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STRUCTURAL ANALYSIS OF ORE SHOOTS AT GREENSIDE LEAD MINE, CUMBERLAND, ENGLAND [1]

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CONTENTS

ABSTRACT

The Greenside lead vein is a relatively isolated ore deposit located in the English Lake District, and has yielded approximately 200,000 tons of lead concentrates. The ore deposit is a simple fissure-infilling along an essentially normal fault. The complex lithologic and tectonic environment of the vein is described.

The ore shoots are controlled by favorable variations in dip and strike of the fault plane along which mineralization occurred. The structural

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analysis of the development of ore shoots is not only concerned with the general relation of the ore shoots with the steeper sections of the fault, but with determining the precise theoretical limits of the ore shoots. The analysis is developed from a geometrical standpoint and then geologic implications are considered.

It is concluded that the development of fissures along a fault plane depends basically on the variations in the profile of the fault plane as measured in a plane containing the net-slip direction. A quantitative measurement of the variations in the profile—termed the "profile-dip"—is defined.

Profile-dip values for the Greenside Vein were determined and a contoured diagram produced. Theoretical and actual ore shoots show, in general, a very good correlation. Stress is laid on the importance of using this geometrical analysis in conjunction with conventional geologic approaches.

INTRODUCTION

GREENSIDE Lead Mine, prior to its closure in 1961, was the property of Greenside Mines Ltd. The mine is situated in the county of Cumberland, on the eastern side of the English Lake District (Fig. 1).

The early history of the mine is obscure. Although in other parts of the Lake District mining was probably carried out in Roman times and flourished in the Elizabethan era, the earliest documentary evidence of mining operations at Greenside is dated 1784. From 1827 until recently the mine was worked almost continuously, firstly by Greenside Mining Company and then by Basinghall Mining Syndicate (later Greenside Mines Ltd.). Lack of ore,

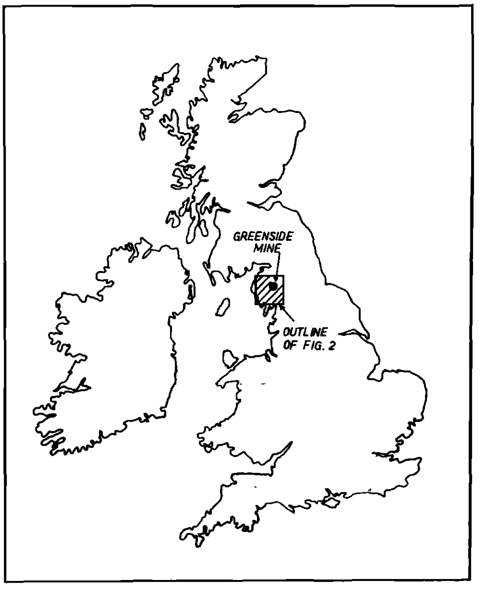

FIG. 1. Location map.

in spite of an intensive exploration program carried out in 1957, finally forced the company to wind up operations.

The mine produced approximately 2,400,000 tons of ore which yielded 200,000 tons of lead concentrates and 2 million ounces of silver. This output was obtained almost entirely from a single vein.

Although the mine has been visited throughout the years by numerous geologists, no single comprehensive report on the geology of the ore deposit has been written. The most complete description among published material is by Eastwood (5, 6), whereas of private reports the fullest account is by Willson (19). The surface area in the vicinity of the mine has been covered, though not in great detail, by the Geological Survey (18) and by Hartley (8). The present paper is based on underground and surface mapping carried out between 1959 and 1962.

REGIONAL GEOLOGY

Stratigraphy, Intrusions and Structure

The geology of the Lake District is well known in British geological circles. A wealth of literature has been written on the region and therefore only a brief description is given here; the reader is referred to a paper by Mitchell (12) for greater detail. Figure 2, illustrating the geology and ore deposits of the region, has been compiled from most existing publications the majority of which, excluding (14, 16), are listed in Mitchell (12).

The fundamental structure of the region is that of an inlier: the central core is composed of folded Lower Palaeozoic rocks and Caledonian intrusions, whereas the peripheral area is formed of gently dipping Carboniferous and Permo-Triassic rocks.

The total thickness of the Lower Palaeozoic rocks is in the order of 35,000 feet. Four divisions are recognized (Fig. 2). The oldest strata—the Skiddaw Slate Series of Lower Ordivician age—are composed mainly of argillaceous and arenaceous rocks. These strata are followed, essentially conformably, by the Borrowdale Volcanic Series which consists of a thick group of lavas, tuffs and breccias, of predominantly andesitic composition. The Coniston Limestone Group, of Upper Ordivician age, unconformably overlies the Borrowdale Volcanic Series, and is in turn followed by Silurian strata—predominantly shales and sandstones. A description of the Carboniferous and later rocks is not pertinent in this context.

Caledonian intrusive rocks, mainly of granitic-granodioritic composition, occupy a large area of the Lake District. Most of the intrusions are stock-like in form.

The oldest rocks of the Lake District have been subjected to four periods of earth movements. The earliest orogenic activity—the pre-Bala earth movements—is evidenced by the unconformity between the Borrowdale Volcanic Series and the Coniston Limestone Group. The strong folding of the Lower Palaeozoic rocks, particularly the Skiddaw Slate Series, was produced by the Caledonian orogeny; the fold axes have an overall ENE-WSW trend, and a cleavage with a similar trend is developed on some horizons.

The Hercynian orogeny caused gentle folding of the Carboniferous rocks which surround the Lower Palaeozoic rocks, and also probably accentuated the existing Caledonian structures. During the minor and intermittent post-Triassic earth movements gentle uplifting and doming took place.

