	23	9.00	1.27
123.0	3 1 1 1717	GREE	3.00	242	32	7	6	37	40	262	33	6	0.05	0.92
125.0	3 1 1 1717	GREE	2.00	206	2	2	7	33	39	260	37	3	0.0	0.85
135.0	3 1 1 14 4	GPMT	3.00	192	61	1	6	52	36	332	136	81	5.90	1.44
136.1	3 1 1 14 4	GPMT	3.00	193	816	22	3	40	32	311	112	75	5.55	1.25
136.2	3 1 1 14 4	GPMT	3.00	203	937	8	5	43	33	310	114	70	5.40	1.30
137.0	3 1 1 14 4	GPMT	3.50	182	1995	38	6	51	27	372	60	25	7.50	1.89
138.0	3 1 1 14 4	GPBD	1.50	183	174	39	4	48	27	398	176	102	1.90	1.78
139.0	3 1 1 14 4	PURP	3.00	194	154	755	6	54	23	571	38	34	10.10	2.35
140.0	3 1 1 14 4	BLPU	3.50	185	289	28	4	45	20	221	0	10	12.70	2.25
140.1	3 1 1 14 4	GREE	2.00	547	-1	-1	-1	59	22	164	13	32	16.10	2.68
142.0	3 1 1 14 4	GREE	3.00	186	434	120	3	55	38	574	145	76	7.40	1.45
143.0	3 1 1 14 4	GREY	3.00	187	122	44	6	49	29	268	11	1	5.30	1.69
144.0	3 1 1 14 4	GPMT	3.50	188	1	10	2	42	26	296	51	14	1.40	1.62
145.0	3 1 1 14 4	GPBD	3.00	189	102	16	3	47	36	356	128	65	4.80	1.31
146.0	3 1 1 14 4	BLPU	3.00	198	43	285	5	54	27	281	2	14	10.60	2.00
147.0	3 1 1 14 4	BLUE	2.50	207	644	0	6	52	20	231	9	28	18.50	2.60
150.0	3 1 1 2523	PU/V	1.50	261	305	88	3	41	85	398	50	9	5.80	0.48
153.0	3 1 1 26 5	GREE	1.50	205	41	14	10	37	29	280	167	84	10.90	1.28
154.1	3 1 1 26 5	GREE	1.50	204	19	26	6	38	29	184	73	29	12.60	1.31
154.2	3 1 1 26 5	WHTE	0.0	266	47	48	5	42	26	168	120	36	12.80	1.62

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
155.1	3 1 1 26 5	GREE	2.20	239	6	0	4	45	62	303	92	41	1.70	0.73
155.2	3 1 1 26 5	PURP	1.50	262	13	9	8	45	33	414	150	64	0.0	1.36
156.0	3 1 1 26 5	GREE	2.50	220	25	9	4	46	36	226	46	20	2.70	1.28
158.0	3 1 1 26 5	GREE	2.00	223	24	1	5	54	34	186	43	17	15.90	1.59
159.0	3 1 1 26 5	GREE	2.50	190	22	0	6	62	20	176	33	40	21.40	3.10
160.0	3 1 1 26 5	GREE	1.50	219	124	4	4	53	45	386	188	121	5.10	1.18
161.0	3 1 1 26 5	GPMT	2.50	241	46	6	5	31	33	262	120	63	2.65	0.94
162.0	3 1 1 27 6	GPMT	2.00	238	84	1	4	0	48	192	0	4	10.80	-1.00
163.0	3 1 1 27 6	GREE	2.00	224	2	0	6	53	34	172	109	55	1.40	1.56
164.0	3 1 1 27 6	PURP	3.00	243	5	1	4	53	51	214	73	34	1.10	1.04
165.1	3 1 1 27 6	PU/V	3.00	191	5	15	7	43	74	198	89	31	0.30	0.58
165.2	3 1 1 27 6	PU/V	2.00	245	4	4	5	43	47	245	95	46	2.20	0.91
166.0	3 1 1 27 6	GREE	1.00	237	10728	81	8	40	21	142	54	32	6.80	1.90
168.1	3 1 1 26 5	GREE	3.00	197	4	0	4	39	53	250	152	59	0.90	0.74
168.2	3 1 1 26 5	GREE	2.00	269	2	0	3	38	61	248	141	61	0.30	0.62
169.1	3 1 1 2625	GREE	2.00	246	5	0	7	49	56	394	189	96	0.15	0.88
169.2	3 1 1 2625	GREE	3.00	247	10	0	3	0	18	235	47	34	11.15	-1.00
170.1	3 1 1 2824	GREE	3.00	234	1430	8	3	63	63	210	43	17	0.65	1.00
170.2	3 1 1 2824	GREE	2.00	235	157	3	3	73	46	230	38	7	0.55	1.59
170.3	3 1 1 2824	GREE	3.00	236	56	6	5	44	51	198	34	1	0.0	0.86
171.0	3 1 1 14 4	BLPU	1.50	211	796	0	4	48	20	139	6	17	12.97	2.40
172.0	3 1 1 14 4	GPMT	1.50	218	1924	34	5	51	20	186	44	33	4.60	2.55
173.0	3 1 1 14 4	WHTE	3.00	227	60	366	6	56	19	272	54	36	10.80	2.95
174.0	3 1 1 14 4	PURP	3.00	244	31	28	7	41	23	330	44	13	1.80	1.78
175.0	3 1 1 14 4	PURP	2.50	216	37	5	0	47	24	236	49	7	0.90	1.96
176.0	3 1 1 6 4	GREE	2.50	231	0	0	1	62	20	260	7	23	11.00	3.10
177.0	3 1 1 6 3	GREE	2.00	248	6	17	2	43	38	261	148	79	8.00	1.13
179.0	3 1 1 14 4	GPBD	1.00	214	23	17	6	42	37	452	221	118	4.80	1.14
180.0	3 1 1 14 4	GPBD	2.70	232	57	683	3	48	51	424	59	30	5.40	0.94
181.0	3 1 1 14 4	GREE	2.00	213	250	7	3	41	33	199	56	7	5.80	1.24
182.0	3 1 1 14 4	BLUE	2.50	225	1	446	4	44	27	387	83	34	4.85	1.63
183.0	3 1 1 14 4	GPBD	3.00	226	125	86	5	39	50	287	57	13	1.35	0.78
184.0	3 1 1 14 4	PURP	2.00	212	34	112	3	43	41	255	61	30	6.70	1.05

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	CCLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
185.0	3 1 1 14 4	IPUR	2.70	249	86	124	6	53	28	291	80	52	10.10	1.89
186.1	3 1 1 14 4	GPMT	0.0	208	153	12	3	55	27	312	-1	-1	13.30	2.04
186.2	3 1 1 14 4	GPMT	1.50	209	130	6	5	51	25	335	60	38	11.30	2.04
186.3	3 1 1 14 4	GPMT	2.50	210	140	12	6	71	25	316	58	30	12.40	2.84
189.0	3 1 1 14 4	GREE	3.00	250	2	22	8	46	41	455	146	60	3.80	1.12
190.0	3 1 1 14 4	GPBD	2.70	229	14	9	6	42	38	539	151	53	0.80	1.11
191.1	3 1 1 1 2	GREE	2.50	251	7	0	5	48	44	167	111	46	0.20	1.09
191.2	3 1 1 1 2	GREE	2.50	252	25	0	6	47	37	149	85	29	2.15	1.27
191.3	3 1 1 1 2	XXXX	3.00	253	36	10	8	43	41	187	67	17	1.45	1.05
191.4	3 1 1 1 2	GREE	2.50	267	4095	1	5	46	37	156	21	15	6.70	1.24
192.0	3 1 1 1 2	GPMT	2.70	228	14	4	5	44	64	239	121	44	0.05	0.69
193.0	3 1 1 20 4	IGRE	2.00	215	4	0	2	41	66	369	320	168	2.35	0.62
194.0	3 13 1 0 0	PURP	2.50	217	2	4	5	48	330	14	39	2	2.20	0.15
195.0	3 13 1 0 0	GREE	2.70	230	0	0	2	51	200	11	26	0	3.15	0.25
196.1	3 1 1 14 4	GREY	1.00	109	4034	9	5	65	18	176	38	81	25.60	3.61
196.2	3 1 1 14 4	CLSS	1.00	136	1288	0	170	148	22	274	0	37	86.50	6.73
197.0	3 1 1 14 4	GREY	1.00	110	274	0	3	122	16	132	0	32	69.00	7.62
198.0	3 1 1 14 4	BLPU	3.00	111	1568	420	6	50	22	197	0	17	19.30	2.27
200.0	3 1 1 14 4	PURP	3.00	112	238	220	5	49	29	334	24	28	12.80	1.69
201.0	3 1 1 14 4	PURP	3.00	113	92	0	5	39	24	217	34	6	6.30	1.62
202.0	3 1 1 14 4	PURP	2.00	114	312	102	8	65	23	185	100	105	22.20	2.83
203.0	3 1 1 14 4	PURP	3.00	147	2168	586	4	62	23	293	17	55	31.60	2.70
205.0	3 1 1 14 4	GREE	3.00	135	104	5	4	43	31	322	127	63	8.85	1.39
206.0	3 1 1 14 4	PURP	2.00	115	95	13	4	48	22	215	12	6	8.65	2.18
213.0	3 1 1 33 4	GREE	4.00	105	12	13	8	41	31	75	0	0	2.10	1.32
214.0	3 1 1 33 4	GREE	3.00	196	538	1	7	42	32	102	54	14	0.70	1.31
215.0	3 1 1 33 4	GREE	2.50	106	418	36	8	51	27	46	53	46	5.75	1.89
216.0	3 1 1 33 4	GREE	3.50	275	7	14	7	50	23	246	37	31	6.05	2.17
217.0	3 1 1 3317	GREE	2.50	274	8	114	8	59	14	104	42	67	29.30	4.21
218.0	3 1 1 3317	GREE	1.50	268	23	4187	27	129	54	431	0	272	70.60	2.39
219.0	2 1 1 1 0	YELL	1.20	272	1	9	28	9999	92	48	0	0	0.0	108.68
226.0	3 3 3 1 1	WHTE	4.50	270	9	189	4	46	45	20	20	0	0.0	1.02
227.0	3 12 1 1 0	GPMT	3.00	271	3	56	5	45	24	144	11	0	0.0	1.87

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
228.0	1 3 1 0 0	IPUR	3.00	273	68	257	7	74	524	14	0	0	2.25	0.14
229.0	1 1 5 1 1	IPUR	3.00	276	8	965	5	42	63	15	0	0	5.10	0.67
230.0	1 1 4 1 0	PURP	3.00	277	0	189	19	96	35	87	0	16	26.80	2.74
231.0	3 20 1 1 0	IPUR	3.50	278	0	1	3	36	16	3	0	0	0.0	2.25
232.0	3 20 1 2 0	PINK	0.0	279	0	8	1	67	119	12	7	0	0.0	0.56
233.1	3 1 1 1817	GREE	0.0	280	0	52	7	51	74	222	58	21	0.12	0.69
239.1	3 26 1 1 0	PINK	0.0	689	-1	-1	-1	48	11	22	0	0	0.20	4.36
243.0	3 1 1 9 9	PL/V	1.00	319	403	4	3	42	50	280	102	56	0.19	0.84
244.0	3 1 1 9 9	PL/V	2.00	324	658	0	3	38	50	236	55	21	0.10	0.76
245.0	3 1 1 9 9	PL/V	2.50	325	0	0	4	35	29	198	41	8	0.07	1.21
248.0	3 1 1 3418	BLPU	1.00	309	16	0	6	44	32	313	247	147	0.28	1.37
250.0	3 1 1 1111	PL/V	1.20	287	3	8	6	59	39	344	117	66	0.10	1.51
251.0	3 1 1 1111	PL/V	1.00	288	8	2	3	50	36	390	117	50	0.10	1.39
252.0	3 1 1 1111	PL/V	1.00	289	10	0	6	60	41	279	80	49	0.20	1.46
253.0	3 1 1 1111	PL/V	1.00	290	3	0	2	49	43	259	35	18	0.20	1.14
254.0	3 1 1 1111	PL/V	1.00	291	3	4	5	39	30	303	46	16	0.10	1.30
255.0	3 1 1 1011	PL/V	1.00	292	0	5	5	50	28	190	41	14	0.66	1.79
256.0	3 1 1 1210	PL/V	1.20	293	5	0	3	38	39	263	39	14	0.08	0.97
257.0	3 1 1 1210	PU/V	1.00	294	20	6	3	44	34	296	42	26	0.10	1.29
258.0	3 1 1 1210	PU/V	1.80	295	20	9	4	49	30	268	34	9	0.20	1.63
259.0	3 1 1 8 8	PL/V	1.20	296	0	3	3	38	32	235	32	7	0.28	1.19
260.0	3 1 1 8 8	PL/V	0.0	297	20	1	2	38	30	216	51	9	2.74	1.27
261.0	3 1 1 8 8	PU/V	2.50	298	14	0	3	56	18	236	0	5	15.10	3.11
262.0	3 1 1 9 8	PU/V	2.00	299	0	1	3	42	36	262	42	16	0.24	1.17
263.1	3 1 1 9 8	PL/V	1.00	300	57	4	6	46	54	264	67	37	0.0	0.85
263.2	3 1 1 9 8		1.00	301	1	3	4	43	49	246	106	60	0.0	0.88
263.3	3 1 1 9 8		1.00	302	14	0	6	48	53	265	107	54	0.0	0.91
264.0	3 1 1 9 8	PL/V	1.00	303	400	0	6	56	35	320	110	58	0.0	1.60
265.0	3 1 1 9 8	PL/V	2.40	304	0	1	1	50	34	277	55	9	1.05	1.47
266.0	3 1 1 9 8	PL/V	1.00	305	13	0	3	51	25	162	45	6	2.65	2.04
269.0	3 1 1 0 4	GREE	0.0	306	254	21	5	34	33	245	83	62	8.45	1.03
270.1	3 1 1 2926	GREE	1.00	307	0	0	7	51	69	327	204	121	0.10	0.74
273.0	3 1 1 3619	GREE	0.0	308	37	60	11	58	67	191	32	40	0.15	0.87

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
273.2	3 1 1 3619	GREE	3.00	570	-1	-1	-1	86	45	137	0	3	5.30	1.91
274.0	3 1 1 20 4	GREE	2.30	326	52	41	4	51	34	211	21	13	6.05	1.50
275.0	3 1 1 20 4	GREE	1.70	340	40	38	4	48	34	419	92	62	5.29	1.41
276.0	3 1 1 20 4	GPMT	1.20	327	26	9	5	55	29	270	94	53	3.50	1.90
277.0	3 1 1 20 4	IGRE	1.00	328	305	43	3	46	50	500	196	86	5.70	0.92
278.0	3 1 1 20 4	GREE	1.20	341	1302	27	5	44	26	323	71	52	4.40	1.69
279.0	3 1 1 20 4	GREE	2.00	329	53	0	5	61	35	364	127	77	5.52	1.74
280.1	3 1 1 20 4	IPUR	1.00	330	630	14	2	52	31	258	14	19	14.40	1.68
281.0	3 1 1 20 4	PURP	1.20	342	869	0	4	116	15	126	14	94	4.12	7.73
283.0	3 1 1 20 4	PURP	1.20	344	85	0	10	59	22	400	67	32	1.20	2.68
285.0	3 1 1 20 4	PURP	2.00	548	-1	-1	-1	44	53	330	43	0	0.0	0.83
287.0	3 1 1 14 4	GPMT	2.00	343	69	115	6	47	24	360	88	46	3.79	1.96
288.0	3 1 1 14 4	GREE	1.00	345	3	503	7	49	31	431	84	41	2.61	1.58
289.0	3 1 1 14 4	GREE	1.20	332	4	148	9	44	31	249	19	19	3.28	1.42
290.0	3 1 1 14 4	GREE	1.00	347	686	21	15	51	31	316	72	44	7.39	1.65
291.0	3 1 1 14 4	GREE	1.20	333	274	274	8	64	24	260	57	52	16.70	2.67
292.0	3 1 1 14 4	GREE	1.20	334	25	16	5	64	21	231	144	108	16.50	3.05
293.0	3 1 1 14 4	GPMT	2.00	346	14	62	4	44	29	302	75	45	2.94	1.52
294.0	3 1 1 14 4	GPBD	1.00	348	39	48	5	53	35	281	35	17	3.08	1.51
295.0	3 1 1 14 4	GREE	1.20	335	95	382	3	55	36	306	41	13	6.69	1.53
296.0	3 1 1 14 4	PURP	1.20	336	535	458	2	58	27	293	16	7	3.00	2.15
297.0	3 1 1 14 4	GREE	2.00	337	113	64	3	50	26	256	39	19	5.75	1.92
298.0	3 1 1 14 4	GPMT	1.20	338	92	6	3	40	39	336	77	47	3.10	1.03
299.0	3 1 1 14 4	GPMT	1.50	339	25	4	4	47	27	270	31	27	5.68	1.74
300.0	3 1 1 14 4	GREE	1.00	349	2	26	4	53	41	270	24	7	0.45	1.29
301.0	3 1 1 14 4	GPMT	2.60	350	0	0	2	48	17	344	39	15	8.57	2.82
302.0	3 1 1 14 4	XXXX	1.50	351	4258	0	4	55	15	260	0	20	13.70	3.67
303.0	3 1 1 14 4	GREE	1.50	352	495	68	3	39	30	295	34	20	2.65	1.30
310.0	3 1 1 3 2	PL/V	0.0	353	2	20	3	18	37	232	168	68	0.0	0.49
311.0	3 1 1 3 2	GREE	1.00	354	7	6	4	39	59	288	252	146	0.70	0.66
312.0	3 1 1 3 2	GREE	2.00	323	1	6	3	46	65	319	92	47	0.56	0.71
314.0	3 1 1 3 2	GREE	1.50	355	7	3	6	48	48	291	161	95	0.20	1.00
316.1	3 1 1 3 3	GREE	2.00	320	9	23	4	49	49	258	112	52	0.19	1.00

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
316.2	3 1 1 3 3		1.20	321	10	0	2	94	53	294	102	51	0.20	1.77
316.3	3 1 1 3 3		0.0	322	15	8	8	56	40	223	118	52	0.20	1.40
317.0	3 6 1 2 1	PURP	2.30	313	4	7	9	49	44	214	0	4	0.10	1.11
318.0	3 23 1 0 0	GREE	3.70	312	0	8	8	59	13	144	18	1	0.0	4.54
319.0	3 6 1 3 0	IPUR	3.50	314	7	12	3	63	71	20	9	0	0.0	0.89
320.0	1 1 4 12 3	BGWB	2.30	311	1	0	2	51	34	138	41	24	5.70	1.50
321.0	3 31 1 1 0	CLSS	3.00	315	1	5	7	43	11	19	0	0	0.0	3.91
322.0	3 1 1 23 5	PU/V	2.50	544	-1	-1	-1	62	34	279	21	9	1.00	1.82
323.1	3 1 1 21 5	PU/V	1.00	356	1922	0	4	116	24	280	0	64	34.50	4.83
323.2	3 1 1 21 5	PU/V	1.00	358	161	21	6	74	19	263	54	52	12.60	3.89
324.0	3 1 1 21 5	PU/V	1.00	357	0	9	4	51	36	194	17	8	0.07	1.42
326.0	3 1 1 22 5	PU/V	1.00	359	855	3	5	48	35	181	84	40	2.25	1.37
327.0	3 1 1 1615	PU/V	1.80	363	1	3	9	8898	50	280	46	17	0.0	177.96
328.1	3 7 0 1 1	YELL	1.20	361	8	2	5	49	79	227	25	10	0.20	0.62
328.2	3 7 0 1 1	YELL	2.90	362	7	6	1	51	57	202	34	1	0.18	0.89
329.0	3 1 1 3033	PU/V	1.70	365	60	0	4	55	68	263	127	74	1.51	0.81
330.1	3 1 1 3234	PU/V	1.30	364	8	0	7	49	49	325	174	96	0.29	1.00
330.2	3 1 1 3234	PU/V	1.70	366	0	0	3	56	51	362	162	92	0.12	1.10
331.0	3 1 1 31 7	PU/V	1.70	367	39	12	5	63	31	273	74	35	0.10	2.03
332.0	3 21 0 1 0	CLSS	1.00	317	8	188	10	37	0	54	131	0	0.50	-1.00
333.0	3 27 2 0 0	IPUR	3.00	318	2	20	6	79	22	27	0	3	3.80	3.59
334.0	3 1 1 20 4	GPBD	1.20	331	108	0	2	53	37	258	66	32	3.90	1.43
335.0	1 1 4 3 0	GREE	2.80	360	3	34	3	48	18	297	11	0	0.0	2.67
336.0	3 2 1 14 1	CLSS	2.50	368	-1	-1	-1	20000	208	49	0	0	0.0	96.15
337.0	3 1 1 14 4	PURP	2.30	369	-1	-1	-1	63	47	265	61	42	0.09	1.34
337.2	3 1 1 14 4	PURP	0.0	686	-1	-1	-1	1	15	283	40	20	0.0	0.07
338.0	3 1 1 3234	PU/V	2.00	0	-1	-1	-1	87	64	261	214	122	0.0	1.36
339.1	3 6 4 1 1	PURP	3.00	441	32	22	16	13902	293	10	0	0	0.0	47.45
339.2	3 6 4 1 1	CLSS	2.90	442	62	28	17	162	58	9	10	0	0.14	2.79
340.0	3 6 4 5 3	WHTE	3.00	370	23	30	17	37170	1126	7	0	0	1.74	33.01
341.0	3 6 4 5 3	WHTE	3.40	371	6	44	3	63	57	8	14	0	1.63	1.11
342.0	3 6 4 5 1	PURP	2.80	440	24	0	9	2770	165	7	0	0	1.05	16.79
343.0	3 6 4 5 1	WHTE	3.50	372	46	10	5	219	63	11	4	0	0.82	3.48

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
344.0	3 6 4 5 2	WHTE	3.50	373	86	58	19	802	85	10	0	0	0.0	9.44
345.0	3 6 4 5 2	WHTE	3.50	374	8	8	4	56	53	8	4	0	0.0	1.06
346.0	3 6 4 5 1	WHTE	3.50	375	64	34	14	77	53	17	38	0	0.0	1.45
347.0	3 6 4 5 1	WHTE	3.00	376	22	12	14	22792	1084	5	0	0	0.10	21.03
349.0	3 6 4 3 1	WHTE	4.00	377	332	67	6	58	60	8	18	0	0.0	0.97
350.0	3 6 4 2 0	WHTE	3.50	378	16	49	9	87	64	11	6	4	1.10	1.36
351.0	3 6 4 6 1	WHTE	3.30	379	5	13	2	5190	178	12	0	0	0.0	29.16
352.0	3 6 4 3 0	WHTE	3.60	380	208	58	8	617	67	13	0	0	0.0	9.21
355.0	3 2 2 1 0	YELL	3.00	443	2320	464	5	183	55	28	0	0	0.0	3.33
356.0	3 2 3 1 1	WHTE	1.90	444	2455	55	9	70	53	26	0	0	0.93	1.32
357.0	3 2 5 1 0	YELL	3.50	579	-1	-1	-1	36631	402	23	0	0	0.30	91.12
358.0	3 3 1 1 0	YELL	3.50	580	-1	-1	-1	5188	1043	11	0	0	7.50	4.97
363.1	1 1 1 1 0	GREE	2.90	381	0	16	3	48	31	209	52	3	1.75	1.55
363.2	1 1 1 1 0	GREE	3.00	382	0	8	0	53	36	215	41	3	0.15	1.47
366.0	1 1 1 2 0	GRWH	2.90	383	57	95	3	53	25	185	42	6	10.10	2.12
367.0	1 1 1 3 0	GRWH	2.90	384	0	0	2	43	36	242	27	3	2.39	1.19
368.0	1 1 1 4 0	GRWH	3.00	385	4144	17	1	47	31	213	55	12	2.45	1.52
370.0	1 1 1 5 0	GREE	2.50	386	3	10	5	54	89	260	1	7	3.18	0.61
372.0	1 1 2 1 0	GREE	3.00	408	25	46	5	40	35	261	25	7	2.70	1.14
373.0	1 1 2 2 0	GREE	2.50	387	0	0	0	49	26	180	7	14	1.25	1.88
374.1	1 1 2 3 0	GREE	2.70	388	0	0	3	50	35	182	16	3	0.0	1.43
374.2	1 1 2 3 0	GREE	2.60	389	0	0	4	53	45	276	34	7	0.05	1.18
376.1	1 1 3 1 0	PURP	1.50	452	-1	-1	-1	40	142	97	0	0	7.10	0.28
376.2	1 1 3 2 0	WHTE	1.50	453	-1	-1	-1	47	65	21	0	0	3.84	0.72
377.0	1 1 4 7 0	GREE	1.90	390	26	18	139	145	34	196	29	28	8.85	4.26
379.0	1 1 4 11 0	IGRE	2.00	391	11	1287	1	37	20	240	18	1	3.05	1.85
380.0	1 1 4 9 0	GREE	2.00	392	25	435	6	31	20	322	116	5	5.76	1.55
381.1	1 1 4 8 0	GREE	1.90	393	282	0	6	46	30	199	22	0	2.08	1.53
381.2	1 1 4 8 0	GREE	2.00	394	5	2988	2	46	36	95	30	0	0.39	1.28
382.0	1 1 4 10 0	GREE	2.30	395	2574	438	4	39	17	298	23	5	1.49	2.29
383.0	1 1 4 5 0	IGRE	2.30	396	0	86	1	53	21	280	28	10	3.60	2.52
384.0	1 1 4 6 0	IGRE	2.50	397	11	258	2	49	24	229	34	13	2.60	2.04
386.0	1 1 4 2 0	GREE	2.60	398	0	112	2	42	18	216	28	0	0.05	2.33