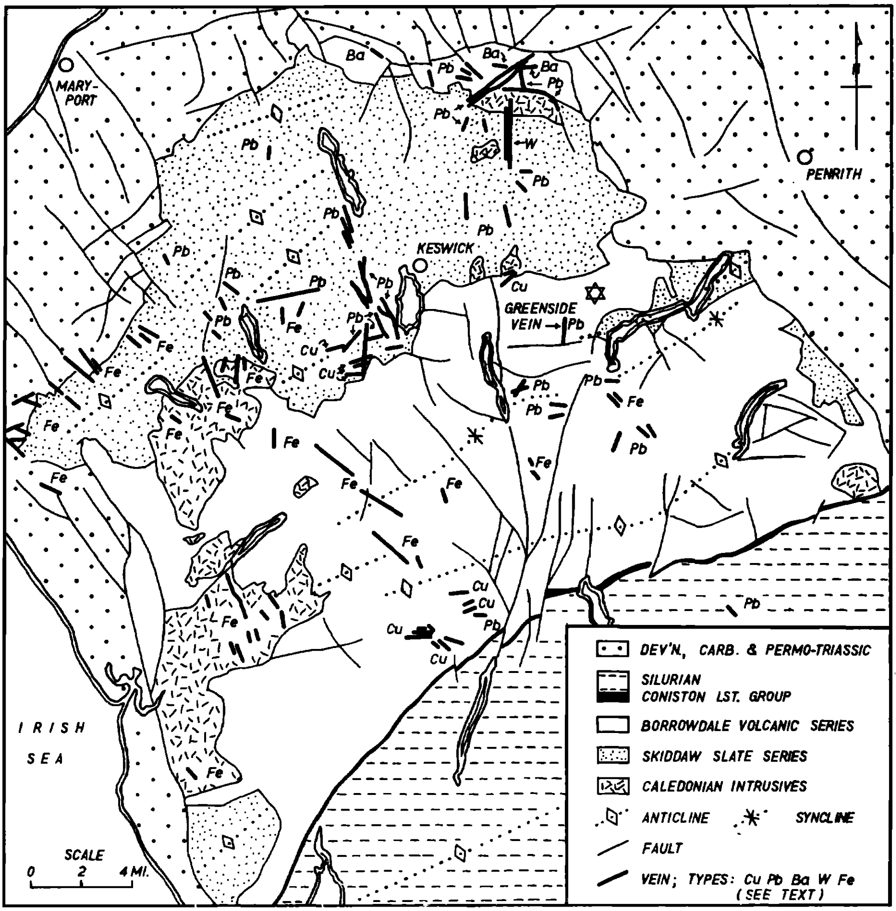

FIG. 2. Geologic map of Lake District.

The predominant fault pattern of the Lake District—two sets of faults lying between NW-SE and NE-SW—has generally been attributed to the Caledonian orogeny (12); however this is almost certainly an over-simplification in view of the four periods of folding.

Ore Deposits

Except for the massive hematite deposits located in the Carboniferous Limestone in the west of the region, the ore deposits of the Lake District are veins that have been formed by fissure-infilling of steeply-dipping, generally normal faults. The majority of the veins are confined to the Skiddaw Slate Series and Borrowdale Volcanic Series. As might be expected in a region that has suffered four periods of earth movements, the relation between mineralization, intrusive activity, folding and faulting is complex.

The veins of the Lake District are classified in this paper as follows:

Designation	Mineralogy (major minerals only)	Age
Copper veins	Chalcopyrite-pyrite-quartz	Caledonian—?
Wolfram veins	Wolframite-scheelite-quartz	Caledonian (3)
Lead veins	Galena-sphalerite-chalcopyrite-quartz-barite	~Hercynian (13)
Barite veins	Barite	Hercynian—?
Hematite veins	Hematite-quartz-carbonate	Post-Triassic

(Quantitative data on geologic dating (3, 13), as interpreted by the present author, substantiate these ages.)

It should be noted that the lead veins as defined here have been exploited at some mines for zinc, copper and barite, in addition to lead. The distribution of the lead veins (s.l.) tends to be more sporadic than that of the copper veins; the Greenside Vein, for example, is relatively isolated. The lead veins have a well developed crustified vuggy structure and can probably be referred to the leptothermal category as defined by Dunham (4).

GEOLOGY OF THE MINE AREA

Stratigraphy and Intrusions

Borrowdale Volcanic Series.—On the basis of lithology the Borrowdale Volcanic Series (Figs. 3, 4) has been divided into three groups. The Greenside Vein is located in the lowermost division—the Ullswater Group. As a broad generalization the wall rocks of the Greenside Vein above the 90 fm (fathom) level are acid andesites, whereas below this level the predominant wall rocks are basic andesites with tuff and breccia intercalations. In the immediate vicinity of the mine and within the mine-workings the strata have a southerly to south-easterly dip, generally between 30° and 60°. The ore shoots, however, show no apparent relation either with the dip of the strata or with the variations in rock-type.

Skiddaw Slate Series.—The uppermost strata of the Skiddaw Slate Series, composed here of dark-colored indurated shales, outcrop in the mine area and are exposed in the lowermost workings of the mine. The Greenside Vein becomes barren on encountering these shales.

The junction of the Skiddaw Slate Series and the Borrowdale Volcanic Series, as encountered in the mine, is essentially conformable, and is marked by a transition zone consisting of thin flows of andesite in the uppermost shales, and bands of shale and shale-andesite breccia in the overlying Borrowdale Volcanic Series. Although the Skiddaw Slate Series has an unfavorable effect on the mineralization, the junction with the more competent overlying volcanic rocks is important since it acted as a plane of weakness that localized the Greenside Vein. The junction is irregular in form but is essentially dome-like, having an approximately N-S long axis. The east limb of the dome is followed by the Greenside Vein (Fig. 5). This dome-like structure is difficult to correlate with the ENE-WSW folding in the mine area, and possibly represents earlier pre-Bala folding; on the other hand it is conceivable that the structure is nondiastrophic in origin.