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADN	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
387.0	1 1 4 1 0	IGRE	2.20	399	0	209	3	46	22	242	48	5	0.45	2.09
390.0	3 1 6 1 0	YELL	3.40	581	-1	-1	-1	177	62	169	7	0	0.10	2.85
393.0	3 1 1 14 4	PGBD	1.90	400	2	6	5	50	37	425	144	77	2.48	1.35
395.0	3 1 1 14 4	PGMT	1.20	401	1437	14	6	63	19	275	74	57	17.00	3.32
396.0	3 1 1 14 4	BLUE	1.20	402	718	25	4	57	23	227	20	16	13.40	2.48
397.0	3 1 1 14 4	YELL	1.40	403	2	80	2	53	99	405	96	32	1.90	0.54
398.0	3 1 1 14 4	IGRE	1.40	404	229	39	5	53	32	390	81	51	6.35	1.66
400.0	3 1 1 14 4	PGMT	2.00	405	83	231	1	58	16	307	238	24	15.20	3.62
401.0	3 1 1 14 4	PGMT	2.70	406	11	31	3	48	28	402	57	28	3.26	1.71
402.0	3 1 1 14 4	PGMT	2.90	407	143	98	3	39	33	576	89	27	4.28	1.18
404.0	3 1 1 14 4	PURP	2.00	410	10	18	4	44	12	122	5	7	6.30	3.67
405.0	3 1 1 14 4	PURP	2.00	411	51	0	4	51	19	277	58	16	8.34	2.68
406.0	3 1 1 14 4	PURP	1.30	412	1279	25	5	51	16	379	72	39	4.80	3.19
407.0	3 1 1 14 4	PURP	2.10	413	36	6	5	44	38	394	61	37	0.58	1.16
408.0	3 1 1 14 4	GREY	2.00	414	140	15	6	47	1398	290	85	88	20.80	0.03
409.0	3 1 1 14 4	GREE	2.00	415	7	0	8	56	34	288	101	66	8.35	1.65
410.0	3 1 1 14 4	GREE	2.00	416	354	15	3	55	21	322	46	25	4.04	2.62
411.0	3 1 1 14 4	GREE	2.00	417	19	31	2	49	28	409	136	82	8.90	1.75
412.0	3 1 1 14 4	PGMT	3.00	418	0	0	3	48	32	393	59	20	1.65	1.50
413.0	3 1 1 14 4	PGBD	1.50	419	0	6	9	39	0	0	50	15	2.40	-1.00
414.0	3 1 5 2 1	PL/V	1.60	420	349	2	6	50	51	243	64	20	0.40	0.98
415.0	3 1 5 3 1	PL/V	1.60	445	4	5	5	49	50	295	58	25	6.33	0.98
416.0	3 1 5 4 1	PL/V	2.00	409	147	9	2	48	42	262	72	28	0.08	1.14
417.0	3 1 4 2 1	PU/V	1.20	421	4758	65	6	36	63	327	90	35	0.62	0.57
418.0	3 1 4 1 1	PL/V	1.20	446	122	98	6	46	61	330	68	17	1.20	0.75
420.0	3 1 4 4 1	PL/V	1.20	447	94	6	5	52	44	310	78	23	0.0	1.18
421.0	3 1 4 5 0	PL/V	1.20	470	-1	-1	-1	48	85	294	60	23	0.0	0.56
422.0	3 1 4 6 0	PL/V	1.50	532	-1	-1	-1	44	48	241	0	0	0.38	0.92
423.0	3 1 1 3928	YELL	1.20	423	1566	26	3	52	74	218	22	9	0.0	0.70
424.0	3 1 1 3727	PL/V	0.0	422	756	2	3	11695	53	272	58	39	4.05	220.66
425.0	3 1 2 4 0	PGBD	2.00	646	-1	-1	-1	71	122	149	0	0	13.30	0.58
426.0	3 1 2 1 3	GPMT	2.70	449	225	58	4	35	17	351	54	37	4.28	2.06
427.0	3 1 2 1 3	WHTE	1.50	450	614	0	2	51	19	166	0	23	22.40	2.68

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADN	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
429.0	3 1 1 14 4	BLUE	1.40	448	66	230	5	60	23	342	30	35	15.85	2.61
430.0	3 1 1 4 3	GREE	1.60	424	10	80	4	42	39	253	0	18	1.14	1.08
431.0	3 1 1 4 3	GREE	2.00	425	160	277	3	49	32	260	19	16	1.40	1.53
432.0	3 1 1 4 3	GREE	2.10	426	336	16	3	62	46	279	99	65	3.29	1.35
433.0	3 1 1 4 3	GREE	2.10	427	52	91	0	55	28	172	36	9	3.94	1.96
434.0	3 1 1 4 3	GREE	2.00	428	69	17	4	67	35	401	61	76	12.15	1.91
435.0	3 1 1 4 3	GPMT	2.50	429	41	139	1	49	25	335	53	34	4.46	1.96
436.0	3 1 1 4 3	GREE	2.60	430	91	317	2	54	14	364	0	45	23.45	3.86
437.0	3 1 1 4 3	PGMT	2.60	431	216	209	2	63	19	419	15	25	14.50	3.32
438.0	3 1 1 4 3	GREE	2.00	432	1434	165	6	56	25	409	120	74	10.48	2.24
439.0	3 1 1 4 3	GPMT	2.30	433	358	685	8	71	18	324	402	235	13.35	3.94
440.0	3 1 1 4 3	GPMT	1.80	471	-1	-1	-1	54	18	602	58	42	10.10	3.00
441.0	3 1 1 4 3	IPUR	2.30	472	-1	-1	-1	42	21	497	47	21	0.22	2.00
442.0	3 1 1 4 3	IPUR	2.20	473	-1	-1	-1	52	29	673	92	54	0.86	1.79
443.0	3 1 1 4 3	PURP	2.30	474	-1	-1	-1	50	15	407	19	9	5.85	3.33
444.0	3 1 1 4 3	GPBD	2.00	475	-1	-1	-1	54	18	409	130	71	5.24	3.00
445.0	3 1 1 4 3	PURP	2.30	476	-1	-1	-1	48	16	307	409	240	7.10	3.00
446.0	3 1 1 4 3	GPBD	2.00	477	-1	-1	-1	47	21	468	117	66	4.95	2.24
447.0	3 1 1 4 3	GPBD	2.00	478	-1	-1	-1	56	14	320	129	95	5.77	4.00
448.0	3 1 1 4 3	GREE	2.00	479	-1	-1	-1	58	19	289	82	55	11.00	3.05
449.0	3 1 1 4 4	IGRE	2.00	480	-1	-1	-1	70	21	218	2	23	24.40	3.33
450.0	3 1 1 4 3	GPMT	2.00	481	-1	-1	-1	66	37	334	0	19	19.40	1.78
451.0	3 1 1 4 3	IGRE	2.00	487	-1	-1	-1	56	41	632	95	46	5.45	1.37
452.0	3 1 1 4 3	GREE	2.00	488	-1	-1	-1	56	22	338	164	106	7.60	2.55
453.0	3 1 1 4 3	GREE	1.90	489	-1	-1	-1	47	37	235	21	19	6.76	1.27
454.0	3 1 1 4 3	XXXX	2.00	490	-1	-1	-1	54	29	239	41	13	5.45	1.86
455.0	3 1 1 4 3	GPMT	2.50	491	-1	-1	-1	47	18	406	44	17	6.42	2.61
456.0	3 1 1 4 3	GREE	2.50	492	-1	-1	-1	48	16	527	78	46	9.57	3.00
457.0	3 1 1 4 3	GREE	2.30	493	-1	-1	-1	52	21	308	52	34	10.48	2.48
458.0	3 1 1 4 3	GPMT	2.40	494	-1	-1	-1	43	25	212	10	3	6.66	1.72
459.0	3 1 1 4 3	GREE	2.30	495	-1	-1	-1	62	26	247	47	50	16.20	2.38
460.0	3 1 1 4 3	GREE	2.30	496	-1	-1	-1	65	13	247	183	164	20.90	5.00
461.0	3 1 1 4 3	GREE	2.20	497	-1	-1	-1	51	32	206	27	11	6.50	1.59

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
462.0	3 1 1 4 3	GREE	2.20	498	-1	-1	-1	62	23	431	20	13	14.20	2.70
463.0	3 1 1 4 3	IGRE	2.50	499	-1	-1	-1	51	24	286	14	9	5.70	2.12
464.0	3 1 1 4 3	GREE	2.20	500	-1	-1	-1	47	22	298	41	26	5.55	2.14
465.0	3 1 1 4 3	GREE	2.20	501	-1	-1	-1	40	33	489	61	37	3.85	1.21
466.0	3 1 1 4 3	GPBD	2.00	502	-1	-1	-1	55	29	191	5	20	11.29	1.90
467.0	3 1 1 1615	GREE	2.00	504	-1	-1	-1	46	43	269	50	9	0.43	1.07
469.0	3 1 1 4 2	GREE	2.50	505	-1	-1	-1	37	22	372	63	24	2.30	1.68
470.0	3 1 1 4 2	GPMT	2.00	506	-1	-1	-1	72	37	427	17	39	24.60	1.95
471.0	3 1 1 4 2	GREE	1.80	507	-1	-1	-1	70	31	299	30	43	20.30	2.26
472.0	3 1 1 4 2	GPBD	1.80	508	-1	-1	-1	32	21	309	77	33	5.26	1.52
473.0	3 1 1 4 2	GREE	1.00	509	-1	-1	-1	47	32	314	51	33	11.31	1.47
474.0	3 1 1 4 3	GPBD	2.00	510	-1	-1	-1	52	20	195	58	34	7.42	2.60
475.0	3 1 1 6 3	GREE	1.00	511	-1	-1	-1	9	19	237	226	148	2.54	0.47
476.0	3 1 1 6 3	GREE	2.00	512	-1	-1	-1	55	38	347	114	60	8.82	1.45
478.0	3 1 1 4 3	GPMT	3.00	513	-1	-1	-1	48	16	311	130	90	7.55	3.00
479.0	3 1 1 4 3	PURP	3.00	514	-1	-1	-1	42	17	551	35	13	3.70	2.47
480.0	3 1 1 4 3	PURP	3.00	515	-1	-1	-1	48	24	570	89	46	0.65	2.00
481.0	3 1 1 4 3	GREE	3.00	516	-1	-1	-1	69	20	434	470	342	17.60	3.45
482.0	3 1 1 4 3	GREE	3.00	517	-1	-1	-1	52	31	294	81	66	13.10	1.68
483.0	3 1 1 4 3	GPBD	3.00	518	-1	-1	-1	43	19	481	107	62	2.53	2.26
484.0	3 1 1 4 3	PURP	3.00	519	-1	-1	-1	46	22	257	18	8	2.12	2.09
485.0	3 1 1 4 3	PURP	3.00	520	-1	-1	-1	67	18	412	971	505	12.68	3.72
486.0	3 1 1 4 4	PURP	3.00	521	-1	-1	-1	49	13	379	60	29	4.21	3.77
487.0	3 1 1 4 4	PURP	2.50	522	-1	-1	-1	46	27	182	22	7	5.57	1.70
488.0	3 1 1 4 4	GPBD	2.00	503	-1	-1	-1	50	62	222	24	18	9.17	0.81
489.0	3 1 1 4 3	PURP	2.10	540	-1	-1	-1	49	20	191	20	17	8.47	2.45
490.0	3 1 1 4 3	PURP	2.50	523	-1	-1	-1	57	25	582	69	41	13.68	2.28
491.0	3 1 1 4 3	GREE	2.80	525	-1	-1	-1	75	34	248	275	198	17.90	2.21
492.0	3 1 1 4 3	GREE	2.80	526	-1	-1	-1	57	19	306	304	188	7.99	3.00
493.0	3 1 1 4 3	GPBD	2.80	527	-1	-1	-1	54	47	288	107	70	4.80	1.15
494.0	3 1 1 4 3	GREE	2.80	528	-1	-1	-1	48	18	417	83	44	3.80	2.67
495.0	3 1 1 4 3	PURP	2.80	529	-1	-1	-1	44	25	327	65	35	3.28	1.76
496.0	3 1 1 4 3	GREE	2.50	530	-1	-1	-1	59	18	258	14	31	19.50	3.28

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
501.0	3 3 2 1 1	WHTE	4.00	434	12	65	1	38	57	26	16	0	0.0	0.67
502.0	3 3 2 1 1	CLSS	2.00	549	-1	-1	-1	215	17	3	0	0	0.0	12.65
503.0	3 3 2 1 1	WHTE	0.0	583	-1	-1	-1	-1	-1	-1	-1	-1	-1.00	-1.00
504.0	3 3 2 2 1	WHTE	3.60	435	14	13	4	49	55	26	10	0	0.0	0.89
505.0	3 3 2 2 1	CLSS	4.80	550	-1	-1	-1	29247	300	15	0	0	0.0	97.49
506.0	3 3 2 3 1	WHTE	3.00	436	14	0	3	56	45	19	18	0	0.0	1.24
507.0	3 3 3 1 1	YELL	3.40	437	104	1488	48	50	44	21	0	0	0.0	1.14
508.0	3 3 3 1 1	CLSS	5.00	551	-1	-1	-1	133	37	25	24	0	0.0	3.59
509.0	3 3 3 1 1	CLSS	5.00	552	-1	-1	-1	62	57	23	9	0	0.0	1.09
510.0	3 3 1 2 1	WHTE	2.90	438	4274	104	6	57	55	27	4	0	0.0	1.04
511.0	3 3 3 1 1	WHTE	5.00	539	-1	-1	-1	41	40	15	4	0	0.0	1.02
512.0	3 3 1 3 1	YELL	5.00	524	-1	-1	-1	1532	55	31	0	0	0.28	27.85
513.0	3 3 1 4 1	WHTE	3.00	439	24	113	6	2866	67	23	0	0	0.0	42.78
514.0	3 3 3 1 1	CLSS	5.00	553	-1	-1	-1	49	41	19	9	0	0.0	1.20
515.0	3 3 3 1 1	YELL	4.80	542	-1	-1	-1	47	47	21	4	0	0.0	1.00
516.0	3 3 3 2 1	CLSS	3.00	554	-1	-1	-1	71	59	12	13	4	0.0	1.20
525.0	3 2 1 1 0	YELL	4.00	555	-1	-1	-1	23655	367	30	0	0	0.30	64.46
526.0	3 2 1 2 0	WHTE	3.70	556	-1	-1	-1	9123	678	17	0	0	0.10	13.46
527.0	3 2 1 2 0	WHTE	3.70	557	-1	-1	-1	5570	997	26	0	0	0.08	5.59
529.0	3 2 1 3 0	CLSS	4.80	628	-1	-1	-1	244	58	50	0	0	0.0	4.21
530.0	3 2 1 4 0	WHTE	4.50	558	-1	-1	-1	94	53	44	11	0	0.0	1.77
531.0	3 2 1 5 0	YELL	4.20	559	-1	-1	-1	419	59	44	0	0	0.0	7.10
532.0	3 2 1 6 0	YEPU	4.30	560	-1	-1	-1	2292	52	38	0	0	0.10	44.08
533.0	3 2 1 7 0	WHTE	4.00	561	-1	-1	-1	14268	268	33	0	0	0.80	53.24
534.0	3 2 1 7 0	PURP	3.60	562	-1	-1	-1	6067	105	46	0	0	0.0	57.78
535.0	3 2 1 8 0		4.00	563	-1	-1	-1	2640	70	50	0	0	0.0	37.71
536.0	3 2 1 9 1	WHTE	3.80	564	-1	-1	-1	21595	232	38	0	0	0.0	93.08
537.0	3 2 1 9 1	WHTE	3.00	565	-1	-1	-1	39495	2431	18	0	0	0.0	16.25
538.0	3 2 1 10 1	YELL	4.00	566	-1	-1	-1	10217	863	15	0	0	0.0	11.84
540.0	3 2 1 11 0	CLSS	4.50	569	-1	-1	-1	24510	273	30	0	0	0.0	89.78
541.0	3 2 1 11 0	CLSS	4.20	567	-1	-1	-1	16312	264	31	0	1	0.0	61.79
542.0	3 6 5 2 1	CLSS	3.00	629	-1	-1	-1	29172	1238	6	0	0	0.0	23.56
543.0	3 6 5 2 2	CLSS	4.80	630	-1	-1	-1	171	72	15	4	0	0.0	2.37

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
544.0	3 6 5 1 1	CLSS	3.00	631	-1	-1	-1	42	82	11	21	0	0.0	0.51
545.0	3 6 5 1 1	CLSS	4.00	632	-1	-1	-1	46	60	15	8	0	0.0	0.77
546.0	3 6 5 1 1	CLSS	5.00	633	-1	-1	-1	849	65	15	0	0	0.0	13.06
547.0	3 6 5 4 1	CLSS	4.90	634	-1	-1	-1	51	61	14	20	0	0.0	0.84
548.0	3 6 5 4 3	CLSS	4.90	635	-1	-1	-1	664	98	38	2	0	2.30	6.78
549.0	3 6 5 4 4	CLSS	4.50	568	-1	-1	-1	739	86	18	0	0	0.0	8.59
550.0	3 6 5 4 5	CLSS	4.00	636	-1	-1	-1	26871	523	14	0	0	0.0	51.38
551.0	3 6 5 4 5	CLSS	1.80	637	-1	-1	-1	9336	270	13	0	0	0.0	34.58
552.0	3 6 5 4 4	CLSS	4.00	638	-1	-1	-1	4309	1651	0	0	0	0.80	2.61
553.0	3 6 5 4 6	CLSS	4.90	571	-1	-1	-1	2842	122	12	0	0	0.10	23.30
554.0	3 6 5 4 4	CLSS	3.00	639	-1	-1	-1	357	80	17	1	0	0.0	4.46
555.0	3 6 5 4 7	CLSS	4.00	640	-1	-1	-1	62	61	16	7	5	0.0	1.02
556.0	3 6 5 3 1	CLSS	4.50	572	-1	-1	-1	997	159	16	0	0	1.20	6.27
557.0	3 6 5 5 1	CLSS	4.00	641	-1	-1	-1	848	73	21	0	9	0.0	11.62
559.0	3 6 5 2 1	CLSS	4.20	619	-1	-1	-1	174	82	14	9	0	0.60	2.12
560.0	3 6 5 2 3	CLSS	4.50	642	-1	-1	-1	110	63	14	14	18	0.30	1.75
564.0	3 6 3 1 0	CLSS	3.90	643	-1	-1	-1	73	64	18	0	0	0.0	1.14
565.0	3 6 3 3 0	CLSS	4.50	573	-1	-1	-1	69	57	14	28	0	0.90	1.21
566.0	3 6 3 4 0	CLSS	3.90	574	-1	-1	-1	79	61	14	15	0	0.0	1.30
567.0	3 6 3 5 1	WHTE	3.50	575	-1	-1	-1	91	45	20	6	2	0.60	2.02
570.0	3 6 3 7 0	CLSS	4.50	644	-1	-1	-1	548	91	16	0	0	0.40	6.02
571.0	3 6 3 8 0	CLSS	4.20	576	-1	-1	-1	12265	223	13	0	0	0.0	55.00
572.0	3 6 3 6 1	WHTE	4.80	537	-1	-1	-1	69	45	12	13	0	0.21	1.53
573.0	3 6 3 6 1	WHTE	4.00	577	-1	-1	-1	52	39	14	0	0	2.90	1.33
574.0	3 6 3 6 1	CLSS	4.20	578	-1	-1	-1	47	41	13	12	0	0.0	1.15
575.0	3 6 2 2 1	WHTE	4.00	482	-1	-1	-1	9387	177	20	0	0	0.70	53.03
576.0	3 6 2 3 1	WHTE	4.00	483	-1	-1	-1	3379	83	14	0	0	4.37	40.71
577.0	3 6 2 1 1	WHTE	2.20	533	-1	-1	-1	239	27	17	5	0	0.02	8.85
578.0	3 6 1 5 0	WHTE	2.90	484	-1	-1	-1	101	82	17	15	0	0.0	1.23
579.0	3 6 1 6 0	WHTE	2.90	485	-1	-1	-1	5681	150	16	0	0	0.0	37.87
580.0	3 6 1 7 0	WHTE	2.50	486	-1	-1	-1	4591	102	17	0	0	0.0	45.01
584.0	3 4 2 1 1	WHTE	4.80	534	-1	-1	-1	49	33	34	9	0	2.78	1.48
585.0	3 4 2 2 1	WHTE	4.80	535	-1	-1	-1	46	29	22	14	0	0.50	1.59

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
586.0	3 4 2 3 1	PL/V	4.70	538	-1	-1	-1	57	30	7	0	0	1.02	1.90
587.0	3 4 1 2 0	CLSS	5.00	546	-1	-1	-1	46	39	9	12	0	0.0	1.18
587.1	3 4 1 2 0	IPUR	4.80	536	-1	-1	-1	63	39	10	0	0	5.62	1.62
588.0	3 4 1 1 0	PURP	3.30	626	-1	-1	-1	551	37	3	0	0	2.30	14.89
596.0	3 1 1 3830		1.50	454	-1	-1	-1	46	20	211	39	50	5.36	2.30
597.0	3 1 1 3830		1.20	455	-1	-1	-1	51	53	176	30	3	2.09	0.96
598.0	3 1 1 3830		1.30	456	-1	-1	-1	54	47	138	0	8	1.40	1.15
599.0	3 1 1 3829		1.20	457	-1	-1	-1	53	66	247	44	38	1.66	0.80
600.0	3 1 1 3830		1.20	458	-1	-1	-1	55	37	227	60	37	1.75	1.49
601.0	3 1 1 3830		1.20	459	-1	-1	-1	49	26	104	0	17	1.22	1.88
602.0	3 1 1 3829		1.30	460	-1	-1	-1	43	37	275	67	49	0.31	1.16
603.0	3 1 1 3829		1.20	461	-1	-1	-1	53	31	253	95	50	2.40	1.71
604.0	3 1 1 3829		1.00	462	-1	-1	-1	45	32	249	152	87	2.77	1.41
605.0	3 1 1 3832		1.20	463	-1	-1	-1	46	50	309	48	18	0.68	0.92
606.0	3 1 1 3831		1.20	464	-1	-1	-1	51	14	124	0	5	11.35	3.64
607.0	3 1 1 3831		1.20	465	-1	-1	-1	43	46	303	50	21	2.56	0.93
608.0	3 1 1 3831		1.30	466	-1	-1	-1	55	35	223	41	18	0.45	1.57
609.0	3 1 1 3832		1.30	467	-1	-1	-1	52	26	237	69	33	6.63	2.00
610.0	3 1 1 3832		1.30	468	-1	-1	-1	49	21	119	0	8	4.40	2.33
611.0	3 1 1 3832		1.20	469	-1	-1	-1	53	26	199	95	59	5.38	2.04
612.0	3 1 3 1 0	PL/V	1.50	531	-1	-1	-1	75	65	300	41	21	0.15	1.15
617.0	3 2 2 2 0	YELL	4.30	585	-1	-1	-1	38	36	34	10	0	0.60	1.06
630.0	1 1 4 4 0	GREE	2.50	586	-1	-1	-1	35	25	228	50	0	0.10	1.40
631.0	1 1 4 14 0	GREE	2.50	587	-1	-1	-1	25	21	202	42	0	0.25	1.19
632.0	1 1 4 15 1	GREE	2.50	588	-1	-1	-1	45	23	195	17	0	0.10	1.96
633.0	1 1 4 16 1	GREE	2.50	589	-1	-1	-1	44	24	265	25	0	0.60	1.83
634.0	1 1 4 18 0	GREE	2.10	590	-1	-1	-1	37	19	268	32	6	1.50	1.95
635.0	1 1 4 17 1	GREE	2.00	591	-1	-1	-1	35	20	209	25	3	2.00	1.75
636.0	1 1 4 19 0	GREE	2.50	592	-1	-1	-1	40	18	260	23	0	0.10	2.22
637.0	1 1 4 20 0	GREE	2.00	593	-1	-1	-1	38	19	192	0	1	3.45	2.00
638.0	1 1 4 21 0	GREE	2.50	594	-1	-1	-1	41	18	215	33	0	4.10	2.28
639.0	1 1 4 13 0	GPBD	2.00	595	-1	-1	-1	40	22	213	8	5	1.85	1.82
640.0	1 1 4 2 0	GREE	2.50	596	-1	-1	-1	38	22	194	35	6	0.0	1.73