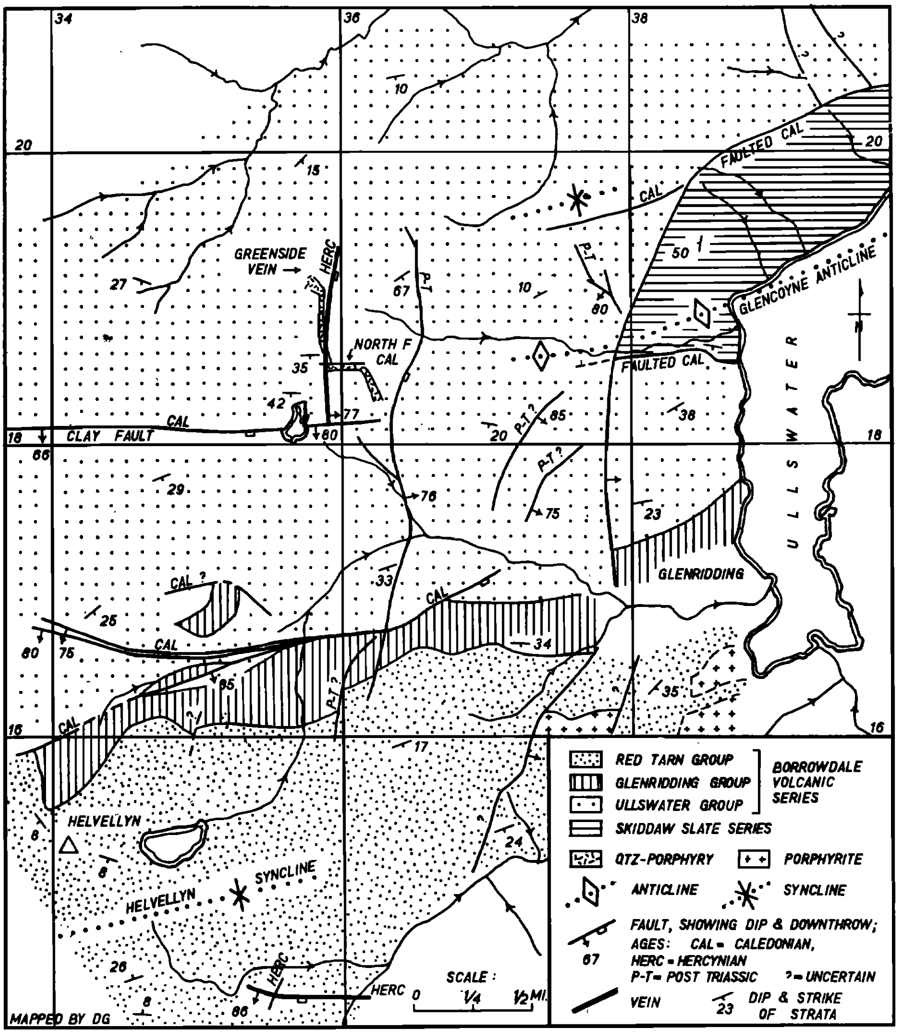

FIG. 3. Geologic map of mine area.

Intrusions.—There are several small dikes and plug-like intrusions in the mine area. Although the intrusions have varying compositions, the majority probably represent a single intrusive suite related to the major Caledonian intrusions of the region.

The most important dike encountered in the mine workings is composed of quartz-porphyry. This dike influenced the localization of the Greenside Vein as a whole, and also controlled the development of individual ore shoots. On surface the dike has a dog's-leg shape (Fig. 3) : the contacts of part of the N-S trending portion afforded planes of weakness that localized the Greenside Vein and branch veins; the E-W trending portion localized the North Fault—an important pre-mineralization structure.

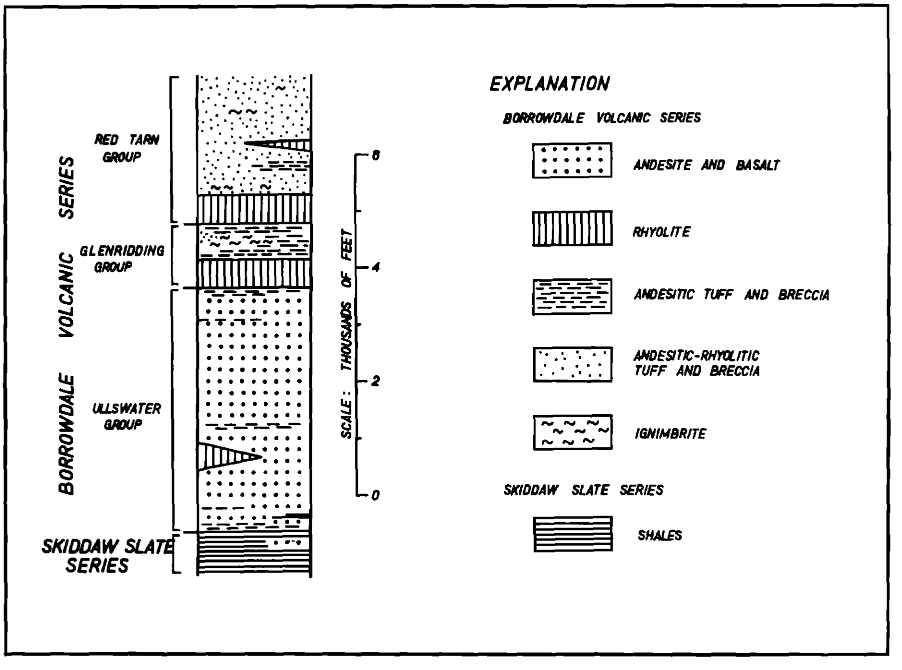

FIG. 4. Stratigraphic succession of mine area.

Folding, Cleavage and Jointing

Two major fold structures—the Helvellyn Syncline and the Glencoyne Anticline—have been delineated in the mine area (Fig. 3). Both folds are broad, open structures with ENE-WSW trends, and are assumed to be Caledonian in age. The Glencoyne Anticline dies out to the west, whereas the Helvellyn Syncline becomes monoclinal to the east and eventually dies out in this same direction.

Cleavage is developed in the Borrowdale Volcanic Series, particularly in the fine-grained tuffs. The strike of the cleavage planes is similar to the trends of the folds, thus pointing to a common origin. The two major joint directions determined—N19°E and N30°W—can tentatively be referred to conjugate tear directions related to the NNW-SSE Caledonian compression. The Greenside Vein shows no significant relation either with the cleavage or the jointing.

Faulting and Mineralization

In the mine area three groups of faults, each with a characteristic type of mineralization, have been recognized. The groups are described below, under headings of their probable ages.

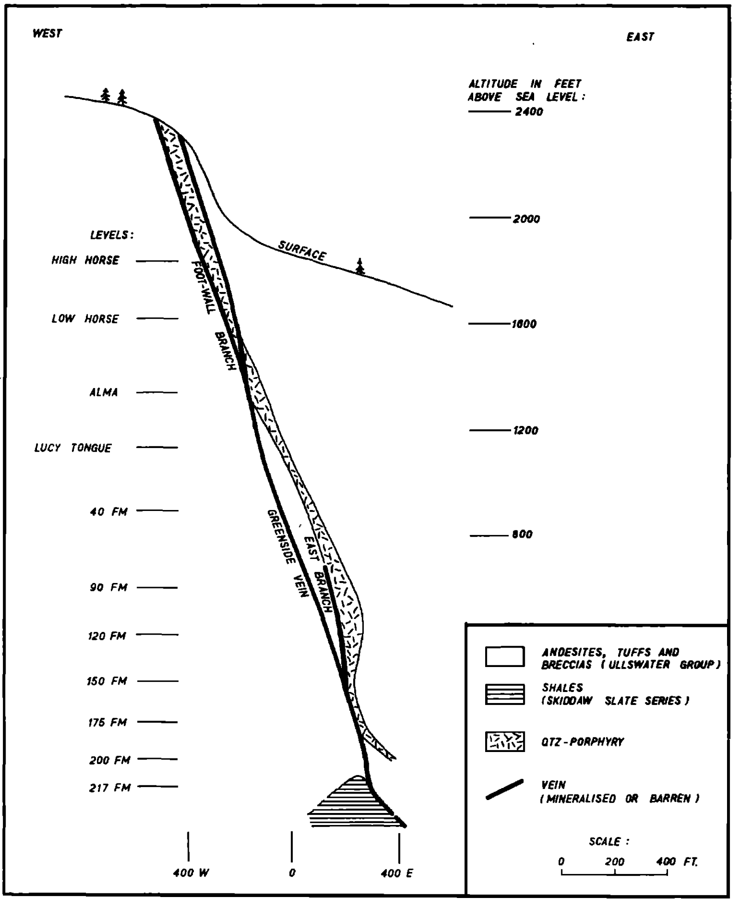

FIG. 5. Transverse section of Greenside Vein at 1,400N.

Caledonian Faults.—These faults have E-W to ENE-WSW trends and normal displacements; locally they show quartz-pyrite-dolomite-ankerite-calcite mineralization. The trend of these faults, like the copper veins in other parts of the Lake District, is parallel to the Caledonian folds, and it is suggested that the faults and copper veins have a similar age and mode of origin. There are two important Caledonian faults in the mine: the Clay Fault limits the extension of the Greenside Vein to the south, and the North Fault has influenced the development of an important ore shoot.

Hercynian Faults.—These faults (or veins) are synonymous with the lead veins described previously. The trend of the lead veins in the mine area is variable: the Greenside Vein strikes almost due N-S whereas other veins have E-W or NE-SW trends.

The Greenside Vein and other lead veins in the mine-workings cut and displace the Caledonian faults; in addition renewed movement and locally lead mineralization took place along these older faults. It is tentatively suggested that the Greenside Vein was formed as a tensional structure as a result of the Hercynian doming, which probably accentuated the Caledonian Glencoyne Anticline.

The Greenside Vein shows a well developed vertical zoning: barite increases markedly upwards whereas sphalerite and chalcopyrite become more important in depth. The paragenetic sequence and the pattern of zoning are closely comparable. A characteristic feature of the paragenesis—typical of many lead veins in the Lake District—is the replacement of barite by quartz and the concomitant introduction of sulfides.

The hydrothermal alteration of the wall rocks of the Greenside Vein—mainly silicification—has been superimposed on an earlier regional alteration. The intensity of alteration increases with depth and with the width of the vein. Mineralization and alteration apparently occurred approximately contemporaneously.

Post-Triassic Faults.—This group of faults is not as well defined, in terms of characteristic mineralization, as the older groups. The majority of the faults have NW-SE or NNE-SSW trends; hematite mineralization (along with minor dolomite, calcite, quartz and barite) occurs along some of the faults, which are thus clearly related to the hematite veins of other parts of the Lake District. During the post-Triassic orogenic activity, renewed movement took place locally along the Caledonian and Hercynian faults.

STRUCTURAL ANALYSIS OF ORE SHOOT FORMATION

Introduction

The Greenside Vein is a simple fissure-infilling along a fault that has suffered essentially dip-slip (normal) movement. The exact displacement of the fault is difficult to determine, owing to the absence of marker horizons or suitably orientated intrusions. The downthrow is probably in the order of 50 to 150 feet, and there is a small strike-slip component in the order of 0–10 feet. The fault has been traced 3,900 feet along the strike and 2,600 feet vertically. At the south end of the mine the fault dies out in a horse-tail structure, but to the north the limit has not been determined. There are two important branch veins—both controlled by the quartz-porphyry dike—the East Branch and the Foot-wall Branch (Fig. 6).

The four ore shoots of the Greenside Vein partially coalesce in the upper part of the mine, but pinch out in depth (Fig. 10). The vein varies in width from a fraction of an inch up to 30 feet, the average width being 6 to 8 feet. The barren sections are composed of a breccia-gouge zone, generally 5 to 7 feet wide.