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	CCLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
642.0	3 33 0 0 0	CLSS	2.00	541	-1	-1	-1	28	290	12	12	0	1.39	0.10
643.0	3 8 1 1 0	BLUE	3.80	543	-1	-1	-1	61	5	47	6	0	0.0	12.20
644.0	3 4 3 1 0	PURP	2.00	545	-1	-1	-1	254	77	30	18	0	0.12	3.30
645.0	3 2 5 1 1	CLSS	3.50	597	-1	-1	-1	18204	192	16	0	0	0.0	94.81
647.0	3 1 1 2 2	PU/V	0.0	598	-1	-1	-1	7	13	172	176	32	0.10	0.54
648.0	3 1 1 2 2	GREE	2.10	599	-1	-1	-1	53	59	271	159	92	0.0	0.90
649.0	3 1 1 26 5	GREE	0.0	600	-1	-1	-1	29	0	142	59	0	39.50	-1.00
650.0	3 1 1 26 5	GREE	1.50	601	-1	-1	-1	47	26	417	182	76	5.40	1.81
651.0	3 1 1 26 5	PU/V	2.00	602	-1	-1	-1	38	66	320	41	13	2.30	0.58
652.0	3 1 1 26 5	GREE	2.00	603	-1	-1	-1	45	34	275	103	74	8.40	1.32
653.0	3 1 1 26 5	GREE	2.00	604	-1	-1	-1	52	52	253	60	39	7.70	1.00
655.0	3 1 1 4037	PURP	2.50	605	-1	-1	-1	47	31	216	53	35	5.00	1.52
656.0	3 1 1 14 4	GREE	3.00	620	-1	-1	-1	48	45	262	71	31	6.90	1.07
657.0	3 1 1 14 4	GREE	2.00	606	-1	-1	-1	45	33	220	85	58	7.20	1.36
658.0	3 1 1 14 4	GREE	3.00	621	-1	-1	-1	53	36	376	76	34	4.80	1.47
659.0	3 1 1 14 4	PGMT	2.00	607	-1	-1	-1	39	22	256	66	28	7.30	1.77
660.0	3 1 1 14 4	PGBC	2.20	608	-1	-1	-1	51	36	268	123	63	6.85	1.42
661.0	3 1 1 14 4	PGMT	2.20	609	-1	-1	-1	44	47	452	197	109	0.70	0.94
662.0	3 1 1 14 4	PURP	2.80	610	-1	-1	-1	44	25	391	50	18	4.95	1.76
663.0	3 1 1 14 4	GREE	3.00	611	-1	-1	-1	53	21	449	43	19	7.90	2.52
664.0	3 1 1 14 4	PURP	2.80	612	-1	-1	-1	39	30	344	53	16	2.00	1.30
665.0	3 1 1 14 4	GREE	2.30	613	-1	-1	-1	47	17	342	89	59	9.25	2.76
666.0	3 1 1 14 4	PGMT	2.30	614	-1	-1	-1	42	27	332	50	27	2.60	1.56
667.0	3 1 1 1411	BLUE	0.0	658	-1	-1	-1	9	62	542	46	15	2.25	0.15
668.0	3 1 1 6 3	GREE	2.20	622	-1	-1	-1	61	25	238	223	164	15.30	2.44
669.0	3 1 1 27 6	CLSS	3.20	615	-1	-1	-1	58	50	198	33	5	4.70	1.16
670.0	3 1 1 27 6	GREE	2.00	616	-1	-1	-1	36	21	182	77	17	1.10	1.71
671.0	3 1 1 26 5	GREE	2.20	623	-1	-1	-1	40	56	209	113	60	3.00	0.71
672.0	3 1 1 20 4	PGBC	2.20	624	-1	-1	-1	45	32	265	63	29	2.60	1.41
673.0	3 1 1 20 4	GREE	2.00	617	-1	-1	-1	52	22	452	130	136	28.90	2.36
674.0	3 1 1 20 4	PGBD	2.20	625	-1	-1	-1	43	41	316	72	21	2.10	1.05
675.0	1 4 1 0 0	IPUR	2.80	584	-1	-1	-1	73	331	31	29	0	0.60	0.22
676.0	3 1 1 4136	GREE	2.00	645	-1	-1	-1	44	44	247	54	36	1.00	1.00

TRACE ELEMENT DATA, PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
677.0	3 1 1 4237	IGRE	0.0	687	-1	-1	-1	1	36	202	151	77	0.10	0.03
678.0	3 13 2 0 0	IGRE	3.30	627	-1	-1	-1	419	98	55	13	1	1.30	4.28
679.0	3 10 1 1 0	IPCS	3.00	647	-1	-1	-1	123	62	5	0	0	0.0	1.98
681.0	3 27 3 1 0	CLSS	2.20	656	-1	-1	-1	53	6	34	11	0	0.0	8.83
682.0	3 31 2 0 0	GREE	0.0	744	-1	-1	-1	4	134	55	35	12	-1.00	0.03
683.0	1 8 1 0 0	GREE	2.50	651	-1	-1	-1	53	12	95	18	0	0.0	4.42
684.0	3 34 0 0 0	CLSS	0.0	751	-1	-1	-1	0	47	6	23	2	-1.00	-1.00
685.0	3 28 1 1 0	GREE	0.0	657	-1	-1	-1	144	57	63	15	9	3.20	2.53
686.0	1 7 1 1 0	PURP	2.50	649	-1	-1	-1	51	33	1673	245	102	0.10	1.55
687.0	1 7 1 1 0	GREE	2.30	648	-1	-1	-1	44	32	5193	490	260	0.0	1.37
688.0	1 6 1 1 0	CLSS	0.0	667	-1	-1	-1	0	52	69	1	0	0.0	-1.00
689.0	1 6 1 2 0	RED.	0.0	672	-1	-1	-1	4	13	127	0	0	0.0	0.31
690.0	1 6 1 3 0	GREE	0.0	668	-1	-1	-1	3	9	102	1	0	2.10	0.33
691.0	1 6 1 4 0	GREE	0.0	690	-1	-1	-1	0	9	198	13	7	3.30	-1.00
692.0	1 6 1 5 0	IGRE	0.0	669	-1	-1	-1	6	49	3663	565	260	0.0	0.12
693.0	1 6 1 6 0	IGRE	0.0	790	-1	-1	-1	0	13	868	120	44	-1.00	-1.00
694.0	1 6 1 7 0	PRWH	0.0	680	-1	-1	-1	14	29	247	0	0	1.60	0.48
695.0	1 6 2 1 0	IPUR	0.0	671	-1	-1	-1	7	11	156	17	0	2.30	0.64
696.0	1 6 2 2 0	IPUR	0.0	691	-1	-1	-1	10	9	110	13	19	4.50	1.11
697.0	1 5 1 2 0	PURP	0.0	681	-1	-1	-1	76	57	51	0	11	30.50	1.33
698.0	1 5 1 1 0	GREE	2.50	650	-1	-1	-1	39	19	313	24	5	0.25	2.05
699.0	1 6 3 1 0	CLSS	0.0	673	-1	-1	-1	2	109	42	8	0	0.0	0.02
700.0	1 6 3 2 0	GREE	0.0	676	-1	-1	-1	1	135	74	25	0	0.60	0.01
701.0	1 6 3 3 0	GREE	0.0	677	-1	-1	-1	7	37	152	21	0	0.40	0.19
702.0	1 6 4 1 0	WHTE	0.0	678	-1	-1	-1	15	171	49	13	1	0.0	0.09
703.0	3 35 1 1 0	IGRE	0.0	679	-1	-1	-1	6	94	24	0	0	0.0	0.06
704.0	3 20 1 3 0	IPUR	2.00	652	-1	-1	-1	30575	2881	1	0	0	10.00	10.61
705.0	3 1 1 4338	PU/V	2.00	653	-1	-1	-1	86	28	354	59	24	0.0	3.07
706.0	3 29 1 1 0	PURP	0.0	662	-1	-1	-1	0	60	4	20	0	0.0	-1.00
707.0	1 9 1 1 0	IPUR	0.0	659	-1	-1	-1	429	22	270	113	53	1.90	19.50
708.0	1 6 3 4 0	PURP	0.0	661	-1	-1	-1	9	60	174	20	0	0.0	0.15
709.0	3 12 2 1 0	PGMT	0.0	675	-1	-1	-1	187	68	121	0	3	11.40	2.75
710.0	3 37 1 1 0	PGBD	0.0	674	-1	-1	-1	16600	537	29	0	0	0.0	30.91

TRACE ELEMENT DATA, PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
711.0	1 1 4 22 1	GREE	0.0	660	-1	-1	-1	5	26	237	2	0	0.80	0.19
712.0	3 31 1 2 0	CLSS	0.0	664	-1	-1	-1	10	10	64	9	0	0.0	1.00
713.0	1 10 1 0 0	IGRE	0.0	666	-1	-1	-1	7	73	64	21	2	0.0	0.10
714.0	1 10 2 0 0	IGRE	0.0	682	-1	-1	-1	6	227	135	10	16	3.30	0.03
715.0	1 10 3 0 0	GRWH	0.0	670	-1	-1	-1	4	62	99	0	0	15.80	0.06
716.0	1 10 4 0 0	PUWH	0.0	683	-1	-1	-1	5	107	10	34	0	0.80	0.05
717.0	1 10 5 0 0	GPBD	0.0	684	-1	-1	-1	0	140	143	37	11	0.50	-1.00
718.0	3 1 3 2 0	PL/V	2.00	654	-1	-1	-1	62	42	430	30	4	0.0	1.48
719.0	3 1 4 7 0	PL/V	2.00	655	-1	-1	-1	67	51	420	58	29	0.40	1.31
720.0	3 24 1 0 0	GREE	0.0	685	-1	-1	-1	0	75	105	14	0	0.10	-1.00
722.0	3 1 3 3 1	YELL	0.0	692	-1	-1	-1	8	80	273	58	22	0.0	0.10
723.0	1 2 1 1 0	YELL	0.0	693	-1	-1	-1	45	15	90	0	0	1.70	3.00
724.0	1 4 1 3 0	IPUR	0.0	695	-1	-1	-1	19	1160	88	0	2	1.80	0.02
728.0	1 11 2 1 0	CLSS	0.0	697	-1	-1	-1	0	75	103	7	0	0.60	-1.00
730.0	1 11 4 1 0	YELL	0.0	699	-1	-1	-1	6	472	0	6	0	0.0	0.01
732.0	1 11 3 2 0	BRWN	0.0	701	-1	-1	-1	5	256	0	4	0	0.50	0.02
733.0	1 11 1 1 0	CLSS	0.0	782	-1	-1	-1	7952	419	0	0	0	-1.00	18.98
734.0	1 11 1 2 0	CLSS	0.0	700	-1	-1	-1	4	33	1	5	0	0.10	0.12
736.0	1 11 1 3 0	BLPU	0.0	715	-1	-1	-1	21	106	3	0	5	-1.00	0.20
738.0	1 11 1 4 0	CLSS	0.0	703	-1	-1	-1	12	361	6	9	0	0.50	0.03
740.0	1 11 1 5 0	PURP	0.0	698	-1	-1	-1	0	69	10	13	0	0.0	-1.00
741.0	1 11 1 6 0	PURP	0.0	716	-1	-1	-1	14	199	20	16	7	-1.00	0.07
743.0	1 6 4 2 0	GREE	0.0	702	-1	-1	-1	0	5	201	35	25	2.30	-1.00
744.0	3 25 1 0 0	PURP	0.0	696	-1	-1	-1	6	15	9	0	0	0.10	0.40
745.0	3 25 3 1 0	PURP	0.0	708	-1	-1	-1	127	65	15	31	0	1.35	1.95
746.0	3 25 2 1 0	CLSS	0.0	711	-1	-1	-1	4614	135	25	0	0	3.00	34.18
747.0	3 25 4 1 0	PURP	0.0	712	-1	-1	-1	25	33	16	9	0	0.0	0.76
748.0	1 4 1 2 1	PGMT	0.0	704	-1	-1	-1	221	2769	533	558	582	0.40	0.08
749.0	1 4 1 2 1	BLPU	0.0	705	-1	-1	-1	13	3346	701	177	74	0.85	0.00
751.0	3 3 4 1 0	PURP	0.0	706	-1	-1	-1	11	39	23	0	0	0.0	0.28
752.0	1 4 1 4 0	PURP	0.0	707	-1	-1	-1	14	45	44	1	0	5.30	0.31
753.0	3 1 1 20 4	PGMT	0.0	709	-1	-1	-1	0	30	279	171	104	5.30	-1.00
754.0	3 1 1 20 4	PGMT	0.0	710	-1	-1	-1	7	36	223	127	127	12.05	0.19