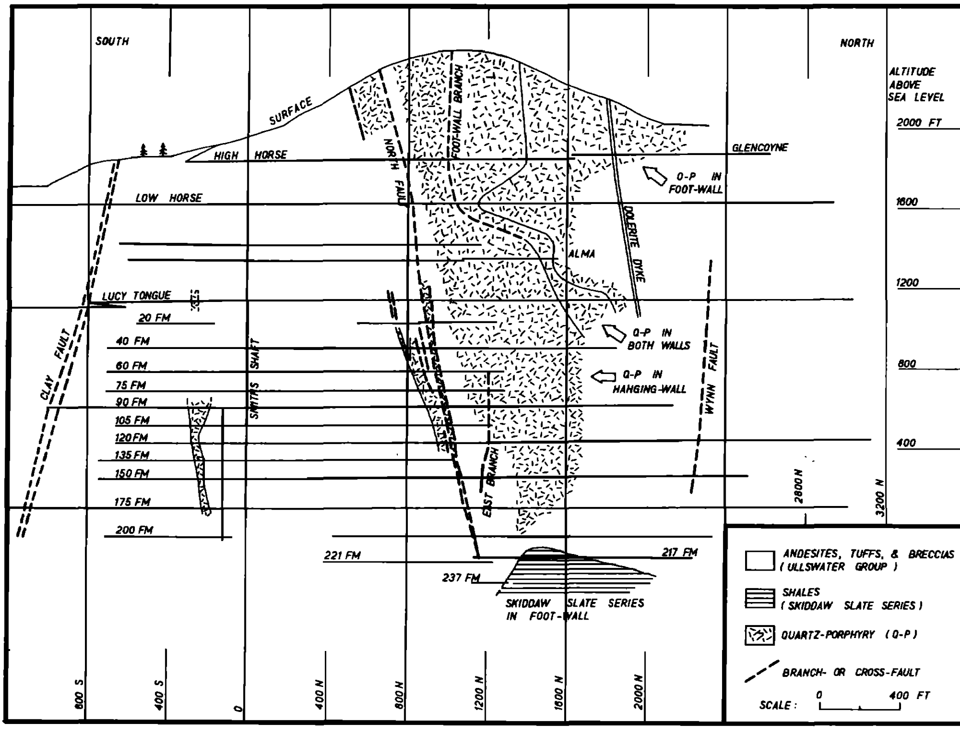

FIG. 6. Longitudinal geologic section of Greenside Vein.

The average assay value of the vein is 7% Pb; the wider sections of the vein, as in many veins, tend to have lower assay values, being diluted with a greater quantity of gangue mineral. Assay data for large sections of the mine, particularly the older workings above the Lucy Tongue level, are not available. As a general rule, the decision on whether a specific section was worth mining depended simply on the extent of the vein along the strike and dip, the ore grade almost invariably being adequate. The analysis of the development of ore shoots is thus simplified, and is reduced to a study of the development of fissures along the fault plane, irrespective of the grade of subsequent mineralization.

The most important single factor controlling the localization of the ore shoots is the variation in strike and dip of the Greenside Vein. This variation, of course, depends in turn on secondary factors, for example the quartz-porphyry dike and the Skiddaw Slate Series-Borrowdale Volcanic Series contact. As with most veins developed by fissure-infilling along normal faults, the ore shoots are developed along the steeper sections of the fault plane. Figure 7 shows the foot-wall of the vein on the major levels—a contour map of the fault plane. The relation of the ore shoots to the bunching of the contours, i.e., to the steeper sections of the fault plane, is obvious. The problem is therefore not one of demonstrating simply that the localization of the ore shoots depend on the steepness of the fault plane—*this is self-evident*—but on determining the factors controlling the *precise limits* of these ore shoots.

Method of Analysis

Previous Approaches.—Although the fundamental principle of the relation between the dip of fault planes and the development of ore shoots was recognized long ago (2), and has since been expanded and utilized by several geologists (7, 9, 10, 11, 17), few workers have examined the principle thoroughly from a geometrical point of view.

One of the chief difficulties of the geometrical approach is to obtain a suitable graphical representation of the fault plane on which the most favorable areas for ore shoot development can easily be plotted. Methods that involve the contouring of the fault plane with reference to a horizontal plane (15), as in Figure 7, or an inclined plane (1) are undoubtedly useful, but nevertheless do not facilitate the determination of the precise limits of potential ore shoots. Another useful method, in which the inclination of the fault plane is contoured, has been developed by Willson (19) and applied to the Greenside Vein. This method, though empirical in approach, in part inspired the analysis shortly to be described.

Geometrical Basis.—The basis of the method developed in this paper lies in a graphical representation of a series of profiles of the fault plane, each profile being orientated with respect to the net-slip direction of the fault.

Consider first of all the incipient stages of fault movement. The net-slip direction of any fault, once the fault-plane has been formed, will depend on two factors. The primary factor is of course the magnitude and direction of the force acting on the fault plane—these forces will determine the *general* direction of movement, i.e., normal, reverse, oblique or horizontal movement. The secondary factor is the shape of the fault plane: the warps and irregularities of the fault surface will clearly modify this general direction of movement.

So that the application of the method to faults with various directions of movement can be understood, the general case for oblique movement will be considered (Fig. 8). Assuming that the general direction of fault movement has been determined, the exact direction of the net-slip will depend solely on the shape of the fault-plane *along the line of movement.* This shape—or profile—can be described in terms of the angle of inclination of the fault plane

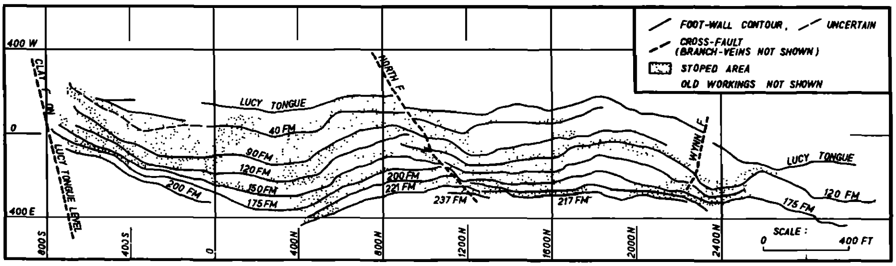

FIG. 7. Plan projection of Greenside Vein showing footwall on major levels.