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	CCLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
755.0	3 1 1 20 4	PGMT	0.0	713	-1	-1	-1	3	39	464	142	92	3.10	0.08
758.0	3 28 2 1 0	GREE	0.0	714	-1	-1	-1	50	39	276	0	0	0.90	1.28
760.0	3 1 1 4039	PL/V	0.0	717	-1	-1	-1	18	83	235	71	65	-1.00	0.22
762.0	3 1 1 4541	PL/V	0.0	718	-1	-1	-1	8	67	248	124	70	-1.00	0.12
765.0	3 2 1 15 1	PLYE	0.0	719	-1	-1	-1	4757	90	51	0	0	-1.00	52.86
766.0	3 2 1 15 1	PURP	0.0	720	-1	-1	-1	11089	199	46	0	0	-1.00	55.72
767.0	3 2 1 15 1	YELL	0.0	721	-1	-1	-1	4266	89	56	0	0	-1.00	47.93
768.0	3 2 1 15 2	YELL	0.0	722	-1	-1	-1	4681	73	72	0	0	-1.00	64.12
769.0	3 2 1 15 2	YELL	0.0	723	-1	-1	-1	1818	63	51	0	0	-1.00	28.86
770.0	3 2 1 16 1	YELL	0.0	724	-1	-1	-1	3058	520	36	0	0	-1.00	5.88
771.0	3 2 1 16 1	YELL	0.0	792	-1	-1	-1	16336	193	59	0	0	-1.00	84.64
774.0	3 1 1 4642	PL/V	0.0	725	-1	-1	-1	80	13	162	0	0	-1.00	6.15
776.0	3 1 7 1 1	PGMT	0.0	745	-1	-1	-1	104	0	397	29	34	-1.00	-1.00
775.0	3 1 1 4642	PLYE	0.0	726	-1	-1	-1	4	74	169	0	0	-1.00	0.05
800.0	3 1 1 4845	GREE	0.0	727	-1	-1	-1	11	43	367	101	58	-1.00	0.26
801.0	3 1 1 4845	PL/V	0.0	748	-1	-1	-1	22	33	311	138	73	-1.00	0.67
802.0	3 1 1 4844	PL/V	0.0	785	-1	-1	-1	0	12	644	116	55	-1.00	-1.00
803.0	3 1 1 4844	PL/V	0.0	730	-1	-1	-1	2	25	436	130	75	-1.00	0.08
805.0	3 1 1 4946	PL/V	0.0	731	-1	-1	-1	13	39	330	198	111	-1.00	0.33
806.0	3 1 1 4946	GREE	0.0	732	-1	-1	-1	10	29	251	124	74	-1.00	0.34
807.0	3 1 5 1 1	GREE	0.0	733	-1	-1	-1	7	29	263	48	46	-1.00	0.24
808.0	3 1 5 1 2	GNYE	0.0	734	-1	-1	-1	2	19	187	0	14	-1.00	0.11
810.0	3 1 1 3832	PURP	0.0	735	-1	-1	-1	11	0	163	1	12	-1.00	-1.00
811.0	3 1 1 3832	PGBD	0.0	736	-1	-1	-1	0	4	218	24	39	-1.00	-1.00
812.0	3 1 1 3832	PGBD	0.0	737	-1	-1	-1	5	18	354	145	82	-1.00	0.28
813.0	3 1 1 3832	YELL	0.0	738	-1	-1	-1	0	28	153	1	16	-1.00	-1.00
814.0	3 1 1 3832	YELL	0.0	739	-1	-1	-1	5	57	180	40	5	-1.00	0.09
815.0	3 1 1 3832	PGBD	0.0	740	-1	-1	-1	0	24	274	48	16	-1.00	-1.00
816.0	3 1 1 3832	GREE	0.0	741	-1	-1	-1	0	7	125	0	15	-1.00	-1.00
817.0	3 1 1 3832	PGMT	0.0	742	-1	-1	-1	0	12	250	42	40	-1.00	-1.00
818.0	3 1 1 3832	YELL	0.0	743	-1	-1	-1	6	52	154	8	11	-1.00	0.12
823.0	3 2 4 2 0	CLSS	0.0	746	-1	-1	-1	99	38	26	0	34	-1.00	2.61
828.0	3 2 4 3 0	CLSS	0.0	749	-1	-1	-1	82	24	26	23	0	-1.00	3.42

TRACE ELEMENT DATA,PPM, -1 = NOT DETERMINED

SPEC	LOCALITY CODE	COLR	RADM	XRF	ZN	CU	NI	BA	SR	Y	CE	LA	%SIO2	BA/SR
830.0	3 2 4 3 0	CLSS	0.0	750	-1	-1	-1	1609	28	22	0	0	-1.00	57.46
842.0	3 1 1 5249	PL/V	0.0	786	-1	-1	-1	68	420	235	0	0	-1.00	0.16
843.0	3 27 2 1 0	GREE	0.0	787	-1	-1	-1	20	39	84	0	1	-1.00	0.51
945.0	3 33 0 1 0	PINK	0.0	757	-1	-1	-1	2	90	32	24	3	-1.00	0.02
946.0	3 33 0 2 0	PURP	0.0	758	-1	-1	-1	0	100	12	25	0	-1.00	-1.00
953.0	3 33 0 3 0	GREE	0.0	759	-1	-1	-1	0	44	25	6	6	-1.00	-1.00
956.0	3 33 0 4 0	PURP	0.0	760	-1	-1	-1	10	104	42	22	0	-1.00	0.10
960.0	3 33 0 5 0	PURP	0.0	761	-1	-1	-1	0	126	5	27	0	-1.00	-1.00
964.0	3 33 0 6 0	CLSS	0.0	762	-1	-1	-1	0	119	9	10	0	-1.00	-1.00
967.0	3 33 0 7 0	GREE	0.0	763	-1	-1	-1	0	84	0	15	0	-1.00	-1.00
977.1	2 1 1 2 0	BLCK	0.0	747	-1	-1	-1	4	1116	52	0	0	-1.00	0.00
977.2	2 1 1 2 0	BLCK	0.0	768	-1	-1	-1	1197	1516	21	0	0	-1.00	0.79
971.0	3 20 2 1 0	IGRE	0.0	764	-1	-1	-1	0	56	93	59	21	-1.00	-1.00
972.0	1 6 5 1 0	IPUR	0.0	765	-1	-1	-1	0	648	125	0	0	-1.00	-1.00
973.0	1 6 3 5 0	IPUR	0.0	766	-1	-1	-1	33	147	16	0	0	-1.00	0.22
974.0	3 31 1 3 0	CLSS	0.0	767	-1	-1	-1	0	0	18	0	0	-1.00	-1.00
983.0	3 1 1 5047	WHTE	0.0	789	-1	-1	-1	0	9	267	84	54	-1.00	-1.00
989.0	3 8 0 2 0	BLUE	0.0	788	-1	-1	-1	35	3	29	0	0	-1.00	11.67

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Pressure-Temperature Estimates for a Late Metamorphic Event in the Dalradian in the Scottish Highlands

SEMI-CONCORDANT quartz veins occur in garnet grade amphibolite facies pelites, semipelites, and siliceous dolomites between Spean Bridge and Roybridge, 15 miles east of Fort William, Inverneshire. Fluid inclusion studies by one of us (F. W. S.) on samples from one such vein provide pressure and temperature information compatible with the results of geothermometric work on carbonates combined with thermodynamic calculations on the carbonate bearing assemblages (R. P.).

Homogenization temperatures of two-phase primary and pseudosecondary[1] fluid inclusions were measured in doubly polished disks on a microscope heating stage. These inclusions homogenized into the liquid phase. The mean and median of twenty-five measurements were 350° C (s.d. 19) and 349° C, respectively. The absolute accuracy of individual measurements was probably not better than ±5° C.

The concentration of dissolved salts in the inclusion liquid was established by the depression of melting point technique. During slow warming from −90° C, ice melted at approximately −22° C, very close to the eutectic temperature of −21.1° C in the NaCl H_2O system. A high relief solid phase, believed to have been $NaCl.2H_2O$, melted in the range −9° C to −5° C (sixteen measurements). Assuming the inclusion fluid approximates to the NaCl H_2O system, this corresponds to a salinity of 25 ± 2 equivalent weight % NaCl. A shadowy low relief solid, believed to be CO_2 hydrate, occurred in some runs. The effect of this CO_2 on the homogenization temperatures and salinities is not known but we believe it to be small.

The degree of filling (percentage of liquid in the primary inclusions)[2] at room temperature was calculated (from photographs) to be 77 (s.d. 9.0). Thus the density[3] of the parent fluid was approximately 0.88 g cm^{-3}.

The parameters, pressure of formation (P), temperature of formation (T), degree of filling (F), and salinity (X) of fluid inclusions are so interrelated that the correction of the homogenization temperature to the actual formation temperature can only be undertaken with a knowledge of P, F, and X.

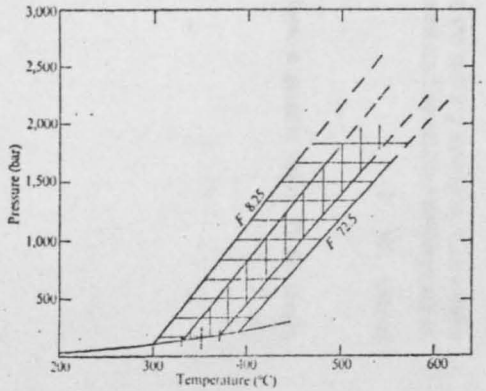

Fig. 1 P–T diagram showing the pressure effect on the homogenization temperature for 25 weight % NaCl brine, where F is the degree of filling. Homogenization temperature 349° C.

In Fig 1 we give the pressure effect on the measured homogenization temperatures using the data of Lemmlein and Klevtsov[4]. The fluid inclusions probably formed in the cross-hatched band on this diagram.

An alternative approach to pressure-temperature evaluation is to consider the mineralogy of the host rocks of these quartz veins. Some of the siliceous dolomites have the very low variance assemblage quartz-calcite-dolomite-talc-tremolite-oligoclase-phlogopite-chlorite-rutile-ilmenite-tourmaline-apatite, and, as a first approximation, this can be considered as quartz-calcite-dolomite-talc-tremolite-vapour in the system CaO-MgO-SiO-CO_2-H_2O. Using total pressure, temperature, and H_2O/CO_2 ratio as the intensive variables during metamorphism, this assemblage is univariant, and thus pressure of formation is directly related to temperature of formation[5,6]. Thermodynamic calculations on this system using the method of Greenwood[7] and literature data[8–10] define the pressure-temperature relationship for this assemblage (Fig. 2) with the vapour phase composition buffered at about 90% CO_2.

Using the experimental calibration of the calcite-dolomite geothermometer[11], probe-analysed calcites in textural equilibrium with dolomites give a range of composition (mean 4.5% $MgCO_3$, s.d. 0.5) which represents, at 1 bar, a temperature range of 480° C to 530° C. Using a pressure correction of 0.12% $MgCO_3$ kbar^{-1}, the pressure-temperature conditions indicated by the calcites are given in Fig. 2. It is important that the presence of calcites with up to 6.2% $MgCO_3$, representing a temperature of 580° C, indicates that the composition of the majority of calcites reflects a later event superimposed on an earlier event of higher temperature. Field and thin-section evidence indicates that this low variance assemblage is developed along centimetre spaced cleavage and fracture planes from an earlier talc and tremolite free assemblage.

The possible close agreement in temperature and pressure of formation of the quartz veins and the mineralogy of the host rocks (Fig. 2) suggests that they are both manifestations of the same process. Following the chief metamorphic event, which produced the garnet bearing pelitic assemblages, deep metamorphic or magmatic brines passed up through the area at a lower temperature and pressure. These brines produced the quartz veins along fractures while producing the low variance assemblage and resetting the calcite temperatures along minor planes of weakness in the more permeable dolomitic rocks.

The indicated high geothermal gradient (approximately 100° C km^{-1}) for this late metamorphic event is interesting. It is reasonable to suggest that the measured conditions prevailed during uplift of this part of the Caledonian belt, possibly 420 m.y. ago (the age of Ar retention representing uplift, from Dewey and Pankhurst[12]).

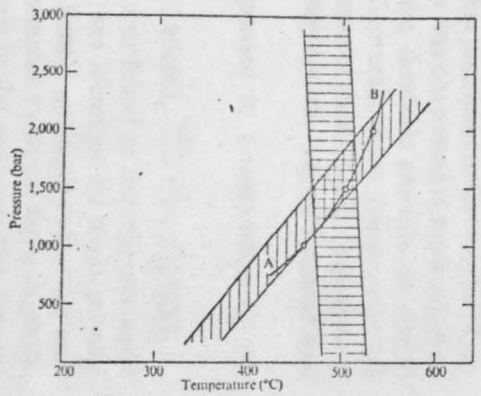

Fig. 2 P–T diagram combining the information from the fluid inclusions, the calcites, and the thermochemical calculations. The curve AB corresponds to the univariant reaction involving talc-tremolite-calcite-dolomite-quartz. ▨, P–T, from calcite; ▥, P–T from fluid inclusions.

In conclusion we point out the possibility of using synmetamorphic quartz veins as an aid to establishing metamorphic conditions, particularly when combined with information about the host rocks.

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R. POWELL

Department of Geology and Mineralogy, Parks Road, Oxford

F. W. SMITH

Department of Geology, Science Laboratories, South Road, Durham

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SHORT COMMUNICATIONS

MINERALOGICAL MAGAZINE, JUNE 1973, VOL. 39, P. 244

Supergene native copper in the Northern Pennine Orefield

PRIMARY copper ore in the form of chalcopyrite is only locally abundant in the Northern Pennine Orefield, and nowhere forms a workable deposit under present-day economic conditions (although its extraction as a by-product may be feasible at some mines). The copper zone of the orefield is central with respect to concentric ore and gangue zones, but chalcopyrite may also be found concentrated in association with quartz at local orebody feeders within mining districts.

Recently, during a visit with British Steel Corporation geologists to Groverake Mine, near Rookhope in Weardale, supergene native copper was discovered in small amounts at the New Firestone Level. The metal forms platy, dendritic growths on etched crystal faces and cleavage planes of fluorite in the Groverake Vein. The growths are often radial around, but separate from, oxidizing crystals of chalcopyrite. Occasionally a thin film of marcasite has formed intermediate between the copper sulphide and metal.

The formation of the native metal may be expressed in general terms by the representative equations:

$$CuFeS_2 + 8O^- \xrightarrow{\text{oxidn.}} CuSO_4 + FeSO_4, \text{ and } CuSO_4 + 2FeSO_4 \xrightarrow{\text{redn.}} Cu + Fe_2(SO_4)_3.$$

A number of the copper-bearing specimens were also found to contain very small botryoidal growths of a pale yellow mineral. This was identified by X-ray powder photography as a member of the copiapite family. Simple qualitative chemical tests suggest it to be the end member ferricopiapite, a complex hydrated ferric sulphate. Copper sulphate, chalcanthite, also occurs as crystals in the workings but was not detected in these particular samples.

Previously, supergene enrichment of ore sulphides in the Northern Pennines has been recorded only from Sedling Mine, Weardale, where Dunham (1932, p. 92) described the occurrence of covelline replacing galena at the Horse Level horizon.

Acknowledgements. I thank the British Steel Corporation for permitting access to Groverake Mine, and Mr. J. Forster and Mr. R. Willmers for their interest and assistance underground.

Department of Geology, University of Durham, South Road, Durham. F. W. SMITH

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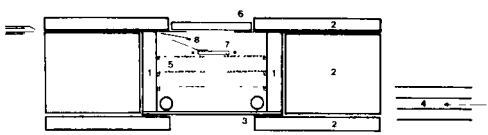
MINERALOGICAL MAGAZINE, SEPTEMBER 1973, VOL. 39, PP. 366–7.

A simple microscope freezing stage

A SIMPLE and highly versatile microscope freezing stage has been developed for studies of fluid inclusions at temperatures down to −100 °C. The stage, utilizing cold gas as the heat exchange medium, has been in use for some time in the laboratories of the University of Durham and has proved to be both reliable and inexpensive to build, maintain, and use. It can be used in any working place with a supply of compressed air or inert gas.

Construction. The stage itself (fig. 1) is composed of a strong Perspex cylinder (1), encased in asbestos insulation (2) and sealed off at the bottom by a clear Perspex plate (3). Dry nitrogen, cooled by passing through a copper coil immersed in liquid nitrogen, is introduced to the chamber through a lagged stiff polythene tube (4). The tube is coiled around the base of the chamber and perforated by a series of upward directed pinpricks. Three copper gauzes (5) supported within the chamber serve to thoroughly mix the gas as it vents upwards. The top gauze also supports the specimen holder—generally a small aluminium wire cage. Used gas escapes around the glass lid (6) which simply rests upon a flat card gasket. The lid thus forms a valve to prevent moist air from entering the chamber and causing frosting when the cold gas flow is reduced. A small jet of dry air directed on to the lid outer surface is sufficient to prevent external frosting. Nitrogen flow is controlled by a very fine needle-valve which can be adjusted to yield cooling rates up to about 25 °C/min. The chamber temperature can be stabilized and maintained at any temperature down to about −100 °C. This limitation is imposed solely by size of cooling coil and gas pressure. Subsequent to inclusion fluid freezing, the temperature may be raised at any suitable rate by decreasing the cold gas flow.



A copper-constantan thermocouple (7) attached to the specimen (cleavage flake or polished 1 mm mineral wafer) reads directly on to a chart recorder adapted to give maximum sensitivity in the required mV range. Another thermocouple (8) is generally kept in the cell to monitor gas temperature and keep a check for possible thermal gradients. The system is calibrated regularly using standard freezing point capillaries containing the following substances: benzene, +5 °C; butyric acid, −6·5 °C; bromine, −7·2 °C; methyl benzoate, −12·3 °C; benzonitrile, −13 °C; quinoline, −15·9 °C; decane, −19·7 °C. Overall precision on calibration and duplicate runs is generally better than ±0·5 °C.

The system has great advantages over other types of freezing stage some of which (including Peltier effect thermomodules, acetone–dry-ice mixtures, and adiabatic expansion of CO_2) have been experimented with here. The extremely rapid cooling rate, for example, far surpasses that attainable using other methods and has proved very useful, not only in speeding up the entire experimental process, but also for shock freezing fluid inclusions, some of which can persist as metastable liquids for long periods at sub-freezing point temperatures.

Low-temperature studies of fluid inclusions in minerals generally involves the measurement of eutectic temperatures and depression of freezing temperatures, and the examination of the behaviour of daughter minerals and liquid gases already present or newly formed at such temperatures (Roedder, 1963, 1972; Bazaroff and Motorina, 1968). They thus provided much information on the nature and composition of mineral-forming fluids.

Department of Geology, F. W. Smith
University of Durham

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Applied earth science

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Volume 82 1973

Technical notes

Fluid inclusion studies on fluorite from the North Wales ore field

F. W. Smith

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Fluid inclusion studies on fluorite from the North Wales ore field

F. W. Smith B.Sc.
Department of Geological Sciences, University of Durham, Durham

553.216.7 : 549.454.2 : 533.441(429)

The North Wales lead–zinc ore field occurs in the Carboniferous Limestone and Millstone Grit bounding, and south of, the Vale of Clwyd and the Clwydian Range (Fig. 1). The main mineralization occurs in two districts. The Talargoch–Halkyn–Llanarmon district comprises a north–south belt stretching from near Prestatyn in the north to the Llanelidan Fault. The Minera district lies to the south of this fault. Dispersed mineralization continues southwards, in Carboniferous rocks, to Oswestry. Weaker mineralization also occurs both to the east, in small limestone inliers along the Llanelidan Fault, and to the west, in the limestone belts flanking the Vale of Clwyd, particularly near Abergele.

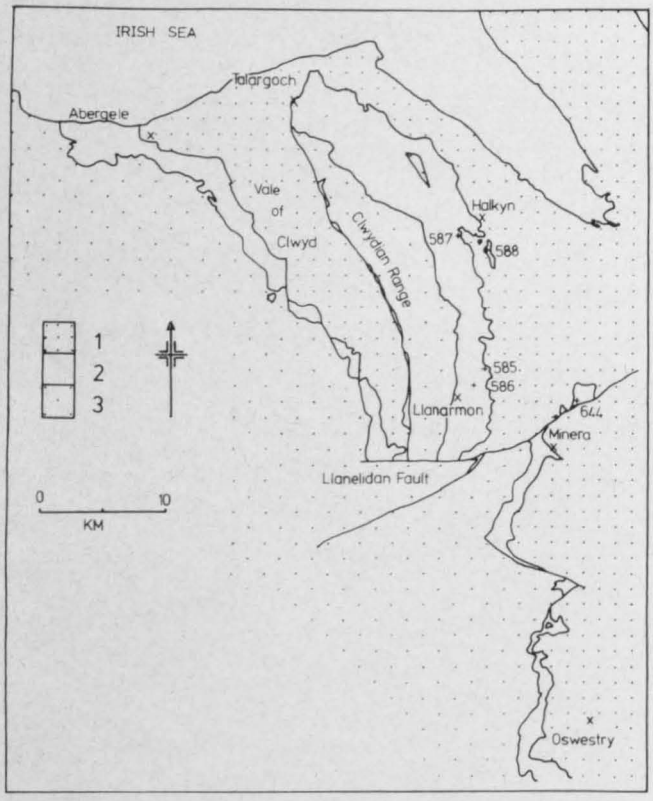

Fig. 1 Geological sketch map of North Wales ore field showing fluorite sample locations: 1, Post-Carboniferous Limestone; 2, Carboniferous Limestone; 3, Silurian and Ordovician. Based on maps of Geological Survey of Great Britain

The ore field has a long history, terminating with the closure of Halkyn District United Mines in 1959. Total production of lead and zinc concentrates has been estimated at 1 870 000 and 290 000 tons, respectively.[1]

Ore is restricted to lodes and replacements in the Carboniferous rocks. Mineralization in the two main ore districts comprises galena and blende in a calcite gangue. Quartz is only locally common and fluorite is uncommon, occurring only in the eastern part of the ore field. Fluorite also occurs at Ffrith in a small limestone inlier on the Llanelidan Fault. Barium minerals are rare in the main ore field, but barite is found in workable amounts in the Vale of Clwyd.[2] Hematite ores occur in a zone in the north of the ore field with galena, blende and calcite, associated in one area with concentrations of cobalt, nickel, manganese and titanium.[3] Broad sulphide zoning is present, the Zn : Pb ratio increasing generally away to the northeast, east and southeast of the Clwydian Range.[1,4,5]

The regional structure is that of a broad north–south elongate pericline, the Clwydian Range, cut by radial and block faulting. The pericline is bounded to the west by the down-faulted Vale of Clwyd, and to the north and east by deep Carboniferous–Permo-Triassic sedimentary basins. The Cheshire basin curves around southwards to flank the Shropshire ore field, which shares many other features in common with the North Wales districts.

One lead isotope model age of 170 ± 80 m.y. has been published.[6]

Fluid inclusions in fluorite from the ore field have been studied to gain new information on the composition of the ore-forming fluids and on the process of ore deposition. The data are compared with new and published results for other similar British deposits.

Location of samples

Fluorites from five separate localities (Fig. 1) have been examined for fluid inclusions. Material from one of these was eventually discarded as being too badly fractured after only one good primary inclusion had been found. All specimens were obtained from mine dumps. No fluorite could be found on dumps at two other recorded localities, the Coed Cynric vein and Park vein. Three further recorded localities (Maeshafn vein, Westminster vein and Tan-y-graig vein[7]) were not visited. Specimens of quartz were also examined for fluid inclusions, but were found to be unsuitable.

Results

Homogenization temperatures of primary fluid inclusions fall within the narrow range 95–115°C (Table 1). The lowest temperatures (96·5° mean) were obtained from late crystals lining vughs from the East Pant Dû mine. The highest temperatures (113·9°C mean) were obtained from the easternmost sample (Ffrith), which is located near a major east–west fault.

The maximum pressure correction to the homogenization temperatures can be estimated from the total overburden on the area at the time of ore deposition. This is unlikely to have been greater than 1·5 km.[8] The maximum pressure correction then lies within the range +10 to +25°C,[9] depending on whether the ore solutions are regarded as having been under purely hydrostatic or lithostatic pressure. In view of the uncertainties as to which is more appropriate, neither being ideal, a mean value of +17°C has been taken.

Freezing-point determinations also fall within a narrow temperature range (Table 2). Cryohalite was formed in the primary inclusions on freezing, and the temperature of disappearance of this phase on heating yields (from data on the NaCl–H_2O system) the brine salinity in terms of equivalent weight per cent NaCl. The range of eutectic temperatures was found to be rather higher than the eutectic in the pure NaCl–H_2O system (−21·1°C)—indicating the presence of other salts. The salinity of the ore-bearing brines determined by this method is thus 24–25 equivalent weight per cent NaCl.

Approximate sodium/potassium (~~atomic~~) ratios in the inclusions were determined by the leaching method described by Sawkins[10] (Table 3). The results show slight

Table 1 Homogenization temperatures, North Wales fluorite

Sample number	Locality	Inclusions measured	Type*	Mean T_H	Standard deviation of mean	Median	Corrected mean
585/1	East Pant Dû mine						
	Massive, colourless	16	*P*	104·5	6·0	104·9	122
585/2	East Pant Dû mine						
	Late, vughy, colourless	12	*P*	96·5	4·3	94·3	114
586	Pant-y-gwlanod vein						
	Massive, purple	1	*P*	105·1	—	—	123
587	Bryn Gwiog mine						
	Massive, purple	19	*P*	107·6	5·2	107·0	125
588	East Halkyn mine						
	Massive replacement, pale purple	31	*P*	107·1	2·2	106·9	124
644	Ffrith quarry,						
	Massive, pale purple	15	*P*	113·9	4·2	115·0	131
		8	*PS* or *S*	89·8	4·9	87·5	107

*P, primary inclusions; *PS*, pseudo-secondary inclusions; *S*, secondary inclusions.
Mean T_H, mean temperature of inclusion homogenization (°C). Corrected mean, homogenization temperature mean with pressure correction.