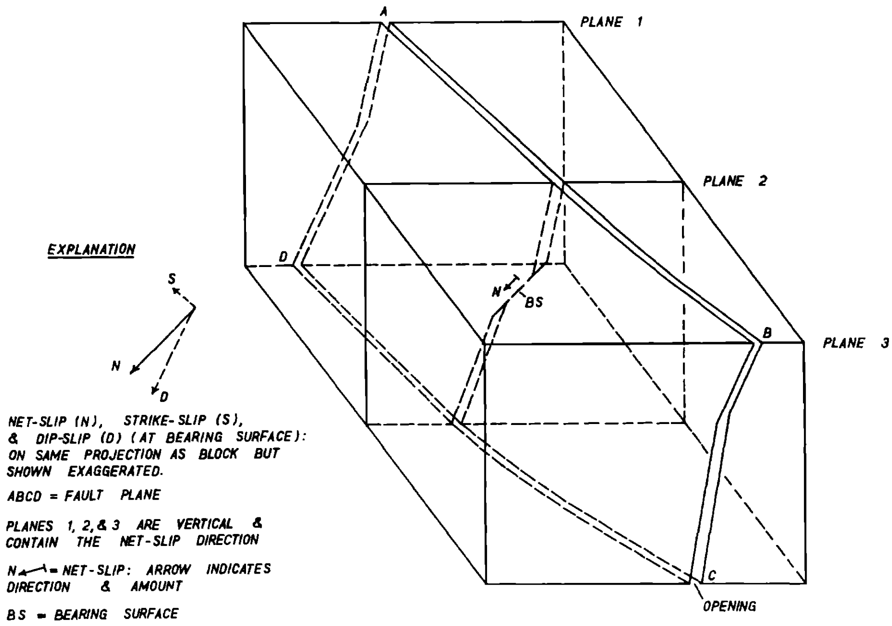

FIG. 8. Isometric block diagram showing theoretical positions of openings developed along an oblique-slip fault.

as measured in a vertical plane containing the net-slip. (This angle, defined with reference to the horizontal, will hereafter be termed the "profile dip.")

The section of the fault surface with the least profile-dip must act as a bearing surface during fault movement and therefore must control the inclination of the net-slip. Assuming, for the present, that the net-slip direction is constant, all other areas of the fault surfaces that have profile-dips exceeding this minimum profile-dip should be pulled apart to form openings. This is illustrated in Figure 8 where the short area of the fault plane having a low profile-dip controls the formation of openings along the *complete* fault plane. If the fault plane is contoured with respect to the profile-dips, then the theoretical positions of openings, i.e., the potential ore shoots, can be determined.

In the example used (Fig. 8) the dip-slip component of fault movement is greater than the strike-slip component. For this type of fault, or for normal faults, it is clearly preferable to measure variations in the profile of the fault, along the line of movement, with reference to a vertical plane. However, for strike-slip faults, or oblique-slip faults where the strike-slip component is greater than the dip-slip component, a horizontal plane of reference should be used.

Factors Controlling the Extent and Width of Openings.—The extent and width of openings will depend on three main factors. These are: a) amount of fault movement, b) nature of wall-rocks, c) variations in profile-dip.

Up to a certain extent an increased displacement will cause an increased development of openings. However beyond a certain value, depending on the variations in the profile-dip, the ill-fitting portions of the fault plane will be brought together; the effect of this on the development of openings is difficult to predict and will depend on local conditions. Increased displacement will also cause a greater amount of gouge and breccia to be produced, which will tend to be transported to the openings, thus clogging them. Probably for this reason fissure-infilling deposits are generally found along faults that have relatively small displacement (15).

Under theoretical conditions, all surfaces of a fault that have profile-dips exceeding the minimum profile-dip should be pulled apart to form openings. In practice the walls of the openings settle and collapse as a result of forces acting normal to the fault plane, and the openings become bridged or partially or completely closed. Collapse of the openings almost certainly will occur, at least to some extent, during fault movement; it is thus probable that the bearing surfaces will have a range of profile-dips, varying from one section of the fault to another. The variation in the profile-dips of the bearing surfaces will be influenced by the extent of the collapse of the openings, and this in turn will depend on the competency, degree of fracturing, etc., of the wall rocks.

In general a large variation in the profile-dip of a fault-plane will tend to promote more extensive and wider fissures than will a small variation in profile-dip. However, probably more important than the actual range of profile-dips, is the rate of change of profile-dips over the fault plane. A gradual change of profile-dips from low to high values will facilitate the partial collapse (or closure by gouge filling) of the relatively narrow openings formed under such circumstances, thus producing a broad transition zone extending from bearing surface to opening. A rapid change in profile-dip will tend to produce a narrow transition zone and thus a better defined opening. Furthermore a rapid change of profile-dip will result in a wider opening. Thus in selecting a profile-dip value to outline possible openings, attention should be paid to any significant rapid change of profile-dip from low to high values.

Application to Greenside Vein

The first step in the production of a contoured diagram of profile-dips is to determine the net-slip direction of the fault. In the case of the Greenside Vein this direction can be determined from the dip-slip and strike-slip data given previously; however, since the strike-slip component (0–10 ft) is small compared with the dip-slip (50–150 ft) component, it was neglected for the purposes of profile-dip calculation. The fault was thus assumed to have true normal displacement, and the profile-dip was measured in a vertical plane containing the dip-slip direction, i.e., at right angles to the average strike of the vein. Measurements were made at 100 feet intervals along the strike; this interval was selected by experiment, and was considered adequate to reflect the variations of profile-dip.

A plan showing the foot-wall of the vein on each level (Fig. 7) was used to determine the profile-dips. The foot-wall of the vein for the greater part of the vein surface was determined by geological mapping; in inaccessible areas, data from old geological maps (19) and mine plans were employed.

The original plan used was at a scale of 1 inch to 100 feet; the average strike of the vein conveniently coincided with the N-S mine coordinates, so that profile-dip measurements were made along successive E-W coordinates of the 100-foot mine grid. The horizontal distance between the vein on successive levels was measured, and utilizing the vertical distance between the levels (from Fig. 10) the profile-dip of the vein was calculated by simple trigonometry (Fig. 9). The profile-dip values were transferred to a longitudinal vertical section, each value being plotted mid-way between successive levels; the values were then contoured (Fig. 11). Profile-dips of the vein above the Lucy Tongue level, betwen the 105 fm. and 120 fm. levels, and between the 75 fm. and 60 fm. levels north of Smith's Shaft were not measured since almost all these old workings are inaccessible, and have not been accurately surveyed. The profile-dips of the vein between the 90 fm. level and the Lucy Tongue level south of Smith's Shaft must be regarded as approximate, since the surveys of these old workings are probably not altogether reliable.