Table 2 Freezing data, North Wales fluorite

Sample number	Type	Eutectic temperature range, °C	Mean eutectic temperature, °C	Measurements	Hydrate m.p. range, °C	Mean hydrate m.p., °C	Measurements	Equivalent wt per cent NaCl
585/1	*P*	−17·4 to −19·75	−18·95	7	−12·3 to −17·1	−15·0	7	24·10
587	*P*	−18·3 to −20·35	−19·5	13	− 6·8 to −12·05	− 9·4	22	24·78
	PS/S	−20·25	—	5	−14·95 to −16·5	−15·6	7	24·15
588	*P*	−21·4 to −21·9	—	1	−14·3 to −18·0	−16·4	30	24·00

enrichment in potassium relative to rather lower-temperature fluorites from the ore fields of the Askrigg Block and Derbyshire, but potassium deficiency relative to higher-temperature fluorites from the north Pennine and Cornish ore fields. Sawkins[11] has shown this ratio to be broadly dependent on the temperature of the hydrothermal brine. Qualitative tests with silver nitrate and barium chloride solutions confirmed chloride in each of the leachates, but did not detect sulphate.

Table 3 Sodium/potassium ratios (~~atomic~~ weight) in leachates of crushed fluorite

Ore field	Specimens	Range	Mean
Devon and Cornwall*	8	5·2– 9·5	7·7
North Penninest	12	4·7–13·1	9·1
North Wales	3	7·5–21·8	14·9
Askrigg Block	9	11·7–32·8	19·6
Derbyshire	5	15·0–28·3	22·1

*Including four determinations by Sawkins.[12]
†Including three determinations by Sawkins.[10]

Solid hydrocarbon inclusions are common in the North Wales fluorites, but no liquid hydrocarbons were found within fluid inclusions. Hydrocarbon seepages are commonly found associated with mineralization throughout the ore field.

Discussion

It is interesting to compare these values with fluid inclusion results from a number of other British lead–zinc–fluorine–barium deposits (Table 4). Temperature and salinity measurements from fluorite of probable connate brine origin from Chilton quarry, Durham,[13] are closely similar to those presented here. The overall temperature range for the deposits listed in Table 4 is again broadly the same. Detailed unpublished work by P. Rogers (south and central Pennines) and T. J. Shepherd (West Cumberland) supports these conclusions. The published results[14,15,16] confirm a range of homogenization temperatures from 70 to 140°C and salinities of 17 to 30 equivalent weight per cent NaCl for fluid inclusions in fluorites from the Derbyshire ore field. It would thus seem that certain similarities exist throughout these particular British deposits in terms of mineralogy, salinity of ore solutions and temperatures of ore deposition. All show model lead ages which correlate with the period of Hercynian tectonism in Britain and all are located near the margins of deep Carboniferous–Permo-Triassic sedimentary basins.

Several aspects of the north Pennine mineralization, characterized by high temperatures (Sawkins[10] and new, corrected, mean homogenization temperatures on 142 specimens, range from 123 to 195°C, author's unpublished results), high concentrations of hydrothermal silica and a suite of typically magmatic trace elements concentrated in the fluorite (author's unpublished results), suggest that, although a connate water origin had been proposed for them,[17] these deposits should be excluded from direct comparison with the others.

Detailed studies of the North Wales orebodies,[7] overall regional structure, broad mineralogical and temperature zonation suggest that the source of the parent brines lay to the north and east in the deep eastern Irish Sea and Cheshire basins. These areas were previously suggested as possible sources by Dunham.[18] The lack of any known igneous rocks in these areas[19] strongly supports a theory that the ore-forming brines were migrating connate fluids. Comparison of fluid inclusion deductions with modern connate brine observations suggests that salinities of 25–30 per cent NaCl may be attained, through membrane filtration, within depths from 1 to 6 km.[20] Taking a normal geothermal gradient of 1°C per 30 m for sedimentary basins, a depth of source area burial of at least 3 km must be envisaged to explain the homogenization results. High brine flow rates through Hercynian structural channelways may have been sufficient to

Table 4 Homogenization temperature data, British lead–zinc deposits

Sample number	Ore field and locality	Inclusion type	Inclusions measured	Mean T_H	Standard deviation	Median
	Central Pennine ore fields					
356	Vughy fluorite, Keld Heads Level, Wensley	*P*	9	102·0	4·5	102·0
617	Vughy fluorite, Seata mine, Aysgarth	*P*	21	95·2	4·7	93·0
645	Vughy fluorite, Fell End vein, Clouds	*P*	8	93·8	0·9	93·5
751	Massive fluorite, Carden Hill, Grassington	*P*	15	91·0	1·6	91·0
679	Massive fluorite, Withgill, Clitheroe	*P*	23	143·3	3·0	143·9
	Derbyshire ore field					
130	Late fluorite, Old Edge vein, Ladywash, Eyam	*P*	11	73·8	4·9	76·0
581	Massive fluorite, Odin vein, Castleton	*P*	17	127·5	4·5	126·5
	West Cumberland ore field					
643	Late fluorite, Florence pit, Egremont	*P*	16	123·3	3·8	123·0
	Caldbeck Fells ore field					
CQ/1	Vein quartz, Sandbeds barytes vein, Calebrack Trials	*P*	14	122·3	8·1	119·4
	Shropshire ore field					
595/B	Barite, Snailbeach mine	*P*	2	90·7	—	—
595/Q	Vein quartz, Snailbeach mine	*P*	6	124·2	7·8	126·4
	Eastern Mendips					
X22	Fluorite, Halecombe quarry, Leigh upon Mendip	*P*	17	84·8	10·3	86·0

maintain elevated temperatures despite convective cooling. Recent geophysical models for the Cheshire and eastern Irish Sea basins provide for thicknesses of 2·4–6 km of Carboniferous and Permo-Triassic sediments in these regions.[19]

In conclusion, the evidence from fluid inclusions in fluorite from the North Wales ore field suggests that the mineralizing solutions were NaCl brines bearing 24–25 equivalent weight per cent NaCl, which deposited ore in the eastern parts of the ore field in the temperature range 105–130°C. These brines are considered to have been connate in origin, derived from buried Carboniferous strata in the eastern Irish Sea and Cheshire basins. Other lead–zinc–fluorine–barium deposits of Hercynian age in Britain yield similar fluid inclusion results and suggest the importance of fluid inclusion studies in future work.

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TECHNICAL NOTE

Yttrium Content of Fluorite as a Guide to Vein Intersections in Partially Developed Fluorspar Ore Bodies

by F. W. Smith

Within the Northern Pennine Orefield, England, intersections of fluorite veins are generally richest in ore, and their recognition enables investigation of the ore potential of the intersecting bodies. A method, based on routine analysis of fluorite for yttrium, has been used with success in mines of the district to predict the location of intersections in partially developed fluorite-bearing ore bodies. This short note is intended as a brief introduction; the details of United Kingdom applications are to be published at a later date.

Geology

The Northern Pennine Orefield is the second largest fluorspar-producing region in Britain. The associated minerals galena, sphalerite, chalcopyrite, barite, and witherite have all been extensively worked in the past but, with the exception of a single barytes mine, all of these operations are now abandoned. Galena alone is recovered as a byproduct of fluorspar beneficiation. At the present time two companies are producing about 38,000 tpy of fluorspar from high grade vein ore bodies, and a number of concerns are actively prospecting in old lead workings.

The mineralization is localized in veins and replacement flats within favorable lithologies in an alternating limestone, sandstone, shale sequence. Since the thickness of individual beds is not great (generally less than 20 m), vein bodies tend to be ribbon-shaped, with length greatly exceeding width and height (Dunham).[1] They thus present difficult exploration targets for conventional diamond drilling techniques.

Ore grade varies greatly along the veins, which can change rapidly in character from mineral stained fault gouge to massive mineral bodies up to 10 m in width.

F. W. SMITH is with Dept. of Geological Sciences, University of Durham, Science Laboratories, Durham, England. TN 73L203. Manuscript, Jan. 31, 1973.

It has been known for a very long time that the richer ore bodies tend to be associated with vein intersections in favorable beds. It is assumed that vein fissure intersections provided vertical channelways through which hot ore-bearing brines were able to ascend from deeper cavities in the sequence. Thus investigation of intersections at other horizons generally yields further ore bodies.

Technique

The relative concentration of yttrium in fluorite is a good indicator, in the North Pennines, of the direction of flow of mineralizing fluids. In all of the ore bodies so far studied in detail in this region, the concentration of yttrium increases markedly in the direction of vein intersections that are believed to have acted as feeder zones to the remainder of the bodies. The reason for this relationship is probably connected with the degradation of soluble rare earths-fluoride complexes by the changes in various physicochemical parameters of the hydrothermal fluids as they entered the ore body cavities from the feeder zones. The simultaneous release of free fluoride ions also contributed to the increased ore values in these intersection zones.

Yttrium values in fluorite taken from a longitudinal traverse of the western ore body, Redburn mine, Rookhope, are plotted in Fig. 1. The position of a major vein branch and three cross veins are clearly indicated by yttrium maxima. The cross veins themselves contain up to 2.5 m of low grade fluorspar ore. The exact positions of *B* and *C* were unknown previous to the geochemical survey. Similar results have been obtained for several other veins and ore bodies in the area.

Clean fluorspar was collected as bulk samples from within 300 mm of the vein wall and, since the vein infilling is simple, with mineral growth from the walls inward, analyses of the samples are considered comparable along the length of the ore body. A number of samples taken from the center of the vein show a

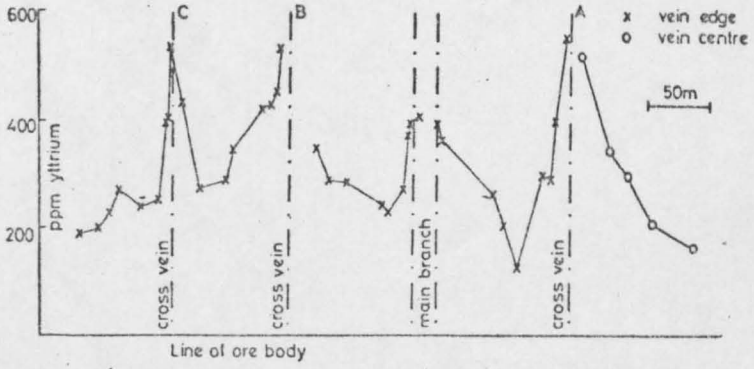

Fig. 1—Yttrium content of fluorite plotted against position of sample in the ore body. Longitudinal traverse of the main western ore body, Red Vein, 17 fm level, Redburn mine, Rookhope, County Durham. The positions of three cross veins, *A*, *B*, *C*, and the main vein branch are shown.

similar relationship between yttrium content and flow direction (see Fig. 1). These samples however should not be directly compared with those from nearer the vein wall. The variation of yttrium across veins is still being studied.

Analysis was by X-ray fluorescence using a Philips PW 1212 automatic spectrometer. The detection limit for yttrium calculated from mean background values is 2 ppm. Precision, using spiked "specpure" calcium fluoride standards, is ±3 ppm at a level of 150 ppm. A certain amount of contamination by quartz (generally less than 2%) was found to be unavoidable, and wherever necessary corrections, in the form of normalization, have been made.

A survey of the regional variations in the yttrium content of fluorites (Smith)[2] indicates that not all fluorite deposits may be studied in this way. In some deposits such as those of the Derbyshire Orefield and the Mississippi Valley (e.g., Illinois, Kentucky deposits) the amounts of yttrium present may be very low. Further, where the deposits have been formed under relatively low pressure-temperature conditions the pattern of variation previously described may not be developed. Tests made on veins in Derbyshire suggest that this is the case in that orefield.

Research into the possibility of using the variation of ceria rare earths in a similar manner is now in progress.

Application

Two potential areas of application of this technique may be outlined.

The first is the situation where, in a working mine, ore width exceeds the safe width for vein drives. As a result vein walls are left untouched (vein width being proved by regular crosscutting or drilling) and intersection sites may go undetected until, and sometimes after, full extraction. It is true, moreover, that ore widths in the proximity of intersections tend to be greater than usual. This application is illustrated in Fig. 1 where the locations of two previously unknown cross veins have been identified.

The second situation is one which frequently confronts the mining geologist in an old mining district, that is the reappraisal of old workings in which the vein has been partially worked, or 'slit' for sulfides, leaving the spar ores untouched. In such workings, very often unsafe, where the geology may be obscured by blankets of mud, a rapid sampling exploration method is invaluable. The technique is being used at present to detect vein intersections in this type of situation in the Northern Pennines.

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