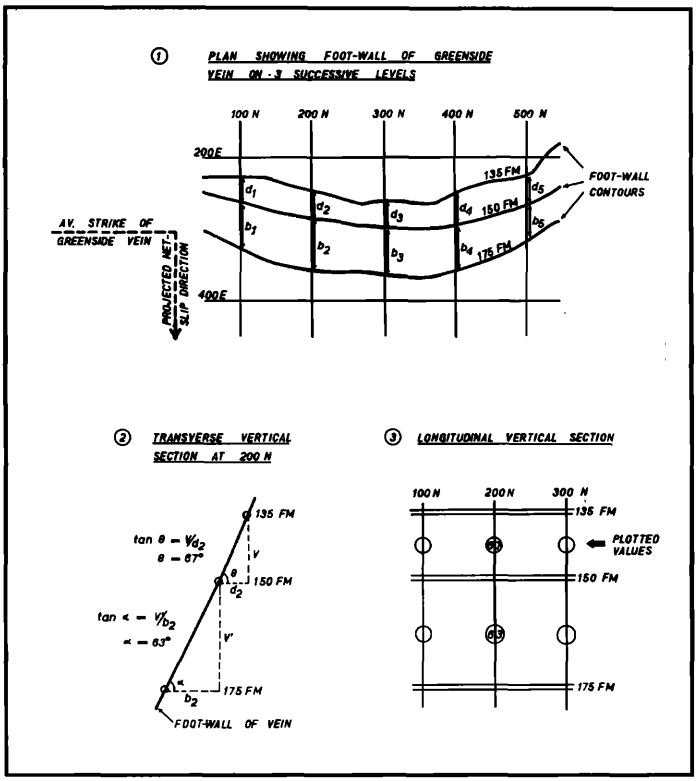

FIG. 9. Diagram showing method of determining profile-dip values.

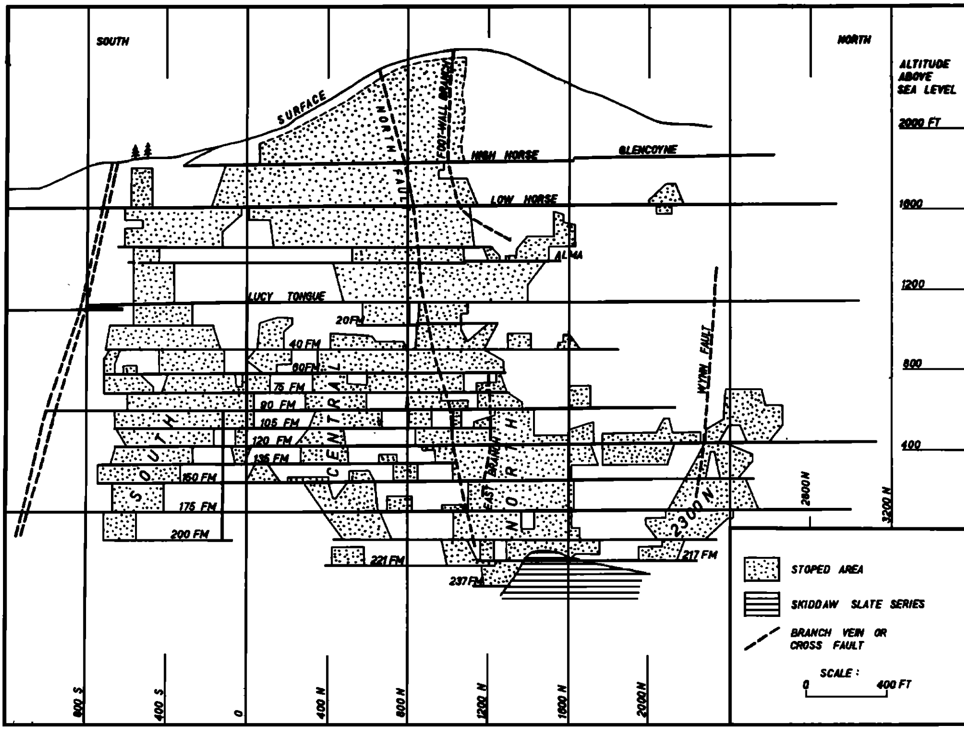

FIG. 10. Longitudinal section of Greenside Vein showing stoped areas.

The profile-dip of the Greenside Vein varies from 58° east to vertical; in one place, at 300 S between the 135 fm. and 120 fm. levels the profile-dip is 83° west. Bearing in mind the factors controlling the formation of openings, as outlined in a previous section, the 70° contour was selected to outline theoretical openings along the fault. This contour, more than any other, marks the change from low to high profile-dips across a zone with a rapid change of values.

Theoretically all areas of the fault plane with profile-dips less than 70° should be bearing surfaces and unmineralized, whereas all areas having a profile-dip greater than 70° should be fissures, now mineralized. In Figure 11 the areas with a profile-dip exceeding 70° are stippled. Comparing these stippled areas with the longitudinal section showing the actual areas stoped (Fig. 10), it can be seen that in general the correlation is very good. (Originally this correlation was facilitated by means of a transparent over-lay.) The relation of each ore shoot to the contoured diagram will now be considered. In addition the geological factors controlling the variations in profile-dip are outlined.

South Ore Shoot.—The southern limit of this ore shoot is fairly well defined by the 70° contour even though the data here are rather incomplete.

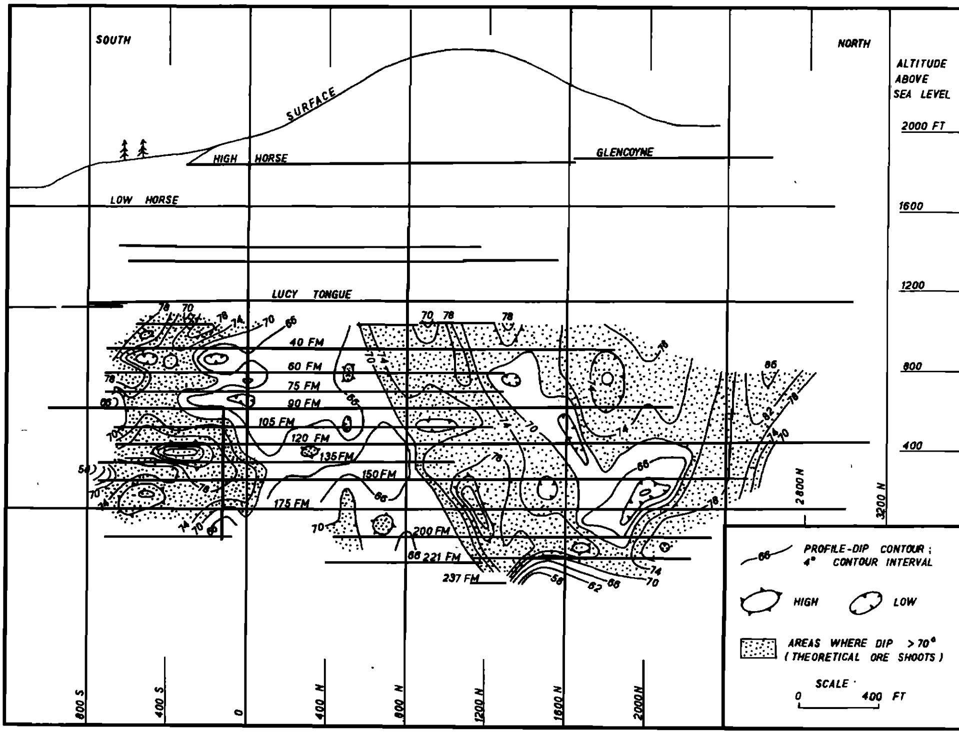

FIG. 11. Longitudinal section of Greenside Vein showing contoured profile-dips.

The Clay Fault, even though it does not intersect the Greenside Vein, has probably exerted some influence on the strike and dip of the vein, since the plunge of the South ore shoot, and also the line joining all points where the Greenside Vein dies out, are approximately parallel to the dip of this cross-fault (Fig. 10).

The northern limit of the South ore shoot is not as well defined as its southern counterpart. Above the 90 fm. level this is perhaps partially due to the rather dubious surveying of the levels in this area. Below the 90 fm. level the northern limit is not marked by the 70° contour but instead can be closely correlated with a significant and rapid change of dip above 78–82°.

Central Ore Shoot.—Compared with the other ore shoots, the Central ore shoot as developed below the Lucy Tongue level is patchy and discontinuous, and has an irregular, ill-defined overall shape. The profile-dip contours, although reflecting the general pattern of the distribution of the stoped areas, fail to outline their limits. Thus the theoretical positions of fissures as indicated by the 70° contour have a considerably smaller extent than the actual areas mined, which are better defined by the 66° contour. The range of profile-dips compared to the remainder of the Greenside Vein is remarkably small; such uniformity of profile-dips, as discussed previously, is not conducive to the formation of openings, and probably accounts for the irregular and discontinuous nature of this ore shoot. The structural or stratigraphical reasons for the relative uniformity of the profile-dips of the Central ore shoot are not known.

North Ore Shoot.—Both the northern and southern limits of the North ore shoot are well defined by the 70° contour. A steep gradient of profile-dips—ranging from 66° to 74°—marks each limit, more especially the southern. This limit roughly coincides with the E-W trending portion of the quartz-porphyry dike, and also with the associated North Fault. The increase in profile-dip on approaching this zone of transverse dikes and faults can probably be attributed to the slightly greater competency of the quartz-porphyry compared with the andesites and andesitic tuffs and breccias. However, since the quartz-porphyry dike is absent in the lower levels, where there is nevertheless a rapid increase in the profile-dips, the North Fault itself must have partially influenced the course of the Greenside Vein. Although the mechanism is not clearly understood, the orientation of the fault plane or fault planes of the North Fault was such that the Greenside Vein was favorably deflected.

To the north of the North Fault, the Greenside Vein is controllel by the foot-wall contact of the N-S section of the quartz-porphyry dike. Although the vein does not everywhere faithfully follow the contact of the dike, the strike and dip of the vein are certainly influenced by the latter, such that a high profile-dip is maintained wherever the vein lies along or near the foot-wall contact of the dike. On the 40 fm., 90 fm. and Lucy Tongue levels, where the Greenside Vein swings abruptly away from the quartz-porphyry contact, and on the 150 fm. and 175 fm. levels where the quartz-porphyry dies out to the north (Fig. 6), the vein becomes barren; the latter position, particularly, is marked by a decrease in profile-dips. The quartz-porphyry dike thus, in effect, controls the North ore shoot.

The profile-dips also indicate a position of theoretical openings between 1,500N and 2,300N above the 90 fm. level, where in fact the vein is largely barren. The geological factors that are responsible for this are uncertain. However, above the Lucy Tongue level the Greenside Vein cuts through the quartz-porphyry dike to the hanging-wall side, the position where the vein enters the dike approximately marking the northern limit of stoping of the North ore shoot. The continuation of this limit below the Lucy Tongue level down to the 90 fm. level is perhaps controlled in a similar fashion.

The North ore shoot is limited in depth by the intersection of the Skiddaw Slate Series; the vein abruptly pinches out on reaching these strata. The 70° contour shows a good correlation with this limit.

2,300N Ore Shoot.—The theoretical positions of openings and the actual areas mined are again in fairly good agreement for this ore shoot. As with the South and North ore shoots the limits are marked by a rapid change of profile-dip. On the basis of the contour diagram, however, the 2,300N ore shoot ought to extend up to the Lucy Tongue level. The dying out of the vein well below this level is probably mainly due to the splitting up of the vein into several stringers, as indicated by diamond drilling.

CONCLUSIONS

The correlation between theoretical and actual positions of ore shoots is in general very good. As expected, the profile-dips of the bearing surfaces vary from one part of the fault plane to another, depending on the range of profile-dips in each specific area of the fault. As a result of this, no single profile-dip contour will define all the ore shoots.

Except for the patchy Central Ore Shoot, the limits of the ore shoots are marked by a steep gradient of profile-dips. This is clearly a most significant factor.

Although the good correlation of theoretical and actual ore shoots has been stressed, there are nevertheless a few areas of the fault plane that show poor correlation. These anomalous areas can be attributed to special geological conditions of local influence, which have resulted in the geometrical analysis being only partially effective. It follows that any geometrical analysis must always be used in conjunction with the conventional geological approach, and only with this proviso can the method presented here be of value.

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